LECTURE NOTES

ON

Aircraft Sytems and Control

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UNIT-I
INTRODUCTION TO AIRCRAFT SYSTEMS

SYSTEM CONCEPTS: is a broad field of practice that covers the behavior of systems across a wide range of subjects including organizational, operational, practical, commercial, economical, human and educational systems. For aircraft systems: elemental building blocks are the components, physical components like pipes, valves, sensors etc. That determines hardware characteristics of systems. Apart from this software systems human is the form of pilot, crew technician, passengers, or a maintainer is also vital part of thesystems.

Based on the complexion of systems, the system will be divided into small subsystems based on their function each. The output of the system can be the input of the other system. Sometimes the output of the system may be the input to improve the output by controlling process.

Skills and experiences are essential part of the capability of the system engineering team, to go with process and support to form the basis of second system engineering. System encompasses a process.

EVERYDAY EXAMPLES OFSYSTEMS:

The word 'system' is often used loosely in everyday speech by people to describe large, Amorphous 'things' or corporations. These are complex things that defy a simple description. Examples include

- Natural systems such as the eco-system or solarsystem
- National HealthService
- Building and constructionindustry
- Integrated transportationsystems
- Manufacturingsystems
- Public utilities

CHARACTERISTICSOFVEHICLEANDAVIONICSSYSTEMS

Although both aircraft vehicle and avionics systems make extensive use of modern digital technology, processors and data buses; the ways in which these technologies are exploited are quite different. The fundamental differences between the tasks that each is performing for the aircraft leads to considerable differences, as described below.

Vehicle Systems Vehicle systems have the following characteristics:

Not data intensive – signal types varied and multiple generally low data rates and iteration rates (some exceptions) Lower data resolution – usually 8 bit and occasionally 12 bit resolution Lower memory and throughput Display intensive on an as-requested basis Physically highly I/O and wiring intensive

Avionics Systems Avionics systems have the followingattributes:

Data and information intensive High data and iteration rates Typically 32-bit floating point arithmetic manipulation High memory and throughput requirements Display intensive Not physically I/O intensive – minimal I/O wiring

MISSIONSYSTEMS:

The military aircraft requires arrange of sensors and computing to enable the crew to prosecute designated missions. The mission systems gain information about the outside world from active andpassivesensorsandprocessthisinformationtoformintelligence.Thisisusedbythecrew, sometimes in conjunction with remote analysts on the ground, to make decisions that may involve attack. These decisions may, therefore, result in the release of weapons of defensive aids, an action which requires a particular set of safety and integrity design considerations:

Attack or surveillance radar to provide information on hostile and friendly targets Electro-optical sensors to provide a passive surveillance of targets

THE AIRCRAFTSYSTEMS:

Electronic support measures (ESM) to provide emitter information, range and bearing of hostile transmitters Magnetic anomalydetector(MAD)toconfirmthepresenceoflargemetallicobjectsunder the sea surface (submarines) prior to attack Acoustic sensors to provide a means of detecting and tracking the passage of underwater objects Mission computing to collate the sensor information and to provide a fused data Defensive aids to provide a means of detecting missile attack and deploying counter measures Weapons system to arm, direct and release weapons from the aircraft weapon stations Communications using a variety of different line-of-sight, high frequency (HF) or satellite communications systems Station keeping to provide a means of safely maintaining formation in conditions where station-keeping lights are not permitted Electronic warfare systems to detect and identify enemy emitters, to collect and record traffic and, if necessary, to provide a means of jamming transmissions Cameras to record weapon effects, or to provide a high resolution image of the ground for intelligence purposes Head-up display to provide the crew with primary aircraft information and weapon aiming information Helmet-mounted displays to provide primary flight information and weapon information to the crew, whilst allowing freedom of movement of the head Data link to provide transmission and receipt of messages under secure communications using data rather thanvoice

GENIRIC SYSTEMDEFINATION:

An aircraft will be equipped with various combinations of these systems according to its particular role. Some of the systems will be integral to the aircraft, others will be carried as role equipment in pallets or wing mounted pods. The majority of these engineering systems are similar in their format. A generic aircraft system is shown in Figure 2.9 to illustrate the main attributes of any system

INPUTS:

Demand (or command) is a conscious input to the system to demand deliberate response. The demand may be from an operator, or from another system. Typically the demand will result from the operator moving a selection mechanism, for example, throttle levers, a switch, control column, steering wheel or tiller.

- Modern techniques have allowed demands to be obtained from direct voice input (DVI) orby cursor control devices such as a mouse or trackerball
- Sensor inputs are provided to modify the behavior of the system or to provide information to enable the function or process to be performed. Typically these data are derived fromsensors or measuring devices that monitor the system performance or environmental parameters such as speed, angular or rotary displacement, rates of change, pressure, and temperature and so on, in analogue or digital form

- Other systems may provide information as determined by there requirements of the function or process to be performed. This data may be provided in analogue, discrete or digitalformat
- Feedback is obtained from measuring devices or sensors in the output devices to allow control to be exercised for reasons of stability of theoutput
- Energyisprovidedtoenablethesystemtooperate.Thisisusuallyintheformofalternating current or direct current from the electrical supply. This usually needs to be conditioned by the systemto ensure that it is the correct voltage and free from transients or noise to ensure correct operation.

A Process or function

Which does something, and may be performed by intellectual, physical, mechanical, electrical, electronic, fluidic or software driven means? The process can be performed by people or by natural or biological events or by a machine or by a combination of person and machine. The latter combination is that most often encountered in aerospace and industrial systems, and it contains large portions of human/machine interface challenges

OUTPUTS:

- Effect orswhich are devices that convert electrical energy into movement–rotary, linear or angular, often using an other medium suchashydraulic oil or air at high pressure, although high voltage electrical devices are becoming more common. These effectors are more commonly known as actuators, and act via mechanisms to move surfaces such as flying control surfaces, doors, landing gear, brake callipers and soon

- Other systems may require data or commands as inputs in order to complete their process. This may be in the form of analogue, discrete or digitaldata
- Crew compartment indications and warnings so that the crew are aware of the correct and incorrect operation of thesystem
- Waste products are produced by the system as a result of the energy transformation or as a result of the operation of the system. Typical waste products are acoustic noise, electrical noise or interference, heat or vibration. All of these products can have a detrimental effect on other systems, or they can be a reason for other systems to exist. For example the heat rejected by a system needs to be diverted to and dissipated by another system, usually a cooling system. Waste products can seriously affect the performance of thevehicle if they are not carefully considered during the designphase

Feedback is used to enable a system to determine that its output command has reached a desired state in the desired time-scales and that the desired state is stable. Feedback appears as an input to the system and is derived from a measuring device that monitors the output of thesystem

External influences are exerted on the system and its components by the outside world and by other systems. Such influences must be clearly understood, and their impact on the design of the system and its performance must be taken into account during the design phase

AIRCRAFT SYSTEMS

1.4.1AIRFRAMESYSTEMS:

Considering the military aircraft as overall main system is classified into 4 imp co systems. The airframe can be viewed as a system since it is a complex and integrated set of structural Components that supports the mass of systems and passengers, and carries loads and stresses throughout the structure.

The airframe is designed and constructed as a set of sub-systems that are integrated to form the whole structure.

VEHICLESYSTEMS:

The aircraft systems are also known as General Systems or Utility Systems. Many of these Systems are common to both civil and military aircraft. They are a mixture of systems with very different characteristics. Some are high speed, closed loop, high integrity control, such as flight controls, others are real time data gathering and processing with some process control functions, such as the fuel system, and yet others are simple logical processing, such as undercarriage sequencing. The functions of many of these systems are performed by software-based controlunits

Coming to individual systems of vehicle systems:

a) **Propulsion system** to provide the primary source of thrust and motive power via pilot demands, electronic and hydro-mechanical fuelcontrols.

b) **Fuel system** to provide a source of energy for the propulsion system. The system consists of tanks, a quantity measuring system, pumps, valves, non-return valves and pipes to transfer fuel from tank to tank and to theengines.

c) **Electrical power generation and distribution** to generate AC and DC power from the engine connected generators and batteries, and to distribute the power to all connected equipment, whilst protecting the electrical bus-bars and the electrical wiring harnesses from connectedfaults

d) **Hydraulic power generation and distribution** to generate hydraulic power from engine driven pumps and to distribute hydraulic power to all connected systems. The hydraulic supply must be ripple free and constant pressure under all demand conditions and provided by clean hydraulic fluid and monitored to detect and isolateleaks.

e) **Secondary power system** to provide a source of electrical, hydraulic and cooling power for aircraft on the ground, and to provide a form of energy to start theengines.

f) **Emergencypowergeneration**toprovideenergytoallowsaferecoveryoftheaircraftinthe event of a major power loss.

g) **Flight control systems** to convert pilot demands or demands from guidance systems into control surface movements to control the aircraftattitude.

h) **Landing gear** to ensure that the aircraft is able to land safely at all loads and on designated runway surfaces. This includes the sequencing of all associated doors legand wheel assemblies to fit in the landing gearbay.

i) **Brakes/anti-skid** to provide a safe form of braking without loss of adhesion under a wide range of landing speeds andloads.

j) **Steering** to provide a means of steering the aircraft under its own power or whilst being towed

k) **Environmental control system** to provide air of an appropriate temperature and humidity to provide a safe and comfortable environment for crew, passengers and avionicsequipment.

l) **Fire protection** to monitor all bays where there is a potential hazard of fire, smoke or overheat, to warn the crew and to provide a means of extinguishingfire.

m) **Ice protection** to monitor external ambient conditions to detect icing conditions and to prevent the formation of ice or to removeice.

n) **External lighting** to ensure that the aircraft is visible to other operators and to ensure runway/taxiway visibility during groundmovements

o) **Probe heating** to ensure that the pitot, static, attitude and temperature probes on the external skin of the aircraft are kept free of ice

p) **Vehicle systems management system** to provide an integrated processing and communication system for interfacing with system components, performing built in test, performing control functions, providing power demands to actuators and effectors, and communicating with the cockpitdisplays.

Military aircraft also require the following systems:

- **Crew escape** to provide a means of assisted escape foraircrew.
- **Canopy jettison or fragmentation** to provide a means of removing the canopy from the aircraft or breaking the canopy material to provide a means of exit for escapingaircrew.
- **Biological and chemical protection** to protect the crew from the toxic effects of chemical or biologicalcontamination.
- **Arrestor mechanism** to provide a means of stopping the aircraft on a carrier deck or at the end of arunway.

- **In-flight refueling** to allow the aircraft to obtain fuel from a tankeraircraft.
- **Galley** to allow meals to be prepared and cooked forpassengers.
- **Passenger evacuation** to allow safe evacuation ofpassengers.
- **Entertainment systems** to provide audio and visual entertainment for passengers Telecommunications to allow passengers to make telephone calls and send e-mail in flight Gaseous oxygen for passenger use in case ofdepressurization

- **Cabin and emergency lighting** to provide general lighting for the cabin and galley, reading Lights, exit lighting and emergency lights to provide a visual path to theexit

AVIONICSSYSTEMS:

- The avionic systems are common to both civil and militaryaircraft.
- Not all aircraft types, however, will be fitted with the complete set listedbelow.
- The age and role of the aircraft will determine the exact suite ofsystems.
- The majority of the systems collects process transfers and responds todata.
- Any energy transfer is usually performed by a command to a vehiclesystem.

The following are the common (module) avionic system s both for civil and military aircrafts:

a) **Displays and controls** to provide the crew with information and warnings with which to operate theaircraft.

b) **Communications** to provide a means of communication between the aircraft and Air Traffic Control and otheraircraft.

c) **Navigation** to provide a worldwide, high accuracy navigationcapability.

d) **Flight Management System** to provide a means of entering flight plans and allowing automatic operation of the aircraft in accordance with theplans.

e) **Automated landing systems** to provide the capability to make automatic approach and landing under poor visibility conditions using instrument landing system (ILS); microwave landing system (MLS) or global positioning system(GPS).

f) **Weather radar** to provide information on weather conditions ahead of the aircraft – both precipitation and turbulence ahead of theaircraft.

g) **IFF/SSR** to provide information on the aircraft identification and height to airtraffic.

h) **Traffic collision avoidance system (TCAS)** to reduce the risk of collision with other aircraft.

i) **Ground proximity warning system (GPWS)/Terrain avoidance warning system (**TAWS) to reduce the risk of aircraft flying into the ground or into highground.

j) **Distance measuring equipment (DME**) to provide a measure of distance from a known beacon.

k) **Automatic direction finding (ADF)** to provide bearing from a knownbeacon.

l) **Radar altimeter** to provide an absolute reading of height above the ground orsea.

m) **Air data measurement** to provide information to other systems on altitude, air speed, outside air temperature and Machnumber.

n) **Accident data recorder** to continuously record specified aircraft parameters for use in analysis of seriousincidents

o) **Cockpit voice recorder** to continuously record specified aircrew speech for use in analysis of seriousincidents.

p) **Internal lighting** to provide a balanced lighting solution on the flight deck for all panels anddisplays

MISSIONSYSTEMS:

- Used for military aircrafts
- The military aircraft requires a range of sensors and computing to enable the crew to prosecute
- Designatedmissions.
- The mission systems gain information about the outside world fromactive
- And passive sensors and process this information to formintelligence.
- This is used by the crew, sometimes in conjunction with remote analysts on the ground, to make decisions that may involve attack. These decisions may, therefore, result in the release of weapons of defensiveaids.

The following are the major systems of a mission system:

- **Attack or surveillance radar** to provide information on hostile and friendlytargets.
- **Electro-optical sensors** to provide a passive surveillance oftargets.
- **Electronic support measures (ESM**) to provide emitter information, range and bearing of hostile transmitters.
- **Magnetic anomaly detector (MAD**) to confirm the presence of large metallic objects under the sea surface (submarines) prior toattack.
- **Acoustic sensors** to provide a means of detecting and tracking the passage of underwater Objects
- **Mission computing** to collate the sensor information and to provide a fused data picture to the cockpit or mission crewstations
- **Defensive aids** to provide a means of detecting missile attack and deploying countermeasures
- **Weapons system** to arm, direct and release weapons from the aircraft weaponstation
- **Communications** using a variety of different line-of-sight, high frequency (HF) or satellite Communicationssystems
- **Station keeping** providing a means of safely maintaining formation in conditions where Station-keeping lights are notpermitted.
- **Electronic warfare systems** to detect and identify enemy emitters, to collect and record Traffic and, if necessary, to provide a means of jammingtransmissions.
- **Cameras** to record weapon effects, or to provide a high resolution image of the ground for Intelligence purposes.
- **Head-up display** to provide the crew with primary aircraft information and weapon aiming Information.
- **Helmet-mounted displays** to provide primary flight information and weapon information to the crew, whilst allowing freedom of movement of thehead.
- **Data link** to provide transmission and receipt of messages under secure communications Using data rather thanvoice.

OPERATING ENVIRONMENTCONDITIONS:

The operating environment is determined by the conditions of use to which the product is put, and the areas of the world (or beyond) in which it has tooperate

HEAT

Heat is a waste commodity generated by in efficiencies of power sources, by equipment using power, by solar radiation, by crew and passengers, and by friction of air over the aircraft surface, especially during high speed flight. Thus all human and physical occupants of the aircraft are subject to the effects of heat. These effects range from those affecting the comfort of human occupants to those that cause irreparable damage to components of equipment. Typical considerations include:

- If the system or systems component is likely to be affected by heat, then it should not be installed near to a major heat source or it should be provided withcooling
- The aircraft environmental control system (ECS) can cool equipment using air or a liquid coolant
- Some systems produce heat in performing their function and must be isolated or insulated from other systems. Examples are engines, high powertransmitters
- Some systems produce heat which is useful/essential, for example, hydraulics for flight controlsystems.

NOISE

Noise is ever present in an aircraft environment. It is produced by the engines or auxiliary power units, by motor driven units, such as fans and motors, and by air flow over the fuselage. It can cause discomfort to passenger and crew, whilst high noise levels external to the aircraft can cause damage. Typical considerations include

- High sound pressures or acoustic noise levels can damage equipment. Installation in areas subject to high noise levels should be avoided. Typical areas are engine bays, external areas subjecttoengineexhaustorbayslikelytobeopenedinhighspeedflightforexample,bombbays
- Equipment can produce noise that is likely to be a nuisance to aircrew, contributing tofatigue

and loss of concentration. Examples are fans and pumps/motors installed in the cockpit. Measures must be taken to install equipment so that excessive noise can be avoided and crew efficiencymaintained

RFRADIATION

Radio frequencies (RF) are radiated from equipment and from the aircraft, either deliberately or accidentally. As far as aircraft systems are concerned, RF emissions generally occur in the electromagnetic spectrum from 10 MHz to tens of GHz. Accidental radiation occurs when equipment or wiring is badly installed, or inadequately or incorrectly screened. Deliberate radiation occurs during radio transmissions, navigation equipment transmissions and operation of radars and other communication equipment. RF radiation can cause interruption or corruption of a system function by affecting system

Component operation or by corrupting data. Typical considerations include:

- Equipment should be protected from the effects of RF radiation by the application of an electromagnetic health (EMH) strategy. This involves the use of signal wire segregation, screening, bonding, separation of wiring and equipment, and RF sealing of equipment. This will obviate the effects of some of the key electromagnetic effects: Electromagnetic interference (EMI) resulting from the effects of local equipment on board theaircraft
- Lightning strike on the structure or in the vicinity of the aircraft High intensity radio frequency (HIRF) from local high power transmitters such as airfield primary surveillance radar or domestic radiotransmitters

- Radiated transmissions can disclose the presence of an aircraft to enemy forces, which can be used as intelligence or as a means of identifying a target forattack
- In the military field, analysis of signals by an Electronic Support Measures (ESM) team can provide valuable intelligence about deployment of militaryassets.

SOLAR ENERGY

Sunlight will impinge on the surface of the aircraft and will enter through windows and canopies, thereby exposing some parts of the interior. Prolonged exposure at high altitudes to unfiltered ultraviolet (UV) and infrared (IR) is likely to damage some materials. UV exposure is also experienced when parked for long periods on the tarmac. Typical considerations include:

- The UV and IR content of solar radiation can cause damage to plastic materials such as discoloration, cracking and brittleness. This can affect interior furnishings such as display bezels and switch/knob handles Items most affected are those situated on the aircraft outer skin for example, antennas, where high altitude, long duration exposure isexperienced
- Cockpit items are also vulnerable if likely to be in direct sunlight in flight or whilst the aircraft is parked – cockpit temperatures have been known to reach over 100◦C in some parts of the world
- All such items must be designed to withstand such effects and must betested
- Glare and reflection will affect crew visual performance, and may adversely affect display visibility.

DESIGNDRIVERS

Design drivers arise in the environment of the system as perceived by different organizational Levels. The system may be considered to have a series of overlapping environments containing Drivers with varying degrees of influence and crossing environment boundaries.

The business environment – the consideration of the value to the business of bidding for a contract taking into account factors within the organization and external pressures. It is Often at this stage that decisions are taken to proceed or not with winning the business.

The project environment – once a contract has been accepted a project team will focus on the impact on the organization of taking the project through its initial stages. This is very much a risk reduction stage to ensure that the business has the appropriate skills, experience and resources to bring the project to a satisfactoryconclusion.

The product environment – the detailed design and production readiness factors that must be considered.

The product operating environment – ensuring that the design incorporates all known factors likely to be encountered when the product enters service.

The sub-system environment – the detailed factors of sub-system and component design.

UNIT II
ELECTRICAL SYSTEMS AND AIR CONDITIONING, PRESSURIZING SYSTEMS

ELECTRICALLOADS:

Once the aircraft electrical power has been generated and distributed then it is available to the aircraft services. These electrical services cover a range of functions spread geographically throughout the aircraft depending upon their task. While the number of electrical services is legion they may be broadly subdivided into the following categories:

- Motors andactuation
- Lightingservices
- Heatingservices
- Subsystem controllers and avionicssystems

MOTORSANDACTUATION:

Motors are obviously used where motive force is needed to drive a valve actuator from one position to another depending upon the requirements of the appropriate aircraft system. Typical uses for motors are:

- Linear actuation: electrical position actuators for engine control; trim actuators For flight controlsystems
- Rotary actuation: electrical position actuators for flap/slatoperation
- Control valve operation: electrical operation of fuel control valves; hydraulic control valves; air control valves; control valves for ancillarysystems
- Starter motors: provision of starting for engine, APU and other systems that require assistance to reach self-sustaining operation
- Pumps: provision of motive force for fuel pumps, hydraulic pumps; pumping for auxiliarysystems
- Gyroscope motors: provision of power to run gyroscopes for flight instruments and autopilots;
- Fan motors: provision of power to run cooling fans for the provision of air topassengers orequipment

POWER GENERATIONCONTROL:

The primary elements of power system control are:

DCSYSTEMS

– Voltage regulation

– Paralleloperation

– Protectionfunctions

– Voltage regulation

– Paralleloperation

– Supervisoryfunctions

DC SYSTEMGENERATION:

Protectionfunctions

VoltageRegulation

- This shows a variable resistor in series with the field winding such that variation of the resistor alters the resistance of the fieldwinding;
- Hence the field current and output voltage may bevaried.
- In actual fact the regulation is required to be an automatic function that takes account of load and enginespeed.
- The voltage regulation needs to be in accordance with the standard used to specify aircraft power generation systems,namelyMIL-STD-704D.
- This standard specifies the voltage at the point of regulation and the nature of the acceptable voltage drops throughout the aircraft distribution, protection and wiring system.
- DC systems are limited to around 400 amps or 12 kW per channel maximum for two reasons:
- The size of conductors and switchgear to carry the necessary current becomesprohibitive
- The brush wear on brushed DC generators becomes excessive with resulting maintenance costs if these levels areexceeded

Parallel operation:

• In multi-engine aircraft each engine will be driving its own generator and in this situation it is desirable that ‘no-break’ or uninterrupted power is provided in cases of engine or generator failure.

• A number of sensitive aircraft instruments and navigation devices which comprise some of the electrical loads may be disturbed and may need to be restarted or re-initialized following a Powerinterruption.

• In order to satisfy this requirement generators are paralleled to carry an equal proportionof the electrical load between them.

• Individual generators are controlled by means of voltage regulators that automatically compensate forvariations.

• In the case of parallel generator operation there is a need to interlink the voltage regulators such that any unequal loading of the generators can be adjusted by means of corresponding alterations in fieldcurrent.

• This paralleling feature is more often known as an equalizing circuit and therefore provides ‘no break’ power in the event of a major systemfailure.

Protection functions:

The primary conditions for which protection needs to be considered in a DC system are as follows:

Reverse current. In a DC system it is evident that the current should flow from the generator to the bus bars and distribution systems. In a fault situation it is possible for current to flow in the reverse direction and the primary system components need to be protected from this eventualityThis could then result in the electrical loads being subject to conditions that could cause permanent damage. Over voltage protection senses these failure conditions and opens the line contactor taking the generator offline

Under voltage protection. In a single generator system under voltage is a similar fault condition as the reverse current situation already described. However, in a multi-generator configuration with paralleling by means of an equalizing circuit, the situation is different. Here an under voltage protection capability is essential as the equalizing circuit is always trying to raise the output of a lagging generator in this situation the under voltage protection is an integral part of the parallel load sharingfunction

AC POWER GENERATIONCONTROL:

- Voltage regulation
- Paralleloperation

Voltage regulation:

AC generators differ from DC machines in that they require a separate source of DC excitation for the field windings although the system described earlier does allow the generator to bootstrap the generation circuits.

The subject of AC generator excitation is a complex topic for which the technical solutions vary according to whether the generator is frequency wild or constant frequency.

Some of these solutions comprise sophisticated control loops with error detectors, pre-amplifiers and power amplifiers.

Parallel operation:

• In the same way that DC generators are operated in parallel to provide ‘no break’ power, AC generators may also be controlled in a similarfashion.

• This technique only applies to constant frequency AC generation as it is impossible to parallel frequency-wild or Variable Frequency (VF) ACgenerators.

• In fact many of the aircraft loads such as anti/de-icing heating elements driven by VF generators are relatively frequency insensitive and the need for ‘no break ’power is not nearly so important. To parallel AC machines the control task is more complex as both real and reactive (imaginary) load vectors have to be synchronized for effective loadsharing.

- The sharing of real load depends upon the relative rotational speeds and hence the relative phasing of the generatorvoltages.
- Constant speed or constant frequency AC generation depends upon the tracking accuracy of the constant speed drives of the generatorsinvolved.
- In practice real load sharing is achieved by control laws which measure the degree of load imbalance by using current transformers and error detection circuitry, thereby trimming the constant speed drives such that the torques applied by all generators areequal.

- The sharing of reactive load between the generators is a function of the voltage generated by each generator as for the DC parallel operationcase.
- The generator output voltages depend upon the relevant performance of the voltage regulators and field excitationcircuitry.
- To accomplish reactive load sharing requires the use of special transformers called mutual reactors, error detection circuitry and pre-amplifiers/power amplifiers to adjust the field excitationcurrent.

POWER DISTRIBUTION

The generic parts of a typical Alternating Current (AC) aircraft electrical system Power generation

- Primary power distribution andprotection
- Power conversion and energystorage
- Secondary power distribution andprotection

Power generation:

1. DC PowerGeneration

- DC systems use generators to develop a DC voltage to supply aircraft systemloads.
- Usually the voltage is 28 VDC but there are 270 VDC systems inbeing.
- The generator is controlled – the technical term is regulated – to supply 28 VDC at all times to the aircraft loads such that any tendencies for the voltage to vary or fluctuate areovercome.
- DC generators are self-exciting, in that they contain rotating electro-magnets that generate the electricalpower.
- The conversion to DC power is achieved by using a device called a commutate which enables the output voltage, which would appear as a simple sine wave output, to be effectivelyhalf-wave rectified.

2. AC PowerGeneration

An AC system uses a generator to generate a sine wave of a given voltage and, in most cases, of a constantfrequency.

The construction of the alternator is simpler than that of the DC generator in that no commutator is required.

Early AC generators used slip rings to pass current to/from the rotor winding show ever these suffered from abrasion and pitting, especially when passing high currents at altitude.

AC generator parallel operation Supervisory and protection functions

Typical supervisory or protection functions undertaken by a typical AC generator controller or GCU are listed below:

- Overvoltage
- Undervoltage
- Under/overexcitation
- Under/overfrequency
- Differential currentprotection
- Correct phaserotation

The overvoltage, under voltageand under/over-excitation functions is similar to the corresponding functions described for DC generationcontrol.

Under/over frequency protection is effectively executed by the real load sharing function already described above for AC parallel operation.

Differential current protection is designed to detect a short-circuit bus bar or feeder line fault which could impose a very high current demand on the short-circuited phase.

2.3.1PRIMARY POWER DISTRIBUTION:

The primary power distribution system consolidates the aircraft electrical power inputs.

In the case of a typical civil airliner the aircraft may accept power from the following sources:

- Main aircraft generator; by means of a Generator Control Breaker (GCB) under the control of the GCU
- Alternate aircraft generator – in the event of generator failure – by means of a Bus Tie Breaker under the control of a Bus Power Control Unit(BPCU)
- APU generator; by means of an APU GCB under the control of theBPCU
- Ground power; by means of an External Power Contactor (EPC) under the control of the BPCU
- Backup converter, by means of a Converter Control Breaker (CCB) under the control of the VSCF Converter (B777only)
- RAT generator when deployed by the emergency electricalsystem
- The power switching used in these cases is a power contactor or breaker. These are special high power switches that usually switch power in excess of 20 amps per phase. As well as the power switching contacts auxiliary contacts are included to provide contactor status – 'Open' or 'Closed – to other aircraftsystems.
- Higher power aircraft loads are increasingly switched from the primary aircraft bus bars by using Electronic Load Control Units (ELCUs) or 'smart contactors' for load protection. Like contactors these are used where normal rated currents are greater than 20 amperes per phase, i.e. for loads of around 7kVA orgreater.

2.3.2SECONDARY POWER DISTRIBUTION:

a. Power Switching

- In order to reconfigure or to change the state of a system it is Innecessary to switch power at various levels within thesystem.
- At the high power levels that prevail at the primary power part of the system, power switching is accomplished by high power electromagnetic devices calledcontactors.
- These devices can switch hundreds of amps and are used to switch generator power on to the primary bus bars in both DC and ACsystems.
- The devices may be arranged so that they magnetically latch, that is they are magnetically held in a preferred state or position until a signal is applied to change thestate.
- In other situations a signal may be continuously applied to the contactor to hold the contacts closed and removal of the signal causes the contacts toopen.

- For switching currents below 20 amps or so relays are generallyused.
- These operate in a similar fashion to contactors but are lighter, simpler and lessexpensive.
- Relays may be used at certain places in the primaryelectricalsystem.
- For lower currents still where the indication of device status is required, simple switches can be employed.

These switches may be manually operated by the crew or they may be operated by other physical means as part of the aircraft operation.

LOADPROTECTION:

a. Circuit Breakers

- Circuit breakers perform the function of protecting a circuit in the event of an electrical overload. Circuit breakers serve the same purpose as fuses or currentlimiters.
- A circuit breaker comprises a set of contacts which are closed during normal circuit operation. The device has a mechanical trip mechanism which is activated by means of a bi-metallic element.

- When an overload current flows, the bi-metallic element causes the trip mechanism to activate, thereby opening the contacts and removing power from thecircuit.
- A push button on the front of the unit protrudes showing that the device has tripped. Pushing in the push button resets the breaker but if the fault condition still exists the breaker will trip again.
- Physically pulling the button outwards can also allow the circuit breaker to break the circuit, perhaps for equipment isolation or aircraft maintenancereasons.
- Circuit breakers are rated at different current values for use in differing current carrying circuits. This enables the trip characteristic to be matched to eachcircuit.

POWER CONVERSION AND ENERGYSTORAGE:

There are, however, many occasions within an aircraft electrical system where it is required to convert power from one form to another.
Typical examples of power conversion are:

- Conversion from DC to AC power – this conversion uses units called inverters to convert 28 VDC to 115 VAC single phase or three-phasepower
- Conversion from 115 VAC to 28 VDC power – this is a much used conversion Using units called Transformer RectifierUnits(TRUs)
- Conversion from one AC voltage level to another; a typical conversion would be from 115 VAC to26VAC
- Battery charging – as previously outlined it is necessary to maintain the state of charge of the aircraft battery by converting 115 VAC to a 28 VDC battery charge voltage
- Battery charging – as previously outlined it is necessary to maintain the state of charge of the aircraft battery by converting 115 VAC to a 28 VDC batterychargevoltage

RECENT SYSTEMSDEVELOPMENTS:
In recent years a number of technology advances have taken place in the generation, switching and protection of electrical power.
These new developments are beginning to have an impact upon the classic electrical systems.

- Electrical Load ManagementSystem(ELMS)
- Variable Speed Constant Frequency (VSCF) – Cycloconverter
- 270 VDCsystems
- More-ElectricAircraft(MEA)

ELECTRICAL LOAD MANAGEMENT SYSTEM(ELMS):
The Boeing 777 Electrical Load Management System (ELMS) developed and manufactured by GE Aviation set new standards for the Industry in terms of electrical load management. The general layout of the ELMS. The system represents the first integrated electrical power distribution and load management system for a civil aircraft.

VARIABLE SPEED CONSTANT FREQUENCY (VSCF):
There are considerable benefits to be accrued by dispensing with the conventional AC power generation techniques using IDGs to produce large quantities of frequency stable 400 Hz 115 VAC power.
Theory of VSCF Cycle converter System Operation

The VSCF system consists of a brushless generator and a solid state frequency converter.

2.6.3270 VDC SYSTEMS:

- An initiative which has been underway for a number of years in the US military development agencies is the 270 VDCsystems.

- The US Navy has championed this concept and the technology has developed to the point that some of the next generation of US combat aircraft will have this system imposed as a tri-Service requirement.
- The aircraft involved are the US Air Force Advanced Tactical Fighter (ATF) (now the Lockheed F-22 Raptor), the former US Navy Advanced Tactical Aircraft (ATA) or A-12, and the US Army Light Helicopter (LHX or LH) (now known asRAH-66Comanche).
- The selected version of JSF – the Lockheed Martin F-35 Lightning II uses 270 VDC for the primary electricalsystem.
- The use of 270 VDC is an extrapolation of the rationale for moving from 28 VDC to 115 VAC: reduction in the size of current carrying conductors thereby minimising weight, voltage drop and powerdissipation.
- There are, however, a number of disadvantages associated with the use of 270 VDC. 270 VDC components are by no means commonplace; certainly were not so at the beginning of development and even now are notinexpensive.

Pressure and Force Measurement

Pressure Measurement

Measurement of pressure inside a pipeline or a container in an industrial environment is a challenging task, keeping

in mind that pressure may be very high, or very low (vacuum); the medium may be liquid, or gaseous. We will not discuss the vacuum pressure measuring techniques; rather try to concentrate on measurement techniques of pressure higher than the atmospheric. They are mainly carried out by using elastic elements: diaphragms, bellows and Bourdon tubes. These elastic elements change their shape with applied pressure and the change of shape can be measured using suitable deflection transducers. Their basic constructions and principle of operation are explained below.

Diaphragms

Diaphragms may be of three types: Thin plate, Membrane and Corrugated diaphragm. This classification is based on the applied pressure and the corresponding displacements. Thin plate (fig. 1(a)) is made by machining a solid block and making a circular cross sectional area with smaller thickness in the middle. It is used for measurement of relatively higher pressure. In a membrane the sensing section is glued in between two solid blocks as shown in fig. 1(b). The thickness is smaller; as a result, when pressure is applied on one side, the displacement is larger. The sensitivity can be further enhanced in a corrugated diaphragm (fig. 1(c)), and a large deflection can be obtained for a small change in pressure; however at the cost of linearity. The materials used are Bronze, Brass, and Stainless steel. In recent times, Silicon has been extensively used the diaphragm material in MEMS (Micro

Electro Mechanical Systems) pressure sensor. Further, the natural frequency of a diaphragm can be expressed as:

$$f_n = \frac{1}{2\pi}\sqrt{\frac{k}{m_{eq}}} \qquad (1)$$

where m_{eq} = equivalent mass, and

k= elastic constant of the diaphragm.

The operating frequency of the pressure to be measured must be less than the natural frequency of the diaphragm.

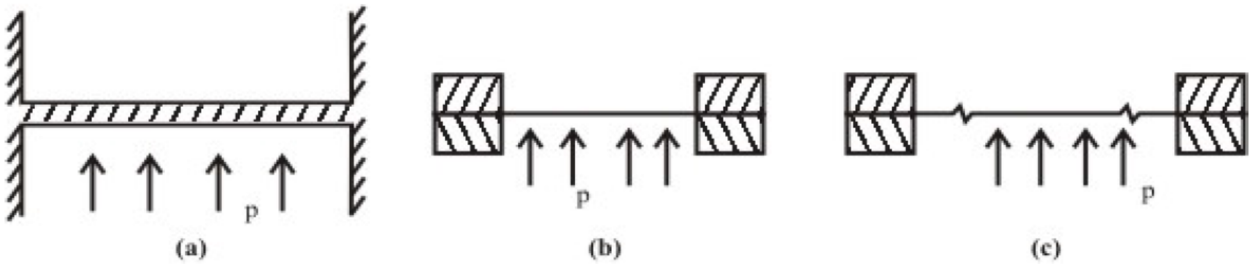


Fig. 1 (a) Thin plate, (b) Membrane and (c) Corrugated diaphragm.

When pressure is applied to a diaphragm, it deflates and the maximum deflection at the centre (y_0) can measured using a displacement transducer. For a Thin plate, the maximum deflection y_0 is small ($y_0 < 0.3t$) and referring fig. 2, a linear relationship between p and y_0 exists as:

$$y_0 = \frac{3}{16} p \frac{(1-\nu^2)}{Et^3} R^4 \qquad (2)$$

where, E= Modulus of elasticity of the diaphragm material, and

ν = Poisson's ratio.

However, the allowable pressure should be less than:

$$p_{\max} = 1.5\left(\frac{t}{R}\right)^2 \sigma_{\max} \qquad (3)$$

where, $\sigma_{\max}$ is the safe allowable stress of the material.

For a membrane, the deflection is larger, and the relationship between p and y_0 is nonlinear and can be expressed as (for $\nu = 0.3$):

$$p = 3.58 \frac{E t^3}{R^4} y_0^{\,3} \qquad (4)$$

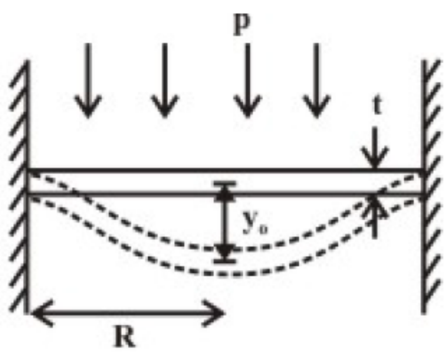


Fig. 2 Displacement of a diaphragm

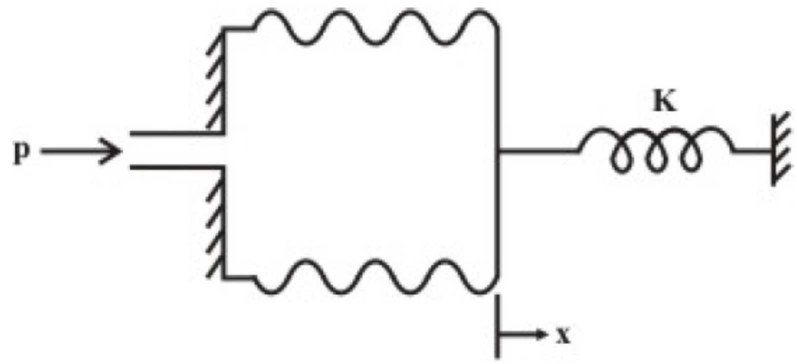


Fig. 3 Bellows

For a corrugated diaphragm, it is difficult to give any definite mathematical relationship between p and y_0; but the relationship is also highly nonlinear.

As the diaphragm deflates, strains of different magnitudes and signs are generated at different locations of the diaphragm. These strains can also be measured by effectively placing four strain gages on the diaphragm. The principle of strain gage will be discussed in the next section.

Bellows

Bellows (fig. 3) are made with a number of convolutions from a soft material and one end of it is fixed, wherein air can go through a port. The other end of the bellows is free to move. The displacement of the free end increases with the number of convolutions used. Number of convolutions varies between 5 to 20. Often an external spring is used opposing the movement of the bellows; as a result a linear relationship can be obtained from the equation:

$$pA = kx \tag{5}$$

where, *A* is the area of the bellows,
k is the spring constant and
x is the displacement of the bellows

Bourdon Tube

Bourdon tube pressure gages are extensively used for local indication. This type of pressure gages were first developed by E. Bourdon in 1849. Bourdon tube pressure gages can be used to measure over a wide range of pressure: form vacuum to pressure as high as few thousand psi. It is basically consisted of a C-shaped hollow tube, whose one end is fixed and connected to the pressure tapping, the other end free, as shown in fig. 4. The cross section of the tube is elliptical. When pressure is applied, the elliptical tube tries to acquire a circular cross section; as a result, stress is developed and the tube tries to straighten up. Thus the free end of the tube moves up, depending on magnitude of pressure. A deflecting and indicating mechanism is attached to the free end that rotates the pointer. The materials used are commonly Phosphor Bronze, Brass and Beryllium Copper. For a 2” overall diameter of the C-tube the useful travel of the free end is approximately" 1/8. Though the C-type tubes are most common, other shapes of tubes, such as helical, twisted or spiral tubes are also in use.

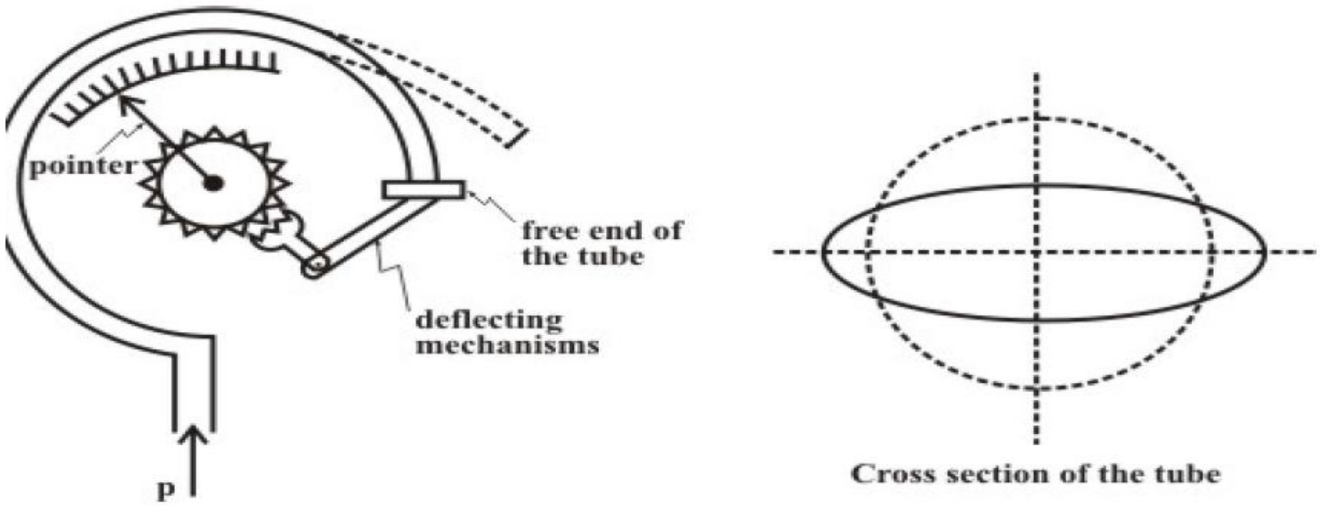


Fig. 4 Bourdon tube

Measurement of Force

The most popular method for measuring force is using strain gage. We measure the strain developed due to force using strain gages; and by multiplying the strain with the effective cross sectional area and Young’s modulus of the material, we can obtain force. Load cells and Proving rings are two common methods for force measurement using strain gages. We will first discuss the principle of strain gage and then go for the force measuring techniques.

Strain Gage

Strain gage is one of the most popular types of transducer. It has got a wide range of applications. It can be used for measurement of force, torque, pressure, acceleration and many other parameters. The basic principle of operation of a strain gage is simple: when strain is applied to a thin metallic wire, its dimension changes, thus changing the resistance of the wire. Let us first investigate what are the factors, responsible for the change in resistance.

Gage Factor

Let us consider a long straight metallic wire of length l circular cross section with diameter d (fig. 5). When this wire is subjected to a force applied at the two ends, a strain will be generated and as a result, the dimension will change

(l changing to $l+\Delta l$, d changing to $d+\Delta d$ and A changing to $A+\Delta A$). For the time being, we are considering that all the changes are in positive direction. Now the resistance of the wire:

$R = \frac{\rho l}{A}$, where ρ is the resistivity.

From the above expression, the change in resistance due to strain:

$$\Delta R = \left(\frac{\partial R}{\partial l}\right)\Delta l + \left(\frac{\partial R}{\partial A}\right)\Delta A + \left(\frac{\partial R}{\partial \rho}\right)\Delta\rho$$
$$= \frac{\rho}{A}\Delta l - \frac{\rho}{A^2}\Delta A + \frac{l}{A}\Delta\rho$$
$$= R\frac{\Delta l}{l} - R\frac{\Delta A}{A} + R\frac{\Delta\rho}{\rho}$$

or,

$$\frac{\Delta R}{R} = \frac{\Delta l}{l} - \frac{\Delta A}{A} + \frac{\Delta\rho}{\rho} \qquad (6)$$

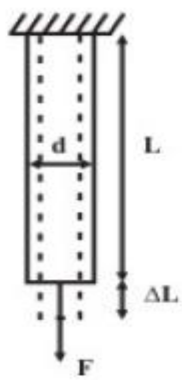


Fig. 5 Change of resistance with strain

Now, for a circular cross section, $A = \frac{\pi d^2}{4}$; from which, $\Delta A = \frac{\pi d}{2}\Delta d$. Alternatively,

$$\frac{\Delta A}{A} = 2\frac{\Delta d}{d}$$

Hence,

$$\frac{\Delta R}{R} = \frac{\Delta l}{l} - 2\frac{\Delta d}{d} + \frac{\Delta\rho}{\rho} \qquad (7)$$

Now, the *Poisson's Ratio* is defined as:

$$\upsilon = -\frac{lateral \quad strain}{longitudinal \quad strain} = -\frac{\Delta d/d}{\Delta l/l}$$

The Poisson's Ratio is the property of the material, and does not depend on the dimension. So, (6) can be rewritten as:

$$\frac{\Delta R}{R} = (1+2\upsilon)\frac{\Delta l}{l} + \frac{\Delta\rho}{\rho}$$

Hence,

$$\frac{\Delta R / R}{\Delta l / l} = 1 + 2\upsilon + \frac{\Delta \rho / \rho}{\Delta l / l}$$

The last term in the right hand side of the above expression, represents the change in resistivity of the material due to applied strain that occurs due to the *piezo-resistance property* of the material. In fact, all the elements in the right hand side of the above equation are independent of the geometry of the wire, subjected to strain, but rather depend on the material property of the wire. Due to this reason, a term *Gage Factor* is used to characterize the performance of a strain gage. The Gage Factor is defined as:

$$G := \frac{\Delta R / R}{\Delta l / l} = 1 + 2\upsilon + \frac{\Delta \rho / \rho}{\Delta l / l} \qquad (8)$$

For normal metals the Poisson's ratio υ varies in the range:

$$0.3 \le \upsilon \le 0.6,$$

while the piezo-resistance coefficient varies in the range:

$$0.2 \le \frac{\Delta \rho / \rho}{\Delta l / l} \le 0.6.$$

Thus, the Gage Factor of metallic strain gages varies in the range 1.8 to 2.6. However, the semiconductor type strain gages have a very large Gage Factor, in the range of 100-150. This is attained due to dominant piezo-resistance property of semiconductors. The commercially available strain gages have certain fixed resistance values, such as, 120Ω, 350 Ω, 1000 Ω, etc. The manufacturer also specifies the Gage Factor and the maximum gage current to avoid self-heating (normally in the range 15 mA to 100 mA).

The choice of material for a metallic strain gage should depend on several factors. The material should have low temperature coefficient of resistance. It should also have low coefficient for thermal expansion. Judging from all these factors, only few alloys qualify for a commercial metallic strain gage. They are:

Advance (55% Cu, 45% Ni): Gage Factor between 2.0 to 2.2

Nichrome (80% Ni, 20% Co): Gage Factor between 2.2 to 2.5

Apart from these two, *Isoelastic* -another trademarked alloy with Gage Factor around 3.5 is also in use. Semiconductor type strain gages, though having large Gage Factor, find limited use, because of their high sensitivity and nonlinear characteristics.

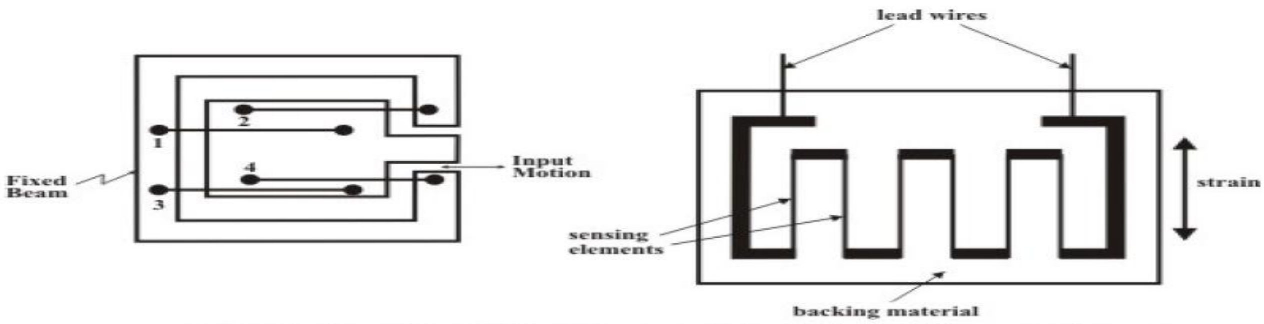


Fig. 6 (a) Unbonded metallic strain gage, (b) bonded metal foil type strain gage

Metallic Strain Gage

Most of the strain gages are metallic type. They can be of two types: *unbonded* and *bonded*. The unbonded strain gage is normally used for measuring strain (or displacement) between a fixed and a moving structure by fixing four metallic wires in such a way, so that two are in compression and two are in tension, as shown in fig. 6 (a). On the other hand, in the bonded strain gage, the element is fixed on a backing material, which is permanently fixed over a structure, whose strain has to be measured, with adhesive. Most commonly used bonded strain gages are *metal foil type*. The construction of such a strain gage is shown in fig. 6(b). The metal foil type strain gage is manufactured by photo-etching technique. Here the thin strips of the foil are the active elements of the strain gage, while the thick ones are for providing electrical connections. Because of large area of the thick portion, their resistance is small and they do not contribute to any change in resistance due to strain, but increase the heat dissipation area. Also it is easier to connect the lead wires with the strain gage. The strain gage in fig. 6(b) can measure strain in one direction only. But if we want to measure the strain in two or more directions at the same point, strain gage *rosette*, which is manufactured by stacking multiple strain gages in different directions, is used. Fig. 7 shows a three-element strain gage rosette stacked at 45^{0}.

The *backing material*, over which the strain gage is fabricated and which is fixed with the strain measuring structure has to satisfy several important properties. Firstly, it should have high mechanical strength; it should also have high dielectric strength. But the most important it should have is that it should be non-hygroscopic, otherwise, absorption of moisture will cause bulging and generate local strain. The backing materials normally used are impregnated paper, fibre glass, etc. The *bonding material* used for fixing the strain gage permanently to the structure should also be non-hygroscopic. Epoxy and Cellulose are the bonding materials normally used.

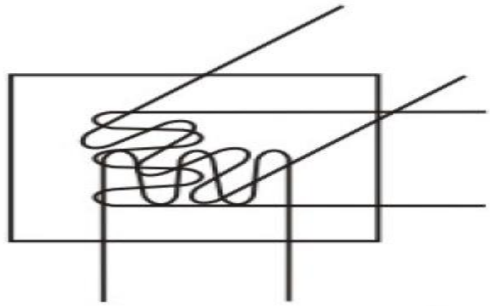


Fig. 7 Three-element strain gage rosette- 45° stacked.

Semiconductor type Strain Gage

Semiconductor type strain gage is made of a thin wire of silicon, typically 0.005 inch to 0.0005 inch, and length 0.05 inch to 0.5 inch. They can be of two types: *p*-type and *n*-type. In the former the resistance increases with positive strain, while, in the later the resistance decreases with temperature. The construction and the typical characteristics of a semiconductor strain gage are shown in fig.8.

MEMS pressure sensors is now a day's becoming increasingly popular for measurement of pressure. It is made of a small silicon diagram with four piezo-resistive strain gages mounted on it. It has an in-built signal conditioning circuits and delivers measurable output voltage corresponding to the pressure applied. Low weight and small size of the sensor make it suitable for measurement of pressure in specific applications.

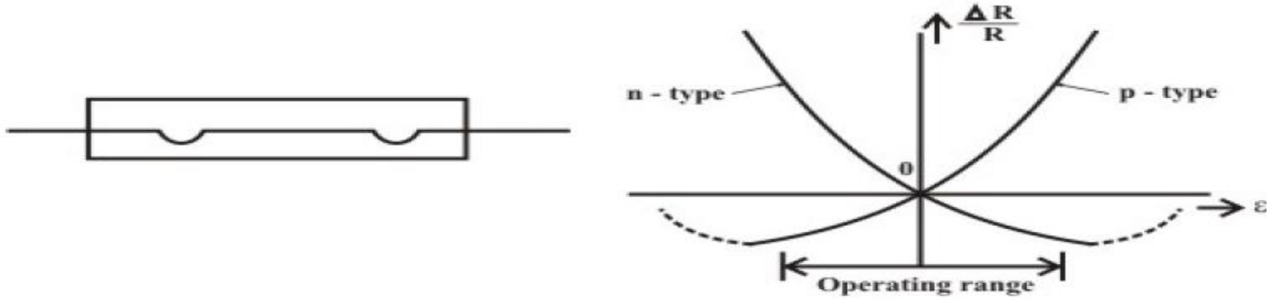


Fig. 8 (a) construction and (b) characteristics of a semiconductor strain gage

Strain Gage Bridge

Normal strain experienced by a strain gage is in the range of micro strain (typical value: 100 x 10^{-6}). As a result, the change in resistance associated with it is small (*R*Δ/RεG=). So if a single strain gage is connected to a wheatstone bridge, with three fixed resistances, the bridge output voltage is going to be linear (recall, that we say the bridge output voltage would be linearly varying with *R*Δ/R, if *RR*Δ does not exceed 0.1). But still then, a single strain gage is normally never used in a wheatstone bridge. This is not because of improving linearity, but for obtaining *perfect temperature compensation*. Suppose one strain gage is connected to a bridge with three fixed arms. Due to temperature rise, the strain gage resistance will change, thus making the bridge unbalance, thus giving an erroneous signal, even if no strain is applied. If two identical strain gages are fixed to the same structure, one measuring compressional strain and the other tensile strain, and connected in the adjacent arms of the bridge, temperature compensation can be achieved. If the temperature increases, both the strain gage resistances will be affected in the same way, thus maintaining the bridge balance under no strain condition. One more advantage of using the push-pull configuration is increasing the sensitivity. In fact, all the four arms of the bridge can be formed by four active gages; this will improve the sensitivity further, while retaining the temperature compensation property. A typical strain gage bridge is shown in fig. 9. It can be shown that if nominal resistances of the strain gages are same and also equal gage factor *G*, then the unbalanced voltage is given be:

$$e_0 = \frac{EG}{4}(\varepsilon_1 + \varepsilon_3 - \varepsilon_2 - \varepsilon_4) \qquad (9)$$

where ε_1, ε_2, ε_3, ε_4 are the strains developed with appropriate signs.

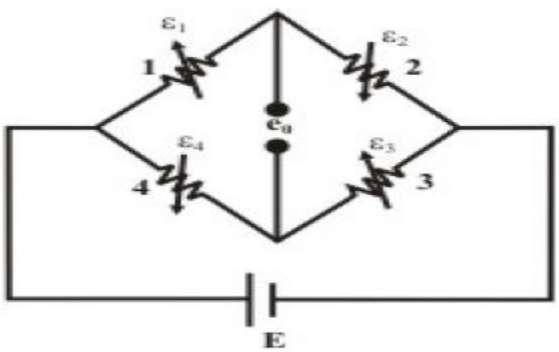


Fig. 9 Strain gage bridge with four active gages

Load Cell

Load cells are extensively used for measurement of force; weigh bridge is one of the most common applications of load cell. Here two strain gages are fixed so as to measure the longitudinal strain, while two other measuring the transverse strain, as shown in fig. 10. The strain gages, measuring the similar strain (say, tensile) are placed in the opposite arms, while the adjacent arms in the bridge should measure opposite strains (one tensile, the other compressional). If the strain gages are identical in characteristics, this will provide not only the perfect temperature coefficient, but also maximum obtainable sensitivity from the bridge. The longitudinal strain developed in the load cell would be compressional in nature, and is given by: $\varepsilon_1 = -\frac{F}{A\ E}$, where F is the force applied, A is the cross sectional area and Y is the Young's modulus of elasticity. The strain gages 1 and 3 will experience this strain, while for 2 and 4 the strain will be $\varepsilon_2 = \frac{\nu F}{AE}$, where ν is the Poisson's ratio.

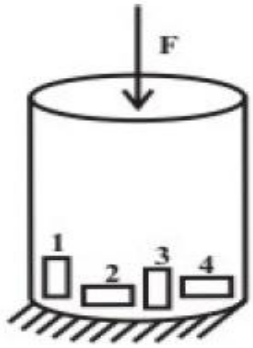


Fig. 10 Load cell with four strain gages

Proving Ring

Proving Rings can be used for measurement of both compressional and tensile forces. The advantage of a Proving Ring is that, because of its construction more strain can be developed compared to a load cell. The typical construction of a Proving Ring is shown in fig.11. It consists of a hollow cylindrical beam of radius *R*, thickness *t* and axial width *b*. The two ends of the ring are fixed with the structures between which force is measured. Four strain gages are mounted on the walls of the proving ring, two on the inner wall, and two on the outer wall. When force is applied as shown, gages 2 and 4 will experience strain $-\varepsilon$ (compression), while gages 1 and 3 will experience strain $+\ \varepsilon$ (tension). The magnitude of the strain is given by the expression:

$$\varepsilon = \frac{1.08FR}{Ebt^2} \qquad (10)$$

The four strain gages are connected in a bridge and the unbalanced voltage can easily be calibrated in terms of force to be measured.

Cantilever Beam

Cantilever beam can be used for measurement up to 10 kg of weight. One end of the cantilever is fixed, while the other end is free; load is applied at this end, as shown in fig. 12. The strain developed at the fixed end is given by the expression:

$$\varepsilon = \frac{6Fl}{Ebt^2} \qquad (11)$$

where,

l = length of the beam
t = thickness of the cantilever
b = width of the beam
E = Young's modulus of the material
The strain developed can be measured by fixing strain gages at the fixed end: two on the top side of the beam, measuring tensile strain $+\varepsilon$ and two on the bottom measuring compressional strain $-\varepsilon$ (as shown in fig. 12) and using eqn. (9).

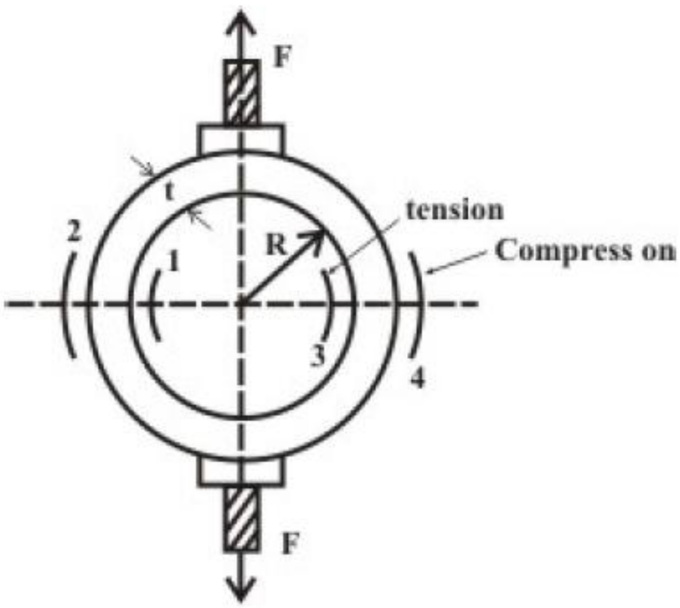


Fig. 11 Proving Ring

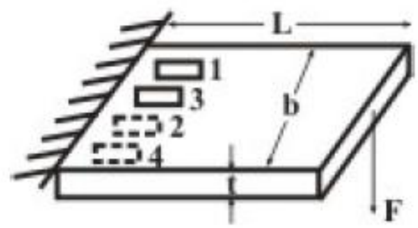


Fig. 12 Cantilever Beam

Displacement Measurement

Broadly speaking, displacement measurement can be of two types: contact and noncontact types. Besides the measurement principles can be classified into two categories: electrical sensing and optical sensing. In electrical sensing, passive electrical sensors are used variation of either inductance or capacitance with displacement is measured. On the other hand the optical method mainly works on the principle of intensity variation of light with distance. Interferometric technique is also used for measurement of very small displacement in order of nanometers. But this technique is more suitable for laboratory purpose, not very useful for industrial applications.

Potentiometer

Potentiometers are simplest type of displacement sensors. They can be used for linear as well as angular displacement measurement, as shown in Fig. 1. They are the resistive type of transducers and the output voltage is proportional to the displacement and is given by:

$$e_o = \frac{x_i}{x_t} E \quad ,$$

where x_i is the input displacement, x_t is the total displacement and E is the supply voltage.
The major problem with potentiometers is the contact problem resulting out of wear and tear between the moving and the fixed parts. As a result, though simple, application of potentiometers is limited.

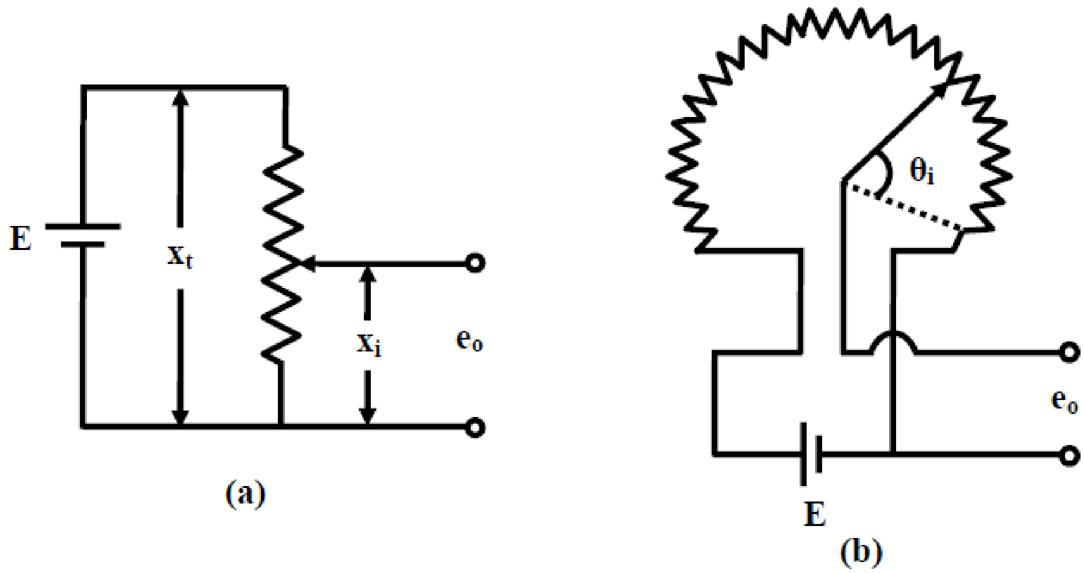


Fig. 1 Potentiometer
(a) Linear
(b) Rotary

Linear Variable Differential transformer (LVDT)

LVDT works on the principle of variation of mutual inductance. It is one of the most popular types of displacement sensor. It has good linearity over a wide range of displacement. Moreover the mass of the moving body is small, and the moving body does not make any contact with the static part, thus minimizing the frictional resistance. Commercial LVDTs are available with full scale displacement range of 0.25mm to ±±25mm. Due to the low inertia of the core, the LVDT has a good dynamic characteristics and can be used for time varying displacement measurement range.
The construction and principle of operation of LVDT can be explained with Fig. 2(a) and Fig. 2(b). It works on the principle of variation of the mutual inductance between two coils with displacement. It consists of a primary winding and two identical secondary windings of a transformer, wound over a tubular former, and a ferromagnetic core of annealed nickel-iron alloy moves through the former. The two secondary windings are connected in series opposition, so that the net output voltage is the difference between the two. The primary winding is excited by 1-10V r.m.s. A.C. voltage source, the frequency of excitation may be anywhere in the range of 50 Hz to 50 KHz. The output voltage is zero

when the core is at central position (voltage induced in both the secondary windings are same, so the difference is zero), but increasing as the core moves away from the central position, in either direction. Thus, from the measurement of the output voltage only, one cannot predict, the direction of the core movement. A phase sensitive detector (PSD) is a useful circuit to make the measurement direction sensitive. It is connected at the output of the LVDT and compares the phase of the secondary output with the primary signal to judge the direction of movement. The output of the phase sensitive detector after low pass filtering becomes a d.c voltage for a steady deflection. The output voltage after PSD vs. displacement characteristics is shown in Fig. 2(c).

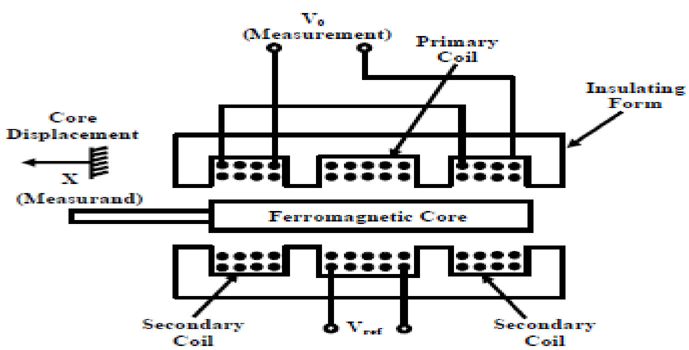


Fig. 2(a) Construction of LVDT.

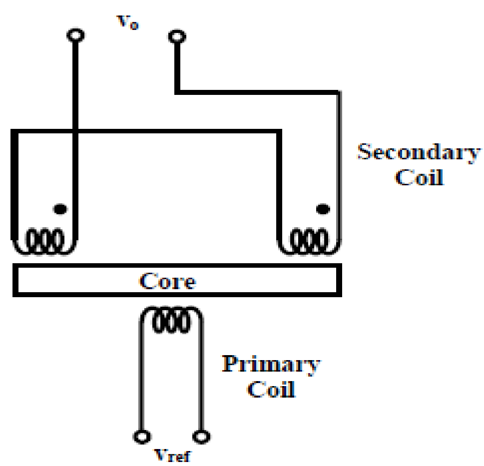


Fig. 2(b) Series opposition connection of secondary windings.

Inductive type Sensors

LVDT works on the principle of variation of mutual inductance. There are inductive sensors for measurement of displacement those are based on the principle of variation of self inductance. These sensors can be used for proximity detection also. Such a typical scheme is shown in Fig. 3. In this case the inductance of a coil changes as a ferromagnetic object moves close to the magnetic former, thus change the reluctance of the magnetic path. The measuring circuit is usually an a.c. bridge.

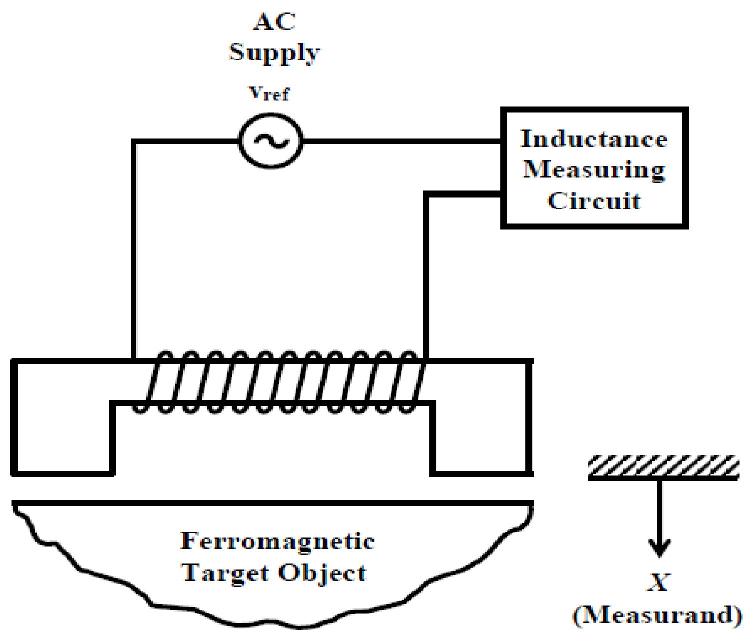


Fig. 3 Schematic diagram of a self inductance type proximity sensor.

Rotary Variable Differential Transformer (RVDT)

Its construction is similar to that of LVDT, except the core is designed in such a way that when it rotates the mutual inductance between the primary and each of the secondary coils changes linearly with the angular displacement. Schematic diagram of a typical RVDT is shown in Fig. 4.

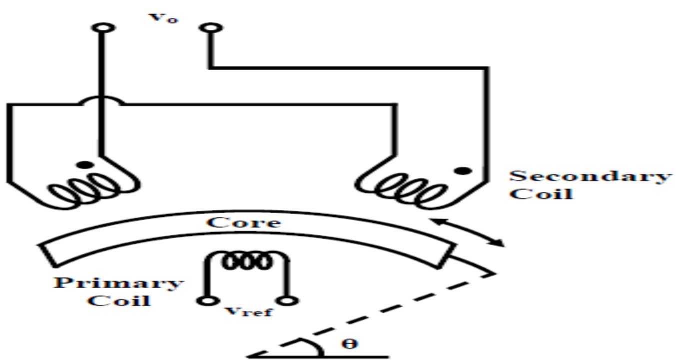


Fig. 4 Rotary Variable Differential Transformer (RVDT)

Resolver

Resolvers also work on the principle of mutual inductance variation and are widely used for measurement of rotary motion. The basic construction is shown in Fig. 5. A resolver consists of a rotor containing a primary coil and two stator windings (with equal number of turns) placed perpendicular to each other. The rotor is directly attached to the object whose rotation is being measured. If a.c.

excitation of r.m.s voltage V_r is applied, then the induced voltages at two stator coils are given by:

$$v_{01} = KV_r \cos\theta$$

and $$v_{02} = KV_r \sin\theta \text{; where } K \text{ is a constant.}$$

By measuring these two voltages the angular position can be uniquely determined, provided . Phase sensitive detection is needed if we want to measure for angles in all the four quadrants. 0(090)θ≤≤
Synchros work widely as error detectors in position control systems. The principle of operation of synchros is similar to that of resolvers. However it will not be discussed in the present lesson.

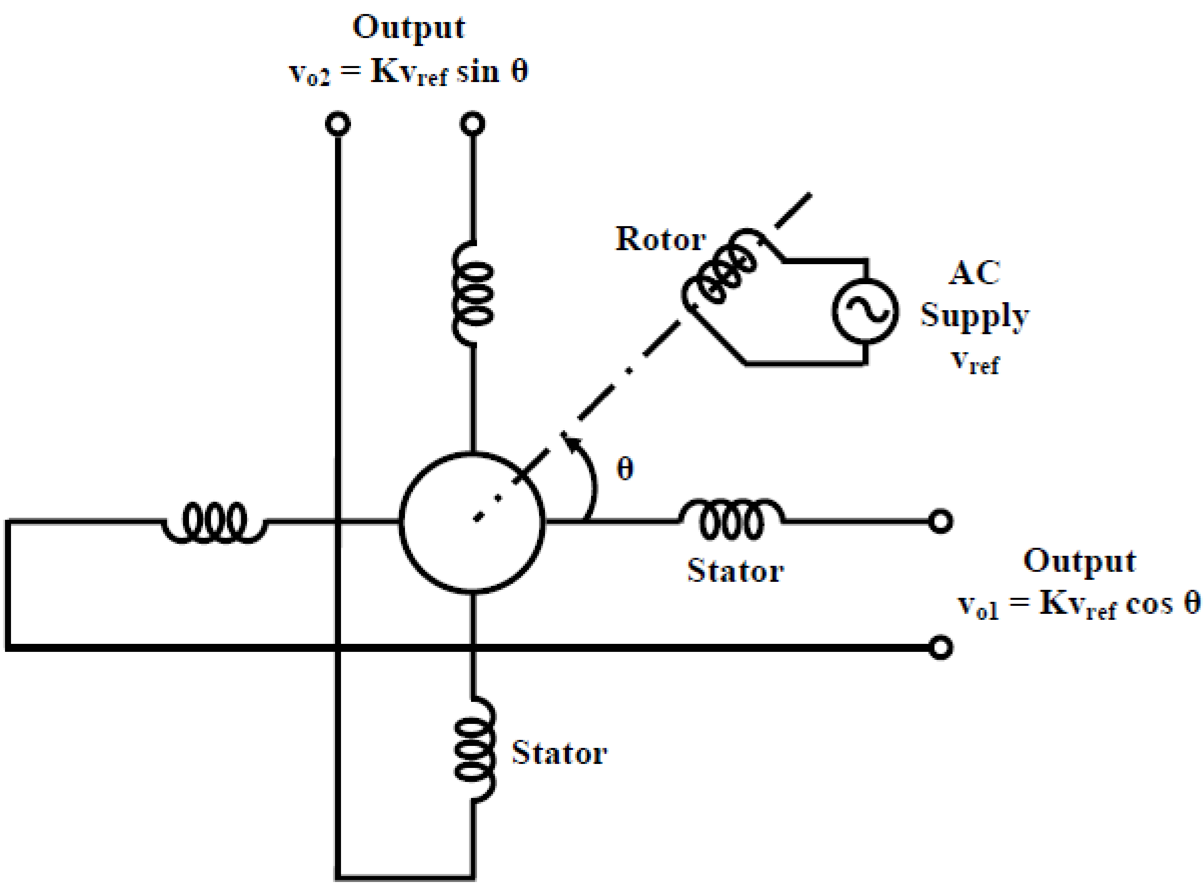


Fig. 5 Schematic diagram of the resolver.

Capacitance Sensors

The capacitance type sensor is a versatile one; it is available in different size and shape. It can also measure very small displacement in micrometer range. Often the whole sensor is fabricated in a silicon base and is integrated with the processing circuit to form a small chip. The basic principle of a capacitance sensor is well known. But to understand the various modes of operation, consider the capacitance formed by two parallel plates separated by a dielectric. The capacitance between the plates is given by:

$$C = \frac{\varepsilon_r \varepsilon_0 A}{d} \qquad (1)$$

where A=Area of the plates

d= separation between the plates

ε_r = relative permittivity of the dielectric

ε_0 = absolute permittivity in free space = $8.854 \times 10^{-12}\ F/m$.

capacitance sensor can be formed by either varying (i) the separation (d), or, (ii) the area (A), or (iii) the permittivity ($_r\varepsilon$). A displacement type sensor is normally based on the first two (variable distance and variable area) principles, while the variable permittivity principle is used for measurement of humidity, level, etc. Fig.6 Shows the basic constructions of variable gap and variable area types of capacitance sensors mentioned above. Fig. 6(a) shows a variable distance type sensor, where the gap between the fixed and moving plates changes. On the other hand, the area of overlap between the fixed plate and moving plate changes in Fig. 6(b), maintaining the gap constant. The variable area type sensor gives rise to linear variations of capacitance with the input variable, while a variable separation type sensor follows inverse relationship.

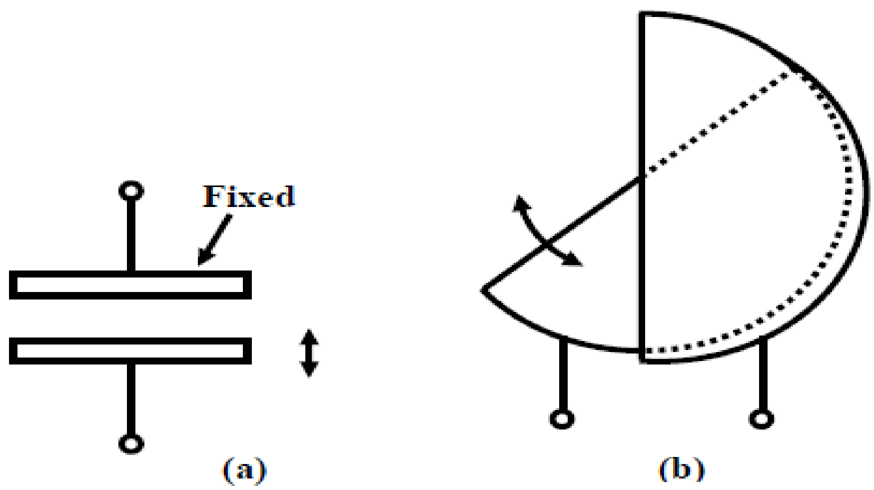


Fig.6 Capacitive type displacement Sensors:
a) variable separation type,
b) variable area type.

Capacitance sensors are also used for proximity detection. Such a typical scheme is shown in Fig. 4. Capacitive proximity detectors are small in size, noncontact type and can detect presence of metallic or insulating objects in the range of approximately 0-5cm. For detection of insulating objects, the dielectric constant of the insulating object should be much larger than unity. Fig. 7 shows the construction of a proximity detector. Its measuring head consists of two electrodes, one circular (B) and the other an annular shaped one (A); separated by a small dielectrical spacing. When the target comes in the closed vicinity of the sensor head, the capacitance between the plates A and B would change, which can be measured by comparing with a fixed reference capacitor.

The measuring circuits for capacitance sensors are normally capacitive bridge type. But it should be noted that, the variation of capacitance in a capacitance type sensor is generally very small (few *pF* only, it can be even less than a *pF* in certain cases). These small changes in capacitor, in presence of large stray capacitance existing in different parts of the circuit are difficult. So the output voltage would generally be noisy, unless the sensor is designed and shielded carefully, the measuring circuit should also be capable of reducing the effects of stray fields.

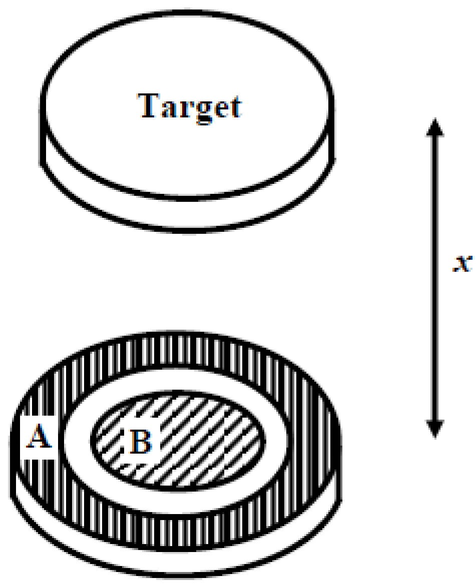


Fig. 7 Capacitance Proximity Detector.

Optical Sensors

Optical displacement sensors work on the basic principle that the intensity of light decreases with distance. So if the source and detector are fixed, the amount of light reflected from a moving surface will depend on the distance of the moving surface from the fixed ones. Measurement using this principle requires proper calibration since the amount of light received depends upon the reflectivity of the surface, intensity of the source etc. Yet it can provide a simple method for displacement measurement. Optical fibers are often used to transmit light to and from the measuring zone. Such a scheme with bundle fibers is shown in Fig. 8. It uses two bundle fibers, one for transmitting light from the source and the other to the detector. Light reflected on the receiving fiber bundle by the surface of the target object is carried to a photo detector. The light source could be Laser or LED; photodiodes or phototransistors are used for detection.

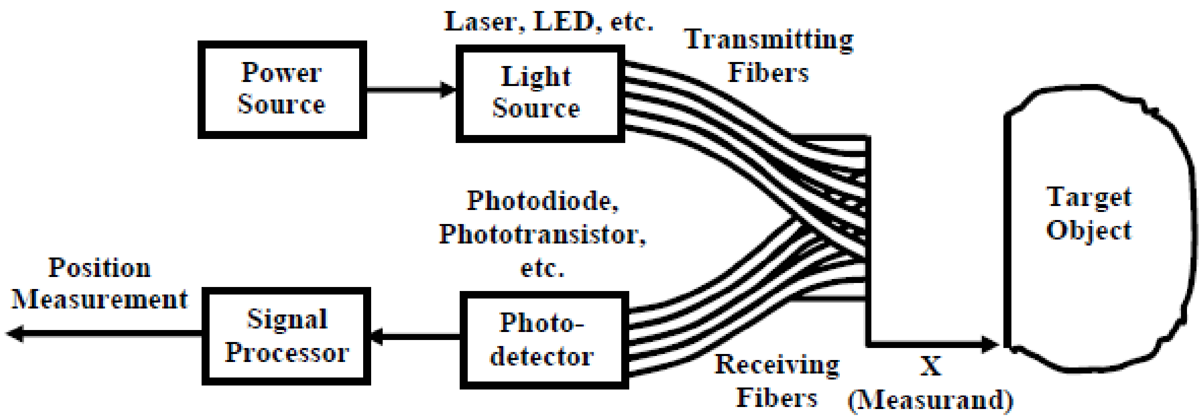


Fig. 8 A Fiber optic position sensor.

Speed Measurement

The simplest way for speed measurement of a rotating body is to mount a tachogenerator on the shaft and measure the voltage generated by it that is proportional to the speed. However this is a contact type measurement. There are other methods also for noncontact type measurements.

The first method is an optical method shown in Fig. 9. An opaque disc with perforations or transparent windows at regular interval is mounted on the shaft whose speed is to be measured. A LED source is aligned on one side of the disc in such a way that its light can pass through the transparent windows of the disc. As the disc rotates the light will alternately passed through the transparent windows and blocked by the opaque sections. A photodetector fixed on the other side of the disc detects the variation of light and the output of the detector after signal conditioning would be a square wave (as shown) whose frequency is decided by the speed and the number of holes (transparent windows) on the disc.

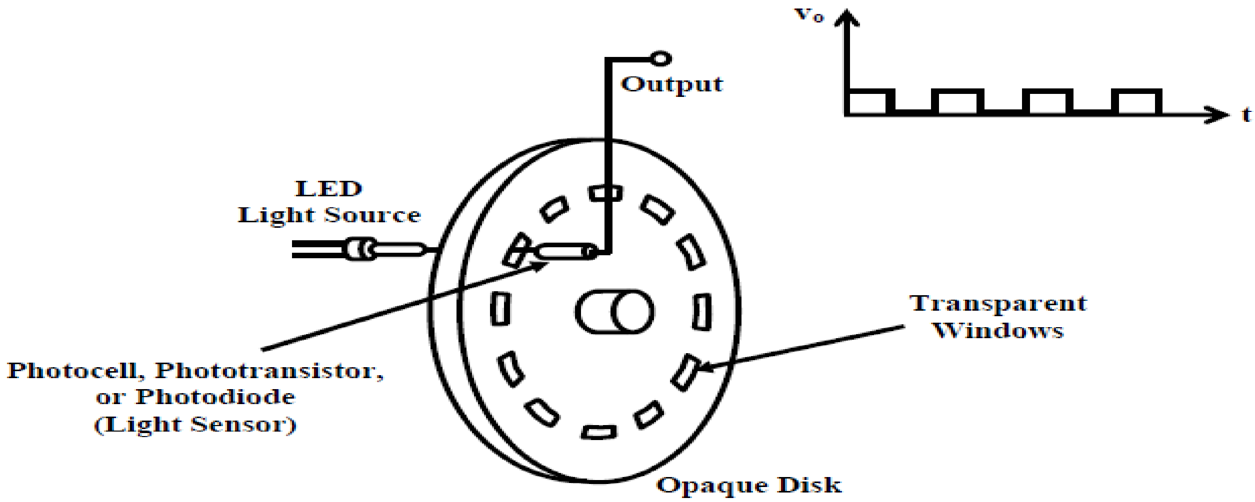


Fig. 9 Schematic arrangement of optical speed sensing arrangement.

Fig.10 shows another scheme for speed measurement. It is a variable reluctance type speed sensor. A wheel with projected teethes made of a ferromagnetic material is mounted on the shaft whose speed is to be measured. The static sensor consists of a permanent magnet and a search coil mounted on the same assembly and fixed at a closed distance from the wheel. The flux through the permanent magnet completes the path through the teeth of the wheel and cut the search coil. As the wheel rotates there would be change in flux cut and a voltage will be induced in the search coil. The variation of the flux can be expressed as:

$$\phi(t) = \phi_o + \phi_m \sin \omega t \tag{2}$$

where ω is the angular speed of the wheel. Then the voltage induced in the coil is:

$$e = -N\frac{d\phi}{dt} = -N\omega\,\phi_m \cos \omega t \tag{3}$$

where N is the number of turns in the search coil. So both the amplitude and frequency of the induced voltage is dependent on the speed of rotation. This voltage is fed to a comparator circuit that gives a square wave type voltage whose amplitude is constant, but frequency is proportional to the speed. A frequency counter is used to count the number of square pulses during a fixed interval and displays the speed.

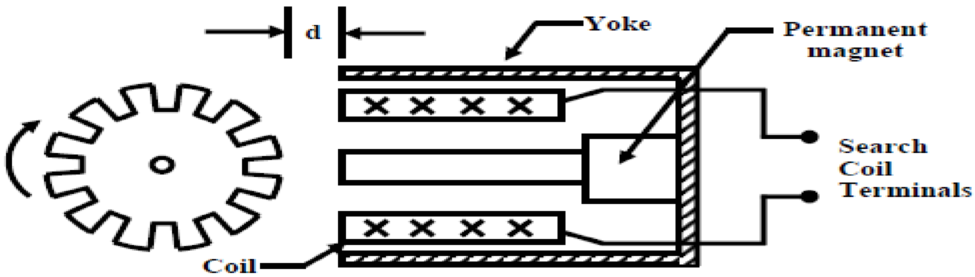


Fig. 10 Variable reluctance type speed sensor.

Signal Conditioning Circuits

The success of the design of any measurement system depends heavily on the design and performance of the signal conditioning circuits. Even a costly and accurate transducer may fail to deliver good performance if the signal conditioning circuit is not designed properly. The schematic arrangement and the selection of the passive and active elements in the circuit heavily influence the overall performance of the system. Often these are decided by the electrical output characteristics of the sensing element. Nowadays, many commercial sensors often have in-built signal conditioning circuit. This arrangement can overcome the problem of incompatibility between the sensing element and the signal conditioning circuit.

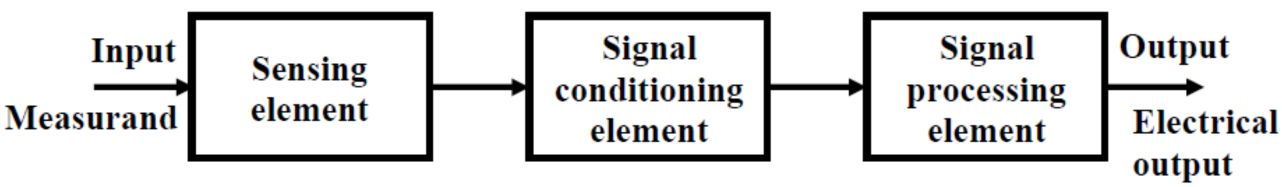


Fig. 1 Elements of a measuring system.

If one looks at the different cross section of sensing elements and their signal conditioning circuits, it can be observed that the majority of them use standard blocks like bridges (A.C. and D.C.), amplifiers, filters and phase sensitive detectors for signal conditioning. In this lesson, we would concentrate mostly on bridges and amplifiers and ponder about issues on the design issues.

lso, a significant number of aircraft services will still require 28 VDC or 115 VAC supplies and the use of higher voltages places greater reliance on insulation techniques to avoid voltage breakdown.

- The US military addressed these technical issues through a wide range of funded technology development and demonstratorprogrammes.
- Some of these are also directed at the greater use of electrical power on thecombat
- Aircraft, possibly to supplant conventional secondary power and hydraulic power systems or at least to augment them to a substantialdegree.
- The high DC voltage poses a risk in military aircraft of increased possibility of fire resulting

from battle damage in carbon-fiber compositeaircraft.

BASIC AIR CONTROLSYSTEMS: VAPOUR CYCLE SYSTEM:

Thevapourcyclesystemisaclosedloopsystemwheretheheatloadisabsorbed by the evaporation of a liquid refrigerant such as Freon® in an evaporator (NB the trade name Freon® is a registered trademark belonging to E.I. du Pont de Nemours & Company (DuPont)). The refrigerant then passes through a compressor with a corresponding increase in pressure and temperature, before being cooled in a condenser where the heat is rejected to a heatsink.

Althoughvapourcyclesystemsareveryefficient,withacoefficientofperformance typically five times that of a comparable closed loop air cycle system, applications are limited due to problems such as their limited temperature range and heavy weight compared to air cycle systems. The maximum operating temperatures of many refrigerants are too low, typically between 65°C and 70°C, significantly less than the temperatures which are required for worldwide operation. It should be noted that chlorofluoro carbons (CFC) endanger the ozone layer and are the subject of much debate calling for a limitation in their use.

BOOTS-TRAPSYSTEM:

- 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 7.11. The turbine of the cold air unit drives acompressor.
- Both are mounted on a common shaft. This rotating assembly tends to be supported on ball bearings, but the latest technology uses airbearings.
- This provides a lighter solution which requires less maintenance, for example no oil is required. 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 shaftas the compressor and turbine.
- Military aircraft tend to use the smaller and simpler two-rotor cold air unit using jet pumps to draw coolant air through the heat exchanger when the aircraft is on the ground and in low speed flight. This provides a lighter solution which requires less maintenance, for example no oil is required. 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 andair.

DE-ICING AND ANTI -ICINGSYSTEMS:

The precise mix of electrical and hot air (using bleed air from the engines) anti/deicing methods varies from aircraft to aircraft. Electrical anti/de-icing systems are high current consumers and require controllers to time, cycle and switch the heating current between heater elements to ensure optimum use of the heating capability and to avoid local overheating. Windscreen heating is another important electrical heating service. In this system the heating element and the controlling thermostat are embedded in the windscreen itself. A dedicated controller maintains

the temperature of the element at a predetermined value which ensures that the windscreen is demisted at all times.
de-icing systems which can consume many tens of kVAs. This power does not have to be frequency stable and can be frequency-wild and therefore much easier and cheaper to generate. Anti/de-icing elements are frequently used on the tail plane and fin leading edges, intake cowls, propellers and spinners. The precise mix of electrical and hot air (using bleed air from the engines) anti/deicing methods varies from aircraft to aircraft. Electrical anti/de-icing systems are high current consumers and require controllers to time, cycle and switch the heating current between heater elements to ensure optimum use of the heating capability and to avoid local overheating.

OXYGEN SYSTEM AND FIRE DETECTION SYSTEM:

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. In military aircraft which are typically designed to fly to altitudes in excess of 50 000ft, 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 000ft, either due to cabin depressurization or following escape from their aircraft, then additional protection is required. In the event of cabin depressurization 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 000ft, 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 000ft. It is possible to overcome this problem by increasing the pressure in thelungs above the surroundingenvironmentalpressure.Thisiscalledpositivepressurebreathing. At altitudes above 40 000ft the rise in pressure in the lungs relative to the pressure external to the body seriously affects

THE NEED FOR CABINCONDITIONING:

- Designconsiderationsforprovidingairconditioninginthecockpitofahigh performance fighter are far more demanding than those for a subsonic civil airliner cruisingbetweenairports.
- 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 wearing a thick rubber immersion suit which grips firmly at the throat andwrists.

- In addition, 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 tocombat
- .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 withoutappreciable

2.10.1 ENVIRONMENTAL CONTROL SYSTEMDESIGN:

- This section describes methods of environmental control in common use and, in addition, outlines some recent advances and applications in environmental control systemdesign.
- The cooling problem brought about by the heat sources described above must be solved to successfully cool the aircraft systems and passengers inflight.
- For ground operations some form of ground cooling system is also required. Heat must be transferred from these sources to a heat sink and rejected from theaircraft.
- Heat sinks easily available are the outside air and the internalfuel.
- The outside air is used either directly as ram air, or indirectly as air bled from theengines.
- Since the available heat sinks are usually at a higher temperature than that required for cooling the systems and passengers, then some form of heat pump is usuallynecessary.

EVAPORATIVE VAPOR CYCLESYSTEMS:

- 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® in an evaporator (NB the trade name Freon® is a registered trademark belonging to E.I. du Pont de Nemours &Company(DuPont)).
- The refrigerant then passes through a compressor with a corresponding increase in pressure and temperature, before being cooled in a condenser where the heat is rejected to a heatsink.
- The refrigerant flows back to the evaporator via an expansion valve. Simple water collection devices can be used in vapour cycle refrigeration systems to reduce humidity levels since the air
- is cooled to its dew point as it flows through the evaporator. Water droplets collect on the heat exchanger surfaces and can be simply trapped and drainedaway.

UNIT-III
HYDRAULIC SYSTEMS AND PNEUMATIC SYSTEMS

3.1 HYDRAULIC CIRCUIT DESIGN:

- The majority of aircraft in use today need hydraulic power for a number oftasks.
- Many of the functions to be performed affect the safe operation of the aircraft and must not operate incorrectly, i.e. must operate when commanded, must not operate when not commanded and must not fail totally under single failureconditions.

Primary flight controls:

- Elevators
- Rudders
- Ailerons
- Canards

Secondary flightcontrols:

- Flaps
- Slats
- Spoilers
- Airbrakes

Utility systems:

- Undercarriage – gear anddoors
- Wheel brakes andanti-skid
- Parking brake Nose wheel steering
- In-flight refueling probeCargo
- Doors Loading rampPassenger
- Stairs Bomb bay doors Gunpurging
- Scoop CanopyActuation

3.1 Hydraulic system loads

- Many other functions are carried out on various aircraft by hydraulics, but those listed above may be used as a typical example of modern aircraftsystems.
- The wise designer will always allow for the addition of further functions during the development of anaircraft
- .From the above list the designer may conclude that all primary flight controls are critical to flight safety and consequently no single failures must beallowed to prevent, or even momentarily interrupt theiroperation.
- This does not necessarily mean that their performance cannot be allowed to degrade to some

predetermined level, but that the degradation must always be controlled systematically and the pilot must be made aware of the state of thesystem.

- The same reasoning may apply to some secondary flight controls, for example, flaps and slats. 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 thepilot.
- In this case the designer must provide for the emergency movement to take place in the correct direction, for example, undercarriages must go down when selected and flight re fuelling probes must go out whenselected.
- It is not essential for them to return to their previous position in an emergency, since the aircraft can land and take on fuel – both safeconditions.

- Wheel brakes tend to be a special case where power is frequently provided automatically or on selection, from threesources.
- One of these is a stored energy source which also allows a parking brake function to beprovided.
- In order to understand each requirement the following parameters need to bequantified
- **Pressure** – What will be the primary pressure of the system? This will be determined by the appropriate standards and the technology of thesystem
- **Integrity** – Is the system flight safety critical 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 ofpower
- **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 desiredaction?
- **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 perflight)
- **Emergency or reversionary use**– Are there any elements of the system that are intended to provide a source of power under emergency conditions for other power generation systems? An example of this is 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 reversionarydevices?
- **Heat load and dissipation**– The amount of energy or heat load that the components of the system contribute to hydraulic fluid temperature Analysis of these aspects enables decisions to be made on the number and type of components required for the complete system. These components include thefollowing:

- A source of energy – engine, auxiliary power unit or ram airturbine
- A filter to maintain clean hydraulicfluid
- A multiple redundant distribution system – pipes, valves, shut-offcocks

- Pressure and temperaturesensors
- A mechanism for hydraulic oilcooling
- A means of exercising demand – actuators, motors,pumps
- A means of storing energy such as anaccumulator

3.5 HYDRAULIC ACTUATION:

- On military aircraft the primary flight control actuator normally consists of two pistons in tandem on a commonram.
- Each piston acts within its own cylinder and is connected to a different hydraulicsystem.
- The ram is connected at a single point to acontrol.
- The philosophy is different on civil aircraft where each control surface is split into two or more independentparts.
- They are essentially two statedevices.
- The actuator can be commanded to one or other of its states by a mechanical or electrical demand.
- This demand moves a valve that allows the hydraulic fluid at pressure to enter the actuator and move the ram in either direction A mechanical system can be commanded by direct rod, lever or cable connection from a pilot control lever to theactuator.
- An electrical system can be connected by means of a solenoid or motor that is operated by a pilot or by a computeroutput.
- In some instances it is necessary to signal the position of the actuator, and hence the device itmoves, back to thepilot.
- This can be achieved by connecting a continuous position sensor such as a potentiometer, or by using micro switches at each end of travel to power a lamp or magneticindicator.

HYDRAULIC FLUID:

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 aircraft fluids. With very few exceptions modern military aircraft have, until recently, operated exclusively on a mineral based fluid known variously as:

- DTD 585 in theUK
- MIL-H-5606 in theUSA
- AIR 320 inFrance
- H 515NATO

This fluid has many 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 otherfluids.
- Unfortunately, being a petroleum based fluid, it is flammable and is limited to a working temperature of about 130_C.
- One of the rare departures from DTD 585 was made to overcome this upper temperature limit. This led to the use of DP 47, known also as Silcodyne, in the ill-fated TSR2. Since the Vietnam War much industry research has been directed to the task of finding a fluid with reduced flammability, hence improving aircraft safety following accident or damage, particularly battle damage in combataircraft.
- This work has resulted in the introduction of MIL-H-83282, an entirely synthetic fluid, now adopted for all US Navyaircraft.
- It is miscible with DTD 5858 and, although slightly more viscous below 20 _C, it compares wellenough.
- In real terms the designer of military aircraft hydraulic systems has little or no choice of fluid since defence ministries of the purchasing nations will specify the fluid to be used for their particularproject

FLUID PRESSURE:

- Similarly little choice is available with respect to working pressure. Systems have become standardized at 3000 psi or4000psi.
- These have been chosen to keep weight to a minimum, while staying within the body of experience built up for pumping and containing thefluid.

FLUID TEMPERATURE:

- 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 fluidused.
- For many years the use of DTD 585 has limited temperatures to about 130 _C, and components and seals have been qualifiedaccordingly.
- The use of MIL-H-83282 has raised this limit to 200 _C and many other fluids have been used from time to time, for example on Concorde and TSR2, to allow high temperature systems to be used.
- 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 bedamaged.

FLUID FLOWRATE:
- Determination of the flow rate is a more difficultproblem.

- When the nominal system pressure is chosen it must be remembered that this is, in effect, a stallpressure.
- That is to say, that apart from some very low quiescent leakage, no flow will be present in the circuit.
- The designer must allocate some realistic pressure drop that can be achieved in full flow conditions from pump outlet toreservoir.
- This is usually about 20–25% of nominalpressure.
- Having established this, the pressure drop across each actuator will be known. The aerodynamic loads and flight control laws will determine the piston area and rate ofmovement.
- The designer must then decide which actuators will be required to act simultaneously and at what speed they willmove.
- The sum of these will give the maximum flow rate demanded of the system. It is important also to know at what part of the flight this demand takes place. It is normal to represent the flow demands at various phases of the flight – take-off, cruise etc. –graphically.

HYDRAULIC PIPING:

- When the system architecture is defined for all aircraft systems using hydraulic power, then it is possible to design the pipe layout in theaircraft.
- This layout will take into account the need to separate pipes to avoid common mode failures as a result of accidental damage or the effect of battle damage in a militaryaircraft.
- Once this layout has been obtained it is possible to measure the lengths of pipe and to calculate the flow rate in each section and branch ofpipe.
- It is likely that the first attempts to define a layout will result in straight lines only, but this is adequate for a reasonably accurate initialcalculation.
- If an allowable pressure drop of 25% has been selected throughout the system, this may now be further divided between pressure pipes, return pipes andcomponents.
- 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 eachcomponent.
- It must be appreciated, however, that these values must eventually be achieved without excessive penalties, being incurred by over-large porting or bodysizes.
- Once pipe lengths, flow rates and permissible pressure drops are known, pipe diameters can be calculated using the normal expression governing friction flow inpipes.
- It is normal to assume a fluid temperature of 0 _C for calculations, and in most cases flow in aircraft hydraulic systems isturbulent.
- Pressure losses in the system piping can be significant and care should be taken to determine accurately pipediameters.
- Theoretical sizes will be modified by the need to use standard pipe ranges, and this must be taken intoaccount.

HYDRAULIC PUMPS:

- A system will contain one or more hydraulic pumps depending on the type of aircraft and the conclusions reached after a thorough safety analysis and the consequent need for redundancy of hydraulic supply to the aircraftsystems.
- The pump is normally mounted on an engine-drivengearbox.
- In civil applications the pump is mounted on an accessory gearbox mounted on the engine casing.
- For military applications the pump is mounted on an Aircraft Mounted Accessory Drive (AMAD) mounted on theairframe.
- The pump speed is therefore directly related to engine speed, and must therefore be capable of working over a wide speed range.
- The degree of gearing between the pump and the engine varies between engine types, and is chosen from a specified range of preferred values.

- A typical maximum continuous speed for a modern military aircraft is 6000 rpm, but this is largely influenced by pump size, the smallest pumps runningfastest.
- The universally used pump type is known as variable delivery, constantpressure.
- Demand on the pump tends to be continuous throughout a flight, but frequently varying in magnitude.
- This type of pump makes it possible to meet this sort of demand pattern without too much wastage ofpower.
- 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 highflow.
- This also helps to optimize the overall efficiency of thesystem.
- The pumps are designed to sense outlet pressure and feed back this signal to a plate carrying the reciprocatingpistons.
- 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. The position of the plate therefore varies the amount of reciprocating movement of eachpiston.

HYDRAULIC RESERVOIR:

- The requirements for this component vary depending on the type of aircraft involved. For most military aircraft the reservoir must be fullyaerobatic.
- 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 gconditions.
- 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 inletport.
- The need to meet pump response times may double the pressure required for stabilized flow conditions.

- The volume of the reservoir is controlled by national specifications and includes all differential volumes in the system, allowance for thermal expansion and a generous emergency margin.
- It is common practice to isolate certain parts of the system when the reservoir level falls below a predeterminedpoint.
- This is an attempt to isolate leaks within the system and to provide further protection for flight safety criticalsubsystems.
- The cut-off point mustensure sufficient volume for the remaining systems under all conditions. The reservoir will be protected by a pressure relief valve which can dumpfluid

LANDING GEARAND BRAKEMANAGEMENTSYSTEM:

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 mounted controls.

1 .Nose Gear

- The tricycle landing gear has dual wheels on eachleg.
- The hydraulically operated nose gear retracts forward into a well beneath the forward equipment.
- The advantage of the doors being normally closed istwofold.
- First, the undercarriage bay is protected from spray on takeoff and landing, and secondly there is a reduction indrag.
- A small panel on the leg completes enclosure on retraction and a mechanical indicator on the flight deck shows locking of thegear.

2 MainGear

- The main gear is also hydraulically operated and retracts inwards into wheelbays.
- Once retracted the main units are fully enclosed by means of fairings attached to the legs and by hydraulically operateddoors.
- Each unit is operated by a single jack and a mechanical linkage maintains the gear in the locked position without hydraulicassistance.
- The main wheel doors jacks are controlled by a sequencing mechanism that closes the doors when the gear is fully extended orretracted.

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 brakingsystem.
- Its design must take into account tyreto ground and brake friction, the brake pressure/volume characteristics, and the response of the aircraft hydraulic system and the aircraft structural 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 andsteering.
- The normal functions of landing, deceleration and taxying to dispersal or the airportgate

require large amounts of energy to be applied to the brakes.

- Wherever possible, lift dump and reverse thrust will used to assistbraking.
- However it is usual for a large amount of heat to be dissipated in the brakepack.
- This results from the application of brakes during the initial landing deceleration, the use of brakes during taxiing, and the need to hold the aircraft on brakes for periods of time at runway or taxiwayintersections.
- When the aircraft arrives at the gate the brakes, and the wheel assembly will be veryhot.
- This poses a health and safety risk to ground crew working in the vicinity of the wheels during the turnaround. This is usually dealt with bytraining.

PNEUMATIC SYSTEMS

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 airextraction 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. 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 onpneumatic

ADVANTAGES OF PNEUMATICSYSTEMS:

• Infinite availability of thesource
Air is the most important thing in the pneumatic system, and as we all know, air is available in the world around us in unlimited quantities at all times and places.

• Easychannelled
Air is a substance that is easily passed or move from one place to another through a small pipe, the long andwinding.
• Temperature is flexible
Air can be used flexibly at various temperatures are required, through equipment designed for specific circumstances, even in quite extreme conditions; the air was still able to work.
• **Safe**
The air can be loaded more safely than it is not flammable and does not short circuit occurs (konsleting) or explode, so protection against both of these things pretty easily, unlike the electrical system that could lead to fires consulting.
• **Clean**
The air around us are tend to clean without chemicals that are harmful, and also, it can be minimized or cleaned with some processes, so it is safe to use pneumatic systems to the pharmaceutical industry, food and beverages and textiles.
• The transfer of power and the speed is very easy to setup
Air could move at speeds that can be adjusted from low to high or vice versa. When using a pneumatic cylinder actuator, the piston speed can reach 3 m / s. For pneumatic motors can spins at 30,000 rpm, while the turbine engine systems can reach 450,000 rpm
Can be stored
The air can be stored through the seat tube fed excess air pressure. Moreover, it can be installed so that the pressure boundary or the safety of the system to be safe.
Easy utilized
Easy air either directly utilized to clean surfaces such as metal and machinery, or indirectly, ie through pneumatic equipment to produce certain movements.

WORKINGPRINCIPLES:

- Pitot systems have been used since the earliest days of flight using pneumatic, c apsule based mechanical flight instruments. The advent of avionics technology led first to centralised 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 civilairliner.

- The easy availability of high pressure air from the modern engine is key to the use of pneumatic power as a means oftransferring energy or providing motive power on the aircraft
- Other areas of the aircraft use pneumatic principles for sensing the atmospheresurrounding the aircraft for instrumentation purposes. The sensing of air data is crucial to ensuring the safe passage of the aircraft in flight.

BRAKE SYSTEM

- A brake which uses air as a working fluid is known as pneumatic brake**.** The system actuated to apply this phenomenon is known as pneumatic brakesystem.
- An pneumatic brake system or a compressed air brake system is a type of friction brake for vehicles in which compressed air pressing on a piston is used to apply the pressure to the brake pad needed to stop thevehicle.

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 isto ensure that, during the taxi back tothetake-offrunway, furtherbrakeapplicationswillnotraisethetemperature 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 by brake 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. An alternative 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 extent that a fire may occur and the 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 will attend the aircraft to extinguish the fire while the passengers disembark. One of the simplest and most widely known anti-skid systemis the Dunlop Minaret unit which consists of a hydraulic valve assembly regulated by the dynamics of a spring loaded g sensitive flywheel. Figure 4.26 shows an axle mounted Max are 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 theunitfromtheeffectsofweatherandstonesthrownupbytheaircraftwheels. Skid conditions are detectedbytheoverrunoftheflywheelwhichopenstheMaxaretvalvetoallowhydraulic pressure to dissipate. A combination of flow sensitive hydraulic units and switches in the oleo leg providemodulation.

The simplest air brake system consists of

- An aircompressor
- A brakevalve
- series of brake chambers at thewheels
- un loadervalve
- A pressure gauge and a safety valve and an airreservoir.

- These are all connected bytubes.

Some air braking systems may have additional components such as

- stop lightswitch
- low pressureindicator
- An air supply valve to supply air for tyreinflation
- A quick release air quickly from the front brake chambers when the brake pedal isreleased
- A limiting valve for limiting the maximum pressure in the front brake chambers and arelay valve to help in quick admission and release of air from the rear brakechambers.

Working of pneumatic braking system

- The air compressor operated by the engine forces air at a pressure of 9-10 kscm (kilo standard cubic meters) through the water and oil separator to the air reservoir.
- The air pressure in the reservoir is indicated by a pressuregauge.
- The reservoir contains enough compressed air for several braking operations. From the reservoir the air is supplied to the brakevalve.
- As long as brake pedal is not depressed, brake valves stop the passage of air to brake chambers and there is no brakingeffect.
-

PNEUMATIC POWERSYSTEM:

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

atomised 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 andprovideshaftpowertodrivetheLPfanandcompressorsections.Whenthe engine reaches self-sustaining 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.

Landing GearSystems

The Raytheon/BAE 1000 is representative of many modern aircraft; its landing gear is shown in Figures 4.22 and 4.23. 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 mounted controls.

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 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 thegear

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 tyre to ground and brake friction, the brake pressure/volume characteristics, and the response of the aircraft hydraulic system and the aircraft structural 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 in Figure 4.25. 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 and reverse thrust 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 aircraft on brakes for periods of time at runway or taxiway intersections. When the aircraft arrives at the gate the brakes, and the wheel assembly will be veryhot. This poses a health and safety risk to ground crew working in the vicinity of the wheels during the turn around. This is usually dealt with bytraining

Multi-WheelSystems

The systems described thus far apply to most aircraft braking systems. However, large aircraft have multi-wheel bogies and sometimes more than two main gears. The B747-400 has 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 utilize multi-lane dual redundant control. The

B777 maingear

For control purposes the wheels are grouped in four lines of three wheels, each corresponding to an independent control channels as shown in the figure. Each of the lines of three wheels – 1, 5, 9; 2, 6, 10 and so on – is controlled by a dual redundant controller located in the Brake System Control 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 systemissuppliedbytheHydro-Airedivision, part of Crane Aerospace, and is indicative of the sophistication which modern brake systems offer for largersystems.

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 withcarbon

UNIT-IV
ENGINE CONTROL AND FUEL SYSTEMS

AIRCRAFT GAS TURBINEENGINES

The early jet engines based on a centrifugal compressor used a method of controlling fuel to the engine combustion chamber that used a fuel pump, a relief valve and a throttle valve. In series with these was a mechanical centrifugal governor. Barometric compensation of there life valve was provided by a suitable bellows mechanism to maintain the full range of throttle movement at altitude. The design of such engines based upon Sir Frank Whittle's design was basically simple, using sound engineering practices and employing technology representing 'state of the art' of the day. As gas turbine engine technology developed, demands for improved performance required substantial increases in pressure ratios and turbine inlet temperatures placing much more stress on the internal components. New developments such as the axial compressor and reheat (afterburning) created a demand for more complex methods of controlling airflow, fuel flow and exhaust gas flow. Early gas turbine control systems were initially entirely hydro-mechanical. As engine and materials development continued a need arose 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 rapid acceleration tended to place the engine under severe conditions of operation. In support of the needed improvements, limited authority electronic trimmers sometimes referred to 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 controlmore

ENGINE/AIRFRAMEINTERFACES:

- The engine is a major, high value item in any aircraft procurement programme. Often an engine is especially designed for a new aircraft – this is particularly true of military projects where a demanding set of requirements forces technology forward in propulsion and airframe areas.
- There is, however, a trend to make use of existing power plant types or variant of types in an airframe the development costs of a newproject.
- Whatever the case, control of the interfaces between the engine and the airframe is essentialto allow the airframecontractor.
- Products independently. The interface may be between the engine and a nacelle in the case of a podded, under-wing engine, as is common in commercial aircraft; or between the engine and the fuselage as is common in fast jet military aircrafttypes.

- When full authority control systems were introduced in analogue form, semiconductor technology demanded that the electronic control units were mounted on the airframe. This led to a large number of wire harnesses and connectors at the engine–airframeinterface.

- 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 bleed less 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 theirinterfaces.
- The nature of the interfaces and the potential for rework usually means that the ICD becomes an important contractualdocument.

THE CONTROLPROBLEM:

- The basic control action is to control a flow of fuel and air to the engine to allow it to operate at its optimum efficiency over a wide range of forward speeds, altitudes and temperatures while allowing the pilot to handle the engine without fear ofmalfunction.
- The degree of control required depends to a large extent upon the type of engine and the type of aircraft in which it isinstalled.
- The military aircraft is usually specified to operate in worldwide conditions, and is expected to experience a wide range of operatingtemperatures.
- To be successful in combat the aircraft must bemaneuverable.
- The pilot, therefore, expects to be able to demand minimum or maximum power with optimum acceleration rates, as well as to make small adjustments with equal ease, without fear of surge, stall, flame-out, over-speed orover-temperature.
- The pilot also needs a fairly linear relationship between throttle lever position andthrust.
- The civil operator requires reliable, economical and long-term operation under clearly defined predictable conditions with minimum risk to passengers andschedules.
- For military engines the key to satisfactory performance is the ability to perform over large speed and altitude ranges as well as significant temperaturevariations.

To obtain these objectives, control can be exercised over the following aspects of engine control:

- Fuel flow – to allow varying engine speeds to be demanded and to allow the engine to be handled without damage by limiting rotating assembly speeds, rates of acceleration and temperatures
- Air flow – to allow the engine to be operated efficiently throughout the aircraft flight envelope and with adequate safetymargins
- Exhaustgasflow–byburningtheexhaustgasesandvaryingthenozzleareatoprovide additional thrust Electronic control has been applied in all these 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 with other aircraft systems.

FUEL FLOWCONTROL:

- Control of power or thrust is achieved by regulating the fuel flow into thecombustor.

- On turbo jet or turbo fan engines thrust can be controlled by setting an engine pressure 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 therotor.
- 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 prevent compressor surge orflameout.
- 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 flightenvelope.
- Airflow modulation through the compressor may also be necessary by the use ofvariable vanes and/or bleed valves to provide adequate surge margin under all operatingconditions.
- The control of power or thrust of the gas turbine engine is obtained by regulating the quantity of fuel injected into the combustionsystem.
- When a higher thrust is required the throttle is opened and the fuel pressure to the burners increases due to the higher fuelflow.
- 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 inthrust.
- 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 meet this 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 orposition.
- Fuel flow must, therefore, be monitored to maintain the conditions demanded by the pilot whatever the changes in the outsideworld.
- Failure to do so would mean that the pilot would constantly need to make minor adjustments 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 managementunits(FMU).
- The FCU/FMU is a hydro mechanical device mounted on the engine. It is a complex engineering mechanism containing valves to direct fuel and to restrict fuel flow,pneumatic capsules to modify flows according to prevailing atmospheric conditions, and dashpot/spring/damper combinations to control acceleration and deceleration rates.

- . 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 without fear ofmalfunction.

AIR FLOWCONTROL:

- 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 maintain a safe margin from the engine surge line.

- Most modern commercial engines have variable compressor vanes and/or bleed valves to provide optimum acceleration without surge though it is not a feature usually associated with militaryapplications.
- In some high Mach number aircraft it was necessary to provide intake ramps and variable intake area control to maintain suitable air flow under all conditions of speed, altitude and man oeuvre. Concorde and Tornado are examples of aircraft with air intake controlsystems.

CONTROLSYSTEMS:

- 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 multi engineaircraft.
- In the first gas turbine engine aircraft, however, the pilot was expected to do justthat.
- A throttle movement causes a change in the fuel flow to the combustion chamber spray nozzles. This, in turn, causes a change in engine speed and in exhaust gastemperature.
- 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 pilot can monitor the readings and move the throttle to adjust the conditions to suit his own requirements or to meet the maximum settings recommended by the enginemanufacturer.
- The FCU, with its internal capsules, looks after variations due to atmosphericchanges.
- In the dynamic conditions of an aircraft in flight at different altitudes, temperatures and speeds, continual adjustment by the pilot soon becomesimpractical.

Control System Parameters:

- To perform any of the control functions electrically requires devices to sense engine operating conditions and to perform a controllingfunction.
- These can usually be conveniently subdivided into input and output devices producing input and output signals to the controlsystem.
- To put the control problem into perspective the control system can be regarded as a box on a

block diagram receiving input signals from the aircraft and the engine and providing outputs to the engine and the aircraftsystems.

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 signaling 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 ACsignal.
- **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.
-
- The latter have the advantage that they are likely to be multiple redundant and safety monitored.

- **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 of enginespeed

- **Engine temperature**– The operating temperature of the engine cannot be 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 obtaina measurement of mean gas temperature and are usually of chromel-alumeljunctions.
- **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. relatively insensitive to temperature variations, an important point because of the harsh environment of the reheat exhaust
- **Fuel flow**– Fuel flow is measured by means of a turbine type flow meter installed in 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 measure of fuelflow
- **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 ratio devices use two high accuracy pressure sensors and electronics to generate pressureratio

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 flightconditions

EXAMPLESYSTEMS:

- 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 an 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 differsignificantly.
- 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 throttlelever.
- 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 orthrust.
- Under varying conditions of temperature and altitude this condition will not normally stay constant,butwillincreaseordecreaseaccordingtoairdensity,fueltemperatureordemandsfor take-off power. To obtain a constant engine condition, the pilot would have continually to adjust the throttle lever, as was the case in the early days of jet engines. Such a system with the pilot in the loop .
- 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 fuelflow.
- This valve is situated in the engine fuel feed line so that flow is constricted, or is by-passed and returned to the fuel tanks, so that the amount of fuel entering the engine .This valve forms part of a servo loop in the control system so that continuous small variations of fuel flowstabilise the engine condition around that demanded by thepilot.
- 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-speedconditions

FULL AUTHORITY CONTROL SYSTEMS:

The emergence of digital technology and serial data transmission systems, as well as higher performance electronic devices led to the introduction of the FADEC (Full Authority Digital Electronic Control). This, in turn led to the opportunity to integrate the control systems with the aircraft avionics and flight control systems, and to consider the mounting of complex electronic control units on the engine itself. When mounting these electronic controls on the engine, great care must be taken to isolate the units from the hostile environment by providing anti-vibration mounts and forced-air (or sometimes fuel) cooling. 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 with considerable improvements in reliability and availability. The core of the gas turbine engine is the gas generator. singleand two shaft versions of the typical gasgenerator.

LIMITED AUTHORITY CONTROLSYSTEMS

Limited authority electronic trimmers sometimes referred to 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 signalling from the throttlelevers.

POWER OFFTAKES:

Power off take to allow rapid engine starting. A cross-drive is provided between the two RB 199 engines, which allow either engine to power both hydraulic pumps should one engine fail.

For the past few decades the way in which aircraft have extracted power from the engine little though longstanding studies exit which examine more – electric means .The three key methods or extracting energy from the engine have been: • Electrical power by means of an accessory gearbox driven generator • Hydraulic power by means of Engine Driven Pumps (EDPs) also run off the accessory gearbox but also by electrical and air driven means • Pneumatic power achieved by bleeding air off the intermediate or HP compressor to provide energy for the environmental control system, cabin pressurization and wing anti-icing system among others. High pressure air has also provided the means by which the engine is started with the air taken from a ground air start trolley, APU or another engine already running. While the engine is in effect a highly optimised gas generator, there are penalties in extracting bleed air which are disproportionate when compared to the power being extracted. This becomes more acute as the bypass ratio increases: originalturbofanshadrelativelylowbypassratiosof~1.4(bypass)to1(engine core); more recent designs~4:1 and next generation turbofans such as the GE GEnexandRolls-RoyceTrent1000arecloseto10:1.Modernengineshvepressure ratios of the order of 30 to 35:1and are more sensitive to the extraction of bleed air from an increasingly smaller and much more highly tuned engine central core. The outcome is that to realize fully the benefits of emerging engine technology, a different and more efficient means of extracting power or energy for the aircraft systems becomes necessary. Efficient energy extraction for the aircraft without adversely affecting the performance of the engine core and the engines whole becomes an imperative reason for changing the architectures and technology utilized. Illustrates the differences between conventionalpowerextractionusingbleedairontheleftversusamore-electricversion

- On the right. These architectures broadly represent the difference between the Boeing 767 (left) and its successor, the Boeing 787 (right). The main differences between the more-electric and conventional configurationsare:
- Reduced bleed air offtake: the only bleed air off take for the B787 is for engine cowl anti-icing – this can be fan air that may be used with much lower penalty than that extracted from the engine compressor
- Increased electrical power generation. The B787 system generates 500 kVA per channel instead of 120 kVA (B767-400). This increased electrical power is required in the main to provide energy to those systems no longer powered by bleedair
- Electric engine start: The B787 uses electric start since bleed air is no longer available forthis

Power Offtakes

- Hydraulic powergeneration
- Electrical powergeneration
- Airbleeds

ENGINEPERFORMANCE

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. In the first gas turbine engine aircraft, however, the pilot was expected to do just that. A throttle movement causes 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 presentedtothepilotasanaloguereadingsoncockpit-mountedindicators.The pilot can monitor the readings and move the throttle to adjust the conditions to suit his own requirements or to meet the maximum settings recommended by the engine manufacturer. The FCU, with its internal capsules, looks after variations due to atmosphericchanges.
impractical.

FUELSYSTEM:

At the onset of aviation aircraft fuel systems were remarkably simple affairs. Fuel was gravity fed to the engine in most cases though higher performance engines would have an engine-mounted fuel pump. Tank configurations were extremely simple and fuel contents were visible float driven indications. In the case of the Tiger Moth, fuel indication was by means of a simple sight glass located on top of the fuel tank between the two upper wing sections. Higher performance gave rise to more complexity within the fuel system. The need for transfer and booster pumps accompanied the arrival of high performance aircraft. More complex tank configurations introduced the need for multi-valve systems such that the flight crew could move fuel around the fuel tanks according to the needs at the time. The arrival of jet turbine powered aircraft brought a range of engines that were much thirstier than their piston-engined predecessors: the early jet aircraft in general had a very short sortie length. More accurate fuel gauging systems were required to give the pilot advanced and accurate information regarding the aircraft fuel state in order that recovery to an air field could be accomplished before running out of fuel. The higher performance jet engine also required considerably greater fuel delivery pressures to avoid cavitation and flame-out. A further effect of the high fuel consumption was the use of under-wing or under-fuselage ventral tanks to enhance the range of the aircraft. These additional tanks further complicated the fuel system and tank pressurizations systems were developed to transfer the external fuel to the aircraft internal tanks. These systemsbroughttherequirementforfurthervalvestocontroltankpressurization and ensure that the tanks could not be damaged by excessivepressure.

Characteristics of 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 cut and with a lower flash point. AVTAG and AVTUR are typical jet engine fuels. The specific gravity ofaviationfuelsisaround0.8 that IS about eight-tenths of the density of water. Therefore fuel may be quantified 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 tankage is fixed and therefore it will not be able to 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 to 10 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 ofoperation:

- Fuelpressurization
- Enginefeed

- Fueltransfer
- Refuel/defuel
- 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 systemrequirements
- Vent systems Use of fuel as heatsink
- Fueljettison
- 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 a companion volume dedicated to aircraft fuelsystems

Fuel SystemComponents

1. Fuel TransferPumps

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 a guaranteed (short-term) supply to each engine. Transfer pumps may also be 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 center 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 tonsoffuelwhichhastobetransferredtomaintaintheaircraftCGwithinacceptablelimits 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 center 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 later in this chapter. An example of a fuel transfer pump is shown in Figure 3.3, this particular example being used on the Anglo-French Jaguar fighter. This is a fuel lubricated pump; a feature shared by most 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 regionof 400 lb/minute at a pressure of 10psi.

2. 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 top reventaeration (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 'cavitation' at high altitudes. Cavitation 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 vapourpressure 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 aircraft system will possess a number of transfer pumps as will be illustrated later in the chapter. The engine manufacturer usually imposes a requirement that fuel feed pressure must remain at least 5 psi above true vapour 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 28VDCsystemwithdeliverypressuresintherange10–15psiandflowratesup 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 refuelling 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 someapplications.

FUEL TANKSAFTY:

Fuel tank safety based upon explosion suppression has been a significant issue in military aircraft for many years. The need to protect the airframe and fuel system from the effects of small arms fire or explosive fragments has been a consideration in battle damage alleviation during the design of many military platforms including the C-130, C-5 Galaxy, F-16, C-17, F-22 and many others. These systems use a variety of techniques:

• Reticulatedfoam

• Stored liquid nitrogen (C-5)

• Fire retarding additive mixing for short term protection (F-16, A-6,F-117)

OBIGGS using air separation technology was first used on C-17. Early separation technology was employed and there was a need for onboard storage of inert gas to cope with the descent case. Fuel tank safety embraces a number of issues relating to the electrical components and installation as well as providing oxygen depleted environment in the ullage volume. These electrical and component issuesinclude:

In-tank wiring. The possibility of electrical energy entering the fuel tank due to normal operation, short circuits, and induced current/voltage on to fuel systems wiring that may potentially lead to ignition of flammable vapors. An earlier energy limit of 200 joules has been superseded by a lower limit of 20 μJoules for in-tank electrical design.∗ Allowable current limits are now 30 mAmps whereas previously no limits were specified. Advisory circular (AC)

- **Pump wiring**. Spark erosion and hot spots due to short circuits in the pumpwiring

- **Pump dry-running**. Mechanical sparks generated due to component wear or Foreign Object Damage (FOD) inside thepumps
- **Bonding.** Electrical discharges occurring with I the fuel tank duet lightning. High Intensity Radiation Fields (HIRF), static and/or faultcurrents
- Adjacent systems. Ignition sources adjacent to the fuel tanks – ignition of the fuel in the tank due to electrical arcing external to the fuel tank penetrating the tank wall and causing auto-ignition of the fuel due to heating of the tank wall – explosions within the adjacentarea
- **Arc gaps**. Inadequate separation between components and structure that could allow electrical arcing due tolightning

FUELINSERTING:

. The JAA produced a similar document – JAA INT/POL 25/12 which was mandatory for all airbus aircraft These documents provided a methodology to categorize the hazards in fuel tanks. On a civil aircraft the main fuel tanks usually comprise left, center and right wing tanks. The center wing fuel tank is categorized as hazardous; requiring fuel tank inserting due to the temperatures encountered and the proximity to external heat sources of which the air conditioning units represent a significant heat source. Left and right wing tanks are usually considered to be nonhazardous, primarily as the fuel contained within is much cooler and the fuel does not suffer from the proximity of hot aircraft components. Other tanks fitted to some aircraft types such as fuselage (long-range) tanks and tailplane trim tanks are similarly unaffected. It follows that aircraft without a centre tank may also avoid the need to fit aninserting system if the hazard analysis provided that the remaining tanks meet the nonhazardouscriteria.

UNIT-V

AIRPLANE CONTROL SYSTEMS

FLIGHT CONTROLSYSTEMS:

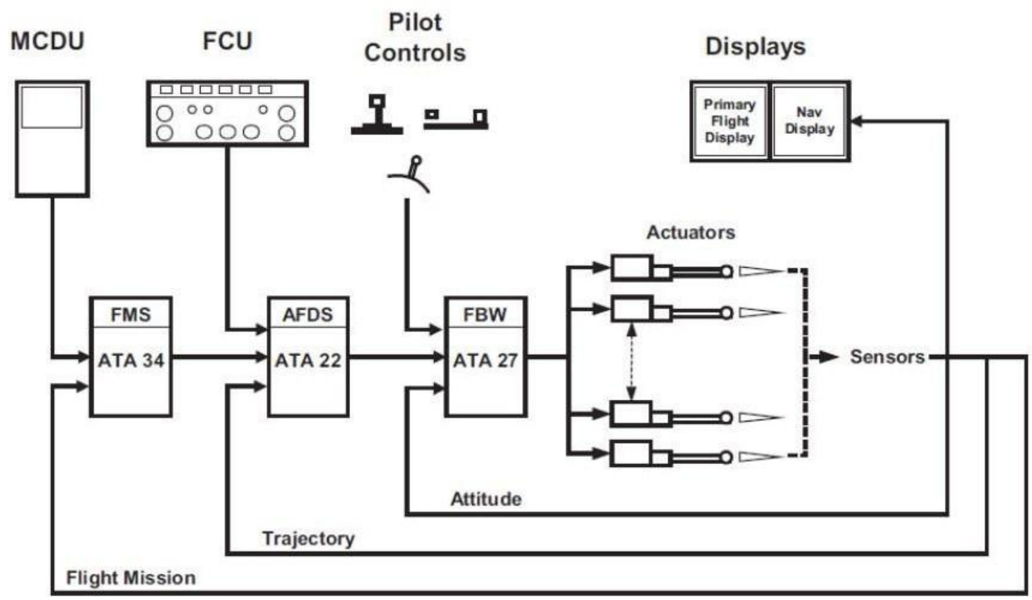


Figure5.1

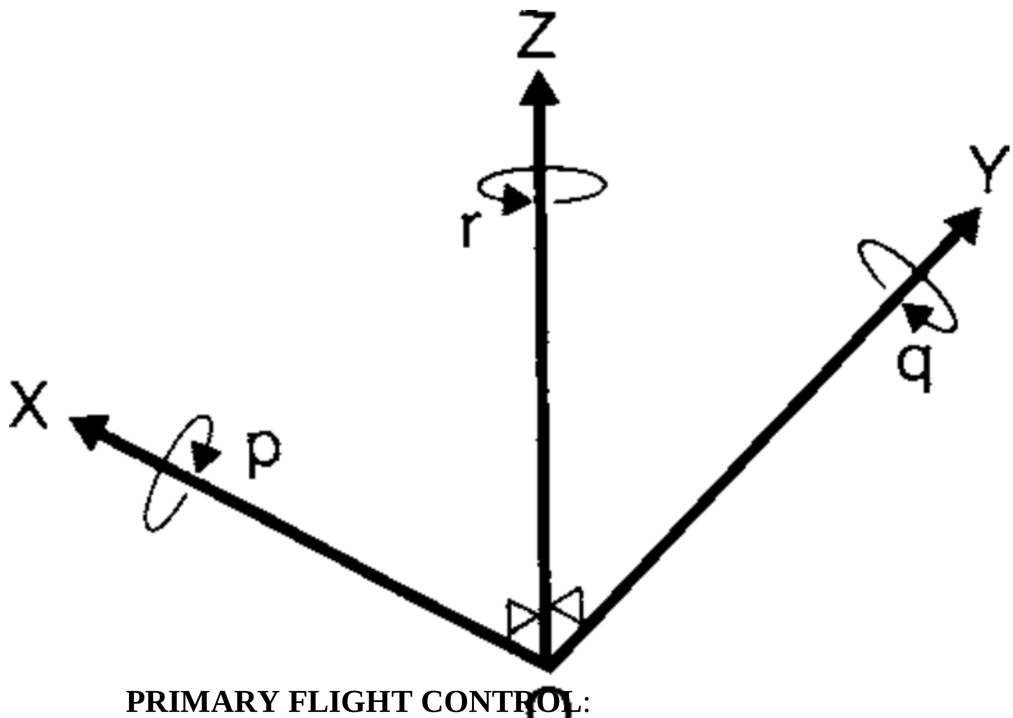
1. The inner loop provided by the FBW system and the pilot's controls effectively controls the attitude of theaircraft.
2. The middle loop is that affected by the AFDS that controls the aircraft trajectory, that is, where the aircraftflies.
3. Inputs to this loop are by means of the mode and datum selections on the FCU or equivalent control panel. Finally, the FMS controls where the aircraft flies on the mission; for a civil transport aircraft this is the aircraftroute.
4. MCDU controls the lateral demands of the aircraft by means of a series of waypoints within the route plan and executed by the FMS computer.
5. Improved guidance required of 'free flight 'or DNS/ATM also requires accurate vertical or 3-Dimensional guidance, often with tight timing constraints upon arriving at a way- point or the entry

PRINCIPLES OFFLIGHTCONTROL:

- All aircraft are governed by the same basic principles of flight control, whether the vehicle is the most sophisticated high-performance fighter or the simplest model aircraft. The motion of an around three defined axes: pitch, roll andyaw.

- Aircraft is defined in relation to translational motion and rotational motion around a fixed set of defined axes. Translational motion is that by which a vehicle travels from one point to another inspace.
- For an orthodox aircraft the direction in which translational motion occurs is in the direction in which the aircraft is flying, which is also the direction in which it ispointing.

figure5.2 primary flight controls



PRIMARY FLIGHT CONTROL:

- Primary flight control in pitch, roll and yaw is provided by the control surfaces described below.
- Pitch control is provided by the moving canard surfaces, or fore planes, as they are sometimes called, located either side of thecockpit.
- These surfaces provide the very powerful pitch control authority required by an agile high performance aircraft.
- The position of the canards in relation to the wings renders the aircraft unstable. Without the benefit of an active computer-driven control system the aircraft would be uncontrollable and would crash in a matter ofseconds.
- While this may appear to be a fairly drastic implementation, the benefits in terms of improved maneuverability enjoyed by the pilot outweigh the engineering required to provide the computer-controlled or ‘active’ flight controlsystem.
- Roll control is provided by the differential motion of the fore planes, augmented to adegree by the flaperons.
- In order to roll to the right, the left fore plane leading edge is raised relative to the airflow generating greater lift than before. Conversely, the right fore plane moves downwards by a corresponding amount relative to the airflow thereby reducing the lift generated.

- The resulting differential forces cause the aircraft to roll rapidly to the right. To some extent roll control is also provided by differential action of the wing trailing edge flaperons (sometimes called elevons). However, most of the roll control is provided by thefore planes.
- Yaw control is provided by the single rudder section.
- For high performance aircraft yaw control is generally less important than for conventional aircraft due to the high levels of excesspower.
- There are nevertheless certain parts of the flight envelope where control of yaw (or sideslip) is vital to prevent roll–yaw divergence.

SECONDARY FLIGHT CONTROL:

• High lift control is provided by a combination of flaperons and leading edge slats. The flaperons may be lowered during the landing approach to increase the wing camber and improve the aerodynamic characteristics of the wing.

• The leading edge slats are typically extended during combat to further increase wing camber andlift.

• The control of these high lift devices during combat may occur automatically under the control of an active flightcontrolsystem.

ENGINE CONTROLSYSTEM:

The early jet engines based on a centrifugal compressor used a method of controlling fuel to the engine combustion chamber that used a fuel pump, a relief valve and a throttle valve. In series with these was a mechanical centrifugal governor. Barometric compensation of their life valvewas provided by a suitable bellows mechanism to maintain the full range of throttle movement at altitude. The design of such engines based upon Sir Frank Whittle’s design was basically simple, using sound engineering practices and employing technology representing ‘state of the art’ of the day. As gas turbine engine technology developed, demands for improved performance required substantial increases in pressure ratios and turbine inlet temperatures placing much more stress on the internal components. New developments such as the axial compressor and reheat (afterburning) created a demand for more complex methods of controlling airflow, fuel flow and exhaust gas flow. Early gas turbine control systems were initially entirely hydro-mechanical. As engine and materials development continued a need arose to exercise greater control of turbine speeds and temperatures to suit prevailing atmospheric conditions and to achieve surge-free operation.Thelatterwasparticularlyimportantinmilitaryengineswherehandlingduringrapid acceleration tended to place the engine under severe conditions of operation. In support of the needed improvements, limited authority electronic trimmers sometimes referred to 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.

POWER ACTUATEDSYSTEM:

Power actuation (as opposed to AFCS series and parallel electrical actuation that will be described later) is provided by three duplex parallel and one duplex tandem actuator respectively. The EH101 is a highly capable and sophisticated helicopter in service with a number of air forces and navies. It has also been selected to provide the US Presidential helicopter as the US101. The aircraft is fitted with a Flight Control System (FCS) that allows many features of such a system to be described in a rotary wing context. To demonstrate and outline the interaction of the various modes of flight control and the associated actuators the EH101 system is described progressively as operating in three distinct modes: • Manual control with no auto-stabilizationoperative

• Manual control with auto-stabilizationengaged

• Full autopilotmode

Digital fly by wiresystems

Fly-by-wire (FBW) is a system that replaces the conventional manual flight controls of an aircraft with an electronic interface. The movements of flight controls are converted to electronic signals transmitted by wires (hence the fly-by-wire term), and flight control computers determine how to move the actuatorsat each control surface to provide the ordered response. It can use mechanical flight control backup systems (Boeing 777) or use fully fly-by-wirecontrols.

Improved fully fly-by-wire systems recognize pilot's input as the required aircraft action, acting in different situations with different rudder elevations or even combining several rudders, flaps and engine controls at once using a closed loop (feedback). Even without the pilot's input, automatic signals can be sent by the aircraft's computers to stabilize aircraft or partially unstable aircraft, or prevent unsafe operation of the aircraft outside its performance envelope

FLY-BY-WIRE CONTROLLAWS:

The authority of each of these levels may be summarized as follows:

- **Normal laws**: Provision of basic control laws with the addition of coordination algorithms to enhance the quality of handling and protection to avoid the exceedanceof certain attitudes and attitude rates. Double failures in computing, sensors or actuation power channels will cause reversion to the Alternatemode
- **Alternate laws**: Provision of the basic control laws but without many of the additional handling enhancement features andprotection.
- **Normal mode.** Further failures cause reversion to the Mechanicalmode
- **Direct laws**: Direct relationship from control stick to control surface, manual trimming, certain limitations depending upon aircraft CG and flight control system configuration. In certain specific cases crew intervention may enable re-engagement of the Alternate mode. Further failures result in reversion toMechanical.

Auto pilot Systems

An aircraft automatic pilot system controls the aircraft without the pilot directly maneuvering the controls. The autopilot maintains the aircraft’s attitude and/or direction and returns the aircraft to that condition when it is displaced from it. Automatic pilot systems are capable of keeping aircraft stabilized laterally, vertically, and longitudinally.

The primary purpose of an autopilot system is to reduce the work strain and fatigue of controlling the aircraft during long flights. Most autopilots have both manual and automatic modes of operation. In the manual mode, the pilot selects each manoeuvre and makes small inputs into an autopilot controller. The autopilot system moves the control surfaces of the aircraft to perform the manoeuvres. In automatic mode, the pilot selects the attitude and direction desired for a flight segment. The autopilot then moves the control surfaces to attain and maintain these parameters.

Autopilot systems provide for one-, two-, or three-axis control of an aircraft. Those that manage the aircraft around only one axis control the ailerons. They are single-axis autopilots, known as wing level systems, usually found on light aircraft. [Figure] Other autopilots are two-axis systems that control the ailerons and elevators. Three-axis autopilots control the ailerons,elevators, and the rudder. Two-and three axis autopilot systems can be found on aircraft of all sizes.There are many autopilot systems available. They feature a wide range of capabilities and complexity. Light aircraft typically have autopilots with fewer capabilities than high performance and transport category aircraft. Integration of navigation functions is common, even on light aircraft autopilots. As autopilots increase in complexity, they not only manipulate the flight control surfaces, but other flight parameters aswell.

Some modern small aircraft, high-performance, and transport category aircraft have very elaborate autopilot systems known as automatic flight control systems (AFCS). These three-axis systems go far beyond steering the airplane. They control the aircraft during climbs, descents, cruise, and approach to landing. Some even integrate an auto-throttle function that automatically controls engine thrust that makes auto landingspossible.

For further automatic control, flight management systems have been developed. Through the use of computers, an entire flight profile can be programmed ahead of time allowing the pilot to supervise its execution. An FMS computer coordinates nearly every aspect of a flight, including the autopilot and auto throttle systems, navigation route selection, fuel management schemes, andmore.

FLIGHT CONTROL LINKAGESYSTEMS:

- The pilot’s manual inputs to the flight controls are made by moving the cockpit control column or rudder pedals in accordance with the universalconvention:
- Pitch control is exercised by moving the control column fore and aft; pushing the column forward causes the aircraft to pitch down, and pulling the column aft results in a pitchup
- Roll control is achieved by moving the control column from side to side or rotating the control yoke; pushing the stick to the right drops the right wing and viceversa

- Yaw is controlled by the rudder pedals; pushing the left pedal will yaw the aircraft to the left while pushing the right pedal will have the reverse effect there are presently two main methods of connecting the pilot’s controls to there of the flight controlsystem.

These are:

- Push-pull control rod systems
- Cable and pulley systems

FLIGHT CONTROLACTUATION:

Actuation has always been important to the ability of the flight control system to attain its specified performance.

The development of analogue and digital multiple control lane technology has put the actuation central to performance and integrity issues.

Addressing actuation in ascending order of complexity leads to the following categories:

- Simple mechanical actuation, hydraulicallypowered
- Mechanical actuation with simple electromechanicalfeatures
- Multiple redundant electromechanical actuations with analogue control inputs and feedback the examination of these crudely defined categories leads more deeply into systems integration areas where boundaries between mechanical, electronic, systems and software engineering become progressively blurred.

COMMUNICATIONS AND NAVIGATIONAIDS:

The aircraft also uses a number of other systems, either for communications or for navigational assistance, that depend upon external agencies in terms of beacons, transmitters, and other support.

Communications systems comprise the following:

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

COMMON NAVIGATION AIDSARE:

- Very High Frequency Omni Range(VOR).
- Distance Measuring Equipment(DME).
- Automatic Direction Finding(ADF).

- Tactical Air Navigation system(TACAN).
- VOR/TACAN (VOR/TAC).
- Hyperbolic navigation systems ñ typically LORANC.
- Instrument Landing System(ILS).
- Microwave Landing System(MLS).
- Global Navigation Satellite Systems (GNSSs), of which the Global Positioning System (GPS) is the mostnotable.

COMMUNICATIONSSYSTEMS:

In aviation, communications between the aircraft and the ground (air traffic/local approach/ground handling) have historically been by means of voice communication.

More recently, data-link communications have been introduced owing to their higher data rates and in some cases superior operating characteristics. As will be seen, data links are becoming widely used in the HF and VHF bands for basic communications, but also to provide some of the advanced reporting features required by FANS. After selecting the appropriate communications channel on the channel selector, the pilot transmits a message by pressing the transmit button which connects the microphone to the appropriate radio.

The voice message is used to modulate the carrier fequency, and it is this composite signal that is transmitted.

HIGHFREQUENCY:

High Frequency covers the communications band between 3 and 30 MHz and is a very common communications means for land, sea, and air. The utilized band is HF SSB/AM over the frequency range 2.000ñ29.999 MHz using a 1 kHz (0.001 MHz) channel spacing.

The primary advantage of HF communications is that this system offers communication beyond the line of sight. This method does, however, suffer from idiosyncrasies with regard to the means of signal propagation.

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

VERY HIGH FREQUENCY:

Very High Frequency (VHF) voice communication is probably the most heavily used method of communication used by civil aircraft. The VHF band for aeronautical applications operates in the frequency range 118.000ñ135.975 MHz with a channel spacing in recent years of 25 kHz (0.025 MHz). In recent years, to overcome frequency congestion, and taking advantage of digital radio technology, channel spacing has been reduced to 8.33 kHz (0.00833 MHz), which permits 3 times more radio channels in the available spectrum.

The VHF band for aeronautical applications operates in the frequency range 118.000ñ135.975 MHz with a channel spacing in recent years of 25 kHz (0.025 MHz). The aircraft communicates via the INMARSAT constellation and remote ground earth station by means of C-band uplinks and downlinks to/from the ground stations and L-band links to/from the aircraft. This will enable the aircraft return to be displayed on an ATC console at a range and bearing commensurate with the aircraft position. Coincident with the primary radar operation, a Secondary Surveillance Radar (SSR) will transmit a series of interrogation pulses that are received by the on-board aircraft transponder

SATELLITECOMMUNICATIONS:

Satellite communications provide a more reliable method of communications using the International Maritime Satellite Organization (INMARSAT) satellite constellation which was originally developed for maritime use. Now, satellite communications, abbreviated to SATCOM, form a useful component of aerospace communications. The aircraft communicates via the INMARSAT constellation and remote ground earth station by means of C-band uplinks and downlinks to/from the ground stations and L-band links to/from the aircraft. In this way, communications are routed from the aircraft via the satellite to the ground station and on to the destination. Conversely, communications to the aircraft are routed in the reverse fashion. Therefore, provided the aircraft is within the area of coverage or footprint of a satellite, then communication may be established.

Air Traffic Control (ATC) transponder

As a means to aid the identification of individual aircraft and to facilitate the safe passage of aircraft through controlled airspace, the ATC transponder allows ground surveillance radars to interrogate aircraft and decode data, which enables correlation of a radar track with a specific aircraft. A ground-based Primary Surveillance Radar (PSR) will transmit radar energy and will be able to detect an aircraft by means of the reflected radar energy ñ termed the aircraft return. This will enable the aircraft return to be displayed on an ATC console at a range and bearing commensurate with the aircraft position. Coincident with the primary radar operation, a Secondary Surveillance Radar (SSR) will transmit a series of interrogation pulses that are received by the on-board aircrafttransponder.

TRAFFIC COLLISION AND AVOIDANCESYSTEM:

The TCAS was developed in prototype form during the 1960s and 1970s to provide a surveillance and collision avoidance system to help aircraft avoid collisions. It was certified by the FAA in the 1980s and has been in widespread use in the United States in its initial form. TCAS is based on the beacon interrogator and operates in a similar fashion to the ground-based

SSR already described. The system comprises two elements: a surveillance system and a collision avoidance system. TCAS detects the range bearing and altitude of aircraft in the near proximity for display to the pilots. TCAS transmits a mode C interrogation search pattern for mode Aand Communications control system The control of the aircraft suite of communications systems, including internal communications, has become an increasingly complex task. This task

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

INSTRUMENT LANDINGSYSTEM:

The ILS is an approach and landing aid that has been in widespread use since the 1960s and 1970s. The main elements of ILS include: ï A localizer antenna centred on the runway to provide lateral guidance. A total of 40 operating channels are available within the band 108ñ112 MHz. The localizer provides left and right lobe signals that are modulated by different frequencies (90 and 150 Hz) so that one signal or other will dominate when the aircraft is off the runway centre-line. The beams are arranged such that the 90 Hz modulated signal will predominate when the aircraft is to the left, while the 150 Hz signal will be strongest to the right. The difference in signal is used to drive a cross-pointer deviation needle so that the pilot is instructed to ëflyrightí when the 90 Hz signal is strongest, and ëflyleftí when the 150 Hz signal dominates. When the aircraft is on the centre-line, the cross-pointer deviation needle is positioned in the central position. This deviation signal is proportional to azimuth out to ±5º of the centre-line. ï A glide slope antenna located beside the runway threshold to rovide lateral guidance. Forty operating channels are available within the frequency band 329ñ335 MHz. As for the localizer, two beams are located such that the null position is aligned with the desired glide slope, usually set at a nominal 3º. In the case of the glide slope, the 150 Hz modulated signal predominates below the glide slope and the 90 Hz signal is stronger above. When the signals are balanced, the aircraft is correctly positioned on the glide slope and the glide slope deviation needle is positioned in a central position. As for the localizer needle, the pilot is provided with fly up or fliesdown guidance to help him or her acquire and maintain the glide slope. shows the general arrangement of ILS. illustrates how guidance information is portrayed for the pilot according to the aircraft position relative to the desired approach path. On older aircraft this would be shown on the compass display, but on modern aircraft, with digital cockpits, this information is displayed on the Primary Flight Display (PFD).

Air Traffic Control (ATC) transponder

As a means to aid the identification of individual aircraft and to facilitate the safe passage of aircraft through controlled airspace, the ATC transponder allows ground surveillance radars to interrogate aircraft and decode data, which enables correlation of a radar track with a specific aircraft. The principle of transponder operation is shown in Fig. 6.13. A ground-based Primary Surveillance Radar (PSR) will transmit radar energy and will be able to detect an aircraft by means of the reflected radar energy ñ termed the aircraft return. This will enable the aircraft return to be displayed on an ATC console at a range and bearing commensurate with the aircraft position. Coincident with the primary radar operation, a Secondary Surveillance Radar (SSR) will transmit a series of interrogation pulses that are received by the on-board aircraft transponder.

The transponder aircraft replies with a different series of pulses that give information relating to the aircraft, normally aircraft identifier and altitude. If the PSR and SSR are synchronized, usually by being co-boresighted, then both the presented radar returns and the aircraft transponder information may be presented together on the ATC console. Therefore, the controller will have aircraft identification (e.g. BA 123) and altitude presented alongside the aircraft radar return, thereby greatly improving the controllerís situational awareness. The system is also known as Identification Friend or Foe (IFF)/Secondary Surveillance Radar (SSR), and this nomenclature is in common use in the militaryfield.

Automatic Direction Finding

Automatic Direction Finding (ADF) involves the use of a loop direction finding technique to establish the bearing to a radiating source. This might be to a VHF beacon or a Non-Directional Beacon (NDB) operating in the 200ñ1600 kHZ band. NDBs in particular are the most prolific and widely spread beacons in use today. The aircraft ADF system comprises integral sense and loop antennae which establish the bearing of the NDB station to which the ADF receiver is tuned.

Very High Frequency OmnirangeThe VOR system was accepted as standard by the United States in 1946 and later adopted by the ICAO as an international standard. The system provides a widely used set of radio beacons operating in the VHF frequency band over the range 108ñ117.95 MHz with 100 kHz spacing. Each beacon emits a morse code modulated tone which may be provided to the flight crew for the purposes of beacon identification. The ground station radiates a cardoid pattern that rotates at 30rev/min, generating a 30 Hz modulation at the aircraft receiver. The ground station also radiates an omnidirectional signal which is frequency modulated with a 30 Hz reference tone. The phase difference between the two tones varies directly with the bearing of the aircraft. At the high frequencies at which VHF operates there are no sky wave effects and the system performance is relatively consistent. VOR has the disadvantage that it can be severely disrupted by adverse weather ñ particularly by electrical storms ñ and as such it cannot be used as a primary means of navigation for a civil aircraft.

Distance Measuring Equipment

Distance Measuring Equipment (DME) is a method of pulse ranging used in the 960ñ1215 MHz band to determine the distance of the aircraft from a designated ground station. The aircraft equipment interrogates a ground-based beacon and, upon the receipt of retransmitted pulses (unique to the on-board equipment), is able to determine the range to the DME beacon (see Fig.6.17). DME beacons are able to service requests from a large number of aircraft simultaneously but are generally understood to have the capacity to handle ~200 aircraft at once.

DME and TACAN beacons are paired with ILS/VOR beacons throughout the airway route structure in accordance with the table set out in Appendix 3 of reference (7). This is organized such that aircraft can navigate the airways by having a combination of VOR bearing to and DME distance to run to the next beacon in the airway route structure. A more recent development ñ scanning DME ñ allows the airborne equipment rapidly to scan a number of DME beacons, thereby achieving greater accuracy by taking the best estimate of a number of distance readings. This combination of VOR/DME navigation aids has served the aviation community well in the United States and Europe for many years, but it does depend upon establishing and maintaining a beacon structure across the land mass or continent beingcovered.

TACAN (Tactical Air Navigation)

Military Omni bearing and distance measuring equipment that employs similar techniques for distance measurement to DME. The bearing information is accomplished by amplitude modulation achieved within the beacon which imposes 15 and 135 Hz modulated patterns and transmits this data together with 15 and 135 Hz reference pulses. The airborne equipment is therefore able to measure distance using DME interrogation techniques while using the modulated data to establish bearing. TACAN beacons operate in the frequency band 960ñ1215 MHz, as opposed to the 108ñ118 MHz used by DME. This means that the beacons are smaller, making them suitable for shipborne and mobile tactical use. Some airborne equipment have the ability to offset to a point remote from the beacon which facilitates recovery to an airfield when the TACAN beacon is not co-located. TACAN is reportedly accurate to within ±1 per cent in azimuth and ±0.1 nm in range, so it offers accuracy improvements over VOR/DME.

VORTAC

As most military aircraft are equipped with TACAN, some countries provide VORTAC beacons which combine VOR and TACAN beacons. This allows interoperability of military and civil air traffic. Military users use the TACAN beacon while civil users use the VOR bearing and TACAN (DME) distance measuring facilities. This is especially helpful for large military aircraft, such as transport or surveillance aircraft, since they are able to use civil air lines and operational procedures during training or in transit between theatres ofoperations.

Satellite navigation systems

These techniques were prevalent from the 1960s through to the 1990s when satellites became commonly available. The use of Global Navigation Satellite Systems (GNSSs), to use the generic name, offers a cheap and accurate navigational means to anyone who possesses a suitable receiver. Although the former Soviet Union developed a system called GLONASS, it is the US Global Positioning System (GPS) that is the most widely used. GPS is a US satellite-based radio navigational, positioning, and time transfer system operated by the Department of Defense (DoD). The system provides highly accurate position and velocity information and precise time on a continuous global basis to an unlimited number of properly equipped users. The system is unaffected by weather and provides a worldwide common grid reference system based on the Earth-fixed coordinate system. For its earth model, GPS uses the world geodetic system of 1984 (WGS-84) datum. The Department of Defense declared Initial Operational Capability (IOC) of the US GPS on 8 December 1993. The Federal Aviation Administration (FAA) has granted approval for US civil operators to use properly certified GPS equipment as a primary means of navigation in oceanic and certain remote areas. GPS equipment may also be used as a supplementary means of Instrument Flight Rules (IFR) navigation for domestic en route, terminal operations and certain instrumentapproaches.

GPS comprises three major components as characterized in the figure:

- The control segment which embraces the infrastructure of ground control stations, monitor stations and ground-based satellite dishes that exercise control over thesystem.

- The space segment which includes the satellite constellation, presently around 25 satellites, that forms the basis of the network.

- The user segment which includes all the users: ships, trucks, automobiles, aircraft, and hand-held sets. In fact, anyone in possession of a GPS receiver is part of the user segment.

The baseline satellite constellation downlinks data in two bands:
L1 on 1575.42 MHz and L2 on 1227.60 MHz A GPS modernization programmer recently announced will provide a second civil signal in the L2 band for satellites launching in 2003 onwards. In addition, a third civil signal, L5, will be provided on 1176.45 MHz on satellites to be launched in 2005 and beyond. Finally, extra signals for military users (Lm) will be included in the L1 and L2 bands for satellites launched in 2005 and beyond. GPS operation is based on the concept of ranging and triangulation from a group or constellation of satellites in space which act as precise reference points. A GPS receiver measures distance from a satellite using the travel time of a radio signal. Each satellite transmits a specific code, called Course/Acquisition (CA), which contains information on the satellite's position, the GPS system time, and the health and accuracy of the transmitted data. Knowing the speed at which the signal travelled(approximately 186 000 mile/s) and the exact broadcast time, the distance travelled by the signal can be computed from the arrival time. The GPS constellation of 24 satellites is designed so that a minimum of 5 are always observable by a user anywhere on Earth. The receiver uses data from a minimum of four satellites above the mask angle (the lowest angle above the horizon at which it can use a satellite). GPS receivers match each satellite's CA code with an identical copy of the code contained in the receiver's database. By shifting its copy of the satellite's code in a matching process, and by comparing this shift with its internal clock, the receiver can calculate how long it took the signal to travel from the satellite to the receiver. The value derived from this method of computing distance is called a pseudo range because it is not a direct measurement of distance but a measurement derived fromtime.

Transponder Landing System (TLS)

Developed by the Advanced Navigation and Positioning Corporation, TLS is a flexible system that appears to the pilot much like a standard ILS. The TLS employs patented and sophisticated closed-loop technology, which uses the aircrafts existing transponder to generate high-quality tracking information obtained from sensors located near the runway or landing zone. Flight guidance commands are transmitted back to the aircraft using standard ILS localizer and glide slope frequency bands. The pilot simply follows the cockpit-displayed guidance commands to the published minimum altitude. Coupled autopilot approaches can also be routinely flown. The flight path of any aircraft is displayed in real time to the local air traffic controllers or transmitted to remote controlling agencies as desired. However, it has a major advantage over an ILS, since installation at difficult terrain sites poses no problem to its easy and rapid deployment within a 350 ft2 area. Unlike other existing and new precision approach system technologies (e.g. MLS, GPS, DGPS), the TLS uses standard on-board aircraft avionics such as localizer/glide slope receivers, Course Deviation Indicators (CDIs), flight directors or Flight Management Systems (FMS), and transponders. Operating on standard FAA-assigned TLS frequencies, this equipment may be coupled to autopilot. No new on-board navigation equipment or pilot training is required. Therefore, for some users TLS provides a high capability at modest outlay. TLS has been certified, and some systems are being procured by the FAA. Microwave Landing System.

Microwave Landing System (MLS)

The MLS is an approach aid that was conceived to redress some of the shortcomings of ILS. The specification of a time-reference scanning beam MLS was developed through the late 1970s/early 1980s, and a transition to MLS was envisaged to begin in 1998. However, with the emergence of satellite systems such as GPS there was also a realization that both ILS and MLS could be rendered obsolete when such systems reach maturity. In the event, the US civil community is embarking upon higher-accuracy developments of the basic GPS system: Wide Area Augmentation System (WAAS) and Local Area Augmentation System (LAAS), which will be described later. In Europe, the United Kingdom, the Netherlands, and Denmarkhave embarked upon a modest programmer of MLS installations at major airports. MLS operates in the frequency band 5031.0ñ5190.7 MHz and offers some 200 channels of operation. It has a wider field of view than ILS, covering ±40º in azimuth and up to 20º in elevation, with 15º useful range coverage. Coverage is out to 20 nm for a normal approach and up to 7 nm for back azimuth/go-around. The co-location of a DME beacon permits three-dimensional positioning with regard to the runway, and the combination of higher data rates means that curved arc approaches may be made, as opposed to the straightforward linear approach offered by ILS. This offers advantages when operating into airfields with confined approach geometry and tactical approaches favored by the military. For safe operation during go-around, precision DME (PDME) is required for a precise back azimuthsignal.

Hyperbolic navigationsystems

Hyperbolic navigation systems operate upon hyperbolic lines of position rather than circles or radial lines. Figure 6.23 illustrates the principle of operation of a hyperbolic system in a very elementary manner. This shows the hyperbolic solid lines representing points that are equidistant from the two stations. These points will all have the same time difference between the arrival of signals from the blue-master and blue-slave stations (the term secondary station is probably a better and more accurate description). This in itself will not yield position, but if a second pair of stations is used ñ angled at approximately 45 to the first and shown as dashed lines ñ then position can be obtained. The relative positioning of the lines in this dual-chain example shows that three outcomes arepossible:

a) At point A the lines cross at almost 90, which represents the most accurate fix. ïAt point B the lines cross at a much more acute angle and the result is a larger errorellipse.
b) At point C there are two possible solutions and an ambiguity exists that can only be resolved by using a furtherstation.

The electromechanical instrumented flightdeck

The first flight of a heavier-than-air machine is generally recognized to have taken place in Kitty Hawk, USA on the 17 December 1903. The aircraft known as the Wright Flyer was built by the Wright brothers and flown by Orville Wright. The pilot lay in a prone position, facedown. There was no flight instruments, flying were by the seat-of-one's pants'. By the mid-1920s, rudimentary flying instruments had found their way onto the Chapter 7 27/11/02 10:08 am Page 161 flight deck (or cockpit as it was then more generally known in a single-seat aircraft), but there was little standardization. The cockpit shown in Fig. 7.1had:

a) Magnetic compass.

b) Tachometer.
c) Fuelgauge.
d) Oilpressure.
e) Clock.
f) Turn and slipindicator.

However, there was no attitude, airspeed, altimeter, or vertical speed instruments, i.e. no flight instruments, as we would know them today.
The 1950s ñ piston engine aircraft World War II had provided significant experience about flying aircraft for long periods in adverse conditions by day and by night. Flight instruments had become standardized to some degree. The Handley Page Hermes designed and built at the end of that war is but one example, which encapsulates best practice of the day. The Hermes was a luxury aircraft. It was the first British aircraft to have a pressurized hull and therefore could fly above the weather and provide a smoother ride to its passengers. A typical route was from London to Sydney. The aircraft had facilities for 40 passengers plus cabin staff. Five crew ñ the captain, first officer, navigator, flight engineer, and radio operator ñ operatedit.
Airspeed, altimeter, and rate of climb (the barometric instruments) operated from static and dynamic air pressure direct from the pitostatic probes. The artificial horizon comprised an integral two-axis gyroscope with mechanical pick-offs to drive the horizon bar to indicate aircraft pitch and roll angles with respect to the ground. The compass was a repeater instrument driven from the navigators station, which could be slaved to one of two gyro compass units indicating aircraft heading or operate as a direction indicator to fly to a selected course. A magnetic compass was installed in the roof. As an option, an Automatic Direction Finding

(ADF) repeater instrument could be fitted to indicate direction to the selected radio beacon. On the left of the basic six instrument cluster there was an option to fit an Instrument Landing System (ILS), which would indicate lateral and vertical deviation Displays 163 Fig. 7.2 Hermes flight deck, pilots station: starboard ñ Duxford Imperial War Museum I.L.S. I.L.S. P. 12 compass Radio Altimeter D.M.E. CL2 compass Control Rudder trim control CL2 compass O.R.B.Rudder control Pedal adjuster Air speed Height Artificial horizon Rate of climb Turn and bank A.D.F. repeater Automatic pilot cut-out switch Elevator and aileron control Flap Chapter 7 27/11/02 10:08 am Page 163 from the ILS glide slope and localizer beams, a low-range radio altimeter to provide greater height accuracy during approach and landing, and Distance Measuring Equipment (DME) to indicate distance to the ILS transmitter (positioned at the runway threshold).

The 1970s ñ jet aircraft The 1970s heralded the mass market for civil transport aircraft with the introduction of the Boeing 747 Jumbo Jet. The 747 first entered service with Pan American in January 1970. The aircraft has continuously been developed throughout its operating life. At its introduction, the flight deck of the 747 had a set of conventional electromechanical instruments and was operated by a three-man crew, the captain, the first officer and the flight engineer, as shown in Fig. 7.3. Today, the 747-400 aircraft has a fully integrated glassy flight deck with six AMLCD displays and is operated by a two man crew.
By today’s standards, the flight deck of the early classic 747 might be considered to be fairly basic, but the aircraft did have some early satellite communications equipment, an automatic

landing system, and an Inertial Navigation (IN) system. The IN was a direct descendant of that used on the Apollo moon landing missions, and its inclusion in the 747 allowed the aircraft to be certificated to fly anywhere in the world without a specialist navigator on-board.

The Attitude Direction Indicator (ADI) and Horizontal Situation Indicator (HSI) are commonly found in 5ATI format, that is, with a physical form factor in accordance with the Air Transport Indicator (ATI) standard and a 5 in., square faceplate. The other instruments are commonly found in 3ATI format, that is, with a 3 in., square faceplate. The instruments are available from a number of manufacturers, have standardized functionality, and are certified to comply with Technical Standards Orders (TSOs) published by the Federal Aviation Authority (FAA) . In addition, a third set of primary flight instruments, known as standby instruments; provide fully independent information to aid the flight crew to resolve discrepancies. The standby instruments (usually in 3ATI format) are totally segregated from the primary instruments and operate on separate electrical power, usually the D.C. essentialbus.

The Attitude Direction Indicator

The instrument shown in Fig5.13 comprises:

1. An attitude ball, shaded blue for sky and brown for ground, which indicates aircraft pitch and bank angles against a fixed aircraft symbol in the centre of the instrument. The attitude ball is inscribed with pitch bar markings. Bank angle is indicated against a scale on the lower circumference of the instrument.

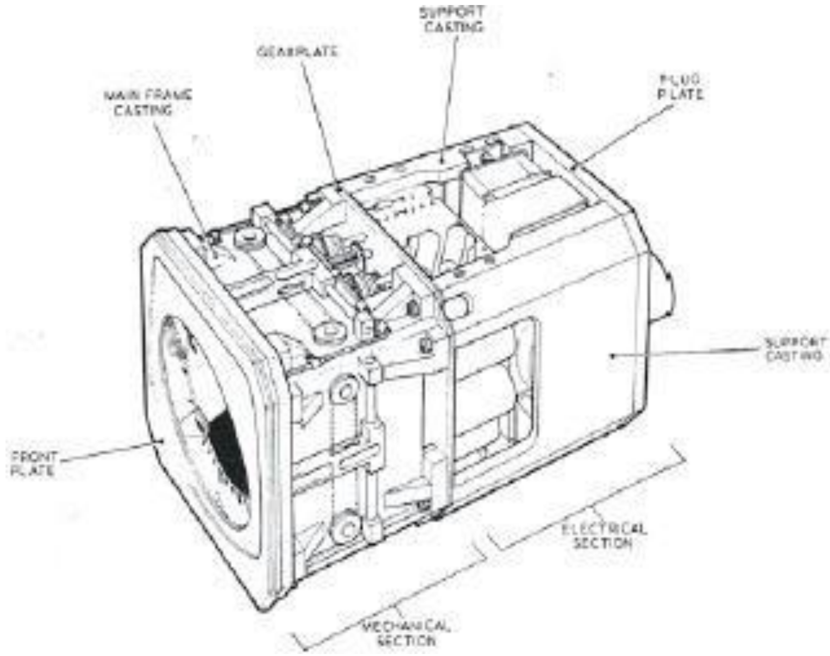


Figure 5.14

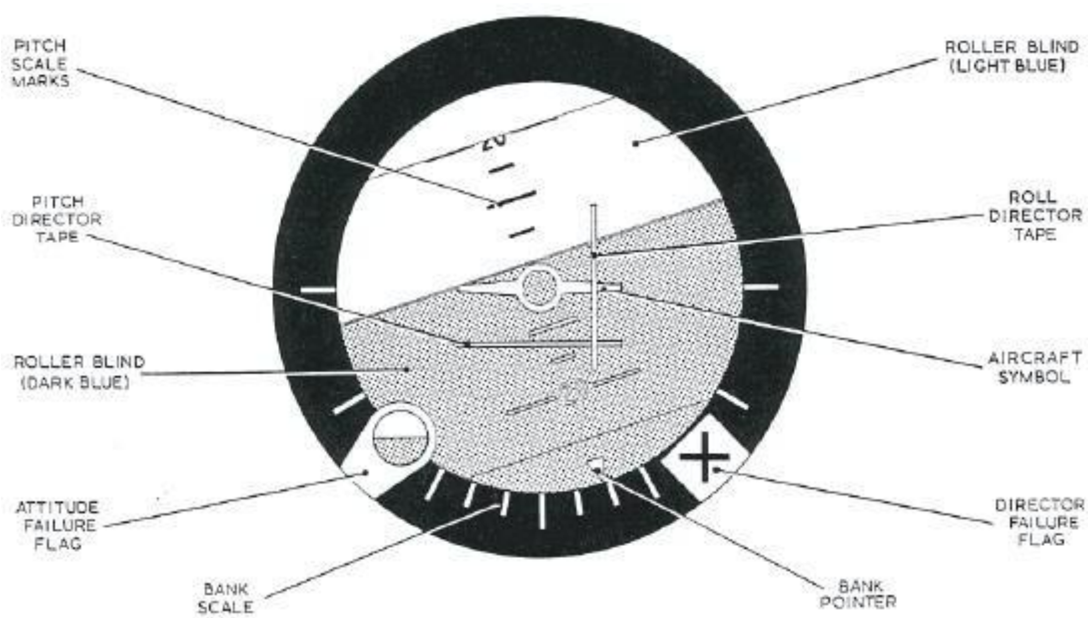


Figure 5.15
Attitude directionindicator

2. A flight director, which consists of two bars indicating lateral and vertical steering guidance to achieve a desired flight path. Different navigation aids are coupled to the flight director, depending on the phase offlight.

ADF, VOR, and TACAN), the flight management computer, and the autopilot itself as a monitor.During approach and landing, these bars are coupled to the ILS receiver to indicate glide slope and localizer deviation. 3. A turn and slip bubble, which is attached to the faceplate of the instrument. 4. Warning flags, to indicate warnings or cautions requiring crew action. The captain and first officers instruments are fed with data from different sources to provide both redundancy and independence. Electrical cross-monitoring triggers a warning flag if a discrepancy is found between the indications on the two instruments. The crew must resolve the discrepancy. The pitch and roll attitudes of the aircraft are represented by the position of a roller blind relative to the aircraft symbol. The blind, shown unrolled in Fig.7. 6, consists of a two-tone band, light-blue representing the sky and brown representing the ground. A white line separating the two zones represents the horizon. The aircraft symbol, in the form of a yellow colored motif, is painted on the rear glass of the instrument. Movement of the blind over rollers attached to a carriage assembly depicts a change in aircraft pitch attitude, while rotation of the roller blind with the carriage assembly depicts a change in aircraft roll attitude. Pitch angle is given by pitch scale marks on the roller blind. Roll or bank angle is given by a pointer, which rotates with the roller blind, against a scale painted on the instrument bezel. Motion of the roller blind carriage is controlled by pitch and roll electromechanicalservomechanisms.

The Horizontal Situation Indicator

This instrument (shown in Fig. 7.7) functions as a magnetic compass or as a directional gyro indicator, depending on the mode selected. It operates as follows: 1. Aircraft heading is indicated by rotation of the compass card against a fixed lubber mark at the top centre of the instrument. 2. Aircraft course is indicated by the course index, which registers against and rotates with the compass card. The selected course may be set relative to the compass card by means of a knob at the bottom right-hand corner of the instrument.

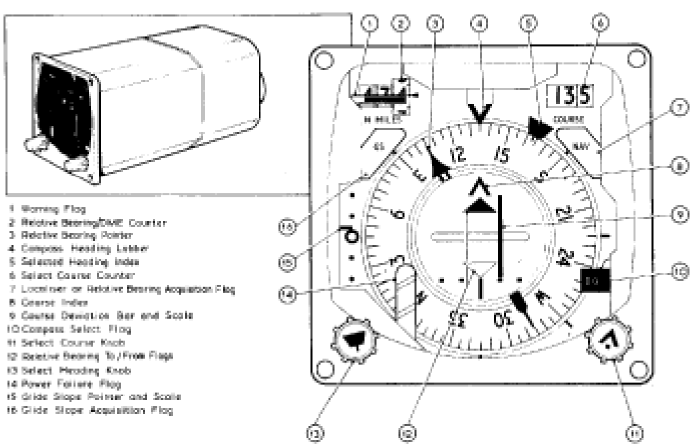


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Figure 5.16

Horizontal situation indicator

A drum counter display of selected course is also incorporated. 3. Selected heading is indicated by the heading index, which registers against and rotates with the compass card. The index may be set relative to the compass card by means of the heading selection knob. 4. Relative bearing information is displayed by the relative bearing pointer, which registers against the compass card but is driven independently of the compass card from the radio navigation equipment. 5. Deviation in azimuth from a selected relative bearing radial or ILS localizer beam is represented by the lateral displacement of the course deviation bar relative to the course deviation scale. 6. Deviation in pitch from the ILS glide path is represented by the vertical displacement of the glide slope deviation scale. 7. The DME counter displays the distance of the aircraft from a beacon. A TO/FROM flag indicates the aircraft direction relative to the beacon.

The altimeter

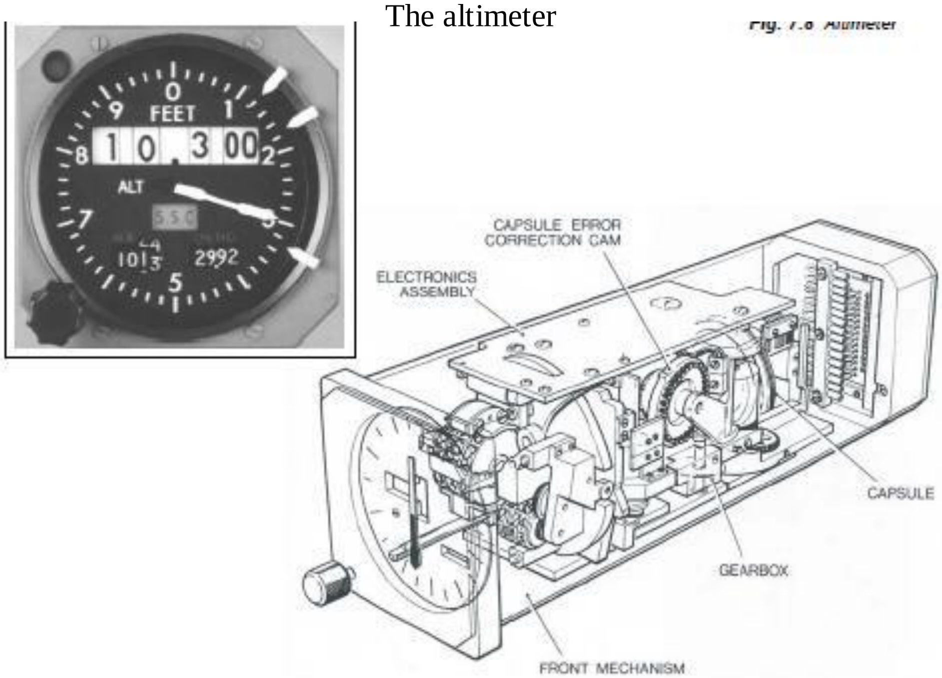

Figure 5.17

The primary altimeter in current-generation aircraft contains an electromechanical servomechanism driven by signals from the Air Data Computer (ADC) to indicate barometric altitude by means of a pointer and a counter (numerical readout) (see Fig. 5.17). 168 Civil Avionics Systems Fig. 5.17 Horizontal situation indicator (HSI) ñ Smiths Aerospace Chapter 7 27/11/02 10:08am Page 168 Early instruments and standby instruments operate directly from air pressure. By means of gears, levers, and cams, the deflection of an aneroid (sealed) capsule is translated into motion of counters and pointers against a scale indicating height (in feet). The capsule operates against aircraft outer atmosphere static pressure (derived from the pitotstatic probe). The cams model the standard atmosphere chart. The pointer completes one revolution for every 1000 ft, rotating clockwise for increasing height. A bimetallic strip provides temperature compensation. A knob with a numerical readout sets the barometric pressure datum.

The Airspeed Indicator (ASI)

As with the primary altimeter, the primary Airspeed Indicator (ASI) in current generation aircraft

is driven by an electromechanical servomechanism slaved to the ADC for the portrayal of such an instrument, see Fig. 7.9. Standby instruments, and early primary instruments, operate directly from air pressure. The deflection of a capsule is translated into motion of counters and pointers against a scale indicating airspeed in knots. In the ASI, the capsule inner atmosphere is airstream total pressure operating against outer atmosphere staticpressure.

Strictly speaking, knowledge of the air density is also required, but the simple mechanical instrument cannot compute this quantity from the information to hand and assumes a Displays 169 Fig. 5.18 Altimeter Chapter 7 27/11/02 10:08 am Page 169 standard air density. The instrument also assumes that air is incompressible (which is true at airspeeds below Mach 1). The parameter computed with these assumptions is called calibrated airspeed (CAS). In addition to airspeed it is not unusual also to find a numerical readout of Mach number. A warning bar indicates maximum safe speed. Bugs may be set around the circumference of the instrument to indicate placardspeeds

Standby instruments

The availability and integrity of flight-critical information is always augmented with standby instruments. The standby instruments must operate independently of the main display suite and the avionic systems that source data to them. They are powered independently, usually bythe d.c. essential bus. By these means, flight-critical data are still available on the flight deck even in the event of major avionic system failures and/or electrical power failure.

The standby instruments (Fig. 5.19) are typically a single set of miniature (2ATI and 3ATI) self-sensing instruments using integral transducers. They are the modern-day equivalents of the pitot and static barometric instruments and gyro artificial horizon found in 1950s aircraft.

Advanced civil flight deck research

Research into the use of CRT technology to display crew information in civil transport aircraft began in the United Kingdom in the mid-1970s. It was carried out at BAe Weighbridge with contributions from GEC and Smiths Industries. The Department of Trade and Industry (DTI) sponsored the program, known as the Advanced Civil Flight Deck (ACFD).

The ground-based simulator had six CRTs, each with a 6 × 4.5 in. (4:3 aspect ratio) usable screen area, arranged in landscape format in a side by-side configuration across the flight deck. The displays were monochrome (white on black) and the images were generated in 625 line 25:50 Hz interlaced video (TV standard). The research activities included extensive human factor evaluation by pilots and demonstrated the viability of an all-glass flight deck and the side-by-side configuration of primary flight (PFD) and navigation (ND) displays.

BAC 1-11 technology demonstrator

In 1980 the ACFD research program moved to a flight demonstration phase. Two displays (the PFD and ND) were installed into one crew station of the BAC 1-11 civil transport aircraft operated by the Royal Aircraft Establishment (RAE) in Bedford. The program was launched with monochrome CRTs (green on black), but, once it was established that color shadow mask CRTs could be ruggedized to withstand the civil air transport environment, the program transitioned to 6.25 × 6.25 in. usable screen area square color displays. The display suite was fully integrated with the aircraft systems and the aircraft could be flown from the left seat, the crewmember on the right acting as the safety pilot. The aircraft first flew in the spring of 1981 and from the autumn of 1981 made an extensive series of test and demonstration flights in Europe and the United States. During a comprehensive US tour the aircraft visited nine sites, inviting guests from aircraft manufacturers, airlines, and research organizations to fly the aircraft. Some 34 sorties were flown (55 flight hours), most by guest pilots who were able to fly enroute and touch-and-go procedures to evaluate the concept. Most pilots found the displays intuitive and easy to use; they adapted quickly to the side-by-side PFD/NDconfiguration.

The display formats used on the BAC 1-11 aircraft drew on the experience of the ACFD ground-based program. The formats mirrored closely the style of the 172 Civil Avionics Systems. The advanced civil flight deck Chapter 7 27/11/02 10:08 am Page 172 electromechanical instruments they were replacing to facilitate transition to the new media.

The flight deck layout is shown in Fig. 5.22. The PFD shown in Fig. 5.23 preserved the basic It configuration of airspeed, attitude, and altitude. Counterpointed presentations of speed and height were retained, but in addition digital readouts of speed and height were presented on the horizontal centre-line and adjacent to the attitude ball so the pilot could rapidly assess the primary flight data without having to scan the whole display. Great care was taken to make numerical readouts emulate the rotation of drum counters in mechanical instruments to aid the ability to read the digits when changing. The pointer emulates the rotation of instrument needles to preserve the perception of rate information. The ND shown in Fig. 7.14 provided two format styles: the compass rose format which preserved the original electromechanical HSI compass rose style, and the map format which presented the planned route, updated with present position, in real time. This later format demonstrated the real freedom of the media to overcome the limitations of the electromechanical instrument and present a picture of the plan situation, a picture that hitherto the pilot had had to form in his or her head. The map could be oriented heading-up, track-up or north-up, with the aircraft position portrayed either in the lower quadrant or in the centre of the display. Map range was selectable. Information on the flight plan included waypoints and navigation aids Displays 173 Fig. 7.12 BAC 1-11 advanced civil flight deck, Royal Aircraft Establishment Chapter 7 27/11/02 10:08 am Page 173 in the local area. Weather radar data could also be added to facilitate route replanningto avoid storm centers. Down each side of the map was presented navigational information relative to the planned route, including waypoint identification, direction, distance, andtime-to-go

British Aerospace advanced turbo-prop

The Advanced Turbo-Prop (ATP) followed the path of the Boeing 757/767 and placed the EADI and EHSI displays above one another as shown in Fig. 7.16. The displays have a CRT with a usable screen area of 5 × 4 in., both in landscape orientation. The original concept had been to include both speed and height in the upper display as tape scales to the left and right respectively of the attitude ball. However, it soon became apparent that the maximum display size that could be accommodated in the instrument panel would not permit the desired information to be written at a sufficiently large size to be read comfortably.

Therefore, the final certificated configuration included only the speed scale on the EADI, with height presented on a conventional electromechanical altimeter to the right of the EADI.

Airbus A320/A330

The Airbus A320, which entered service in March 1988, was the first civil transport aircraft to adopt the side-by-side PFD/ND configuration with six 6.25 × 6.25 in. CRT displays installed on the flight deck. The A330 has a similar configuration (see Fig.7.17). The two systems displays are installed one above the other in the centre of the flight deck. The PFD shown in Fig. 7.18 introduces airspeed and altitude as two tape scales positioned either side of the attitude ball. A numerical readout is positioned as a window in the tape scales on the horizontal centre axis ofthe attitude ëballí. This concept allows the pilot quickly to acquire the key flight parameters without having to scan the whole display surface. The tape scales facilitate the acquisition of selected speed and height cues, which are presented on and attached to the moving scales. The moving scales also offer a representation of rate of change in the parameter, although it has to be said that this is recognized as being inferior to a circular scale and pointer. A vertical speed scale therefore augments the height tape. At the bottom of the PFD format the upper segment of a compass rose provides heading and lateral guidance cues. Autopilot-mode annunciators are incorporated along the top of the display

Boeing 747-400

Boeing adopted the side-by-side, six display configuration for its ñ400 variant of the 747 aircraft, which entered service in June 1990 and then subsequently for the Boeing 777 aircraft (see Fig. 7.19). The two systems displays are positioned one above the other in the vertically extended centre portion of the instrument panel. The 747-400 configuration is depicted inFig.

The displays employ CRT technoloy. The display formats are similar to those of the Airbus A340, with strip speed and height scales positioned either side of the attitude ball. In this configuration, the Boeing 747 operates with a two-man crew. The flight engineers panel functions have been absorbed into the aircraft systems and are presented and controlled through the two power/systems displays. The Boeing 777 (in-service date June 1995) adopts a similar flight deck configuration but a significantly different avionics system architecture. The displays themselves were the first in a wide-body civil transport aircraft to utilize AMLCD technology.

systems to support a fully integrated glass flight deck is neither practical nor affordable. Replacement of the existing electromechanical instruments with form, fit but functionally enhanced .glass. Instruments are a viable option. One such example is the upgrade to the fleet of 747-Classic aircraft operated by KLM. Seven 5ATI .glass. Instruments replace the existing 5ATIADI and HSI instruments, together with some of the engine instruments. These instruments use AMLCD technology. The instruments are identical, their function being contained in software that configures itself when the instruments are installed, sensing their location in the aircraft by program mepins.

The EADI emulates the pre-existing electromechanical ADI but with improved flight director presentation. The EHSI emulates the pre-existing electromechanical HIS but with the addition of the map format optionally overlaid with weather radar. Two instruments combined provide engine data in tape scale format. These formats are shown in Fig. 5.28. A combined EHSI and EADI format, shown in Fig. 5.28, is provided as a standby instrument in the event of failure of either or both of the prime displays.

The displays have a 6.7 × 6.7 in. useable screen area. The Boeing 777 Navigation Display (ND) shown in Fig. 7.20 provides planned and actual route, together with lateral guidance command cues optionally overlaid with weather data.

Upgrade of Classic aircraft flight decks

The power of the glass flight deck has been demonstrated and new air traffic Procedures are being introduced to take advantage of the improved route planning and freedoms afforded by the glass flight deck and other aids. There is a demand to upgrade the flight deck of legacy (or classic) aircraft originally fitted with electromechanical instruments to a .glass. Flight deck so that those aircraft too can enjoy more efficient route structures and operating procedures. Complete stripping and replacement of the instrument panel and reconstruction of theaircraft

Glass standby instruments

As described earlier, the availability and integrity of flight-critical information is always augmented with standby instruments. These remains true in a .glass flight deck In early glass flight decks the standbys are the traditional set of miniature (2ATI and 3ATI) dedicated electromechanical instruments. More recently these have been superseded by electronic displays using AMLCD technology with integral solid-state sensors. Piezo-resistive pressure sensors have replaced the aneroid capsules. Micro machined rate sensors and accelerometers have replaced the rotating gyroscope. A single instrument can replace all the dedicated instruments, pin programmed to provide the desired display format. This display, shown in Fig. 7.24, is known as the Integrated Standby Instrument System, or ISIS.

The ISIS provides a display of:

- Attitude.
- Indicated airspeed and Machnumber.
- Baro-corrected altitude andbaro-set.

- Slip/skid.
- Heading.
- The display formats are designed to be compatible with the primary EFIS formatsto Reduce pilot adaptation time andworkload.

The ISIS shown is in 3ATI form factor and uses a high-resolution full-color AMLCD with a usable screen area of 2.4   2.4in. It operates from the 28V DC essentialbusandconsumes 15W at full brightness.

Radar sensors

Civil aircraft carry a number of radar sensors that permit the aircraft to derive data Concerning the flight of the aircraft. The principle radar sensors in use on civil aircraft are:

1. Radaraltimeter.
2. Dopplerradar.
3. Weatherradar.

Radar altimeter

The radar altimeter (rad alt) uses radar transmissions to reflect off the surface of the sea or the ground immediately below the aircraft. The radar altimeter therefore provides an absolute reading of altitude with regard to the terrain directly beneath the aircraft. Absolute distance

above terrain. This contrasts with the barometric or air data altimeter where the altitude maybe

referencedto sea level (altitude) or some other datum such As the local terrain (height). The radar altimeter is therefore of particular value in warning pilots that they are close to the terrain and need to take corrective action. Alternatively, the radar altimeter may provide the flight crew with accurate altitude with respect to terrain during the final stages of a precision approach. Comparison of barometric and radar altitude is shown in Fig. 5.33. The radar altimeter principle of operation is shown in Fig. 5.28. The oscillator and modulator provide the necessary signals to the transmitter and transmit antennae which direct radar energy towards the terrain beneath the aircraft. Reflected energy is received by the receive antenna and received and passed to a frequency counter. The frequency counter demodulates the received signal and provides a radar altimeter reading to a dedicated display (see Fig. 5.32). Alternatively, the information may be presented on an Electronic Flight Instrument System (EFIS). In modern systems, radar altitude will be provided to a range of systems such as the Flight Management System (FMS), the Enhanced Ground Proximity Warning System (EGPWS), autopilot, etc., as well as being displayed directly to the flight crew. Radar altimeters usually operate over a maximum range of 0.5000 ft; the display shown has a maximum reading of 2000ft.

Doppler radar

Doppler radar transmits energy in three or four beams skewed to the front and rear of the aircraft, as shown in Fig. 5.31. In this example, a three-beam system is depicted. The beams are also skewed laterally to the sides of the aircraft track. As with the radar altimeter, Doppler radar depends upon the radiated energy being reflected from the terrain within the Doppler beams. As before, a frequency difference between the radiated and reflected energy carries vital information. Owing to the effects of the Doppler principle, energy reflected from beams facing forward will be returned with a higher frequency than the radiated energy. Conversely, energy from a rearward facing beam will have a lower frequency than that radiated. In Fig. 5.31, beams 2 and 3 will return higher frequencies where the frequency increase is proportional to the aircraft groundspeed, while beam 1 will detect a lower frequency where the frequency decrease is also proportional to groundspeed. This enables the aircraft groundspeed to be derived. If the aircraft is drifting across track on account of a crosswind, then the beams will also detect the lateral frequency difference component, and the cross-track velocity may be measured. Finally, by using computation within the radar, the aircraft *Vx*, *Vy*, and *Vz*velocity components may be determined, as may the overall aircraft velocity vector. Doppler radar velocity outputs may be compared with those from the inertial navigation system, thereby making possible a more accurate estimate of aircraft velocities and position. Terrain over which the aircraft is flying may not reflect enough energy for the aircraft velocities to be determined. Such conditions may be presented while flying over an expanse of water where the surface is very smooth, givinga

millpond. Effect Similarly, flying over snow-covered or glacial terrain may cause the Doppler radar to lose lock., and readings may become unreliable. For autonomous dead reckoning Navigation, an external attitude reference source is needed such as an MHRS or the inertial system already described. As for inertial systems, velocity accuracy degrades with time, and there are obvious consequences for long-term navigation. The choice of the depression angle of the Doppler beams is a compromise between two major considerations. The first is high sensitivity to velocity. In terms of Hz per knot. In which lower values of depression give higher accuracy. This has to be balanced against the fact that, as the depression angle decreases, particularly over water or other terrain with low radar reflectivity, proportionately less energy is returned. Typical values of the depression angle vary from 65 to 80û depending upon the system Requirements. For typical aircraft systems, the sensitivity of Doppler is 30 Hz per knot of speed. For the forward and aft beam geometries of the type shown in Fig. 5.37 also known as a Janus configuration. The horizontal velocity error is of the order of 0.015 per cent per degree of error inpitch angle. Doppler may be used in either stabilized or strap down configuration, in which case the overall system error will depend respectively on stabilization accuracy or computational accuracy available. Doppler radar was commonly used in the 1960s, but the advent of inertial systems and more recently GPS means that this technique is little used in the civil transport and Business jet systems produced today. Doppler radar is still commonly used onhelicopters.

Weather radar

The weather radar has been in use for over 40 years to alert the flight crew to the presence of adverse weather or terrain in the aircraft’s flight path. The weather radar radiates energy in a narrow beam with a beam width of ~3_ which may be reflected from clouds or terrain ahead of the aircraft. The radar beam is scanned either side of the aircraft centre-line to give a radar picture of objects ahead of the aircraft. The antenna may also be tilted in elevation byaround±15_ from the horizontal to scan areas above and below the aircraft. The principle of operation of weather radar is shown in Fig. 5.39. This shows a storm cloud directly ahead of the aircraft, with some precipitation below, and also steadily rising terrain. Precipitation can be indicative of severe vertical wind shear which can cause a hazard to theaircraft.

The radar antenna is stabilized in pitch and roll using aircraft attitude data from an Attitude and Heading Reference System (AHRS) or inertial reference system. The pulse width and pulse repetition frequency vary depending upon mode of operation. Useful though the weather radar may be, its usefulness does greatly depend upon interpretation by the flight crew. As in other areas, the flight crew is unlikely to depend upon the information provided by the weather radar alone, but is likely to confer with air traffic controllers and take account of status reports from aircraft that have already flown through the area. Reference (**5**) gives a more detailed description of the operation of modern weather radar.