LECTURE NOTES

ON

AIRCRAFT SYSTEMS

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UNIT-1

INTRODUCTION TO AIRCRAFT SYSTEMS

1.1 SYSTEM ENGINEERING: 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 determine 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 the systems.

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.

1.1.1 EVERYDAY EXAMPLES OF SYSTEMS:

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 solar system
- National Health Service
- Building and construction industry
- Integrated transportation systems
- Manufacturing systems
- Public utilities

1.2 AIRCRAFT SYSTEM OF INTREST:

1.2.1 AIRFRAME SYSTEMS:

- 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.

1.2.2 VEHICLE SYSTEMS:

- The aircraft systems are also know 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 control units

Coming to individual systems of vehicle systems:

Propulsion system to provide the primary source of thrust and motive power via pilot demands, electronic and hydro-mechanical fuel controls.

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 the engines.

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 connected faults

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 isolate leaks.

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 the engines.

Emergency power generation to provide energy to allow safe recovery of the aircraft in the event of a major power loss.

Flight control systems to convert pilot demands or demands from guidance systems into control surface movements to control the aircraft attitude.

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 leg and wheel assemblies to fit in the landing gear bay.

Brakes/anti-skid to provide a safe form of braking without loss of adhesion under a wide range of landing speeds and loads.

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

Environmental control system to provide air of an appropriate temperature and humidity to provide a safe and comfortable environment for crew, passengers and avionics equipment.

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 extinguishing fire.

Ice protection to monitor external ambient conditions to detect icing conditions and to prevent the formation of ice or to remove ice.

External lighting to ensure that the aircraft is visible to other operators and to ensure runway/taxiway visibility during ground movements

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

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 cockpit displays.

Military aircraft also require the following systems:

Crew escape to provide a means of assisted escape for aircrew.

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 escaping aircrew.

Biological and chemical protection to protect the crew from the toxic effects of chemical or biological contamination.

Arrestor mechanism to provide a means of stopping the aircraft on a carrier deck or at the end of a runway.

In-flight refueling to allow the aircraft to obtain fuel from a tanker aircraft.

Galley to allow meals to be prepared and cooked for passengers.

Passenger evacuation to allow safe evacuation of passengers.

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 of depressurization

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 the exit.

1.2.3 AVIONICS SYSTEMS:

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

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

Displays and controls to provide the crew with information and warnings with which to operate the aircraft.

Communications to provide a means of communication between the aircraft and Air Traffic Control and other aircraft.

Navigation to provide a worldwide, high accuracy navigation capability.

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

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).

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

IFF/SSR to provide information on the aircraft identification and height to air traffic.

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

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

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

Automatic direction finding (ADF) to provide bearing from a known beacon.

Radar altimeter to provide an absolute reading of height above the ground or sea.

Air data measurement to provide information to other systems on altitude, air speed, outside air temperature and Mach number.

Accident data recorder to continuously record specified aircraft parameters for use in analysis of serious incidents.

Cockpit voice recorder to continuously record specified aircrew speech for use in analysis of serious incidents.

Internal lighting to provide a balanced lighting solution on the flight deck for all panels and displays

1.2.4 MISSION SYSTEMS:

- Used for military aircrafts
- The military aircraft requires a range of sensors and computing to enable the crew to prosecute
- Designated missions.
- The mission systems gain information about the outside world from active
- And passive sensors and process this information to form intelligence.
- 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 defensive aids.

The following are the major systems of a mission system:

Attack or surveillance radar to provide information on hostile and friendly targets.

Electro-optical sensors to provide a passive surveillance of targets.

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 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 picture to the cockpit or mission crew stations

Defensive aids to provide a means of detecting missile attack and deploying countermeasures

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 providing 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 than voice.

1.3 GENERIC SYSTEM DEFINITION

- 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.

INPUTS: Are broadly

Demands or commands

Sensors

Other systems

Feedback

1.4 INTEGRATION:

1.4.1 INTEGRATION AT THE COMPONENT LEVEL:

- Integration at the component level is important as this provides the building blocks from system or system is constructed.
- The ability of component or LRU to ensure that discrete function it offers contributes to the overall systems in which it resides.
- A number of electronic components when assembled together on an electronic circuit board provide a module that forms a building block for an LRI or system. Similarly, an electric motor, rotary valve, associated pipework, mounting flanges and connectors may be assembled to form a motorized valve to be used in an aircraft fuel system.
- In a large aircraft there may be 30 or 40 such valves used in various ways to provide all the fuel systems functions, such as refuel, defuel, engine feed and fuel transfer.

- At a smaller level, such component integration takes place in specially designed electronic devices designed to meet specific customer specifications. This may require devices to be programmed or substrates to be designed to incorporate logical functions.
- These results in a device designed to perform a specific function, often referred to as 'firmware' and require a software program as a part of the design process. Such devices may also be known as application specific integrated circuits (ASIC).

1.4.2 INTEGRATION AT THE SYSTEM LEVEL:

a. Avionics Integration

- On the basis of the reduction of discrete control units and the performance of functions in general purpose computing systems and data bus interconnections.'
- An example of this can be seen in the development of a system for controlling general systems in the Experimental Aircraft programmed – a UK programmed which first flew in1986.
- This system, known as a utility systems management system (USMS), performed the functions previously hosted in 20 to 25 individual items of equipment in 4 general purpose computing modules.
- This not only reduced the number of items of equipment in the aircraft, but also reduced the bulk of wiring with an overall reduction in weight.

b. Cockpit Integration

- On the basis of the reduction of discrete, single purpose displays and the emergence of multifunction displays and voice based systems.'
- Cockpits and flight decks were once designed or evolved as a layout of individual switches, control knobs, indicators and lamps.
- These were grouped in such a manner that the pilot instinctively knew where to look or reach. Nevertheless, the overall impression was of a mass of items providing information in different formats and methods of presentation.
- This may have led to accidents from the misreading of instruments and incorrect selection of controls.

- Most modern aircraft have flight decks or cockpits that present information to the crew on multifunction displays based on flat, liquid crystal display (LCD) screens.
- These are able to present information to the crew in color, using graphics and text in 'pages' that can be selected as required.

1.4.3 INTEGRATION AT THE PROCESS LEVEL:

- The progressive testing from sub-system or module level through system to complete product is often referred to as 'integration'
- Integration in this case involves the progressive build-up of fully tested functions, modules and interfaces, and their eventual progression to final testing on the completed product. Much of this activity takes place in a test laboratory, eventually transferring to the aircraft during build and then to flight testing.
- The right-hand part of the V portrays a breakdown and validation of the top-level system requirements so that they flow down towards a module design.
- The left-hand branch shows a progressive procedure by which module integration, hardware and software integration and system test are achieved – this is the verification process.
- The first step involves the application of a traceability matrix to confirm that all of the original requirements have been satisfied and fully met.
- This activity enables each element of a system to be thoroughly tested and the test results validated prior to connection with other systems and subsequent testing as a whole.

1.4.4 INTEGRATION AT THE FUNCTIONAL LEVEL:

- Requirements for the functions that the aircraft must perform are drawn from a number of sources.
- Some of these requirements are explicitly stated by the customer, whereas others are derived from experience, from performance requirements or by an understanding of standards ,regulatory standards, processes and technology
- These requirements are 'flowed down' into a work breakdown structure (WBS) that reflects the constituent systems and sub-systems of the aircraft.
- The requirements then flow down into specifications for sub-systems and equipment. Very often the organization required to develop this work is structured as teams with responsibility for delivering the products.
- This task is often performed by a separate team, known as the engineering integration team, its task is to ensure that the individual products combine to form an integrated functional whole.

1.4.5 INTEGRATION AT THE INFORMATION LEVEL:

- The products of the life cycle are controlled by documenting every stage of the aircraft development.
- Each stage of development during the process must be recorded to show the flow down of requirements, the links to the design and the evidence gained by testing and modeling to prove that the final product is safe, robust and fit for purpose.
- The information collected in this way is essential in demonstrating to the customer and the regulatory bodies that the aircraft is safe to fly without danger to the operators and the over-flown population.

- Control of the product is exercised by the application of configuration control. This means that the issue of all models, drawings, reports, analyses and parts is recorded for the aircraft type. Any deviations or modifications to the type record are introduced in a controlled manner.

2. DESIGN DRIVERS

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 satisfactory conclusion.

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 2
ELECTRICAL SYSTEMS

2.1 ELECTRICAL LOADS:

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 and actuation
- Lighting services
- Heating services
- Subsystem controllers and avionics systems

2.2 MOTORS AND ACTUATION:

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:

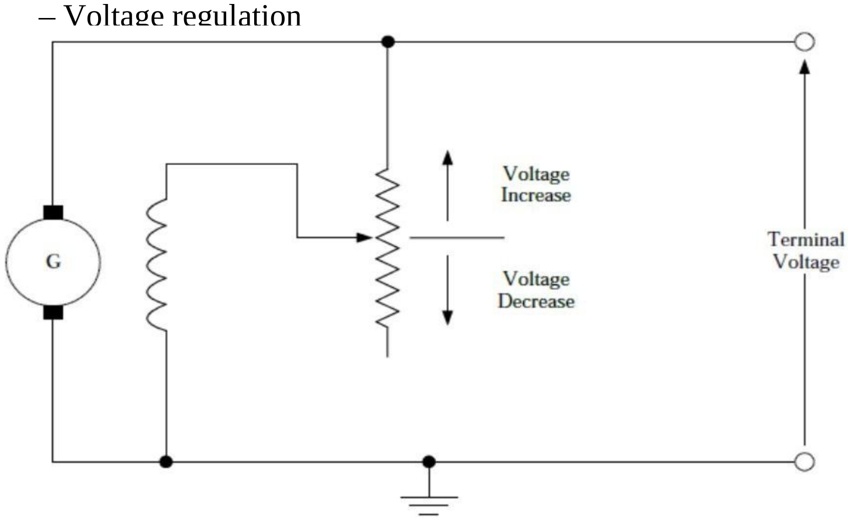
- Linear actuation: electrical position actuators for engine control; trim actuators For flight control systems
- Rotary actuation: electrical position actuators for flap/slat operation
- Control valve operation: electrical operation of fuel control valves; hydraulic control valves; air control valves; control valves for ancillary systems
- 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 auxiliary systems
- 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 to passengers or equipment.

2.3 POWER GENERATION CONTROL:

The primary elements of power system control are:

• DC systems

– Voltage regulation



2.3.1 Control Voltage Regulation

This shows a variable resistor in series with the field winding such that variation of the resistor alters the resistance of the field winding;

- Hence the field current and output voltage may be varied.
- In actual fact the regulation is required to be an automatic function that takes account of load and engine speed.
- The voltage regulation needs to be in accordance with the standard used to specify aircraft power generation systems, namely MIL-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 becomes prohibitive
- The brush wear on brushed DC generators becomes excessive with resulting maintenance.

2.3.2 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 Power interruption.
- In order to satisfy this requirement generators are paralleled to carry an equal proportion of the electrical load between them.
- Individual generators are controlled by means of voltage regulators that automatically compensate for variations.
- 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 field current.
- This paralleling feature is more often known as an equalizing circuit and therefore provides 'no break' power in the event of a major system failure.

2.3.3 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 eventuality.
- This is usually achieved by means of reverse current circuit breakers or relays.
- These devices effectively sense reverse current and switch the generator out of circuit, thus preventing any ensuing damage
- Overvoltage protection. Faults in the field excitation circuit can cause the generator to over-excite and thereby regulate the supply voltage to an erroneous overvoltage condition.
- This 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 sharing function.

2.4 AC POWER GENERATION CONTROL:

2.4.1 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.

2.4.2 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 similar fashion.
- This technique only applies to constant frequency AC generation as it is impossible to parallel frequency-wild or Variable Frequency (VF) AC generators.
- 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 load sharing.
- The sharing of real load depends upon the relative rotational speeds and hence the relative phasing of the generator voltages.
- Constant speed or constant frequency AC generation depends upon the tracking accuracy of the constant speed drives of the generators involved.
- 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 are equal.
- The sharing of reactive load between the generators is a function of the voltage generated by each generator as for the DC parallel operation case.
- The generator output voltages depend upon the relevant performance of the voltage regulators and field excitation circuitry.
- 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 excitation current.

2.5 AIRCRAFT ELECTRICAL SYSTEM:

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

Power generation

- Primary power distribution and protection
- Power conversion and energy storage
- Secondary power distribution and protection

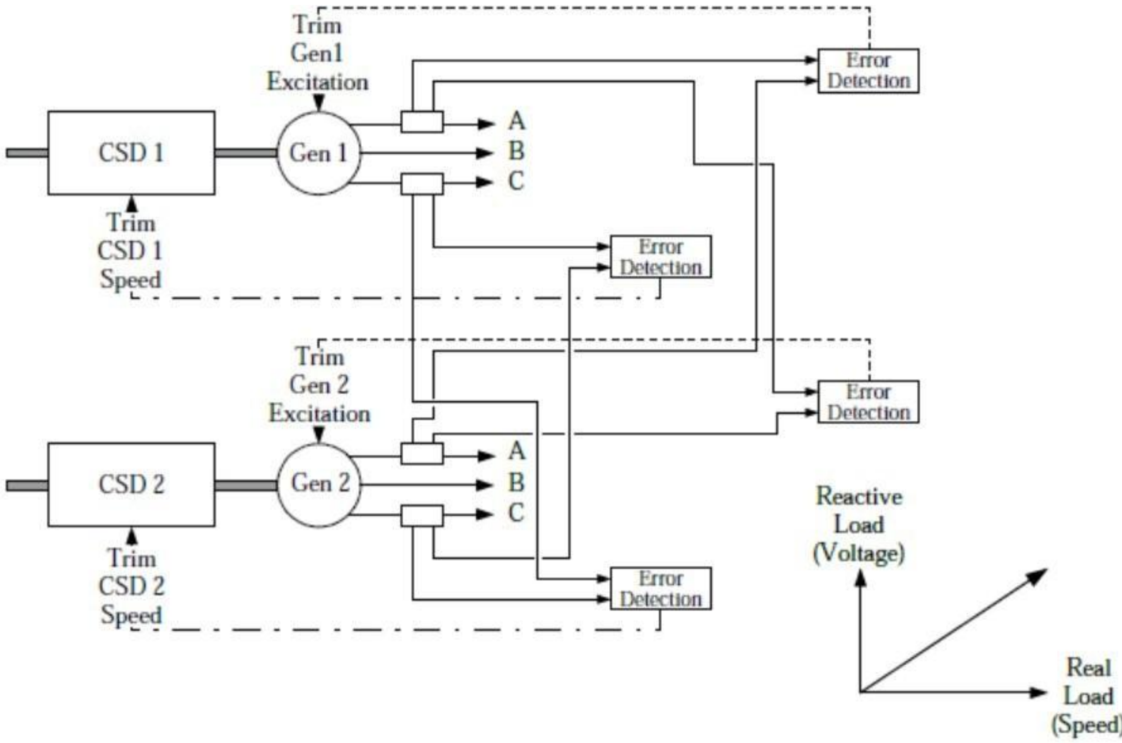
2.5.1 POWER GENERATION:

a. DC Power Generation

1) DC systems use generators to develop a DC voltage to supply aircraft system loads.
2) Usually the voltage is 28 VDC but there are 270 VDC systems in being.
3) 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 are overcome.
4) DC generators are self-exciting, in that they contain rotating electro-magnets that generate the electrical power.
5) 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 effectively half-wave rectified .

b. AC Power Generation

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



2.5.1 **AC generator parallel operation**

2.5.2 SUPERVISORY AND PROTECTION FUNCTIONS:

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

- Overvoltage
- Under voltage
- Under/over excitation
- Under/over frequency
- Differential current protection
- Correct phase rotation

The overvoltage, under voltage and under/over-excitation functions is similar to the corresponding functions described for DC generation control.

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.

2.5.3 PRIMARY POWER DISTRIBUTION:

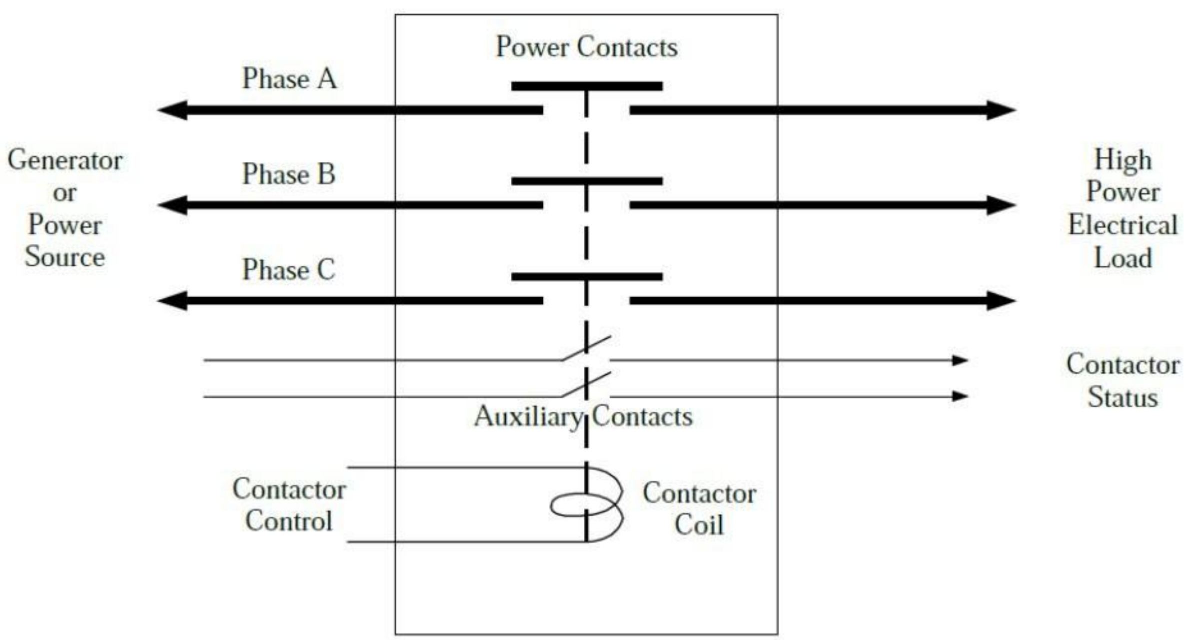
The primary power distribution system consolidates the aircraft electrical power inputs.

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 the BPCU
- 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 (B777 only)
- RAT generator when deployed by the emergency electrical system

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 aircraft systems.

- 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 or greater.



2.5.3Power contacts

2.5.4 SECONDARY POWER DISTRIBUTION:

a. Power Switching

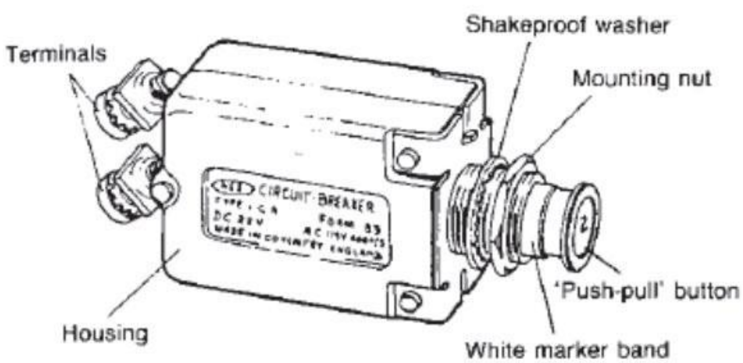
- In order to reconfigure or to change the state of a system it is necessary to switch power at various levels within the system.
- At the high power levels that prevail at the primary power part of the system, power switching is
- Accomplished by high power electromagnetic devices called contactors.
- These devices can switch hundreds of amps and are used to switch generator power on to the primary bus bars in both DC and AC systems.
- 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 the state.
- 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 to open.
- For switching currents below 20 amps or so relays are generally used.
- These operate in a similar fashion to contactors but are lighter, simpler and less expensive.

- Relays may be used at certain places in the primary electrical system.
- 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.

2.5.5 LOAD PROTECTION:

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 current limiters.
- 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 the circuit.
- 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 maintenance reasons.
- Circuit breakers are rated at different current values for use in differing current carrying circuits. This enables the trip characteristic to be matched to each circuit.

2.5.6 POWER CONVERSION AND ENERGY STORAGE:

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-phase power

• Conversion from 115 VAC to 28 VDC power – this is a much used conversion Using units called Transformer Rectifier Units (TRUs)

• Conversion from one AC voltage level to another; a typical conversion would be from 115 VAC to 26 VAC

• 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

2.6 RECENT SYSTEMS DEVELOPMENTS:

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 Management System (ELMS)

• Variable Speed Constant Frequency (VSCF) – Cyclo converter

• 270 VDC systems

• More-Electric Aircraft (MEA)

2.6.1 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.

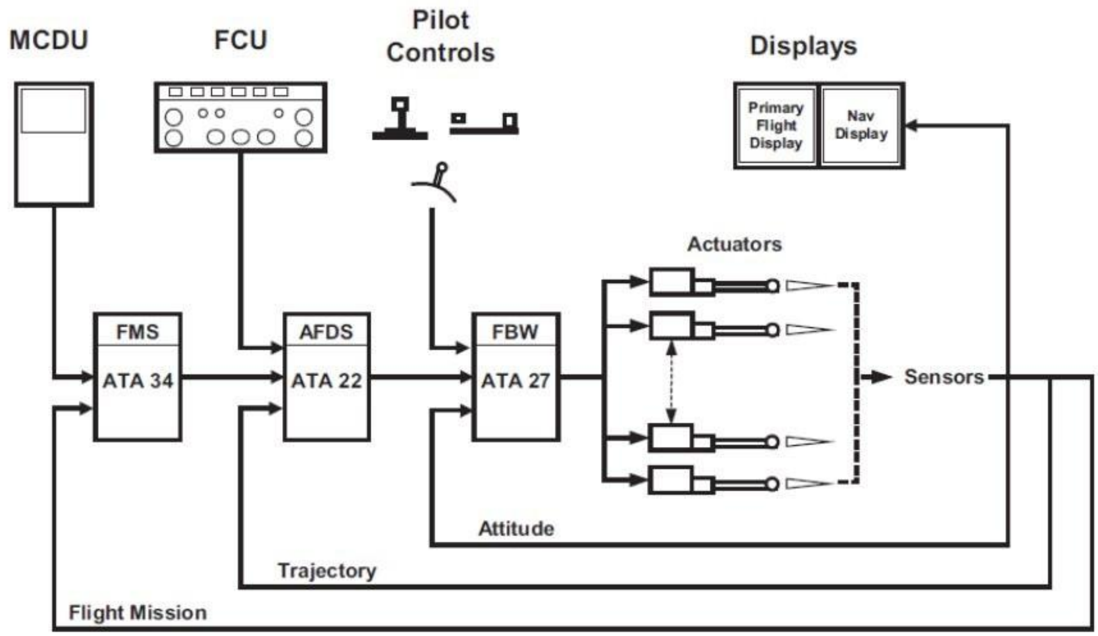
Theory of VSCF Cyclo converter System Operation

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

2.6.2 270 VDC SYSTEMS**:**

- An initiative which has been underway for a number of years in the US military development agencies is the 270 VDC systems.
- 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 as RAH-66 Comanche).
- The selected version of JSF – the Lockheed Martin F-35 Lightning II uses 270 VDC for the primary electrical system.
- 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 power dissipation.
- 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 not inexpensive.
- Also, 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 demonstrator programmes.
- Some of these are also directed at the greater use of electrical power on the combat
- Aircraft, possibly to supplant conventional secondary power and hydraulic power systems or at least to augment them to a substantial degree.
- The high DC voltage poses a risk in military aircraft of increased possibility of fire resulting from battle damage in carbon-fiber composite aircra

2.7 FLIGHT CONTROL SYSTEMS:



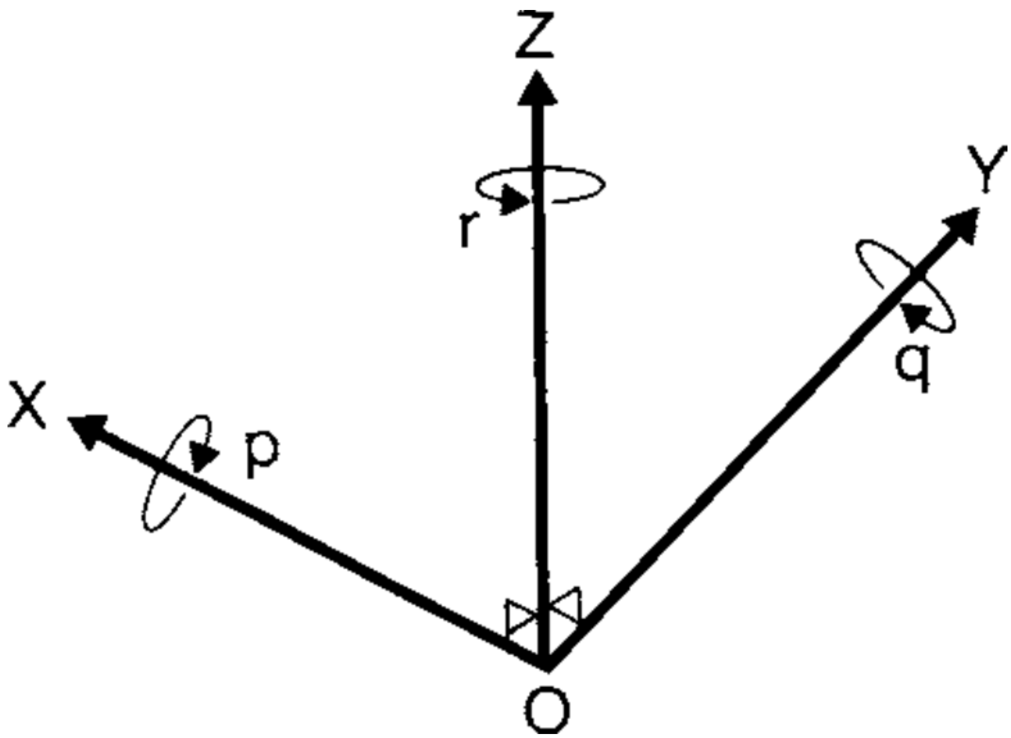
1. The inner loop provided by the FBW system and the pilot's controls effectively controls the attitude of the aircraft.
2. The middle loop is that affected by the AFDS that controls the aircraft trajectory, that is, where the aircraft flies.
3. Inputs to this loop are by means of the mode and datum 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 aircraft route.
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

2.7.1 PRINCIPLES OF FLIGHT CONTROL:

- 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 and yaw.
- 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 in space.

• 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 is pointing.

2.7.2 PRIMARY FLIGHT CONTROL:



2.7 primary flight controls

- 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 the cockpit.
- 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 of seconds.
- 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 control system.

- Roll control is provided by the differential motion of the fore planes, augmented to a degree 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 the fore 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 excess power.
- There are nevertheless certain parts of the flight envelope where control of yaw (or sideslip) is vital to prevent roll–yaw divergence.

2.7.3 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 and lift.
- The control of these high lift devices during combat may occur automatically under the control of an active flight control system.

2.8 FLIGHT CONTROL LINKAGE SYSTEMS:

The pilot’s manual inputs to the flight controls are made by moving the cockpit control column or rudder pedals in accordance with the universal convention:

- 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 pitch up

- 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 vice versa

- 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 control system.

These are:

• Push-pull control rod systems

• Cable and pulley systems

2.9 FLIGHT CONTROL ACTUATION:

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, hydraulically powered
- Mechanical actuation with simple electromechanical features
- 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.

2.9.1 SIMPLE MECHANICAL/HYDRAULIC ACTUATION:

- The conventional linear actuator used in powered flight controls would be of the type.
- This type of actuator would usually be powered by one of the aircraft hydraulic
- In functionally critical applications a dual hydraulic supply from another aircraft hydraulic system may be used.
- A mechanically operated Servo Valve(SV) directs the hydraulic supply to the appropriate side of the piston ram.
- As the pilot feeds a mechanical input to the flight control actuator, the summing link will rotate about the bottom pivot, thus applying an input to the servo valve.
- Hydraulic fluid will then flow into one side of the ram while exiting the opposite side resulting in movement of the ram in a direction dependent upon the direction of the pilot’s command.
- As the ram moves, the feedback link will rotate the summing link about the upper pivot returning the servo valve input to the null position as the commanded position is achieved.

- The attributes of mechanical actuation are straightforward; the system demands a control movement and the actuator satisfies that demand with a power assisted mechanical response.
- The BAE Hawk 200 is a good example of a system where straightforward mechanical actuation is used for most of the flight control surfaces.
- For most applications the mechanical actuator is able to accept hydraulic power from two identical/redundant hydraulic systems.
- The obvious benefit of this arrangement is that full control is retained following loss of fluid or a failure in either hydraulic system.

2.9.2 MECHANICAL ACTUATION WITH ELECTRICAL SIGNALLING:

- The use of mechanical actuation has already been described and is appropriate for a wide range of applications.
- However the majority of modern aircraft uses electrical signaling and hydraulically powered (electro-hydraulic) actuators for a wide range of applications with varying degrees of redundancy.
- The demands for electro-hydraulic actuators fall into two categories: simple demand signals or auto stabilization inputs.
- As aircraft acquired autopilots to reduce pilot work load then it became necessary to couple electrical as well as mechanical inputs to the actuator .
- The manual (pilot) input to the actuator acts as before when the pilot is exercising manual control. When the autopilot is engaged electrical demands from the autopilot computer drive an electrical input which takes precedence over the pilot’s demand.
- The actuator itself operates in an identical fashion as before with the mechanical inputs to the summing link causing the Servo-Valve (SV) to move.
- When the pilot retrieves control by disengaging the autopilot the normal mechanical link to the pilot through the aircraft control run is restored. Simple electrical demand signals are inputs from the pilots that are signaled by electrical means. For certain noncritical flight control surfaces it may be easier, cheaper and lighter to utilize an electrical link.

2.9.3 MULTIPLE REDUNDANCY ACTUATION:

- Modern flight control systems are increasingly adopting fly-by-wire solutions as the benefits to be realized by using such a system are considerable.
- .These benefits include a reduction in weight, improvement in handling performance and crew/passenger comfort.
- In the civil field the Airbus A320 and the Boeing 777 introduced modern state-of the-art systems into service.
- For obvious reasons, a great deal of care is taken during the definition, specification, design, development and certification of these systems.
- Multiple redundant architectures for the aircraft hydraulic and electrical systems must be considered as well as multiple redundant lanes or channels of computing and actuation for control purposes.
- The implications of the redundancy and integrity of the other aircraft systems will be addressed.

2.9.4 MECHANICAL SCREWJACK ACTUATOR:

- The linear actuators described so far are commonly used to power aileron, elevator and rudder control surfaces where a rapid response is required but the aerodynamic loads are reasonably light.
- There are other applications where a relatively low speed of response may be tolerated but the ability to apply or withstand large loads is paramount.
- In these situations a mechanical screw jack is used to provide a slow response with a large mechanical advantage.
- This is employed to drive the Tail plane Horizontal Stabilator or Stabiliser (THS),otherwise known years ago as a ‘moving tail plane’.

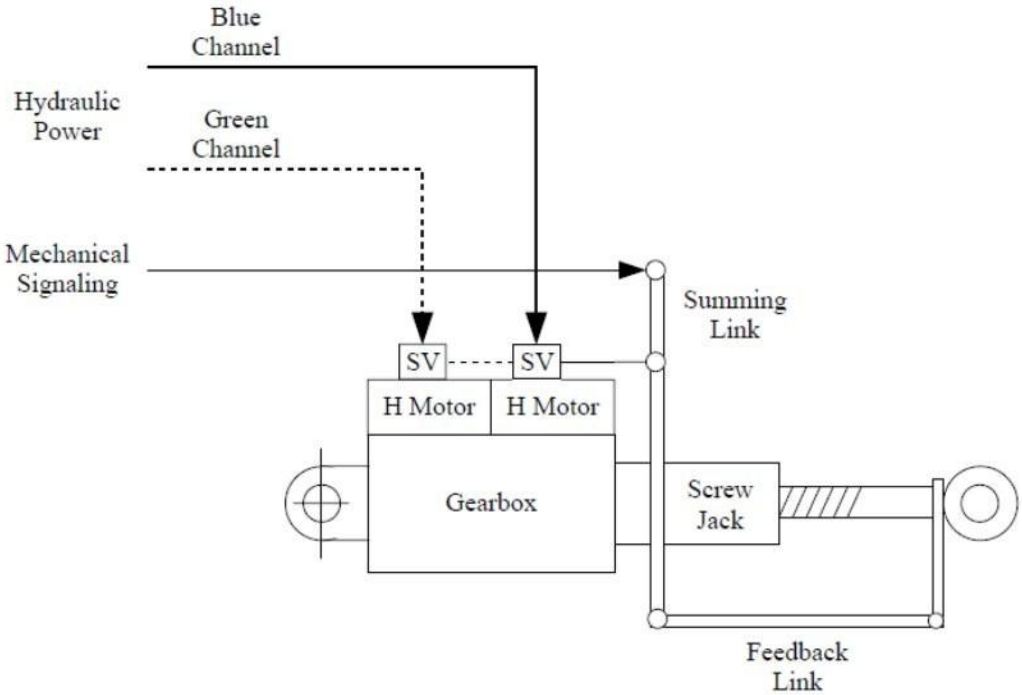


Figure 1.18 Mechanical screwjack actuator

- The THS is used to trim an aircraft in pitch as airspeed varies; being a large surface it moves slowly over small angular movements but has to withstand huge loads.
- The mechanical screw jack shown in Figure 1.18 often has one or two aircraft hydraulic system supplies and a summing link that causes SVs to move in response to the mechanical inputs.
- In this case the SVs moderate the pressure to hydraulic motor(s) which in turn drive the screw jack through a mechanical gearbox. As before the left-hand portion of the jack is fixed to aircraft structure and movement of the screw jack ram satisfies the pilot's demands, causing the tail plane to move, altering tail plane lift and trimming the aircraft in pitch.
- As in previous descriptions, movement of the ram causes the feedback link to null the original demand, whereupon the actuator reaches the demanded position.

2.10 ADVANCED ACTUATION IMPLEMENTATIONS**:**

- The actuation implementations described so far have all been mechanical or electro-hydraulic in function using servo valves.
- There are a number of recent developments that may supplant the existing electro- hydraulic actuator.

- These newer types of actuation are listed below and have found application in aircraft
- over the past 10–15 years:
- Direct drive actuation
- Fly-by-Wire (FBW) actuation
- Electro-Hydrostatic Actuator (EHA)
- Electro-Mechanical Actuator (EMA)

2.10.1 DIRECT DRIVE ACTUATION:

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

2.10.2 FLY-BY-WIRE ACTUATOR:

The advent of Fly-By-Wire (FBW) flight control systems in civil aircraft commencing with the Airbus A320 introduced the need for a more sophisticated interface between the FCS and actuation.

Most first generation FBW aircraft may operate in three distinct modes that may be summarized in general terms as follows:

- Full FBW Mode. This mode encompasses the full FBW algorithms and protection and is the normal mode of operation
- Direct Electrical Link Mode. This mode will usually provide rudimentary algorithms or

possibly only a direct electrical signaling capability in the event that the primary FBW mode is not available

- Mechanical Reversion Mode. This provides a crude means of flying the aircraft – probably using a limited number of flight control surface following the failure of FBW and direct electrical link modes
- In later implementations such as the Airbus A380 and Boeing 787 no mechanical reversion is provided.
- The digital FBW or direct link demands from the flight control system are processed by the ACE which supplies an analogue command to the actuator SV. This allows aircraft systems hydraulic power to be supplied to the appropriate side of the ram piston moving the ram
- to the desired position.
- In this implementation the ram position is detected by means of a Linear Variable Differential Transducer (LVDT) which feeds the signal back to the ACE where the loop around the actuator is closed.
- Therefore ACE performs two functions: conversion of digital flight control demands into analogue signals and analogue loop closure around the actuator.

2.10.3 ELECTRO-HYDROSTATIC ACTUATOR (EHA):

- The move towards more-electric aircraft has coincided with another form of electrical actuation – the Electro-Hydrostatic Actuator (EHA) which use state-of-the-art power electronics and control techniques to provide more efficient flight control actuation.
- The conventional actuation techniques described so far continually pressurize the actuator whether or not there is any demand.
- In reality for much of the flight, actuator demands are minimal and this represents a wasteful approach as lost energy ultimately results in higher energy off take from the engine and hence higher fuel consumption.

2.11 FLY-BY-WIRE CONTROL LAWS:

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 exceedance of certain attitudes and attitude rates. Double failures in computing, sensors or actuation power channels will cause reversion to the Alternate mode
- Alternate laws: Provision of the basic control laws but without many of the additional handling enhancement features and protection offered by the
- Normal mode. Further failures cause reversion to the Mechanical mode
- 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 to Mechanical.

UNIT-3

HYDRAULIC SYSTEMS

3.1 HYDRAULIC CIRCUIT DESIGN**:**

- The majority of aircraft in use today need hydraulic power for a number of tasks.
- 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 failure conditions.

3.2 PRIMARY FLIGHT CONTROLS:

- Elevators
- Rudders
- Ailerons
- Canards

3.3 SECONDARY FLIGHT CONTROLS:

- Flaps
- Slats
- Spoilers
- Airbrakes

3.4 UTILITY SYSTEMS**:**

- Undercarriage – gear and doors
- Wheel brakes an anti-skid
- Parking brake
- Nose wheel steering
- In-flight re fuelling probe Cargo doors
- Loading ramp Passenger stairs

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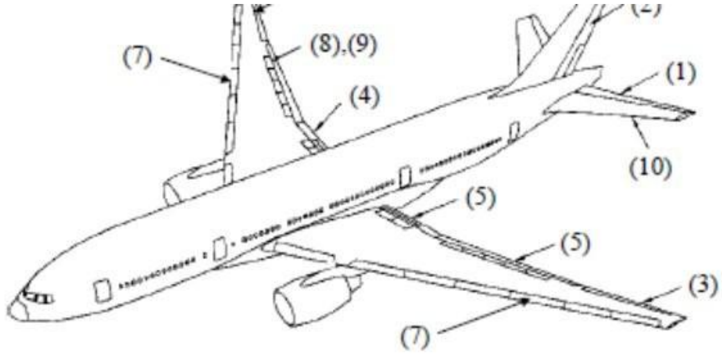

3.1 Hydraulic system loads

- Many other functions are carried out on various aircraft by hydraulics, but those listed above may be used as a typical example of modern aircraft systems.
- The wise designer will always allow for the addition of further functions during the development of an aircraft
- .From the above list the designer may conclude that all primary flight controls are critical to flight safety and consequently no single failures must be allowed to prevent, or even momentarily interrupt their operation.
- 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 the system.
- 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 the pilot.
- 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 when selected.
- 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 safe conditions.

- Wheel brakes tend to be a special case where power is frequently provided automatically or on selection, from three sources.
- One of these is a stored energy source which also allows a parking brake function to be provided.

In order to understand each requirement the following parameters need to be quantified:

- Pressure – What will be the primary pressure of the system? This will be determined by the appropriate standards and the technology of the system
- 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 of power
- Flow rate – What is the rate of the demand, in angular or linear motion per second, or in litres per second in order to achieve the desired action?
- Duty cycle – What is the ratio of demand for energy compared to quiescent conditions. This will be high for continuously variable demands such as primary flight control actuation on an unstable aircraft (throughout the flight), whereas it will be low for use as a source of energy for undercarriage lowering and retraction (twice per flight)
- Emergency 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 reversionary devices?
- 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 the following:
- A source of energy – engine, auxiliary power unit or ram air turbine

- A filter to maintain clean hydraulic fluid
- A multiple redundant distribution system – pipes, valves, shut-off cocks
- Pressure and temperature sensors
- A mechanism for hydraulic oil cooling
- A means of exercising demand – actuators, motors, pumps
- A means of storing energy such as an accumulator

3.5 HYDRAULIC ACTUATION:

- On military aircraft the primary flight control actuator normally consists of two pistons in tandem on a common ram..
- Each piston acts within its own cylinder and is connected to a different hydraulic system.
- The ram is connected at a single point to a control.
- The philosophy is different on civil aircraft where each control surface is split into two or more independent parts.

They are essentially two state devices.

- 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 the actuator.
- An electrical system can be connected by means of a solenoid or motor that is operated by a pilot or by a computer output.
- In some instances it is necessary to signal the position of the actuator, and hence the device it moves, back to the pilot.

- 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 magnetic indicator.

3.5.1 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 the UK
- MIL-H-5606 in the USA
- AIR 320 in France
- H 515 NATO

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 other fluids.
- 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 combat aircraft.
- This work has resulted in the introduction of MIL-H-83282, an entirely synthetic fluid, now adopted for all US Navy aircraft.
- It is miscible with DTD 5858 and, although slightly more viscous below 20 _C, it

compares well enough.

- 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 particular project

3.5.2 FLUID PRESSURE:

- Similarly little choice is available with respect to working pressure. Systems have become standardized at 3000 psi or 4000 psi.
- These have been chosen to keep weight to a minimum, while staying within the body of experience built up for pumping and containing the fluid.

3.5.3 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 fluid used.
- For many years the use of DTD 585 has limited temperatures to about 130 _C, and components and seals have been qualified accordingly.
- The use of MIL-H-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 be damaged.
-

3.5.4 FLUID FLOW RATE:

- Determination of the flow rate is a more difficult problem.

- When the nominal system pressure is chosen it must be remembered that this is, in effect, a stall pressure.
- 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 to reservoir.
- This is usually about 20–25% of nominal pressure.
- 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 of movement.
- The designer must then decide which actuators will be required to act simultaneously and at what speed they will move.
- 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.

3.5.5 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 the aircraft.

- 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 military aircraft.
- 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 of pipe.
- 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 initial calculation.

- If an allowable pressure drop of 25% has been selected throughout the system, this may now be further divided between pressure pipes, return pipes and components.
- The designer will eventually control the specifications for the components, and in this sense he can allocate any value he chooses for pressure drop across each component.
- It must be appreciated, however, that these values must eventually be achieved without excessive penalties, being incurred by over-large porting or body sizes.
- Once pipe lengths, flow rates and permissible pressure drops are known, pipe diameters can be calculated using the normal expression governing friction flow in pipes.
- It is normal to assume a fluid temperature of 0 _C for calculations, and in most cases flow in aircraft hydraulic systems is turbulent.
- Pressure losses in the system piping can be significant and care should be taken to determine accurately pipe diameters.
- Theoretical sizes will be modified by the need to use standard pipe ranges, and this must be taken into account.

3.5.6 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 aircraft systems.
- The pump is normally mounted on an engine-driven gearbox.
- In civil applications the pump is mounted on an accessory gearbox mounted on the engine casing.
- For military applications the pump is mounted on an Aircraft Mounted Accessory Drive (AMAD) mounted on the airframe.

- The pump speed is therefore directly related to engine speed, and must therefore be capable of working over a wide speed range.
- The degree 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 running fastest.
- The universally used pump type is known as variable delivery, constant pressure.
- 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 of power.
- Within the flow capabilities of these pumps the pressure can be maintained within 5% of nominal except during the short transitional stages from low flow to high flow.
- This also helps to optimize the overall efficiency of the system.
- The pumps are designed to sense outlet pressure and feed back this signal to a plate carrying the reciprocating pistons.
- The plate is free to move at an angle to the longitudinal axis of the rotating drive shaft. There are normally nine pistons arranged diametrically around the plate. The position of the plate therefore varies the amount of reciprocating movement of each piston.

3.5.7 HYDRAULIC RESERVOIR:

- The requirements for this component vary depending on the type of aircraft involved. For most military aircraft the reservoir must be fully aerobatic.
- This means that the fluid must be fully contained, with no air/fluid interfaces, and a supply of fluid must be maintained in all aircraft attitudes and g conditions.

- In order to achieve a good volumetric efficiency from the pump, reservoir pressure must be sufficient to accelerate a full charge of fluid into each cylinder while it is open to the inlet port.
- The 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 predetermined point.
- This is an attempt to isolate leaks within the system and to provide further protection for flight safety critical subsystems.
- The cut-off point must ensure sufficient volume for the remaining systems under all conditions. The reservoir will be protected by a pressure relief valve which can dump fluid over boar

3.6 LANDING GEAR SYSTEMS:

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 each leg.
- The hydraulically operated nose gear retracts forward into a well beneath the forward equipment.
- The advantage of the doors being normally closed is twofold.
- First, the undercarriage bay is protected from spray on takeoff and landing, and secondly there is a reduction in drag.

- A small panel on the leg completes enclosure on retraction and a mechanical indicator on the flight deck shows locking of the gear.

2 Main Gear

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

3 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 taxiing, 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 very hot.
- 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 by training.

3.7 ELECTRONIC CONTROL:

- In this system the electronic control box contains individual wheel deceleration rate skid detection circuits with cross reference between wheels and changeover circuits to couple the control valve across the aircraft should the loss of a wheel speed signal occur.
- If a skid develops the system disconnects braking momentarily and the adaptive pressure coordination valve ensures that brake pressure is re-applied at a lower pressure after the skid than the level which allowed the skid to occur.
- A progressive increase in brake pressure between skids attempts to maintain a high level of pressure and braking efficiency.
- The adaptive pressure control valve dumps hydraulic pressure from the brake when its first stage solenoid valve is energized by the commencement of a skid signal.
- On wheel speed recovery the solenoid is de-energized and the brake pressure re-

applied at a reduced pressure level, depending on the time interval of the skid.

- Brake pressure then rises at a controlled rate in search of the maximum braking level, until the next incipient skid signal occurs.

3.8 FLIGHT CONTROL ACTUATION

a.Conventional Linear Actuator

- This type of actuator would usually be powered by one of the aircraft hydraulic systems – in this case the blue channel is shown.
- In functionally critical applications a dual hydraulic supply from another aircraft hydraulic system may be used.
- A mechanically operated Servo Valve (SV) directs the hydraulic supply to the appropriate side of the piston ram.
- As the pilot feeds a mechanical input to the flight control actuator, the summing link will rotate about the bottom pivot, thus applying an input to the servo valve.
- Hydraulic fluid will then flow into one side of the ram while exiting the opposite side resulting in movement of the ram in a direction dependent upon the direction of the pilot's command.

- As the ram moves, the feedback link will rotate the summing link about the upper pivot returning the servo valve input to the null position as the commanded position is achieved.
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b. Mechanical Actuation with Electrical Signaling

- The use of mechanical actuation has already been described and is appropriate for a wide range of applications.
- However the majority of modern aircraft uses electrical signaling and hydraulically powered (electro-hydraulic) actuators for a wide range of applications with varying degrees of redundancy.
- The demands for electro-hydraulic actuators fall into two categories: simple demand signals or auto stabilisation inputs.
- The manual (pilot) input to the actuator acts as before when the pilot is exercising manual control.
- When the autopilot is engaged electrical demands from the autopilot computer drive an electrical input which takes precedence over the pilot's demand.
- The actuator itself operates in an identical fashion as before with the mechanical inputs to the summing link causing the Servo-Valve (SV) to move.
- When the pilot retrieves control by disengaging the autopilot the normal mechanical link to the pilot through the aircraft control run is restored.

c. Multiple Redundancy Actuation

- Modern flight control systems are increasingly adopting fly-by-wire solutions as the benefits to be realized by using such a system are considerable.
- These benefits include a reduction in weight, improvement in handling performance and crew/passenger comfort.
- Concorde was the first aircraft to pioneer these techniques in the civil field using a flight control system jointly developed by GEC (now Finmeccanica) and SFENA.[3] The Tornado, fly-by-wire Jaguar and EAP have extended the use of these techniques; the latter two were development programmes into the regime of the totally unstable aircraft.

- In the civil field the Airbus A320 and the Boeing 777 introduced modern state-of the- art systems into service.

3.9 ADVANCED ACTUATION IMPLEMENTATIONS:

The actuation implementations described so far have all been mechanical or electro-hydraulic in function using servo valves. There are a number of recent developments that may supplant the existing electro- hydraulic actuator. These newer types of actuation are listed below and have found application in aircraft over the past 10–15 years:

1. Direct drive actuation
2. Fly-by-Wire (FBW) actuation
3. Electro-Hydrostatic Actuator (EHA)
4. Electro-Mechanical Actuator (EMA)

1. Direct Drive Actuation

- In the electro-hydraulic actuator a servo valve requires a relatively small electrical
- Drive signal, typically in the order of 10–15 mA.
- The reason such low drive currents are possible is that the control signal is effectively amplified within the hydraulic section of the actuator.
- In the direct drive actuator the aim is to use an electrical drive with sufficient power to obviate the need for the servo valve/1st stage valve.
- The main power spool is directly driven by torque motors requiring a higher signal current, hence the term ‘direct drive’.

2. Fly-By-Wire Actuator

The advent of Fly-By-Wire (FBW) flight control systems in civil aircraft commencing with the Airbus A320 introduced the need for a more sophisticated interface between the FCS and actuation.

Most first generation FBW aircraft may operate in three distinct modes that may be summarized in general terms as follows:

- Full FBW Mode. This mode encompasses the full FBW algorithms and protection and is the normal mode of operation
- Direct Electrical Link Mode. This mode will usually provide rudimentary algorithms or possibly only a direct electrical signalling capability in the event that the primary FBW mode is not available
- Mechanical Reversion Mode. This provides a crude means of flying the aircraft – probably using a limited number of flight control surface following the failure of FBW and direct electrical link modes
- In later implementations such as the Airbus A380 and Boeing 787 no mechanical reversion is provided.
- The interface with the actuator is frequently achieved by means of an Actuator Control Electronics (ACE) unit that closes the control loop electrically around the actuator rather than mechanical loop
- The digital FBW or direct link demands from the flight control system are processed by the ACE which supplies an analogue command to the actuator SV.
- This allows aircraft systems hydraulic power to be supplied to the appropriate side of the ram piston moving the ram to the desired position.
- In this implementation the ram position is detected by means of a Linear Variable Differential Transducer (LVDT) which feeds the signal back to the ACE where the loop around the actuator is closed.
- Therefore ACE performs two functions: conversion of digital flight control demands into analogue signals and analogue loop closure around the actuator.

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UNIT-4

PNUEMATIC AND ENVIRONMENTAL CONTROL SYSTEMS

4.1 USE OF BLEED AIR:

- The use of the aircraft engines as a source of high-pressure, high-temperature air can be understood by examining the characteristics of the turbojet, or turbofan engine as it should more correctly be described.
- Modern engines bypass' a significant portion of the mass flow past the engine and increasingly
- A small portion of the mass flow passes through the engine core or gas generation section. The ratio of bypass air to engine core air is called the bypass ratio and this can easily exceed 10:1 for the very latest civil engines; much higher than the 4 or 5:1 ratio for the previous generation.
- The characteristics of a modern turbofan engine are shown in Figure 6.1. This figure shows the pressure (in psi) and the temperature (in degrees centigrade)at various points throughout the engine for three engine conditions: ground idle, take-off power and in the cruise condition.
- It can be seen that in the least stressful condition – ground idle – the engine is in a state of equilibrium but that even at this low level the compressor air pressure is 50 psi and the temperature 180 °C.
- At take-off conditions the compressor air soars to 410 psi/540 °C. In the cruise condition the compressor air is at 150 psi/400 °C. The engine is therefore a source of high pressure and high temperature air that can be 'bled' from the engine to perform various functions around the aircraft.
- The fact that there are such considerable variations in air pressure and temperature for various engine conditions places an imposing control task upon the pneumatic system. Also the variations in engine characteristics between

similarly rated engines of different manufactures poses additional design constraints.

- Some aircraft such as the Boeing 777 offer three engine choices, Pratt & Whitney, General Electric and Rolls-Royce, and each of these engines has to be separately matched to the aircraft systems, the loads of which may differ as a result of operator specified configurations.
- As well as the main aircraft engines the Auxiliary Power Unit (APU) is also a source of high pressure bleed air.
- The APU is in itself a small turbojet engine, designed more from the viewpoint of an energy and power generator than at thrust provider which is the case for the main engines. The APU is primarily designed to provide electrical and pneumatic power by a shaft driven generator and compressor.
- The APU is therefore able to provide an independent source of electrical power and compressed air while the aircraft is on the ground, although it can be used as a backup provider of power while airborne.
- Some aircraft designs are actively considering the use of in-flight operable APUs to assist in in-flight engine re-lighting and to relieve the engines of off take load in certain areas of the flight envelope.
- It is also usual for the aircraft to be designed to accept high pressure air from a ground power cart, for aircraft engine starting.
- These three sources of pneumatic power provide the muscle or means by which the pneumatic system is able to satisfy the aircraft demands

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

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

- ECS and cooling: the provision of the main air source for environmental temperature control and cooling
- Pressurization: the provision of a means by which the aircraft may be pressurized,
- giving the crew and passengers a more comfortable operating environment
- Air downstream of the PRSOV may be used in a number of ways:

- By means of a cross flows Shut-Off Valve (SOV) the system may supply air to the opposite side of the aircraft during engine start or if the opposite engine is inoperative for any reason .A SOV from the APU may be used to isolate the APU air supply SOVs provide isolation as appropriate to the left and right air conditioning packs and pressurization systems.additional SOVs provide the means by which the supply to left and rightwing anti-icing systems may be shut off in the event that these functions are not required this is a simplified model of the use of engine bleed air in pneumatic systems.

4.2 ENGINE BLEED AIR CONTROL:

Air is taken from an intermediate stage or high pressure stage of the engine compressor depending upon the engine power setting.

- At lower power settings, air is extracted from the high pressure section of the compressor while at higher power settings the air is extracted from the intermediate compressor stage.
- This ameliorates to some degree the large variations in engine compressor air pressure and temperature for differing throttle settings.
- A pneumatically controlled High Pressure Shut-Off Valve (HP SOV) regulates

the pressure of air in the engine manifold system to around 100 psi and also controls the supply of bleed air from the engine.

- The Pressure-Reducing Shut-Off Valve (PRSOV) regulates the supply of the outlet air to around 40 psi before entry into the pre-cooler.
- Flow of cooling air through the pre-cooler is regulated by the fan valve which controls the temperature of the LP fan air and therefore of the bleed air entering the aircraft system. Appropriately located pressure and temperature sensors allow the engine bleed air temperature and pressure to be monitored and controlled within specified limits.

4.3 BLEED AIR SYSTEM USERS:

The largest subsystem user of bleed air is the air system. Bleed air is used as the primary source of air into the cabin and fulfils the following functions:

Cabin environmental control – cooling and heating

- Cabin pressurization
- Cargo bay heating
- Fuel system pressurization in closed vent fuel system used in some military aircraft
- However there are other subsystems where the use of engine bleed air is key. These subsystems are:
- Wing and engine anti-ice protection
- Engine start
- Thrust reverser actuation
- Hydraulic system

4.3.1 WING AND ENGINE ANTI-ICE:

- The protection of the aircraft from the effects of aircraft icing represents one of the greatest and flight critical challenges which confront the aircraft.

- Wing leading edges and engine intake cowlings need to be kept free of ice accumulation at all times.
- In the case of the wings, the gathering of ice can degrade the aerodynamic performance of the wing, leading to an increased stalling speed with the accompanying hazard of possible loss of aircraft control.
- Ice that accumulates on the engine intake and then breaks free entering the engine can cause substantial engine damage with similar catastrophic results.
- Considerable effort is also made to ensure that the aircraft windscreens are kept clear of ice by the use of window heating so that the flight crew has an unimpeded view ahead.
- Finally, the aircraft air data sensors are heated to ensure that they do not ice up and result in a total loss of air data information that could cause a hazardous situation or the aircraft to crash. The prevention of ice build-up on the windscreen and air data system probes is achieved by means of electric heating elements.
- In the case of the wing and engine anti-icing the heating is provided by hot engine bleed air which prevents ice forming while the system is activated.
- The air flow is modulated by the electrically enabled anti-icing controller; this allows air to pass down the leading edge heating duct.
- This duct can take the form of a pipe with holes appropriately sized to allow a flow of air onto the inner surface of the leading edge – sometimes known as a ‘piccolo tube’.
- The pressure of air in the ducting is controlled to about 20–25 psi. Telescopic ducting is utilized where the ducting moves from fixed wing to movable slat structure and flexible couplings are used between adjacent slat sections.
- These devices accommodate the movement of the slat sections relative to the main wing structure as the slats are activated.
- The air is bled out into the leading edge slat section to heat the structure before being dumped overboard.

- Engine anti-icing is similarly achieved. An Engine Anti-Ice (EAI) valve on the engine fan casing controls the supply of bleed air to the fan cowl in order to protect against the formation of ice.
- As in the case of the wing anti-ice function, activation of the engine anti-icing system is confirmed to the flight crew by means of the closure of a pressure switch that provides an indication to the display system.
- The presence of hot air ducting throughout the airframe in the engine nacelles and wing leading edges poses an additional problem; that is to safeguard against the possibility of hot air duct leaks causing an overheat hazard.
- Accordingly, overheat detection loops are provided in sensitive areas to provide the crew with a warning in the event of a hot gas leak occurring.

4.3.2 ENGINE START:

The availability of high pressure air throughout the bleed air system lends itself readily to the provision of motive power to crank the engine during the engine start cycle. As can be seen from earlier figures, a start valve is incorporated which can be activated to supply bleed air to the engine starter. On the ground the engines may be started in a number of ways:

- By use of a ground air supply cart
- By using air from the APU – probably the preferred means
- By using air from another engine which is already running

4.3. 3THRUSTREVERSERS:

- Engine thrust reversers are commonly used to deflect engine thrust forward during the landing roll-out to slow the aircraft and preserve the brakes.
- Thrust reversers are commonly used in conjunction with a lift dump function ,whereby all the spoilers are simultaneously fully deployed, slowing the aircraft

by providing additional aerodynamic drag while also dispensing lift.

- Thrust reversers deploy two buckets, one on each side of the engine, which are pneumatically operated by means of air turbine motor actuators to deflect the fan flow forward, thereby achieving the necessary braking effect when the aircraft has a ‘weight- on-wheels’ condition.
- The air turbine motor has an advantage in that it is robust enough to operate in the harsh temperature and acoustic noise environment associated with engine exhaust, where hydraulic or electrical motors would not be sufficiently reliable.
- Interlock mechanisms are provided which prevent inadvertent operation of the thrust reversers in flight.
- The Tornado thrust reversers are selected by rocking the throttle levers outboard in flight.
- On touchdown a signal is sent by the engine control systems to an air turbine motor connected to a Bowden cable and a screw jack mechanism to deploy the buckets.

There are two key parameters which the pitot static system senses:

- Total pressure Pt is the sum of local static pressure and the pressure caused by the forward flight of the aircraft. The pressure related to the forward motion of the aircraft by the following formula:
- Pressure =½ _V2 Where _ is the air density of the surrounding air and V is The velocity
- Static pressure or Ps is the local pressure surrounding the aircraft and varies with altitude Therefore total pressure, Pt
- =Ps+ ½ _V2
- The forward speed of the aircraft is calculated by taking the difference between Pt and Ps
- An aircraft will have three or more independent pitot and static sensors Figure

6.11 shows the principle of operation of pitot and sensors.

- The pitot probe shown in the top diagram is situated such that it faces in the direction of the airflow, thereby being able to sense the variation in aircraft speed using the formula quoted above.
- The sensing portion of the pitot probe stands proud from the aircraft skin to minimize the effect of the boundary layer.
- Pitot pressure is required at all stages throughout flight and a heater element is incorporated to prevent the formation of ice that could block the sensor or create an erroneous reading.
- The pitot heating element is active throughout the entire flight.
- The static probe shown in the lower diagram is located perpendicular to the airflow and so is able to sense the static pressure surrounding the aircraft.
- Like the pitot probe the static probe is provided with a heater element that continuously heats the sensor and prevents the formation of ice.
- On some aircraft the pitot and static sensing functions are combined to give a pitot-static probe capable of measuring both dynamic and static pressures.
- A typical installation on a civil transport aircraft is depicted
- This shows a configuration where three pitot probes are used; pitot 2 on the right side and pitot 1 and pitot 3 on the left side of the aircraft nose.
- Three static probes are located on the left and right sides of the aircraft.
- Pitot and static probes are carefully towards the nose of the aircraft such that the sensitive air data measurements are unaffected by other probes or radio antenna.
- Residual instrumentation errors due to probe location or installation are calibrated during the aircraft development phase and the necessary corrections applied further downstream in the system.

Three major parameters be calculated from the pitot-static pressure information sensed by the pitot and static probes or by a combined pitot-static probe as shown in the diagram:

- Airspeed may be calculated from the deflection in the left hand instrument where Pt and Ps are differentially sensed. Airspeed is proportionate to Pt – Ps and therefore the mechanical deflection may be sensed and airspeed deduced. This may be converted into a meaningful display to the flight crew value in a mechanical instrument by the mechanical gearing between capsule and instrument dial
- Altitude may be calculated by the deflection of the static capsule in the centre instrument. Again in a mechanical instrument the instrument linkage provides the mechanical scaling to transform the data into a meaningful display

- Vertical speed may be deduced in the right hand instrument where the capsule deflection is proportional to the rate of change of static pressure .

The examples given above are typical for aircraft instruments used up to about 40 years ago.

There are three methods of converting air data into useful aircraft related parameters etc. that the aircraft systems may use:

• On older aircraft conventional mechanical flight instruments may be used, these tend to be relatively unreliable, expensive to repair, and are limited in the information they can provide to an integrated system. Mechanical instruments are also widely used to provide standby or backup instrumentation

• On some integrated systems the pitot-static sensed pressures are fed into centralized Air Data Computers (ADCs). This allows centralization of the air data calculations into dedicated units with computational power located in electrical bay racks. The ADCs can provide more accurate air data calculations more directly aligned to the requirements of a modern integrated avionics system. When combined with digital computation techniques within the ADC and the use of modern data buses such as MIL-STD-1553B, ARINC 429 and ARINC 629 to communicate with other aircraft systems, higher degrees of accuracy can be achieved and the overall aircraft system performance improved

• More modern civil aircraft developed in the late 1980s and beyond use Air Data Modules (ADMs) located at appropriate places in the aircraft to sense the pitot and static information as appropriate. This has the advantage that pitot-static lines can be kept to a minimum length reducing installation costs and the subsequent maintenance burden. By carefully selecting appropriate architecture greater redundancy and improved fault tolerance may be designed at an early stage, improving the aircraft dispatch availability

- An example of a modern air data system using ADMs is shown in Figure 6.14. This architecture equates to the probe configuration installation shown in Figure 6.12, namely, three pitot probes and a total of six static probes, three each on the left and right hand side of the aircraft.

4.4 INNOVATIVE METHODS OF PITOT-STATIC MEASUREMENT:

Conventional pitot-static sensing methods have been described. More recently the use of pitot- static sensing plates has been adopted; particularly on stealth aircraft where the use of conventional pitot-static probes can severely compromise the aircraft low observable radar signature.

These pressure plates are able to derive data relating to:

• Pitot pressure

• Static pressure

• Angle of attack (_)

• Angle of sideslip (_)

4.5 THE NEED FOR A CONTROLLED ENVIRONMENT:

In the early days of flight, pilots and passengers were prepared to brave the elements for the thrill of flying. However, as aircraft performance has improved and the operational role of both civil and military aircraft has developed, requirements for Environmental Control Systems (ECS) have arisen.

They provide a favorable environment for the instruments and equipment to operate accurately and efficiently, to enable the pilot and crew to work comfortably, and to provide safe and comfortable conditions for the fare-paying passengers.

In the past, large heating systems were necessary at low speeds to make up for the losses to the cold air outside the aircraft. With many of today's military aircraft operating at supersonic speeds, the emphasis is more towards the provision of cooling systems, although heating is still required, for example on cold night flights and for rapid warm-up of an aircraft which has been Soaked in freezing conditions on the ground for long periods.

The retirement of Concorde has eliminated this as an issue for commercial aircraft.

Providing sufficient heat for the aircraft air conditioning system is never a problem, since hot air can be bled from the engines to provide the source of conditioning air.

The design requirement is to reduce the temperature of the air sufficiently to give adequate conditioning on a hot day.

The worst case is that of cooling the pilot and avionics equipment in a high performance Military aircraft. The following heat sources give rise to the cooling problem

4.5.1 Kinetic Heating:

Kinetic heating occurs when the aircraft skin heats up due to friction between itself and air molecules.

4.5.2 Solar Heating:

- Solar radiation affects a military aircraft cockpit directly through the windscreen and canopy. Equipment bays and civil aircraft cabins are only affected indirectly.
- A fighter aircraft is the worst case, since it usually has a large transparent canopy to give the pilot good all round vision, and can fly typically up to twice the maximum altitude of a civil aircraft. At such altitudes solar radiation intensity is much higher.

- The combined effect of internal heating and direct solar radiation has an effect on the pilot, especially when wearing survival gear and anti-g trousers and vest which requires considerable cooling air in the cockpit.
- Solar heating significantly affects both cabin and equipment bays on ground standby, since surfaces exposed to direct solar radiation will typically rise20 °C above the ambient temperature, depending on the thermal capacity of the surface material. This is of special concern in desert areas of the world where the sun is hot and continuous throughout the day

4.5.3 Avionics Heat Loads

- While advances in technology have led to reductions in heat dissipation in individual electronic components, the increased use of avionics equipment and the development of high density digital electronics have increased the heat load per unit volume of avionics equipment.
- This has resulted in an overall increase in heat load.
- The avionic equipment is generally powered continuously from power up to power down and, hence, dissipates heat continuously.
- The equipment, usually in standard form equipment boxes, is installed in designated avionic equipment bays in small aircraft, or in equipment cabinets in larger aircraft.
- Air is ducted to these areas for the specific purpose of cooling equipment and is then re circulated or dumped overboard.
- The system must be designed to protect the components of the equipment throughout the aircraft flight envelope, and in whatever climatic conditions the aircraft must operate.

4.5.4 Airframe System Heat Loads

- Heat is produced by the environmental control system itself, as well as hydraulic systems, electrical generators, engines and fuel systems components.

- This takes the form of heat produced as radiation from energy consuming components in the systems such as pumps or motors, or from heat rejected in cooling fluids such as oil.
- To maintain operating efficiency and to prevent chemical breakdown of fluids with resulting degradation in their performance it is essential to cool these fluids.

4.6 The Need for Cabin Conditioning

- Design considerations for providing air conditioning in the cockpit of a high performance fighter are far more demanding than those for a subsonic civil airliner cruising between airports.
- The cockpit is affected by the sources of heat described above, but a high performance fighter is particularly affected by high skin temperatures and the effects of solar radiation through the large transparency.
- However, in designing a cabin conditioning system for the fighter, consideration must also be taken of what the pilot is wearing.
- If, for example, he is flying on a mission over the sea, he could be wearing a thick rubber immersion suit which grips firmly at the throat and wrists.
- 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 to combat
- .All these factors make it very difficult to cool the pilot efficiently so that his body temperature is kept at a level that he can tolerate without appreciable.

4.7 ENVIRONMENTAL CONTROL SYSTEM DESIGN:

- This section describes methods of environmental control in common use and, in addition, outlines some recent advances and applications in environmental control system design.

- The cooling problem brought about by the heat sources described above must be solved to successfully cool the aircraft systems and passengers in flight.
- 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 the aircraft.
- Heat sinks easily available are the outside air and the internal fuel.
- The outside air is used either directly as ram air, or indirectly as air bled from the engines.
- 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 usually necessary.

4.7.1 RAM AIR COOLING:

- Ram air cooling is the process of rejecting aircraft heat load to the air flowing round the aircraft. This can be achieved by scooping air from the aircraft boundary layer or close to it.
- The air is forced through a scoop which faces into the external air flow, through a heat exchanger matrix and then rejected overboard by the forward motion of the aircraft.
- The heat exchanger works just like the radiator of a car.
- This system has the disadvantage that it increases the aircraft drag because the resistance of the scoop, pipe work and the heat exchanger matrix slows down the ram airflow.
- The use of ram air as a cooling medium has its limitations, since ram air temperature increases with airspeed and soon exceeds the temperature required for cabin and equipment conditioning.
- For example, at Mach 0.8 at sea level on a 40 °C day, the ram air temperature is about 80 °C. Ram air is also a source of heating itself as described above (Kinetic

heating).

- In addition, at high altitude the air density becomes very low, reducing the ram air mass Flow and hence it's cooling capacity.
- In fact, when conditioning is required for systems which require cooling on the ground, then ram air cooling alone is unsuitable.
- However, this situation can be improved by the use of a cooling fan, such as used on a civil aircraft, or a jet pump, mainly used on military aircraft, to enhance ram air flow during taxi-ing or low speed flight.

4.7.2 ENGINE BLEED:

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

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

4.7.3 BLEED FLOW AND TEMPERATURE CONTROL:

- Typically air at a workable pressure of about 650 kpa absolute (6.5 atmospheres)and a temperature of about 100 °C is needed to provide sufficient system flow and a temperature high enough for such services as rapid demisting and anti icing.
- However, the air tapped from the engine high pressure compressor is often at higher pressures and temperatures than required.
- For example ,in a high performance fighter aircraft the air can be at pressures as high as3700 kpa absolute (37 atmospheres) and temperatures can be over 500 °C, high, enough to make pipes manufactured from conventional materials glow red hot.

- Tapping air at lower pressures and temperatures from a lower compressor stage would be detrimental to engine performance.

- On many civil aircraft, different bleed tappings can be selected according to engine speed.

4.8 COOLING SYSTEMS:

There are two main types of refrigeration systems in use:

- Air cycle refrigeration systems
- Vapor cycle refrigeration systems

4.8.1 AIR CYCLE REFRIGERATION SYSTEMS:

- The basic principle is that energy (heat) is removed by a heat exchanger from compressed air which then performs work by passing through a turbine which drives the compressor, and hence energy is transferred resulting in a reduction in temperature and pressure.
- The resultant air is then at a temperature (and to a small extent pressure) below that at which it entered the compressor.
- Air cycle refrigeration systems are used to cool engine bleed air down to temperatures required for cabin and equipment conditioning.
- Since engine bleed air is generally available, air cycle refrigeration is used because it is the simplest solution to the cooling problem, fulfilling both cooling and cabin pressurization requirements in an integrated system.

- However, although lighter and more compact than vapor cycle, air cycle systems have their limitations.
- Very large air flows are required in high heat load applications which require large diameter ducts with the corresponding problems of installation.

4.8.2 TURBOFAN SYSTEM:

This will typically be used in a low-speed civil aircraft where ram temperatures will never be very high.

4.8.3 BOOTSTRAP SYSTEM

- 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 a compressor.
- Both are mounted on a common shaft. This rotating assembly tends to be supported on ball bearings, but the latest technology uses air bearings.
-
- 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 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.

4.8 .4 REVERSED BOOTSTRAP:

- The reversed bootstrap system is so named because the charge air passes through the turbine of the cold air unit before the compressor.

- Following initial ram air cooling from a primary heat exchanger the air is cooled further in a regenerative heat exchanger and is then expanded across the turbine with a corresponding decrease in temperature.

4.8.9 RAM POWERED REVERSE BOOTSTRAP:

- In some cases equipments may be remotely located where it is not practicable to duct an air supply from the main ECS.
- In such cases a separate cooling package must be employed.
- This situation is becoming particularly common on military aircraft with equipment mounted in fin tip or under-wing pods, where it is not possible to find a suitable path to install ducting or pipes.
- A ram-powered reverse bootstrap air-cycle system can be used to meet such ‘standalone’ cooling requirements.

4.8.10 VAPOR CYCLE SYSTEMS:

- 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 Pontde 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 heat sink.
- The refrigerant flows back to the evaporator via an expansion valve.

4.8.11 LIQUID COOLED SYSTEMS:

- Liquids such as Cool anol® are now more commonly being used to transport the heat away from avionics equipment. (NB COOLANOL® is a registered rade mark of Exxon for Silicate Ester dielectric heat transfer fluids.)Liquid can easily replace air as a transport medium flowing through the cold wall heat exchanger.
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- A typical liquid loop consists of an air/liquid heat exchanger which is used to dump the heat load being carried by the liquid into the air conditioning system, a pump and a reservoir.
- The advantages are that it is a more efficient method of cooling the heat source, and the weight and volume of equipment tends to be less than the air conditioning equipment which would otherwise be required.
- The disadvantages are that it is expensive, and the liquid Cool anol® is toxic.
- Self sealing couplings must be provided to prevent spillage wherever a break in the piping is required for maintenance purposes.
- The Boeing AH-64C/D Longbow Apache attack helicopter uses such a vapor cooling system to cool the extended forward avionics bays.

4.9 HUMIDITY CONTROL:

- Passenger comfort is achieved not only by overcoming the problems of cooling and cabin pressurization, but also by controlling humidity in the passenger cabin.
- This is only a problem on the ground and at low altitudes, since the amount of moisture in the air decreases with increasing altitude.
- There is a particular difficulty in hot humid climates.
- In addition to the aim of ensuring passenger comfort, humidity levels must be controlled to prevent damage to electrical and electronic equipment due to excessive condensation.
- Humidity control also reduces the need for wind screen and window de-misting and anti-misting systems.
- The fine mist of water droplets in the cold cabin inlet supply must be coalesced into large droplets that can then be trapped and drained away.
- Two types of water separator are in common use with air cycle refrigeration systems: a centrifugal device and a mechanical device.
- In the centrifugal devices a turbine is commonly used to swirl the moist air. The

relatively heavy water droplets are forced to the sides of a tube, where the water and a small amount of air is trapped and drained away, thus reducing the water content of the air downstream of a water separator

4.10 AIR DISTRIBUTION SYSTEMS:

4.10.1 AVIONICS COOLING:

- In civil aircraft the total avionics heat load is low when compared with the many applications which have been, and continually are being, found in military aircraft.
- In civil aircraft it is often sufficient to draw cabin ambient air over the avionics equipment racks using fans.
- This will have the effect of increasing the overall cabin temperature but, since the total avionics heat load is not massive, the environmental control system has sufficient capacity to maintain cabin temperatures at acceptable levels.
- However, on a military aircraft with a high avionics heat load, only a few items of the avionics equipment are located in the cabin.
- The majority are located in either conditioned or non conditioned equipment bays, an installation decision which is made by taking into consideration such criteria as the effect of temperature on equipment reliability or damage, and the amount of engine bleed available for air conditioning.
- Since the equipment can operate in ambient temperatures higher than humans can tolerate, the air used to condition it tends to be cabin exhaust air.
- There is usually very little space in equipment bays as they are tightly packed with equipment. There is little space left for the installation of cooling air ducts.
- Therefore, the equipment racking and air distribution system must be carefully designed to ensure an even temperature distribution.

4.10.2 UNCONDITIONED BAYS:

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

4.10.3 CONDITIONED BAYS:

Equipment can be cooled by a variety of methods, including the following;

- cooling by convection air blown over the outside walls of the equipment boxes (external air wash)
- Air blown through the boxes and over the printed circuit boards (direct forced air)
- Air blown through a cold wall heat exchanger inside the box (indirect forced air)
- Fans installed in the box to draw a supply of cooling air from the box surroundings
- The first method of cooling is adequate for equipment with low heat loads.
- As the heat load increases it tends to become very inefficient, requiring a lot more cooling air than the other three methods to achieve the same degree of cooling.
- It is very difficult to design an avionics equipment box with a high heat load to enable the efficient dissipation of heat by convection via the box walls. Local ‘hot spots’ inside the box will lead to component unreliability.
- The other three methods of cooling are very much more efficient, but the boxes must have a good thermal design to ensure precious conditioning air is not wasted.
- The second method is often the most efficient way of cooling.

- The box is thermally designed so that the component heat load is conducted to a cold wall heat sink. The cold wall acts as a small heat exchanger.
- The final method is only acceptable in an equipment bay layout where there is no chance of re-ingestion of hot exhaust air from another box.
- This is not practical in a closely packed equipment bay. Particular attention must be given to the cooling requirements of equipment whose correct operation is critical to the safety of the aircraft
- such computers must be continuously fully conditioned, since failure of all computers would render the aircraft uncontrollable.
- Otherwise computers performing flight critical functions must be designed to operate un cooled for the duration of a flight albeit in a limited bay environmental temperature. What suffers is long-term reliability of the computer.

4.11 CABIN DISTRIBUTION SYSTEMS:

- Cabin distribution systems on both civil and military aircraft are designed to provide as comfortable an environment as possible.
- The aircrew and passenger’s body temperature should be kept to acceptable levels without hotspots, cold spots or draughts.
- Civil aircraft are designed to maintain good comfort levels throughout the cabin since passengers are free to move about.
- On some aircraft each passenger has personal control of flow and direction of local air from an air vent above the head (often known as a ‘punkahlouvre’), although on modern large aircraft total air conditioning is provided
- The personal air vent is no longer provided, partly because of the better performance of air conditioning systems, and also because the increased height
- Passenger cabins mean that passengers are no longer able to reach the vent while seated.
- There are usually additional vents which blow air into the region of the

passengers' feet so that there is no temperature gradient between the head and feet.

4.12 CABIN PRESSURIZATION:

- Cabin pressurization is achieved by a cabin pressure control valve which is installed in the cabin wall to control cabin pressure to the required value depending on the aircraft altitude by regulating the flow of air from the cabin.
- For aircraft where oxygen is not used routinely, and where the crew and passengers are free to move around as in a long range passenger airliner, the cabin will be pressurized so that a cabin altitude of about 8000 ft is never exceeded.
- This leads to a high differential pressure between the cabin and the external environment. Typically for an airliner cruising at 35 000 ft with a cabin altitude of 8000 ft there will be a differential pressure of about 50 kpa (0.5atmosphere) across the cabin wall.
- The crew is able to select a desired cabin altitude from the cockpit and cabin pressurization will begin when the aircraft reaches this altitude.
- This will be maintained until the maximum design cabin differential pressure is reached. This is also true for large military aircraft such as surveillance platforms or air-to-air re fuelling tankers.

4.13 MOLECULAR SIEVE OXYGEN CONCENTRATORS:

- Until recently the only practical means of supplying oxygen during flight has been from a cylinder or a liquid oxygen bottle.
- This has several disadvantages, particularly for military aircraft. It limits sortie duration (fuel may not be the limiting factor if in-flight re fuelling is used), the equipment is heavy and the bottles need replenishing frequently.
- Molecular Sieve Oxygen Concentrators (MSOC) is currently being developed for

military applications.

- The MSOCs use air taken from the environmental control systems as their source of gas. Most of the gases in air have larger molecules than oxygen.
- These molecules are sieved out of the air mixture until mostly oxygen remains.
- This means that a continuous supply of oxygen can be made available without needing to replenish the traditional oxygen storage system after each flight.
- The residual inert gases can be used for fuel tank pressurization and inserting. A system designed specifically for the production of inert gases is known as On-Board Inert Gas Generating System(OBIGGS).
- However, MSOCs have a major disadvantage. If the environmental air supply from the engines stops then so does the supply of oxygen.

- Therefore, small backup oxygen systems are required for emergency situations to enable the pilot to descend to altitudes where oxygen levels are high enough for breathing.
- Developments of MSOCs are watched with interest, and further systems may be efficient enough to provide oxygen enriched air for civil aircraft cabins.
- In military aircraft which are typically designed to fly to altitudes in excess of50 000 ft, both cabin pressurization and oxygen systems are employed to help alleviate the effects of hypoxia.
- In cases where aircrew are exposed to altitudes greater than 40 000 ft, either due to cabin 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.

4.14 G TOLERANCE:

- For aircraft which are likely to perform frequent high g man oeuvres such as Typhoon, a ‘relaxed g protection’ system is beneficial.
- This consists of increased coverage g trousers and pressure breathing with g and altitude which requires a breathing gas regulator and mask capable of providing increased pressure gas, and a pressurized upper body garment to provide external counter pressure(a chest counter pressure garment).
- This enables the pilot to perform repeated high g man oeuvres without the need for g straining.
- It also provides altitude protection in the case of a cabin decompression in a manner similar to a full pressure suit.
- Engineers strive constantly to improve the agility and combat performance of military aircraft. Indeed technology is such that it is now man who is the limiting factor and not the machine. Accelerations occur whenever there is a change in velocity or a change in direction of a body at uniform velocity.

UNIT-5

ENGINE CONTROL AND FUEL SYSTEMS

5.1 ENGINE/AIRFRAME INTERFACES:

- 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 effort to reduce the development costs of a new project.

- Whatever the case, control of the interfaces between the engine and the airframe is essential to allow the airframe contractor and the engine contractor to develop their
- Products independently. The interface may be between the engine and a nacelle in the case of a podded, under-wing engine, as is common in commercial aircraft; or between the engine and the fuselage as is common in fast jet military aircraft types.
- 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–airframe interface.
- Together with the mechanical, fluid and power off take interfaces, this was a measure of complexity that had the potential for interface errors that could compromise an aircraft development programme.
- Although the emergence of rugged electronics, data buses and 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 their interfaces.
- The nature of the interfaces and the potential for rework usually means that the ICD becomes an important contractual document.

5.2 THE CONTROL PROBLEM:

- 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 of malfunction.
- The degree of control required depends to a large extent upon the type of engine

and the type of aircraft in which it is installed.

- The military aircraft is usually specified to operate in worldwide conditions, and is expected to experience a wide range of operating temperatures.
- To be successful in combat the aircraft must be maneuverable.
- The pilot, therefore, expects to be able to 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 or over-temperature.
- The pilot also needs a fairly linear relationship between throttle lever position and thrust.
- The civil operator requires reliable, economical and long-term operation under clearly defined predictable conditions with minimum risk to passengers and schedules.
- For military engines the key to satisfactory performance is the ability to perform over large speed and altitude ranges as well as significant temperature variations.

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 safety margins
- Exhaust gas flow – by burning the exhaust gases and varying the nozzle area to provide 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.

5.3 FUEL FLOW CONTROL:

- Control of power or thrust is achieved by regulating the fuel flow into the combustor.
- On turbo jet or turbo fan engines thrust can be controlled by setting an 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 the rotor.
- When changing the thrust or power setting the fuel control system must limit the rate of acceleration and deceleration of the engine rotating assemblies in order to prevent compressor surge or flame out.
- This control process is further complicated by the change in engine inlet conditions, i.e. inlet temperature, inlet pressure and Mach number that can occur as the aircraft moves around the flight envelope.
- Airflow modulation through the compressor may also be necessary by the use of variable vanes and/or bleed valves to provide adequate surge margin under all operating conditions.
- The control of power or thrust of the gas turbine engine is obtained by regulating the quantity of fuel injected into the combustion system.
- When a higher thrust is required the throttle is opened and the fuel pressure to the burners increases due to the higher fuel flow.
- This has the effect of increasing the gas temperature which, in turn, increases the acceleration of the gases through the turbine to give a higher engine speed and correspondingly greater air flow, resulting in an increase in thrust.
  The relationship between the air flow induced through the engine and the fuel supplied is, however, complicated by changes in altitude, air temperature and aircraft speed.
- 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 or position.

- Fuel flow must, therefore, be monitored to maintain the conditions demanded by the pilot whatever the changes in the outside world.
- 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 management units (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 of malfunction.

5.4 AIR FLOW CONTROL:

- 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 military applications.
- 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 control systems.

5.5 CONTROL SYSTEMS:

- The number of variables that affect engine performance is high and the nature of the variables is dynamic, so that the pilot cannot be expected constantly to adjust the throttle lever to compensate for changes, particularly in multiengine aircraft.
- 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 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 engine manufacturer.
- The FCU, with its internal capsules, looks after variations due to atmospheric changes.
- In the dynamic conditions of an aircraft in flight at different altitudes, temperatures and speeds, continual adjustment by the pilot soon becomes impractical.

5.5.1 Control System Parameters:

- To perform any of the control functions electrically requires devices to sense engine operating conditions and to perform a controlling function.

- These can usually be conveniently subdivided into input and output devices producing input and output signals to the control system.
- To put the control problem into perspective the control system can be regarded as a box on a block diagram receiving input signals from the aircraft and the engine and providing outputs to the engine and the aircraft systems.

a) Input Signals:

- 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 AC signal.
- 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 aircraft structure
- 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 engine speed
- 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 obtain a measurement of mean gas temperature and are usually of chromel - alumel junctions.

- Nozzle position – For those aircraft fitted with reheat (or afterburning) the position of the reheat nozzle may be measured using position sensors connected to the nozzle actuation mechanism or to the nozzle itself. An inductive pick-off is usually used since such types are relatively insensitive to temperature variations, 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 fuel flow

- 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 pressure ratio

b) Output Signals:

- 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 own adherents

- Air flow control – The control of air flow at different stages of the engine can be applied by the use of guide vanes at the engine inlet, or by the use of bleed valves between engine stages. These are controlled automatically to preserve a controlled flow of air through the engine for varying flight conditions

5.6 EXAMPLE SYSTEMS:

- 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 differ significantly
- In a simple control system, such as may be used in a single engine trainer aircraft the primary pilot demand for thrust is made by movements of a throttle lever.
- Rods and levers connect the throttle lever to a fuel control unit (FCU) so that its position corresponds to a particular engine condition, say rpm or thrust.
- Under varying conditions of temperature and altitude this condition will not normally stay constant, but will increase or decrease according to air density, fuel temperature or demands for take-off power.
- To obtain a constant engine condition, the 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 fuel flow.
- 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 isThis valve forms part of a servo loop in the control system so that continuous small variations of fuel flow stabilise the engine condition around that demanded by the pilot.

- This will allow the system to compensate for varying atmospheric and barometric conditions, to ensure predictable acceleration and deceleration rates and to prevent over-temperature or over-speed conditions

5.7 ENGINE INDICATIONS:

- Despite the fact that engine control systems have become very comprehensive in maintaining operating conditions at the most economic or highest performance, depending on the application,
- There is still a need to provide the pilot with an indication of certain engine parameters. Under normal conditions the pilot is interested in engine condition only at the start and when something goes wrong.
- The engine control system, with its monitoring and warning capability, should inform the pilot when something untoward does happen.
- During engine start the pilot monitors (and checks with his co-pilot in a multi-crew aircraft) that start progresses satisfactorily with no observed sluggish accelerations, no low oil pressures or over-temperatures.
- Much of this monitoring involves pilot familiarity with the aircraft type and engine type, incurred over many starts. The crew may accept certain criteria that an automatic
- System would not.
- During normal operation the control system should provide sufficient high Integrity observation by self-monitoring and by checking certain parameters Engine Indications Against preset values.
- In this way the system can monitor accelerations, rates of change, value exceedance and changes of state and issue the necessary warning. Control systems are good at detecting sudden changes of level or state.
- However, slow, gradual but persistent drift and transient or intermittent changes of

state are a designer's nightmare.

- The first may be due to degradation in performance of a component, e.g. a component becoming temperature sensitive, a gradually blocking filter or the partial occlusion of a pipe or duct. The second may be due to a loose connection some where in the system.
- The pilot can observe the effects of these circumstances. In a four-engine aircraft, for example, one indicator reading differently to three others can be easily seen because the indicators are grouped with just such a purpose in mind.
- Until recently all aircraft had at least one panel dedicated to engine instruments.

These were in view at all times and took the form of circular pointer instruments, or occasionally vertical strip scales, reading such parameters as:

- Engine speed – NH and NL
- Engine temperature
- Pressure ratio
- Engine vibration
- Thrust (or torque)