Module - 2

MATERIALS AND MANUFACTURING & SYSTEMS

Syllabus:

Materials and manufacturing:

Criteria for selection of materials. Heat ranges of metals, high temperature strength. Surface finishing. Powder metallurgy. Use of composites and Ceramics. Super alloys for Turbines.

Systems:

Fuel systems and components. Sensors and Controls. FADEC interface with engine. Typical fuel system. Oil system components. Typical oil system. Starting systems. Typical starting characteristics. Various gas turbine starters.

2.1 Gas Turbine materials

- High-temperature, high-strength materials and unique methods of manufacture have made the gas turbine engine a practical reality in a few decades.
- To a large measure, the performance of turbojet and turboprop engines depend on the temperature at the inlet to the turbine.
- Increasing the turbine inlet temperature from the present limit (for most engines in high production) of approximately 927 to 1370°C will result in a specific thrust increase of approximately 130 percent, along with a corresponding decrease in specific fuel consumption.
- For this reason, obviously, high cycle temperatures are desirable. Just as obvious is the fact that not all materials can withstand the hostile operating conditions found in parts of the gas turbine engine.
- Research in material technology is continuing to restructure molecules to conform to whatever properties are deemed desirable.
- For example, titanium is being restructured to withstand high turbine inlet temperatures, and ceramics are being made more flexible, which will increase their usability in high-stress situations.
- It is predicted that molecular manipulation will soon result in more powerful and safer engines.

2.1.1 Commonly Used Terms

Some of the more commonly used terms and characteristics considered in the selection of materials in the field of metallurgy and metalworking are listed below.

- **Strength**
  - **Creep strength**—Defined as the ability of a metal to resist slow deformation due to stress, but at a stress level less than that needed to reach the yield point. Creep strength is usually stated in terms of time, temperature, and load.
  - **Yield strength**—This point is reached when the metal exhibits a permanent set under load.
  - **Rupture strength**—That point where the metal will break under a Continual load applied for periods of 100 and 1000 h. Metals are usually tested at several temperatures.
  - **Ultimate tensile strength**—The load under which the metal will break in a short time.
- **Ductility**—The ability of a metal to deform without breaking.
- **Coefficient of expansion**—A measure of how much a metal will expand or grow with the application of heat.
- **Thermal conductivity**—The measure of the ability of a metal to transmit heat.
- **Corrosion and oxidation resistance**—An important factor that indicates how well a metal can resist the corrosive effects of the hot exhaust stream.
- **Melting point**—The temperature at which the metal becomes a liquid.
- **Critical temperature**—As a metal is cooled, it passes through distinct temperature points where its internal structure and physical properties are altered. The rate of cooling will greatly influence the ultimate properties of the metal.
- **Heat treatability**—A measure of how the metal's basic structure will vary under an operation, or series of operations, involving heating and cooling of the metal while it is in a solid state. Ferritic, austenitic, and martensitic steels all vary as to their heat treatability. (All of these terms have to do with the physical and chemical properties of metal)
- **Thermal shock resistance**—The ability of a metal to withstand extreme changes in temperature in short periods of time.

- **Hardness**—An important characteristic in that it influences ease of manufacture and therefore cost.

Metalworking terms listed here and discussed further in this chapter include the following:

- **Casting**—A process whereby metal, in a molten state, solidifies in a mold.
- **Forging**—A process of plastic deformation under a pressure that may be slowly or quickly applied.
- **Electrochemical machining (ECM)** - ECM is accomplished by controlled high-speed deplating using a shaped tool (cathode), an electricity-conducting solution, and the workpiece (anode).
- **Machining**—Any process whereby metal is formed by cutting, hot or cold rolling, pinching, punching, grinding. or by means of laser beams.
- **Extrusion**—Metal is pushed through a die to form various cross-sectional shapes.
- **Welding**—A process of fusing two pieces of metal together by locally melting part of the material through the use of arc welders, plasmas, lasers, or electron beams.
- **Pressing**—Metals are blended, pressed, sintered (a process of fusing powder particles together through heat), and then coined out of the prealloyed powders.
- **Protective finishes and surface treatments**—These include plating by means of electrical and chemical processes, by use of ceramic coatings, or by painting. Surface treatments for increased wear may take the form of nitriding, cyaniding, carburizing, diffusion coating, and flame plating.
- **Shot peening**—A plastic flow or stretching of a metal's surface by a rain of round metallic shot thrown at high velocity.
- **Heat treatment**—A process to impart specific physical properties to a metal alloy. It includes normalizing, annealing, stress relieving, tempering, and hardening.
- **Inspection**—Strictly speaking, not a part of the metal working process, inspection is nevertheless integrally associated with it. Inspection methods include magnetic particle and dye penetrant inspection, x-ray inspection, dimensional and visual inspection, and inspection by devices using sound, light, and air.

2.2 Heat Ranges of Metals

The operating conditions within a gas turbine engine vary considerably, and metals differ in their ability to satisfactorily meet these conditions.

2.2.1 Aluminum Alloys

- Aluminum and its alloys are used in temperature ranges up to 260^0 C.
- With low density and good strength- to-weight ratios, aluminum forgings and castings are used extensively for centrifugal compressor wheels and housings, air inlet sections, accessory sections, and the accessories themselves.
- Some newer aluminum alloys include aluminum lithium, which is about 10 percent lighter than conventional aluminum and about 10 percent stiffer.
- Aluminum lithium presents a hazard in its molten form when moisture is present and it costs more than conventional alloys, but it will last two to three times longer because of its superior fatigue performance.
- Aluminum alloyed with iron and cerium will allow continued aluminum alloy use up to 344^0 C.

2.2.2 Titanium Alloys

- Titanium and its alloys are used for centrifugal-flow rotors, axial-flow compressor wheels and blades, and other forged components in many large, high-performance engines.
- Titanium combines high strength with low density and is suitable for applications up to 538^0 C.
- Newer titanium alloys include titanium aluminide, which is good for temperatures to 816^0 C.
- Titanium is alloyed with vanadium, aluminum, chromium, tin, zirconium, and molybdenum to improve its manufacturability.

2.2.3 Steel Alloys

- This group includes high-chromium and high-nickel iron base alloys in addition to low alloy steels.
- Because of their relatively low material cost, ease of fabrication, and good mechanical properties, the low-alloy steels are commonly used for both rotating and static engine components, such as compressor rotor blades wheels, spacers, Stator vanes, and structural members.
- Low-alloy steels can be heat-treated and used in temperatures up to 538^0 C.
- High nickel-chromium, iron-base alloys can be used up to 677^0 C.

- The use of steel may decrease because of the increasing use of the aluminum and titanium alloys mentioned above.

2.2.4 Nickel-Base Alloys

- The nickel-base alloys constitute some of the best metals for use between 649^0 C and 982^0 C.
- Most contain little or no iron.
- They develop their high-temperature strength by age hardening and are characterized by long-time creep-rupture strength and high ultimate and yield strength combined with good ductility.
- Many of these materials, originally developed for turbine bucket applications, are also being used in turbine wheels, shafts, spacers, and other parts.

2.2.5 Cobalt-Base Alloys

- Cobalt-base alloys form another important group of high temperature, high-strength, and high-corrosion-resistance metals.
- Again, as a group, they contain little or no iron.
- These alloys are used in afterburners, turbine vanes and blades, and other parts of the engine subjected to very high temperatures.
- Their use is somewhat restricted due to cost and the limitation imposed because of cobalt's status as a critical material.

2.3 Chemical Elements Used in Alloys

- The percentages of the various elements used partially determines the physical and chemical characteristics of the alloy and its suitability to a particular application.
- Three characteristics that must be considered are
  - High-temperature strength
  - Resistance to oxidation and corrosion
  - Resistance to thermal shock

2.4 High-Temperature Strength

- The most highly stressed parts of the gas turbine engine are the turbine blades and disks. Centrifugal forces tending to break the disk vary as the square of the speed.

- For example, the centrifugal force on a disk rotating at 20,000 rpm will be four times that at 10,000 rpm. Blades weighing only 6.2 grams may exert loads of over 1814 kg at maximum rpm.
- The blades must also resist the high bending loads applied by the moving gas stream to produce the thousands of horsepower needed to drive the compressor.
- There is also a severe temperature gradient (difference) between the central portion of the disk and its periphery of several hundred degrees centigrade.
- Many metals that would be quite satisfactory at room temperatures will lose much of their strength at the elevated temperatures encountered in the engine's hot section.
- The ultimate tensile strength of a metal at one temperature is not necessarily indicative of its ultimate tensile strength at a higher temperature.
- The Creep strength, which is closely associated with ultimate tensile strength, is probably one of the most important considerations in the selection of a suitable metal for turbine blades.
- Engine vibration and fatigue resistance will also have some influence on the selection and useful life of both disks and blades.
- Although many materials will withstand the high temperature encountered in the modern gas turbine engine (for example, carbon, columbium, molybdenum, rhenium, tantalum, and tungsten, all have melting points above 2200^0 C, the ability to withstand high temperatures while maintaining a reasonable tensile strength is not the only consideration.
- Such factors as critical temperature, rupture strength, thermal conductivity, coefficient of expansion, yield strength, ultimate tensile strength, corrosion resistance, workability, and cost must all taken into account when selecting any particular metal.

2.5 Resistance to Oxidation and Corrosion

- Corrosion and oxidation are results of electrical and chemical reactions with other materials.
- The hot exhaust gas stream encountered in the engine Speeds up this reaction. While all metals will corrode or oxidize, the degree of oxidation is determined by the base alloy and the properties of the oxide coating formed.

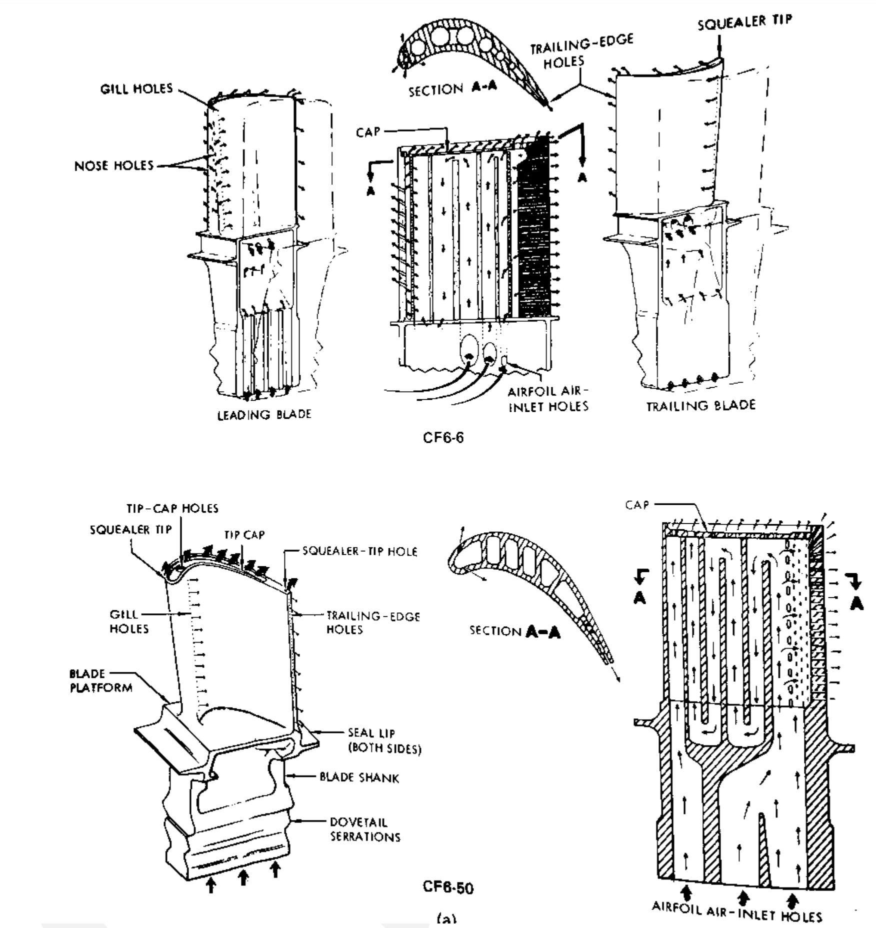
- If the oxide coating is porous or has a coefficient of expansion different from that of the base metal, the base metal will be continually exposed to the oxidizing atmosphere.
- One solution to the problem of oxidation at elevated temperatures has been the development and use of ceramic coatings.
- One product called Solaramic coating, manufactured by Solar, a division of International Harvester Company located in San Diego, California, is a ready-to-use ceramic slurry that can be thinned with water and applied to a part by spraying, brushing, or dipping.
- After drying, the Solaramic material will change to a white powder, which in turn is transformed to a ceramic coating when baked at 510^0 C.
- Ceramic-coated afterburner liners and combustion chambers are in use today.
- The ceramic coating has two basic functions
  - Sealing the base metal surface against corrosion, oxidation, and carbonization
  - Insulating the base metal against high temperatures
- These coatings are not without disadvantages, in that they are more susceptible to thermal shock, they must have the same coefficient of expansion as the base metal, they are brittle, and they have low tensile strength, which, Of course, restricts their use in the engine.
- Some work that shows promise is being done with various metal-ceramic combinations called Cermets or Ceramels.
- Ceramic materials being used include aluminum, beryllium, thorium, and zirconium oxides, to name a few.

2.6 Thermal Shock Resistance

- Many materials otherwise quite suitable must be rejected because of their poor thermal shock characteristics.
- Several engine failures have been attributed to thermal shock on the turbine disk.
- Ceramic coatings in particular are vulnerable to this form of stress.
- Improved fuel controls, starting techniques, and engine design have lessened this problem.

2.7 Convective, Film, and Impingement Cooling

- The effort to achieve higher turbine inlet temperatures, and therefore higher thermal efficiencies, has been approached from two directions.
- The first has been the development and use of high-temperature materials, both metals and ceramics.



- The second avenue of approach has been to cool the highly stressed turbine components.
- One method of cooling the nozzle guide vanes and turbine blades on gas turbine engines is to pass compressor bleed air through the hollow blades to cool them by convective heat transfer.
- A newer procedure called film cooling also uses compressor bleed air, which is made to flow along the outside surface of both vanes and blades, thus forming an insulating blanket of cooler air between the metal and the hot gas stream. The layer of air also reduces temperature gradients and thermal stress.

- Advanced manufacturing techniques such as shaped-tube electrolytic machining (STEM) and Electro-Stream (trademark of General Electric) drilling have made the production of the necessary small holes in the superhard turbine material possible.
- Some engines also use the air bled from the compressor to cool the front and rear face of the turbine disks.

2.8 Transpiration Cooling

- Transpiration cooling is a novel and efficient method of allowing the turbine blades and other parts within the hot section to operate at much higher turbine inlet temperatures.
- In this type of cooled blade the air passes through thousands of holes in a porous airfoil made from a sintered wire mesh material.
- Since the sintered wire mesh is not strong enough by itself, an internal strut is provided as the main structural support carrying all airfoil and centrifugal loads.
- Fabrication techniques involve rolling layers of woven wire mesh and then sintering these layers to form a porous metal sheet, which is then rolled into an airfoil shape.
- Porous materials, for example, Poroloy made by the Bendix Corporation, have been tested for use in combustion chambers and for afterburner liners.
- A similar material called —Rigimesh has also been used in rocket engines to help keep the fuel nozzles cool.
- Many manufacturers are experimenting with other types of porous materials for use in blades in an attempt to obtain higher turbine inlet temperatures.

2.9 Ceramics

- Experiments are being performed using ceramic materials in many of the engine's hot section parts, such as the combustor, nozzle diaphragm, turbine blades, and turbine disks.
- Materials being looked at are hot-pressed and/or bonded silicon nitride or silicon carbide, with some materials being reinforced with carbon or silicon carbide fibers.
- Glass ceramics reinforced with fiber also show promise for use in gas turbine engines.
- Advances in material development and new cooling techniques have allowed modem engines to be designed that have operating turbine inlet temperatures of

1371^0 C and higher, with a resulting 100 percent increase in specific weight (thrust-to-weight ratio) and with a lower specific fuel consumption in comparison with previous engines.

2.10 Composite Materials

- Relatively new types of materials called composites are coming to the foreground for use in both airframes and engines.
- In these products, graphite, glass or boron filaments are embedded in an epoxy-resin matrix or base substance.
- Other types of filaments and matrices such as reinforcing materials of continuous silicon carbide, boron carbide, and graphite embedded in a ductile matrix of aluminum or titanium alloys are called metal matrix composites (MMC) and are being tried to meet the demands of higher temperature ardor stress.
- The chief advantage of the composite material is its favorable strength-to-weight ratio, which can lead to the lightening of many structural parts. For example, a lighter fan blade will allow a lighter fan disk, which will in turn permit a lightening of other parts all the way down the line.
- Composite materials may be used in conjunction with other load-bearing materials to provide a support function.
- Typical of this type of structure are fan blades made with a steel spar and base and with an airfoil composite shell.
- In an attempt to reduce deformation and failure of large fan blades, the General Electric Company is experimenting with blades made of graphite epoxy material with a nickel leading edge.
- These fan blades may prove to be much more durable than those made from titanium, and they also suffer little deformation after impact.
- Closely associated with the future use of composite materials is the development of new manufacturing techniques to pro- duce these materials.

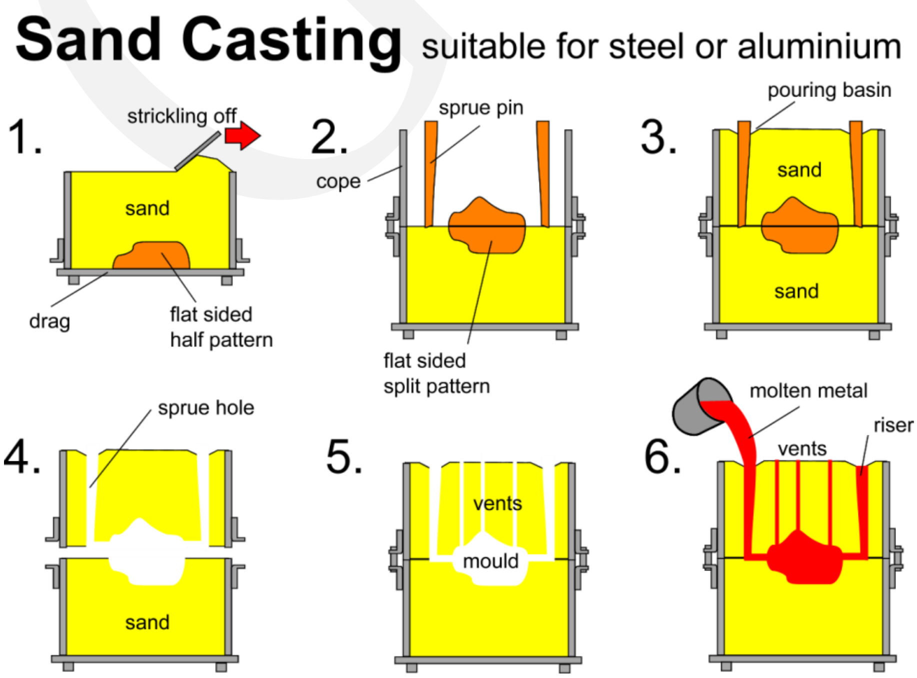
2.11 Manufacturing Techniques

- The variety of manufacturing techniques is large and depends on a number of factors, such as the material from which the part is made, the duties the part must perform, and the cost of the process.

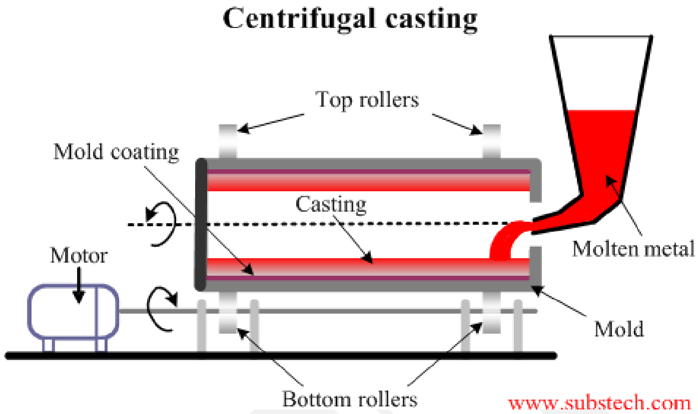
- As a result, basic parts of the engine are produced by several casting and forging processes, literally dozens of machine operations, and fabrication procedures using a variety of metal-joining methods.

2.11.1 Casting

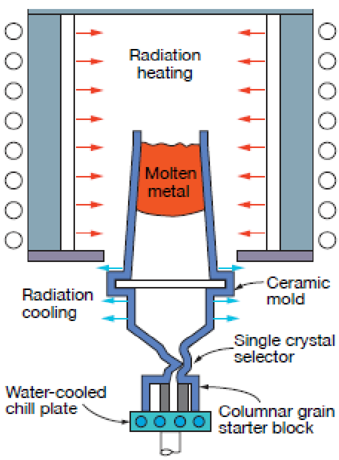
- Several engine parts are cast in aluminum, magnesium, steel, or exotic alloys.
- These parts include intake and compressor housings, accessory cases, and blading, to name a few.
- Casting methods differ and include the following:
  - Sand casting
  - Spin casting
  - Single-crystal casting
  - Lost-wax or investment casting
  - Resin-shell mold casting
  - Slip casting
  - Mercasting
- Sand casting uses a wood or metal pattern around which a clay-free sand has been packed to form the mold. The mold is then split, the pattern removed, the mold reassembled, and any cores that are necessary added. Molten metal at a precise temperature is poured into the mold and allowed to cool. The mold is removed and various heat treatments may be performed to obtain the desired physical characteristics.



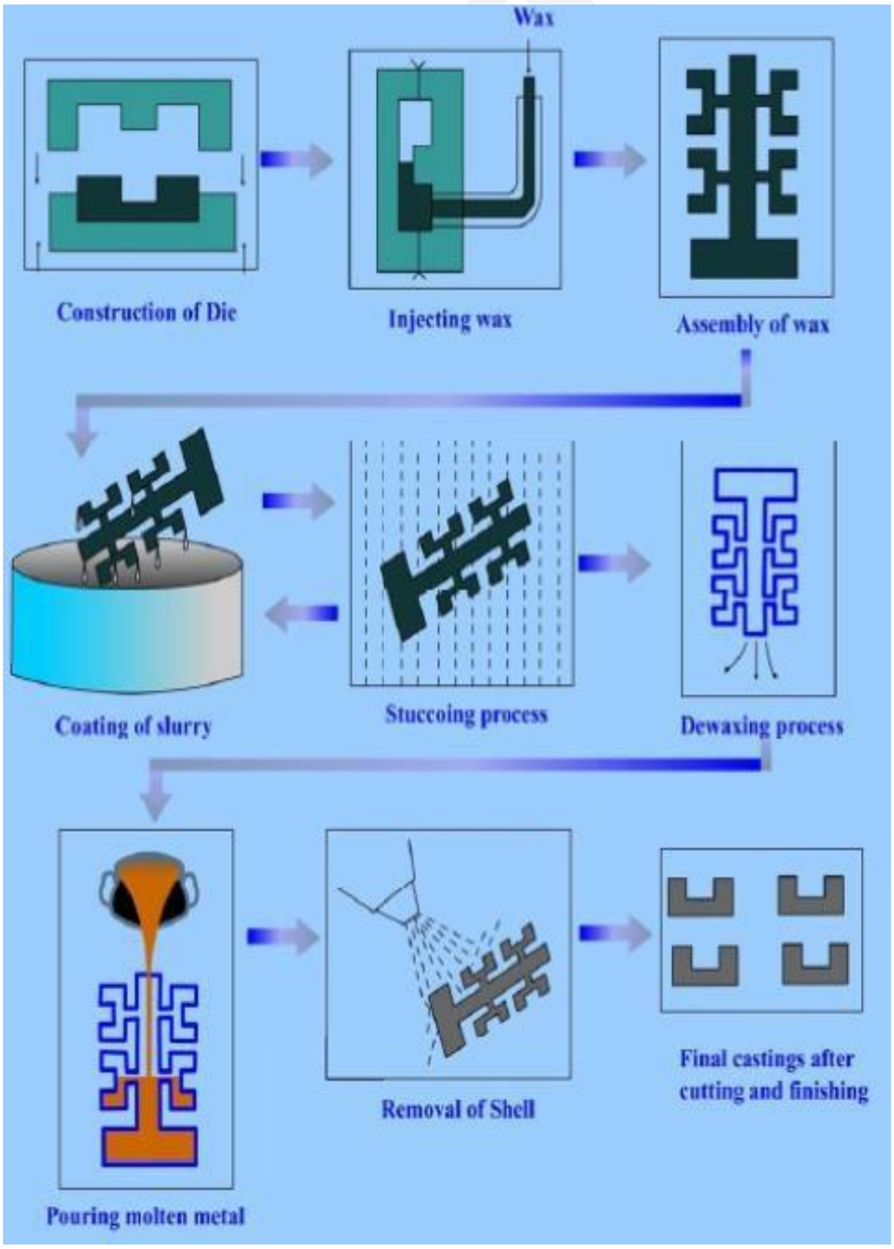
- The casting may be spun while being poured. Spin casting (centrifugal casting) results in a denser, more sound casting. Spinning is normally performed on small ring sections. Cooling of the metal radially inward results in fewer stresses. Other casting techniques result in greater tensile strength by causing the normally random grain structure of the casting to become oriented in me direction like the grain of wood.



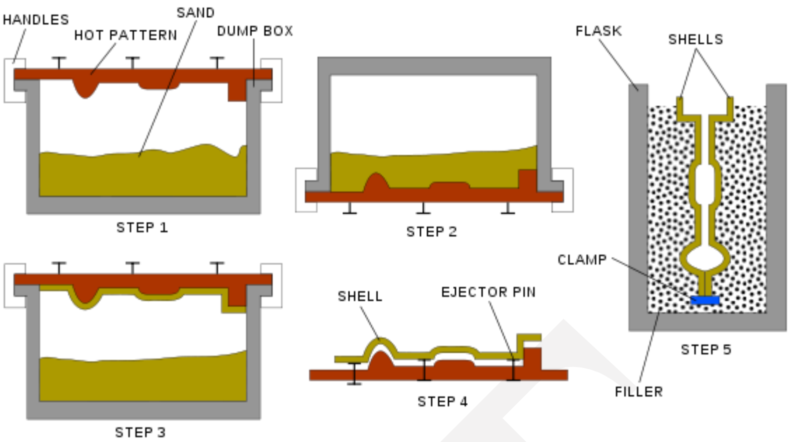
- An even newer method of turbine blade casting, which not only causes higher strength but allows higher turbine inlet temperatures and increased thermal fatigue and corrosion resistance, is called single-crystal casting. In both directional solidification and single-crystal casting, the metal is poured into a heated ceramic mold that is water cooled on the bottom. The part of the molten metal touching the water- cooled end begins to solidify first and forms the type of grain Structure. However, the directional solidification is not allowed to proceed the entire length of the mold in the production of a Single-crystal air- foil. The helical grain selector or pigtail, which is designed into the mold next to the cooled end, permits only one grain to successfully pass through to the top. That grain then propagates through the rest of the metal, integrating it into a single crystal, thus eliminating the weakening effect of the boundaries between the metal grains.



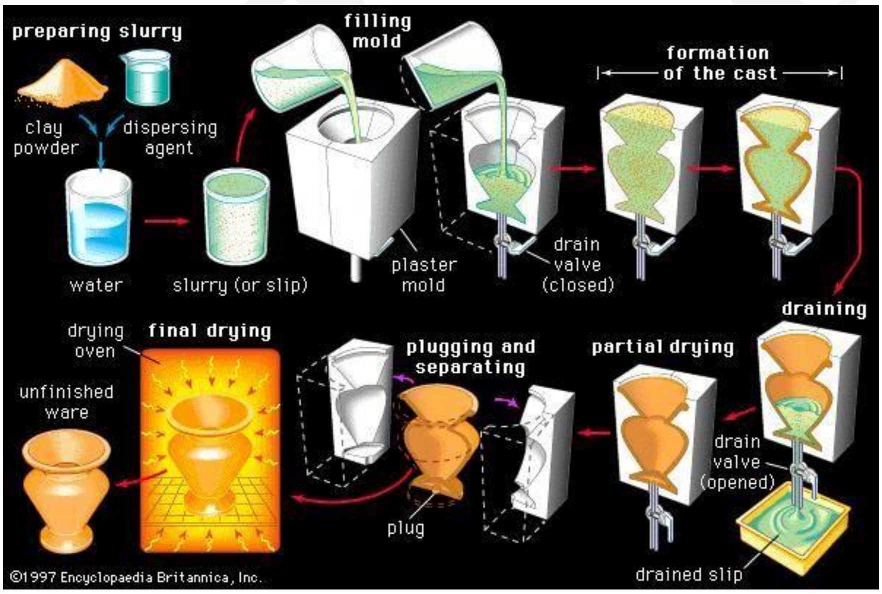
- The investment casting process involves the use of heat-disposable wax or plastic patterns surrounded with a refractory material to form a monolithic mold. Patterns are removed from the mold in ovens, and molten metal is poured into the hot mold. Sometimes this pouring is done in a vacuum furnace. After cooling, the mold material is quite fragile and easily removed from the castings. Because the finished product duplicates the pattern exactly, the production of patterns is a critical factor. They are made by injecting molten wax or plastic into metal dies. The finished castings have an exceptionally smooth surface finish and require very little further machining. Incidentally, this process is not new. It was used by the ancient Greeks and Egyptians to cast lightweight statues, intricate bowls, and pitchers, and is used today to make complex jewelry.



- Resin-shell mold casting is a high production method similar to investment casting except that the tolerances are not held as closely. In many ways it rivals sand casting in economy.



- Slip casting borrowed from the ceramics industry, is used to form super-heat-resistant materials. Often it is the only way certain materials can be shaped. Metal ceramics, silicon nitride, and refractory metals cast this way can be used in temperatures over 1200^0 C.



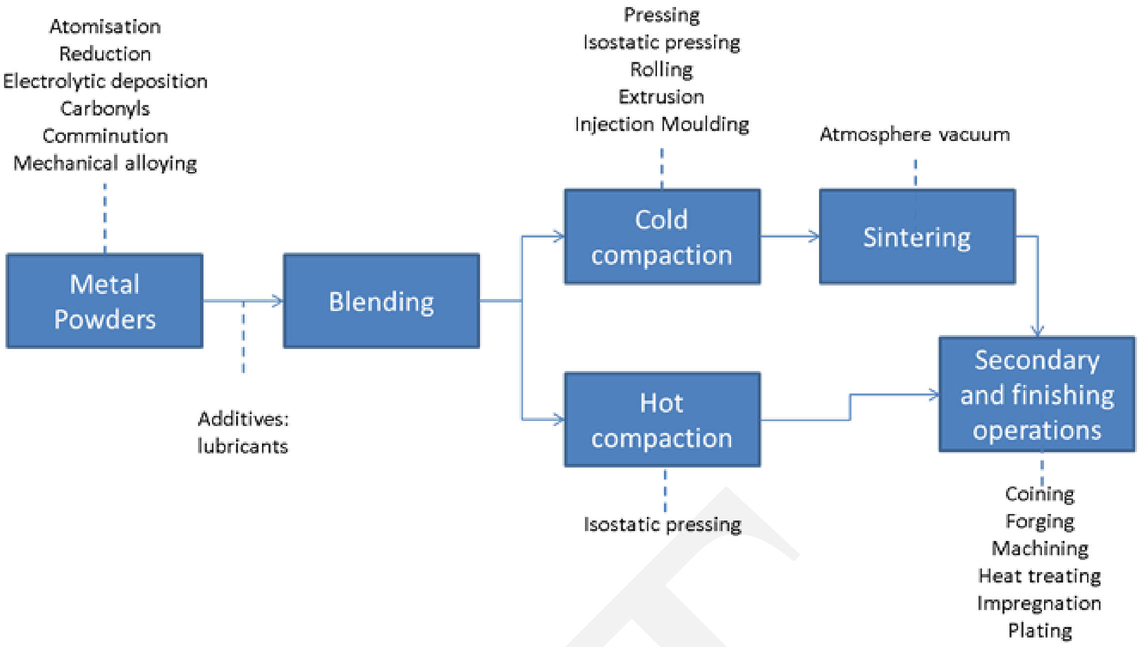
- The Mercast process is a precision-casting technique. It is essentially the same kind of method as the lost-wax precision-investment process, except that frozen mercury is used as a pattern instead of wax. Liquid mercury is poured into a master mold, where it is frozen at temperatures below - 40^0 C. Then it is removed and coated with a cold refractory slurry to a thickness of 1/8 in [3.175 mm] or more. The refractory shell is dried at low temperature; then the shell and mercury are brought room temperature, and the mercury is melted out. The refractory shell is fired to give it strength and then is used as the mold for a usual casting process. Complicated parts can be made by use of the Mercast process, and very close tolerances and excellent surface finish can be obtained. The cost, however, is higher than that of some other methods.

2.11.2 Forging

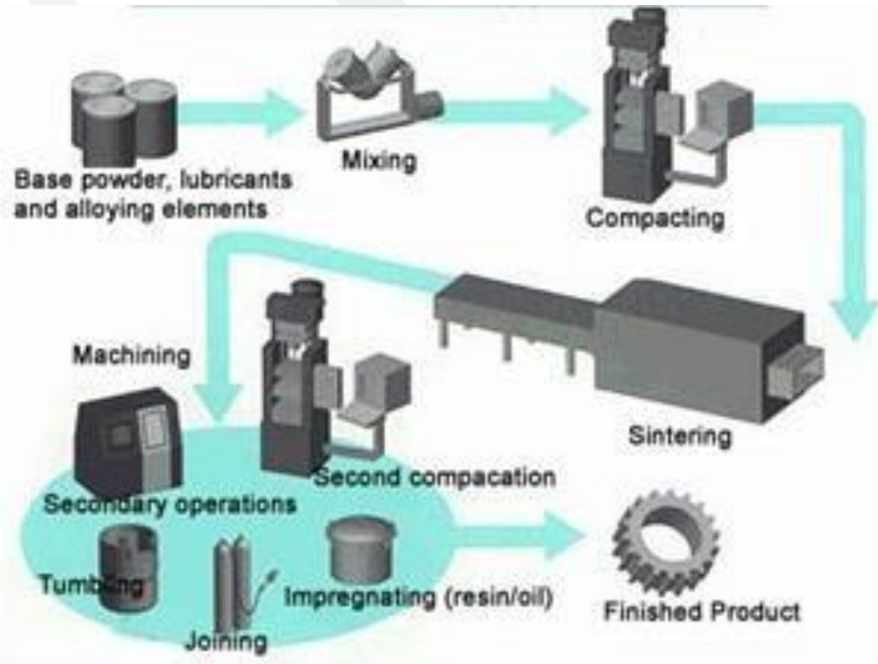
- Disks, drive shafts, rings, gears, vanes, blades, and numerous other parts of the gas turbine engine are manufactured by forging.
- This process allows the development of a grain structure and results a fine-grain, more ductile, strong, dense product.
- Forging can be accomplished by rapid hammering or slow pressing. The choice of technique depends mainly on the resistance of metal to rapid deformation.
- The workpiece is generally heated to improve plasticity and reduce forging forces and will often pass through several different dies before the final shape is obtained.
- All ductile materials can be forged, but their forgeability varies considerably. At the forging temperature, forgeability generally depends on the melting point, ductility, yield strength, crystallographic structure, and recovery from forging stresses, surface reactivity, die friction, and cost.
- Some parts are rolled or swaged, which essentially simulates the forging process. By using this method, a well-defined grain structure is established, which increases tensile strength considerably.
- Prior to forging some turbine blades, the end of the forging blank (usually a rod) is upset by heating, or the shank is swaged to develop natural "flow lines" in the root and shank section of the blade.

2.11.3 Powdered Metallurgy

- The increasing demands for higher temperature materials and the rising costs of alloying elements such as cobalt have led to the development of new kinds of forging or pressing techniques using a powder metallurgy process.
- Several variations of the basic method can be used and generally involve forming a metal powder under heat and pressure, a process called hot isostatic pressing (HIP), followed by sintering or further forging using very hot dies.
- When heated dies are used, the thermal gradient between the workpiece and the die is reduced, eliminating the thick envelope that would normally have to be machined away.



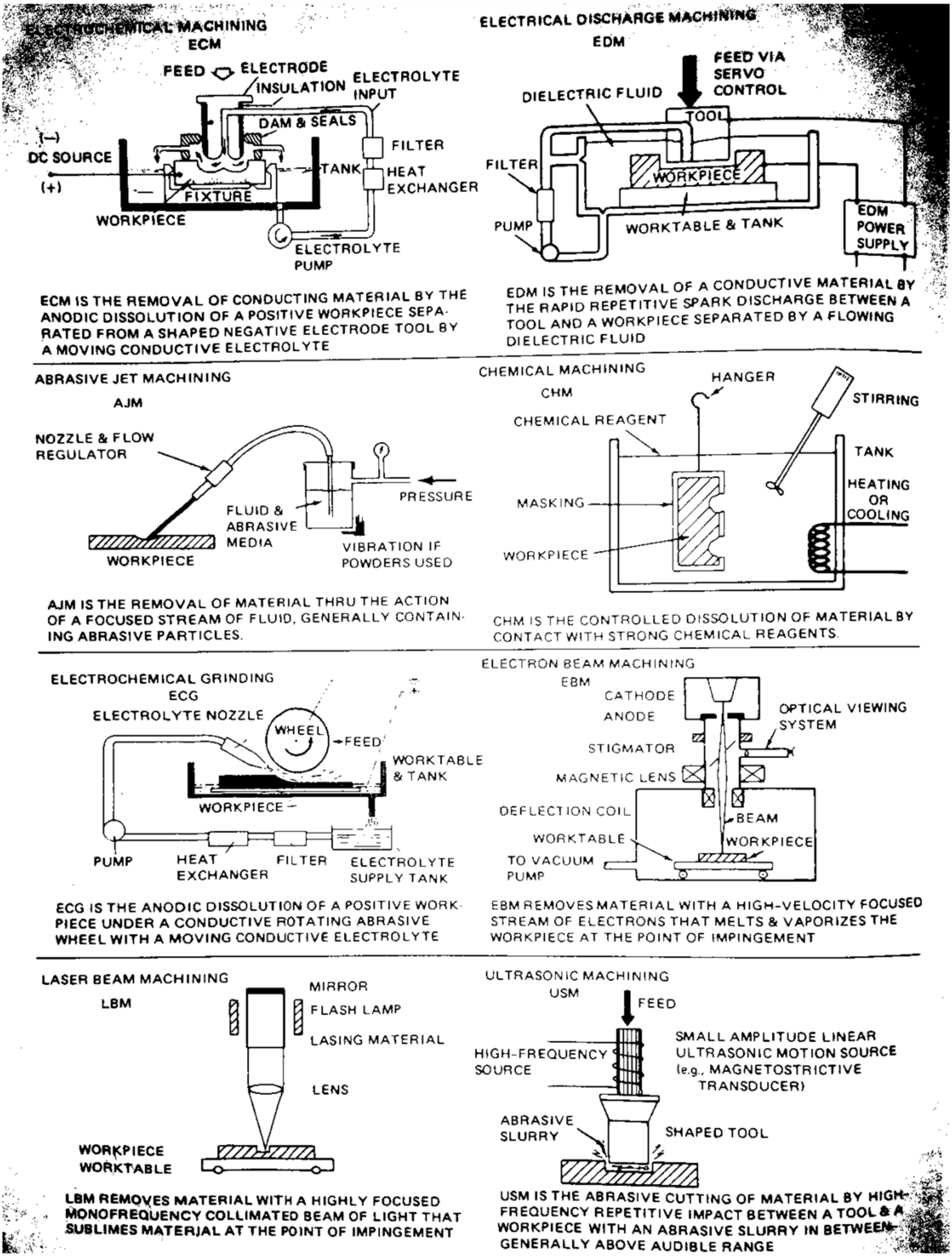
- The entire technique results in a part much closer to the final shape and large savings in costs and materials.
- The use of HIPing is being further investigated as a method of repairing and rejuvenating engine turbine blades.
- The microstructure of the used turbine components is restored by the simultaneous applications of heat and pressure (approximately 1205^0 C and 28,000 psi, respectively) followed by rapid cooling.
- This process also restores mechanical properties, eliminates creep rupture and metal fatigue, and heals voids and porosity in castings and forgings.



2.11.4 Machining

- In addition to the hammers, presses, and other tools mentioned above, the inventory of machinery for manufacturing gas turbine parts includes all of the common varieties, such as lathes, mills, broaches, grinders, shapers and planers, polishers and buffers, drills, saws, shears, filers, threaders, contour machines of all kinds, and a host of other devices to cut and form metal.
- Many of these devices use a numerical tape control or other automatic Control devices to reduce human error and produce a more uniform, less expensive product.
- Some nontraditional machining techniques for removing metal from super hard and super tough alloys and from other materials whose complex shapes preclude machining with conventional metal-cutting tools include
    - chemical milling,
    - electrochemical machining (ECM),
    - electric discharge machining (EOM),
    - electron-beam machining, and
    - laser- beam machining.
- Other nonconventional machining includes everything from using a high-pressure jet of water that may contain an abrasive to ultrasonic machining.
- Chemical milling involves the removal of metal by dissolving it in a suitable chemical. Those areas that are not to be dissolved away are masked with nonreactive materials. The process can be used on most metals, including aluminum, magnesium, titanium, steels, and superalloys for surface sculpturing. Both sides of the workpiece can be chemically milled simultaneously, In addition, the process can be used to machine very thin sheets.
- ECM is basically a chemical deplating process in which metal, removed from a positively charged workpiece using high-amperage—low-voltage dc, is flushed away by a highly pressurized electrolyte before it can plate out on the cathode tool. The cathode tool is made to produce the desired shape in the workpiece, and both must be electrically conductive. The work proceeds while the cathode and workpiece are both submerged in an electrolyte such as sodium chloride.
- A variation and extension of electrochemical machining is electrostream drilling. In this process a negatively charged electrolyte, usually an acid, drills holes in a

workpiece that has been positively charged, Holes as small as 0.005 in [0.127 mm] in diameter and 0.5 in [12.7 mm] deep in super alloys can be drilled in this manner.



- In EDM, high voltages are used to produce a high electrical potential between two conductive surfaces, the work piece and electrode tool, both of which are immersed in dielectric fluid. Material is removed from both the electrode and the workpiece by a series of very short electric discharges or sparks between the two and is swept away by the dielectric fluid. More material is removed from the workpiece than from the tool by proper selection of the two materials. This process can be used to shape complex parts to close tolerances from refractory metals and alloys that were formerly impossible to machine. The use of electric dis- charge machining is limited in that it is slower than electro- chemical machining, tool replacement can become expensive, and the surface of the workpiece is damaged as a result of the sparks. On the other hand, the EDM process is less expensive than the ECM process.

- Electron-beam and laser-beam machining are being used experimentally and may find future use in the production of gas turbines and other aerospace components.

2.11.5 Fabrication

- Welding is used extensively to fabricate and repair many engine parts.
- Fabricated sheet steel is used for combustion chambers, exhaust ducts, compressor casings, thrust reversers, sound suppressors, etc.
- Common methods include resistance and inert-gas (usually argon) welding. Uncommon methods utilize plasmas and lasers (Light Amplification by Stimulated Emission of Radiation).
- Electric-resistance welding is used to make spot, stitch (overlapping spots), and continuous-seam welds.
- Inert-gas welding employs a nonconsumable electrode (tungsten-thorium alloy) surrounded by some inert gas such as argon or helium. The gas prevents an adverse reaction with the oxygen present in the normal atmosphere.
- The inert gas can be applied in the immediate area of the arc or, in the case of production runs, the work- piece and/or the entire welding machine can be enclosed in a thin plastic balloon, sometimes as large as a room, entire plastic bubble is filled with and supported by the inert gas.
- After welding, many parts must stress-relieved, where temperature or working loads are not large, brazing or silver soldering may be used to join such parts as fittings and tube assemblies.
- Electron-beam welding is showing great promise as a method of fabricating parts from heretofore difficult-to-weld or unweldable materials. Electron-beam welding uses a stream of focused electrons traveling at speeds approaching 60 percent the speed of light, Even though the mass of electrons that form the beam is small, they are traveling-at such speeds that they contain a great amount of kinetic energy.

When the beam strikes the work- piece, the kinetic energy is transformed into heat energy. The welding usually takes place in a vacuum, although non- vacuum techniques can be used. Deep, narrow welds with a very narrow heat-affected zone in the base metal, the ability to weld materials as thin as 0.00025 in (0.00635 mm) and as thick as 4 in (101.6 mm) of stainless steel, and the ability to weld many different types of materials make this welding process a valuable one in the gas turbine manufacturing area.

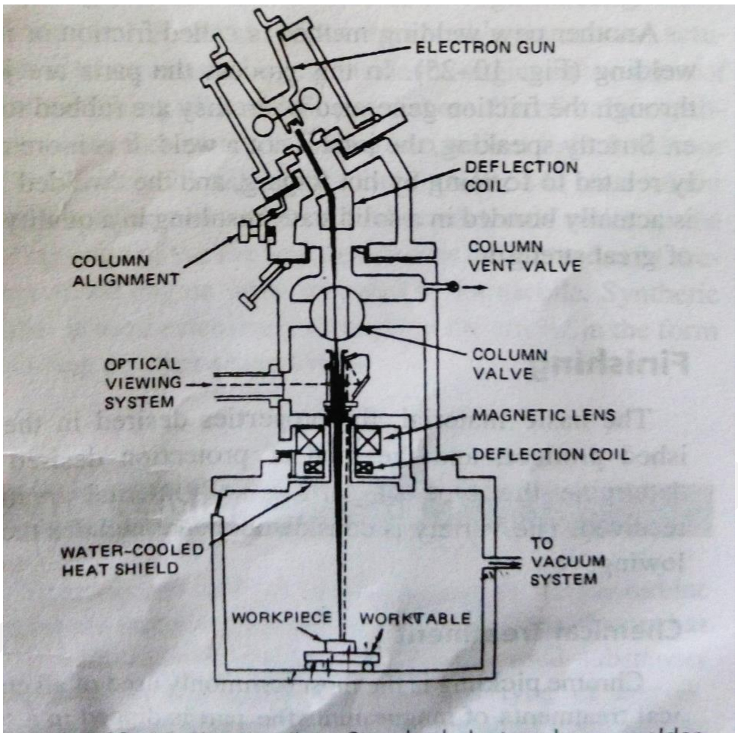


FIGURE 10–24 The Hamilton Standard electron-beam welder

- Another new welding method is called friction or inertia welding. In this process the parts are joined through the friction generated when they are rubbed together Strictly speaking, the joint is not a weld. It is more closely related to forming by hot forging, and the "welded" joint is actually bonded in a solid state, resulting in a quality joint of great strength.

2.11.6 Finishing (Surface finishing)

The basic material, the properties desired in the finished product, and the kind of protection desired will determine the type of surface and internal treatment received. The variety is considerable and includes the following:

- **Chemical Treatment**
    - Chrome pickling is the most commonly used of all chemical treatments of magnesium.

- The part is dipped in a solution of sodium dichromate, nitric acid and water.

- **Electrochemical Treatment**
  - Anodizing is a common surface treatment for aluminum alloys whereby the surface aluminum is oxidized to an adherent film of aluminum oxide.
- **Painting**
  - A thin, preservative, resin-varnish coating is used to protect internal steel, aluminum, and magnesium parts.
  - The characteristic color of this shiny, transparent coating is usually green or blue-green.
  - A graphite powder may be mixed with the varnish to act as an antigalling agent.
  - Gray, black, or aluminum enamel (or epoxy paint) is also used extensively as a protective finish.
- **Shot Peening**
  - This procedure can increase the life of a part many times.
  - It is essentially a plastic flow or stretching of a metal's surface by a rain of round metallic shot thrown at high velocity by either mechanical or pneumatic means.
  - The 0.005 to 0.035 in [0.127 to 0.889 mm] stretched layer is placed in a state of compression with the stress concentration uniformly distributed over the entire surface.
  - Glass beads are sometimes used as the shot for cleaning purposes.
- **Plating**
  - A great number of plating materials and procedures are used.
  - Plating materials involving the use of chemical or electrochemical solutions include cadmium, chromium, silver, nickel, tin, and others.
  - The exact procedure is determined by the plating and base metal, Aluminizing is another plating method whereby pure molten aluminum is sprayed onto the aluminum alloy base material to form a protective coating against oxidation and corrosion.
  - The Coating Service Of Union Carbide Corporation has developed and is producing machines for applying extremely wear-resistant and other specialized coatings to gas tur- bine parts, tools, and other machines.

- The different coatings are applied by either of two methods—the detonation gun (D-gun) or the plasma gun.
- In the D-gun, measured quantities of oxygen, acetylene, and Suspended particles of the coating material are fed into the chamber of the gun. Four times a second a spark ignites the mixture and creates a detonation that hurls the coating particles, heated to a plastic State by the 3316^0 C temperature in the gun, out of the barrel at a speed of 2500 ft/s [762 m/s]. The part to be plated is kept below 149^0 C by auxiliary cooling streams. The high-level sound of 150 dB necessitates housing the gun in a double-walled, sound-insulated construction. Operation is controlled from outside this enclosure.

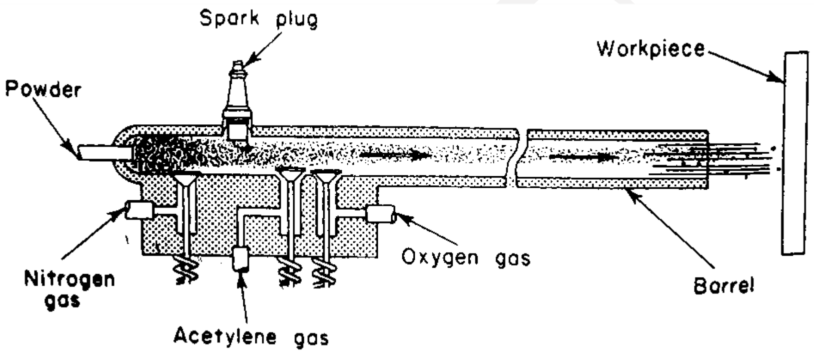


FIGURE 10–27 The Union Carbide detonation gun.

- The plasma gun or torch produces and controls a high-velocity, inert-gas stream that can be maintained at temperatures above 11000^0 C. Unlike the D-gun process, no combustion takes place. The high-temperature plasma is formed by ionizing argon gas in the extreme heat of an electric arc. Gas molecule absorb heat energy from the arc, split into atoms, and the further decompose into electrically charged particle, without decomposition, any known material. When the molten particles, which are introduced in powdered form, strike the part being coated, a permanent welded bond is formed. While the D-gun is a patented Union Carbide machine, other manufacturers make and distribute a variety of plasma plating and cutting devices.

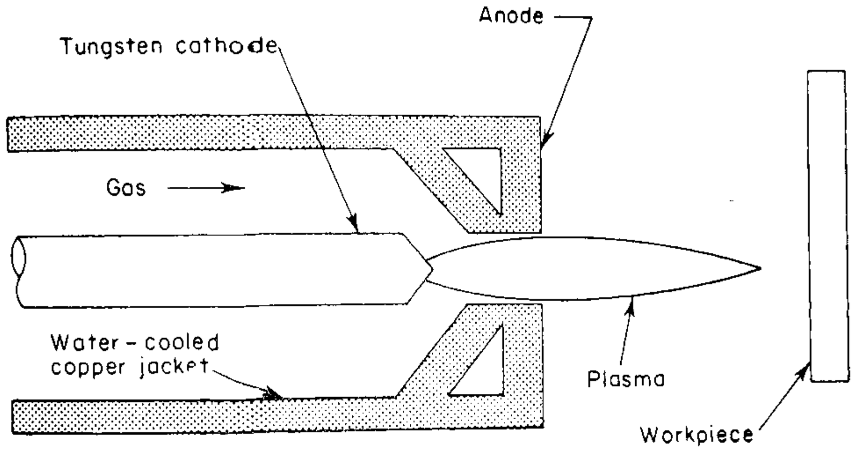


FIGURE 10–28 A schematic of the plasma torch.

- **Heat Treatments**
  - All the following procedures alter the mechanical properties of steel to suit the end use;
  - **Normalizing** - The steel is heated to a temperature above the critical range and allowed to cool slowly. Normalizing promotes uniformity Of Structure and alters mechanical properties.
  - **Annealing**—Consists of heating to a point at or near the critical range, then cooling at a predetermined rate. It is used to develop softness, improve machinability, reduce Stress, improve or restore ductility, and modify other properties.
  - **Stress relieving**—The metal is heated throughout to a point below the critical range and slowly cooled. 'The object of this treatment is to restore elastic properties or reduce stresses that may have teen induced by machining, cold working, or welding.
  - **Hardening**—involves heating the metal to a temperature above the critical range and then quenching. The cooling rate will determine hardness.
  - **Tempering**—The steel is usually too brittle for use after quenching. Tempering restores some of the ductility and toughness of steel at the sacrifice of hardness or strength. The process is accomplished by heating the hardened steel to a specific point below the critical temperature.

2.12 Fuel system's Sensors and Controls

Depending on the type of engine and the performance expected of it, fuel and engine controls range in complexity from simple valves to automatic computing devices containing hundreds of intricate and highly machined parts.

Types of controls:

Modern fuel engine controls can be divided into three basic groups -

- Hydromechanical fuel control
- Hybrid fuel control
- Electronic fuel control

The above systems **senses** the following engine variables based on pilot's demands.

- Compressor-inlet temperature
- Compressor-discharge pressure
- Burner pressure
- RPM
- Turbine temperature

The electronic controls, especially the full authority digital electronic control (FADEC), which may be part of sophisticated engine electronic control (EEC) system, will sense many more operating parameters.

Electronic systems may also use fiber optics instead of wire to provide immunity from electromagnetic (EM) effect.

Fiber optic systems are safer (no fire hazard), have fever components, and require less maintenance.

Many controls in use today are of the hydromechanical type, although there is a definite trend toward the electronic control of the engine, especially in the larger transport and military aircrafts.

Hydromechanical fuel controls are complex devices composed of speed governors, servo systems and feedback loops, valves, metering systems, and various sensing mechanisms.

The electronic fuel controls contain Thermocouples, amplifiers, relays, electrical servo systems, switches, solid state devices, solenoids, and variety of sensors.

2.13 Hydromechanical fuel controls

Hydromechanical Fuel Control Components:

- Metering valve – To regulate fuel flow to engine (valve orifice/pressure drop)
- Fuel pump – To pressurize the fuel
- Shutoff valve - To stop fuel flow
- Relief valve - To protect the control when the shutoff valve is closed.
- Acceleration limiter – fuel flow increased but only to the limit temperature.

The amount of fuel required to run the engine at rated RPM varies with the inlet air condition. For example, it requires less fuel to run the engine on a hot day than on a cold day. So for the fine refinement, a speed governor, is added to simple fuel control.

Modern fuel controls will incorporate the following things:

- Servo system to boost weak input signals and thus make the control more sensitive.
- Devices to prevent undershooting and overshooting by returning the metering valve to its desired position before the governor alone can do this job.
- Auxiliary functions, such as inlet guide vanes positioning and nozzle, afterburner and thrust reverser signals.

2.14 Engine Electronic Control (EEC)/Full authority Digital Electronic Control (FADEC)

FADEC is primarily an interface between the engine and aircraft. It affects the engine in the following manner.

- Efficiency of engine is improved by controlling the following: Variable stator vanes, Nacelle cooling and engine oil cooling.
- Basic engine control functions are enhanced, such as the following: Starting, idle, Acceleration, Deceleration, Stability and thrust control.
- Engine is protected by limiting: critical speeds and pressures, thrust and Over boost.
- Operational reliability of engine is improved by using: A two channel control and an automatic fault diagnostic system.

- Engine maintenance made easier by incorporation for systems for: engine monitoring, Self-testing and fault isolation.
- Interface between the flight deck and engine is improved through: automatic engine pressure ratio control, limit protection.

FADEC Interface with Engine:

Inputs to the FADEC from engine are as follows:

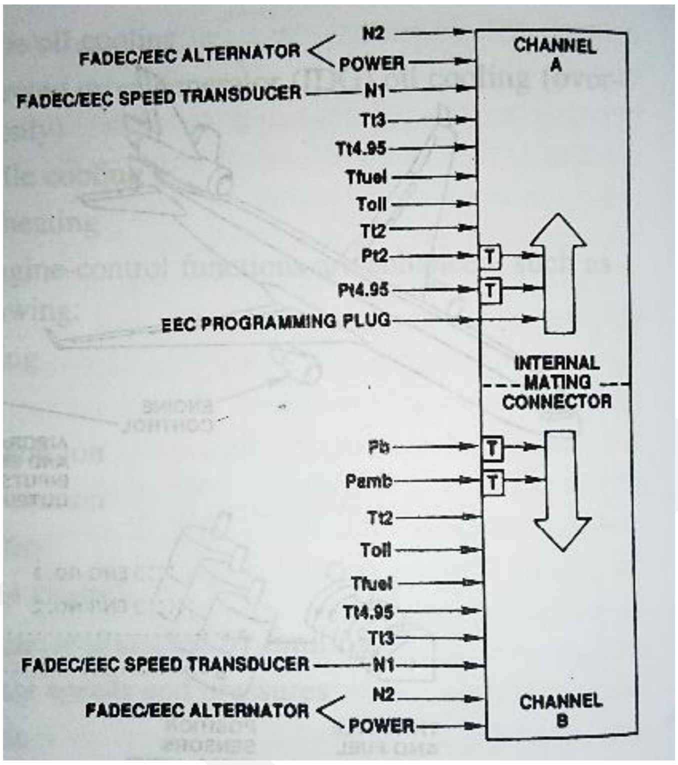
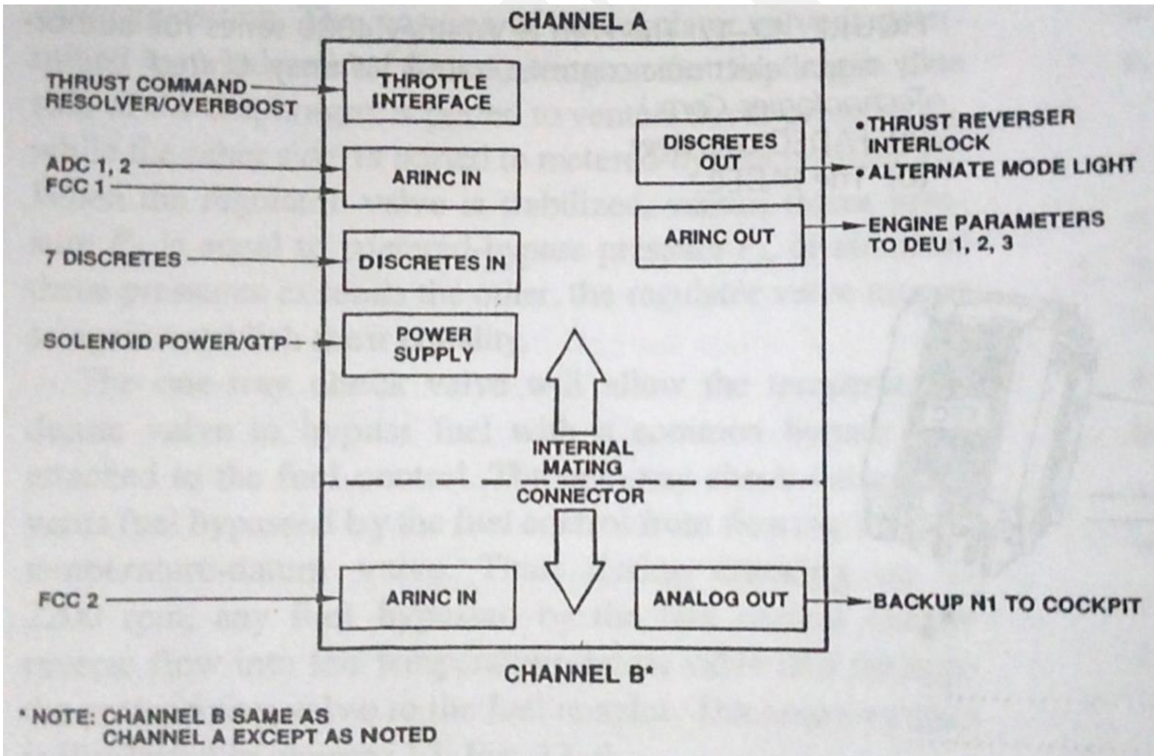


Fig: FADEC Interface with Engine

- N2 rpm and Power, comes from the FADEC alternator and is used for limiting, scheduling system and setting engine speeds.
- N1 rpm, which comes from FADEC transducer (Transform pneumatic signals to electrical signals) and is used for limiting and scheduling the system.
- Compressor exit temperature (Tt3), comes from the diffuser case, used to calculate starting fuel flow.
- Exhaust gas temperature (Tt4.95), comes from the exhaust case, used for indication
- Fuel temperature (Tfuel), comes from the fuel pump, used to schedule the fuel heat management system.
- Oil temperature (Toil), comes from the main gearbox, used to schedule the fuel heat management system and oil cooling system.

- Inlet total temperature (Tt2), comes from the inlet cowl, used to calculate fuel flow and rotor speed.
- Inlet total pressure (Pt2), comes from the inlet cowl, used to calculate EPR (engine pressure ratio).
- Exhaust gas pressure (P4.95), comes from exhaust case, and is also used to calculate EPR.
- The EEC programming plug is used to determine the engine thrust rating and EPR correction.
- Burner pressure (Pb), comes from diffuser case, used for surge detection.
- Ambient pressure (Pamb), comes from the inlet cowl, used to validate altitude and inlet total pressure.

FADEC Interface with aircraft:



Inputs to the FADEC come from the following:

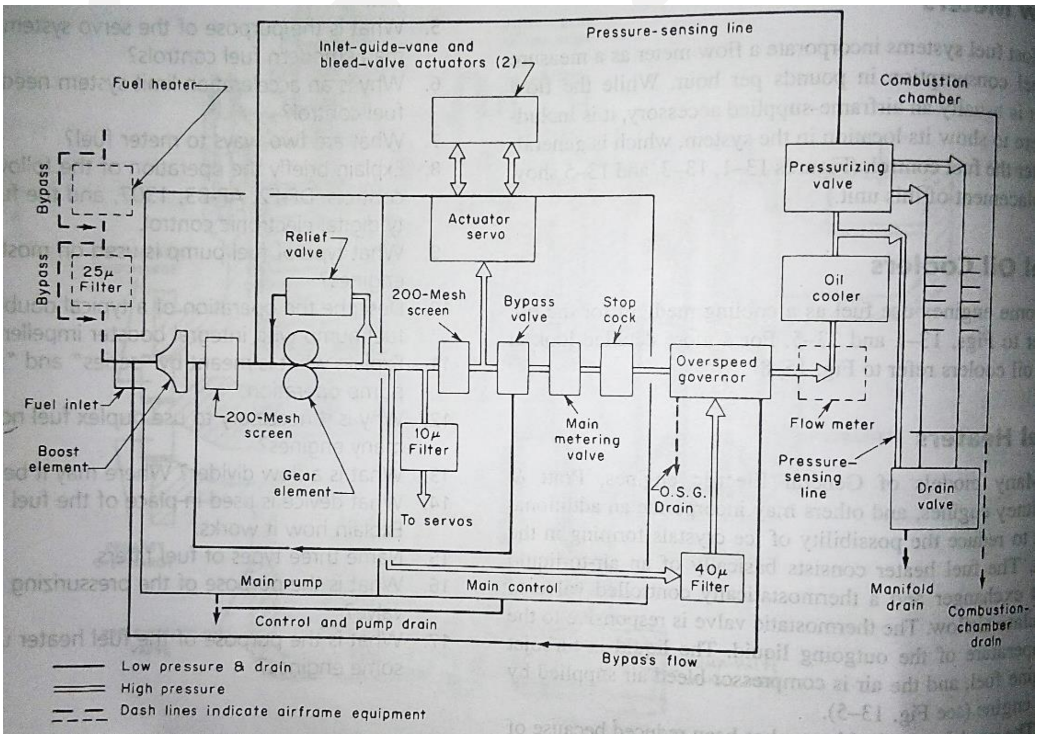
- The power levers. Two analog signals come from each power-lever resolver. (The resolver is an electromechanical device to measure angular movement.)
- The air-data computers (ADC) in the form of: Total pressure, Pressure altitude and Total air temperature.

- The flight control computer for adjusting the engine pressure ratio (EPR) for all three engines as a part of the engine thrust trim system (ETTS). The ETTS logic starts when the engine pressure ratio (EPR) on any two engines is above 1.2. There are two modes of ETTS operation: In the **master mode,** a high EPR and the low EPR engines are adjusted to the middle EPR engine. In the **target mode**, a target EPR from the flight management system (FMS) is used to set all three engines.
- Seven discrete (electrical signals) inputs: Pt2/Tt2 probe heat, Fire, Alternate mode, External reset (fuel control switch), Bump rate selector, Maintenance (data retrieval), Engine location identification.
- Two sources of 28 VDC power (DC bus and ground test power)

Outputs from the FADEC are as follows:

- Engine pressure ratio (EPR)
- Low speed spool (N1). There is a backup N1 speed output from channel B.
- Exhaust gas temperature (EGT)
- High speed spool (N2)
- Flap/slat position and weight on wheels status is also sent to the FADEC. The flight control computer (FCC) acts as a backup for the air-data computer (ADC).

2.15 Typical Fuel System



General Electric CJ610 fuel system schematic.

The CJ610 consists of the following engine mounted components:

- Fuel pump
- Fuel control
- Overspeed governor
- Fuel oil cooler
- Fuel pressurizing valve
- Fuel manifolds
- Fuel manifold drain valve
- Fuel nozzles (with integral flow divider)
- Actuator assembly
- Bleed valves
- Fuel flowmeter (airframe furnished equipment

Fuel pump:

The fuel pump comprises a single element, positive displacement pump, centrifugal boost pump, filter, and bypass circuit with a pressure-relief valve. The pump supplies fuel to the fuel control and is mounted on and driven by the accessory gearbox.

Fuel Control:

The fuel control is mounted on and driven by the fuel pump. The control incorporates a hydromechanical computers section and fuel-regulating section to operate the control servos. Parameters of engine speed, power-lever setting, compressor inlet temperature, and compressor discharge pressure are used in the computer section to schedule the operation of the fuel-metering valve and the VG servo valve. The fuel-regulating section meters fuel to the engine under all operating conditions.

Overspeed Governor:

The isochronous overspeed governor is mounted on and driven by the accessory gearbox. Fuel is supplied to the governor bypass section from the fuel control and to the governing section from the fuel pump. Overspeed governing is controlled by bypassing the fuel, when it is in excess of engine maximum limiting speed requirements, to the fuel pump inlet port.

Fuel Oil Cooler:

The oil cooler is used to reduce the temperature of the oil by transmitting heat from the oil to another fluid.

Fuel Pressurizing Valve:

Pressurizing valve is mounted on the fuel-oil cooler and connects to the fuel manifolds, manifold drain valve, and fuel pump interstage reference pressure line. During starting, boost pressure and spring force close the pressurizing valve to prevent low-pressure fuel flow to the fuel nozzles and to allow the fuel control to build up sufficient pressure to operate the servos and VG actuators. The control pressure then opens the pressurizing valve and closes the manifold drain valve. Fuel is then distributed to the fuel nozzles at sufficient pressure for satisfactory atomization.

Fuel Manifolds:

Two fuel manifold tubes are located around the mainframe casing. Each manifold tube connects to six fuel nozzles. Fuel is supplied from the pressurizing valve, through the manifold tubes, to the fuel nozzles.

Fuel Manifold Drain Valve:

The fuel manifold drain valve drains the fuel manifolds at engine shutdown to prevent residual fuel from dribbling out the fuel nozzles, thus creating a fire hazard. It also prevents the formation of gum and carbon deposits in the manifold and nozzles The valve consists of a piston, which is spring-loaded, to open the manifold drain passage at shutdown and a fuel filter with a bypass valve that opens if thee filter becomes clogged. During engine operation, the pressurizing valve actuates to close the manifold drain passageof the valve and admit fuel to the fuel manifolds.

Fuel Nozzles:

Twelve fuel nozzles, mounted on the main frame, spray atomized fuel into the combustion chamber. The fuel nozzle incorporates a flow divider a primary and secondary flow passage; and an air-shrouded, spin-chamber-type orifice. During starting, low-pressure fuel in the primary passage sprays a mixture adequate for ignition, As the engine accelerates, increased fuel pressure opens the flow divider and additional fuel flows into the secondary passage to the spin chamber where it merges with the primary passage fuel flow. The air shroud sweeps air across the nozzle orifice to prevent carbon formation.

Actuator Assembly (VG):

Two variable-geometry actuators, mounted on the compressor casing, position the inlet guide vanes and interstage bleed valves. They are linear travel, piston-type actuators hydraulically actuated high-pressure fuel from a servo valve in the fuel control. The actuator piston rods are connected to bell cranks that position the inlet guide vanes and interstage bleed valves. A feedback cable is connected from the bellcrank assembly to the fuel control and supplies the fuel-control servo valve with a position signal.

Bleed valves:

Two bleed valves are mounted on each side of the compressor stator casing. During transient engine speeds, the valves bleed air from the third, fourth, and fifth stages of the compressor according to a bleed schedule, which is a function of compressor speed and inlet air temperature, prescribed by the fuel control. The valves are actuated by the fuel control and two VG actuators through a bellcrank-linkage arrangement. A Fuel synchronizing cable synchronizes the bleed-valve positions and, in case of malfunction in either VG actuator, transmits the motion of the functioning VG actuator to the other.

2.16 Typical Oil System and its Components

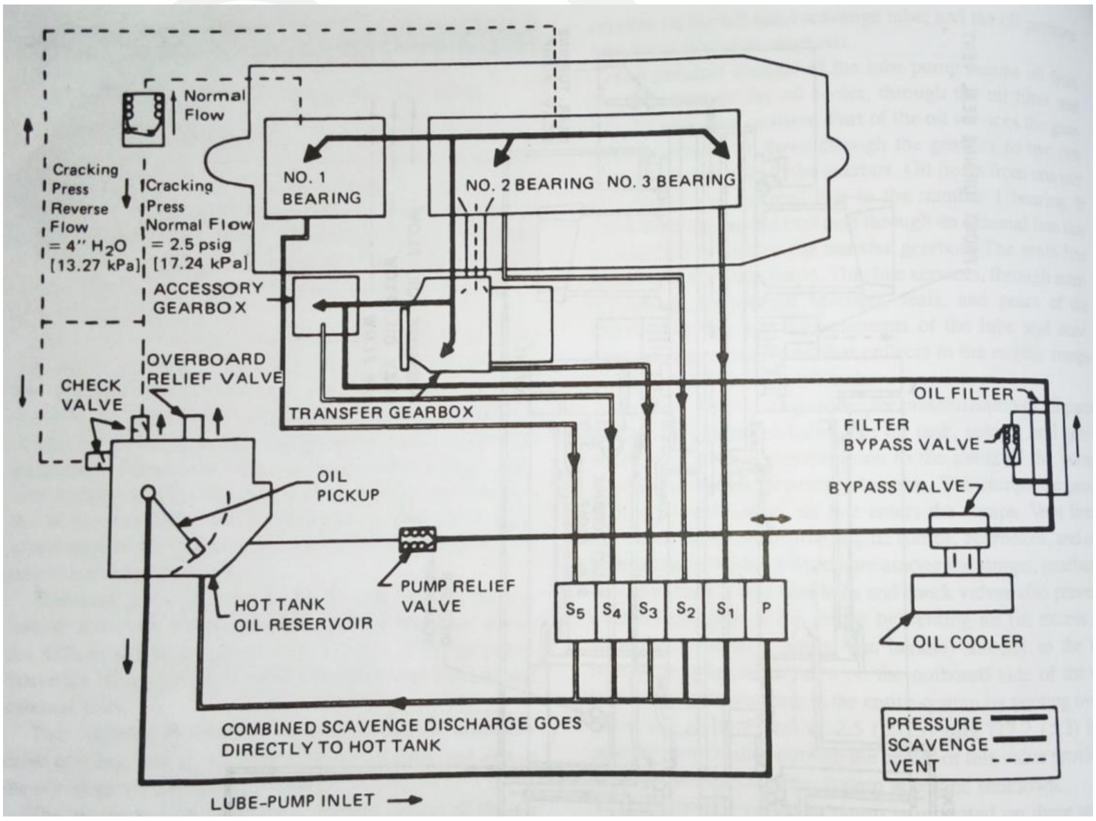


Fig: The General Electric CJ610 oil system

The oil-system component used on gas turbines are as follows:

- Oil Tank(s)
- Pressure pump(s)
- Scavenger pumps
- Filters
- Oil coolers
- Relief valves
- Pressure and temperature gages
- Temperature regulating valves
- Oil jet nozzles
- Fitting, valves and plumbing
- Seals

Oil Tanks:

Tanks can be either an airframe-supplied or engine-manufacturer supplied unit. Usually constructed of welded sheet aluminum or steel, the tank provides a storage place for the oil and in most engines is pressurized to ensure a constant supply of oil to the pressure pump. It can contain a venting system, a deaerator to separate entrained air from the oil, an oil level transmitter and/or dipstick, a rigid or flexible oil pickup, coarse mesh screens, and various oil and air inlets and outlets.

Pressure Pumps:

Both the gear- and gerotor-type pumps are used in the lubricating system of the turbine engine. The gear-type pump consists of a driving and driven gear. The rotation of the pump, which is driven from the engine accessory section, causes the oil to pass around the outside of the gears in pockets formed by the gear teeth and the pump casing. The pressure developed is proportional to engine rpm up to the time the relief valve opens, after which any further increase in engine speed will not result in an oil-pressure increase.

Scavenger Pumps:

Scavenger pumps are similar to the pressure pumps but are of much larger total capacity. An engine is generally provided with several scavenger pumps to drain oil from various parts of the engine. Often one or more of the scavenger elements are incorporated in the same housing as the pressure pump. Different capacities can be provided for each system, despite the common driving shaft speed, by varying the diameter or thickness of the gears to vary the volume of the tooth chamber. A vane-type pump may sometimes be used.

Filters:

The three basic types of oil filters for the jet engine are the cartridge, screen, and screen-disk types. The cartridge filter must be replaced periodically, while the other two can be cleaned and reused. In the screen-disk filter, there are a series of circular screen-type filters, with each filter being composed of two layers of mesh to form a chamber between the mesh layers. The filters are mounted on a common tube and arranged in a manner to provide a space between each circular element, Lube oil passes through the circular mesh elements and into the chamber between the two layers mesh. This chamber is ported to the center of a common tube that directs oil out of the filter.

Oil Coolers:

The oil cooler is used to reduce the temperature of the oil by transmitting heat from the oil to another fluid. The fluid is usually fuel, although air-oil coolers have been used. Since the fuel flow through the cooler is much greater than the oil flow, the fuel is able to absorb a considerable amount of heat from the oil, thus reducing the size of the cooler greatly as well as the weight. Thermostatic or pressure-sensitive valves control the temperature of the oil by determining whether the oil shall pass through or bypass the cooler.

Breathers and Pressurizing Systems:

In many modern engines internal oil leakage is kept to a minimum by pressurizing the bearing sump areas with air that is bled off the compressor The airflow into the sumps minimizes oil leakage across the seals in the reverse direction.

Seals:

Dynamic (running) seals used in gas turbine engines can basically be divided into two groups:

1. Rubbing or contact seals: Two varieties are face and circumferential types and are constructed of metals, carbon, elastomers, and rubbers, or combinations of these materials.

2. Non rubbing labyrinth or clearance seals

In both cases the type of seal and the material used is determined mainly by the range of pressures, temperatures, and speeds over which the seal must operate; the requirements of a reasonable service life; the media to be sealed; and the amount of leakage that can be tolerated.

Bearings:

The efficiency, reliability, and, to a lesser extent, the cost of a gas turbine depends on the number and type of bearings used to support all of the major and minor rotating parts in this type of powerplant.

There are two basic types of bearings used in gas turbine engines: the ball bearing and the roller bearing. However, within these two basic designs are hundreds of variations. Nonconventional bearings made out of plastic or materials such as silicon nitride are also now being used or are contemplated for future engines. The main rotating component of a gas turbine, the compressor/turbine assembly, must be supported both axially and radially. When the direction of a load is at right angles to the shaft, it is called a radial load, and when it is parallel to the shaft, it is called a thrust or axial load. Radial loads are due to rpm changes and aircraft maneuvering, while axial loads result from thrust loads (forward and rearward) from the compressor and turbine. A ball bearing will limit or support both radial and axial loads, while a roller bearing will limit or support only radial loads. Since there is always engine growth because of temperature changes in the engine, one bearing supporting the compressor must always be a ball bearing to absorb both radial and axial loads, while the other must always be a roller bearing to allow axial movement due to changing dimensions in the engine. This is also true for the turbine rotor in larger engines.

Bearings require special storage, cleaning, handling, and installation. These procedures should be adequately covered in the maintenance and overhaul manuals for the engine.

2.17 Starting System

The purpose of any starter system is to accelerate the engine to the point where the turbine is producing enough power to continue the engine’s acceleration. This point is called the Self-accelerating speed.

Characteristics (the choice of starting system depends on several factors):

- ***Length of starting cycle:***

  For military equipment, starting time may be of primary importance. In addition, the speed with which the starter can accelerate the engine to idle speed will influence not only peak exhaust gas temperatures, but also the length of time the engine spends at these high starting temperatures. Unlike the reciprocating engine starter, the gas turbine starter must continue to accelerate the engine even after "light-off." Slower than normal accelerations or starters that "drop out" too soon may cause "hot" or "hung" starts. A hung start is a situation where the engine accelerates to some intermediate rpm below idle and stays there. Hot starts are, of course, what the name implies: a start where turbine or exhaust gas temperature limits are exceeded.

- ***Availability of starting power:***

  Even small gas turbine engines require large amounts of either electric or pressure energy. Large engines require correspondingly more. Some starting systems are completely self-contained, while others require power from external sources. Many airplanes carry their own energy source in the form of a self-contained, small auxiliary gas turbine engine that produces electric and/or pressure energy. Power may also be taken from a running engine in multiengine installations. In such a situation, one engine might be started using a starter requiring no external source of power, such as a solid propellant, or fuel-air combustion starter. The other engine(s) can then be started in turn with power taken from the running engine. Starting power requirements for gas turbine engines differ from those of engines. In the reciprocating engine, the peak load to the starter is applied in the first moments of starter engagement, but because of the increasing compressor aerodynamic load, the load on the turbine starter is actually increasing during engine acceleration prior to light-off.

- ***Design features:***

  Included in this area are such things as specific weight (pounds of starter weight per foot pound of torque produced), simplicity, reliability, cost, and maintainability.

The following is a list of various forms of gas turbine starters:

- Electric motor starter
- Electric motor generator (starter generator
- Pneumatic or air turbine starter
- Cartridge or solid propellant starter
- Fuel-air combustion starter
- Gas turbine starter (jet fuel starter
- Hydraulic motor starter
- Liquid monopropellant starter
- Air-impingement starter
- Hand –crank starter

Electric Motor Starter:

Electric motor starters are 28-V, series-wound electric motors, designed to provide high starting torque. Their use is limited to starting smaller engines because of the very large current drain (over 1000 A for some models) and because they are relatively heavy for the amount of torque they produce. The starter includes an automatic jaw-meshing mechanism, a set of reduction gears, and a clutch. The straight electric motor starter as a means for starting gas turbine engines has generally given way to the starter-generator in order to save weight and simplify accessory gear arrangements.

Electric Motor-Generator (Starter-Generator):

Most small gas turbine engines, such as the General Electric CJ610, Pratt & Whitney JT12 and PT6, Allison T63, Teledyne CAE J69, and the AlliedSignal Lycoming T53, use a starter-generator. This system has the advantage of being lighter than a separate starter and generator a common armature is and it requires no engaging or reduction gear mechanism. The engine accessory section also requires one less gear.

Air Turbine Starter:

Models of the air turbine starter are installed in the Boeing 720, 747, Kc135, and B52: McDonnell Douglas DC-8, D and DC-10; Lockheed Electra; General Dynamics F-111; and others. Its, primary advantage is its light weight (about 20 to 25 lb) 9 to 11 to ratio when compared with the electric motor starter and starter-generator. The principal disadvantage is it requires a supply of high-volume airflow of approximately 40 lb/min [18 kg/min] at a pressure of about 50 psi 1345 kPa]. Sources include compressed air from an auxiliary gas turbine engine carried on board the aircraft or maintained as a part of the airport facilities, compressed air bled from the other running engine(s), or compressed air from an air storage system. Very often one engine of a multiengine military airplane will equipped with a cartridge, fuel-air combustion, or gas turbine starter, having self-start capabilities. Air bled from the running engine can then be supplied to the air turbine starters installed on the other engines. This starter and other types may be supplied with a quick-attach-detach (QAD) coupling, v band, or keyhole-type pad that attaches to a mounting flange, which, in turn, is designed for direct attachment to a standard engine accessory drive.

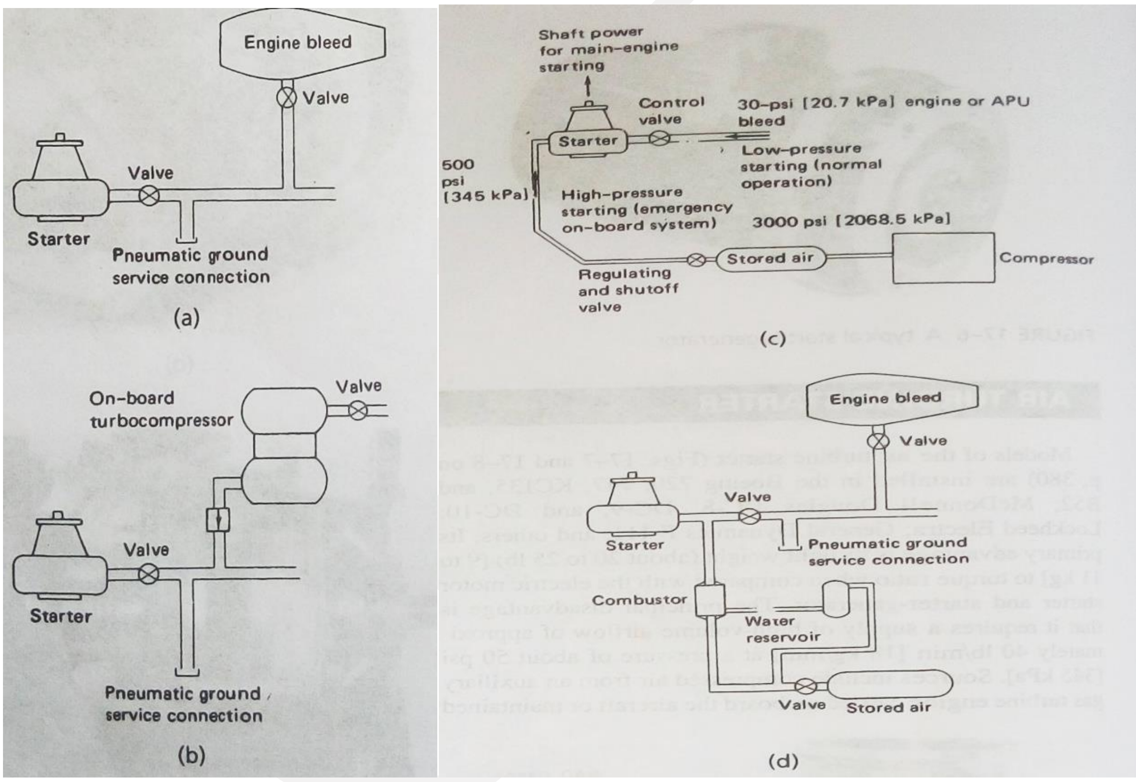


Fig: Sources of air for starting. (a)(b)(c) Simplified schematics showing several air sources.

The air turbine starter converts energy from compressed air to shaft power. To start the system, an air valve is opened by the "start" switch, after which the operation of the valve and starter is automatic. The same switch is used as a "stop" switch in emergencies. As air enters the starter inlet, the radial- or axial flow starter turbine wheel assembly rotates. The reduction gears contained within the starter convert the high speed and low torque of the turbine wheel to a relatively low-speed and high-output torque.

Cartridge or Solid-Propellant Starter:

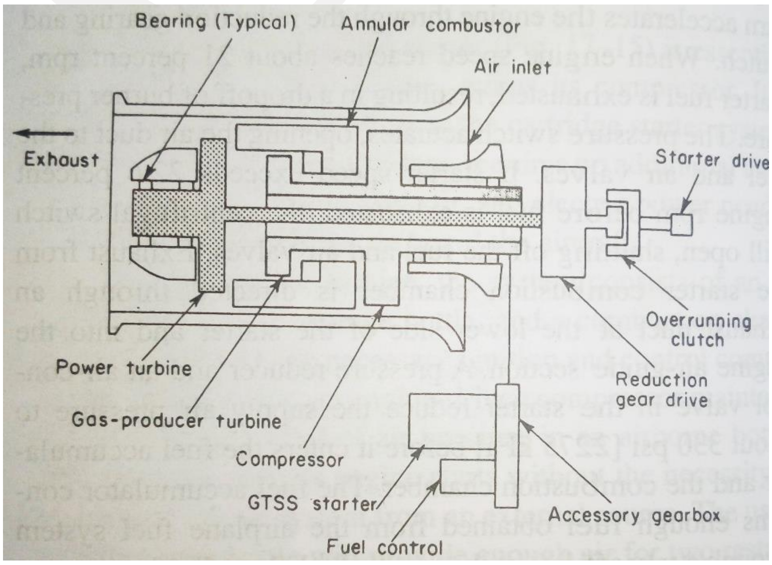
Originally, cartridge or solid-propellant starters were constructed to operate solely by means of high-pressure, high-temperature gas generated by the burning of a solid-propellant charge. Changes in the cartridge-type starter have added the additional capability of starting with compressed air from an external source. A charge, about the size of a two-pound coffee can, is inserted in the breech and ignited electrically. The relatively slow-burning propellant produces gases at approximately 2000 F 1927°C) and 1200 psi (8274 kPa] to turn the starter for about 15 s.

Fuel-Air Combustion Starter:

The fuel-air combustion starter is essentially a small gas turbine engine, minus its compressor. It is completely self-contained, as is the cartridge starter system, but unlike the preceding system, requires no additional components to function. All fuel, air, and electric power needed for operation are carried on board the aircraft.

In addition to the turbine, the system consists of an air storage bottle, fuel storage bottle, and a combustion chamber, together with the necessary ignition and control components. During flight, an engine-driven compressor maintains 3000 lb (20,685 kPa] of air pressure in an airborne bottle. This pressure permits engine starts without the necessity of recharging the air system from an external source. The usual high-pressure bottle will provide enough air for two rest without recharging. Provision is also made to connect an external 600 psi (4137-kPa) air supply. In either case, the starter receives a reduced air pressure of 350 psi (2413kPa).

Gas Turbine Starter:

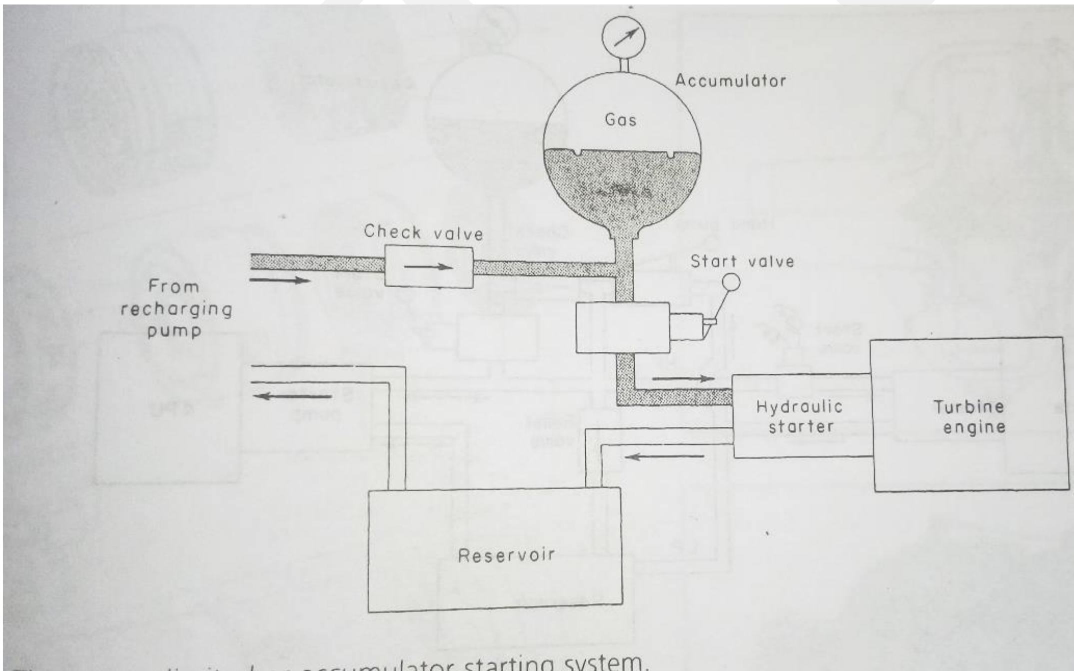


The gas turbine starter is another completely self-sufficient starting system. Relatively high power output is available for a comparatively low weight. The starter is actually a small, free power turbine engine, complete with a gas-generator section containing a centrifugal compressor, combustion chamber, and turbine to drive the compressor. It also contains its own fuel control, starter, lubrication pump and system, and ignition system. The gases flowing through the gas-generator section drive the free turbine, which, in turn, drives the main engine through a reduction gear and clutch mechanism to automatically engage and disengage the starter's free power turbine from the engine. The starter is itself started by using a small electric motor, compressed air, or hydraulic ower from the aircraft system.

Hydraulic Starters:

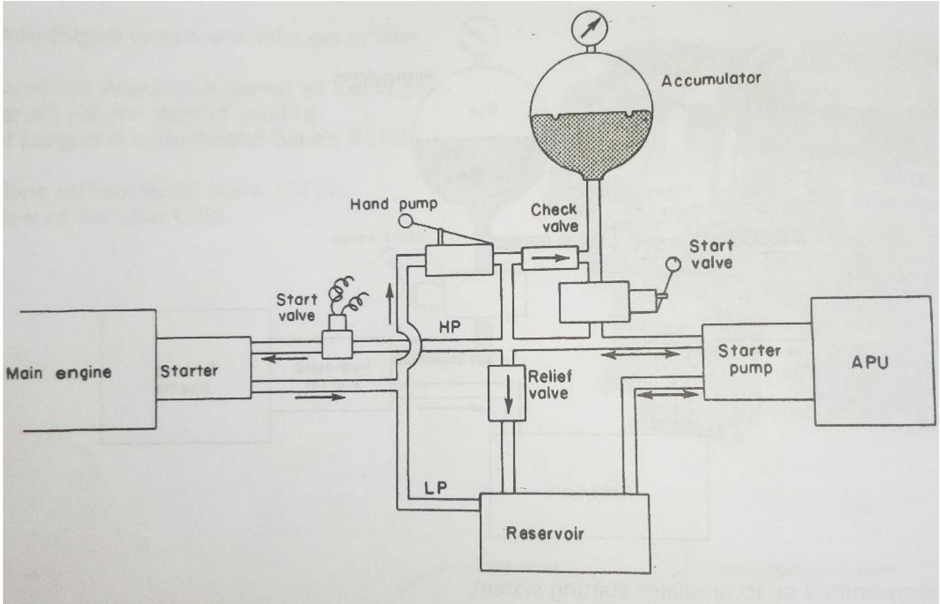
Hydraulic starting systems fall into two categories:

1. Energy limited
2. Power limited



The energy-limited or accumulator starting system.

The energy-limited system uses a highly pressurized accumulator and a large, positive-displacement motor. Examples of other starting systems that are also energy-limited are the electric motor, when supplied from a battery, and the cartridge starter. The energy-limited system is designed to complete the start in as short a time as possible in order to minimize the amount of stored energy required. The accumulator system is best suited to small engines up to 150 hp [112 kW).



The power-limited starting system.

A power limited system uses an auxiliary power unit (sometimes a small gas turbine engine, which is itself started by an energy limited system) to drive a pump that supplies the correct amount of flow and pressure to variable-displacement hydraulic starter motor. The variable-displacement motor permits high torque to be applied without exceeding the power limits of the main engine at starter cutoff speed.

Liquid Monopropellant Starter:

In this system a charge of liquid monopropellant (a monopropellant fuel is one that requires no separate air supply to sustain combustion) is decomposed to produce the high energy gas needed for turbine operation. Monopropellants that can be used include highly concentrated hydrogen peroxide, isopropyl nitrate, and hydrazine. All are difficult materials to handle.

Air Impingement Starter:

In many ways the air-impingement starter system is the simplest of all starter types, consisting essentially of nothing more than a duct. An air supply from either a running engine or a ground power unit is directed through a check valve onto the turbine blades (most commonly) or the centrifugal compressor. Engines using this starting system are the Fairchild J44, on which the air is fed to the compressor, and some models of the General Electric J85 and J79. In the latter two engines, air is directed onto the rear or middle turbine wheel stages. Obviously, the advantage of this system is manifested in its extreme simplicity and light weight. It is best suited to smaller engines because of the high-volume air supply necessary for larger engines.

Hand-Crank Starter:

The hand-crank method of starting gas turbine engines is, of course, limited to very small units, on the order of 50 to 100 hp [37 to 75 kW). As the name implies, starting is accomplished by turning a hand crank, which, through a series of gears, turns the engine to the self-sustaining rpm. Hand-crank to engine-shaft speed ratios are on the order of 100:1.

Previous exam questions:

1. (10AE74 - Dec. 2017/Jan. 2018)

a. What are the characteristics that must be considered in selection of any metal used in gas turbine engine? (10M)

b. Explain powder metallurgy technique in manufacturing of gas turbine components.(5M)

c. Explain the different types of surface treatment that is used in gas turbine materials.(5M)

d. What do you mean by FADEC? How FADEC does interacts with aircraft and FADEC interacts with engine? Explain. (10M)

e. Explain starting system of gas turbine engine. Write the various (any 2) starter used for this purpose. (5M)

f. What are the components required for a typical fuel system? (5M)

2. (10AE74 - Dec. 2016/Jan. 2017)

a. What are the characteristics, that must be considered in the selection of materials in the gas turbine engine and briefly explain it. (6M)

b. List and explain the six methods of casting. (10M)

c. Briefly explain the heat ranges of: (4M)

(i) Nickel base alloys (ii) Cobalt base alloys

d. Explain the general electric CJ610 lubricating oil system with sketch. (10M)

e. Draw and explain typical starting characteristics of starting system. (5M)

f. Explain about air turbine starter with sketch. (5M)

3. (10AE74 - Dec. 2015/Jan. 2016)

a. Briefly explain the heat range of the following alloy: (10M)

(i) Aluminum alloys; (ii) Titanium alloys; (iii) Steel alloys;

(iv) Nickel based alloys; (v) Cobalt based alloys.

b. Explain briefly about manufacturing processes used for gas turbine component. (10M)

c. Name different types of fuel controls and explain. (10M)

d. Explain briefly about fuel system components. (10M)

4. (10AE74 - Dec. 2014/Jan. 2015)

a. Briefly explain some commonly used terms and characterization considered in the selection of materials in the gas turbine engine of aircraft. (10M)

b. Write a short notes on use of composites and ceramics in different parts of aircraft engine as well as in airframes. (10M)

c. Explain the interface of FADEC on an aircraft jet engine. (10M)

d. List the various gas turbine starters and explain any one starter. (10M)

5. (10AE74 - Dec. 2013/Jan. 2014)

a. Briefly explain the heat range of any 3 following alloy: (6M)

(i) Aluminum alloys; (ii) Titanium alloys; (iii) Steel alloys;

(iv) Nickel based alloys; (v) Cobalt based alloys.

b. Describe the concept of high temperature strength requirement for materials selected for a gas turbine engine. (6M)

c. What are the various techniques available for the manufacturing of gas turbine engine components? Explain the methods of casting used to manufacture engine parts. (8M)

d. Explain the interface of FADEC on an aircraft jet engine. (10M)

e. What are the various components of a typical aircraft engine oil system and explain their working? (10M)

6. (6AE74 – December 2012)

a. List six methods of casting. Give a short description of each method and it advantages and disadvantages. (10M)

b. List 5 alloys that are used in the construction of the gas turbine engine. Describe the properties of each the makes desirable for use in specific locations in the engine. (10M)

c. Describe FADEC interface with engine. (10M)

d. Explain the general electric CJ610 fuel system with simple schematic. (10M)

7. (6AE74 – December 2011)

a. What are characteristics to be considered in selection of materials gas turbines.(12M)

b. What are the metal cutting operations are used in production of gas turbines? Write briefly. (8M)

c. Write briefly the different types of controls used in fuel system. (6M)

d. Explain the starting system of a gas turbine. Write the various starters used for this purpose. (8M)

e. Write the oil system of a gas turbine with component details. (6M)

8. (6AE74 – Jun/July 2011)

a. What are major components of a typical gas turbine engine and materials used? (12M)

b. What are heat ranges of metals for aero engine application? (8M)

c. What are the components of typical fuel system? (12M)

d. What is FADEC and how does it affect the engine operation? (8M)

9. (6AE74 – December 2010)

a. Explain the various manufacturing techniques used for engine parts. (20M)

b. What are various components of a fuel system? (10M)

c. What is FADEC? Explain its interface with the engine. (10M)

10. (6AE74 – Dec.09/Jan.10)

a. What are the characteristics that must be considered in the selection of any metal for use in the gas turbine engines? Discuss. (10M)

b. List the surface finish processes and explain any three processes. (10M)

c. What is FADEC and how it affects the engine? (15M)

d. What are the components required for a typical fuel system? (5M)