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

1. High-temperature, high-strength materials and unique methods of manufacture have made the gas turbine engine a practical reality in a few decades.
2. To a large measure, the performance of turbojet and turboprop engines depend on the temperature at the inlet to the turbine.
3. 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.
4. 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.
5. Research in material technology is continuing to restructure molecules to conform to whatever properties are deemed desirable.
6. 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.
7. 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 (Criteria) considered in the selection of materials in the field of metallurgy and metal workings 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.

2.2 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

1 High-temperature strength
2 Resistance to oxidation and corrosion
3 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 modem 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

1 Sealing the base metal surface against corrosion, oxidation, and carbonization
2 Insulating the base metal against high temperatures

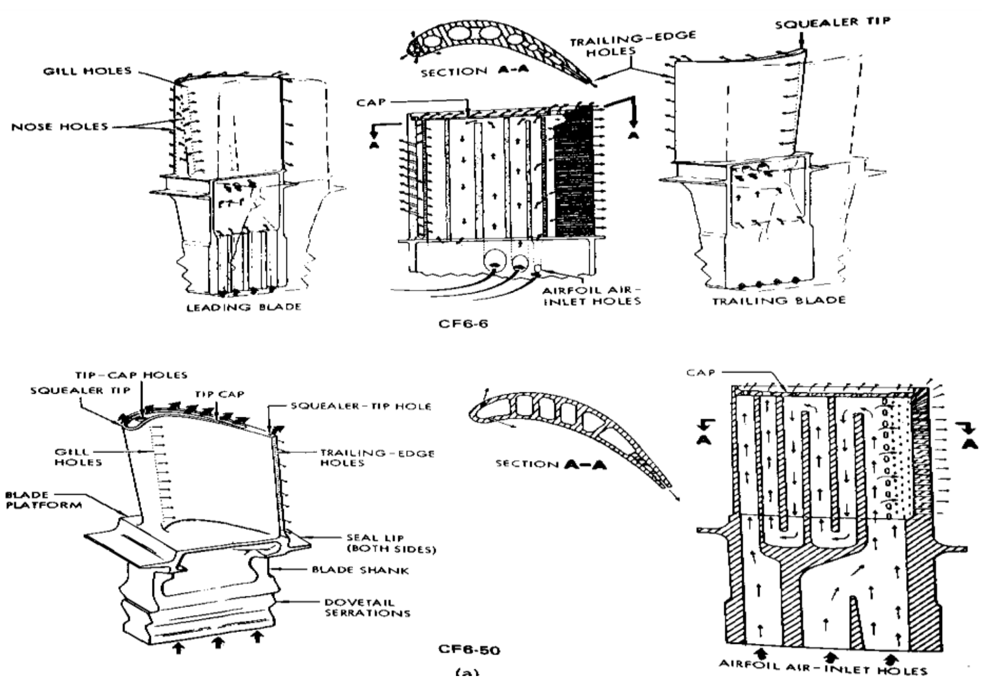
- These coatings are not without disadvantages, in that they are more susceptible to thermal shock, they must have the same coefficient of expansion as the base metal, they are brittle, and they have low tensile strength, which, Of course, restricts their use in the engine.
- Some work that shows promise 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 super hard 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

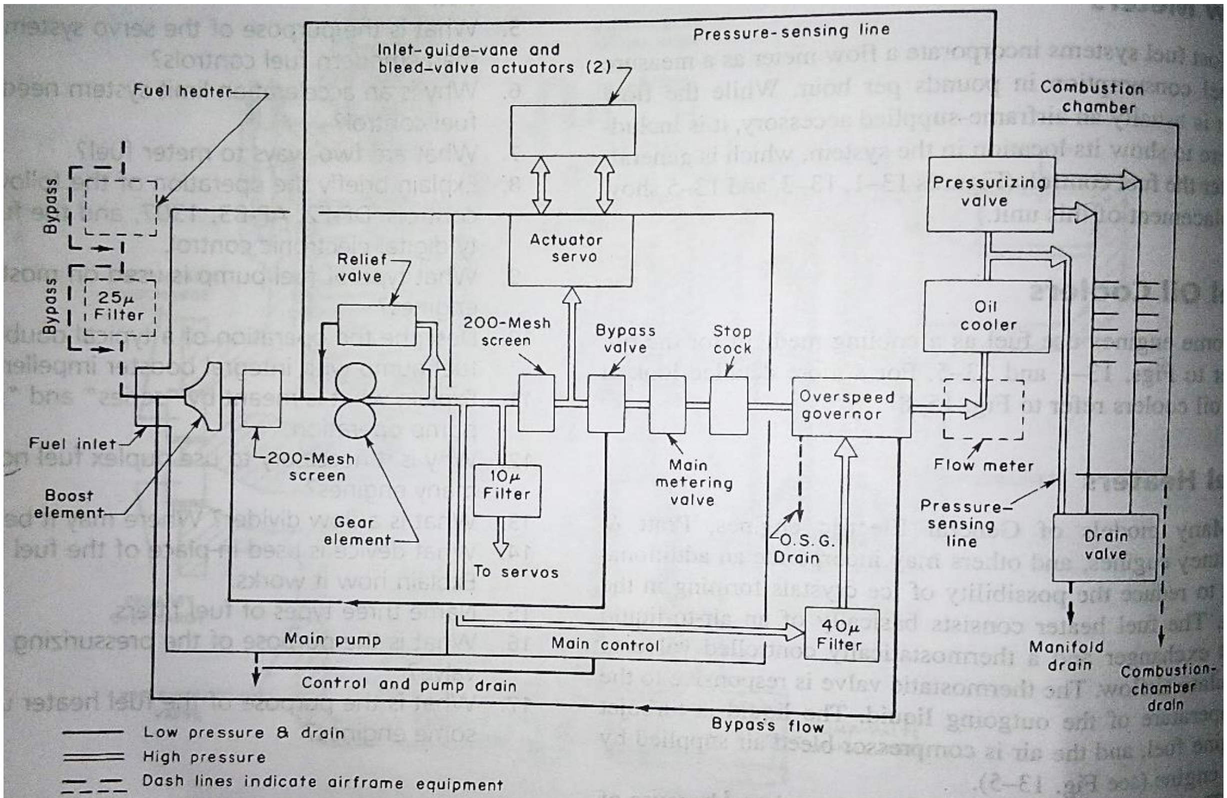
- Experiments are being performed using ceramic materials in many of the engine's hot section parts, such as the combustor, nozzle diaphragm, turbine blades, and turbine disks.
- Materials being looked at are hot-pressed and/or bonded silicon nitride or silicon carbide, with some materials being reinforced 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.

2.15 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 the filter becomes clogged. During engine operation, the pressurizing valve actuates to close the manifold drain passage of 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.

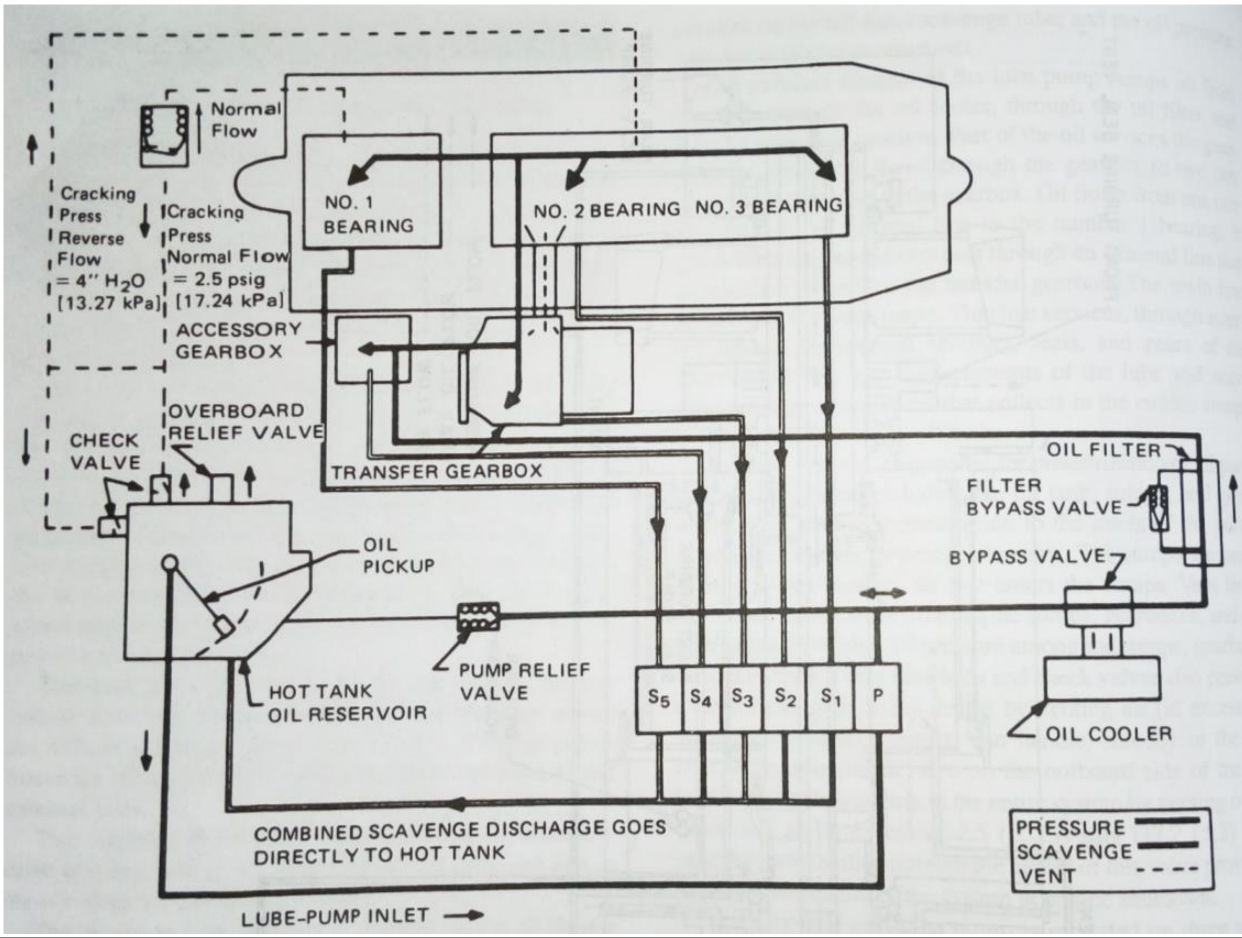
Actuator Assembly (VG):

Two variable-geometry actuators, mounted on the compressor casing, position the inlet guide vanes and inter stage 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 inter stage bleed valves. A feedback cable is connected from the bell crank 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



The oil-system component used on gas turbines is 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 generator-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.