Cairo University
Faculty of Engineering
Mech. Power Department

ACC Virtual Labs
Automatic Control Circuits & Virtual Labs for Mechanical Power Systems
معمل التحكم الأوتوماتيكي و المعامل الافتراضية لأنظمة القوى الميكانيكية

دبلوم تطبيقات التحكم الأوتوماتيكى فى نظم القوى الميكانيكية

MEP 599 Diploma Project-Fall 2020-2021

Automatic Control Systems for LM6000-PC Gas Turbine Generator: Basic Operation & Package Familiarization

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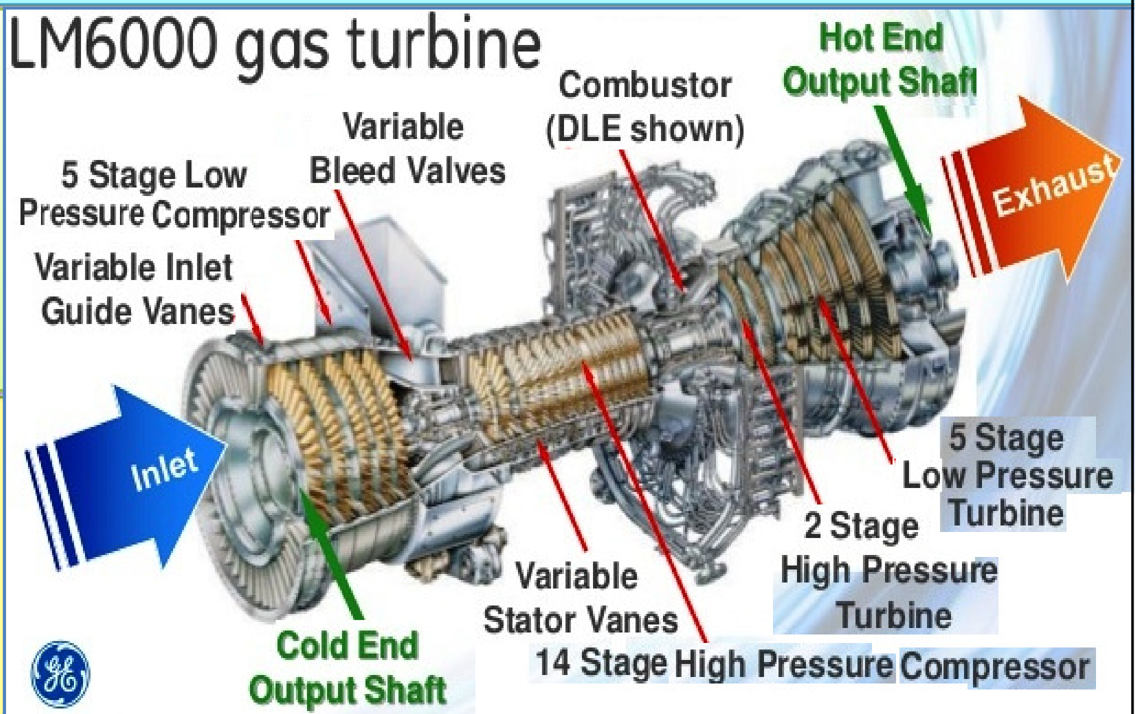
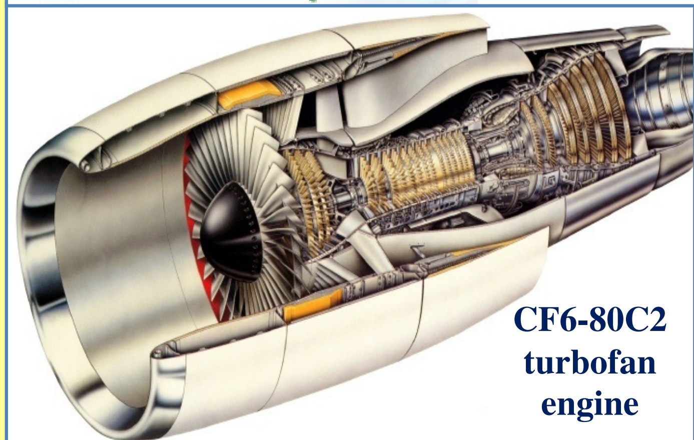
Abstract: This project presents some technical specifications of GT Generator. It includes investigation of various control & operating systems for GE LM6000 PC GT which is an industrial 47.5 MW. The aero-derivative GT is lighter weight, 2-speeds, 2-shafts variation of GT. Described data are extracted &compiled from practical basic GT operation & package familiarization documents. The GT operates on principle of Brayton cycle, where compressed air is mixed with fuel, burned under constant pressure conditions. The resulting hot gases are then allowed to expand through a turbine to perform work.

LM6000 GT overview: Developed from CF6-80C2 turbofan engine. Liquid, Gas &Dual Fuel packages available. Steam/Water Injection &DLE Dry Low Emissions combustor systems are available. It is the most efficient simple-cycle GT in its class. Some changes made to convert CF6-80C2 to LM6000: Front fan is removed & inlet guide vanes added. LP compressor from CF6-50/LM5000 is used. Front and rear frames are adapted. Output shafts added to LPC front &back of LPT. Bearing 7R are added. New industrial fuel system are added. Balancing disk is added to LPT. Hydraulic control system for variable geometry. Since it's introduction in 1992, the original LM6000PA was followed by model PB, dry low emissions (DLE) version. In 1998, PC model was introduced and incorporated design changes to the LPC, HPC, LPT, balance piston system and the fuel system. These design changes increased shaft power output by approximately 3.4 MW, and engine efficiency by approximately 2%. The LM6000 PD is the LM6000 PC modified with the Dry Low Emission Combustion System (DLE). This GT-PC model made its appearance in mid-1998. DLE system requires changes to be made to the fuel nozzles and the annular combustion chamber is added.

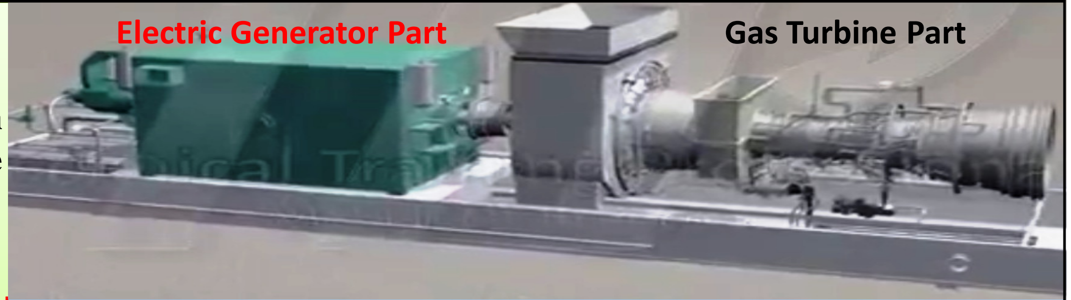


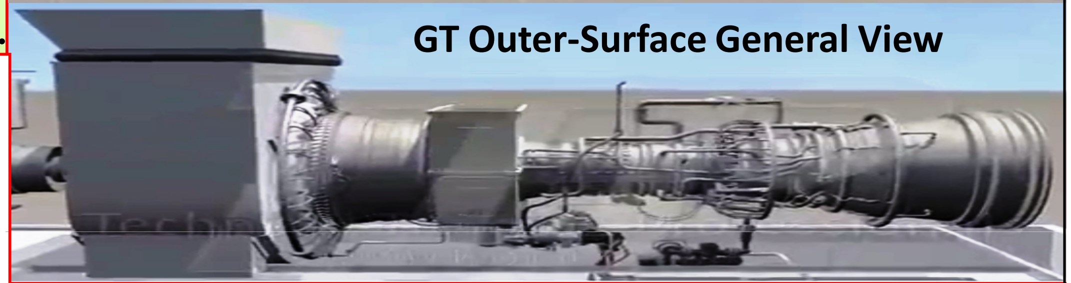


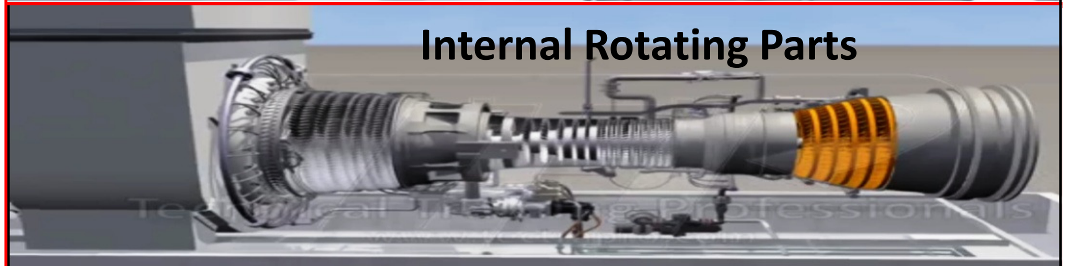
CF6-80C2 turbofan engine

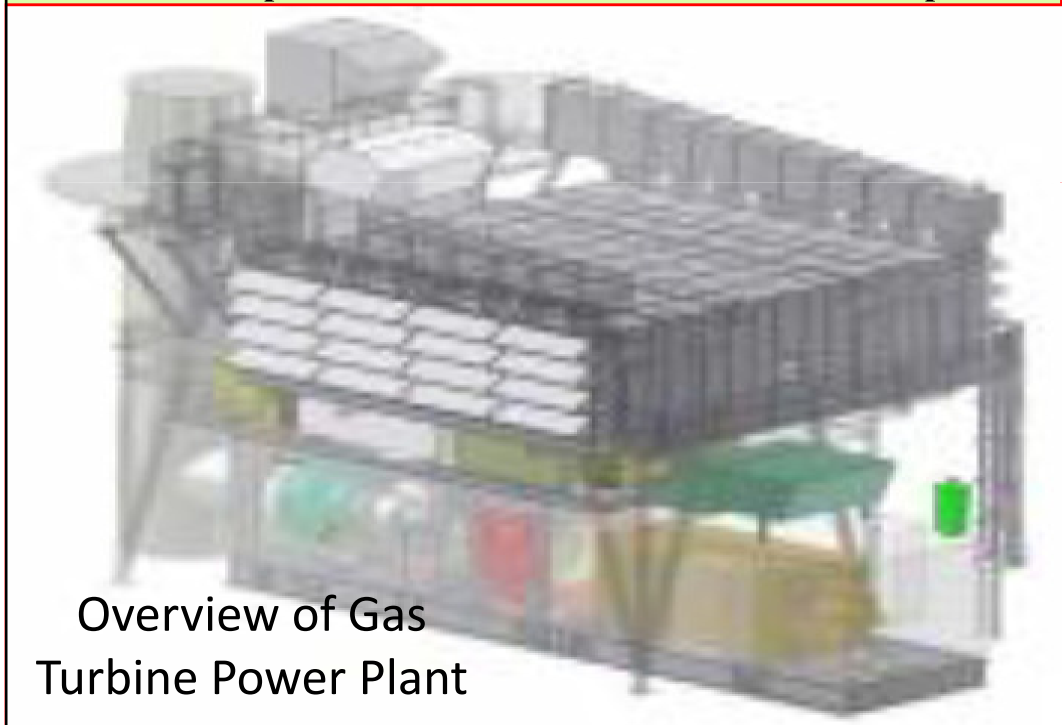
TURBINE CONTROL PANEL (TCP)

Objectives of LM6000 GT Generator Basic Operation & Package Familiarization Documents: Is to provide system operators with:
•Understand basic GT&Generator operation. •Understand how each of the sub systems operates, individually and as part of total package •Ability to initiate & maintain normal system operation. •Ability to recognize system alarm &fault information & take the appropriate actions. •Understand system documentation. •Knowledge of various serviceable components& maintenance needed for normal operation.



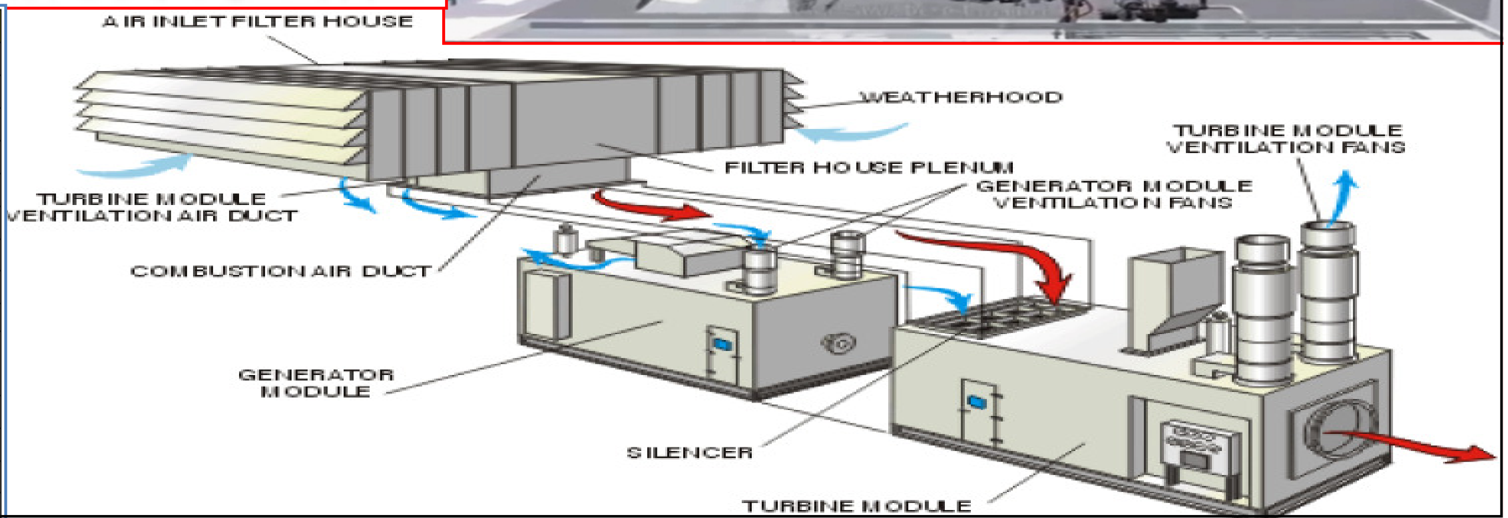






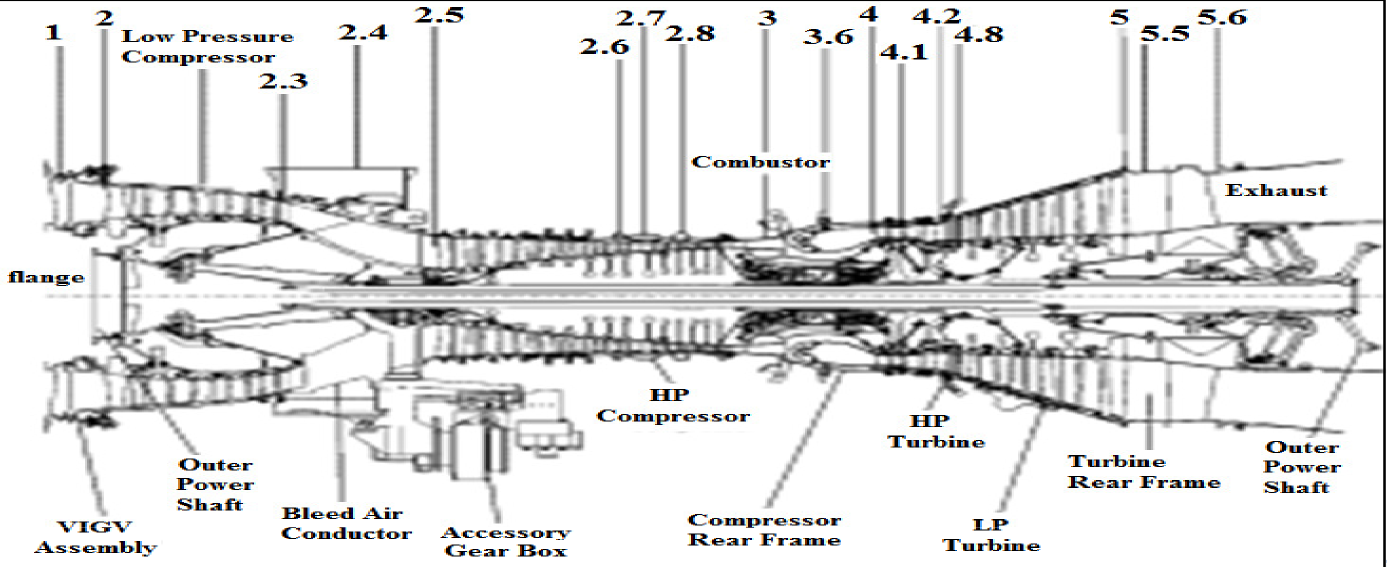
Overview of Gas Turbine Power Plant

Details of the GT-Project documents	
Chapter 1	Introduction
Chapter 2	Turbine Basic Theory
Chapter 3	Details of Construction
Chapter 4	Turbine Support Systems
Chapter 5	Turbine Lube Oil System
Chapter 6	Variable Geometry System
Chapter 7	Hydraulic Start System
Chapter 8	Dual Fuel System
Chapter 9	Ventilation& Combustion Air System
Chapter10	Vibration Monitoring System (Bently Nevada 3500 Series)
Chapter11	Fire Protection System
Chapter12	Water Wash System
Chapter13	Turbine Control System
Reference	

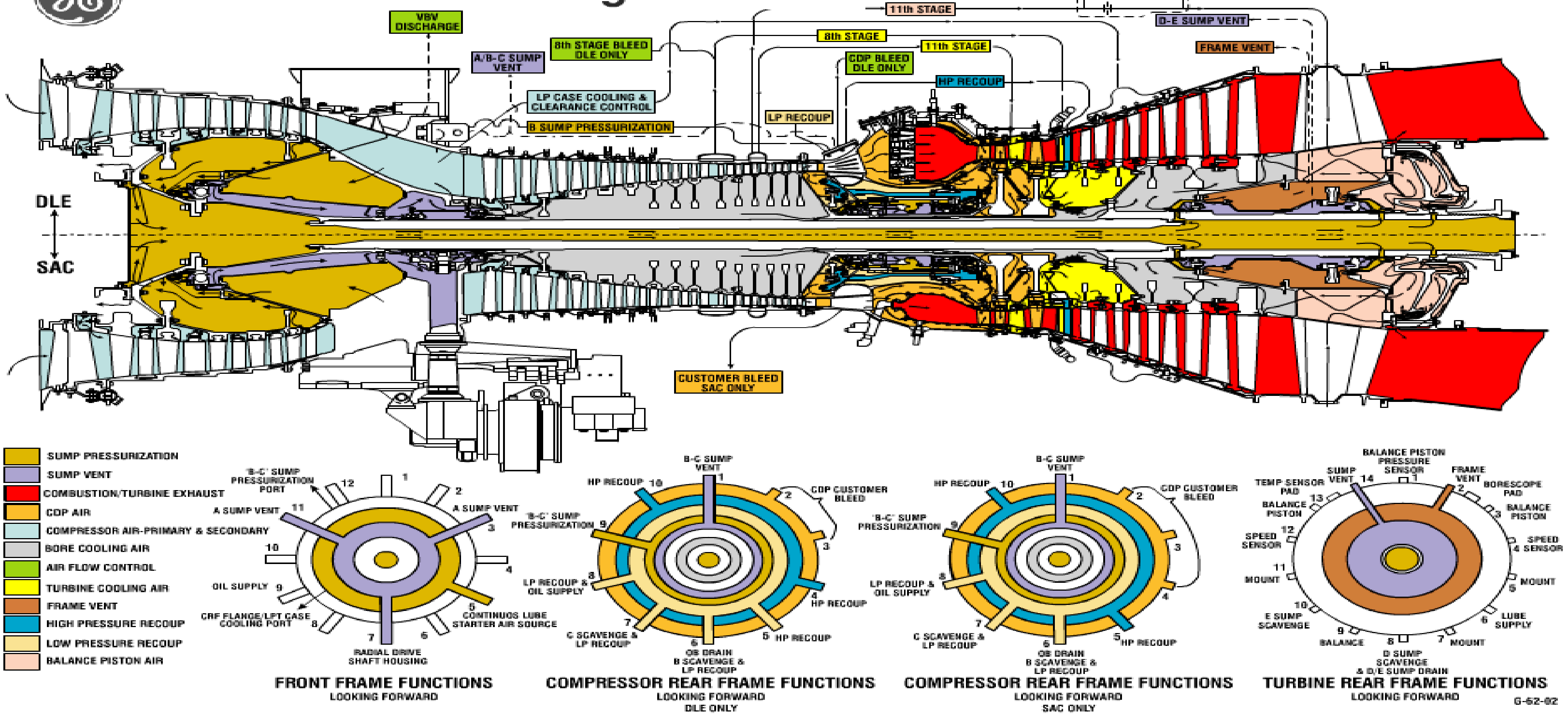


Complete list of LM6000 stations:

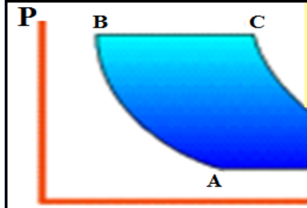
1 VIGV inlet (Variable Inlet guide Vanes)
2 LPC inlet
2.3 LPC discharge
2.4 LPC bleed
2.5 HPC inlet
2.6 HPC bleed 7th stage
2.7 HPC bleed 8th stage
2.8 HPC bleed 11th stage
3 HPC discharge
3.6 Fuel nozzle
4 HPT inlet (nozzle)
4.1 HPT 1st stage blade
4.2 HPT exhaust
4.8 LPT inlet
5 LPT exhaust
5.5 LPT rear frame exhaust
5.6 LPT exhaust diffuser



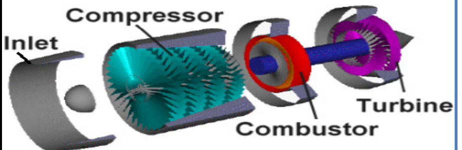
LM6000 PD/PCC Engine Airflow



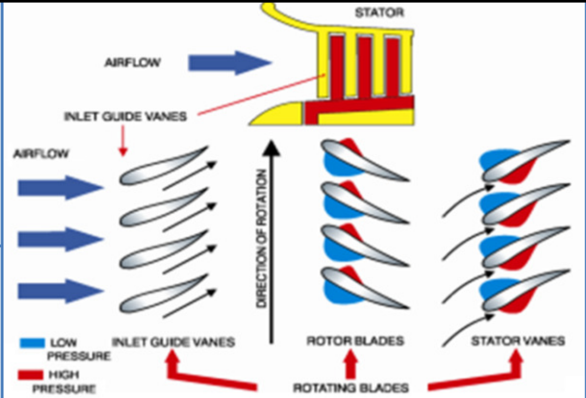
GT Basics



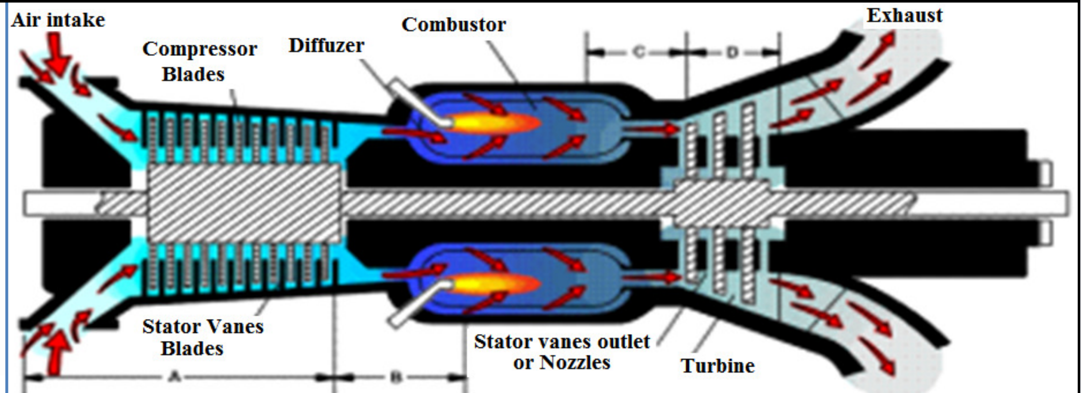
Pressure Vouume, BRAYTON Cycle
(Gas Turbine Engine)



Gas Turbine Components

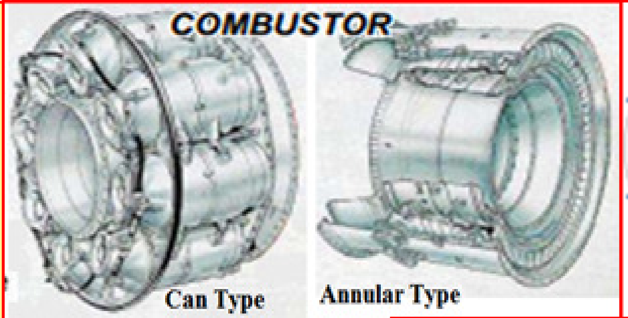


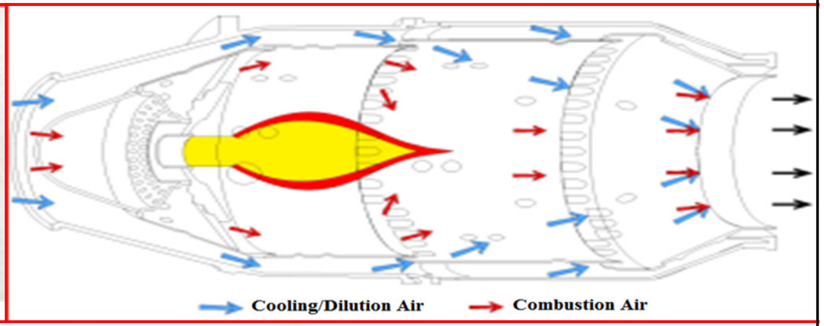
Inlet Guide Vanes and Stator Vanes

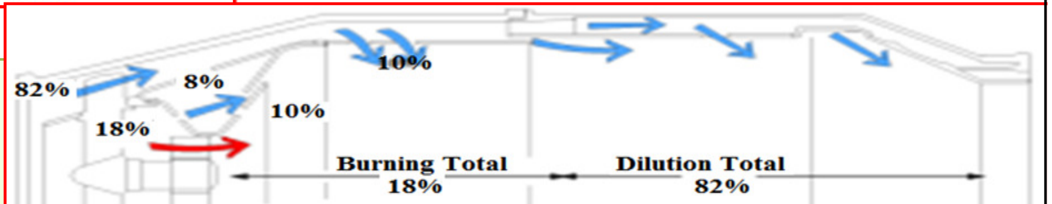


Continous Combution process

<u>Combustors</u>: main types & designs found in GTs: 1-Annular combustor with liner sitting inside the outer casing which has been peeled open in the drawing. Many modern combustors are annular. 2-Older can or tubular design. Photo shows some actual combustor cans. Each can has both a liner and a casing, and the cans are arranged around the central shaft. 3-A compromise design is a can-annular design, in which the casing is annular and the liner is can-shaped. The advantage to the can-annular design is that the individual cans are more easily designed, tested, and serviced.



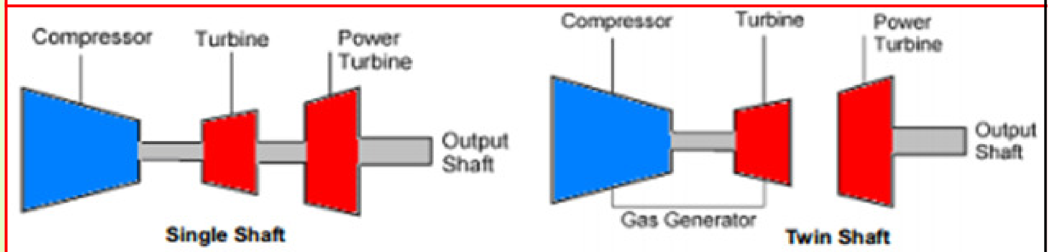


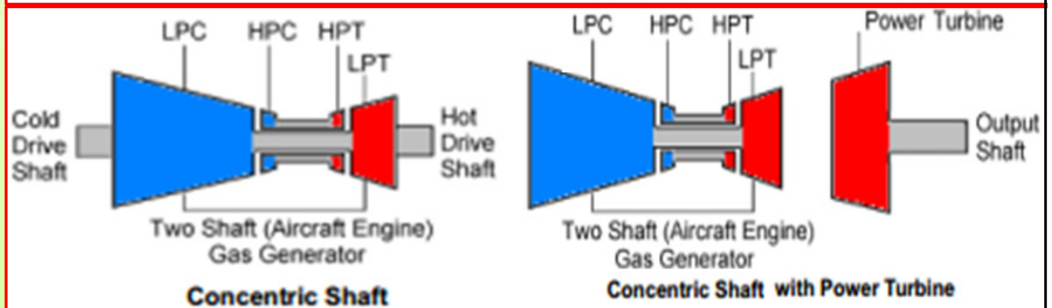


Apportioning the air flow

Flame Stabilizing and General-Flow Pattern

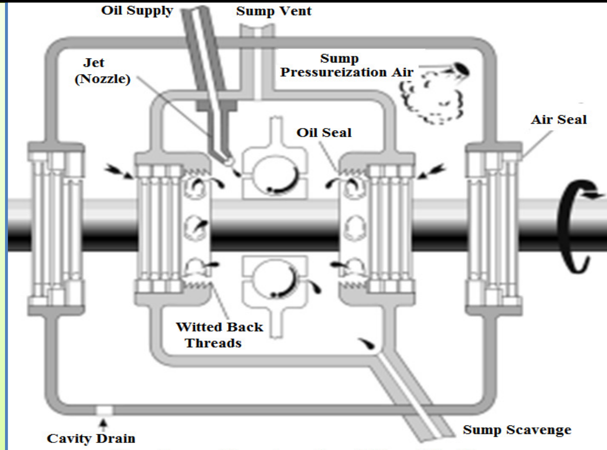
<u>*TURBINE CONFIGURATIONS*</u> Single shaft illustration is the traditional single shaft assembly. It consists of the axial flow compressor; Turbine and Power Turbine are all mechanically linked. If we add to this shaft the generator and gearbox, we have a shaft system with a high moment of inertia. This is the favored configuration for electrical generation because this provides additional speed (Frequency) stability of the electrical current during large load fluctuations. This configuration is typical of heavy-duty industrial "frame" turbines, such as the MS7001. The twin shaft illustration shows the standard two shaft arrangement with the compressor and turbine only connected, and an unconnected power turbine and output shaft that will rotate independently. This configuration is favored for variable speed-drive packages, such as pumps and compressors, because the gas generator or gas producer can run at its own optimum speed for a given load. The LM2500 utilizes this configuration and has been applied to both electric power generation and a variety of mechanical drive applications. Aircraft jet engines have for many years been adapted for industrial use as shown in the diagrams above. The concentric shaft illustration, above left, shows a more complicated an aero-derivative industrial turbine arrangement. This type, too, is still essentially a two shaft configuration but the gas generator core (an original jet-engine) was designed with two spools, a Low Pressure Shaft and a High Pressure Shaft. This engine configuration allows the load to be driven from either the exhaust end or the compressor air intake end. This is the configuration used by the LM6000. The concentric shaft with power turbine illustration is essentially a two shaft arrangement with a gas generator originally designed for propulsion. An independently rotating Power Turbine, manufactured especially to match the flow of the jet engine, is added to the gas path as the power/torque producer. This configuration is found in the LM1600 and the LMS100.



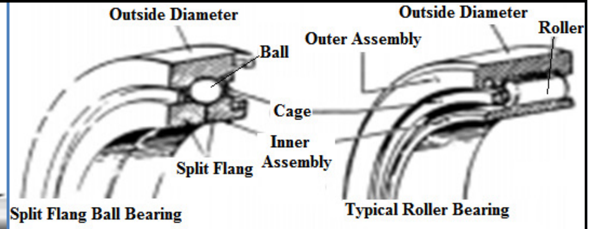


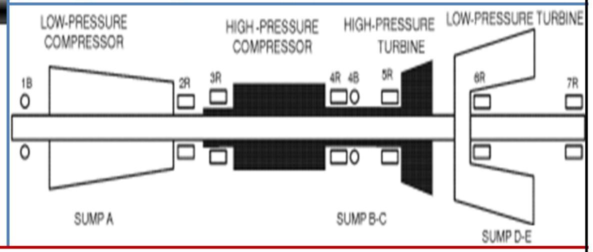
BEARINGS AND SUMPS: **8 anti-friction roller- and ball-type bearings support the rotating components and the aerodynamic loads in the LM6000. The bearings are held together with a cage and race assembly. By design, the bearings do not generate significant heat from friction. They do, however, absorb heat transmitted from the engine's hot-gas path and because of this, lube oil is supplied to the bearings for cooling purposes. The roller bearings support radial loads and axial thrust loads are supported by ball bearings. These bearings are located in the sumps A, B, C, D, and E areas. Bearings are classified into two broad categories; friction, also commonly known as plain or Babbitt type, and anti-friction, which contain rollers or balls that makes a rolling contact with the shaft. The gas turbine utilizes anti-friction type bearings, whereas the generator has friction type bearings. Bearings have the following functions:**

- **Support the load on shaft. The load may be a gear or the shaft itself. Reduce friction created by turning. This is accomplished both by design and by lubrication and is one of the most important functions of bearings. Reduce friction created by thrust. A specially designed bearing is required for this purpose. Hold a shaft in rigid alignment. A high speed-rotating shaft has a tendency to "whip" unless adequately supported by bearings.**



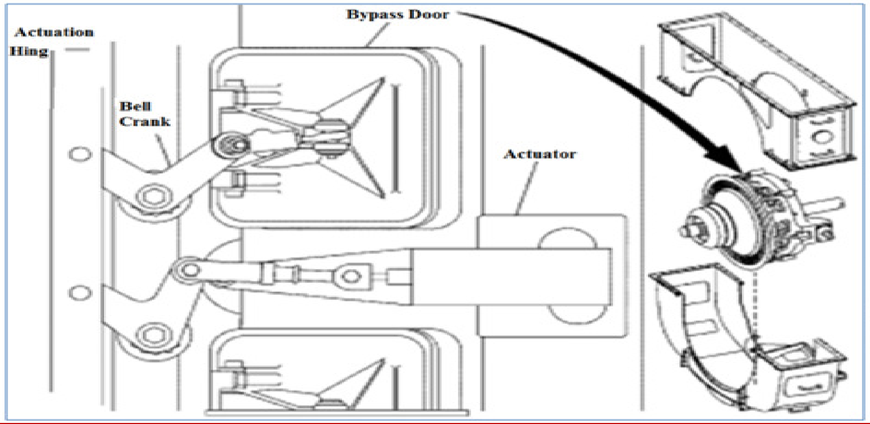
Dry Sump Construction (Simplified)

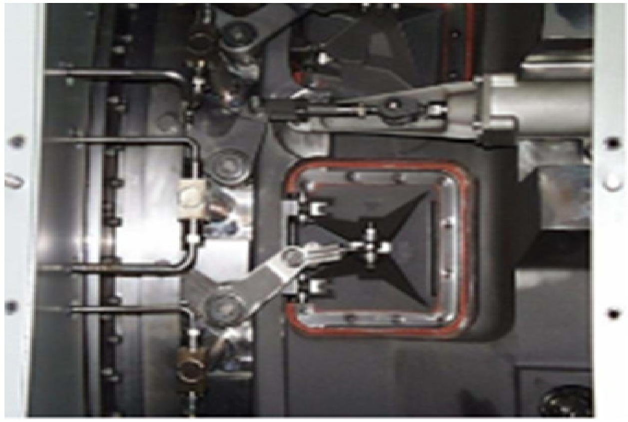


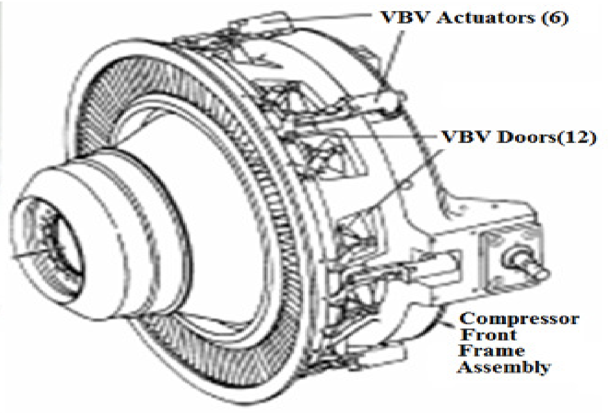


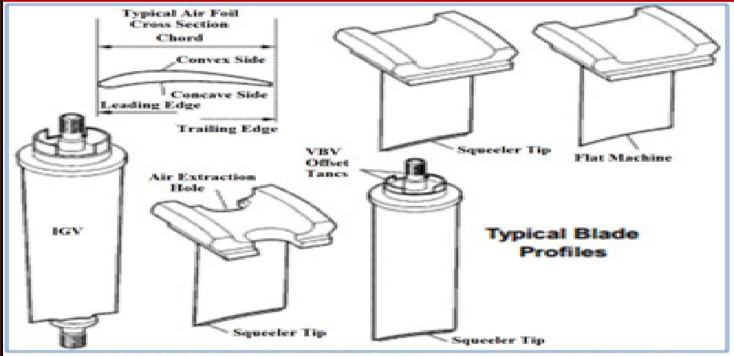
LOW PRESSURE COMPRESSOR BYPASS AIR COLLECTOR

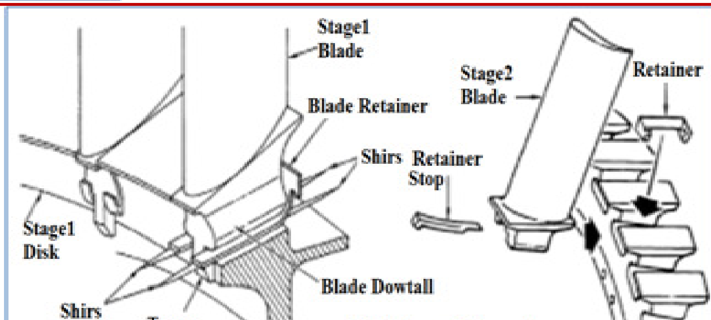
The LPC bypass-air collector is a duct attached to the front frame. It collects LPC discharge air, vented through the LPC bypass doors, and directs it overboard through packager-provided ducting.



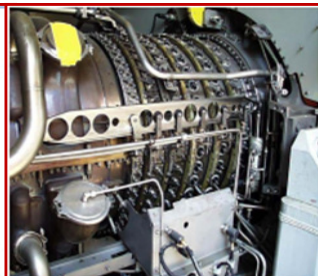


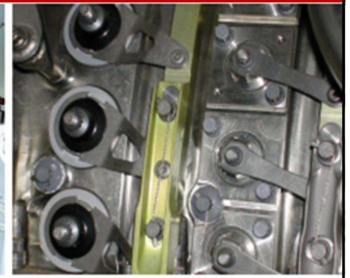


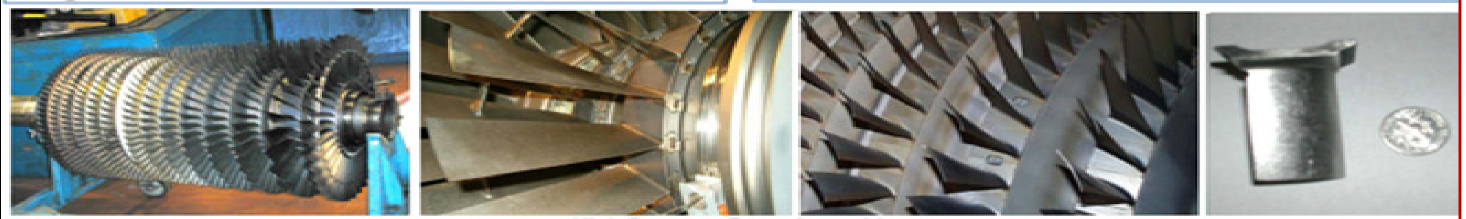


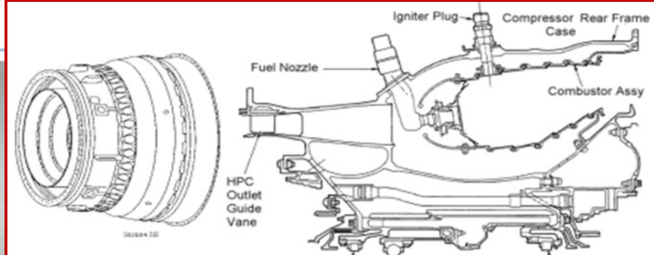


Disk 1 and 2 Loading

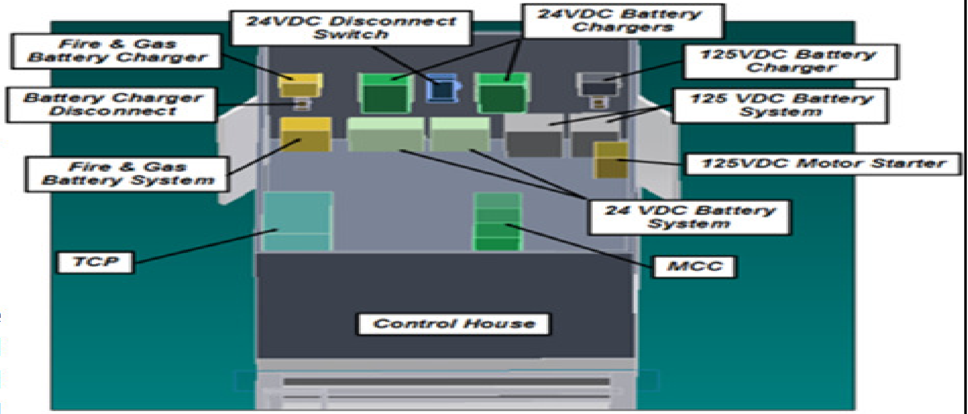

Variable Stator Vane Assembly


Variable Stator Vane Actuation Rings


High Pressure Rotor Assembly



Compressor Rear Frame Assembly



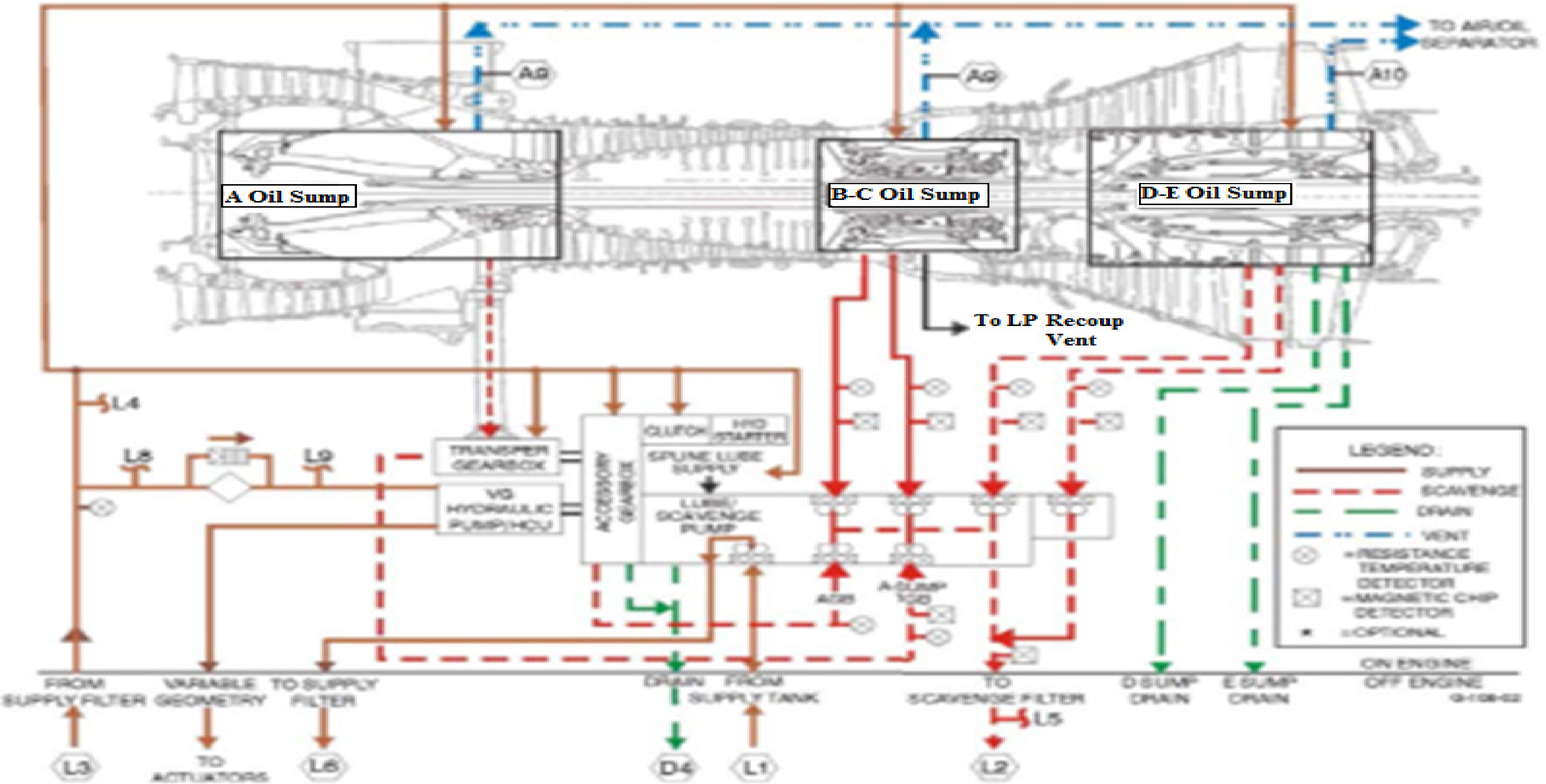
CONTROL ROOM

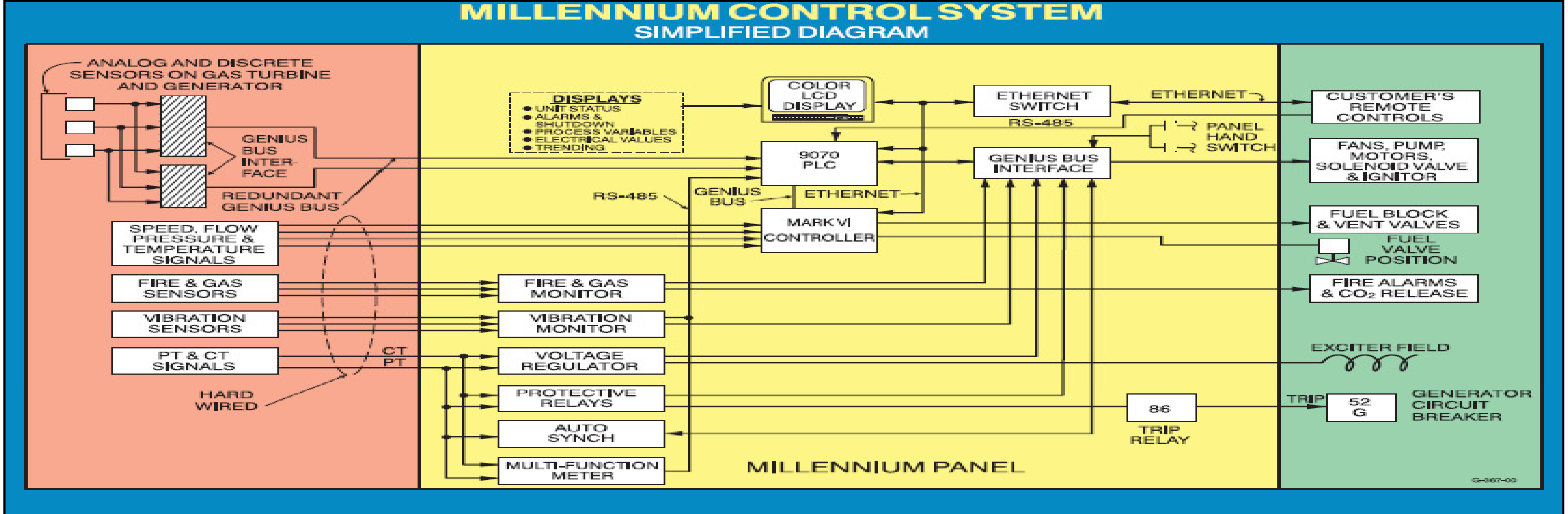
The packaging of the LM6000 GTG set includes a turbine generator control panel(TCP), digital generator protection relay system,400-V motor control center (MCC), and 24 and 125-VDC battery systems, including battery racks and chargers. The Power Control Module or Control Module consists of following major groups of components;

· Turbine Control Panel (TCP), · Unit Motor Control Center (MCC), .Battery Systems with Chargers

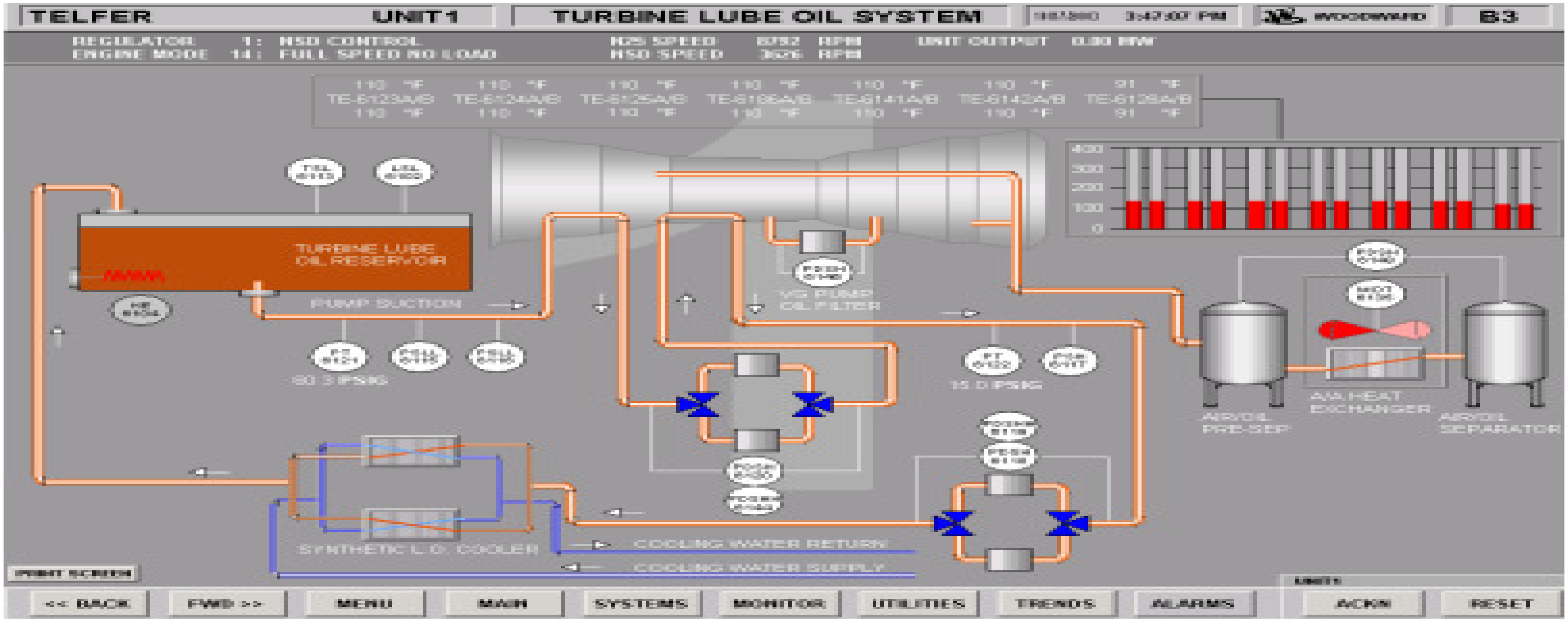
Turbine-Generator Control System

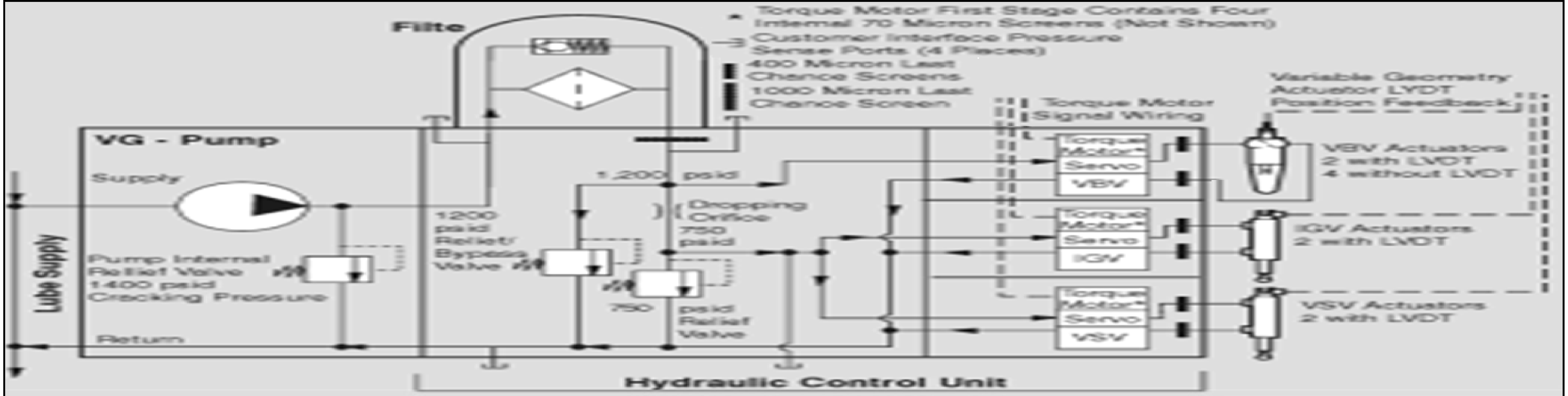
The turbine-generator control-and-monitoring systems regulate the lubrication, fuelsupply, ventilation and cooling, fire safety, and maintenance functions. Fuel supply isregulated by a computerized fuel control system. The operator's HMI displays the statusof all operating systems and initiates alarms and shutdowns when hazardous conditionsoccur. The status of all system parameters are displayed on individual system screens.Manual emergency shutdowns can be initiated with an emergency



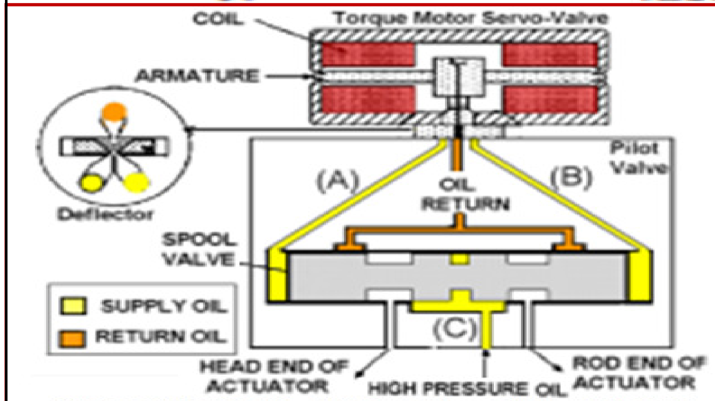


Millennium Control System Simplified Diagram

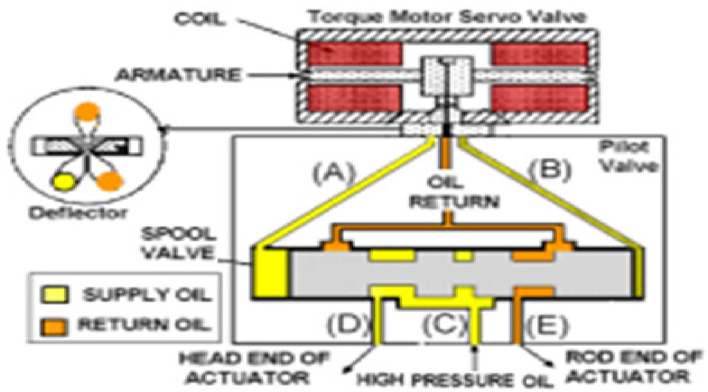




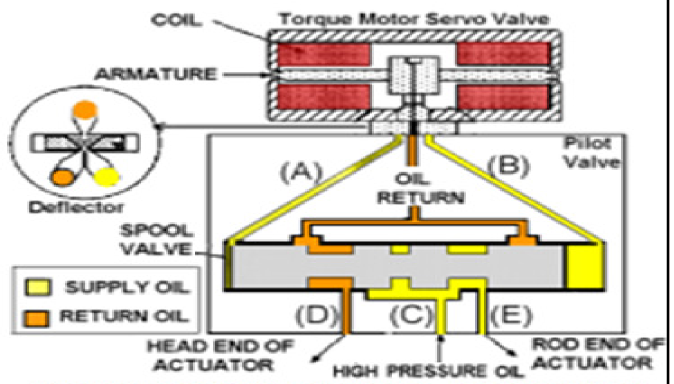
Pump Internal Relief Valve	1400 psid (9653 kPaD)	Dropping Orifice	750 psid (5171 kPaD)
Relief / Bypass Valve	1200 psid (8273 kPaD)	Relief Valve	750 psid (5171 kPaD)



HYDRAULIC SERVO EXAMPLE A – NULL POSITION



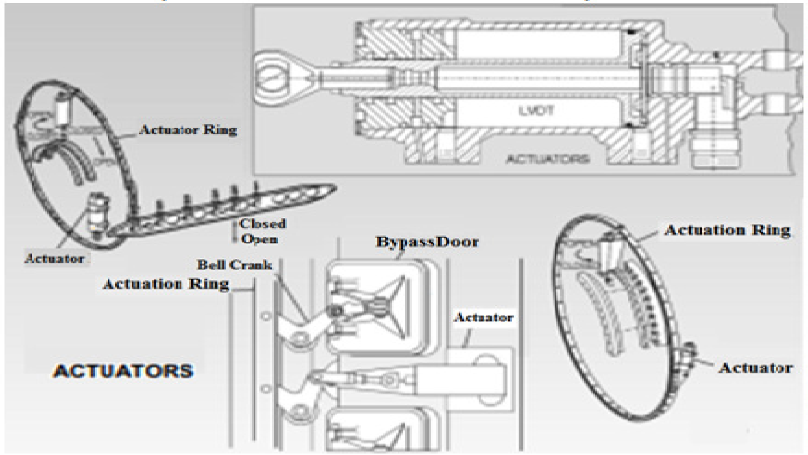
HYDRAULIC SERVO EXAMPLE B – HEAD POSITION

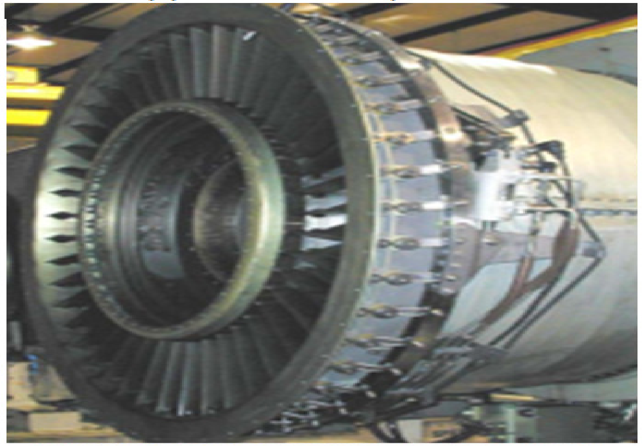


HYDRAULIC SERVO EXAMPLE C – ROD POSITION

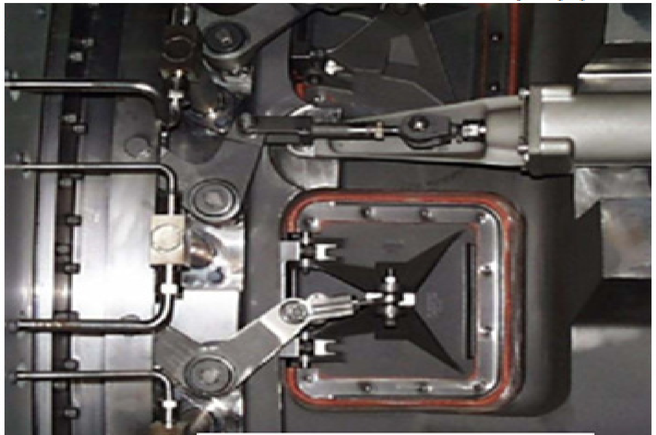
Variable Stator Vane Actuators

There are two variable stator vane (VSV) actuators. The actuators are double-acting hydrauliccylinder-piston type actuators. The HCU pressures one side of the piston and vents the oppositeside to position the VSV's. Both actuators are LVDT equipped





Variable Inlet Guide Vane Assembly



Variable Bypass Valve (VBV) System

TYPICAL SYSTEM DIAGRAM

TO OPTIONAL CUSTOMER NETWORK
(ENTERPRISE LAYER)