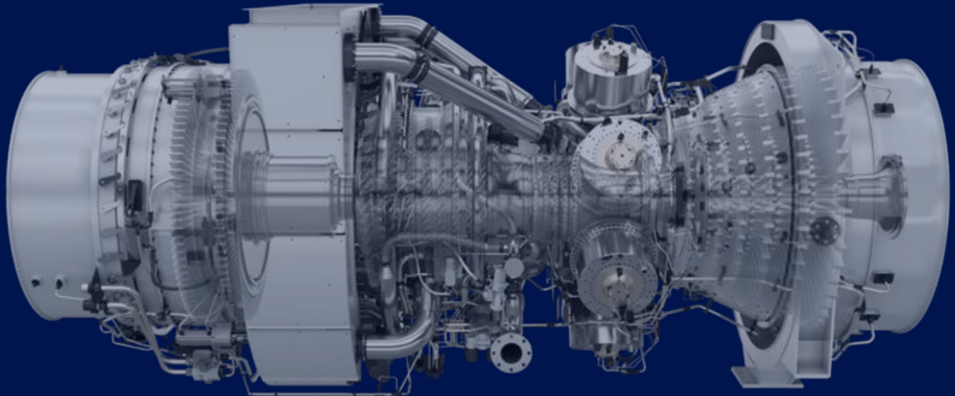

Gas Turbine Power Plants

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Combustion Chamber

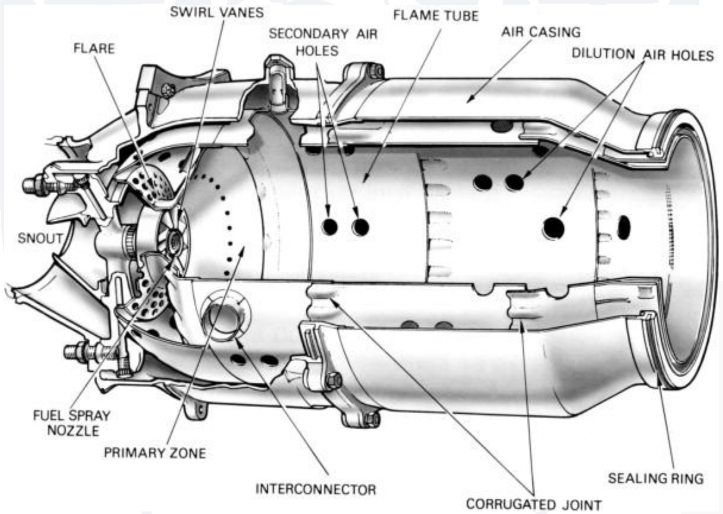


Figure 2. Combustion Chamber. [2]

Function:

The combustion chamber is the area inside the engine where the fuel/air mixture is compressed and then ignited.

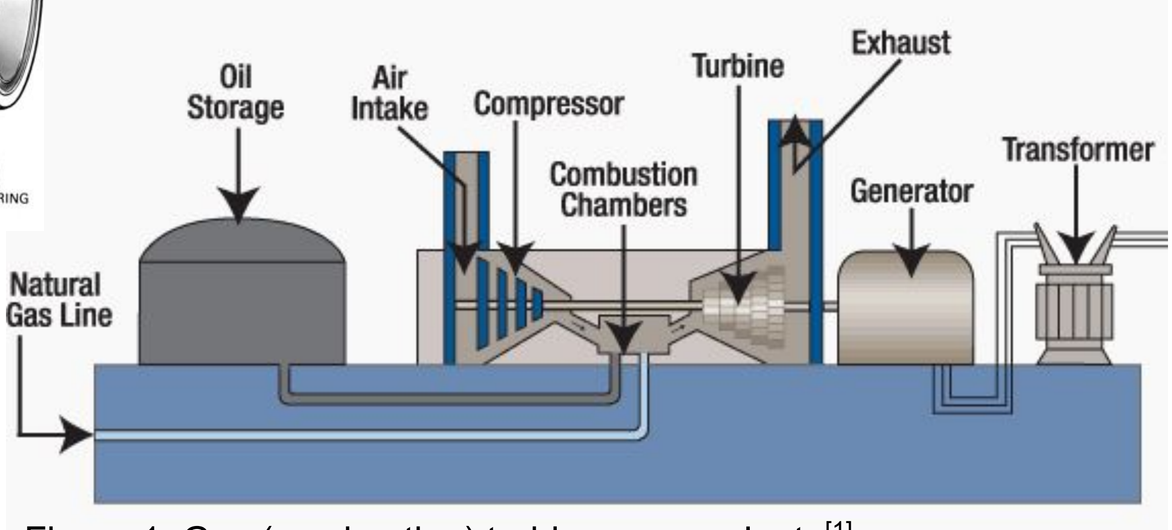


Figure 1. Gas (combustion) turbine power plant. [1]

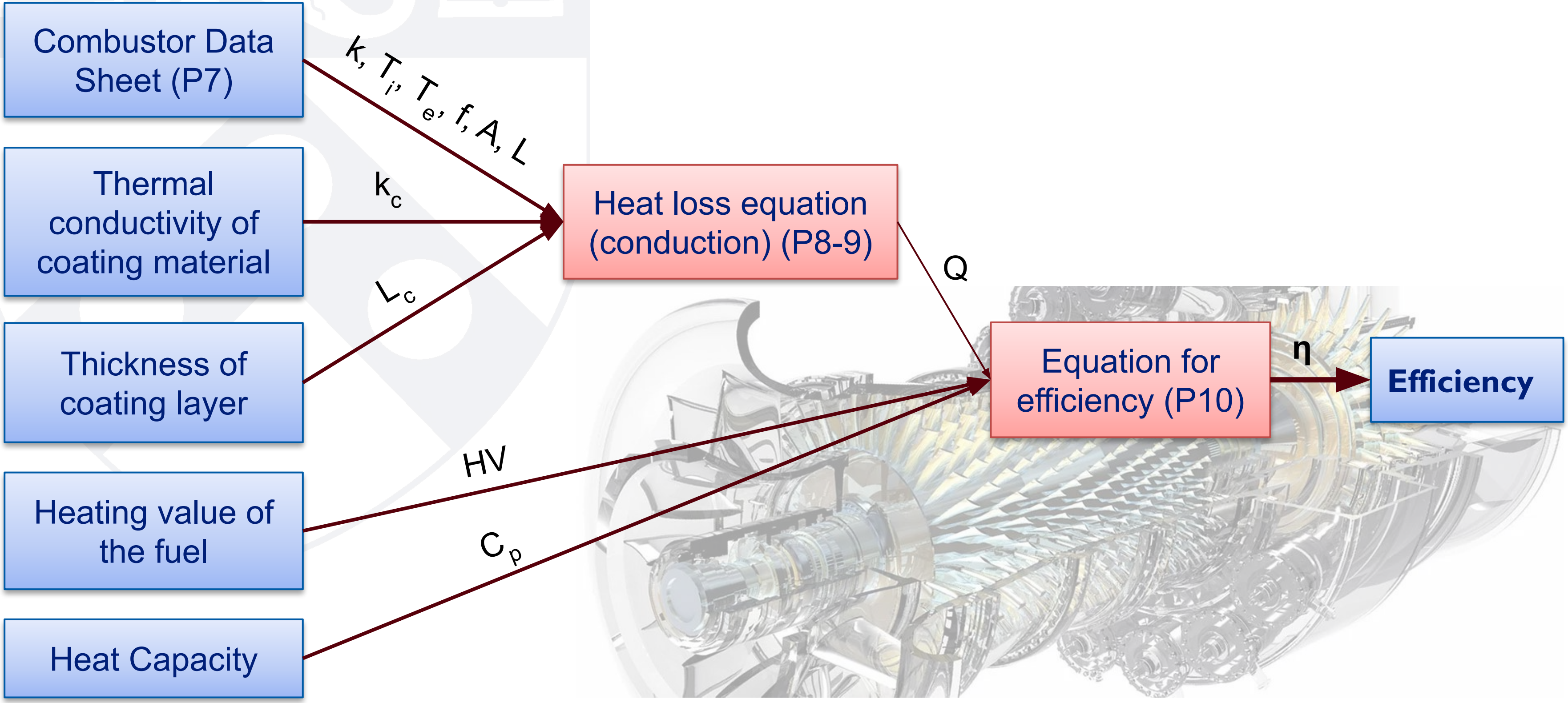
Current Problems

- Low efficiency:
  - ☹ 40-45% of fuel energy is converted into a useful work.[3]
  - ☹ Remaining fuel energy in form of heat losses is transferred to environment.
    - One possible solution to decrease heat losses from the engine is by insulation of combustion.
    - **Plan:** Evaluate the application of thermal barrier coating (TBC) on combustion chamber as a solution to reduce the heat loss and design a system with an improved efficiency.

Project Prospects (Method: TBC)

Goal Parameter	Efficiency
Current Efficiency	40-45% [3]
Target Efficiency	Increased by at least 3%
Design Variable(s) to be Manipulated in this Project to Attain Target	Coating material [4] (Thermal conductivity), Coating thickness [5]
Constraint	Operating temperature > 870 °C [6]

Flow Diagram



Nomenclature

Symbol	Description	Unit
A	Heat transfer area	m^2
C_p	Specific heat capacity	kJ/kg-K
f	Fuel/Air ratio	-
HV	Heating value	J/kg
k	Thermal conductivity	W/m-°C
k_c	Thermal conductivity of the coating material	W/m-°C
L	Wall thickness	m
L_c	Coating layer thickness	m
Q	Heat transfer rate	J/kg
T	Temperature	°C
η_{th}	Thermal efficiency	-
η_{comb}	Combustion efficiency	-

Appendix: A1. Manufacturer Data

Manufacturer	General Electric	
Model	DLN-2.6 Combustor [6]	
Material	HASTELLOY® X alloy [7]	A nickel-chromium-iron-molybdenum alloy
Thermal conductivity	26.7 W/m-°C [7]	Thermal conductivity at 900 °C
Material constraint	Capability of 1177 ℃ [7]	Still in good condition after operating for 8,700 hours
Inlet temperature	396 - 404 ℃ [8]	Temperature of the preheated inlet fuel/air mixture
Fuel/Air ratio	83% fuel - 17% air [9]	Mass ratio of the inlet fuel and air
Wall thickness	0.01 m [10]	The wall thickness of the combustion chamber
Surface area	0.5 m^2 [10]	The effective heat transfer area

A2. Engineering Principles

- Fuel energy:[3]
  - Work 40 - 45%
  - Heat losses to coolants 25 - 30%
  - Heat losses to exhaust gas 25%
  - Friction 5% (neglected)

- Conductive heat transfer (loss):[11]
  - The basic equation of conductive heat transfer is Fourier's law: $$\dot{Q} = -k_t A \left(\frac{dT}{dx}\right)$$

  where Q is the conductive heat transfer rate, k_t is the thermal conductivity of the material, A is the cross-sectional area normal to the heat transfer direction, and dT/dx is the temperature gradient in the direction of heat transfer.

- Thermal efficiency:[12]
  - The thermal efficiency of a gas turbine power plant is defined as the ratio of net work output to heat input.

A3. Engineering Principles

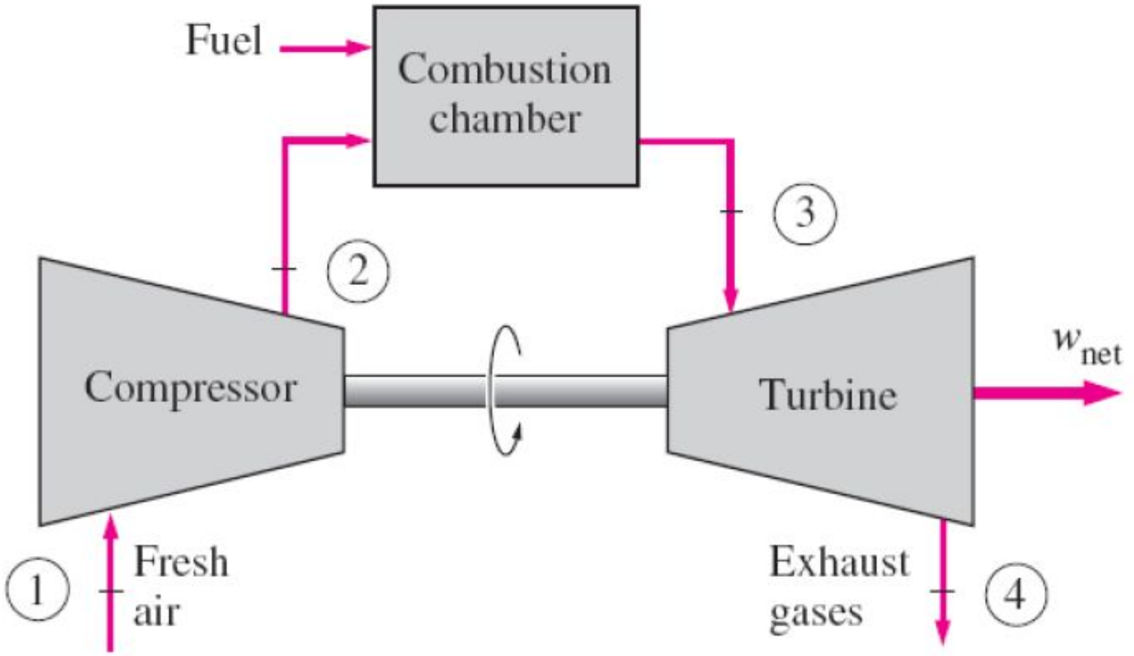


Figure A3. Schematic of a gas turbine power plant (Brayton cycle). The numbers label the different states in the system.

A4. Conductive Heat Loss

- Conductive heat transfer to the coolants:[7] $$\dot{Q} = \frac{A(T_h - T_l)}{L/k}$$

  where Q is the heat transfer rate, A is the surface area, L is the wall thickness, k is the thermal conductivity of the material, T_h and T_l are the high and low temperatures.

- Conductive heat transfer to the wall with layers in series: $$\dot{Q} = \frac{A(T_h - T_l)}{\frac{L}{k} + \frac{L_c}{k_c}}$$

  where k_c and L_c are the thermal conductivity and the wall thickness of the coating material

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A5. Thermal Efficiency

- The definition of thermal efficiency gives the following equation:

$$\eta_{th} = \frac{\dot{w}_{out} - \dot{w}_{in}}{\dot{q}_{in}}$$

where w_{out} is the total work generated by the turbine, w_{in} is the total work done by the compressor, and q_{in} is the total heat added to the cycle.

- In order to find the heated (q_{in}) added to the cycle, apply energy balance around the combustion chamber:

$$(1+f)C_{pg}(T_3 - T_2) + \dot{q} = \eta_{comb} f HV = \dot{q}_{in}$$

where f is the fuel-to-air mass flow ratio, C_{pg} is the specific heat capacity of combustion gas, T_2 and T_3 are the inlet and outlet temperatures of the combustion chamber, q is the rate of heat loss, η_{comb} is the combustion efficiency, and HV is the heating value of the fuel.

A6. Thermal Efficiency Cont.

- Work (w_{in}) introduced by the compressor can be calculated as:

$$\dot{w}_{in} = C_p(T_2 - T_1)$$

where C_p is the specific heat capacity, T_1 is the inlet temperature of the compressor.

- Work (w_{out}) created by the turbine can be determined as:

$$\dot{w}_{out} = (1 + f)C_{pg}(T_3 - T_4)$$

where T_4 is the outlet temperature of the turbine.

- Therefore, the thermal efficiency of a gas turbine plant is then determined

$$\eta_{th} = \frac{(1 + f)C_{pg}(T_3 - T_4) - C_p(T_2 - T_1)}{\eta_{comb} f HV}$$

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