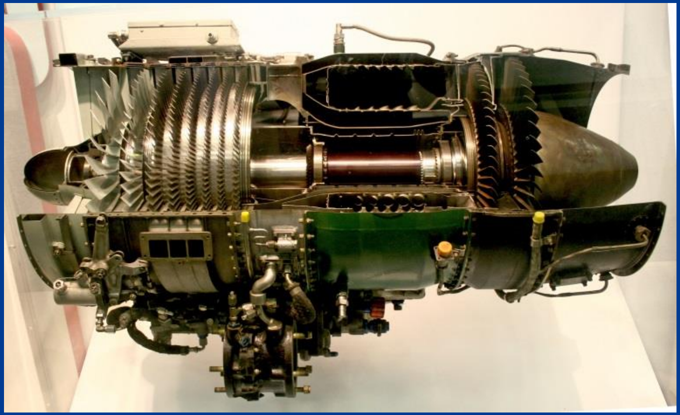
Applied Thermodynamics - II



Gas Turbines - Cycle Arrangements

Sudheer Siddapureddy sudheer@iitp.ac.in

Department of Mechanical Engineering

Auxiliary Devices

Other components/arrangements

- Intercoolers between the compressors
- Reheat combustion chambers between the turbines
- Heat-exchanger which uses some of the energy in the turbine exhaust gas to preheat the air entering the CC

Advantages of these refinements

- Increase the power out and η of the plant
- At the expense of added complexity, weight and cost

How to link together?

- Affects the maximum overall $\eta_{thermal}$
- Variation of power output
  - One arrangement for varying load at constant speed
  - Another for driving a ship's propeller, Power $\propto$ (Speed)^3

Open & Closed Cycles

Broad classification

1. Open cycle arrangement
2. Closed cycle arrangement

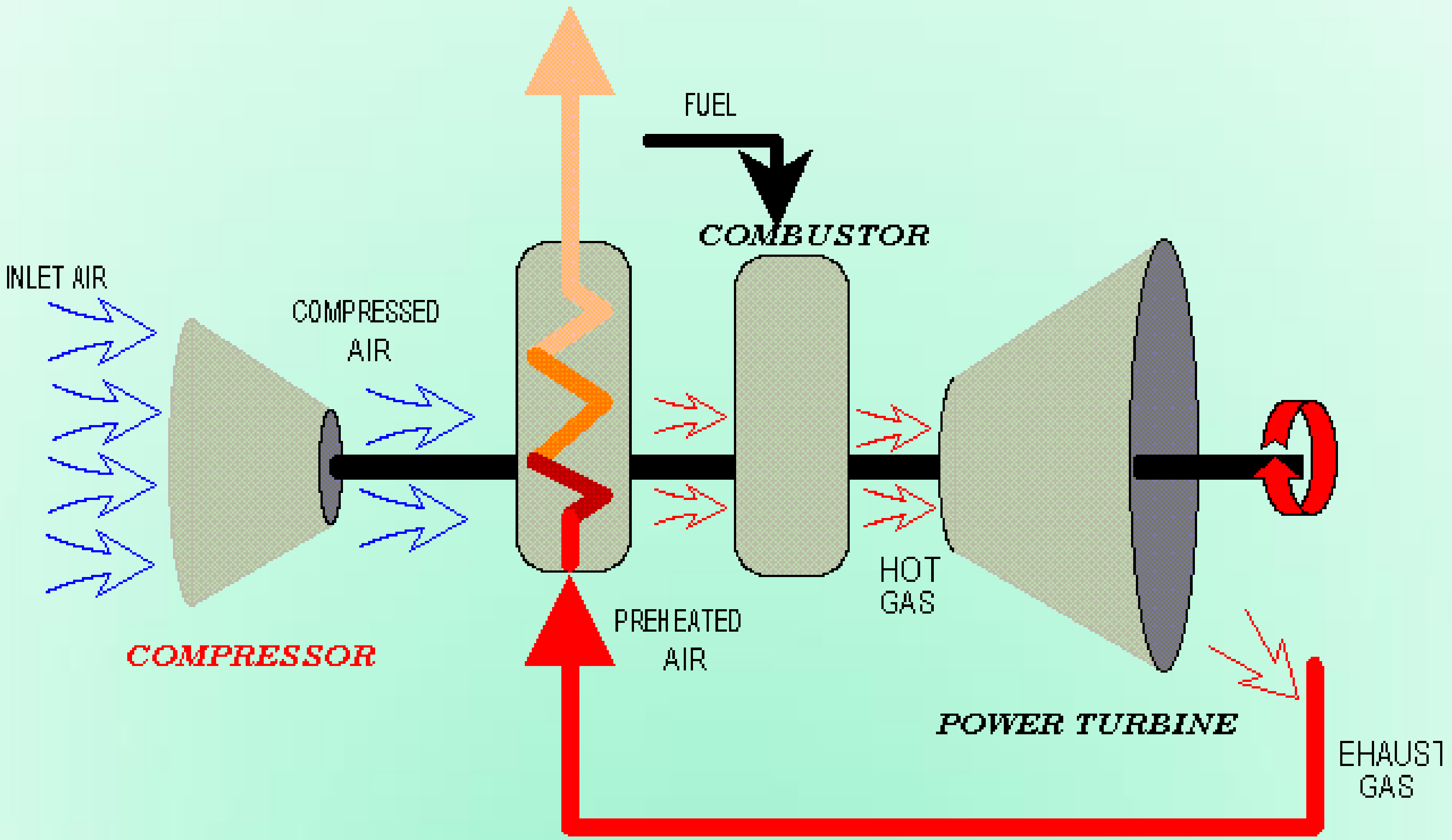
Open cycle arrangements

- Fresh atmospheric air is drawn into the circuit continuously
- Energy is added by the combustion of fuel in the working fluid
- Products of combustion expanded through turbine and exhausted into the atmosphere
- Most common

Closed cycle arrangements

- Usually, working fluid is not spoiled
- Heater or a gas boiler
- Similar to a steam turbine

Single Shaft Arrangement with Regeneration



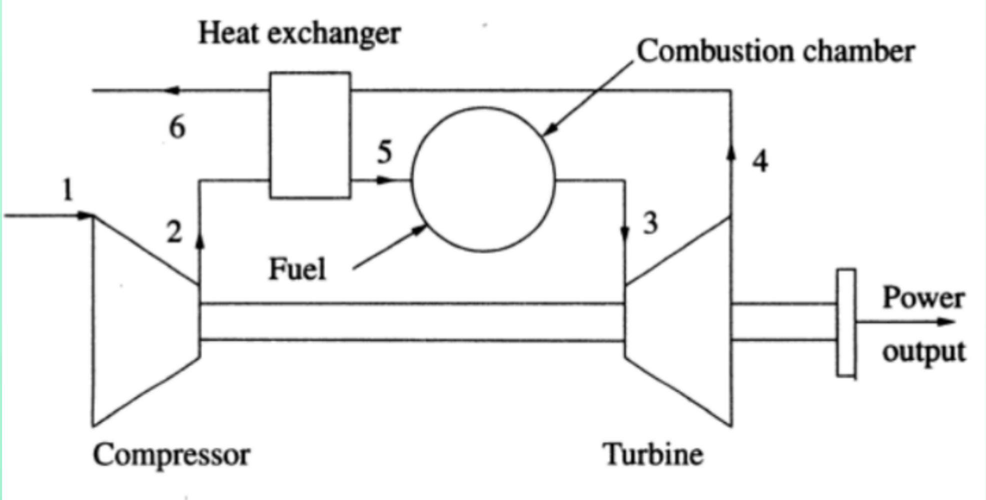
Single Shaft Arrangement with Regeneration

When?

- Fixed speed & load conditions (peak load power generation)
- Immediate response to change in load is not important
- η at part load is not important

Heat exchanger

- Improves $\eta_{thermal}$, for a given size of the plant
- Power output reduces by 10% due to pressure losses in HE
- Reduces the fuel
- Advantage only at low *r*

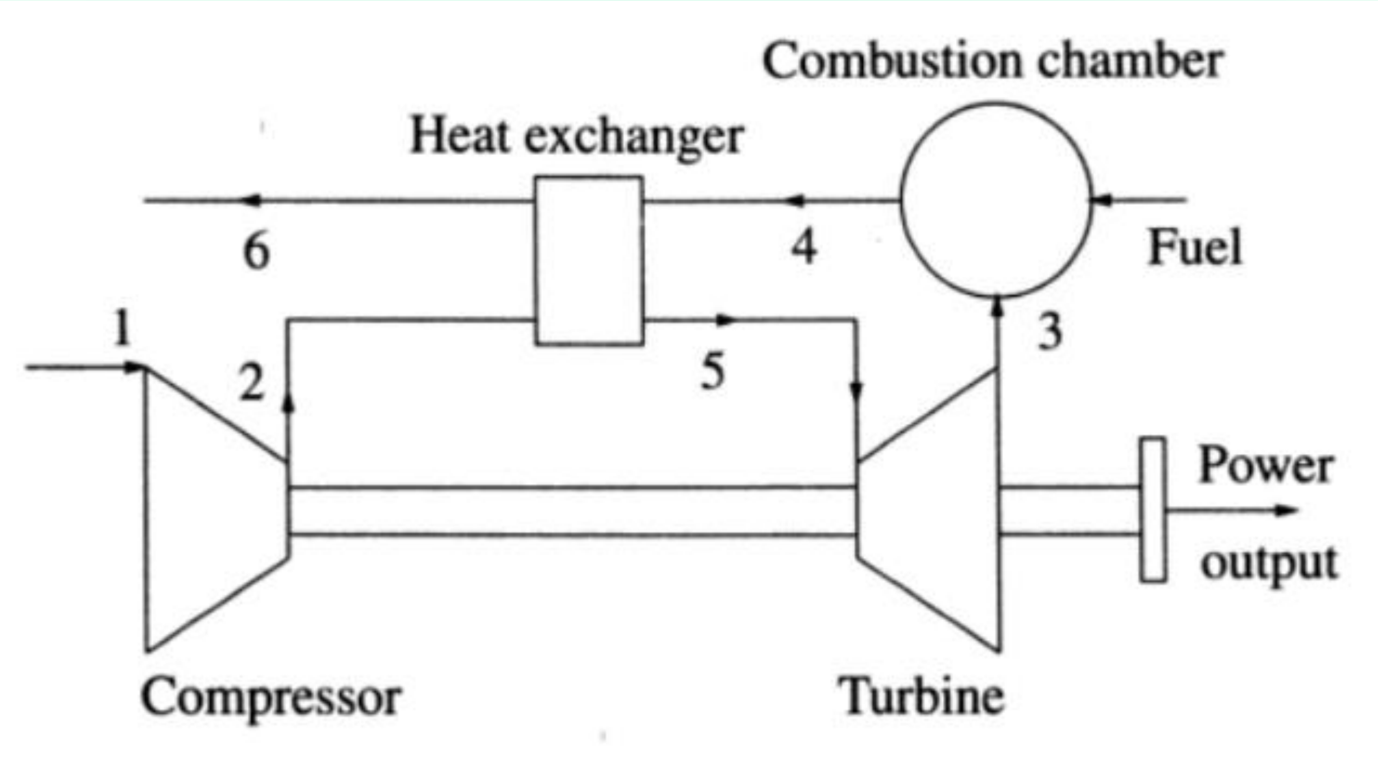


Single Shaft Arrangement – Alternative Arrangement

When?

Possibility of corrode or erode the blades

Availability of dirty fuel (pulverized coal)



Twin Shaft Arrangement

When?

Flexibility in operation

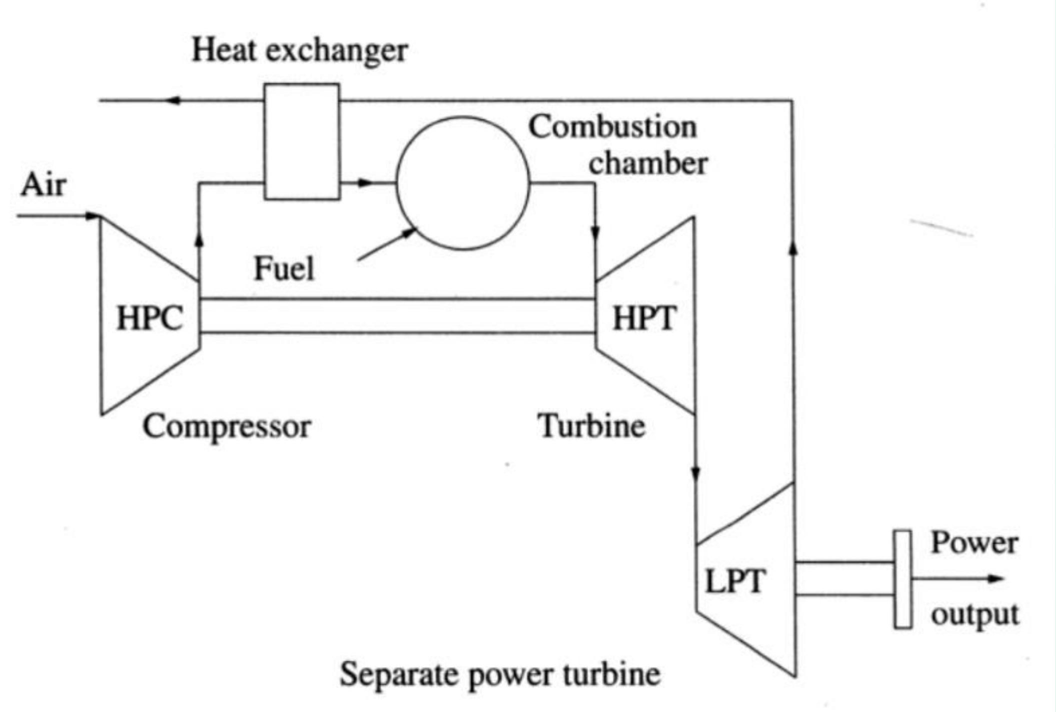
Pipeline compressor, marine propeller, road vehicle

Advantages

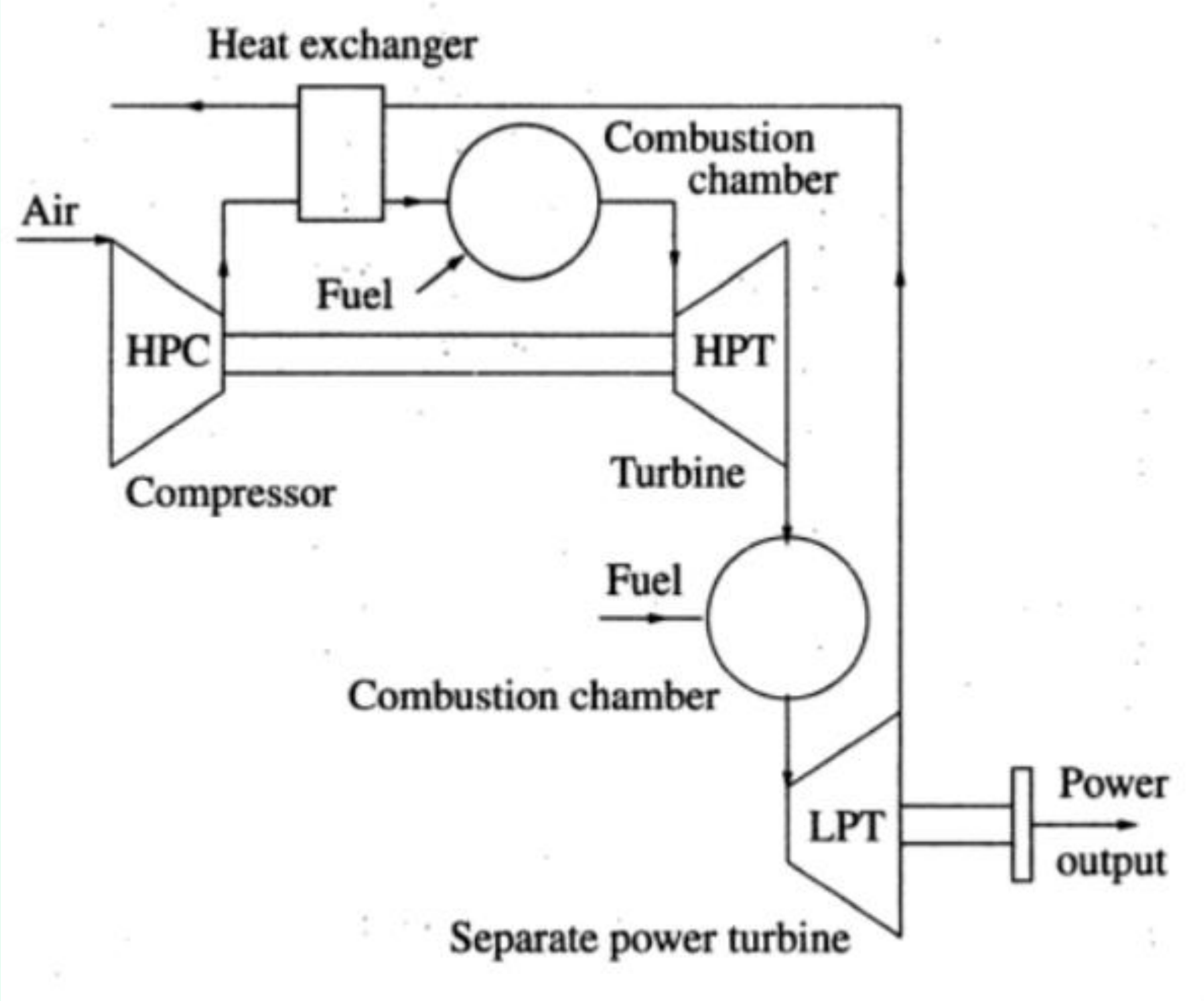
Easy start

Disadvantages

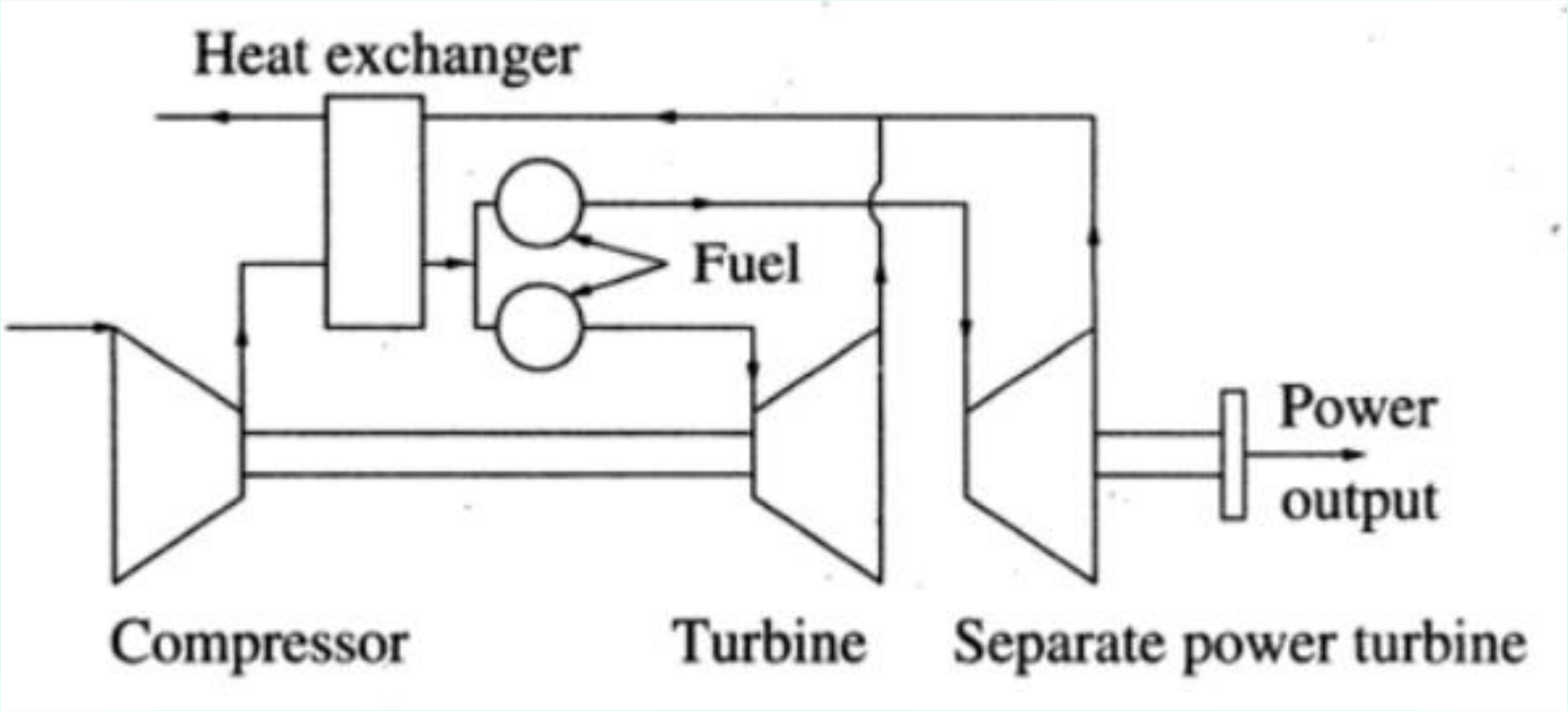
- Electrical shedding leads to overspeeding
- HPT, HPC at off loads?



Series Flow Twin Shaft Arrangement



Parallel Flow Twin Shaft Arrangement



Improving Performance

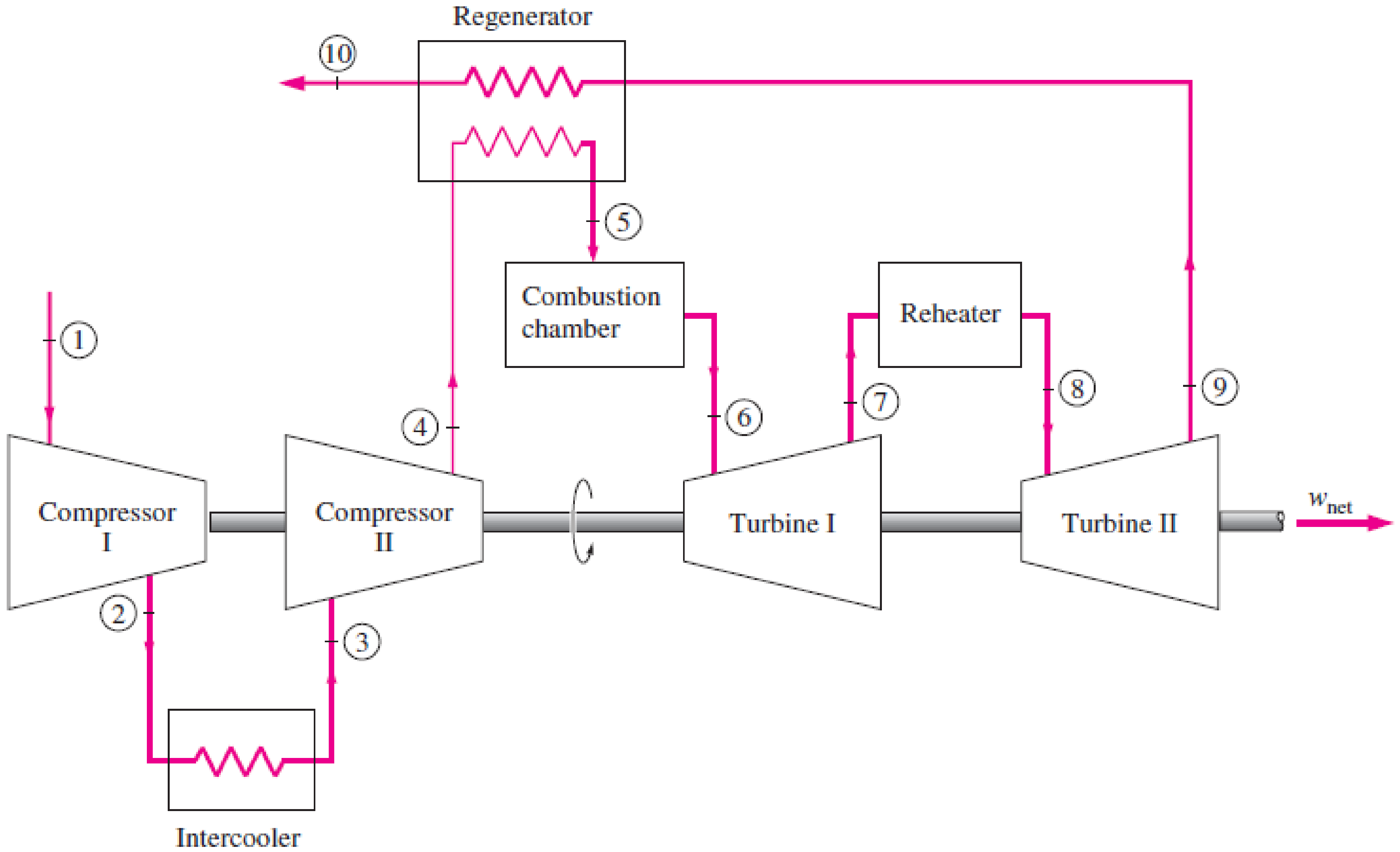
Performance can be improved

1. Reducing the work of compression
2. Increasing the work of expansion

How?

- For a given r, Power per unit quantity of working fluid $\propto T_{inlet}$
- Compression in stages with intercooling
- Expansion in stages with reheating the gas to the max. permissible temperature

Parallel Flow with Intercooling & Reheating



High Thermal Efficiency

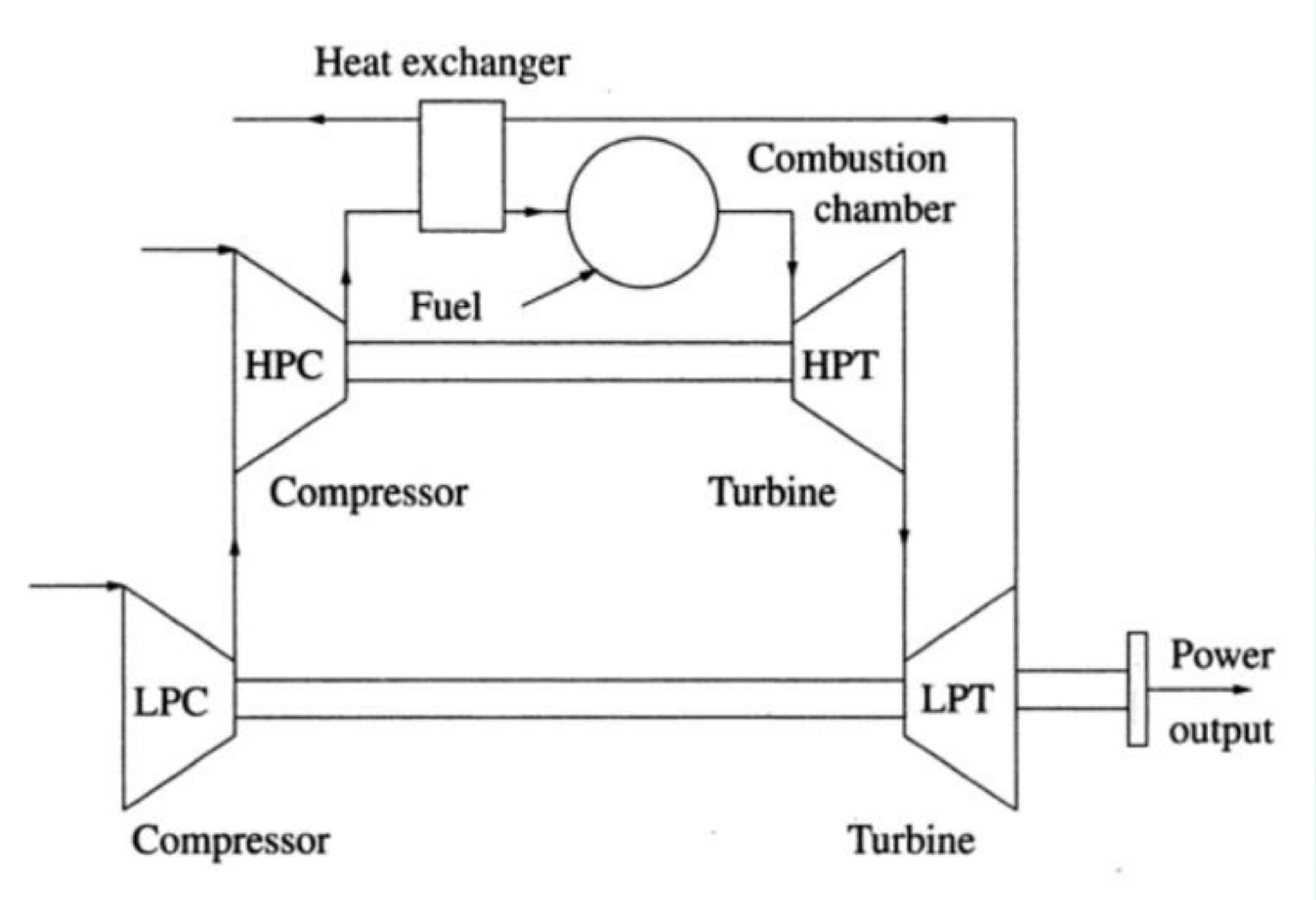
High pressure ratios are required

- $\eta_{axial} > \eta_{centrifugal}$ compressor
- Axial compressors - instability at off-design conditions
  - Vibrations – even at startup
  - Compressor exit is designed on the basis of flow and density
  - $\rho_{exit} >> \rho_{inlet}$
  - At low speeds ρ_{exit} falls
- More dangerous at $r > 8$ in one compressor

How?

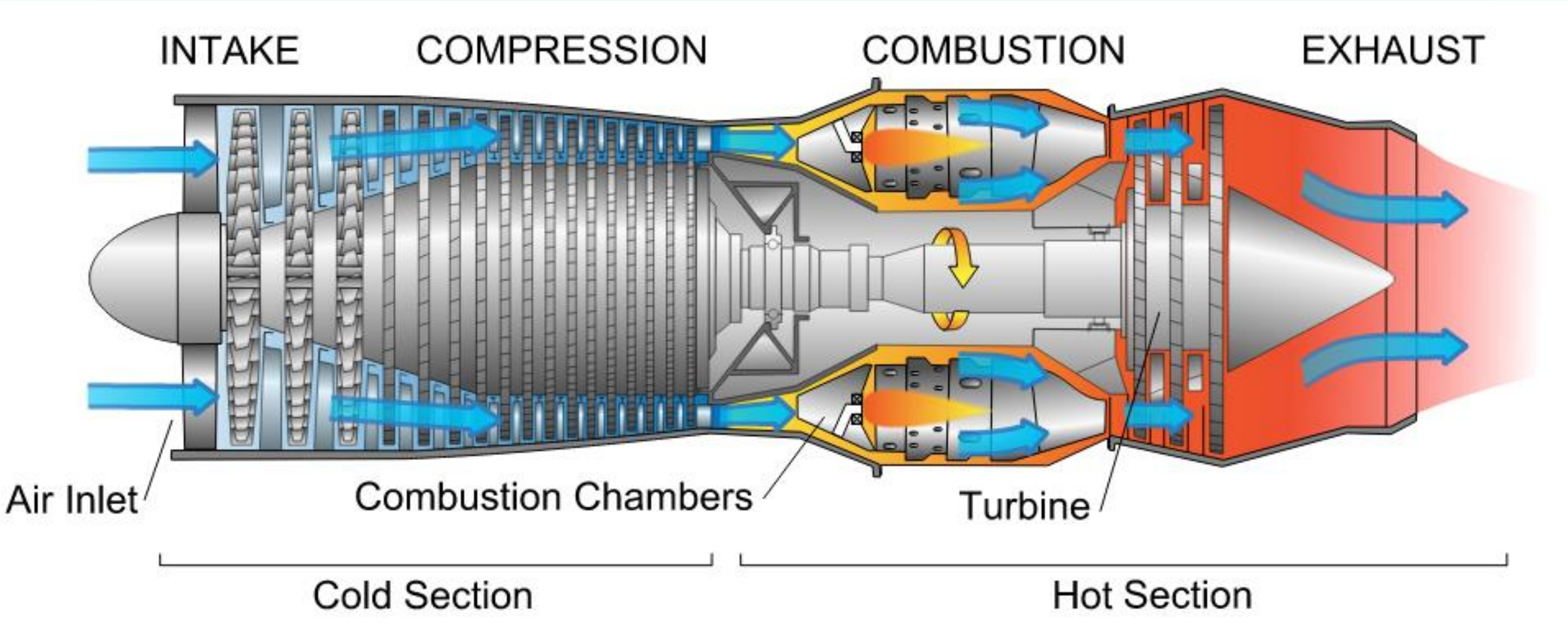
- Compressors at different rotational speeds
- Mechanically independent – needs individual turbines

Twin Spool Arrangement

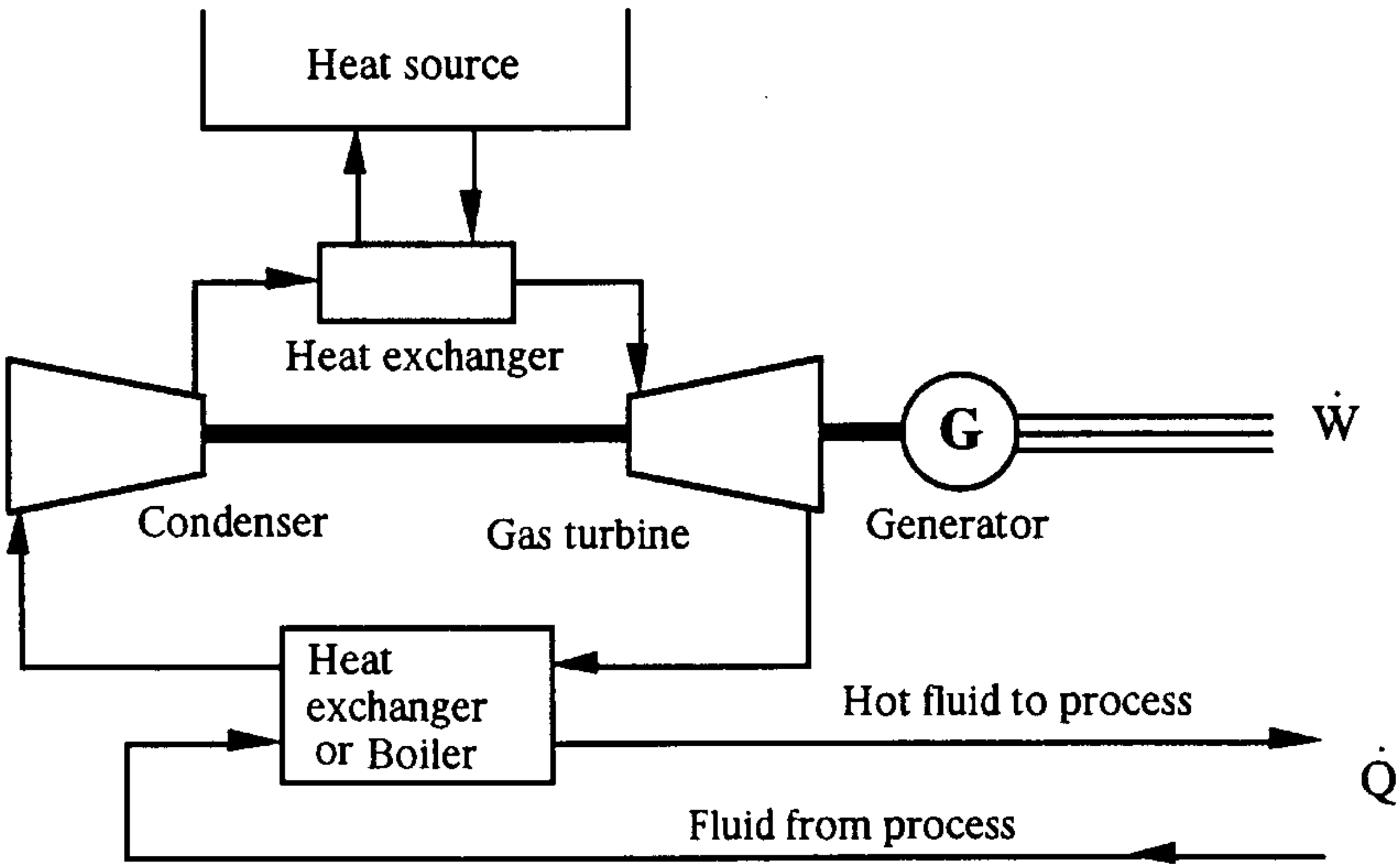


Multistage Compressor

High r or $\eta_{thermal}$ can also be safely achieved in a single compressor with several stages of variable stator blades



Closed Cycle Gas Turbine with Cogeneration System



Closed Cycles - Advantages

Advantages

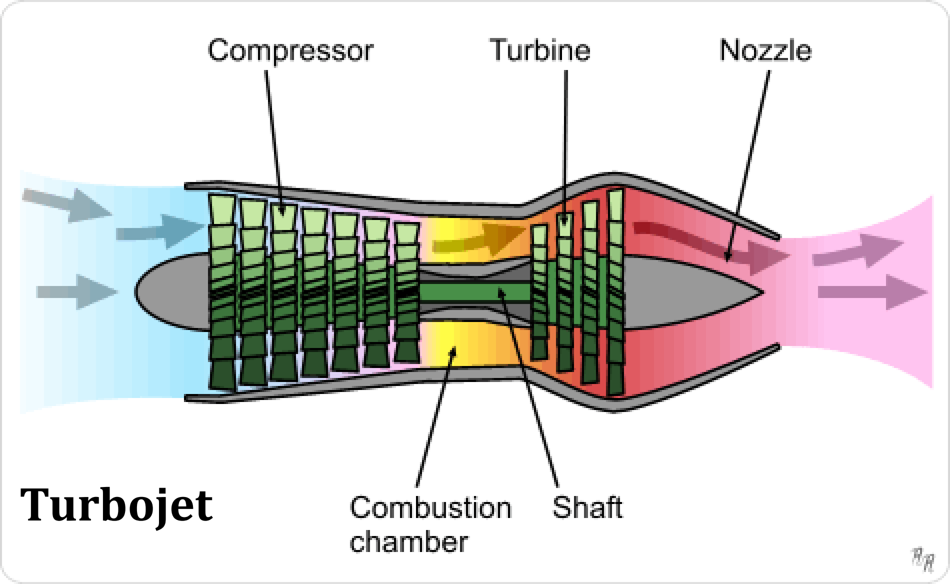
- No Erosion of turbine blades
- Continuous filtration of working fluid is not there
    - Once at startup
- Gases other than air can be used
- Cheaper fuels can be used
- Maintain r but increase pressure (there by increasing ρ)
- Reduces size of the plant for a given output
- Change the pressure level for dynamic control
    - However, maximum cycle temperature maintained
    - No change in overall efficiency

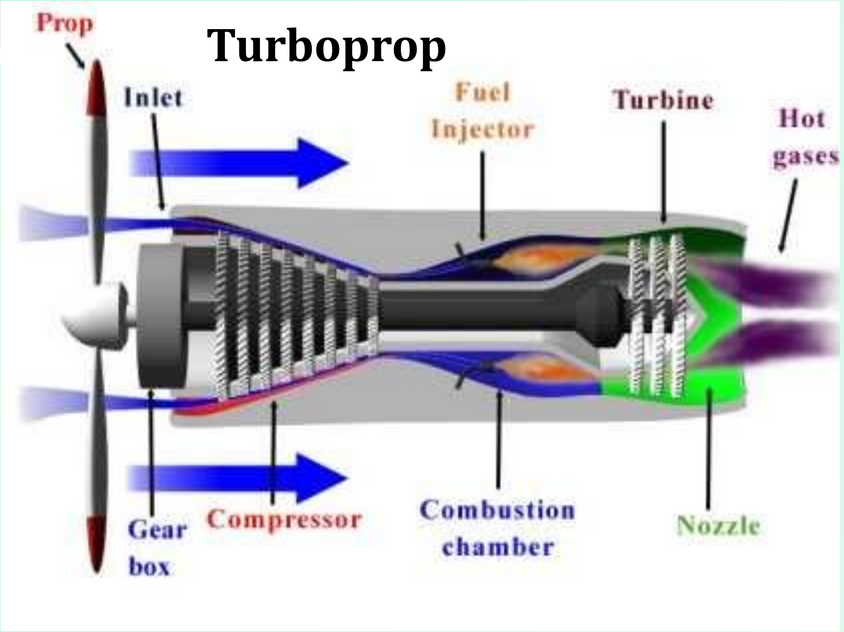
Closed Cycles - Disadvantages

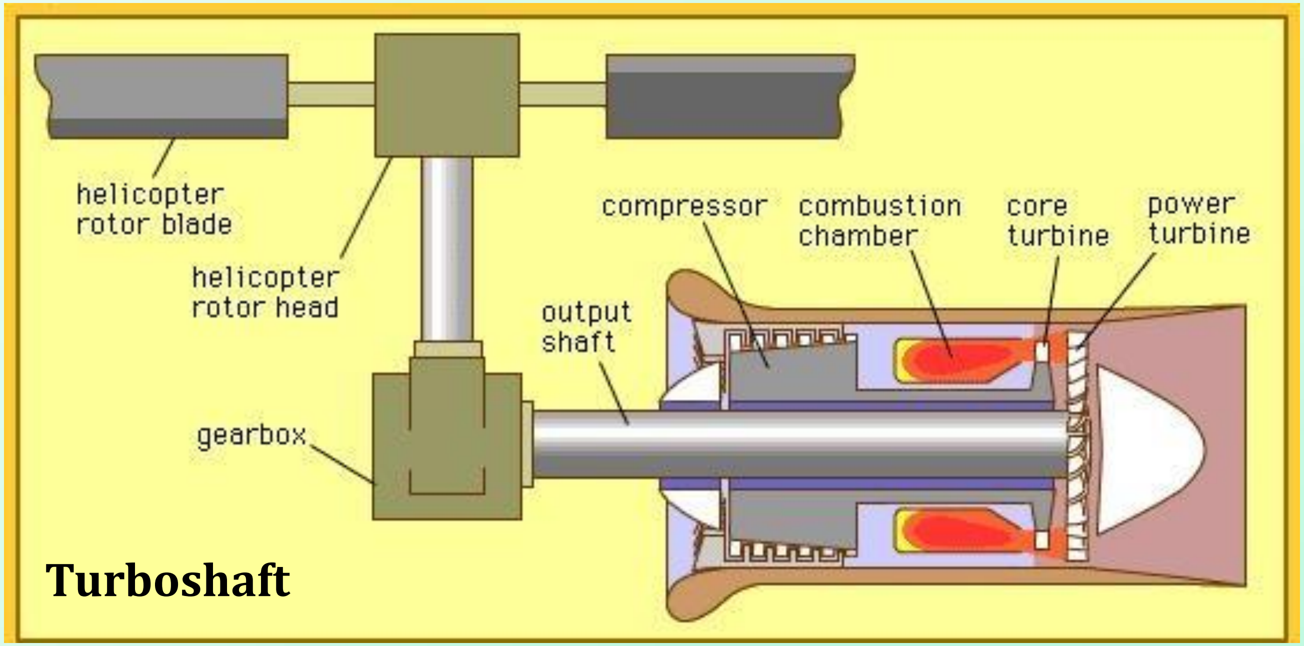
Disadvantages

- We are again back to steam turbine mechanism
- Bulky heating system (gas boiler)
- Leak proof of the system
- Large capacity of cooler is necessary
- Only for stationary power plants

Aircraft Propulsion

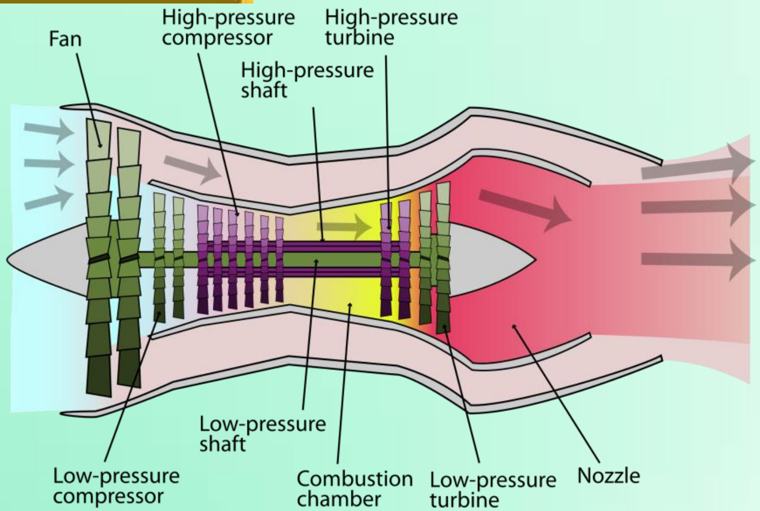






Turboshaft

Turbofan (or bypass)



Industrial Applications

Compared with Aircraft gas turbine:

- The life of an industrial plant is of 11.5 years
- Size and weight is not of much importance
- The kinetic energy at turbine exhaust is wasted

Industrial Applications

Advantages over other Power plants

- Compact
- No cooling tower like that in a Steam Turbine
- Complete packages, built, tested and transported
  - Not often erected on site

Large Gas Turbines Manufacturers

Alstom

General Electric

Siemens-Westinghouse

Siemens, SGT-750, 39 MW

0.25 MW Steam turbine (right), AC generator (left)

Tube condenser is set beneath the turbine

Advantages of Gas Turbines

Over Reciprocating engines

- High $\eta_{mechanical}$ due to less friction
- Better balancing
- Low cost than multi-cylinder petrol or diesel engines
- Power to weight to ratio

- External shape and size
- Cheaper fuels: benzene, powdered/pulverized coal
- Less lubrication
- Minimum maintenance
- Low operating pressures
- High operation speeds
- Silent, smokeless exhaust (abundant air)

Disadvantages of Gas Turbines

Over Reciprocating engines

- Poor $\eta_{overall}$
  - Most of the energy goes in feeding compressor
- T_{max} limitation
- How to cool the blades?
- How to start the engine?

  Complicated

Environmental Issues

Jet exhaust was noisy but ignored for military applications

- Noise $\propto$ (Jet velocity)^8
- Turbofan - Maintain thrust with low velocity but at higher airflow

Gas turbines for non-aircraft applications offer relatively clean-burning power plant

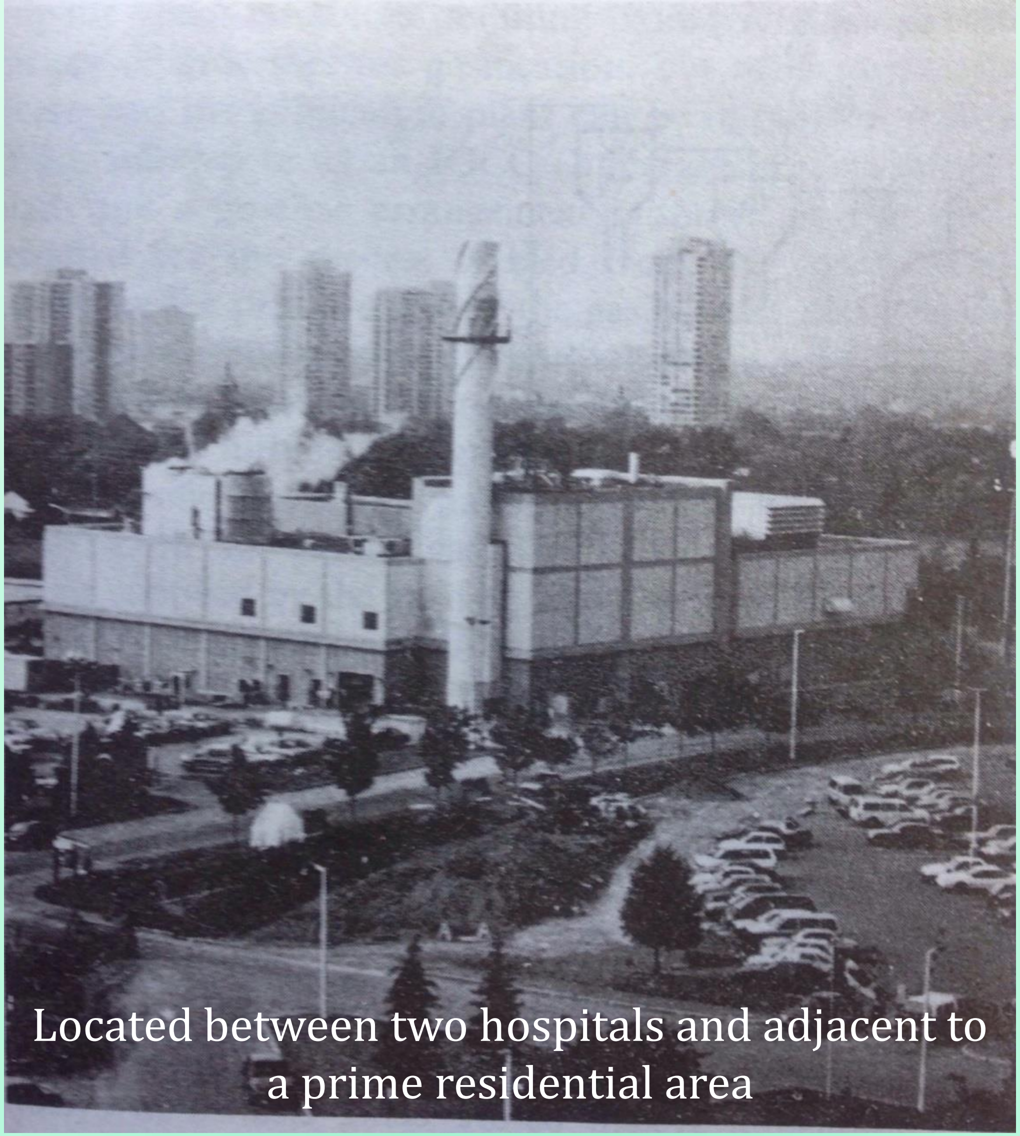
Main combustion product of any hydrocarbon fuel is CO_2

- Global warming – Greenhouse effect

Improve engine efficiencies to burn less fuel

Alternative fuels

70 MW Combined Cycle Plant



Located between two hospitals and adjacent to a prime residential area