47201 Engineering thermodynamics

Lecture 9c: Gas turbines and the Brayton cycle (Ch. 10.4-5)

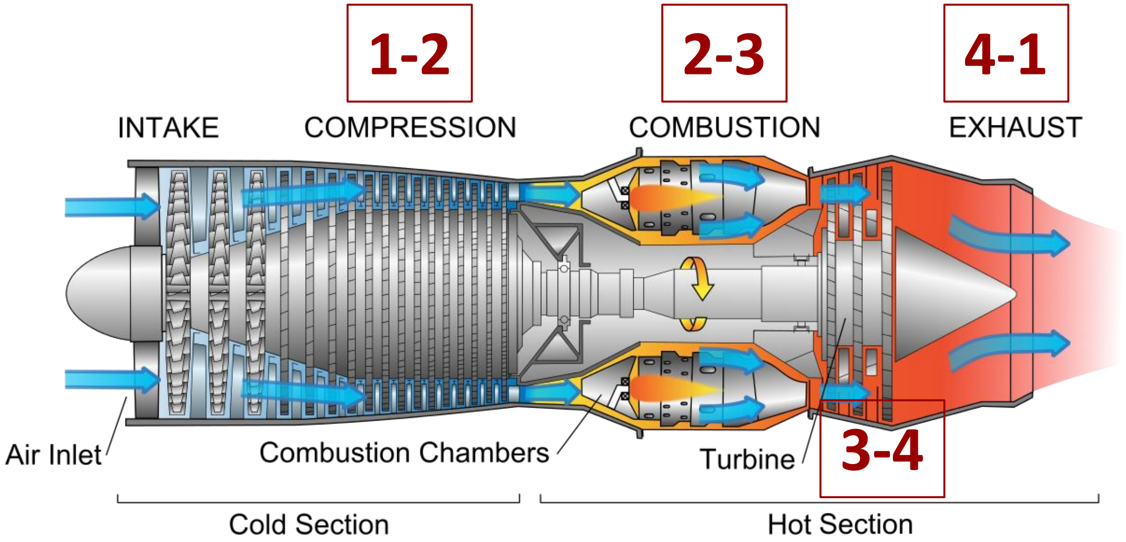
Gas turbine

- Gas turbines use rotary compressors to increase the pressure of air as it enters the combustion chamber

- Fuel is then injected into the combustion chamber, and it ignites, which causes a large increase in temperature and pressure

- The high pressure gas then is exhausted through a turbine where the enthalpy of the exhaust gas is converted to mechanical work

- The cycle can be optimized to produce work (often as electricity) or for propulsion
  - For work, the turbine should remove as much energy from the exhaust as possible.
  - For propulsion, the turbine only recovers enough work to power the compressor



Gas turbine components

- We can simplify a gas turbine engine as having three components: the compressor, combustor and turbine
- The compressor and turbine are mounted on a common shaft, which allows the turbine to power the compressor
- Air is taken in from the atmosphere and exhaust gas is rejected back to the atmosphere
- No heat exchanger for heat rejection is necessary because the heat is carried out with the exhaust gases

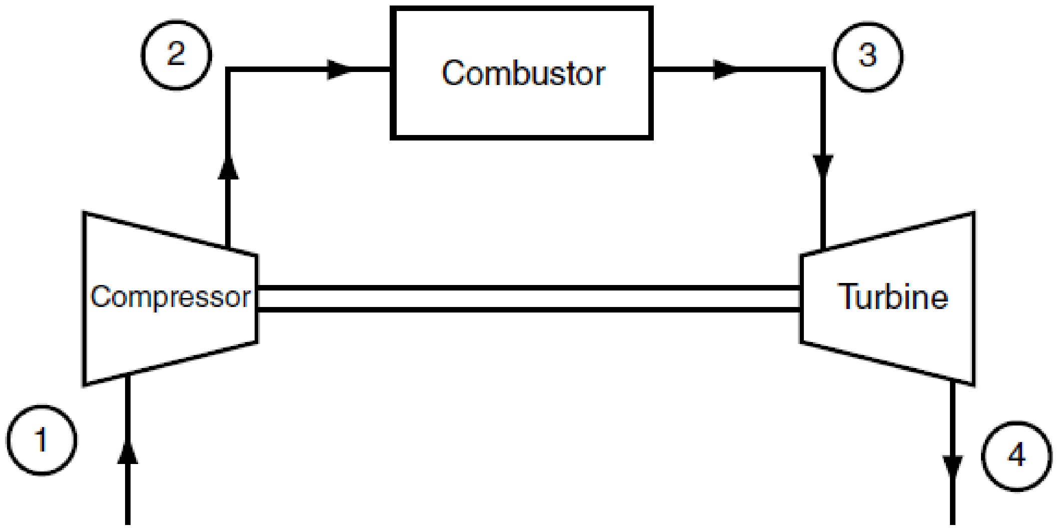


Figure 10.8 Schematic diagram of a gas turbine.

Gas turbine thermodynamic model – the Brayton cycle

An air standard model of a gas turbine engine is the Brayton cycle: It is modelled as having two heat exchangers, a compressor and a combustor. The cycle steps are:

1. Isentropic compression
2. Constant pressure heat addition
3. Isentropic expansion
4. Constant pressure heat rejection

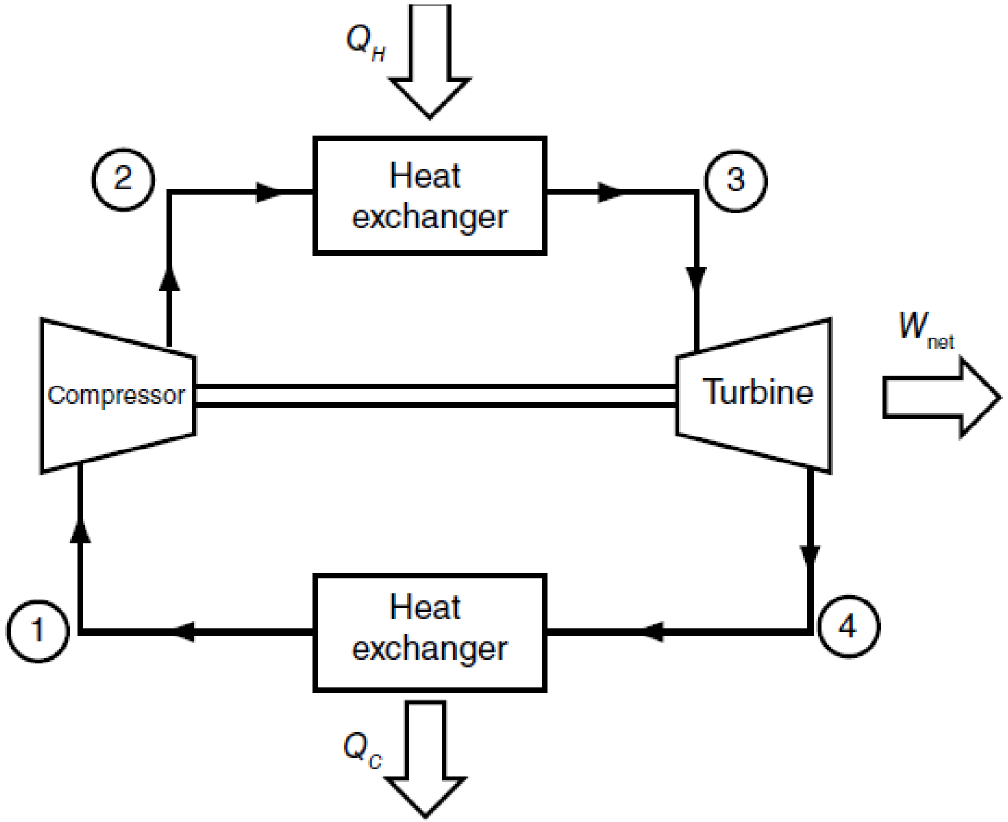
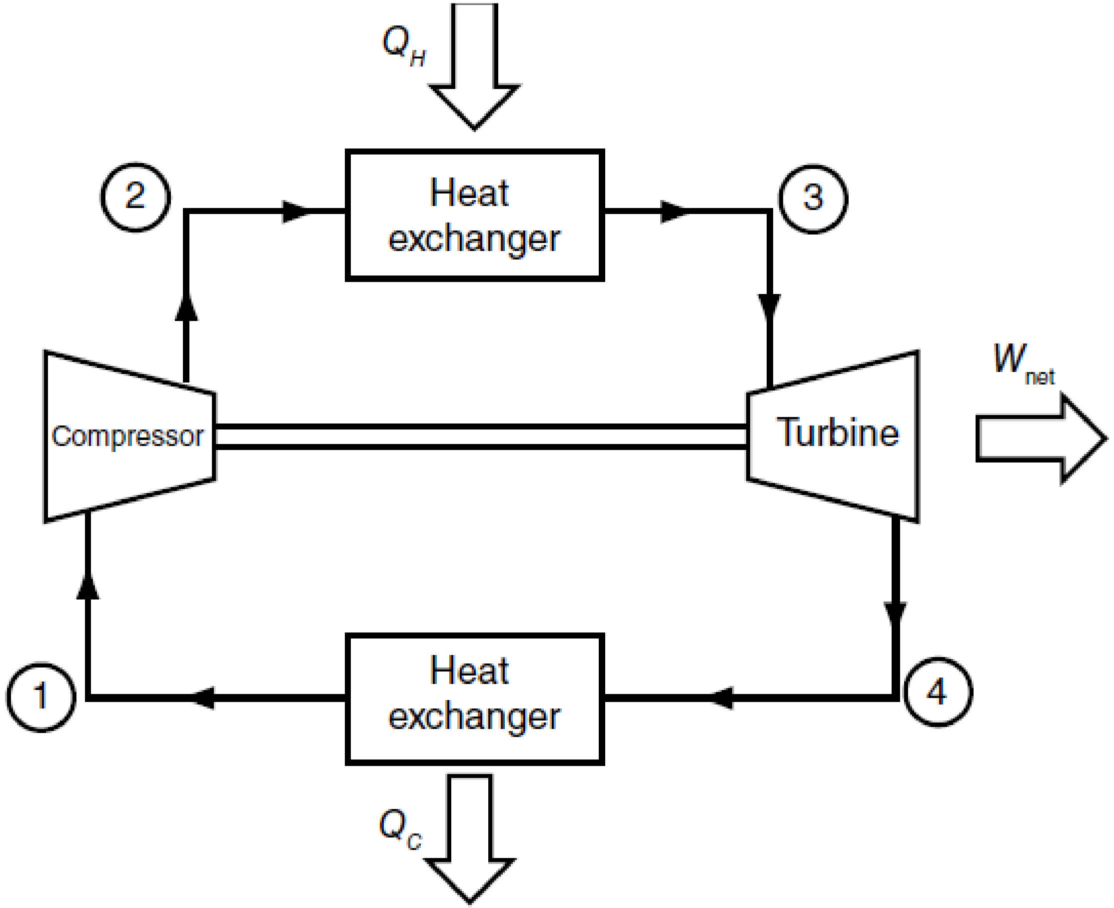
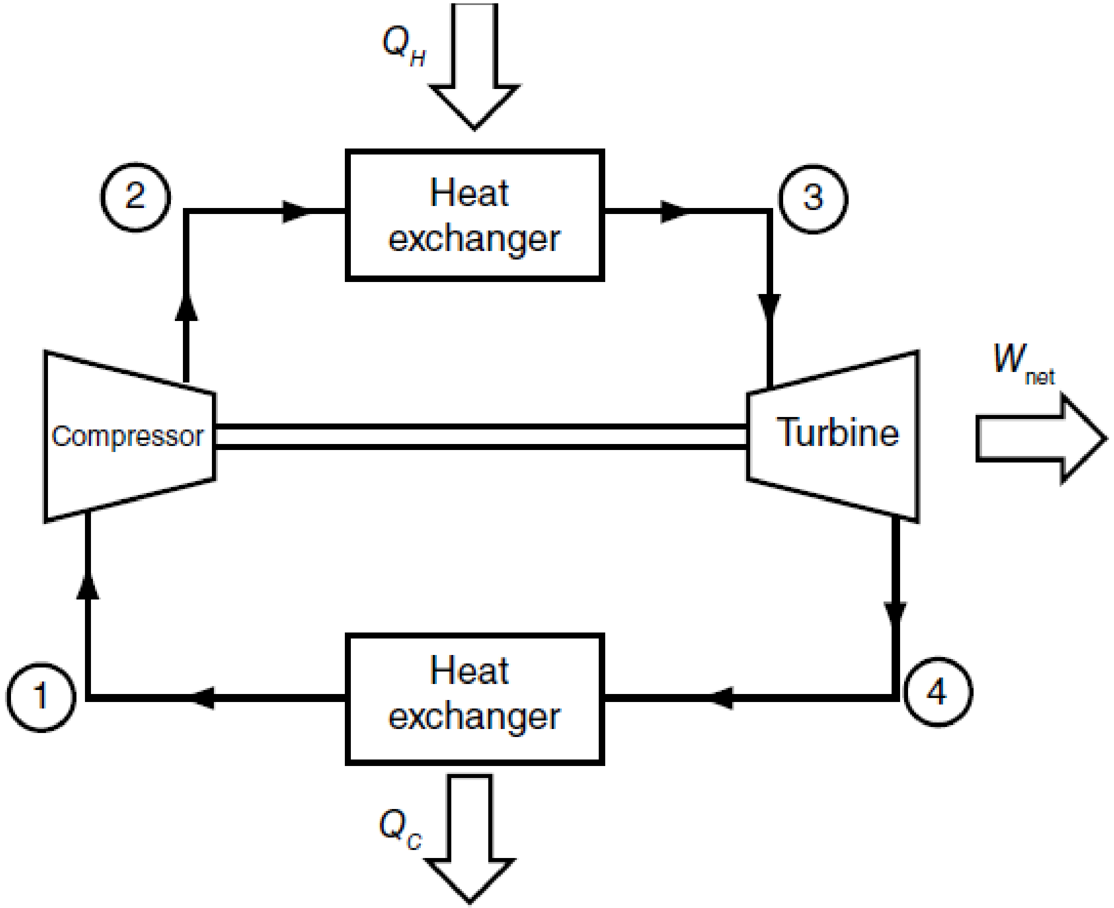


Figure 10.9 Gas turbine modelled as a closed cycle.

Brayton cycle P-v diagram



Brayton cycle T-s diagram



Brayton cycle analysis

Looking at the work done at constant entropy:

$1 \rightarrow 2$ Isentropic compression

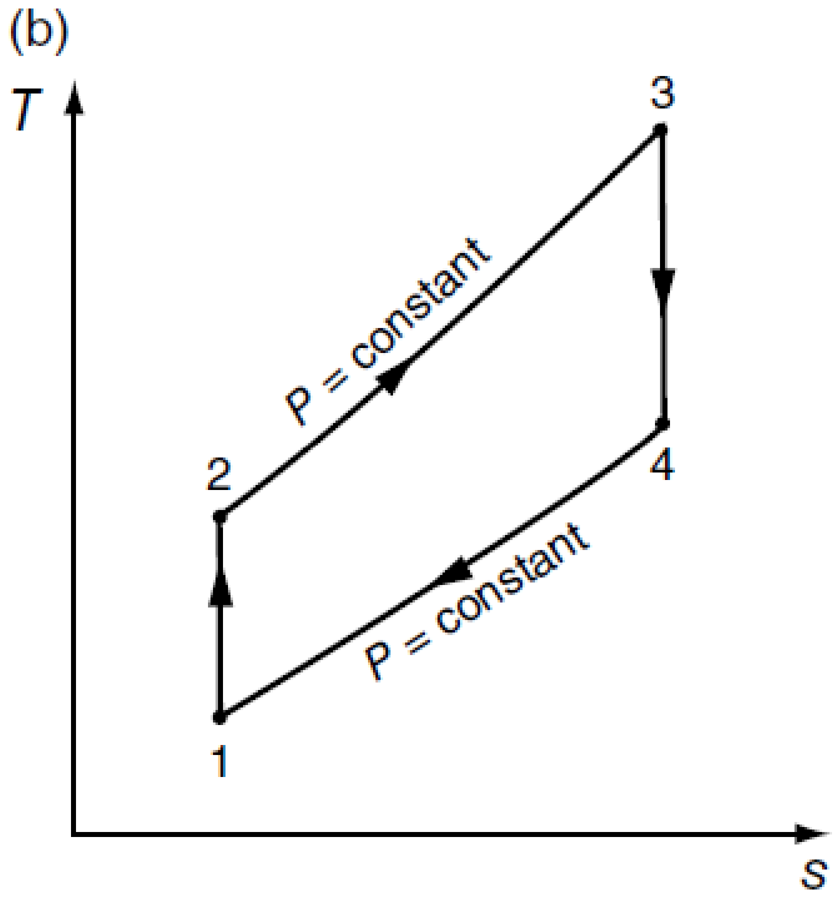
$$w_{comp} = h_2 - h_1 = c_p(T_2 - T_1)$$

$3 \rightarrow 4$ Isentropic expansion

$$w_{turb} = h_3 - h_4 = c_p(T_3 - T_4)$$

We can then express how much of the turbines work is taken by the compressor:

$$bwr = \frac{w_{comp}}{w_{turb}} = \frac{h_2 - h_1}{h_3 - h_4}$$



Brayton cycle efficiency

- The efficiency for the Brayton cycle is:

$$\eta_{th,Brayton} = \frac{W_{net}}{Q_H} = \frac{W_{turb} - W_{comp}}{Q_H} = \frac{Q_H - Q_C}{Q_H}$$

Example 10.3

Problem: An air standard Brayton cycle with a compressor pressure ratio of 10 takes in air at 100 kPa and 300 K and a mass flow rate of 5 kg / s. The air leaves the combustor at 1260 K. Find the efficiency of the cycle and the net power output. Use air tables to find the properties of air.

Find: Efficiency $\eta_{th,\mathrm{Brayton}}$ of the cycle, net power output W_{net} of the cycle.

Assume:

1. Steady state
2. Isentropic compression and expansion
3. Constant pressure heat addition and extraction

Example 10.3 solution

The solution procedure is mostly the same as for the other air standard cycles. To solve, we will using the following steps:

1. State 1 is fully defined, so we can look up enthalpy, entropy etc. directly.

2. We can find state 2 because we know the entropy (s_1) and the pressure ratio

3. For state 3, we know the pressure and the temperature, which will fully define the state. We can look up entropy, enthalpy etc.

4. For state 4, the entropy is known (same as s_3) and we know pressure is the same as the inlet.

5. The cycle is fully defined, and we can calculate the specific work and efficiency