Gas Power Cycle - Jet Propulsion Technology, A Case Study
Ideal Brayton Cycle

1-2 Isentropic compression
2-3 Constant pressure heat addition
3-4 Isentropic expansion
4-1 Constant pressure heat rejection
The thermal efficiency of the ideal Brayton cycle is

\[
\eta_{\text{th}} = \frac{w_{\text{net}}}{q_{\text{in}}} = \frac{w_{\text{out}} - w_{\text{in}}}{q_{\text{in}}} = \frac{q_{\text{in}} - q_{\text{out}}}{q_{\text{in}}} = 1 - \frac{q_{\text{out}}}{q_{\text{in}}} = 1 - \frac{(h_4 - h_1)}{(h_3 - h_2)}
\]

\[
= 1 - \frac{c_p(T_4 - T_1)}{c_p(T_3 - T_2)} = 1 - \frac{T_1(T_4/T_1 - 1)}{T_2(T_3/T_2 - 1)} \quad \text{equation (1)}
\]

Processes 1-2 and 3-4 are isentropic (adiabatic), therefore

\[
\frac{T_2}{T_1} = \left(\frac{P_2}{P_1}\right)^{(k-1)/k}, \quad \text{and} \quad \frac{T_3}{T_4} = \left(\frac{P_3}{P_4}\right)^{(k-1)/k}
\]

Also, \(P_2 = P_3\) and \(P_4 = P_1\), therefore \(\frac{T_2}{T_1} = \frac{T_3}{T_4}\) and \(\frac{T_2}{T_3} = \frac{T_1}{T_4}\)

Equation (1) becomes

\[
\eta_{\text{th}} = 1 - \frac{T_1}{T_2} = 1 - \frac{T_4}{T_3} = 1 - \frac{1}{\left(\frac{P_2}{P_1}\right)^{(k-1)/k}} = 1 - \frac{1}{r_p^{(k-1)/k}}
\]

where \(r_p = \frac{P_2}{P_1}\) is the pressure ratio of the compressor and the turbine
Jet Propulsion Cycle

• 1-2, inlet flow decelerates in the diffuser; pressure and temperature increase

• 5-6, outlet flow accelerates in the nozzle section, pressure and temperature decrease
Due to the action force $F_A$, the momentum of the air flowing through the engine increases:

$$F_A = (\text{linear momentum change}) = \left[ \frac{d}{dt} (mV) \right]_{\text{exit}} - \left[ \frac{d}{dt} (mV) \right]_{\text{in}} = \dot{m}V_{\text{exit}} - \dot{m}V_{\text{in}}$$

From Newton's third law: $F_A = F_R = \text{Propulsive force}$

$$F_R = \dot{m}(V_{\text{exit}} - V_{\text{in}})$$

**Propulsive Power**

$$\dot{W}_P = F_R V_{\text{aircraft}} = \dot{m}(V_{\text{exit}} - V_{\text{in}})V_{\text{aircraft}}$$
Gas Turbine Improvements

- Increase the gas combustion temperature ($T_3$) before it enters the turbine since $\eta_{th} = 1 - (T_4/T_3)$
  - Limited by metallurgical restriction: ceramic coating over the turbine blades
  - Improved intercooling technology: blow cool air over the surface of the blades (film cooling), steam cooling inside the blades.

- Modifications to the basic thermodynamic cycle: intercooling, reheating, regeneration

- Improve design of turbomachinery components: multi-stage compressor and turbine configuration. Better aerodynamic design on blades (reduce stall).
PW8000 Geared Turbofan Engine

- Twin-spool configuration: H-P turbine drives H-P compressor
- L-P turbine drives L-P compressor, on separated shafts
- Gearbox to further decrease the RPM of the fan
- More fuel efficiency
- Less noise
- Fewer engine parts

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