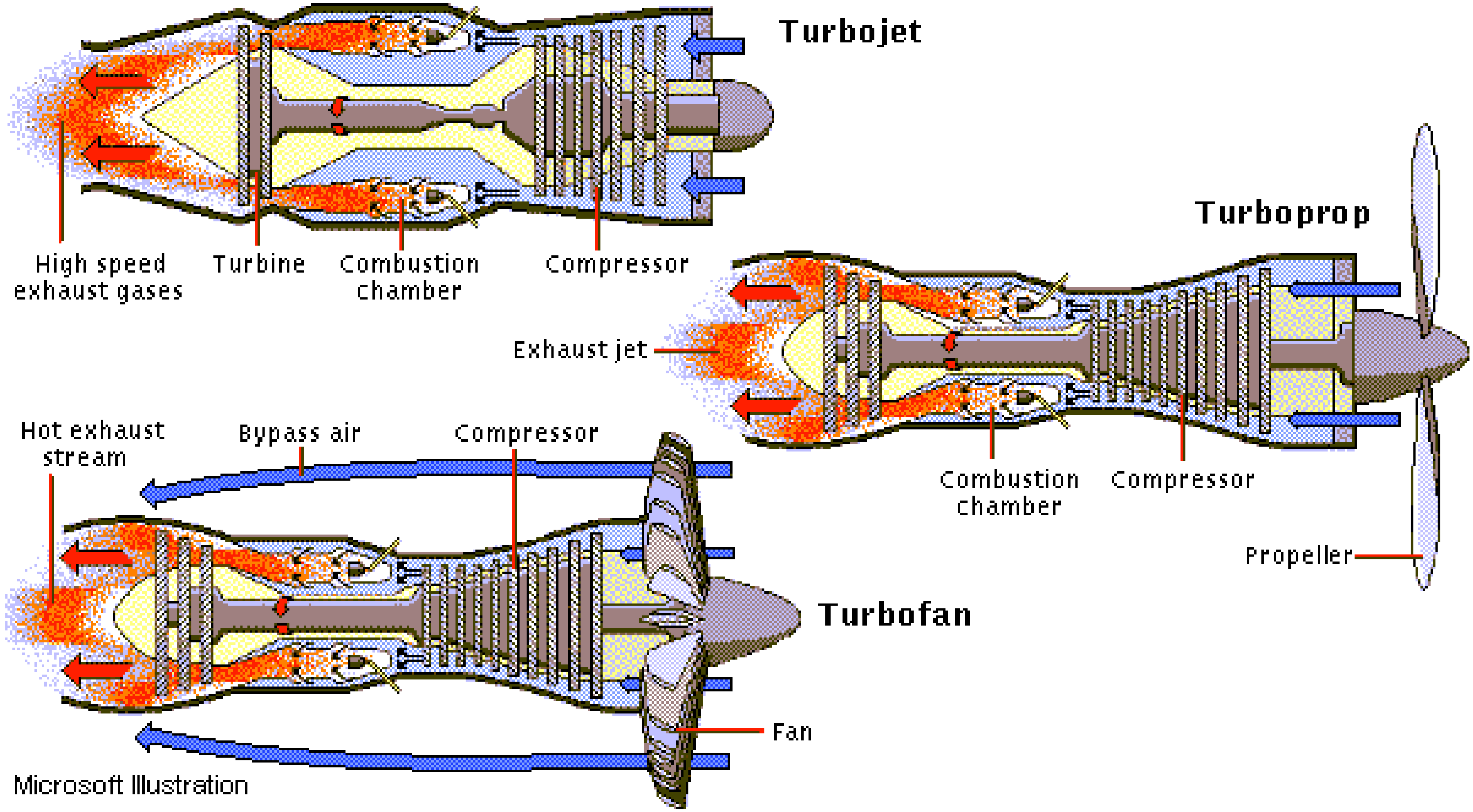
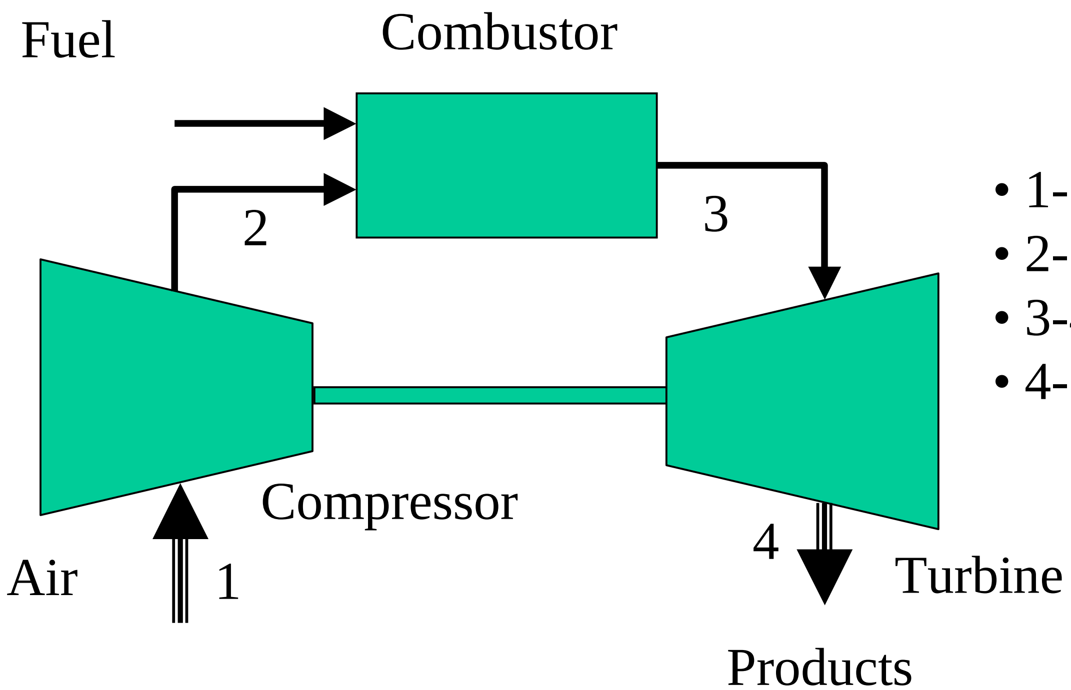
Gas Power Cycle - Jet Propulsion Technology, A Case Study

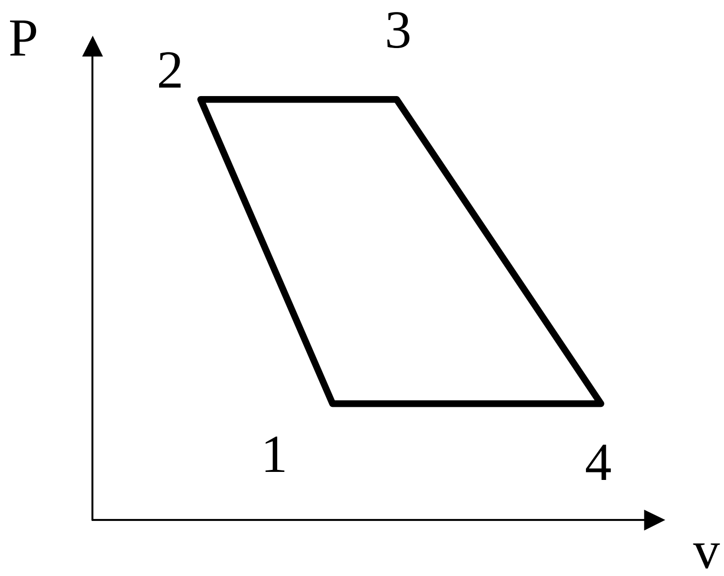


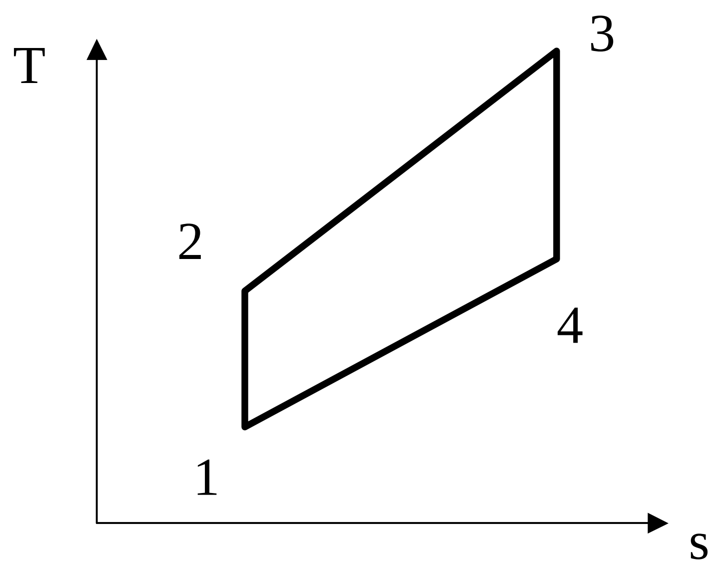
Microsoft Illustration

Ideal Brayton Cycle



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





Ideal Brayton Cycle - 2

The thermal efficiency of the ideal Brayton cycle is

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

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

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

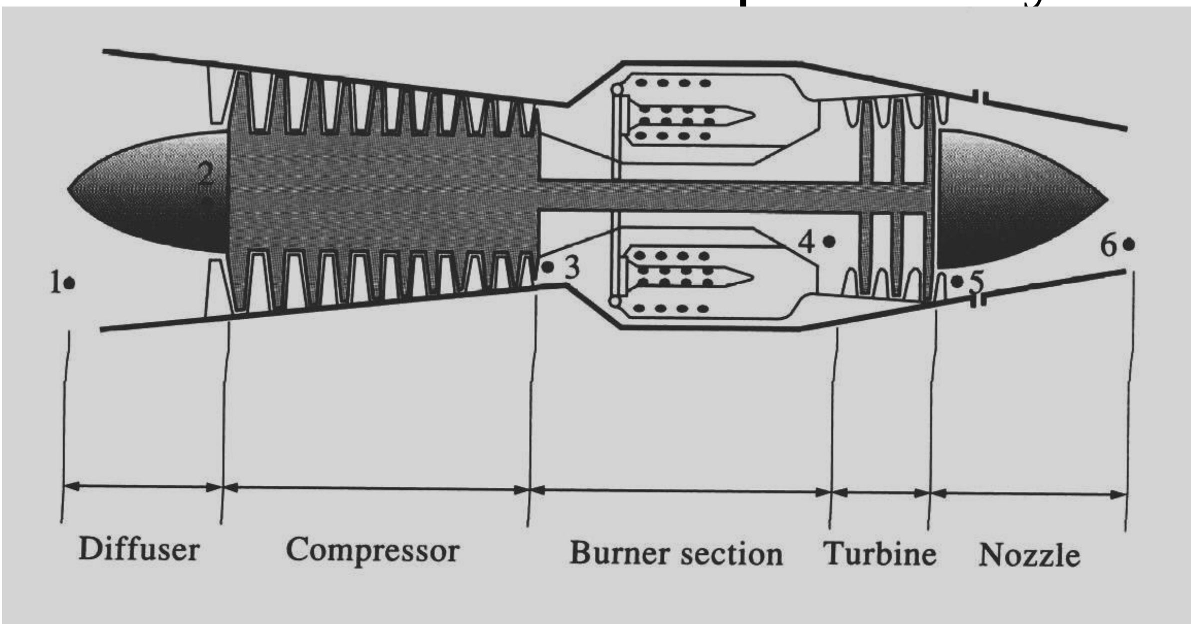
$$\frac{T_2}{T_1} = \left(\frac{P_2}{P_1}\right)^{(k-1)/k}, \ and \ \frac{T_3}{T_4} = \left(\frac{P_3}{P_4}\right)^{(k-1)/k}$$

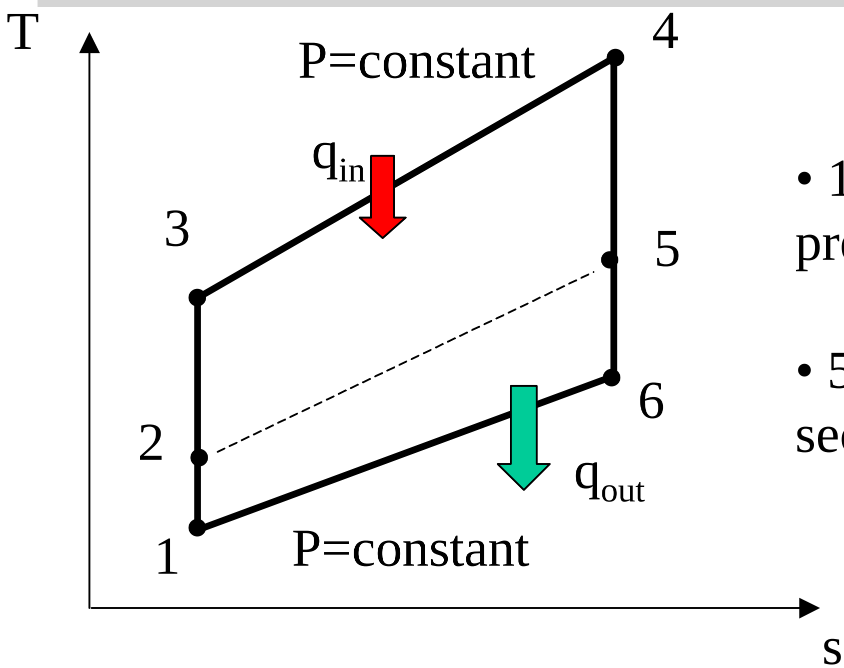
Also, $\mathrm{P}_2 = P_3$ and $\mathrm{P}_4 = P_1$, therefore $\frac{T_2}{T_1} = \frac{T_3}{T_4}$ and $\frac{T_2}{T_3} = \frac{T_1}{T_4}$

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 $\mathrm{r_p} = \frac{P_2}{P_1}$ is the pressure ratio of the compressor and the turbine

Jet Propulsion Cycle



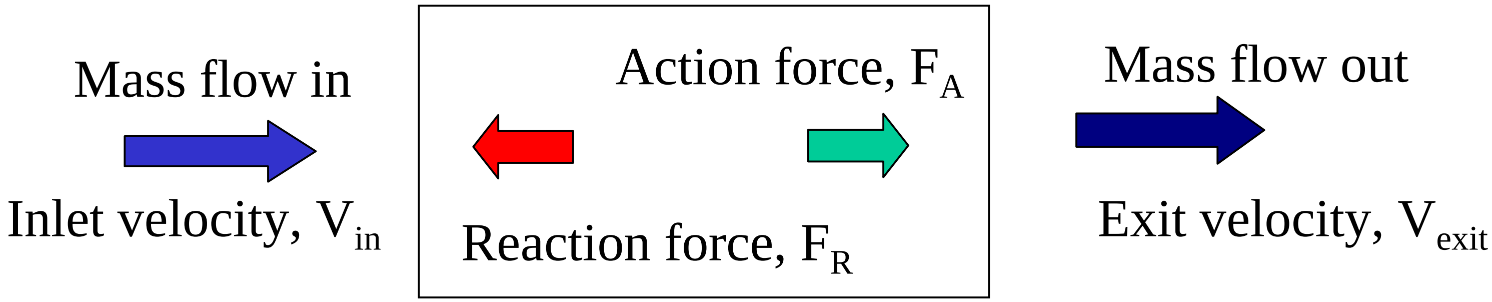


• 1-2, inlet flow decelerates in the diffuser; pressure and temperature increase

• 5-6, outlet flow accelerates in the nozzle section, pressure and temperature decrease

Propulsive Power

Jet Engine



Due to the action force F_A, the momentum of the air flowing through the engine increases:

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

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

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

Propulsive Power

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

Gas Turbine Improvements

• Increase the gas combustion temperature (T_3) before it enters the turbine since $\eta_{th} = 1 - (T_4/T_3)$

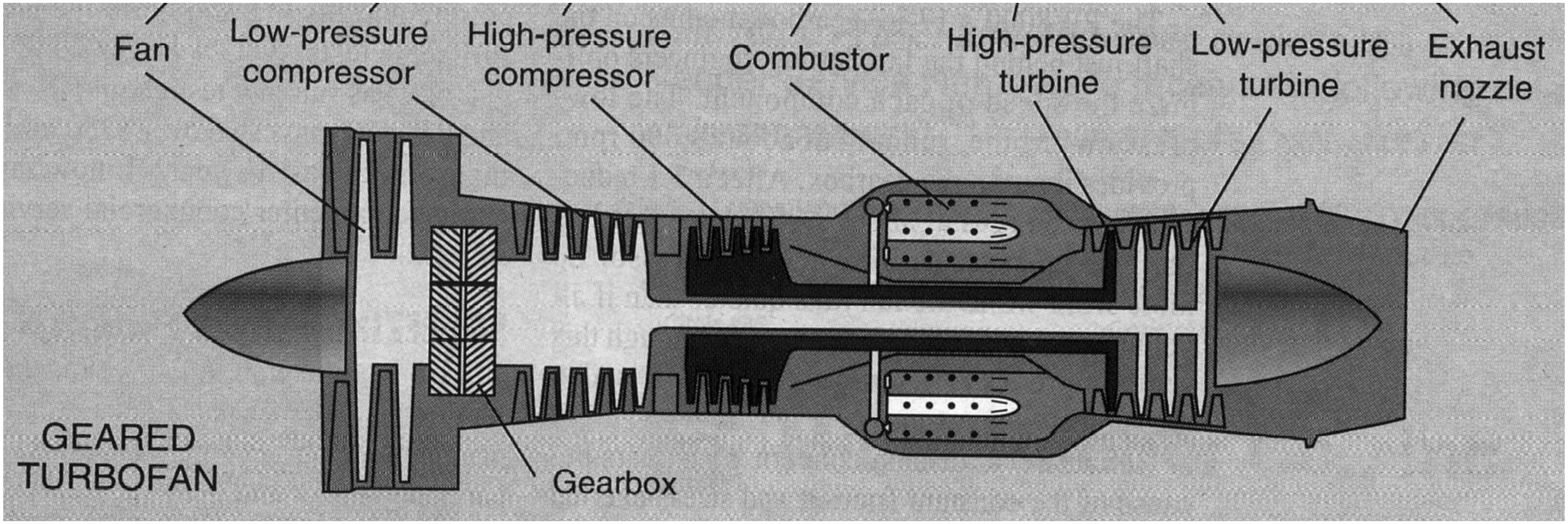
➔ Limited by metallurgical restriction: ceramic coating over the turbine blades

➔ 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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