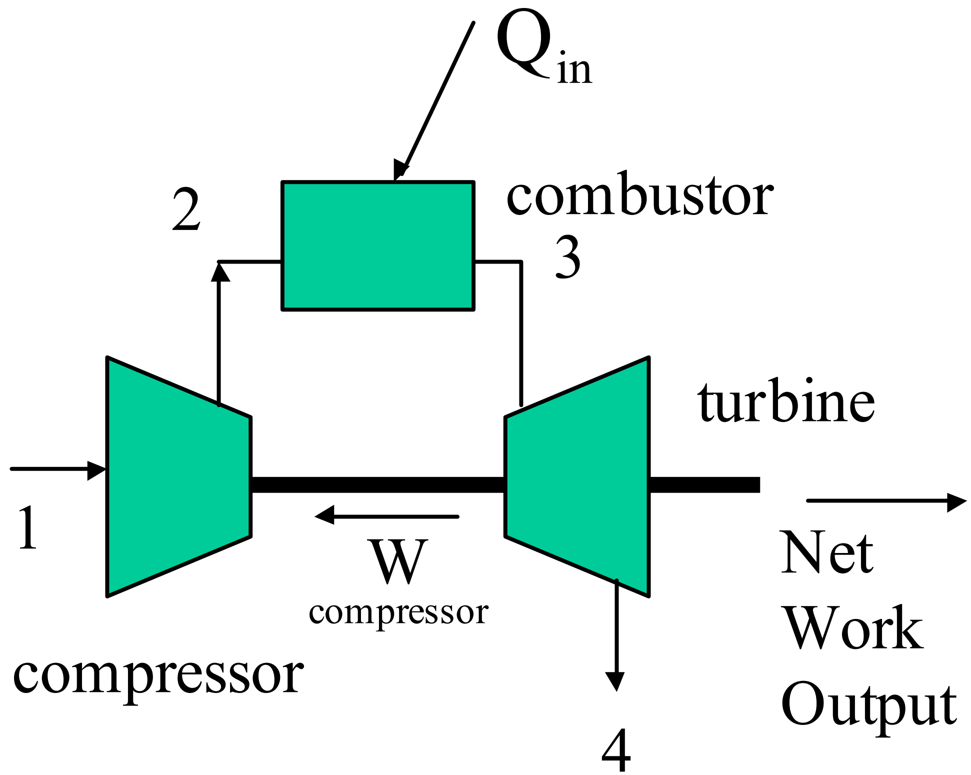
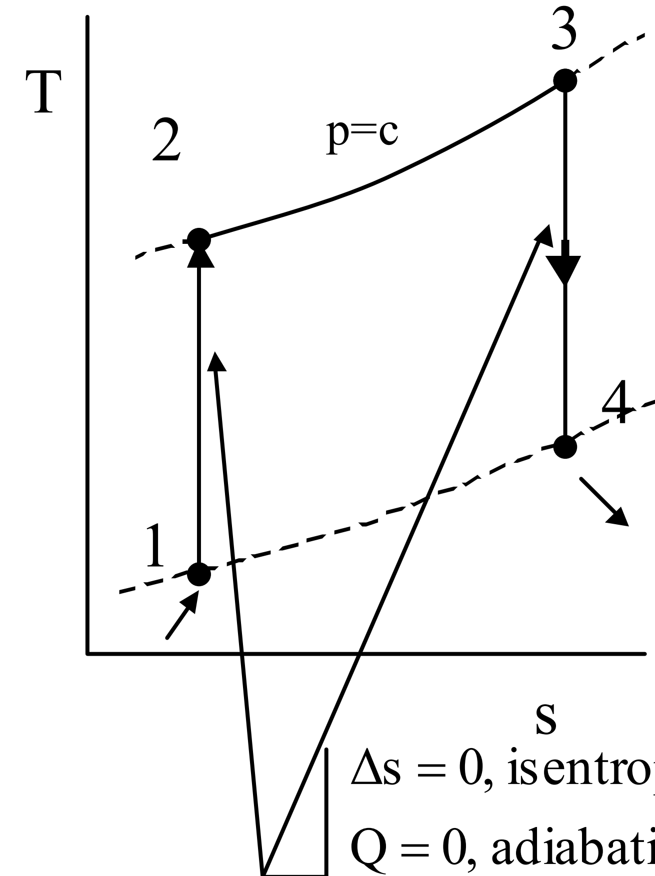
Simple Brayton, Gas Turbine, Cycle





$\Delta s = 0$, isentropic

$Q = 0$, adiabatic

pv^k = constant

reversible

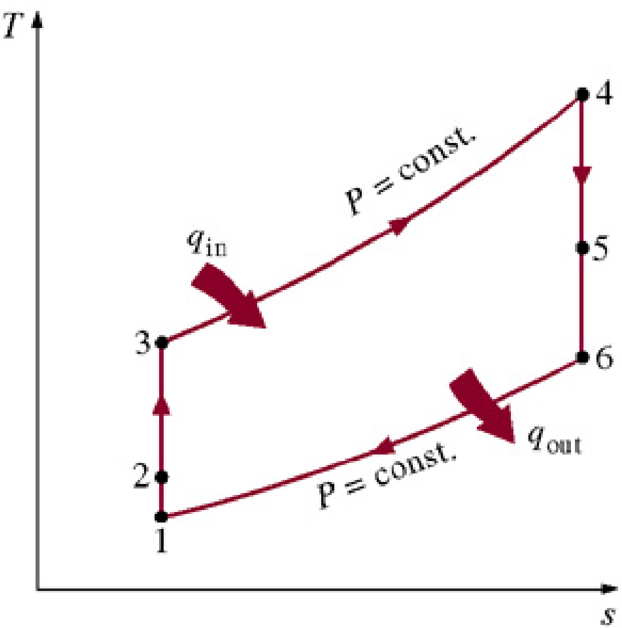
Compressor, Combustion, and Turbine are

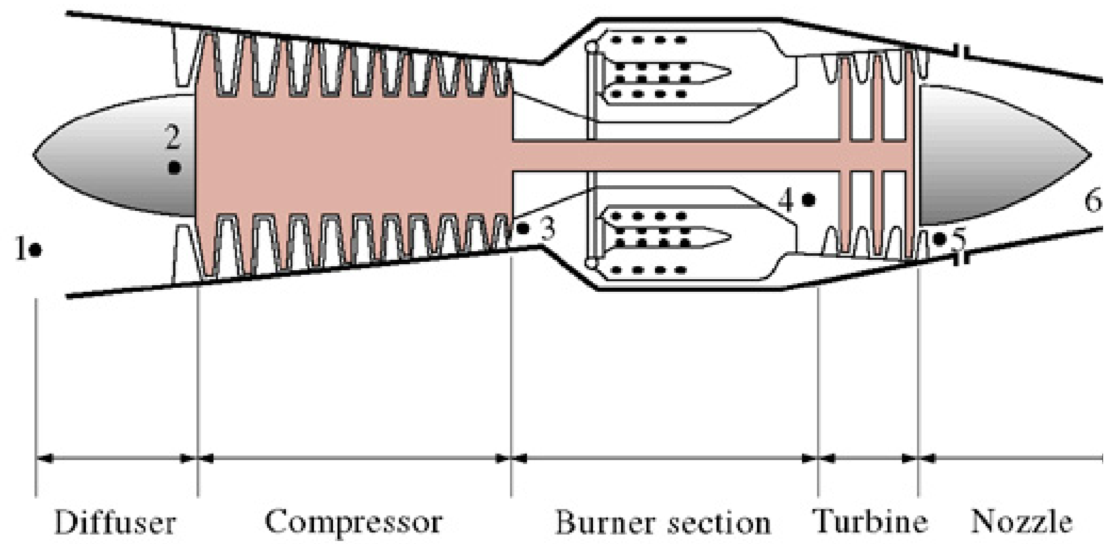
Open Thermodyanic Systems

Steady Flow Energy Equation Form of First Law

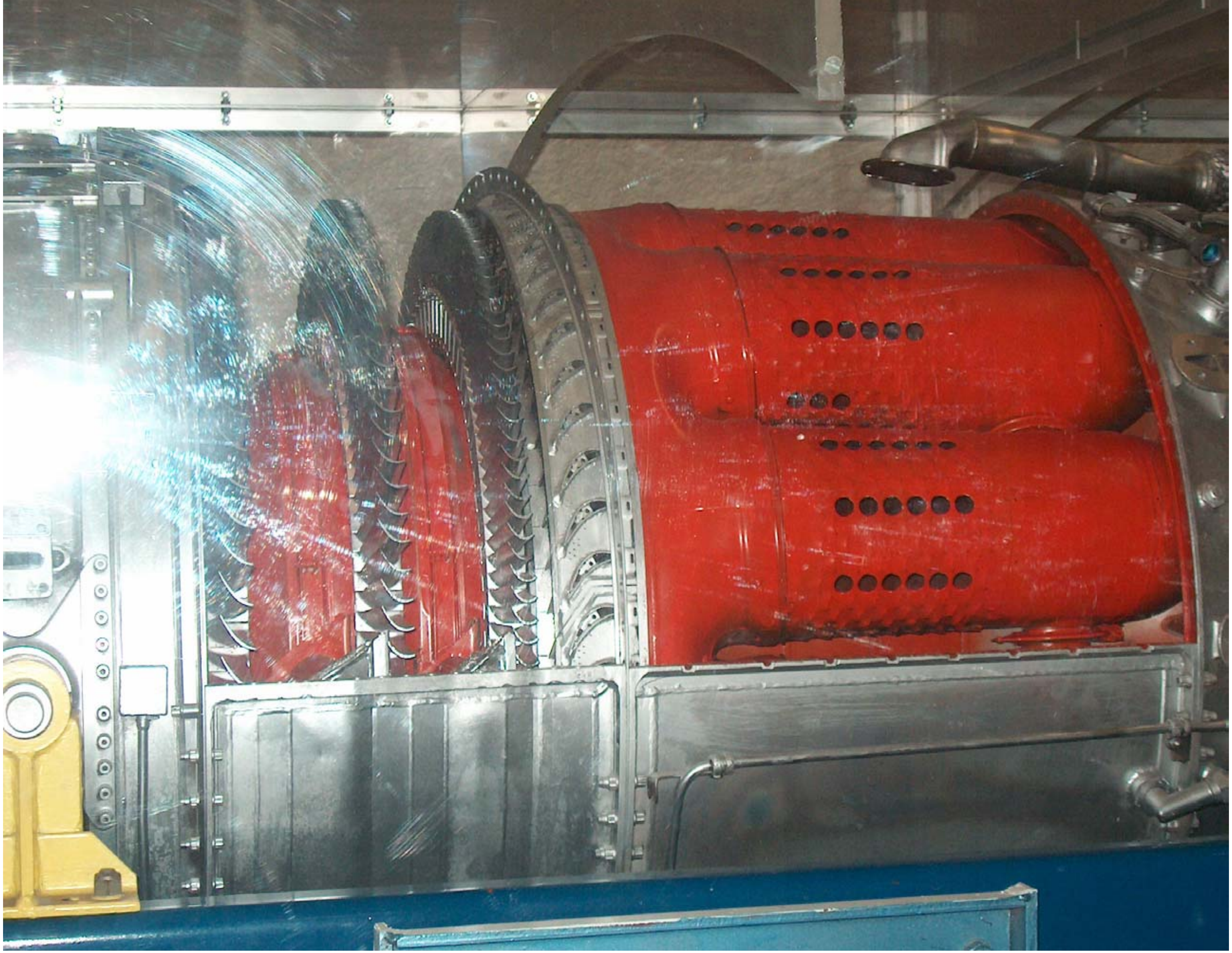
$$Q = \Delta(h + KE) + W_{net}$$

Propulsion Gas Turbine

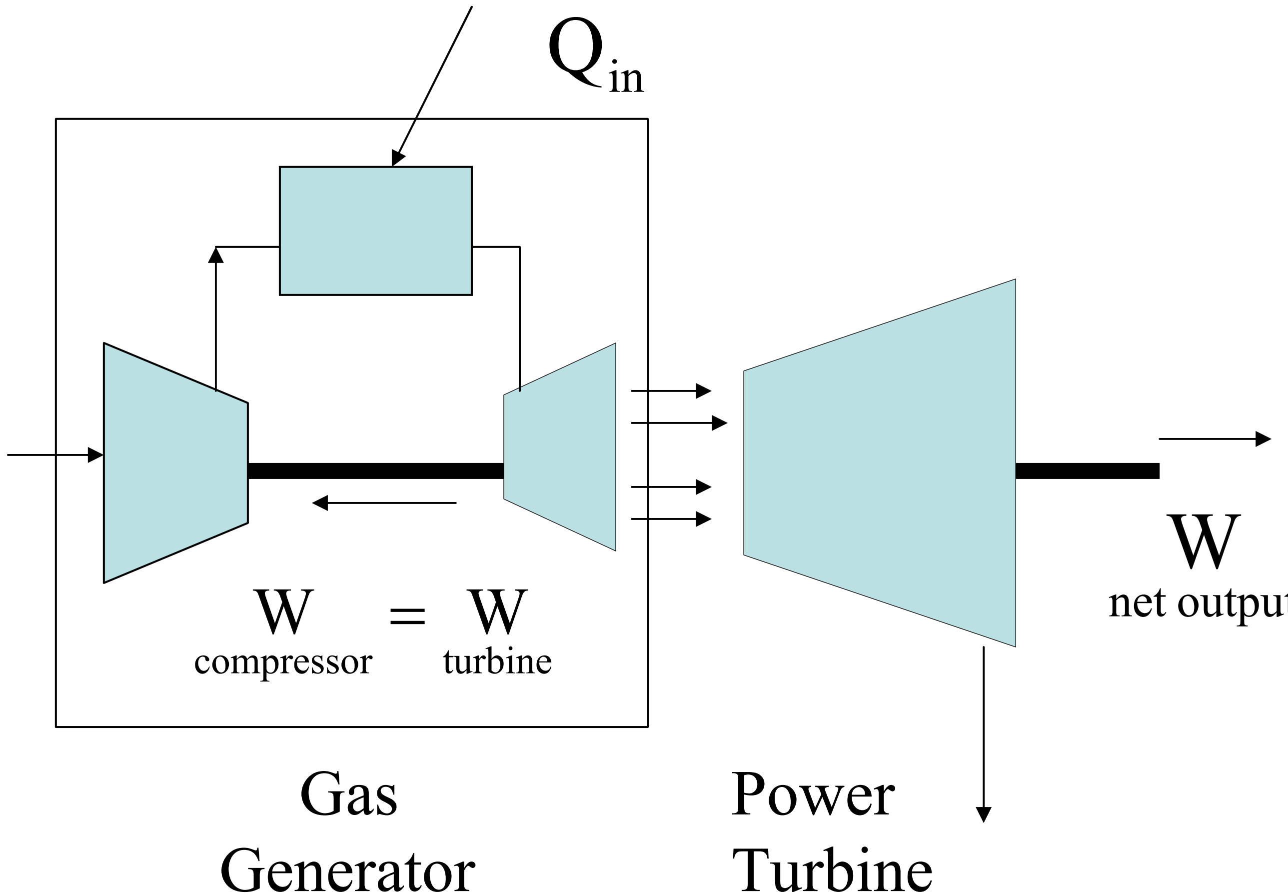




Furnas Hall J79-GE-8A Turbojet Engine
Compressor (right end), Combustor (red) Turbine (left end)



Furnas Hall J79-GE-8A Turbojet Engine
Combustor (red) and Turbine Stages



Aero-derivative Gas Turbine

Brayton Cycle with Real Compression and Expansion

Turbine Efficiency

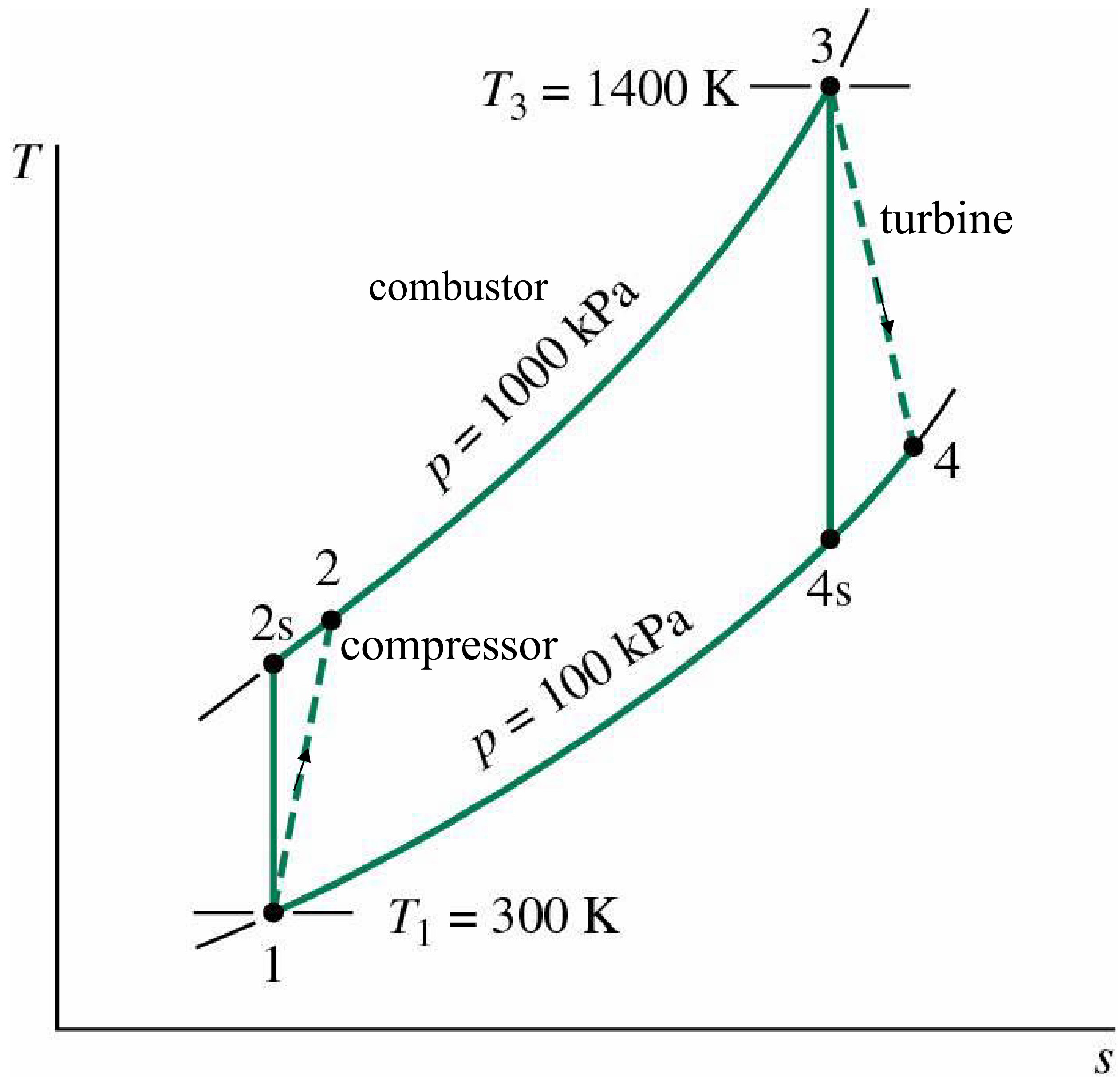
$$\eta_t = \frac{\text{actual work}}{\text{isentropic work}}$$

$$\eta_t = \frac{h_3 - h_4}{h_3 - h_{4s}}$$

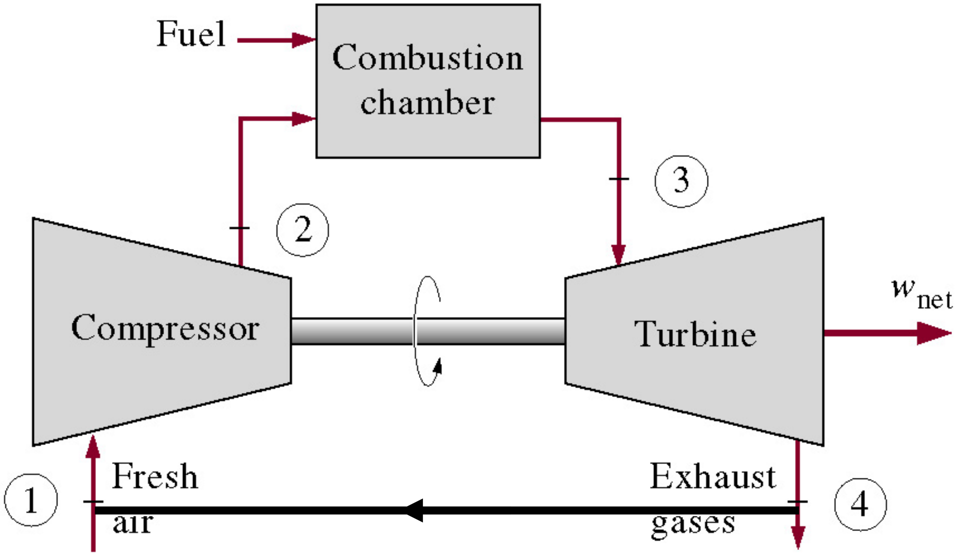
Compressor Efficiency

$$\eta_c = \frac{\text{isentropic work}}{\text{actual work}}$$

$$\eta_c = \frac{h_{2s} - h_1}{h_2 - h_1}$$

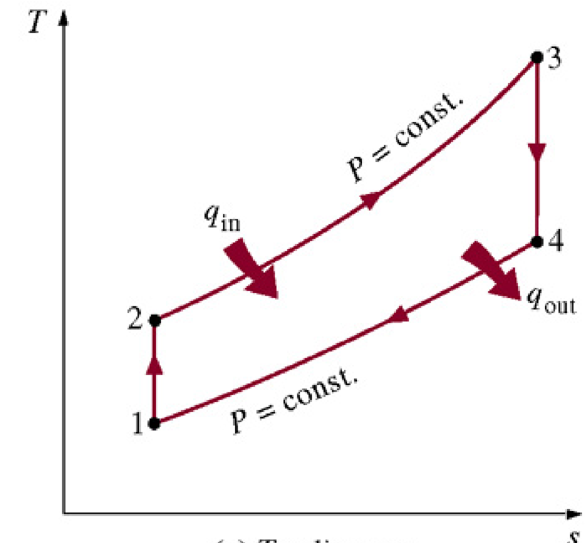


Brayton Air Standard Cycle

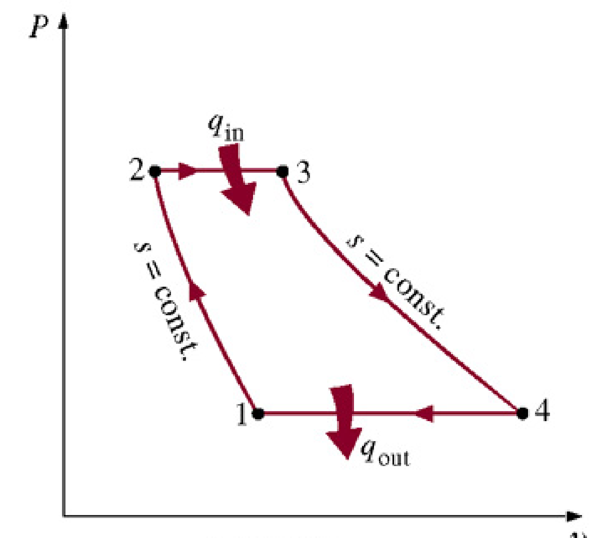


Air Standard Process

Actual Process



(a) T-s diagram



(b) P-v diagram

Steady Flow, Open System - region in space

Steady Flow Energy Equation

$$Q = m \times \Delta(u + pv + \frac{V^2}{2} + \rho gh) + W_{shaft}$$

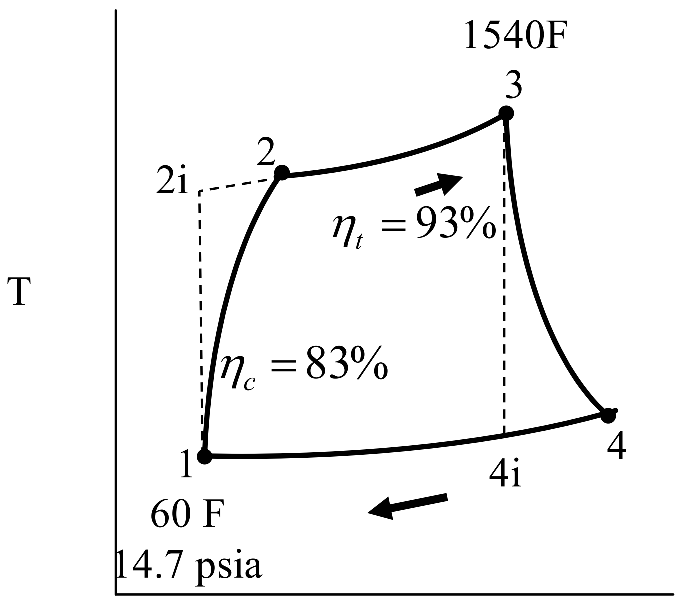
Compression Process, $Q = 0,\ W = m(h_2 - h_1)$

Combustion Process, $W = 0,\ Q = m(h_3 - h_2)$

Expansion Process, $Q = 0,\ W = m(h_3 - h_4)$

Exhause Process, $W = 0,\ Q = m(h_4 - h_1)$

In an air COLD standard gas turbine, 60 F and 14.7 psia air is compressed through a pressure ratio of 10. Air enters at 1540 F and expands to14.7 psia. If the isentropic efficiency of the compressor and turbine are 83% and 93% respectively.What is the thermal efficiency of the cycle?



$$\text{Check}: \sum w = \sum q$$

$$213.59 - 139.92 = 215.26 - 142.33$$

$$73.67 = 72.93$$

$$T_{2i} = T_1\left(\frac{p_2}{p_1}\right)^{\frac{k-1}{k}} = (460+60)\times 10^{2857} = 1003.9^{\circ}R$$

$$\eta_{compressor} = \frac{W_{ideal}}{W_{actual}} = \frac{h_{2is}-h_1}{h_2-h_1} = \frac{c_p(T_{2is}-T_1)}{c_p(T_2-T_1)} = .83$$

$$T_2 = T_1 + \frac{T_{2is}-T_1}{.83} = 520 + \frac{1003.9-520}{.83} = 1103.01^{\circ}R$$

$$q_{2-3} = h_3 - h_2 = c_p(T_3 - T_2)$$

$$q_{2-3} = .241(2000-1103.01) = 215.26\,BTU/lb$$

$$w_{1-2} = h_2 - h_1$$

$$w_{1-2} = c_p(T_2 - T_1) = .241(1103.01-520) = 139.92\,BTU/lb$$

$$T_{4i} = T_3\left(\frac{p_4}{p_3}\right)^{\frac{k-1}{k}} = 2000\times\left(\frac{1}{10}\right)^{.2857} = 1035.9^{\circ}R$$

$$\eta_{turbine} = \frac{w_{actual}}{w_{ideal}} = \frac{h_3-h_4}{h_3-h_{4i}} = \frac{c_p(T_3-T_4)}{c_p(T_3-T_{4i})} = \frac{1959.7-T_4}{1959.7-1029.5} = .93$$

$$T_4 = T_3 - .92\times(T_3 - T_{4is}) = 2000 - .93\times(2000-1035.9) = 1113.03^{\circ}R$$

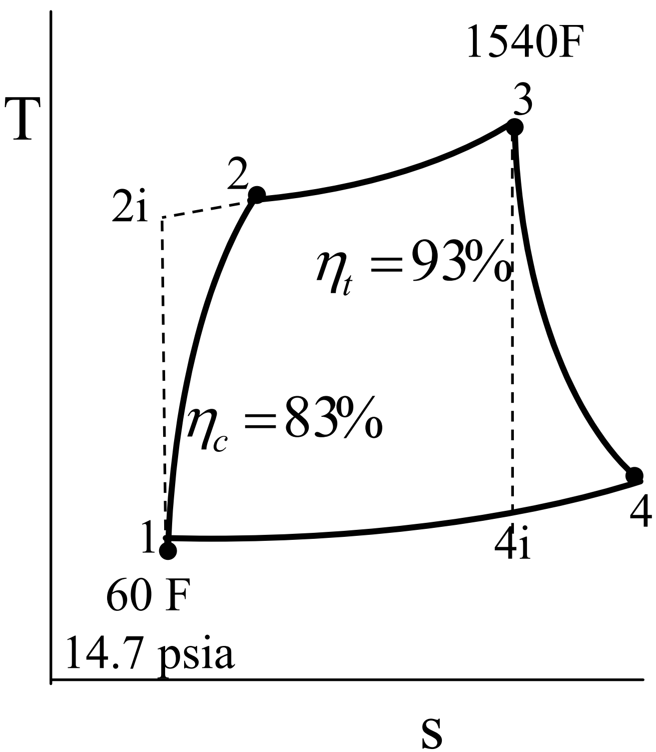
$$w_{3-4} = h_3 - h_4 = .241(2000-1110.03) = 213.59\,BTU/lb$$

$$q_{4-1} = h_4 - h_1 = .241(T_4 - T_1) = .241(1113.03-520.) = 142.33\,BTU/lb$$

$$\eta_{cycle} = 1 - \frac{h_4-h_1}{h_3-h_2} = 1 - \frac{1113.03-520}{2000-1103.01} = 33.9\%$$

$$\eta_{cycle} = \frac{w_{net}}{q_{in}} = \frac{215.26-139.92}{215.26} = 33.9\%$$

In an air standard gas turbine, 60 F and 14.7 psia air is compressed through a pressure ratio of 10. Air enters at 1540 F and expands to 14.7 psia. If the isentropic efficiency of the compressor and turbine are 83% and 93% respectively. What is the thermal efficiency of the cycle?



at $520^\circ R$, $p_{r1} = 1.2147$, $h_1 = 124.27$ BTU/lb

$$p_{r2is} = p_{r1}\left(\frac{p_{2is}}{p_1}\right) = 1.2147 \times 10 = 12.147$$

T	p_r	h
980	10.61	236.02
998	12.147	240.48
1000	12.30	240.98
ratio $\frac{.17}{1.69} = .1006$		

$h_{2is} = 240.48$ BTU/lb

$$\eta_{compressor} = \frac{W_{ideal}}{W_{actual}} = \frac{h_{2is} - h_1}{h_2 - h_1} = .83$$

$$h_2 = h_1 + \frac{h_{2is} - h_1}{.83} = 124.27 + \frac{240.48 - 124.27}{.83}$$

$h_2 = 264.28$ BTU/lb

At $2000^\circ R$, $p_{r3} = 174.$, $h_3 = 504.71$

$$p_{r4is} = p_{r3}\left(\frac{p_{4is}}{p_1}\right) = 174. \times 1/10 = 17.4$$

by interpolation at $p_{r4is} = 1.74$, $h_{4is} = 265.99$ BTU/lb

$$\eta_{turbine} = \frac{W_{actual}}{W_{ideal}} = \frac{h_3 - h_4}{h_3 - h_{4i}} = .93$$

$h_4 = h_3 - .92 \times (h_3 - h_{4is}) = 282.7$ BTU/lb

$q_{in} = h_3 - h_2 = 504.7 - 264.28 = 240.42$ BTU/lb

$q_{out} = h_4 - h_1 = 282.7 - 124.27 = 155.43$ BTU/lb

$$\eta = 1 - \frac{Q_{in}}{Q_{out}} = 1 - \frac{155.43}{240.42} = 35.3\%$$