Thermodynamics 1

Lecture 13:
Kringprocessen
Gasturbines
Joule-Brayton

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Energy Technology

TU Delft
Delft University of Technology

College 12

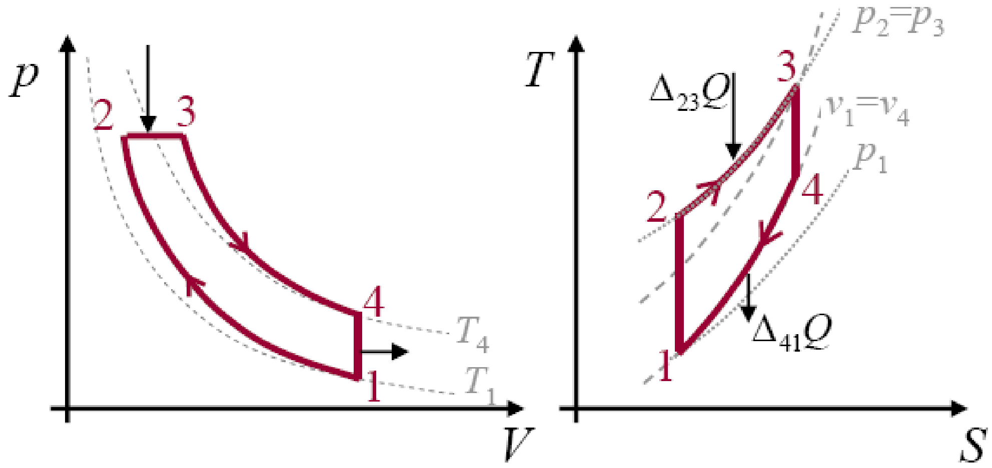
- Diesel process
- dual cycle

Recapitulation

- **<u>Diesel</u> cycle (s, p, s, v).**

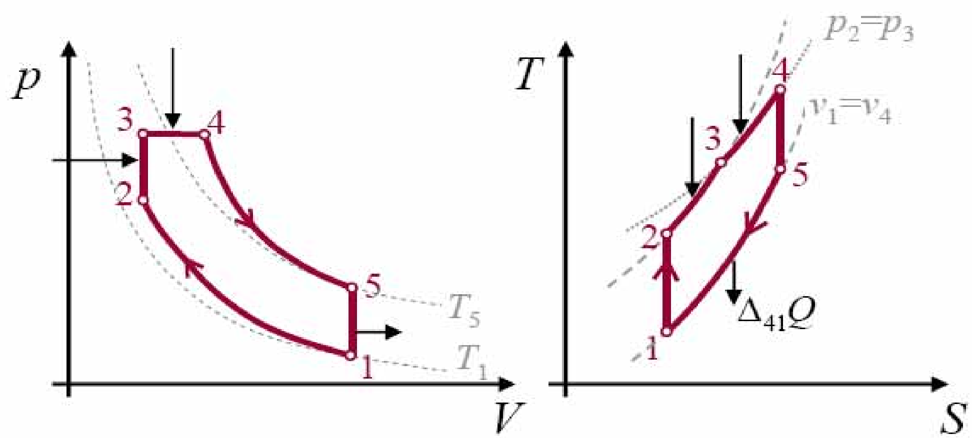
->Compression ratio $r = \frac{V_1}{V_2}$

-> cut-off ratio $r_c = \frac{V_3}{V_2}$



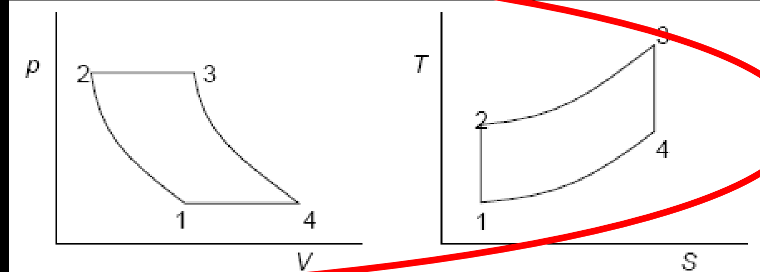
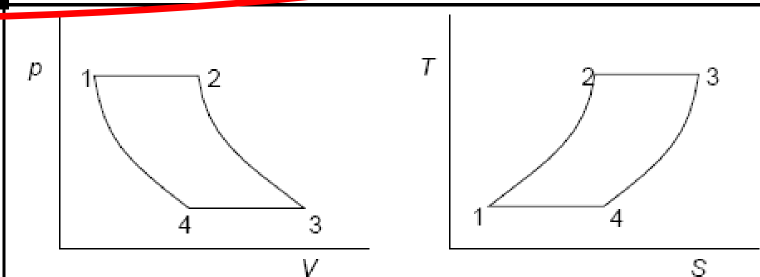
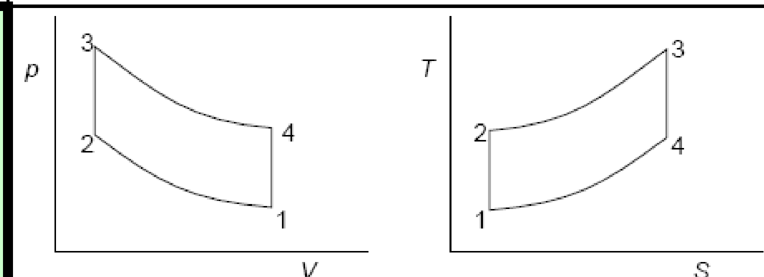
- **Relation work per cycle and power.**

- **<u>Dual</u> cycle (s, v, p, s, v)**



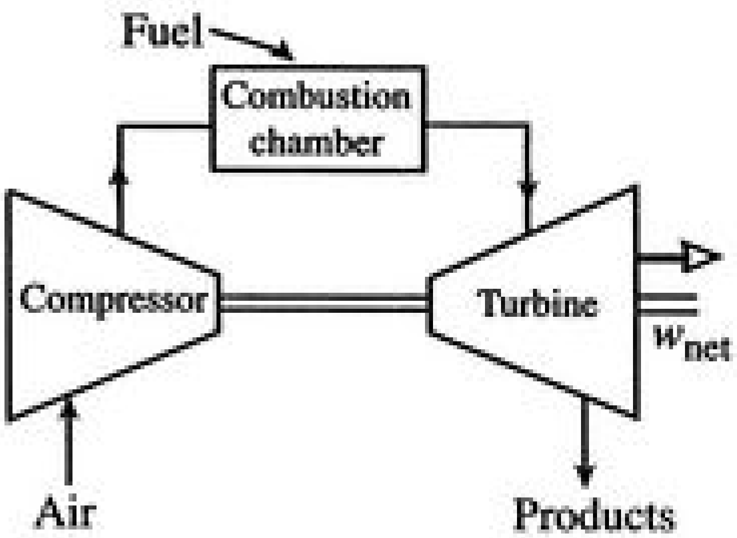
New

- **Joule-Brayton-process (gas-turbine process)**

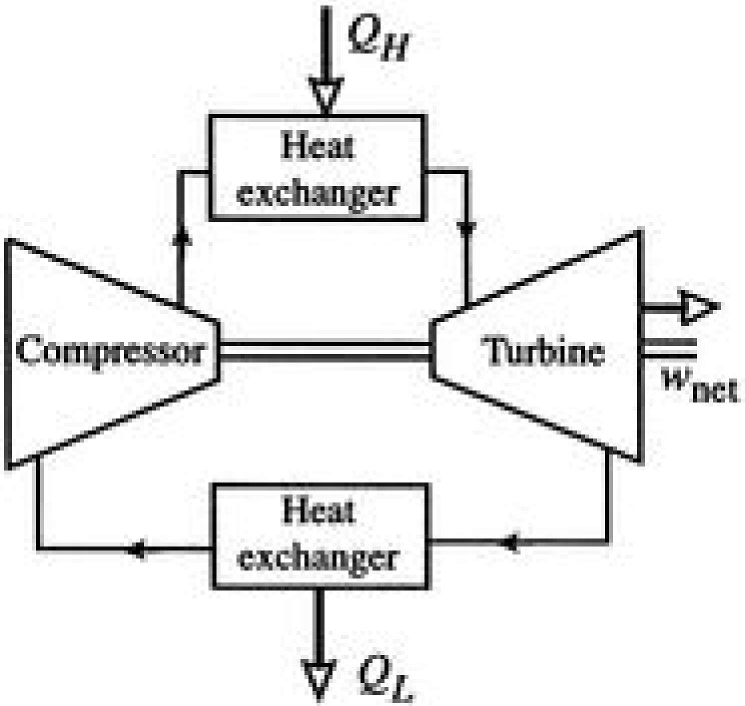
Historisch	p =const	V =const	T =const	dQ =0	
Ericsson 1833 Joule 1852 Brayton 1867	p			dQ	
Ericsson 1853	p		T		
Otto 1867 (Barsanti - Matteucci 1854)		V		dQ	

TUDelft

Simple gas-turbine cycle: configurations

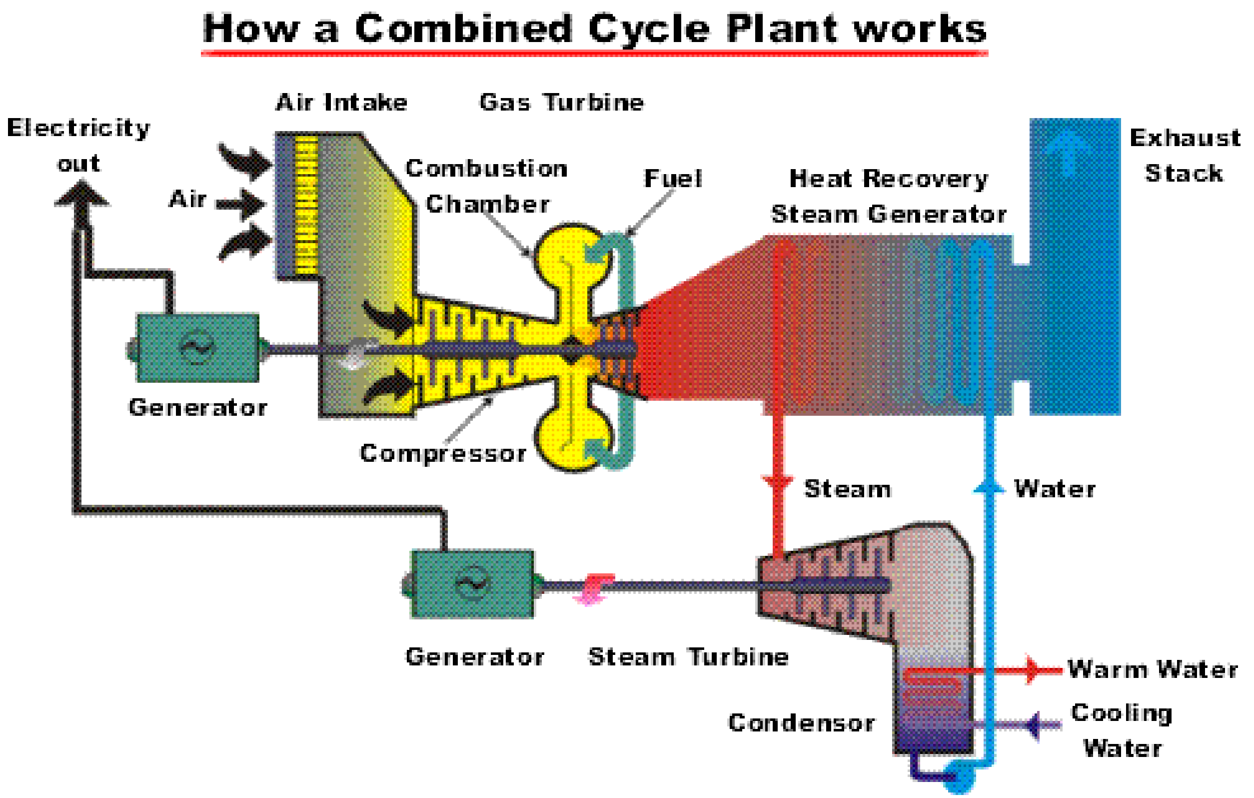


Open



Closed

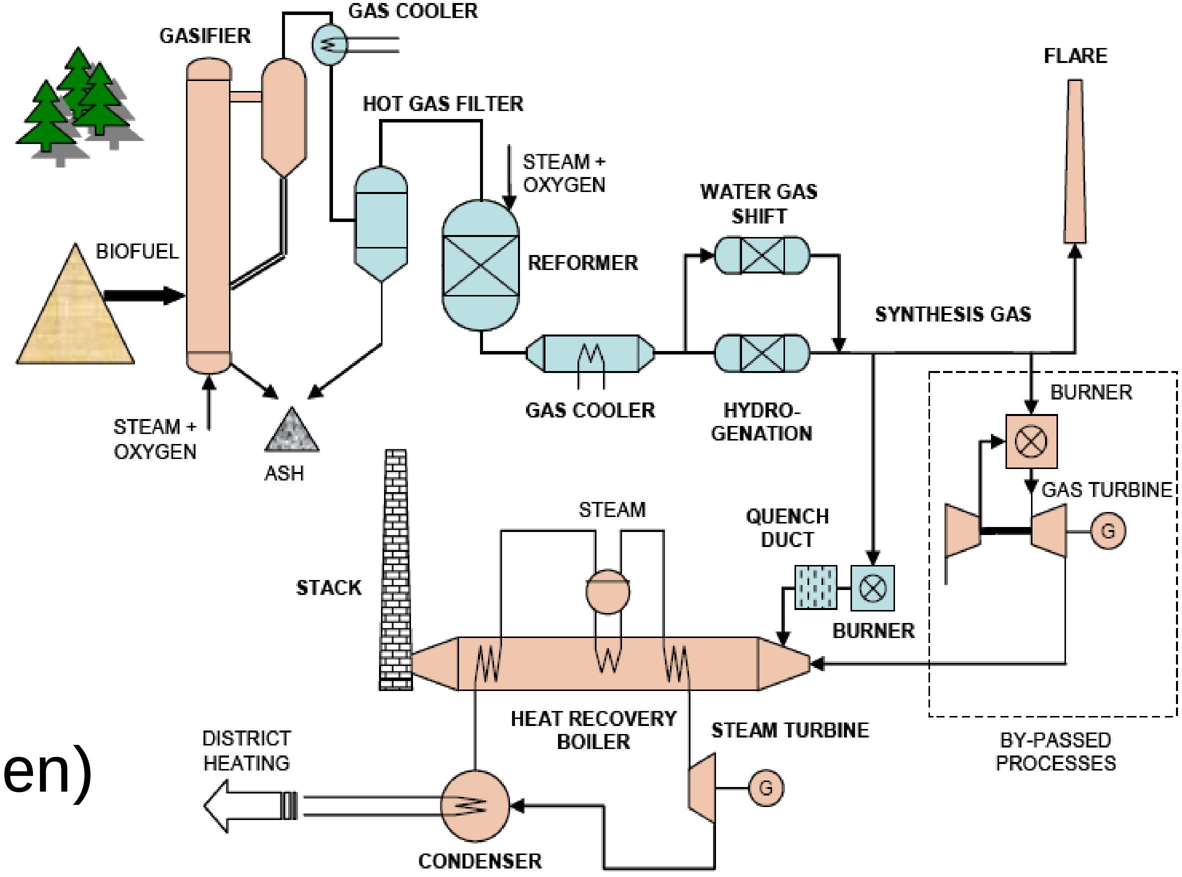
Advanced gas-turbine cycle: combined cycle



- Higher thermal efficiencies as hot flue gas from gas turbine is used as input heat for a steam cycle

A biomass gasification integrated combined cycle (IGCC)

Varnamo (South Sweden)
18 MW_{th}



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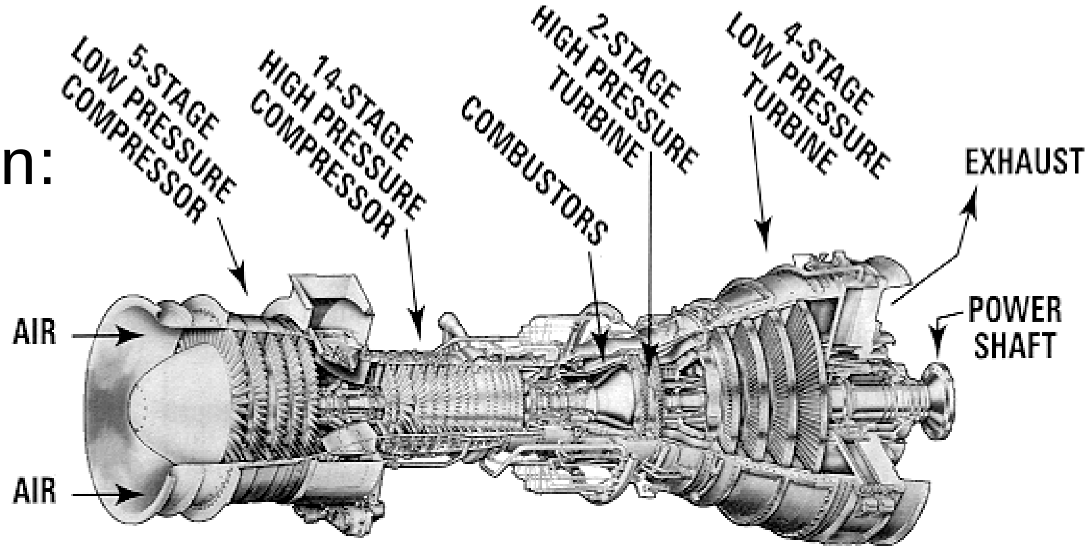
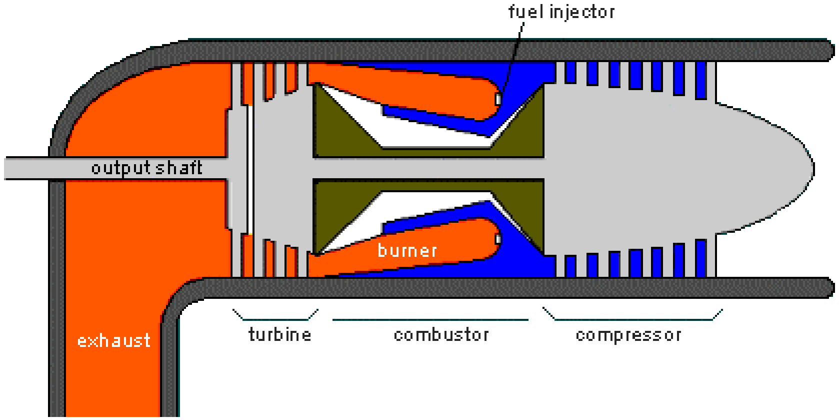
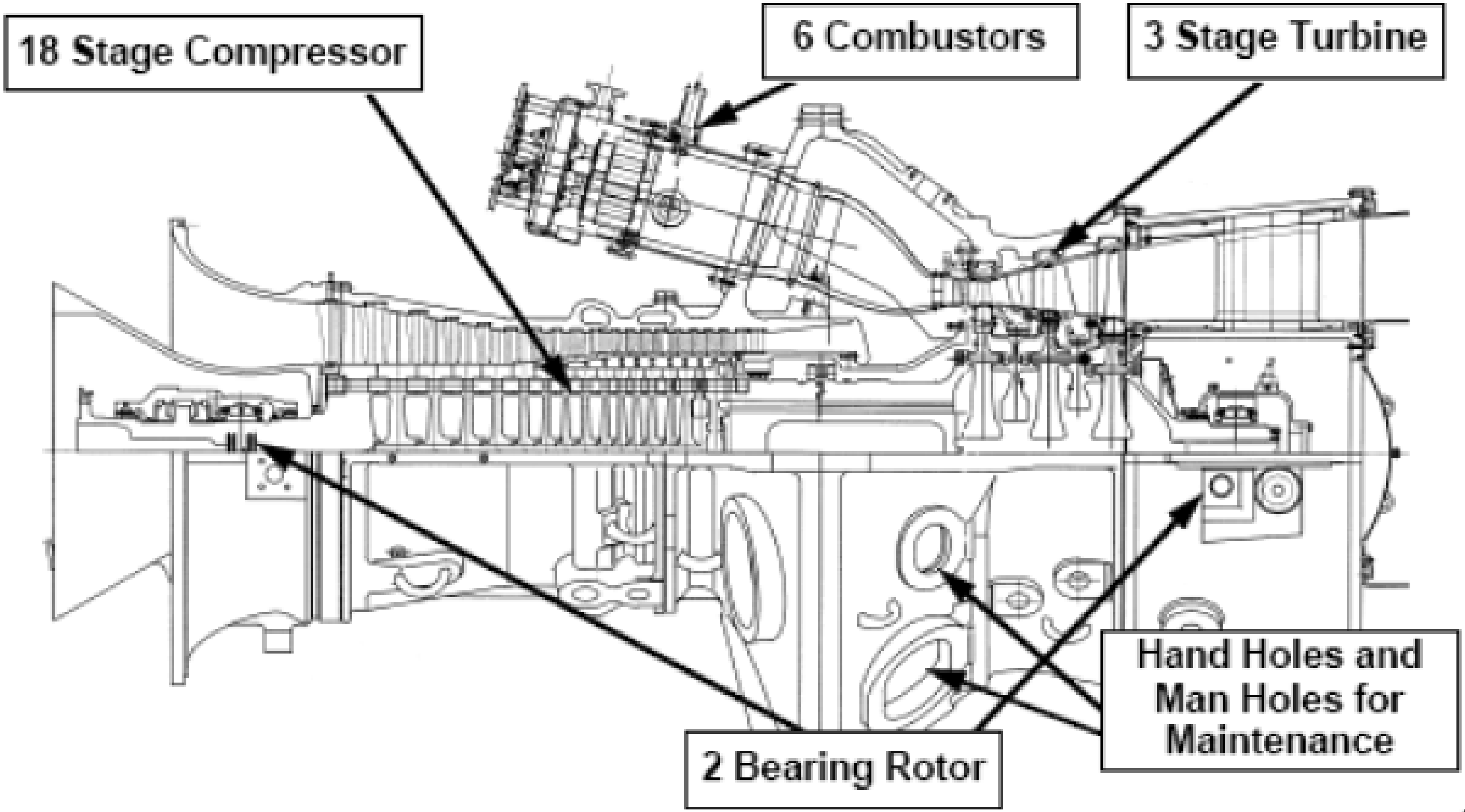
Gas-turbines: equipment

Marine application, propulsion:

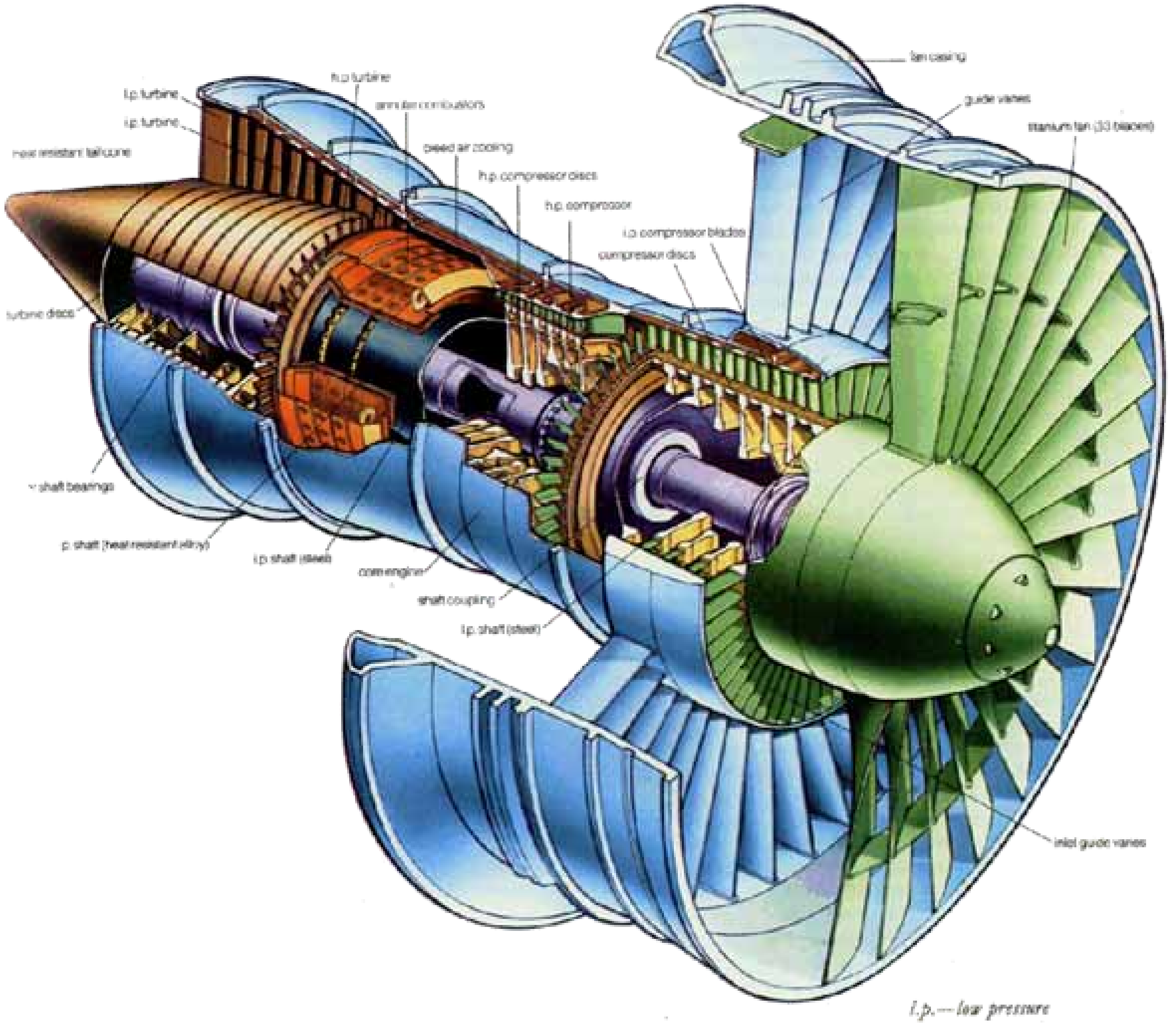




Gas-turbines: equipment



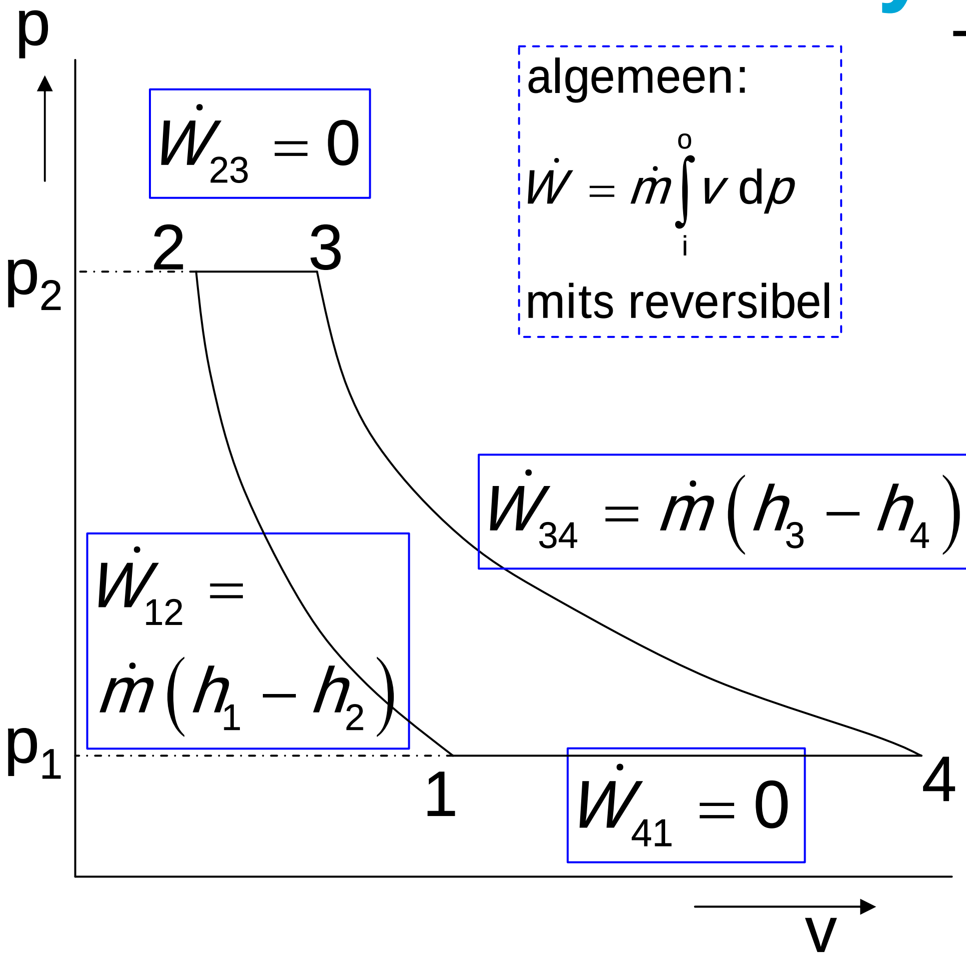
Gas-turbines: equipment

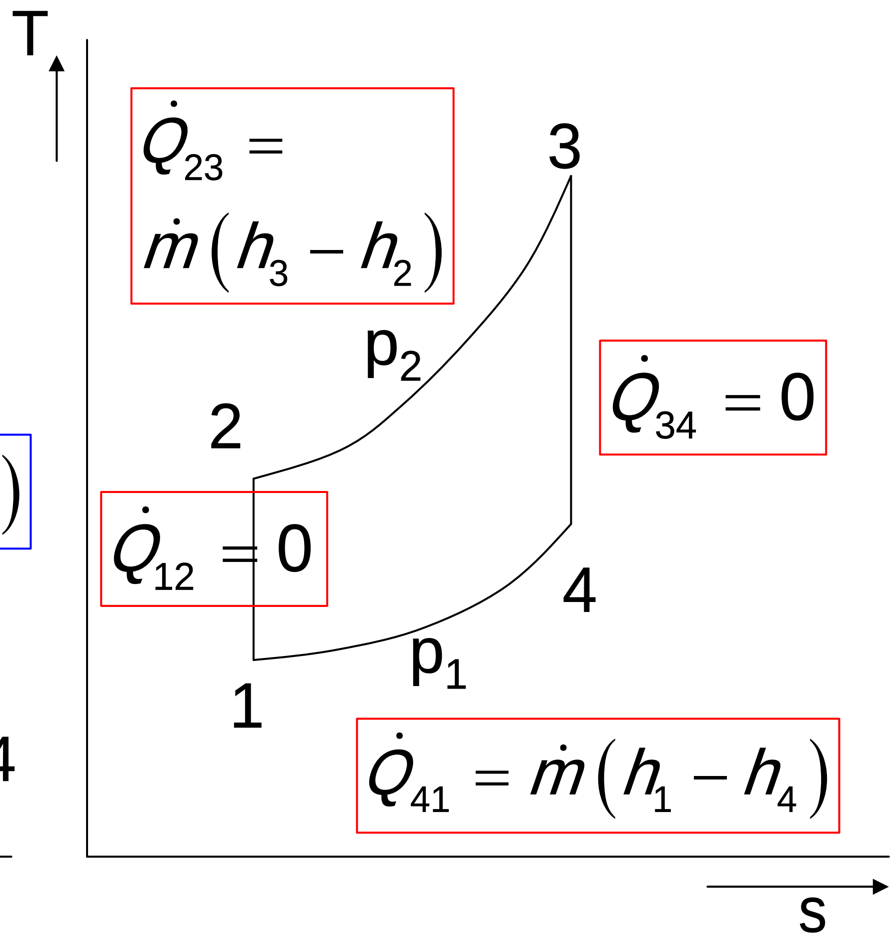


Aviation, important:

High power to mass ratio
Compact
Low emissions (CO,UHC)

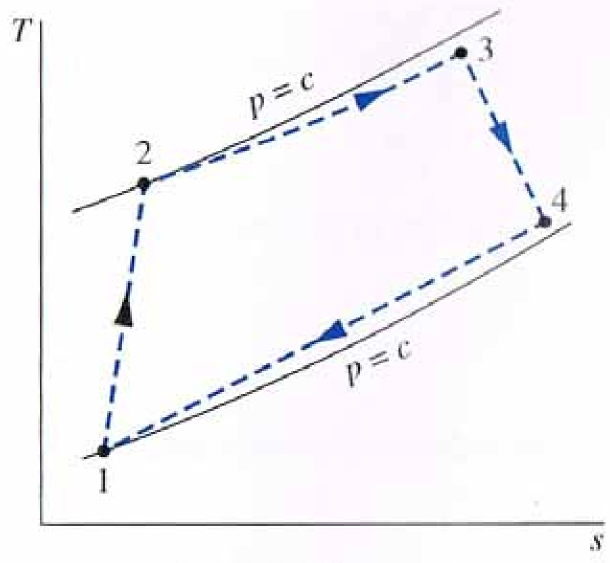
Joule – Brayton cycle (p,s)

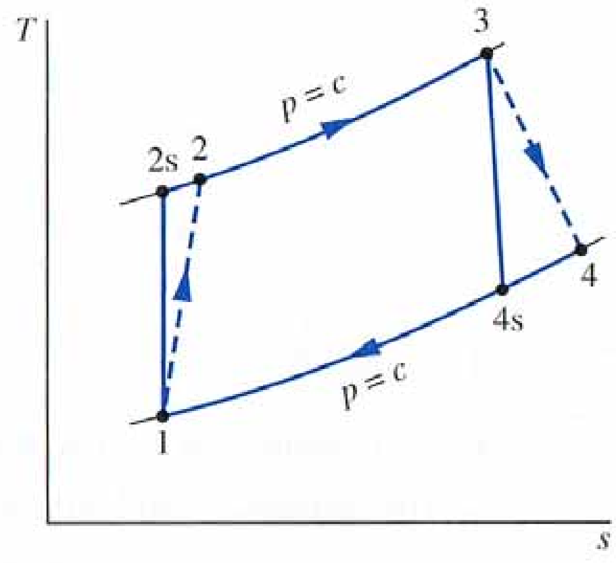




$$\dot{W} = \dot{Q} + \dot{m}\left\{\left(h_i - h_o\right) + \frac{1}{2}\left(V_i^2 - V_o^2\right) + g\left(z_i - z_o\right)\right\}$$

Irreversibilities in the cycle

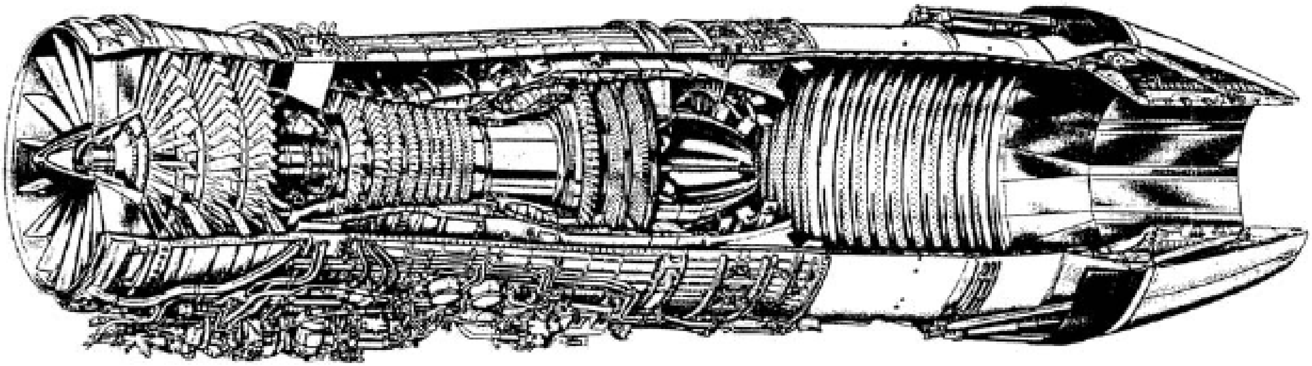




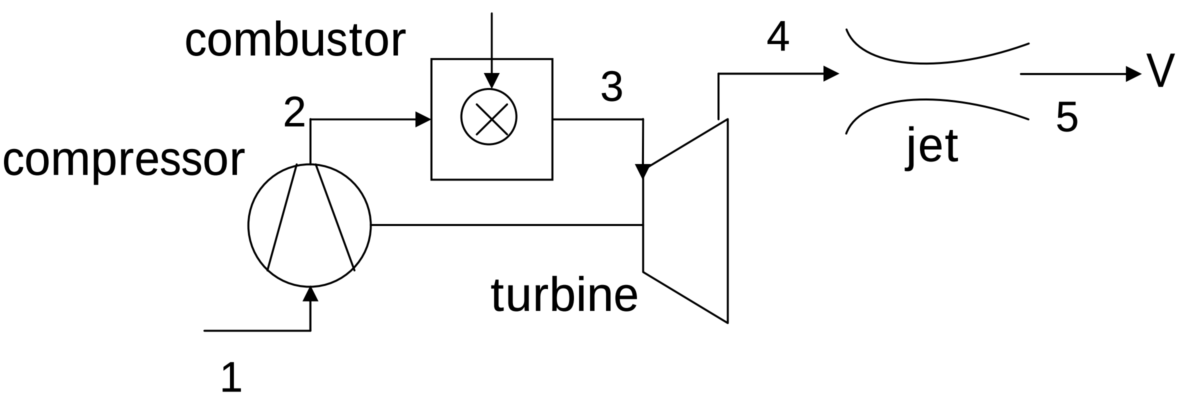
$$\eta_t = \frac{\left(\dot{W}_t / \dot{m}\right)}{\left(\dot{W}_t / \dot{m}\right)_s} = \frac{h_3 - h_4}{h_3 - h_{4s}}$$

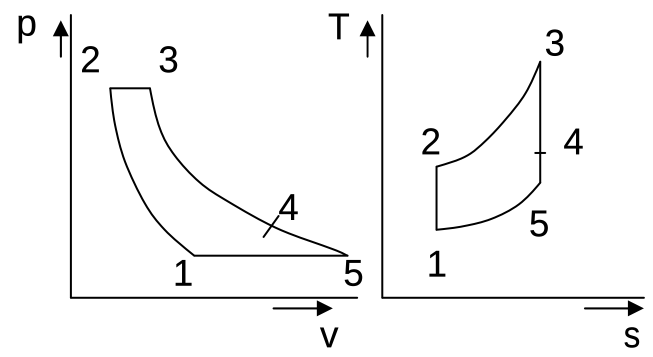
$$\eta_c = \frac{\left(\dot{W}_c / \dot{m}\right)_s}{\left(\dot{W}_c / \dot{m}\right)} = \frac{h_{2s} - h_1}{h_2 - h_1}$$

Aircraft gas-turbine



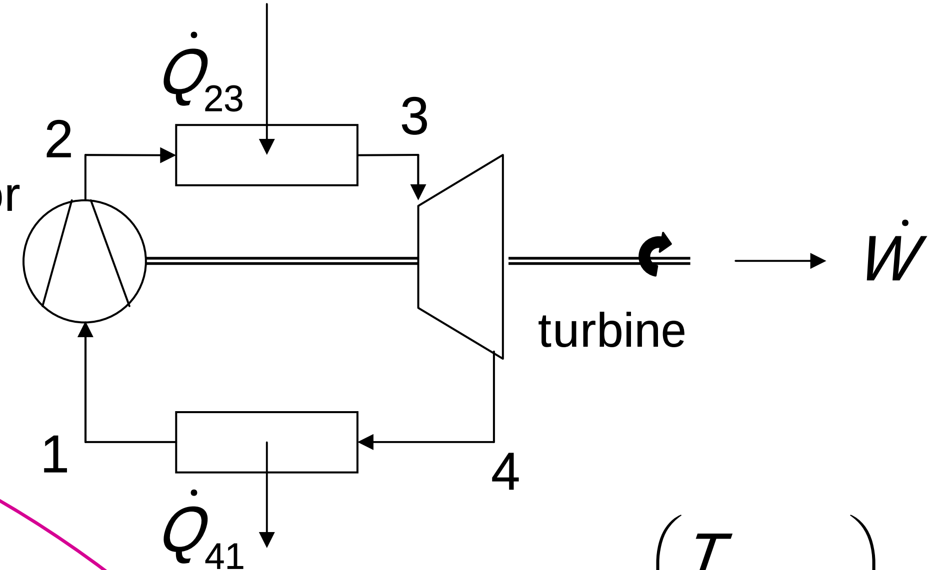
General Electric F110-GE-100 Augmented Turbofan Engine -> T_2~ 600 °C





Brayton-cycle

$$\dot{W} = \dot{Q}_{23} + \dot{Q}_{41}$$



Cold air standard

$$\eta = \frac{\dot{W}}{\dot{Q}_{23}} = 1 + \frac{\dot{Q}_{41}}{\dot{Q}_{23}} = 1 + \frac{T_1 - T_4}{T_3 - T_2} = 1 - \frac{T_1}{T_2} \frac{\left(\frac{T_4}{T_1} - 1\right)}{\left(\frac{T_3}{T_2} - 1\right)}$$

Poisson

$$T_4 p_4^{-\frac{\kappa-1}{\kappa}} = T_3 p_3^{-\frac{\kappa-1}{\kappa}}$$

$$T_1 p_1^{-\frac{\kappa-1}{\kappa}} = T_2 p_2^{-\frac{\kappa-1}{\kappa}}$$

$$\Rightarrow \frac{T_4}{T_1} = \frac{T_3}{T_2} \text{ en ook } \frac{T_3}{T_4} = \frac{T_2}{T_1}$$

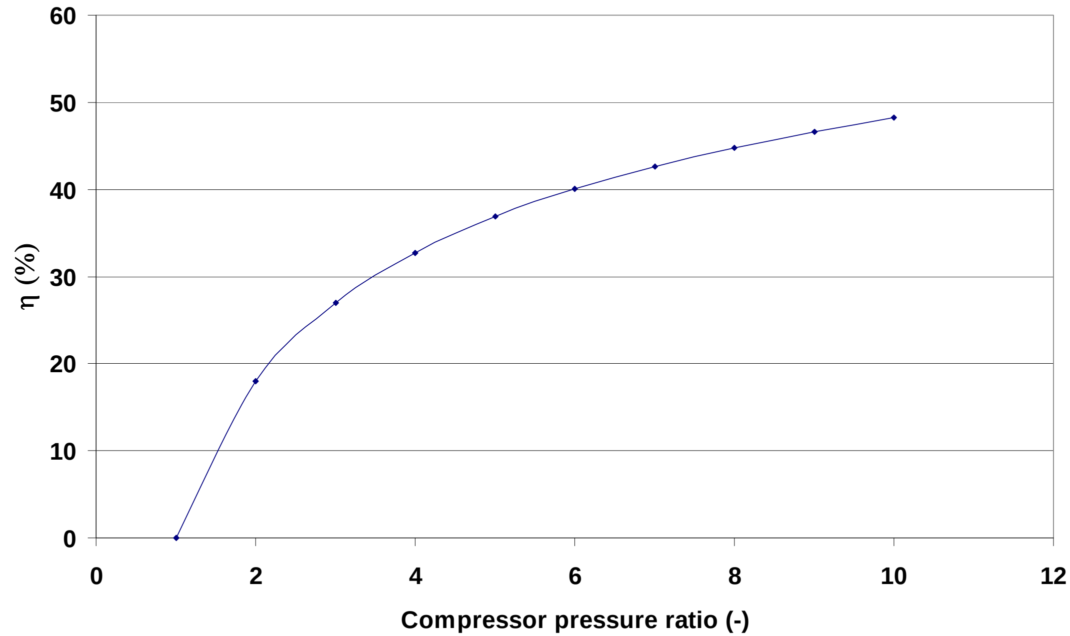
Brayton cycle

$$\eta = 1 - \frac{T_1}{T_2}$$

$$T_2 = T_1 \left(\frac{p_2}{p_1}\right)^{\frac{\kappa-1}{\kappa}}$$ -> derived in working class 4!!

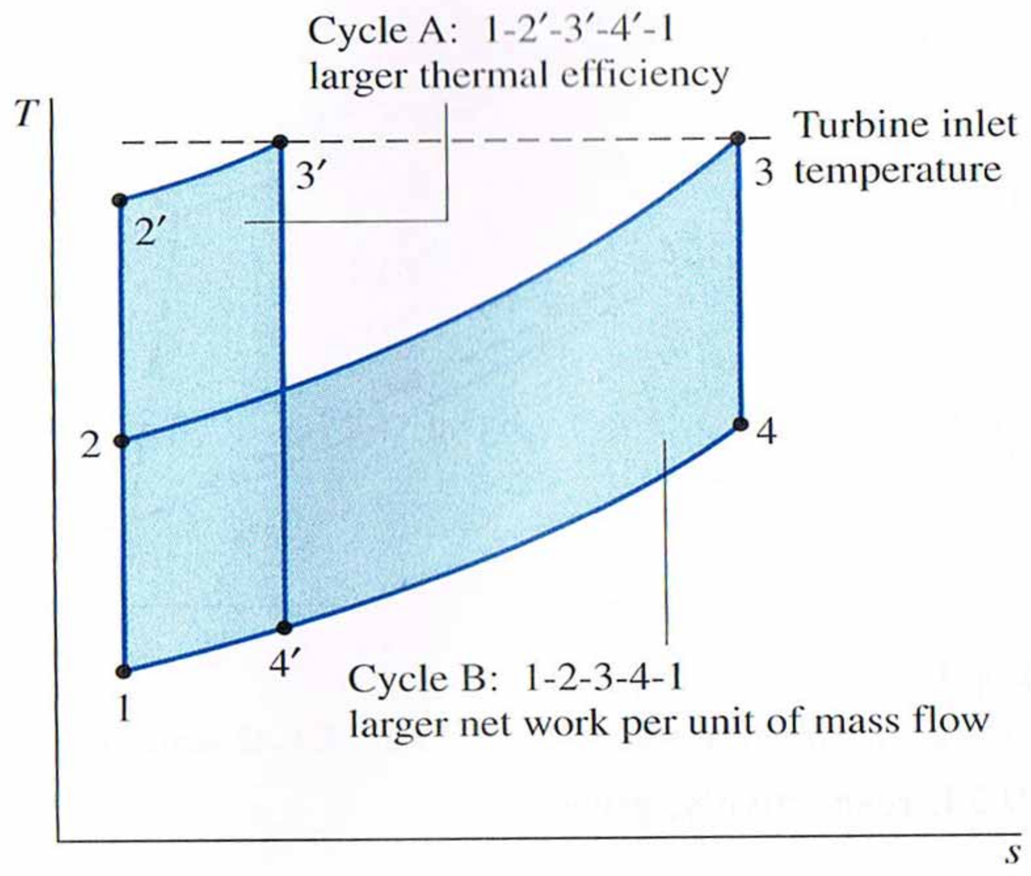
$$\frac{T_1}{T_2} = \left(\frac{p_2}{p_1}\right)^{\frac{-(\kappa-1)}{\kappa}}$$

$$\Rightarrow \eta = 1 - \frac{1}{\left(\frac{p_2}{p_1}\right)^{\frac{(\kappa-1)}{\kappa}}}$$

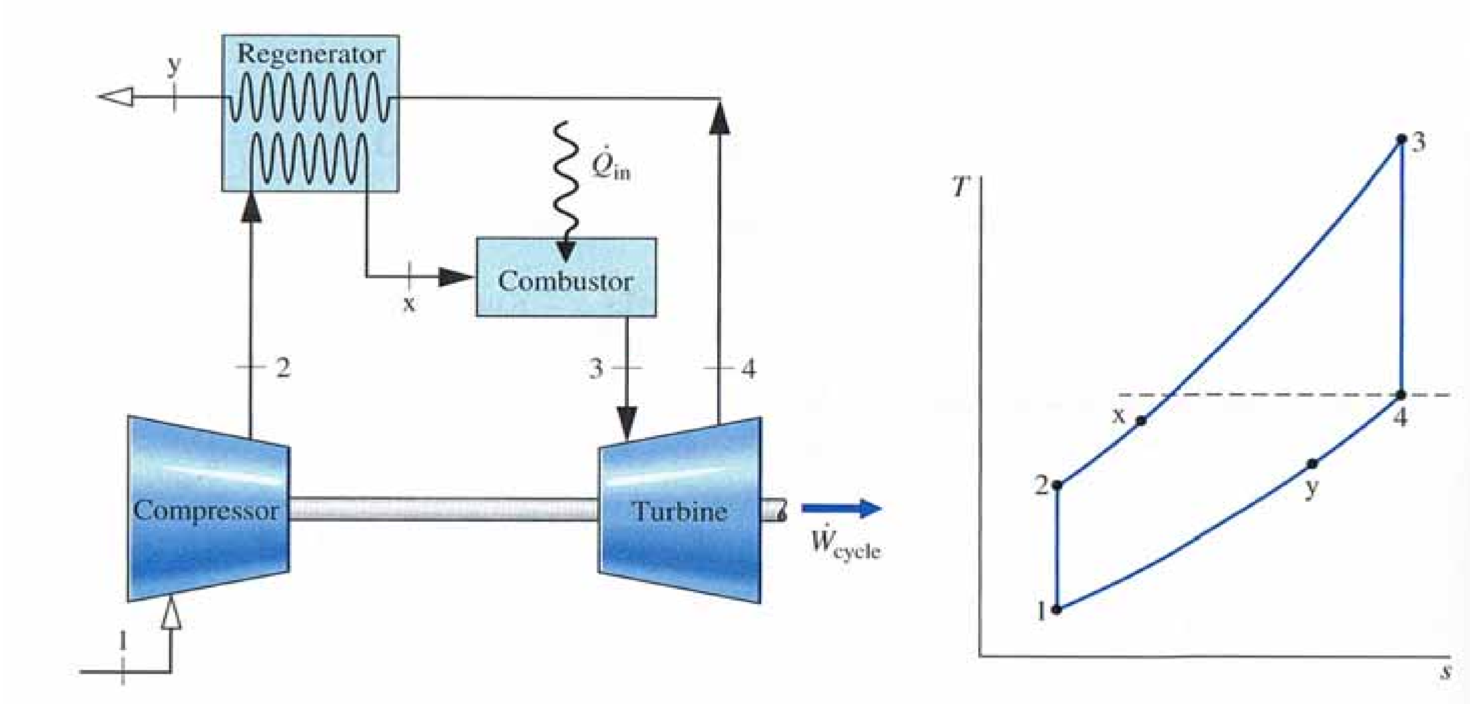


Practical limit:
Turbine inlet T_3

System design considerations



Regenerative Gas Turbines

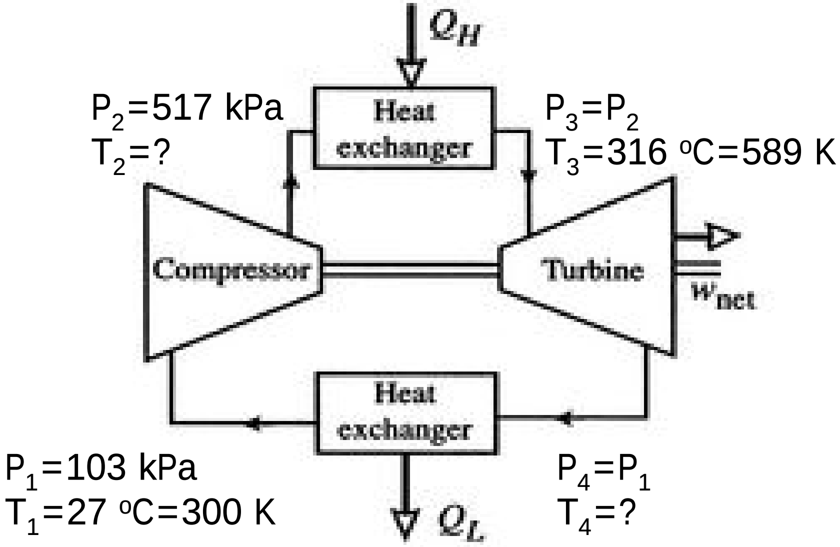


Regenerator effectiveness: $\eta_{reg} = \dfrac{h_x - h_2}{h_4 - h_2}$

Typically, $60\% < \eta_{reg} < 80\%$

Example problem 1

An internally reversible air-standard Brayton cycle receives air at 27 °C and 103 kPa. The upper limits of pressure and temperature of the cycle are 517 kPa and 316 °C. Determine the thermal efficiency of the cycle, assuming constant specific heat, Cp=1,0035 kJ/(kg.K).



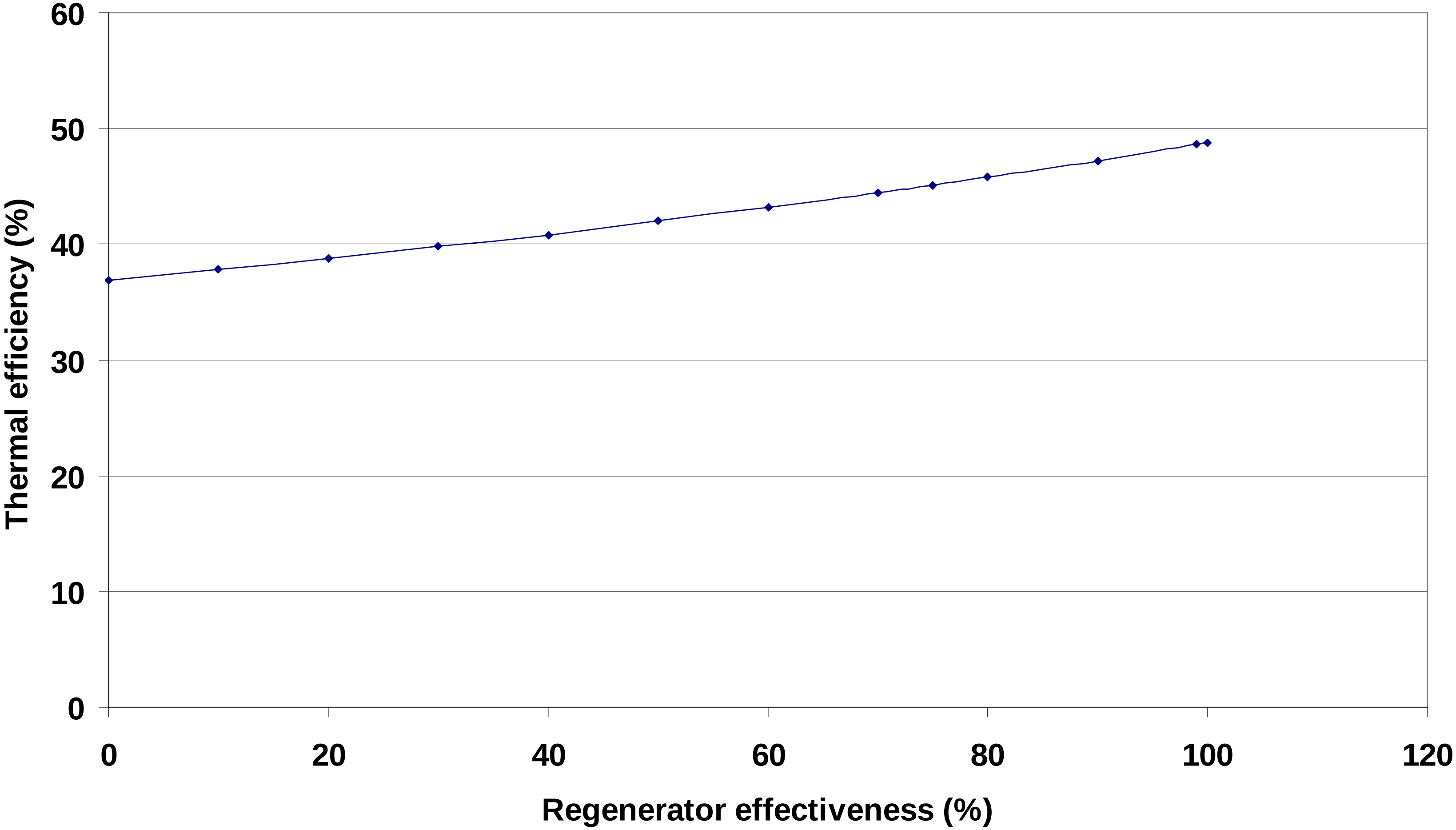
Example problem 2

A *regenerator* of 75% effectiveness is used in an air standard Brayton cycle working between pressures of 1030 hPa and 5,17 bar.

Determine the work per kg of air and the thermal efficiency of the cycle if the maximum and minimum temperatures of the cycle are 671,3 ^{o}C and 32,4 ^{o}C, respectively. Assume constant C_p of 1,004 kJ/(kg.K) and κ=1,4.

Sensitivity study on influence of regenerator effectiveness

(example problem 2)



Study-suggestions

- Study Chapter 9.1 - 9.8 and 9.11
- Do some of the exercises 9.28 - 9.35 (Brayton-cycles)
  Especially: finish 9.28, do 9.29
- Exercises 9.36-9.39 regenerator
- Problems 9.40 - 9.44 reheat
- Problems 9.45 - 9.50 intercooling
- 9.51 intercooling and reheat
- 9.52 intercooling, reheat and regenerator