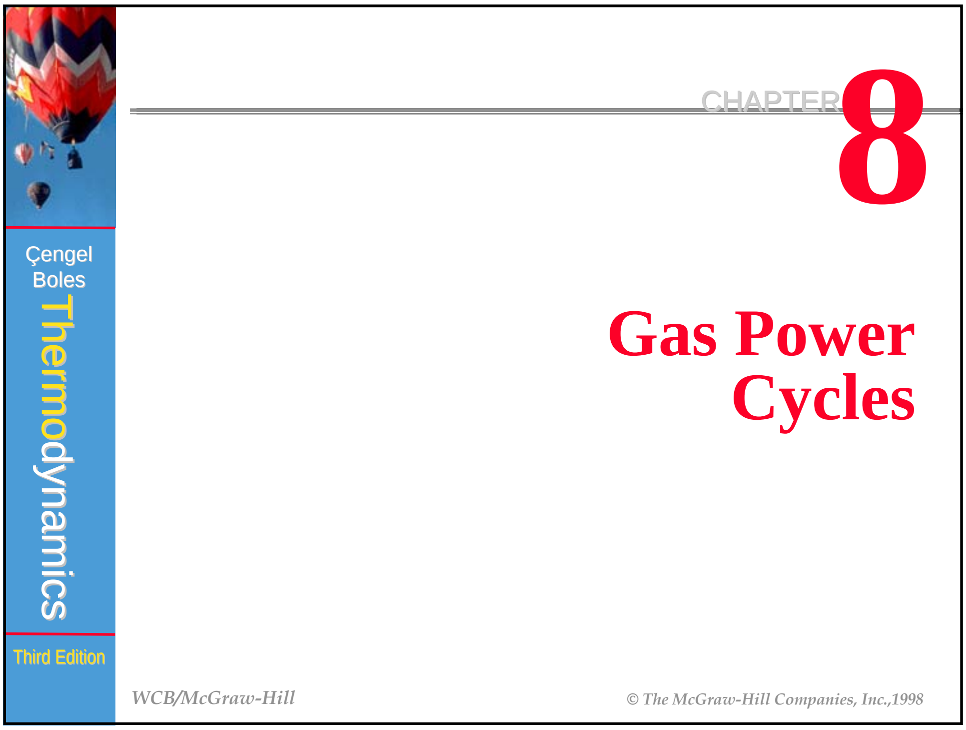

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CHAPTER 8

Gas Power Cycles

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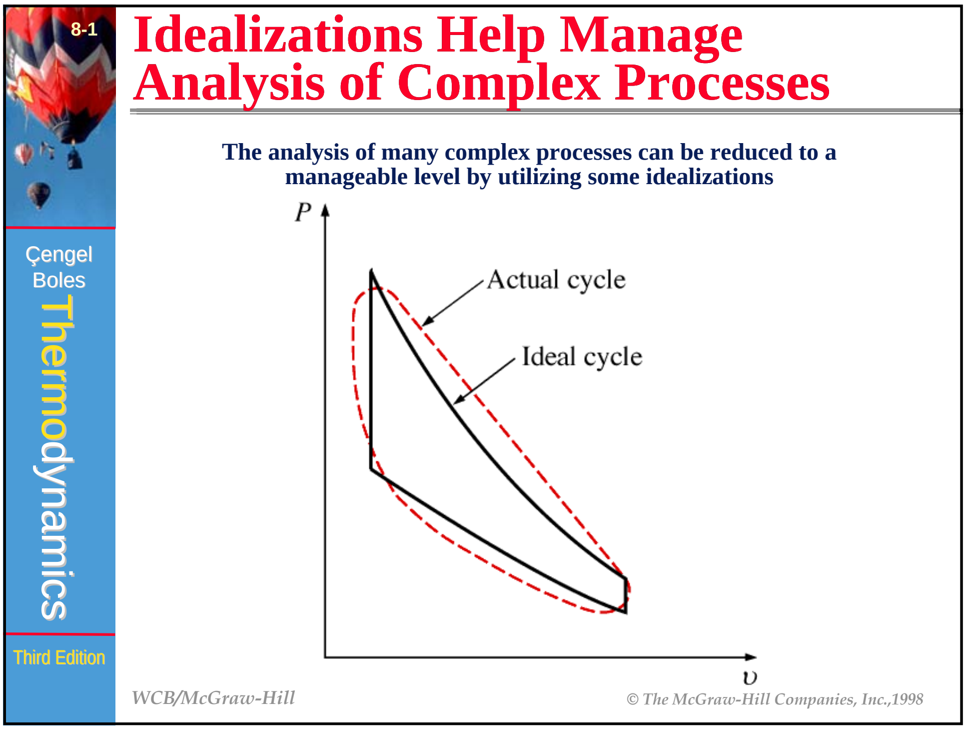

Idealizations Help Manage Analysis of Complex Processes

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The analysis of many complex processes can be reduced to a manageable level by utilizing some idealizations

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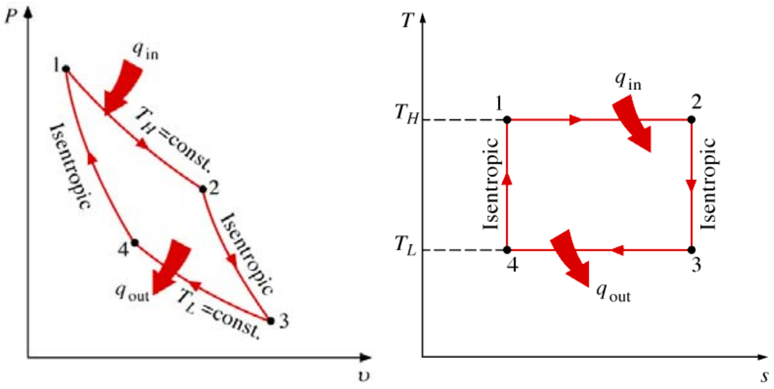
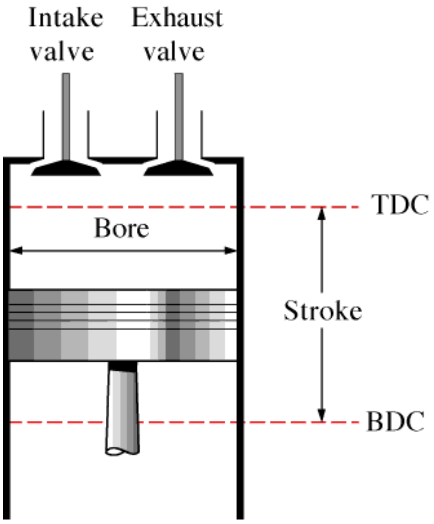
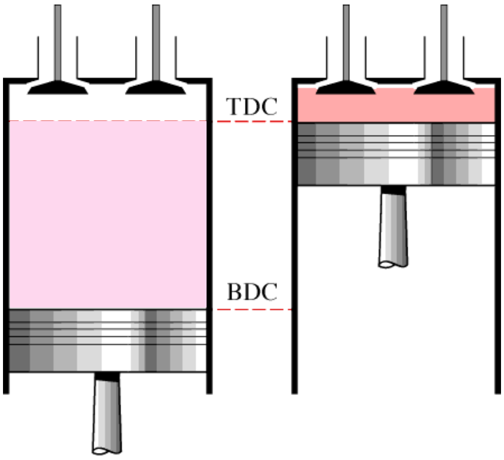
P-*v* and *T*-*s* diagrams of a Carnot Cycle



Nomenclature for Reciprocating Engines



Reciprocating Engine Displacement and Clearance Volumes

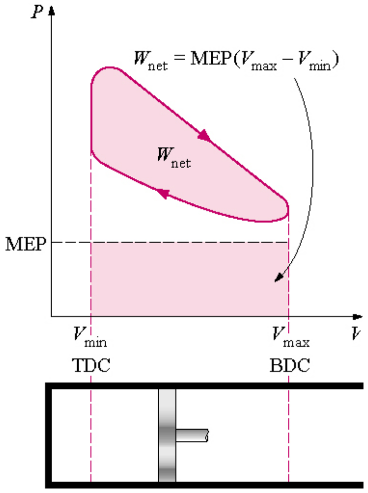


(*a*) Displacement volume

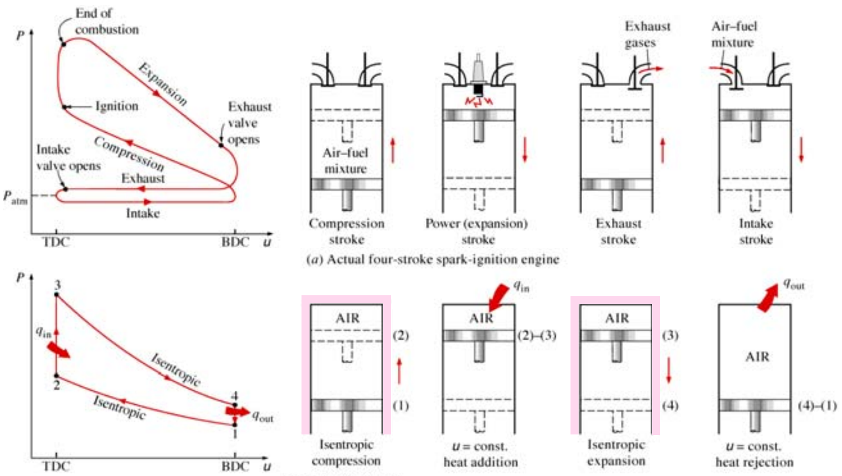
(*b*) Clearance volume

The Net Work Output of a Cycle

The net work output of a cycle is equivalent to the product of the mean effect pressure and the displacement volume



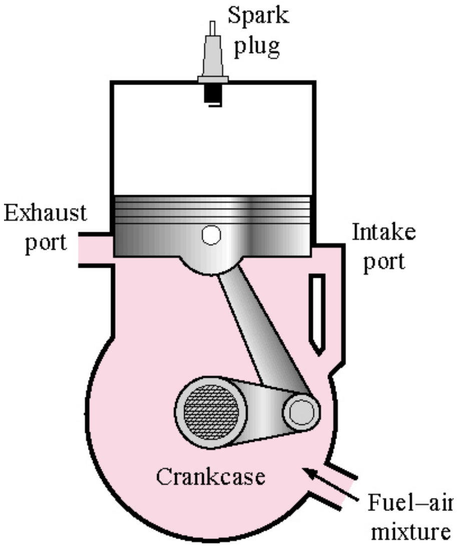
Actual and Ideal Cycles in Spark-Ignition Engines and Their *P*-*v* Diagram



(*a*) Actual four-stroke spark-ignition engine

(*b*) Ideal Otto cycle

Schematic of a Two-Stroke Reciprocating Engine



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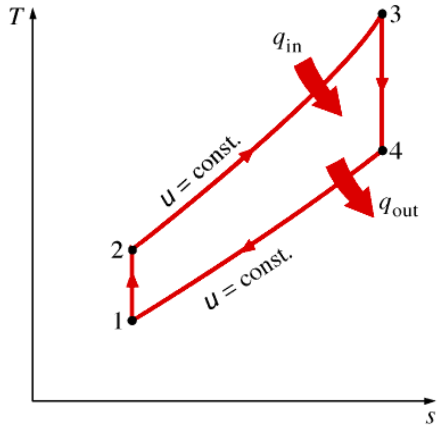
T-s Diagram for the Ideal Otto Cycle



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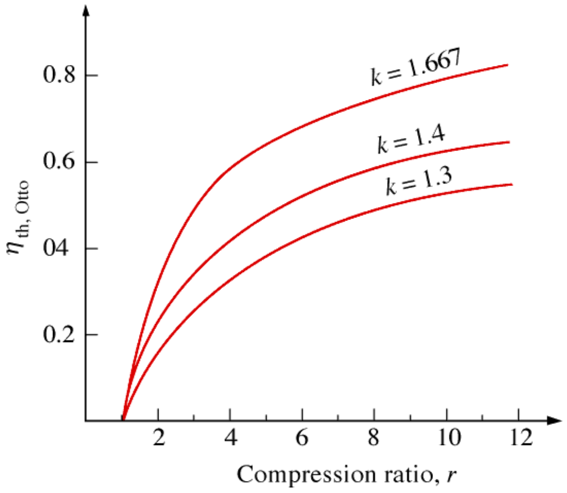
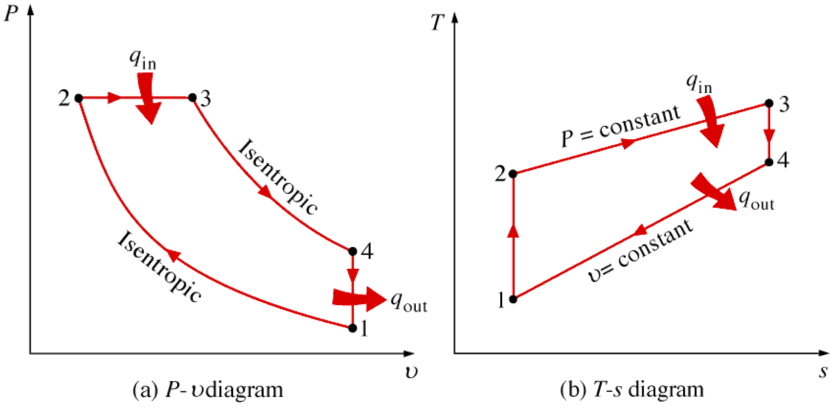
The Thermal Efficiency of the Otto Cycle

The thermal efficiency of the Otto Cycle increases with the specific heat ratio *k* of the working fluid



T-s and *P-v* Diagrams for the Ideal Diesel Cycle

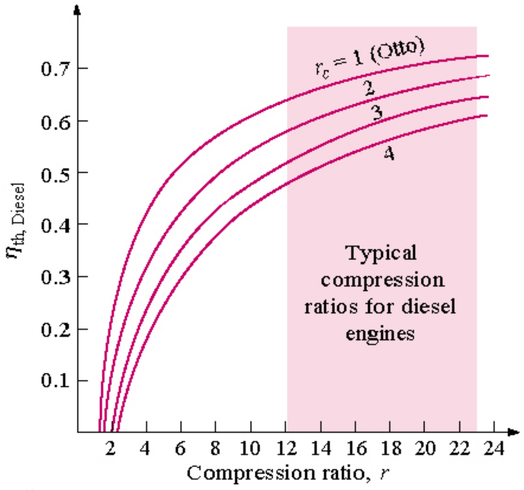


(a) *P*- υdiagram

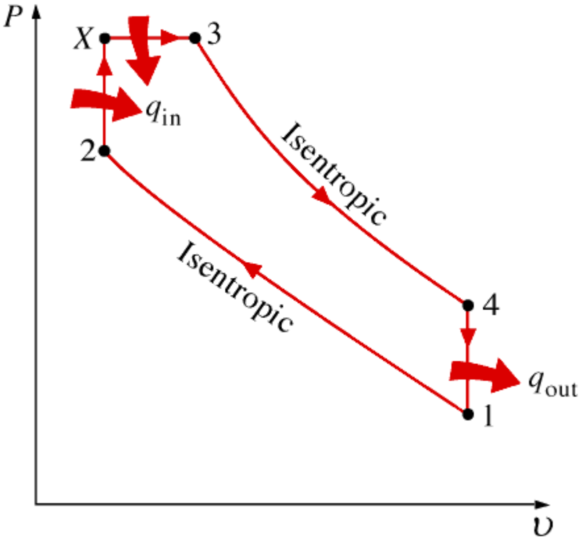
(b) *T-s* diagram

Thermal Efficiency of the Ideal Diesel Cycle

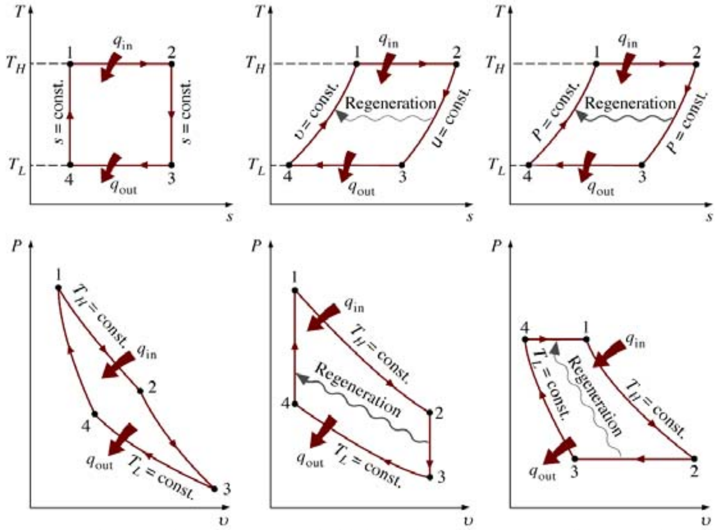
The thermal efficiency of the ideal Diesel cycle as a function of compression and cutoff rates (*k*=1.4)



P-v Diagram of an Ideal Dual Cycle

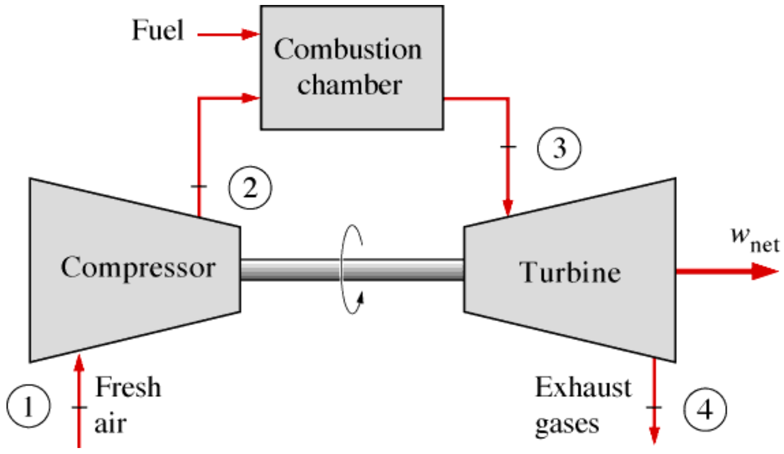


T-s and *P-v* Diagrams of Carnot, Stirling, and Ericsson Cycles

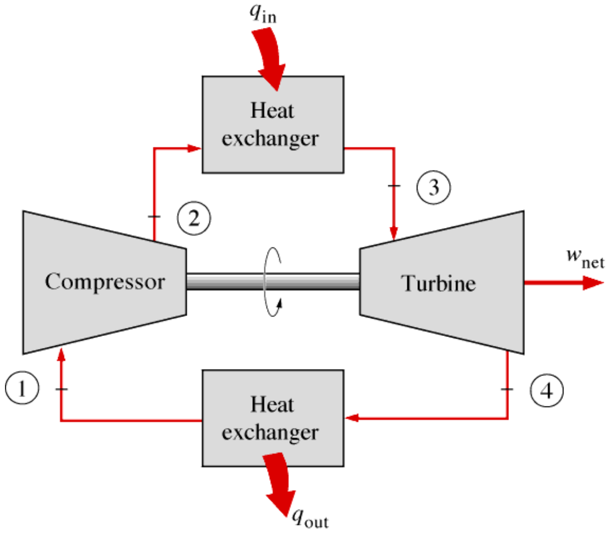


(*a*) Carnot cycle (*b*) Stirling cycle (*c*) Ericsson cycle

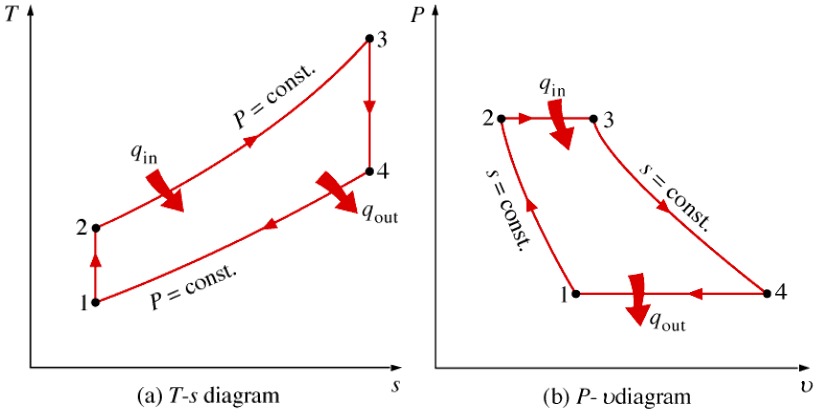
An Open-Cycle Gas-Turbine Engine



A Closed-Cycle Gas-Turbine Engine



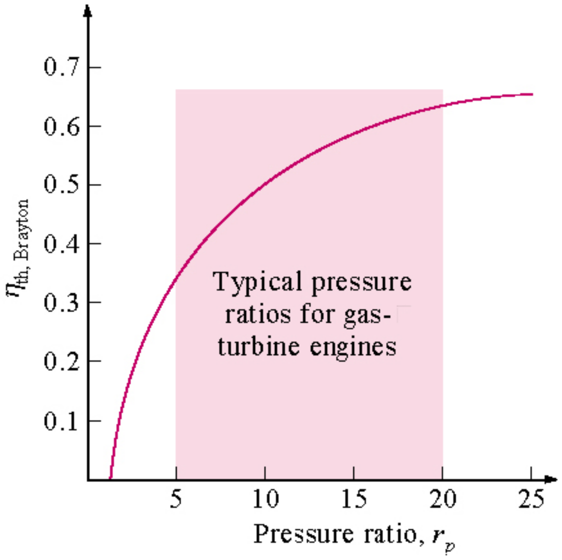
T-s and *P-v* Diagrams for the Ideal Brayton Cycle



(a) *T-s* diagram

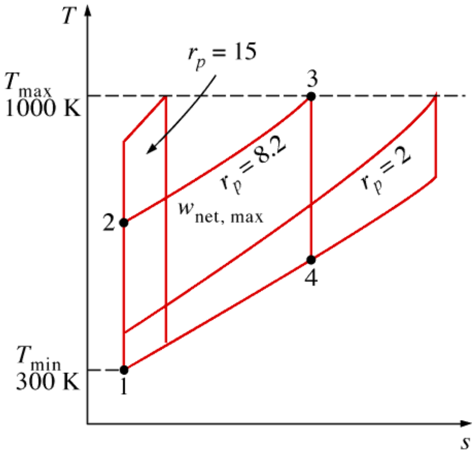
(b) *P-* υdiagram

Thermal Efficiency of the Ideal Brayton Cycle as a Function of the Pressure Ratio

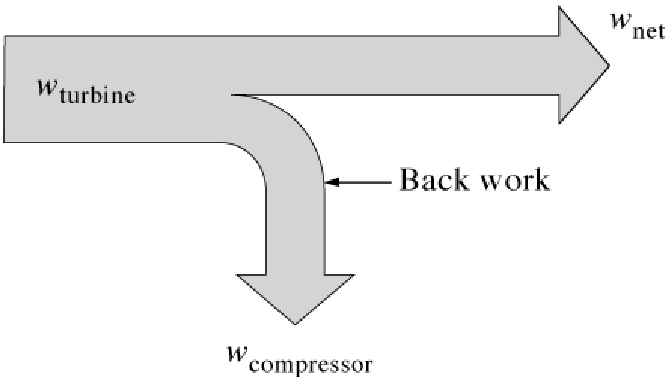


The Net Work of the Brayton Cycle

For fixed values of T_{min} and T_{max}, the net work of the Brayton cycle first increases with the pressure ratio, then reaches a maximum at $r_p=(T_{max}/T_{min})^{k/[2(k-1)]}$, and finally decreases

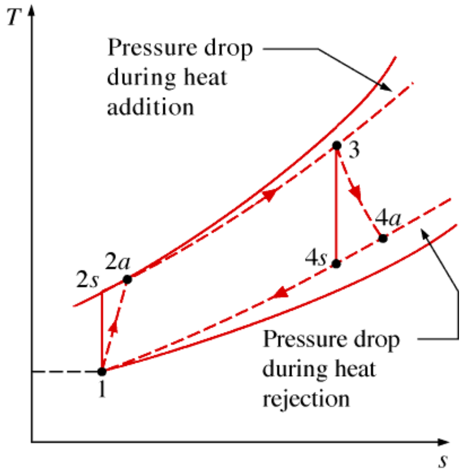


The Back-Work Ratio is the Fraction of Turbine Work Used to Drive the Compressor

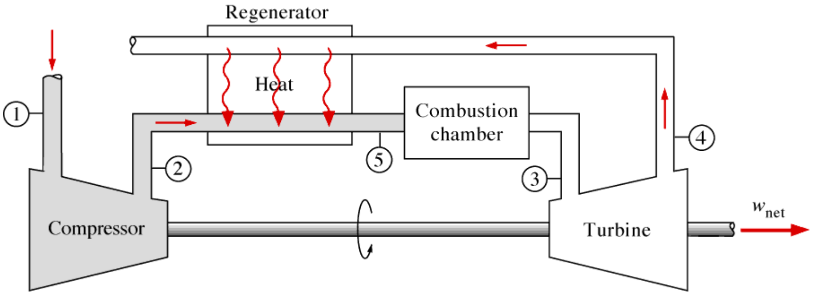


Deviation of Actual Gas-Turbine Cycle From Brayton cycle

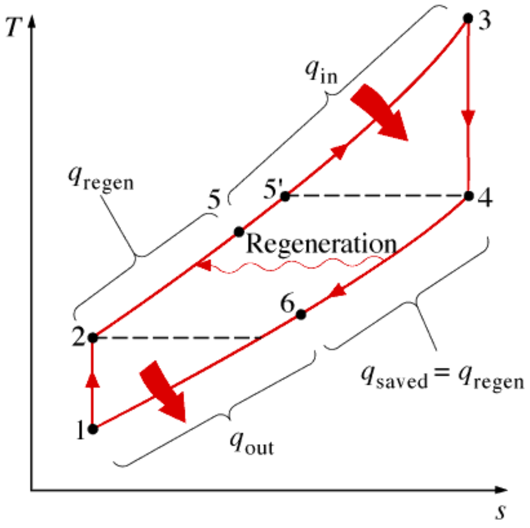
The deviation of an actual gas-turbine cycle from the ideal Brayton cycle as a result of irreversibilities



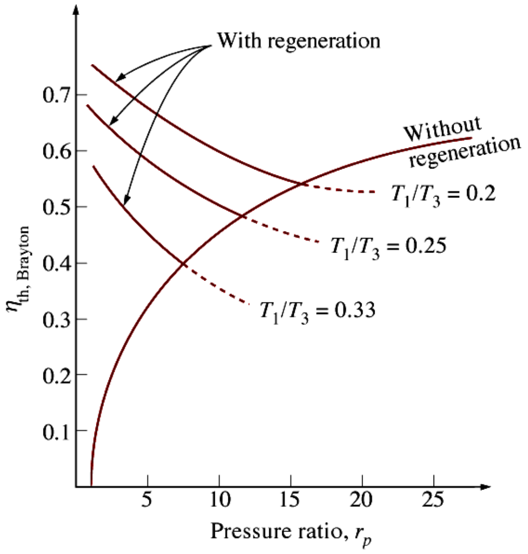
A Gas-Turbine Engine With Regenerator

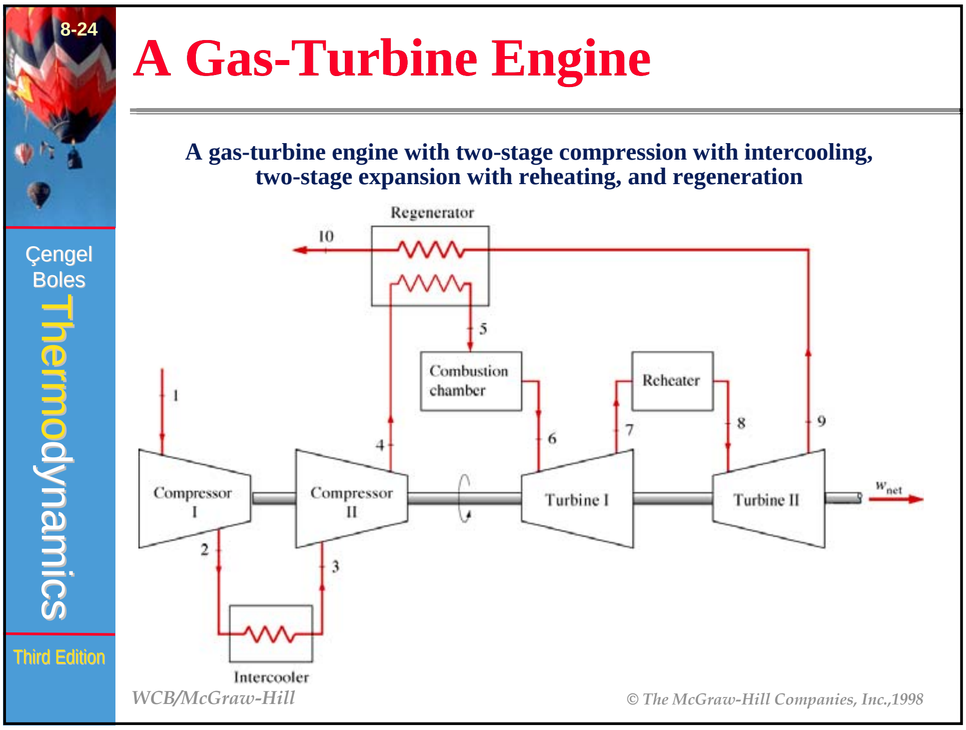


T-s Diagram of a Brayton Cycle with Regeneration



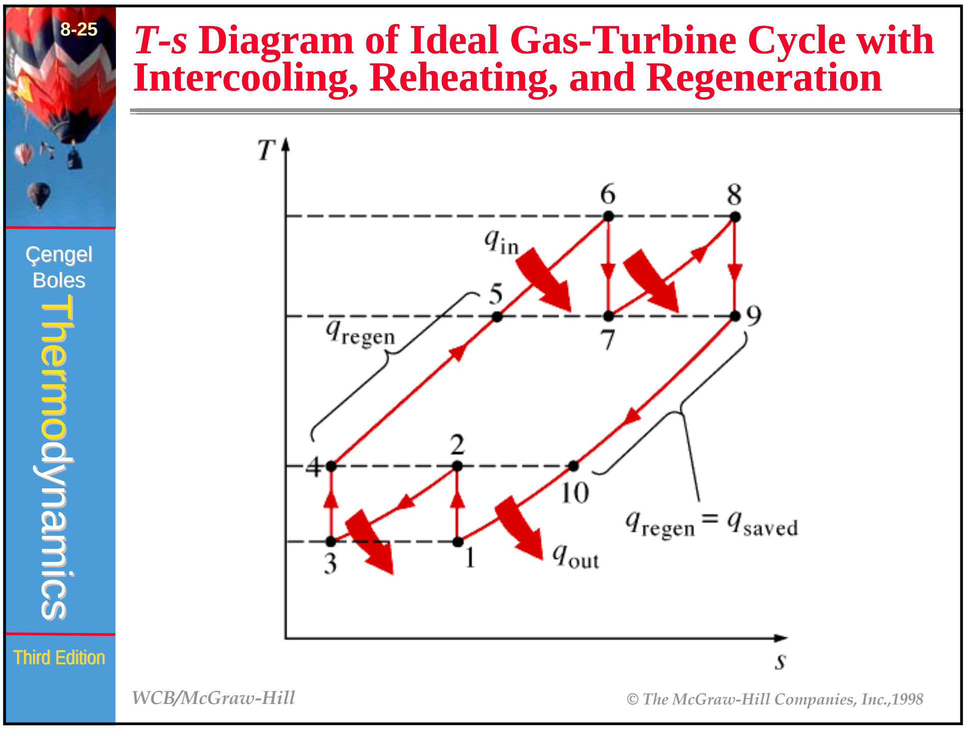
Thermal Efficiency of the ideal Brayton cycle with and without regeneration





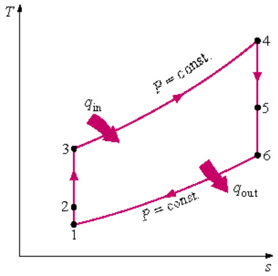
A Gas-Turbine Engine

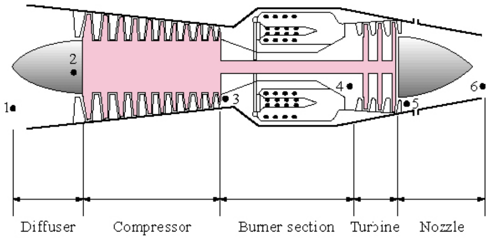
A gas-turbine engine with two-stage compression with intercooling, two-stage expansion with reheating, and regeneration



T-s Diagram of Ideal Gas-Turbine Cycle with Intercooling, Reheating, and Regeneration

Turbojet Engine Basic Components and *T-s* Diagram for Ideal Turbojet Cycle





Schematic of A Turbofan Engine

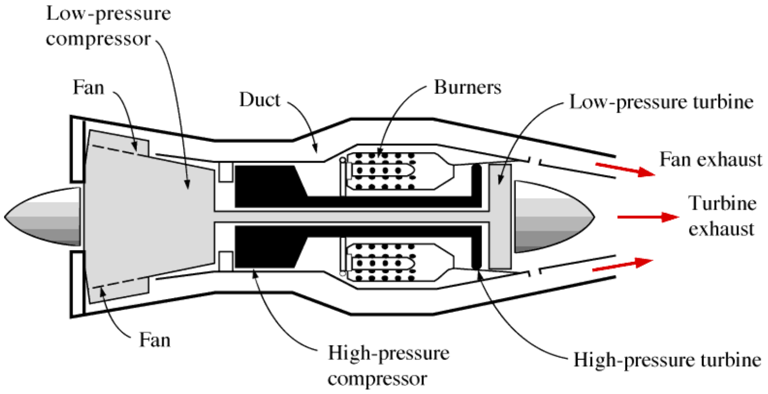
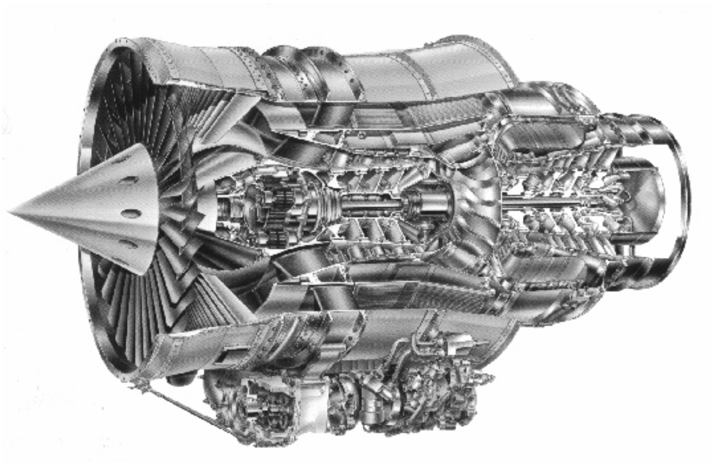
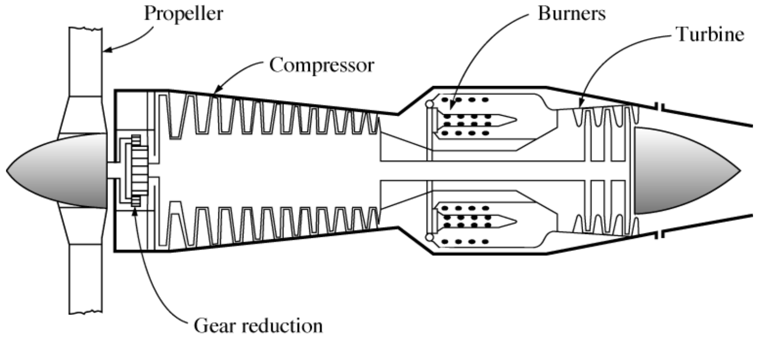


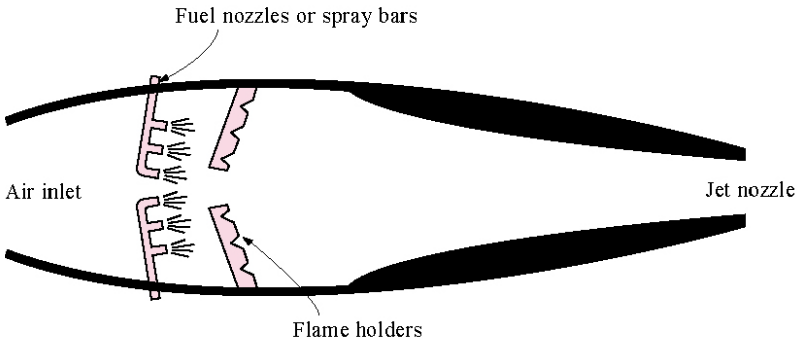
Illustration of A Turbofan Engine



Schematic of a Turboprop Engine



Schematic of a Ramjet Engine



Chapter Summary

- A cycle during which a net amount of work is produced is called a *power cycle*, and a power cycle during which the working fluid remains a gas throughout is called a *gas power cycle*.

Chapter Summary

- The most efficient cycle operating between a heat source at temperature T_H and a sink at temperature T_L is the Carnot cycle, and its thermal efficiency is given by

$$\eta_{th,\,Carnot} = 1 - \frac{T_L}{T_H}$$

Chapter Summary

- The actual gas cycles are rather complex. The approximations used to simplify the analysis are known as the *air-standard assumptions*. Under these assumptions, all the processes are assumed to be internally reversible; the working fluid is assumed to be air, which behaves as an ideal gas; and the combustion and exhaust processes are replaced by heat-addition and heat-rejection processes, respectively.

Chapter Summary

- **The air-standard assumptions are called *cold-air-standard assumptions* if, in addition, air is assumed to have constant specific heats at room temperature.**

Chapter Summary

- **In reciprocating engines, the *compression ratio r* and the *mean effective pressure* MEP are defined as**

$$r = \frac{V_{\max}}{V_{\min}} = \frac{V_{BDC}}{V_{TDC}}$$

$$MEP = \frac{w_{net}}{v_{\max} - v_{\min}} \qquad (kPa)$$

Chapter Summary

- The *Otto cycle* is the ideal cycle for the spark-ignition reciprocating engines, and it consists of four internally reversible processes: isentropic compression, constant volume heat addition, isentropic expansion, and con-stant volume heat rejection.

Chapter Summary

- Under cold-air-standard assumptions, the thermal efficiency of the ideal Otto cycle is

$$\eta_{th,\,Otto} = 1 - \frac{1}{r^{k-1}}$$

where *r* is the compression ratio and *k* is the specific heat ratio C_p / C_v.

Chapter Summary

- The ***Diesel cycle*** is the ideal cycle for the compression-ignition reciprocating engines. It is very similar to the Otto cycle, except that the constant volume heat-addition process is replaced by a constant pressure heat-addition process.

Chapter Summary

- The Diesel cycle thermal efficiency under cold-air-standard assumptions is

$$\eta_{th,\ Diesel} = 1 - \frac{1}{r^{k-1}}\left[\frac{r_c^k - 1}{k(r_c - 1)}\right]$$

where r_c is the ***cutoff ratio***, defined as the ratio of the cylinder volumes after and before the combustion process.

Chapter Summary

- *Stirling* and *Ericsson cycles* are two totally reversible cycles that involve an isothermal heat-addition process at T_H and an isothermal heat-rejection process at T_L. They differ from the Carnot cycle in that the two isentropic processes are replaced by two constant volume regeneration processes in the Stirling cycle and by two constant pressure regeneration processes in the Ericsson cycle. Both cycles utilize *regeneration*, a process during which heat is transferred to a thermal energy storage device (called a *regenerator*) during one part of the cycle that is then transferred back to the working fluid during another part of the cycle.

Chapter Summary

- The ideal cycle for modern gas-turbine engines is the *Brayton cycle*, which is made up of four internally reversible processes: isentropic compression, constant pressure heat addition, isentropic expansion, and constant pressure heat rejection.

Chapter Summary

- Under cold-air-standard assumptions, the Brayton cycle thermal efficiency is

$$\eta_{th,\,Brayton} = 1 - \frac{1}{r_p^{(k-1)/k}}$$

where $r_p = P_{max}/P_{min}$ is the pressure ratio and k is the specific heat ratio. The thermal efficiency of the simple Brayton cycle increases with the pressure ratio.

Chapter Summary

- The deviation of the actual compressor and the turbine from the idealized isentropic ones can be accurately accounted for by utilizing their adiabatic efficiencies, defined as

$$\eta_C = \frac{w_s}{w_a} \cong \frac{h_1 - h_{2s}}{h_1 - h_{2a}}$$

and

$$\eta_T = \frac{w_a}{w_s} \cong \frac{h_3 - h_{4a}}{h_3 - h_{4s}}$$

where states 1 and 3 are the inlet states, 2a and 4a are the actual exit states, and 2s and 4s are the isentropic exit states.

Chapter Summary

- In gas-turbine engines, the temperature of the exhaust gas leaving the turbine is often considerably higher than the temperature of the air leaving the compressor. Therefore, the high-pressure air leaving the compressor can be heated by transferring heat to it from the hot exhaust gases in a counter-flow heat exchanger, which is also known as a *regenerator*.

Chapter Summary

- The extent to which a regenerator approaches an ideal regenerator is called the *effectiveness* eε nd is defined as

$$\varepsilon = \frac{q_{regen,act}}{q_{regen,\max}}$$

Chapter Summary

- **Under cold-air-standard assumptions, the thermal efficiency of an ideal Brayton cycle with regeneration becomes**

$$\eta_{th,\,regen} = 1 - \left(\frac{T_1}{T_3}\right)(r_p)^{(k-1)/k}$$

where T_1 and T_3 are the minimum and maximum temperatures, respectively, in the cycle.

Chapter Summary

- **The thermal efficiency of the Brayton cycle can also be increased by utilizing *multistage compression with intercooling, regeneration, and multistage expansion with reheating*. The work input to the compressor is minimized when equal pressure ratios are maintained across each stage. This procedure also maximizes the turbine work output.**

Chapter Summary

- Gas-turbine engines are widely used to power aircraft because they are light and compact and have a high power-to-weight ratio. The ideal *jet-propulsion cycle* differs from the simple ideal Brayton cycle in that the gases are partially expanded in the turbine. The gases that exit the turbine at a relatively high pressure are subsequently accelerated in a nozzle to provide the thrust needed to propel the aircraft.

Chapter Summary

- The *net thrust* developed by the turbojet engine is

$$F = \dot{m}(\vec{V}_{exit} - \vec{V}_{inlet}) \qquad (N)$$

where *m* is the mass flow rate of gases, $\vec{V}_{exit}$ is the exit velocity of the exhaust gases, and $\vec{V}_{inlet}$ is the inlet velocity of the air, both relative to the aircraft

Chapter Summary

- The power developed from the thrust of the engine is called the *propulsive power* $\dot{W}_p$ and it is given by

$$\dot{W}_P = \dot{m}(\vec{V}_{exit} - \vec{V}_{inlet})\vec{V}_{aircraft} \qquad (kW)$$

Chapter Summary

- *Propulsive efficiency* is a measure of how efficiently the energy released during the combustion process is converted to propulsive energy, and it is defined as

$$\eta_P = \frac{\text{Propulsive power}}{\text{Energy input rate}} = \frac{\dot{W}_P}{\dot{Q}_{in}}$$

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Chapter Summary

- For an ideal cycle that involves heat transfer only with a source at T_H and a sink at T_L, the irreversibility or exergy destruction is determined to be

$$i = T_o\left(\frac{q_{out}}{T_L} - \frac{q_{in}}{T_H}\right) \qquad (kJ/kg)$$