Chapter 8 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.*

- 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

$$\eta_{\text{th, Carnot}} = 1 - \frac{T_\mathrm{L}}{T_\mathrm{H}}$$

- 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.

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

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

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

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

- 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 constant volume heat rejection.

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

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

where r is the compression ratio and k is the specific heat ratio $C_\mathrm{p}/C_\mathrm{v}$.

- 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.

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

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

  where r_{c} is the *cutoff ratio,* defined as the ratio of the cylinder volumes after and before the combustion process.

- *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.

- 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.

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

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

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

- 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.

- 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 counterflow heat exchanger, which is also known as a *regenerator*.

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

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

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

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

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

- 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.

- 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.

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

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

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

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

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

- *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

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

- 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

$$i = T_0\left(\frac{q_{\text{out}}}{T_L} - \frac{q_{\text{in}}}{T_H}\right) \qquad \text{(kJ/kg)}$$