1. An ideal gas Carnot cycle uses air as the working fluid, accepts heat from an energy reservoir at 1027 °C, is repeated 1500 times per minute, and has a compression ratio of 12. Determine the maximum temperature of the low temperature energy reservoir, the cycle's thermal efficiency, and the amount of heat that must be supplied each time the cycle is repeated if this device is to produce 1500 kW of power. (481 K, 0.63, 20 kJ/Cycle, 31.75 kJ/Cycle)

2. The thermal energy reservoirs of an ideal gas Carnot cycle are at 1240 °F, and 40 °F, and the device executing this cycle rejects 100 BTU of heat each time the cycle is executed. Determine the total heat supplied to and the total work produced by this cycle each time it is executed.

3. An ideal gas Carnot cycle uses helium as the working fluid and rejects heat to a lake which is at 15 °C. Determine the pressure ratio, compression ratio and minimum temperature of the energy source reservoir for this cycle to have a thermal efficiency of 50%. (576 K, 5.654, 2.827)

4. Repeat Problem 8.3 when the lake is at 60 °F and the Carnot cycle efficiency is 60%.

5. Can any ideal gas power cycle have a thermal efficiency greater than 55% when using energy reservoirs at 627 °C and 17 °C? (yes)

6. What is the maximum possible thermal efficiency of a gas power cycle when using thermal energy reservoirs at 940 °F and 40 °F?

7. An Otto cycle has a compression ratio of 12, takes in air at 100 kPa, 20 °C, and is repeated 1000 times a minute. Determine the thermal efficiency of this cycle and the rate of heat input if this cycle is to produce 200 kW of power. (0.63, 317.5 kW)

8. If all the conditions of Problem 7 remain the same except the compression ratio, which is changed to 10, how will the thermal efficiency and rate of heat input change?

9. A spark ignition engine has a compression ratio of 8:1, an isentropic compression efficiency of 85%, and an isentropic expansion efficiency of 95%. At the beginning of the compression, the air in the piston-cylinder is at 13 psia and 60 °F. The maximum gas temperature is found to be 2300 °F by measurement. Determine the thermal efficiency, specific heat addition, and the mean effective pressure of this engine when it is modeled by an Otto cycle. (0.4749, 48.99 psia)

10. Determine the mean effective pressure of an Otto cycle which uses air as the working fluid, whose state at the beginning of the compression is 14 psia and 60 °F, whose temperature at the end of the combustion is 1500 °F, and whose compression ration is 9:1

11. Determine the rate of heat addition for the Otto cycle of Problem 10 when it produces 140 hp and the cycle is repeated 1400 times per minute. (609,000 Btu/hr, -253,000 Btu/hr)

12. A typical hydrocarbon fuel produces 42,000 kJ/kg of heat when used in a spark ignition engine. Determine the compression ratio required for an Otto cycle to use 0.0013 grams of this fuel to produce 1 kJ of work.
13. When we double the compression ratio of an Otto cycle, what happens to the maximum gas temperature and pressure when the state of the air at the beginning of the compression and the amount of heat addition remain the same.

14. In a spark ignition engine, some cooling occurs as the gas is expanded. This may be modeled by using a polytropic expansion process in lieu of the isentropic expansion process. Determine if the polytropic exponent used in this model will be greater than or less than the isentropic exponent.

15. A 6 cylinder, four-stroke, spark ignition engine takes in air at 14 psia, 65 °F, and is limited to a maximum cycle temperature of 1600 °F. Each cylinder has a bore of 3.5 in. and each piston has a stroke of 3.9 in. The minimum enclosed volume is 14% of the maximum volume. How much power will this engine produce at 2500 rpm? (1.646 hp)

16. A 6 cylinder, 4 liter, four-stroke, spark ignition engine takes in air at 90 kPa, 20 °C. The minimum enclosed volume is 15% of the maximum enclosed volume. When operated at 2500 rpm, this engine produces 90 hp. Determine the rate of heat addition to this engine.

17. An Otto cycle has a compression ratio of 7. At the beginning of the compression process, \( P_1 = 90 \text{ kPa} \), \( T_1 = 27 \text{ °C} \), and \( V_1 = 0.004 \text{ m}^3 \). The maximum cycle temperature is 1127 °C. Calculate for each repetition of this cycle the heat rejection, and the net work production. Also calculate the thermal efficiency and mean effective pressure of this cycle. (-1.028 kJ, 0.5408)

18. It has been suggested that the air standard Otto cycle is more accurately modeled by replacing the two isentropic processes with polytropic processes whose \( n = 1.3 \). Consider such a cycle when the compression ratio is 8, \( P_1 = 14.3 \text{ psia} \), \( T_1 = 65 \text{ °F} \), and the maximum cycle temperature is 2000 °F. Determine the specific heat added to and rejected from this cycle, and the thermal efficiency of this cycle.

19. How do the results of Problem 8.18 change when isentropic processes are used in place of the polytropic processes? (214.6 Btu/lbm, 93.3 Btu/lbm, 0.566)

20. An air-standard limited pressure cycle has a compression ratio of 14, an \( \alpha \) of 1.5, and an \( r_c \) of 1.2. Determine the thermal efficiency, the amount of heat added, the maximum gas pressure, and the maximum gas temperature when this cycle is operated with 80 kPa and 20 °C at the beginning of the compression. (0.646, 554.5 kJ/kg, 4.83 MPa, 1515 K)

21. Determine the amount of heat added and the maximum gas pressure and temperature of Problem 8.21 when the state of the air at the beginning of the compression is 80 kPa and -20 °C.

22. An air-standard, limited pressure cycle has a compression ratio of 20, \( \alpha \) of 1.2, and \( r_c \) of 1.3. Determine the thermal efficiency, amount of heat added, and the maximum pressure and temperature when this cycle is operated at 14 psia, 70 °F at the beginning of the compression. (0.686, 211.7 Btu/lbm, 1114 psia, 2741 °R)

23. If the compression ratio of Problem 8.24 were reduced to 12, how would the thermal efficiency, amount of heat added, and the maximum gas pressure change? (0.78, 172 Btu/lbm, 545 psia, 2231 °R)

24. The \( \alpha \) and \( r_c \) parameters determine the amount of heat added to the limited pressure cycle. Develop an equation for \( q_{in} / (T_1 r_c^{k-1}) \).
25. An air-standard, limited pressure cycle has a compression ratio of 18, an \( \alpha = 1.1 \), and a \( r_c = 1.1 \). At the beginning of the compression, \( P_1 = 90 \text{ kPa}, T_1 = 18 \text{ °C}, \) and \( V_1 = 0.003 \text{ m}^3 \). How much power will this cycle produce when repeated 4000 times per minute? (24.83 kW)

26. The compression efficiency of Problem 8.27 is 85% and the expansion efficiency is 90%. How much does the power produced by this cycle change because of these process efficiencies?

27. A limited pressure cycle has a compression ratio of 15, an \( \alpha = 1.1 \), a \( r_c = 1.4 \), \( P_1 = 14.2 \text{ psia} \), and \( T_1 = 75 \text{ °F} \). Calculate the net specific work produced, specific heat addition, and thermal efficiency of this cycle.

28. A pure Diesel cycle has a compression ratio of 20 and a cutoff ratio of 1.4. Determine the maximum cycle temperature and the rate of heat addition to this cycle when it produces 250 kW of power and the state of the air at the beginning of the compression is 90 kPa, 15 °C. (1337 K, 371 kW)

29. A pure Diesel cycle has a compression ratio of 18 and a cutoff ratio of 1.5. Determine the maximum cycle temperature and the rate of heat addition to this cycle when it produces 200 hp of power. The state of the air at the beginning of the compression is 13.8 psia, 65 °F.

30. Rework Problem 8.32 when the compression efficiency is 90% and the expansion efficiency is 95%.

31. Develop an expression for the cutoff ratio which expresses it in terms of \( \frac{q_{in}}{(c_p r_v k^{-1} T_1)} \) for an air-standard Diesel cycle.

32. A Diesel cycle has a maximum cycle temperature of 2300 °F, a cutoff ratio of 1.4, \( P_1 = 14.4 \text{ psia} \), and \( T_1 = 50 \text{ °F} \). This cycle is executed in a four-stroke, eight cylinder engine whose cylinder bore is 4 inches and stroke is 4 inches. The minimum volume enclosed in the cylinder is 4.5% of the maximum enclosed cylinder volume. How much power does it produce when operated at 2000 RPM?

33. A Diesel cycle has a maximum cycle temperature of 2000 °C, \( P_1 = 95 \text{ kPa} \), and \( T_1 = 15 \text{ °C} \). This cycle is executed in a four-stroke, eight cylinder engine whose cylinder bore is 10 cm and stroke is 12 cm. The minimum volume enclosed in the cylinder is 5% of the maximum enclosed volume. Determine the power produced by this engine when it is operated at 1600 RPM.

34. Develop an expression for the thermal efficiency of a limited pressure cycle when \( \alpha = r_c \), What is the thermal efficiency of such an engine when the compression ratio is 20 and \( a = 2 \)? (0.82)

35. How can one change \( \alpha \) of Problem 8.37 such that the same thermal efficiency is maintained when the compression ratio is reduced?

36. A sterling cycle operates between thermal energy reservoirs at 27 °C and 527 °C. It is filled with one kilogram of air such that the maximum cycle pressure is 2 MPa and the minimum cycle pressure is 100 kPa. Determine the net work produced by this engine each time this cycle is repeated and the cycle's thermal efficiency. (289 kJ/cycle, 0.625)

37. Determine the external rate of heat input and power produced by the cycle of Problem 36 when the cycle is executed 500 times per minute.

38. A Sterling cycle uses energy reservoirs at 40 °F and 640 °F, and uses hydrogen as the working gas. It is designed such that its minimum volume is 0.1 ft³, the
maximum volume is 1 ft$^3$, and maximum pressure is 400 psia. Calculate the amount of external heat addition, external heat rejection, and heat transfer between the working fluid and regenerator for each time the cycle is executed. (17.04 Btu/cycle, -7.48 Btu/cycle, 9.89 Btu/cycle)

39. A Sterling cycle filled with air uses a 50 °F energy reservoir as a sink. This engine is designed so that the maximum air volume is 0.5 ft$^3$, the minimum air volume is 0.06 ft$^3$, and the minimum air pressure is 10 psia. It is operated such that it produces 2 Btu of work when 6 Btu of heat are externally transferred to the engine. Determine the temperature of the source energy reservoir, the amount of air in the engine, and the maximum air pressure.

40. How would the temperature of the source energy reservoir and maximum cycle pressure of Problem 8.42 change if the engine were to be operated to produce 2.5 Btu of work for the same external heat input? (875 °R, 143 psia)

41. An air-standard Sterling engine operates with a maximum pressure of 600 psia and a minimum pressure of 10 psia. The maximum volume of the air is 10 times the minimum volume. The minimum cycle temperature is 100 °F. Calculate the heat added to and rejected from this engine and the net work produced by this engine.

42. How much heat is exchanged with the regenerator of Problem 8.44? (64.0 Btu/lbm)

43. An air-standard Sterling cycle operates with a maximum pressure of 3600 kPa and a minimum pressure of 50 kPa. The maximum volume is 12 times the minimum volume and the low temperature sink reservoir is at 20 °C. Allowing a 5 °C temperature difference between the external reservoirs and the cycle air when appropriate, calculate the heat added to the cycle and the work produced by the cycle.

44. How much heat is exchanged with the regenerator of Problem 43? (1068 kJ/kg)

45. Calculate the lost work potential for each process of Problem 43.

46. A Brayton cycle operates with minimum and maximum temperatures of 27 °C and 727 °C. It is designed such that the maximum cycle pressure is 2 MPa and the minimum cycle pressure is 100 kPa. Determine the net work produced each time this cycle is executed and the cycle's thermal efficiency. (169.6 kJ/kg, 0.5749)

47. Determine the work production and thermal efficiency of the Brayton cycle in Problem 8.49 when the isentropic efficiency of the turbine is 90%.

48. If the compressor isentropic efficiency of Problem 8.50 is 80%, how much work will this cycle produce and what is its thermal efficiency? (9.03 kJ/kg, 4.7%)

49. Determine the work production and thermal efficiency for Problem 48 when there is also a 50 kPa pressure drop across the heat addition unit.

50. A simple Brayton cycle uses helium as the working fluid, operates with 12 psia, 60 °F at the compressor inlet, has a pressure ratio of 14, and a maximum cycle temperature of 1300 °F. How much power will this cycle produce when the helium is circulated about the cycle at a rate of 100 lbm/min? (506 hp)

51. If the compressor efficiency of Problem 50 is 95%, how much power will the Brayton cycle produce?

52. The back-work ratio for a gas turbine is defined as the ratio of the work used by the compressor to the work produced by the turbine. Consider a simple Brayton
cycle using air as the working fluid, has a pressure ratio of 12, has a maximum cycle temperature of 600 °C, and operates the compressor inlet at 90 kPa, 15 °C. Which will have the greatest impact of the back-work ratio, a compressor efficiency of 90% or a turbine efficiency of 90%? (they are approximately equivalent)

53. Use availability analysis to answer Problem 52.

54. A simple Brayton cycle uses argon as the working fluid. At the beginning of the compression, $P_1 = 15$ psia and $T_1 = 80 ^\circ F$, the maximum cycle temperature is 1200 °F, and the pressure during heat addition is 150 psia. The argon enters the compressor through a 3 ft² opening with a velocity of 200 ft/s. Determine the rate of heat addition, power produced, and the cycle's efficiency. (2339 Btu/s, 1405 Btu/s, 0.60)

55. Determine the rate at which entropy is generated by the Brayton cycle of Problem 8.57. The temperature of the energy source reservoir is the same as the maximum cycle temperature and the temperature of the energy sink reservoir is the same as the minimum cycle temperature.

56. An aircraft engine operates as a simple Brayton cycle. Consider such an engine whose pressure ratio is 10, heat is added to the engine at a rate of 500 kW, air passes through the engine at a rate of 1 kg/s, and the air at the beginning of the compression is at 70 kPa, 0 °C. Determine the power produced by this engine and its thermal efficiency. (241 kW, 0.482)

57. How will the results of Problem 56 change if the pressure ratio is increased to 15?

58. A gas turbine for an automobile is designed with a regenerator. Air enters the compressor of this engine at 100 kPa, 20 °C. The compressor pressure ratio is 8, the maximum cycle temperature is 800 °C, and the cold air stream leaves the regenerator 10 °C cooler than the hot air stream entering the regenerator. Determine the rate of heat addition and rejection for this cycle when it produces 150 kW. (302 kW, -152 kW)

59. Rework Problem 58 for a compressor efficiency of 87% and a turbine efficiency of 93%.

60. Determine the lost work potential for each of the processes of Problem 59. (19.59 kJ/kg, 56.84 kJ/kg, 16.69 kJ/kg, 88.48 kJ/kg, 1.6 kJ/kg)

61. The regenerator of a regenerative Brayton cycle is arranged such that the hot and cold-streams enter the regenerator at the same end and leave together at the other end. Consider such a system when air enters the compressor at 14 psia, 70 °F, the pressure ratio is 7, the maximum cycle temperature is 1240 °F, and the difference between the hot and cold stream temperatures is 10 °F at the end of the regenerator where the streams exit. Is this regenerator more or less efficient than the standard regenerator arrangement?

62. An ideal regenerator is added to a simple Brayton cycle. Air enters the compressor of this cycle at 13 psia, 50 °F, it has a pressure ratio of 8, and the maximum cycle temperature is 1500 °F. What is the thermal efficiency of this cycle? (0.55)

63. Calculate the thermal efficiency of the cycle in Problem 62 when the regenerator is removed.
64. A gas turbine operates with an ideal regenerator and two stages of ideal reheating and intercooling. Air enters the first compressor at 14 psia, 60 °F, the pressure ratio for each stage of compression is 3, and the air temperature entering the turbine is 940 °F. Determine the mass flow rate through this engine and the rate of external heat addition and rejection when it produces 1000 hp. (7.84 lbm/s, 1425 Btu/s, 718 Btu/s)

65. What is the rate of heat addition to the cycle of Problem 64 when the efficiency of each compressor is 88% and the efficiency of each turbine is 93%?

66. Which one of the processes of Problem 65 loses the greatest amount of work potential when the energy source temperature is the same as the maximum cycle temperature and the energy sink temperature is the same as the minimum cycle temperature? (the intercooler and heat rejection processes)

67. Air enters a two-stage gas turbine at 100 kPa, 17 °C. This system incorporates ideal reheating and intercooling and the regenerator increases the temperature of the cold stream by 20 °C as it passes through the regenerator. The pressure ratio of each compressor is 4 and 300 kJ/kg of heat are added to the air as it passes through each combustion chamber. Determine the thermal efficiency of this system.

68. Rework Problem 67 for 3 stages of ideal reheating and intercooling. (0.40)

69. How much would the thermal efficiency of Problem 68 change if the temperature of the cold-air stream leaving the regenerator is 40 °C lower than the temperature of the hot-air stream entering the regenerator?

70. A gas turbine has 2 stages of ideal compression, expansion, intercooling and reheating. Air enters the first compressor at 13 psia, 60 °F, the total pressure ratio (across all compressors) is 12, the rate of external heat addition is 500 Btu/s, and the cold-air stream temperature is increased by 50 °F as it passes through the regenerator. Calculate the power produced by each turbine, power consumed by each compressor, and the rate of heat rejection of this gas turbine. (264 kW, -173 kW, -328 Btu/s)

71. Rework Problem 70 with each compressor having an efficiency of 85% and each turbine having an efficiency of 90%.

72. Compare the thermal efficiency of a two-stage gas turbine with regeneration, reheating, and intercooling to that of a three-stage gas turbine with the same equipment when: (a) all components operate ideally, (b) air enters the first compressor at 14 psia, 40 °F, (c) the total pressure ratio across all compressors is 16, and (d) the maximum cycle temperature is 1000 °F. (0.49 vs. 0.55)

73. An Ericsson cycle operates using thermal energy reservoirs at 627 °C and 7 °C while producing 500 kW of power. Determine the rate of heat addition to this cycle when it is repeated 2000 times a minute.

74. If the cycle of Problem 73 is repeated 3000 times per minute while the heat added per cycle repetition remains the same, how much power will the cycle produce? (750 kW)

75. A turboprop aircraft propulsion engine operates where the air is at 8 psia, -10 °F. This engine is on an aircraft flying at a speed of 600 ft/s. The Brayton cycle pressure ratio is 10 and the air temperature at the inlet to the turbine is 940 °F. The propeller diameter is 10 ft and the mass flow rate through the propeller is 20
times that through the compressor. Determine the thrust force generated by this propulsion system.

76. If the propeller of Problem 75 were 8 ft in diameter and the mass flow rate entering the compressor the same, what would the thrust force be? (9070 lbf)

77. A turbofan propulsion unit on an aircraft flying at 200 m/s at an altitude where the air is at 50 kPa, -20 °C is to produce 50 kN of thrust. The inlet diameter of this unit is 2.5 m, the compressor pressure ratio is 12, and the mass flow rate ratio is 8. Determine the air temperature at the turbine inlet required to produce this thrust.

78. A pure jet engine propels an aircraft at 300 m/s through air at 60 kPa, 0 °C. The inlet diameter of this engine is 2 m, the compressor pressure ratio is 10, and the temperature at the turbine inlet is 450 °C. Determine the air velocity at the exit of this engine's nozzle and the thrust force produced by this engine. (530 m/s, 166 kN)

79. The specific impulse of an aircraft propulsion system is the thrust force produced per unit of thrust-producing mass flow rate. Consider a pure jet engine operating where the air is at 10 psia, 30 °F and propelling the aircraft at 1200 ft/s. Determine the specific impulse of this engine when the compressor pressure ratio is 9 and the air temperature at the turbine inlet is 700 °F.