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PERFORMANCE OF A BRAYTON POWER SYSTEM WITH A SPACE TYPE RADIATOR

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16. Abstract

Test results of an experimental investigation to measure Brayton engine performance while operating at the sink temperatures of a typical low Earth orbit are presented. The results indicate that the radiator area was slightly oversized. The steady-state and transient responses of the power system to the sink temperatures in orbit were measured. During the orbital operation, the engine did not reach the steady-state operation of either sun or shade conditions. The alternator power variation during orbit was ±4 percent from its mean value of 9.3 kilowatts.

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PERFORMANCE OF A BRAYTON POWER SYSTEM

WITH A SPACE TYPE RADIATOR

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SUMMARY

An investigation of a Brayton power system with a space type radiator was conducted at the Lewis space power facility. The purpose was to measure the steady-state and transient responses of the power system to the sink temperatures of a typical low Earth orbit. The steady-state alternator power at sink temperatures between 195 and 250 K was determined at four different engine operating modes. The power ranged from 9 kilowatts at the 250 K sink temperature to 9.7 kilowatts at the 195 K sink temperature for three of the modes. During the constant turbine-inlet-temperature, constant-compressor-discharge operating mode, the alternator power ranged from 8.7 to 10.3 kilowatts.

The optimum coolant flow rate of 0.07 to 0.08 kilogram per second through the waste heat exchanger was reasonably close to the design flow rate of 0.065 kilogram per second. The minimum compressor inlet temperature of 296 K (design temperature was 300 K) indicated the radiator was slightly oversized. Also, the compressor-inlet temperature using helium-xenon working gas mixture, was 3 to 5 K lower than using krypton.

The compressor-inlet temperature could be held constant during changes in sink temperature by shunting a portion of the waste heat exchange coolant flow around the high-temperature radiator. Also in the event of loss of coolant flow, the secondary coolant system must be activated within 4½ minutes to prevent high compressor-inlet temperature.

The power system was subjected to simulated orbits, each orbit consisting of 62 minutes of sun and 34 minutes of shade. The alternator response during these orbits was similar in the four modes. The alternator power varied ±4 percent reaching a maximum at the end of the shade portion of the orbit. A typical engine operating mode had an average alternator output of 9.4 kilowatts, with a maximum of 9.7 kilowatts and a minimum of 9.1 kilowatts. During the orbital operation, the engine did not reach the steady-state operation of either sun or shade conditions.

INTRODUCTION

The Brayton space power system, has been extensively tested at the Lewis Research Center (refs. 1 to 5). The Brayton engine converts thermal energy to electrical energy, operates on a closed-loop Brayton thermodynamic cycle and uses a helium-xenon gas mixture as its working fluid. The turbomachinery consists of the turbine, alternator, and compressor, mounted on a single shaft and supported entirely by gas bearings. Other major components include the heat source, recuperator, waste heat exchanger, gas management system, electrical system, and cooling system. In previous system testing (refs. 6 and 7) the two components that were not designed for space used were the electric heat source and the radiator simulator heat exchanger.

As a part of the development program of the Brayton system, the Space Power Facility Division at the Plum Brook Station designed and fabricated a space type of radiator as a waste heat rejector (ref. 8). This report presents the results of operating the Brayton engine with the radiator in a space environment. The performance testing was conducted at a vacuum of 5×10^{-6} torr with a variable sink temperature between 250 and 195 K. These temperatures are representative of sun and shade conditions for the radiator in low Earth orbit. The orbit temperatures were achieved by using a cold wall for the shade condition and illuminating one side of the radiator with a quartz lamp array for the sun condition.

The objective of the test program was to determine the effect of the radiator on the power conversion system over a range of space-simulated operating conditions. Of particular importance was the response of the combined system to the sun shade transitions experienced in a typical near Earth orbit. In addition, the steady-state operation of the power system at effective sink temperatures from 250 to 195 K was measured.

APPARATUS AND PROCEDURE

Test Facility

The Brayton engine with the radiator was installed and tested in the space power facility (fig. 1). The aluminum test chamber is 30.5 meters in diameter and 37 meters high and is enclosed by a 2-meter-thick concrete shell. Both the test chamber and enclosure have 15- by 15-meter movable doors on each end, which open to an assembly and a disassembly room. Three sets of standard gage railroad tracks run through the test chamber. The chamber vacuum is obtained by 32 diffusion pumps mounted in the floor, which exhaust to mechanical roughing pumps.

A 12-meter-diameter by 12-meter-high cylindrical cold wall was located in the center of the test chamber. The cold wall was fabricated from 5-centimeter-diameter aluminum tubing welded to 40-centimeter manifolds. It was painted black on the inside for high absorptivity at all wave lengths and insulated on the outside to minimize heat transfer to the chamber. The temperature of the cold wall was controlled by pumping cold gaseous nitrogen through the tubes.

A quartz lamp array, consisting of 216 iodine-quartz lamps, was installed inside the cold wall to radiate heat directly to one side of the radiator. This lamp array was operated at 25 kilowatts of electric power to simulate the solar power that the radiator would receive in a low Earth orbit, and is referred to in this report as the solar simulator. A plan view of its position relative to the radiator and cold wall is shown in figure 2.

Brayton Engine

The turbomachinery of the Brayton engine consisted of a 12.6-centimeter-diameter, single-stage radial-flow turbine and a 10.8-centimeter-diameter, single-stage radial-flow compressor. These were mounted on a single shaft with the alternator between them and operated at 36 000 rpm. These components were supported by gas bearings with no external pressurizing gas required except during startup and shutdown (ref. 9). The engine was tested with the shaft in a vertical position, turbine end up.

The other major components that are included in the engine are a gas-to-gas recuperator, a liquid-to-gas waste heat exchanger, and a heat source. A photograph of the engine during the early installation phase is shown in figure 3 and of the engine installed in the vacuum chamber in figure 4.

A cooling system was required for removing heat from the waste heat exchanger, the alternator windings, and the electrical package cold plates. The system used DC-200 as the coolant (a silicone liquid of $2\text{x}10^{-6}$ m^2/sec viscosity at 295 K) and is shown schematically in figure 5. Two similar and separate cooling systems were installed on the engine, the second system beeing merely a backup to the first.

The gas entering the turbine was heated by an electric resistance heater. It was capable of heating the gas to 1145 K, which is the maximum design temperature for the Brayton engine. The heater had two modes of control operation: constant temperature and constant power. In the constant temperature mode the heater controlled the turbine-inlet temperature by regulating the power into the heater. In the constant power mode the power into the heater was constant regardless of other changes in the engine operation.

The design working gas for the Brayton engine was a mixture of helium and xenon with a molecular weight of 83.8, the same molecular weight as krypton. It was selected to provide the maximum efficiency from the engine because the thermal conductivity of helium is greater than krypton (ref. 10). Some engine data were taken with krypton for comparison.

Radiator

The radiator for the Brayton engine (fig. 6) was fabricated by welding together 0.75- by 2.5-meter aluminum panels. Each panel had 12 trapezoidal cross-section tubes with a cross-sectional area of 0.10 square centimeter per tube for the high-temperature radiator and 0.18 square centimeter per tube for the low-temperature radiator. Every other tube was a part of the main cooling system, with the adjacent tube in the secondary cooling system. The tubes were spaced 13 centimeters apart, and were approximately 9 meters in circumferential length (ref. 11).

The coolant flow from the Brayton waste heat exchanger, (fig. 5), which had a temperature between 400 to 425 K, was cooled in the high-temperature radiator to approximately 315 K. It then mixed with the fluid from the cold plates and alternator and was cooled to approximately 295 K in the low-temperature radiator. The cooled DC-200 then returned to the Brayton coolant pump for recirculation. A portion of the high-temperature fluid could be bypassed directly into the low-temperature radiator by opening a remote controlled valve.

The radiator was designed to reject 17.6 kilowatts of heat to an effective sink temperature of 250 K. This is the amount of heat rejected by a Brayton engine with a 25-kilowatt isotope heat source operating at a compressor inlet temperature of 300 K. The design coolant flow rate for the high-temperature radiator was 0.065 kilogram per second, and the design coolant flow rate for the low-temperature radiator was 0.16 kilogram per second. The low-temperature radiator area was 27.1 square meters, and the high-temperature radiator was 26.4 square meters. The interior of the radiator was insulated with a multilayer foil insulation, and the exterior was painted with a high emissivity white paint (emissivity = 0.93) to promote radiation heat transfer to the cold wall and reflect visible light.

Operating Procedure

The three independent engine variables, which could be controlled and which directly affect the performance of the engine, are the turbine-inlet temperature, the compressor-inlet temperature, and the system pressure. The system pressure was taken to be the compressor discharge pressure, which is the highest pressure in the engine.

The pressure at all other stations in the engine is fixed by component pressure drops. The engine control system had an automatic mode of pressure control, where any deviations from the set pressure were controlled by bleeding gas in to or out of the engine to maintain the set pressure. When the automatic mode of pressure control was not used and the amount of gas in the engine remained constant, the pressure could fluctuate as other variables were changed. This mode of operation is referred to as constant gas inventory.

The turbine-inlet temperature was controlled by the heat source, either in a constant temperature mode or a constant power mode. The constant power mode was representative of how an isotope heat source would supply heat to the engine, and the constant temperature mode was representative of a nuclear heat source.

The compressor-inlet temperature was controlled by varying the coolant flow rate in the waste heat exchanger or by varying the sink temperature. Because the compressor-inlet temperature was the one variable most affected by radiator performance, it provided a convenient means of measuring the engine output as a function of changes in coolant flow rate or sink temperature. An increase in compressor-inlet temperature resulted in a decrease of engine power output (refs. 6 and 7).

After the engine and radiator were installed in the test chamber, the chamber was closed and evacuated. The engine and vacuum chamber were operated from a control room. With a chamber vacuum of 10^{-5} torr, the cold wall was lowered to 250 K. A preheat period for the heat source increased the heater core to about 1050 K and the heater surface temperature to 700 K. The engine was motored up to 12 000 rpm by using the alternator as a synchronous motor. When the turbine-inlet temperature had increased to 750 K, the motoring was terminated and the engine accelerated to the design speed (36 000 rpm). At design speed the speed control applied parasitic load to hold 36 000±200 rpm for all engine tests. A typical speed and turbine-inlet temperature history during startup is shown in figure 7.

The cold wall was adjusted to provide the effective sink temperature desired for a test series. The effective sink temperature is defined as the equilibrium temperature that a body in space, with no heat addition, will reach. This equilibrium temperature is dependent on the proximity and temperature of other bodies, their emissivity, and its own emissivity. To measure the effective sink temperature, eight calorimeters were installed on the outside surface of the radiator. These calorimeters were fabricated from aluminum and given the same surface treatment as the radiator. The cold wall was adjusted so that the calorimeters were at the effective sink temperature calculated for this radiator in low Earth orbit.

Brayton engine performance was measured during a variety of steady-state test points. With all the test variables constant, a data point was considered to be steady-state when all the temperatures and pressures on the engine and radiator had reached equilibrium. After this data point was recorded, a test variable was changed to a new condition and the engine and radiator were allowed to reach a new equilibrium condition. Generally 2 hours was ample time for the engine to reach its new steady-state condition.

Another important series of tests was conducted to determine the response of the Brayton power system as it traversed a simulated low Earth orbit. The typical temperatures for such an orbit were an effective sink temperature of 195 K in the shade and 250 K in the sun. The engine was first stabilized at a sink temperature of 250 K with the solar simulator off. The cold wall temperature was then reduced to provide the 195 K sink, and the engine was allowed to reach the new equilibrium condition. The solar simulator was then turned on, and its power adjusted until the engine operating conditions were identical to the initial 250 K temperature. The solar simulator power required to create the 250 K sink temperature condition was 25 kilowatts. The orbit was then simulated by having the cold wall maintain the 195 K shade condition, while varying the solar simulator power between zero (shade) and 25 kilowatts (sun). A typical low Earth orbit is 62 minutes in the sun and 34 minutes in the shade. The variation of the effective sink temperature during such an orbit is shown in figure 8. This variation was used for all testing in this study.

STEADY-STATE RESULTS

Effect of Variable Coolant Flow Rate

The effect of varying the coolant flow rate through the wast heat exchanger and hence the high-temperature radiator is presented in figure 9. The data are shown for sink temperatures of 250 and 195 K. The results indicate an optimum flow rate for the high-temperature radiator between 0.07 and 0.08 kilogram per second. Changing the flow rate resulted in an increased compressor-inlet temperature and thus a decreased engine output. Engine testing (refs. 6 and 7) indicated that a change of 5 K in the compressor-inlet temperature would affect the alternator gross output by about 330 watts.

The curve in figure 9 with an engine compressor discharge pressure of 21.5 newtons per square centimeter at an effective sink temperature of 250 K is near the design point for the radiator and the engine. At a compressor-inlet temperature of 296 K the radiator rejected 17.5 kilowatts of heat, and at a compressor-inlet temperature of 300 K the radiator rejected 18.5 kilowatts of heat. This indicates that the radiator was slightly larger than necessary to maintain the design compressor-inlet temperature of 300 K and reject 17.6 kilowatts of heat.

Comparison of Krypton and Helium-Xenon

The effects of using krypton or helium-xenon as the working gas in the Brayton engine is presented in figure 10. The compressor-inlet temperature was lower when using the helium-xenon gas mixture than when using krypton gas. At the 250 K sink temperature, this difference ranged from 3 to 5 K. The recuperator and the waste heat exchanger always had a higher effectiveness with the helium-xenon gas mixture because of its higher thermal conductivity. The higher recuperator effectiveness with the helium-xenon mixture resulted in less heat being transferred in the waste heat exchanger. The results indicate that a smaller radiator size would be required for a helium-xenon working gas than for Krypton to achieve the same compressor-inlet temperature.

Effect of Sink Temperature on Engine Output

The effect of sink temperature on the engine output in four different modes of operation is shown in figure 11. The working fluid was the helium-xenon gas mixture, and the coolant flow rate was constant at 0.086 kilogram per second for this test series. With the heat input constant, an increase of approximately 0.7 kilowatt occured as the sink temperature was decreased from 250 to 195 K. Other changes in the engine variables as sink temperature was decreased were that the turbine-inlet temperature fell from 1150 to 1120 K and the compressor discharge pressure dropped from 21.5 to 21.0 newtons per square centimeter. These two changes alone would tend to decrease engine power output. However, the compressor-inlet temperature decreased from 296 to 278 K, and thus the net effect was to increase power output.

During the constant turbine-inlet temperature (1145 K) and constant gas inventory mode of control, the alternator power varied 0.6 kilowatt as sink temperature dropped from 250 to 195 K. Other changes were a decrease in compressor discharge pressure from 21.6 to 20.0 newtons per square centimeters and a decrease in compressor-inlet temperature from 296 to 273 K.

The largest change in power output, 1.6 kilowatts, occured during the constant-turbine-inlet-temperature, constant-compressor-discharge-pressure mode of operation. The compressor-inlet temperature changed from 292 to 277 K as sink temperature was lowered from 241 to 204 K. The corresponding heat source power increased from 37 to 39 kilowatts to maintain the turbine-inlet temperature at 1145 K during the decrease in sink temperature.

Effect of Radiator Bypass Coolant Flow

Constant engine power output could be obtained if the compressor-inlet temperature was held constant during changes in sink temperature, while turbine-inlet temperature and system pressure also were constant. The bypass valve, which bypassed the waste heat exchanger flow from the high-temperature radiator directly to the low-temperature radiator, was used to maintain the compressor-inlet temperature at 300 K while the sink temperature was varied. The bypass flow ratio is defined as the ratio of the amount of coolant flow bypassing the high-temperature radiator to the amount of flow through the waste heat exchange. The bypass ratio required for constant compressor-inlet temperature is presented in figure 12 as it varies with effective sink temperature. At a zero bypass ratio, the waste heat exchanger flow was 0.096 kilogram per second at 23.5 newtons per square centimeter and 0.06 kilogram per second at 21.5 newtons per square centimeter. Gross alternator power was 9.3 and 8.5 kilowatts at 23.5 and 21.5 newtons per square centimeter, respectively.

As the sink temperature decreased and the bypass flow increased, the low-temperature radiator rejected more heat. At 23.5 newtons per square centimeter both the low-temperature radiator and the high-temperature radiator rejected 9.5 kilowatts of heat at a sink temperature of 220 K. For 21.5 newtons per square centimeter equal radiator heat rejection occurred at 210 K.

TRANSIENT RESULTS

Effect of Orbiting on Alternator Output

The preceding steady-state data established the mutual interaction of the various system parameters after allowing the engine and radiator to reach a steady-state operating condition. The transient data that follow are the response of the power system, using helium-xenon as the working gas, during the time the system was subjected to space simulated operating conditions.

The responses of the engine power to the sun-shade transitions experienced in the typical near Earth orbit are presented in figure 13. The cold wall provided the 195 K shade condition, and the solar simulator provided the energy for the sun portion of orbit. The power to the solar simulator was automatically controlled by a preprogrammed power supply. The maximum 25 kilowatts of solar power resulted in an effective sink temperature of 250 K. Figure 13 shows the time during the last two orbits of a four-orbit test for the four different modes of engine operation.

The data show that the alternator power response was similar in all four engine operating modes investigated. For the constant-heat-input, constant-gas-inventory mode of operation, the minimum alternator power was 8.9 kilowatts and the maximum was 9.5 kilowatts. In other words, the alternator power varied plus or minus 4 percent around the average value (9.2 kW) during the orbit. For the constant-heat-input, constant-compressor-discharge-pressure operating mode, the minimum alternator power was 9.1 kilowatts and the maximum power was 9.7 kilowatts. For both modes of constant-temperature operation, the power variation was similar and ranged from 9.2 to 9.8 kilowatts. In all the operating modes the maximum alternator power output occurred at the beginning of the sun (or end of shade), and the minimum power output occurred approximately 45 minutes after the start of the sun portion of the orbit.

The variation of compressor-inlet temperature and turbine-inlet temperature when the power system is exposed to the simulated orbit is presented in figure 14. The selected operating mode is one of a constant heat source power of 37 kilowatts and a constant gas inventory. The coolant flow rate in the waste heat exchanger was 0.086 kilogram per second. The two orbits shown are the second and third of a three orbit test. By the third orbit the engine variables had essentially reached their maximum and minimum values, and further orbits would not significantly alter performance.

The turbine-inlet temperature did not vary significantly during the orbit, reaching a maximum of 1140 K near the end of the sun portion. The minimum temperature of 1135 K was reached shortly after the beginning of the sun. This small variation of turbine-inlet temperature had less than a 0.1-kilowatt effect on the engine output. The compressor-discharge pressure (not shown in fig. 14) varied between

21.25 and 21.35 newtons per square centimeter, which had a negligible effect on engine output.

The compressor-inlet temperature ranged from a low of 282 K at the beginning of the sun portion to a high of 290 K at the end of it. This temperature lagged less than 2 minutes in responding to a change of sink temperature. The change in compressor-inlet temperature is also chiefly responsible for change in alternator power output.

The steady-state values of compressor-inlet temperature (296 K sun and 278 K shade) and turbine-inlet temperature (1150 K sun and 1120 K shade) are shown in figure 14. Significantly, the engine did not reach the steady-state operation of either sun or shade conditions during orbital operation. Thus, the power system should be designed for the transient rather than the steady-state sink temperature.

Effect of Coolant Flow Loss

The effect of loss of coolant flow on the compressor-inlet temperature and alternator power is shown in figure 15. When the pump was turned off, stopping coolant flow, the compressor-inlet temperature began to rise immediately. From 293 K at loss of flow, the temperature increased to 309 K in $4\frac{1}{2}$ minutes, after which time the pump was restarted. After restart the temperature dropped to its original 293 K in 4 minutes. The alternator power response lagged the compressor-inlet temperature change by less than 1 minute. The alternator power began dropping from 6.73 kilowatts 1 minute after loss of coolant flow and reached its minimum power of 5.63 kilowatts after $4\frac{1}{2}$ minutes. These data indicate that the engine will operate about $4\frac{1}{2}$ minutes after a coolant flow loss before the secondary cooling system would be required to continue engine operation.

Effect of Step Change in Sink Temperature

The response of the power system to a step change in effective sink temperature is shown in figure 16. The cold wall provided a sink temperature of 205 K, and the solar simulator was powered to 33 kilowatts to provide the step change. The compressor-discharge pressure was initially 21.5 newtons per square centimeter, heat input constant at 36.5 kilowatts, and the coolant flow rate was 0.082 kilogram per second.

The compressor-inlet temperature indicated an immediate response to the sink temperature change, while the turbine-inlet temperature began to change approximately 30 minutes after the step change. Because of the immediate response of compressor-inlet temperature, the gross alternator power also indicated an immediate change. Approximately 60 minutes after the step change occurred, the alternator power was constant at its new value for the sink temperature condition. At this time the decrease in both turbine-inlet temperature and compressor-inlet temperature had a compensating effect on maintaining constant alternator power. The compressor discharge pressure decreased from 21.5 to 21.1 newtons per square centimeter during the shade portion of the test, and it decreased to 20.8 newtons per square centimeter in the 33-kilowatt power portion. This accounts for the small difference in alternator power output of 8.75 kilowatts at the beginning of the test and the 8.25 kilowatts at the end of the test.

SUMMARY OF RESULTS

A Brayton power system with a space type radiator was tested in a vacuum while being subjected to the conditions of a near Earth orbit. The effective sink temperatures of the orbit ranged from 195 K to 250 K. The optimum coolant flow rate through the waste heat exchanger and the high-temperature radiator was from 0.07 to 0.08 kilogram per second. This flow rate resulted in the minimum compressor-inlet temperature and the maximum power output. It was slightly higher than the design flow rate of 0.065 kilogram per second. The minimum compressor-inlet temperature of 296 K at a compressor-discharge pressure of 21.5 newtons per square centimeter compared with the design temperature of 300 K indicated the radiator was slightly oversized.

The compressor-inlet temperature when using the design working gas mixture of helium-xenon was 3 to 5 K lower than when using krypton in the engine. The results indicate that a smaller radiator can be used with helium-xenon in the engine.

The steady-state alternator power increased from 9 kilowatts at a 250 K sink temperature to 9.7 kilowatts at a 195 K sink temperature for three engine operating modes. During the constant turbine-inlet-temperature, constant-compressor-discharge mode of operation, the alternator power increased from 8.7 kilowatts at a 250 K sink temperature to 10.3 kilowatts at a 195 K sink temperature.

The compressor-inlet temperature could be maintained constant during changes in effective sink temperature by bypassing a portion of the waste heat exchanger flow around the high-temperature radiator. This method could be used to maintain a constant engine power output during the varying sink temperatures encountered in an Earth orbit.

In the event of loss of coolant flow to the engine, approximately $4\frac{1}{2}$ minutes were required for the compressor-inlet temperature to increase from 293 to 309 K. This indicates that the secondary coolant system must be activated within $4\frac{1}{2}$ minutes to avoid a high compressor-inlet temperature.

The power system was subjected to a series of simulated orbits, each orbit consisting of 62 minutes of sun and 34 minutes of shade. The transient response of the engine power indicated a variation of approximately ±4 percent from the mean value during orbit. The average value ranged between 9.2 and 9.5 kilowatts for the four different engine operating modes. No significant differences of engine power variation were noted between the four operating modes. The maximum power output during orbiting always occurred at the end of the shade portion of the orbit. During the orbital operation, the engine did not reach the steady-state operation of either sun or shade conditions. This indicates the power system should be designed for the transient rather than the steady-state sink temperature.

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National Aeronautics and Space Administration,

Cleveland, Ohio, March 21, 1974,

502-25.

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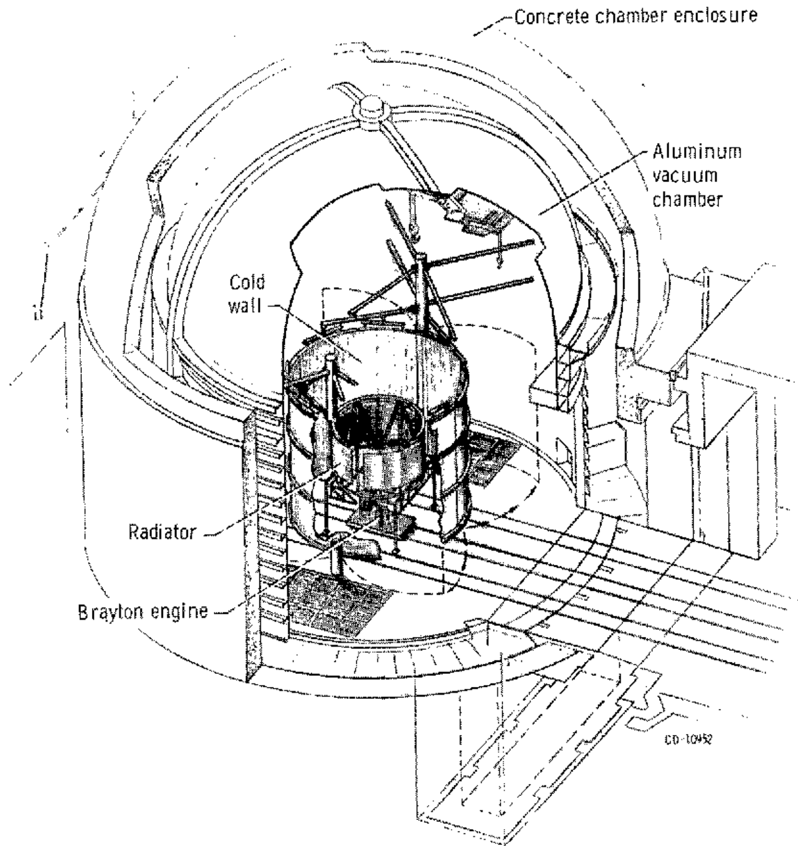


Figure 1. - Space power facility test chamber with Brayton power system.

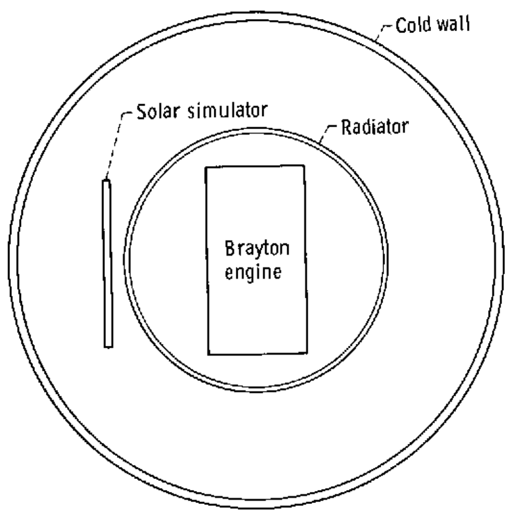


Figure 2. - Plan view of Brayton engine, radiator, solar simulator, and cold wall.

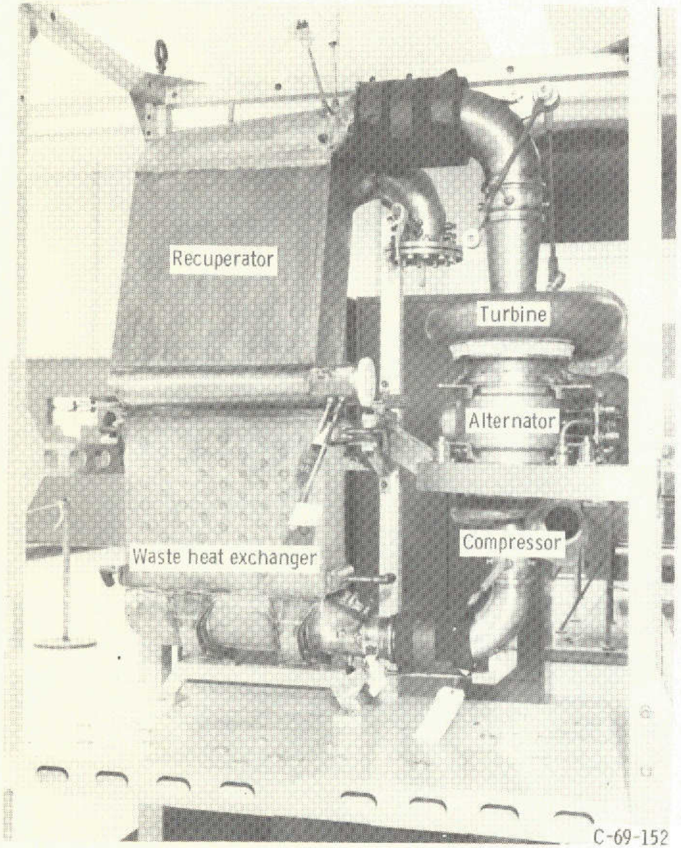


Figure 3. - Brayton engine during installation phase.

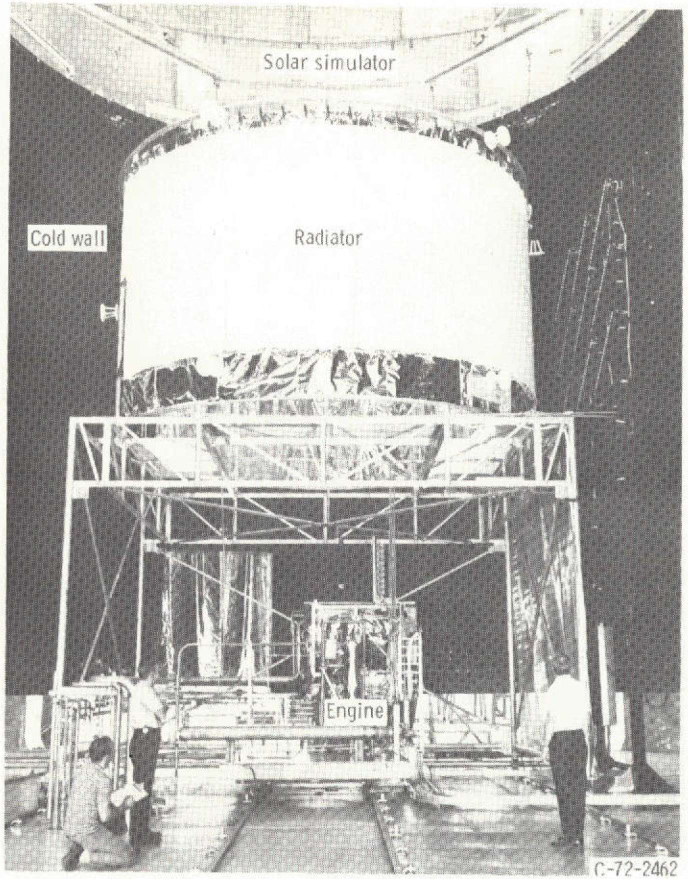


Figure 4. - Brayton engine in space power facility.

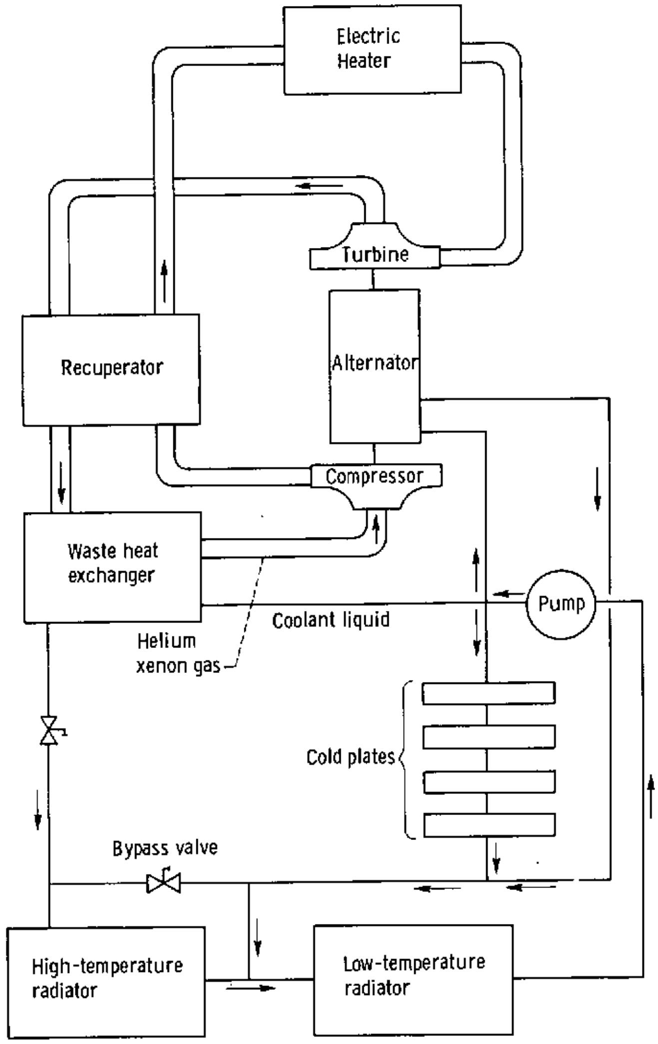


Figure 5. - Brayton power system.

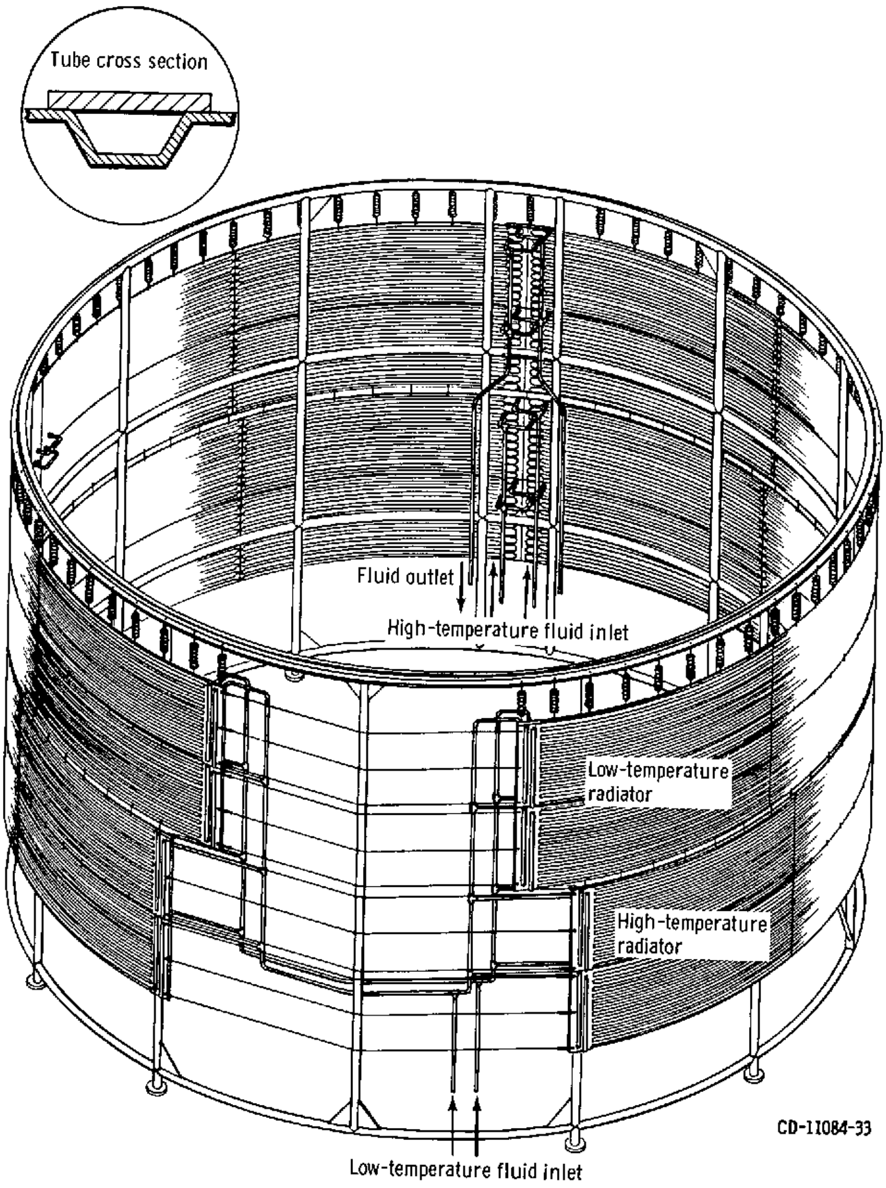


Figure 6. - Radiator.

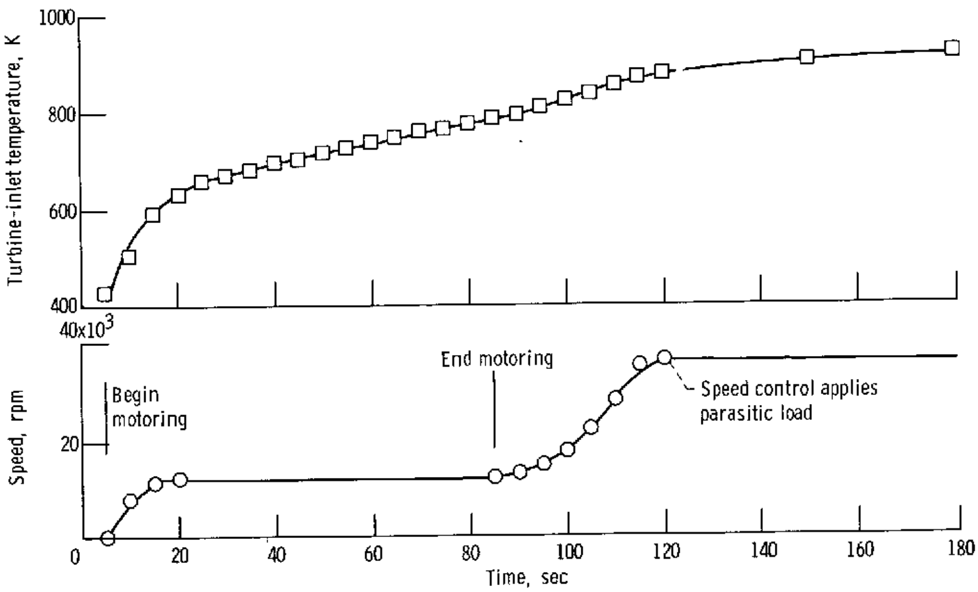


Figure 7. - Speed and turbine-inlet temperature during typical Brayton system startup.

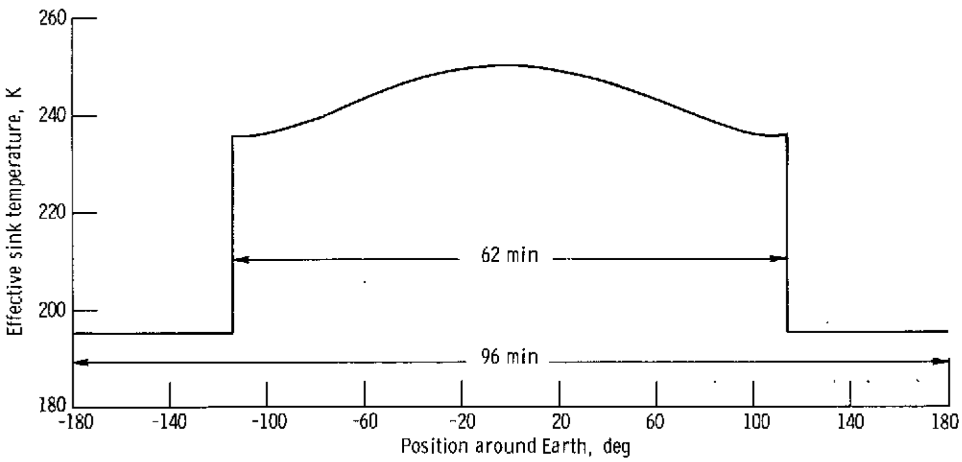


Figure 8. - Sink temperature as function of orbital position in low Earth orbit for Brayton radiator.

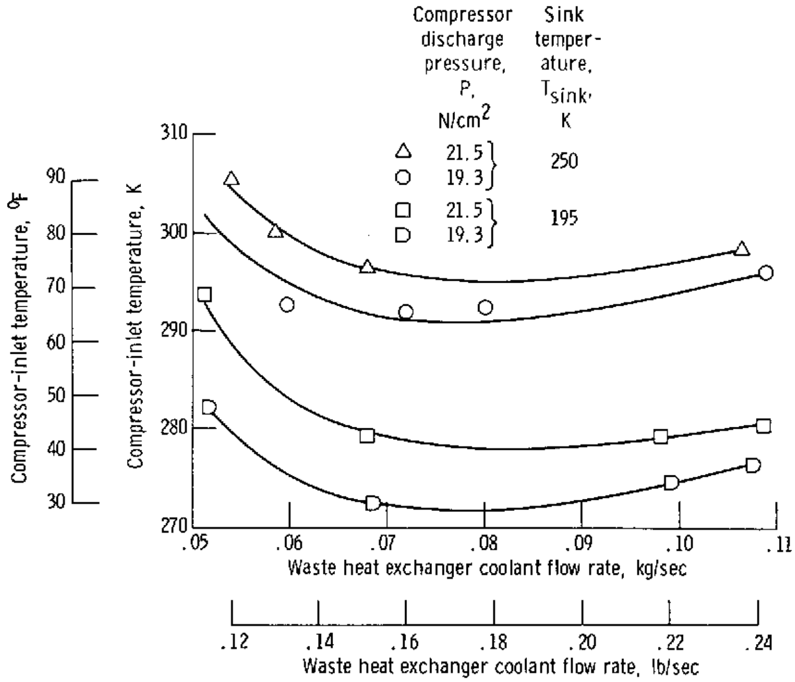


Figure 9. - Effect of coolant flow on compressor-inlet temperature. Working gas, helium-xenon mixture; turbine-inlet temperature, 1145 K.

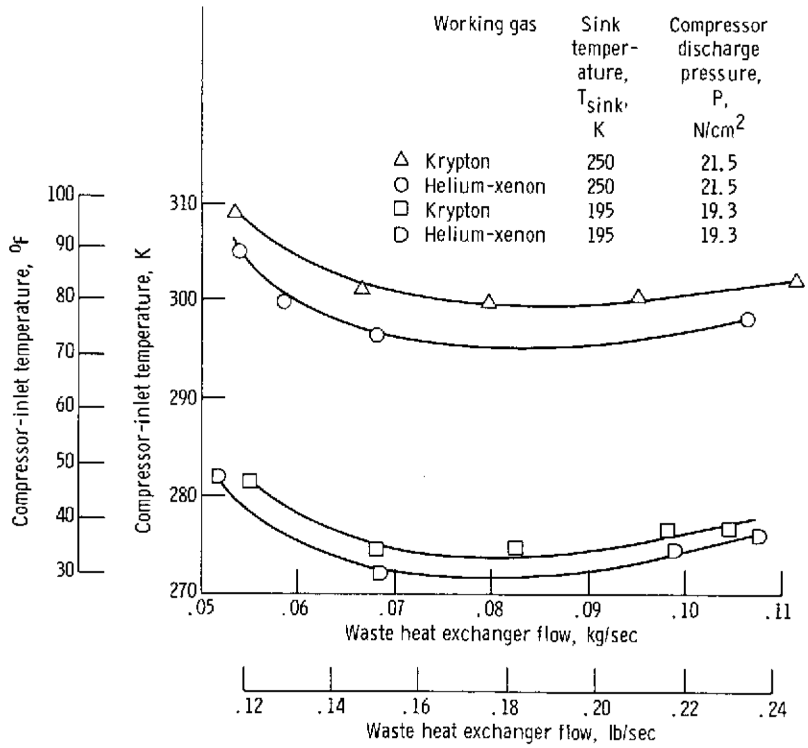


Figure 10. - Comparison of helium-xenon and krypton on compressor-inlet temperature. Turbine-inlet temperature, 1145 K.

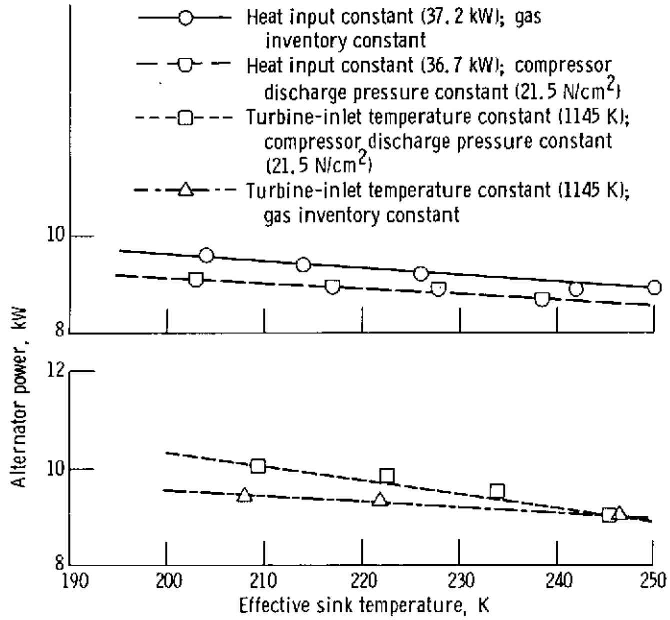


Figure 11. - Effect of sink temperature on engine output.

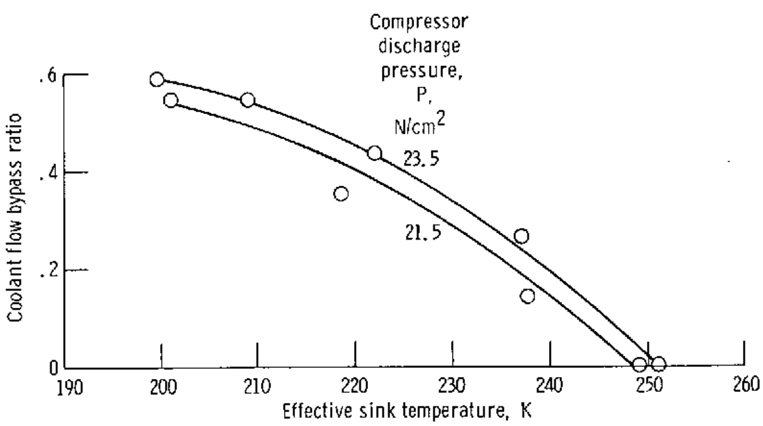


Figure 12. - Coolant bypass flow variation with sink temperature for constant engine operation. Working gas, helium-xenon mixture; turbine-inlet temperature, 1145 K; compressor-inlet temperature, 300 K.

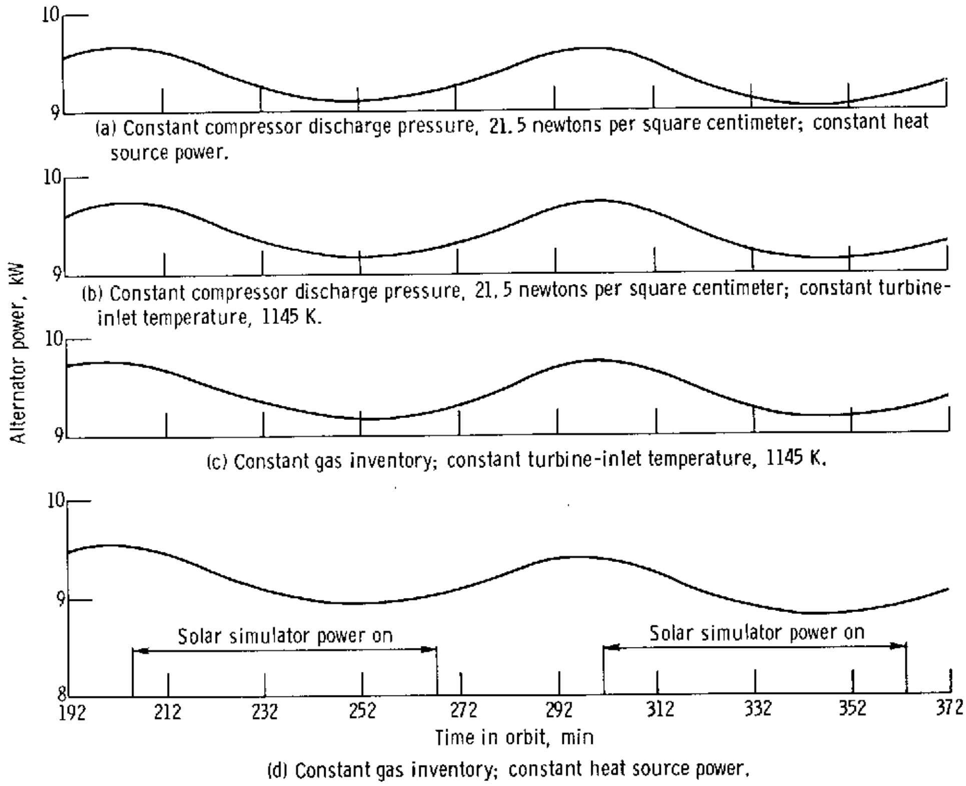
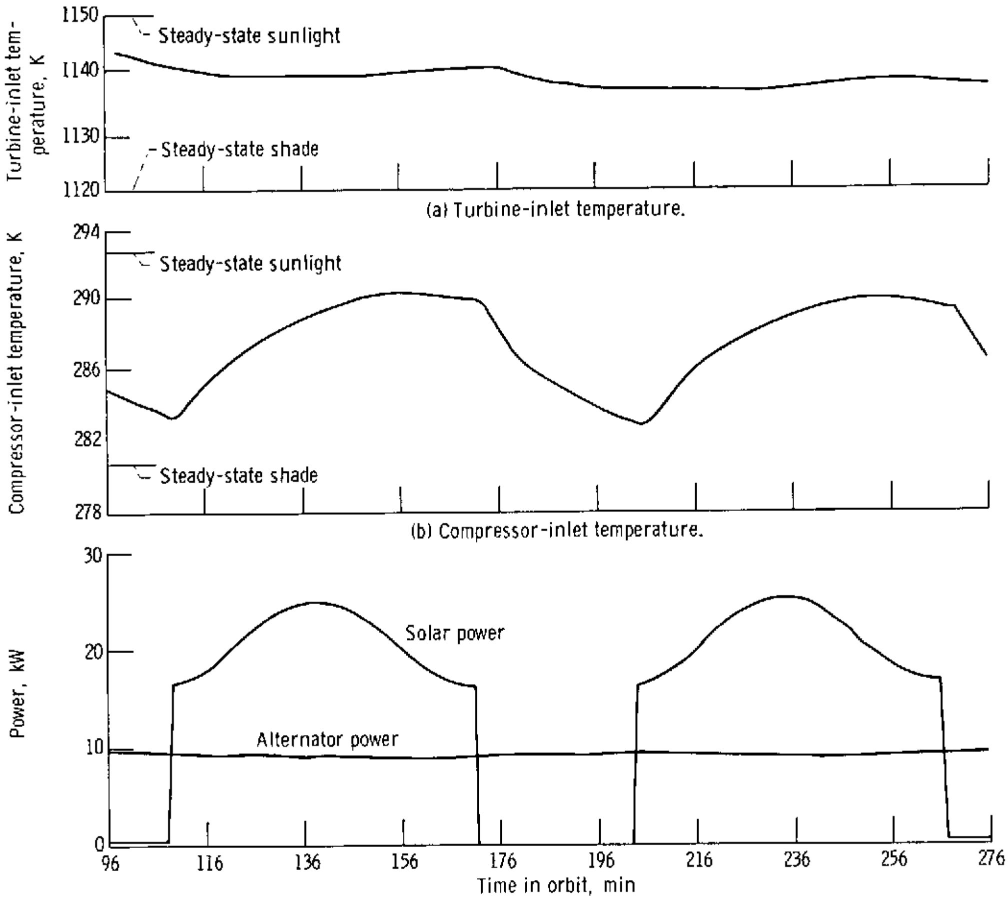


Figure 13. - Alternator power output during low Earth orbit at various operating modes.



(a) Turbine-inlet temperature.

(b) Compressor-inlet temperature.

(c) Solar and alternator powers.

Figure 14. - Effect of orbiting on various parameters with constant heat input and constant gas inventory.

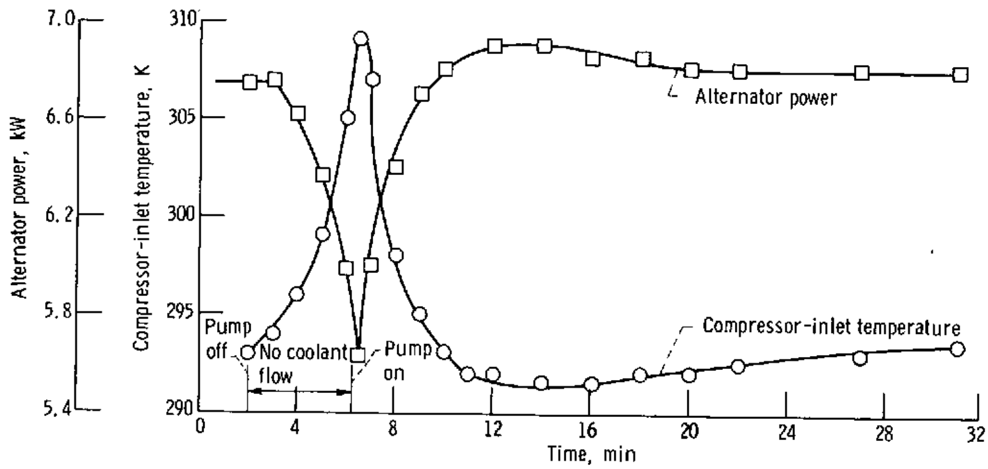


Figure 15. - Variation of compressor-inlet temperature and alternator power with loss of coolant flow. Turbine-inlet temperature, 1070 K; compressor-discharge pressure, 19.3 newtons per square centimeter; coolant flow rate, 0.088 kilogram per second.

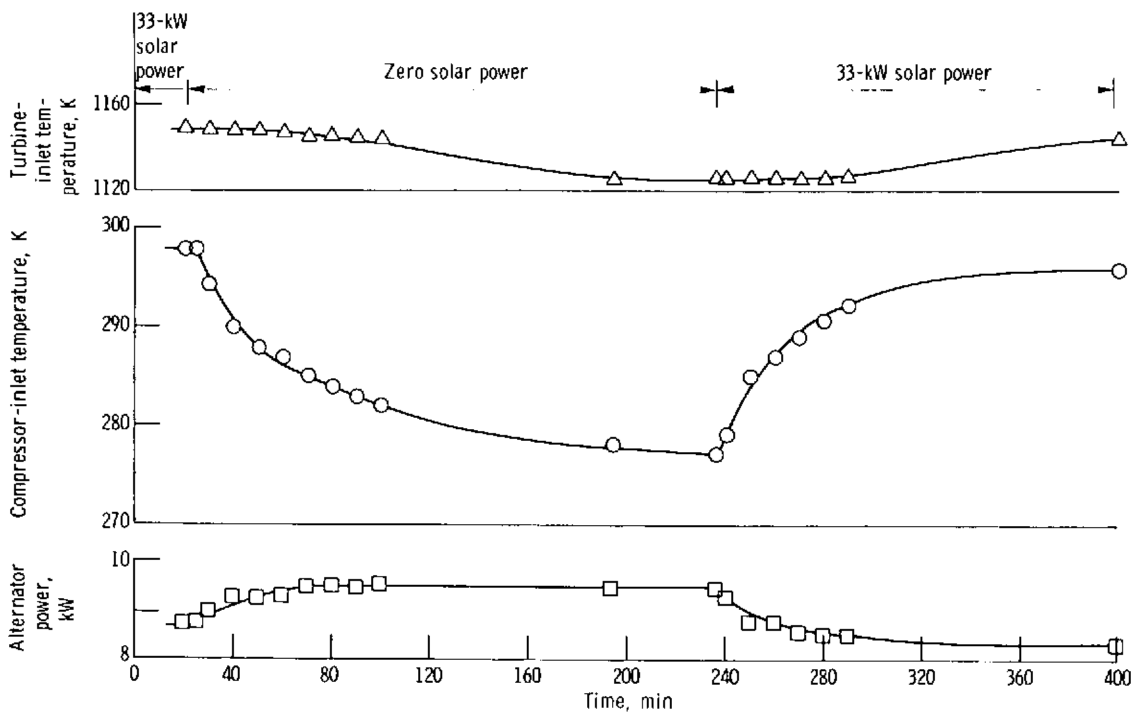


Figure 16. - Variation of engine operation with step change in effective sink temperature.

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