NASA TECHNICAL MEMORANDUM

NASA TM X-68069

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CONCEPTS FOR APPLICATION OF 500- TO 2500-We BRAYTON POWER SYSTEMS FOR SHUTTLE-LAUNCHED MISSIONS

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TECHNICAL PAPER proposed for presentation at
Seventh Intersociety Energy Conversion Engineering Conference
San Diego, California, September 25-29, 1972

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A MINI-BRAYTON STUDY, in the power range of 500 to 2500 watts electrical (We), utilizing the Multi-Hundred Watt (MHW) isotope heat source was conducted at the Lewis Research Center. Existing Brayton technology was applied along with major design goals of system simplicity, high efficiency, and low parasitic losses. The study is summarized in reference (1).*

The objective of this report is to present mini-Brayton power system conceptual configurations integrated with typical shuttle-launched experiments and designed with nuclear safety considerations and shuttle integration in mind. Also presented are a number of mini-Brayton mission advantages and general operation descriptions for various mission phases.

SYSTEM DESCRIPTION

The power system consists of a single closed gas loop containing the following components: a single-shaft, gas-cooled, compressor-alternator-turbine assembly (rotating unit) supported and restrained by foil gas bearings; a heat-source heat-exchanger assembly; a recuperator; a gas radiator; an electrical control module; a parasitic load resistor (PLR); a startup battery package; and a multifoil superinsulation system.

Table 1 presents the mini-Brayton's major performance parameters for power systems with one to four MHW heat sources. A single heat source provides 2400 watts thermal (Wt). Each column in table 1 represents a separate power system designed specifically for that power level. Even at the lowest efficiency, which is 23 percent for the single-heat-source 550-We case, mini-Brayton has the advantage of supplying the required power with a low isotope inventory.

BASIC CONFIGURATION OF MAJOR COMPONENTS

The three major power system components (rotating unit, heat-source heat-exchanger assembly, and recuperator) and their basic configuration, which was developed in the mini-Brayton study, are presented in figure 1. From criteria such as low pressure loss, low heat loss, heat-source temperature control, and minimum packaging volume, this component configuration evolved. As the required output power is increased from 550 We, the recuperator and heat-source heat-exchanger dimensions will change; however, the basic configuration will remain the same. These components can be arranged in many configurations, and no single configuration is optimum for all missions.

The rotating unit with compressor discharge cooling was designed to operate in the 500- to 1500-We range. This rotating unit will be used in all configurations presented in this paper. If a mission would require 2500 We, it was assumed that two 1260-We mini-Brayton systems would be used.

MAJOR NUCLEAR PAYLOAD/SHUTTLE INTEGRATION CONSIDERATIONS

Major considerations as reported in reference (2) are as follows: heat-source thermal control; radiation protection; blast and fragmentation protection; heat-source handling; and dimensional integration with the shuttle.

Thermal control is required to retain the physical integrity of the heat source. In the concepts presented, it was assumed that no heat was intentionally rejected into the shuttle cargo bay. Figure 2 shows the heat-source heat-exchanger assembly installed in a multifoil superinsulation system. Several heat-source thermal control concepts are presented in this figure. In this figure, an auxiliary coolant heat exchanger (ACHX) was included to provide prelaunch, launch, and recovery cooling of the heat source. Nitrogen gas would be used as the ACHX cooling fluid and then vented overboard. Another concept for cooling the heat source during the launch phase, which is not shown in figure 2, would use a heat pipe. One end of the heat pipe would be positioned in the open insulation door, the other end would be exposed and radiating to space.

During normal operation, system gas flows through the primary heat exchanger, thus maintaining a 1750° F heat-source skin temperature. In space, the normal mode of heat-source thermal control is radiation to space through an open multifoil superinsulation door (heat-source skin at 1600° F). If the power system should shut down and the door actuators fail to operate, several other methods could be used to remove the heat. The insulation door foils could be made of a lower-melt-temperature material such as nickel (2600° F). Also, the door hinges could be spring

*Numbers in parentheses designate References at end of paper.

loaded to the open position and a low-melt-temperature latch could be installed inside the insulation container. For either case, preliminary calculations indicate that the heat-source skin temperature would not exceed 2900° F (1000° F margin on the heat-source iridium liner melt temperature) during the door or latch melt time. After melting occurs the heat-source skin temperature will drop back down to 1600° F.

Radiation protection and blast and fragmentation protection were considered as one assembly. A conceptual shield assembly is shown in figure 3 integrated with the insulated heat-source heat-exchanger assembly. Radiation shielding is not required for the plutonium-fueled MHW heat sources used in this application. Calculation indicate that a shuttle crew 30 ft away from four MHW heat sources (9.6 kWt) would receive 5.8 rem in 30 days. The crew radiation limit reported in reference (3) is 13 rem for 30 days (testes). However, if curium fuel is used in the future to lower the heat-source cost, as has been suggested, radiation shielding must be incorporated in the design (a shadow shield). Using the limit of 13 rem for 30 days and the same conditions as above, a maximum of 200 lb of shielding would be required. The shielding could be decreased and weight saved if the manned portion of the mission would be less than 30 days. Thus, a higher radiation-dose rate, requiring less shielding, would be permitted for a shorter time period.

The blast and fragmentation problem was not analyzed in this study. However, it is recognized that a shield is required. Reference (2) states that the expected blast pressures of the shuttle are greater than those of the Saturn V (due to the close proximity of the payload to the shuttle fuel tanks).

A MHW heat source is shown being loaded in figure 2. In all concepts considered, the heat-source heat-exchanger assembly has been located at a port in the power system module's skin. The heat source (or sources) are to be loaded through the port with manipulators; and when the system is not operating in space, heat will be radiated out through the port. Heat-source loading with this concept could be accomplished quickly and late in a launch countdown. This approach is desirable from the launch operations viewpoint.

All the preceding nuclear considerations require a complete safety analysis and an additional effort to achieve detailed design solutions.

Dimensional integration with the shuttle is no problem for this power system. One of the basic features of the mini-Brayton is that it is versatile and can be packaged in many different configurations. The major shuttle dimensional limits utilized in this report include a maximum payload diameter of 14 ft and a maximum length of 58 ft. Standard 9-ft docking ports are installed on the ends of modules as required.

SYSTEM CONFIGURATIONS

Two system configuration types are presented in this report. The first type is the cylindrical module which will be shown in 5-ft, 9-ft, and 14-ft diameters. The second general type has no definite module shape but is configured to fit in available space, such as inside the framework of a palletized experiment module.

Both configuration types do have the following common features: the three major components will remain in one basic configuration; and ports viewing space will be provided in the power module to radiantly cool the heat-source heat-exchanger assembly, the electrical control module (or modules), and the parasitic load resistor (or resistors). An optional battery pack and inverter (total 60 lb maximum) could be included in any concept to provide startup power. The user could also utilize the shuttle's onboard power supply for startup. Insulation and the required shields are not shown in the concepts so that individual components may be more easily recognized.

The mini-Brayton concepts presented are planned to be capable of flying any earth orbital mission, including those through the Van Allen belt, with little degradation in performance. These systems should also perform equally well on interplanetary missions.

CYLINDRICAL CONCEPTS - All the cylindrical concepts presented in this paper could be used as original mission power equipment or as add-on units for missions requiring additional power. Module diameter and power level can be selected to best suit specific mission requirements. Any power level system discussed could fit in any diameter module up to 14 ft; only the radiator length would have to be adjusted to match the power level.

The original 550-We mini-Brayton 5-ft-diameter concept, of which a model was made, is shown in figure 4(a). To obtain a 550-We output, a single heat source and a 5-ft-long radiator are required. (If 1260 We were needed, two heat sources and a 7-ft-long radiator could be used.) This configuration meets the initial study guidelines of designing a simple compact system. In figure 4(a), the heat-source heat-exchanger assembly, the PLR, and the electrical control module can be seen installed in ports on the side of the power module. The radiator tubes are shown to run axially between two manifolds.

The major application area of the 5-ft-diameter module would be shuttle- or rocket-launched satellites (fig. 4(b)) or small orbiting experiment packages.

A 9-ft-diameter configuration producing about 1260 We is shown in figure 5. This diameter was selected primarily because docking adaptors of the same diameter are presently being incorporated in programs such as RAM (Research and Applications Module (4)). No reducing or expanding sections would be required to mate the module with the docking adaptors and, therefore, the overall package length would be shorter. This diameter is probably the minimum practical size to use with full 14-ft-diameter modularized experiments as shown in figure 5. Smaller diameters would make inefficient use of the shuttle cargo bay.

The major components' configuration is again incorporated in the 9-ft concept. Two heat sources will supply 1260 We. The radiator has axial tubes, is 4 ft long, and contains ports to space for the three components requiring cooling.

Figure 5 also shows the 9-ft mini-Brayton concept mounted on a typical palletized experiment. In this case, only a 4-ft length of the pallet (probably at the aft end) would be required to mount the power system.

The 14-ft-diameter mini-Brayton configuration as shown in figure 6 makes more efficient use of the available shuttle cargo bay volume than any other cylindrical concept. This figure shows a two-engine, four-heat-source, 2500-We module. The radiator for this concept is 5 ft long and has circumferential tubes. If this configuration was installed in the rear of the shuttle cargo bay attached to a modularized experiment as shown in figure 6, only one docking adaptor would be required and the overall power system length would be about 7.5 ft. As in the other concepts, component cooling ports viewing space must be provided.

PALLETIZED CONCEPT - The palletized mini-Brayton concept shown in figure 7 demonstrates the adaptability of this system to irregular packaging. This concept shows the major components' basic configuration stowed within the lower framework of a typical pallet. More power may be obtained by increasing the number of basic component configurations and radiator sections.

The radiator can be mounted anywhere on the pallet frame exterior surface. Panels would run axially. Only a small amount of the total pallet surface area is required to mount the radiator. It is suggested that the radiator be split in half with each panel mounted on opposite sides of the pallet. This arrangement should eliminate any need for power system orientation. However, if the mission experiments require a specific orientation, the radiator panels could be located on the pallet to yield optimum heat transfer and minimum size.

The parasitic load resistor and electrical control module could also be mounted on the pallet and have a view toward space. The pallet offers a number of locations where these components could be satisfactorily mounted. When in orbit, the heat-source heat exchanger would have a view to space through the bottom of the pallet.

GENERAL SYSTEM OPERATION

The following is an account of the expected mini-Brayton system operations through the various mission phases. This information is considered preliminary.

During the prelaunch phase the experiment package and the power system would be mated and installed in the shuttle cargo bay. The heat source (or sources) would be loaded through the power module port and open insulation door as late as possible in the countdown. Heat-source cooling could be accomplished by using either the auxiliary coolant heat exchanger (ACHX) or the heat-pipe concept. Shuttle cargo doors would then be closed.

In the launch phase the user has two options. The first option consists of keeping the insulation door open and maintaining heat-source cooling with the ACHX or heat pipes. The second option includes closing the insulation door and allowing the heat-source assembly temperature to rise. Calculations indicate that in a minimum of about 1.7 hours the heat-source assembly would be at startup temperature (about 1750° F on heat-source skin). The power system would then have to be started, or the insulation doors would have to be reopened to space.

Once in orbit, the shuttle cargo doors should be opened. ACHX or heat-pipe cooling would no longer be needed as the heat-source assembly would now radiate to space. The user could stay in this stand-by mode or could close the insulation door, heat up the heat-source assembly, and start the system. Startup power can be supplied by the shuttle or by an optional battery-inverter package. When the checkouts are complete, the shuttle can disconnect the payload and return to earth.

Recovery, if applicable, would be accomplished by having the shuttle redock and then shut down the experiments and power system. At this time the insulation door would be opened and the payload would be retracted into the cargo bay. ACHX or heat-pipe cooling would be reconnected, the shuttle doors would be closed, and the shuttle could then return to earth. The heat source (or sources) should be cooled until removed from the heat-source heat-exchanger assembly.

MISSION ADVANTAGES

Mini-Brayton power systems have significant mission advantages. The high efficiency (23% minimum) of these systems means low isotope loadings per electrical watt output. Preliminary calculations indicate that mini-Brayton will lower electric power cost when compared with other power systems such as solar array/battery systems and radioisotope thermoelectric generator systems.

Mini-Brayton systems are planned to be capable of flying any earth orbital mission with little degradation in performance. It is expected that these systems will perform equally well on interplanetary missions. Also, the systems presented should have little or no impact on their associated mission as they can be packaged in many different configurations and generally require no orientation.

CONCLUDING REMARKS

A number of mini-Brayton power system conceptual configurations in the 500- to 2500-We range are presented. These systems are highly versatile in their packaging and hence are readily adaptable to a variety of payload configurations. Being easily packaged and requiring no orientation, mini-Brayton systems should have little or no impact on their associated missions.

Nuclear safety issues are briefly addressed. A number of conceptual solutions to these problems are suggested, and it appears that nuclear safety solutions are within the present technological state of the art.

Dimensional integration with the shuttle can be easily accomplished. However, heat-source cooling inside the shuttle during launch and recovery may be required and could impose a heat-rejection scheme on the shuttle.

Mini-Brayton systems exhibit a number of substantial mission advantages. These systems will have low isotope inventories and high electrical output per thermal input. They will be cost-superior to other isotope and solar power systems and have the capability of flying all earth orbital and interplanetary missions with little degradation in performance.

REFERENCES

1. R. P. Macosko, G. J. Barna, H. B. Block, and W. D. Ingle, "An Isotope-Brayton Power System for the 500 to 2500 Watt Range," Intersociety Energy Conversion Engineering Conference, San Diego, California, Sept. 1972.

2. "Space Base Nuclear System Safety Study - Task 8. Nuclear System Safety - Transportation by Earth Space Shuttle," GESP-7068, General Electric Co., Space Systems Organization, Philadelphia, Pa., Contract NAS8-26283, Oct. 1971.

3. W. H. Langham, et al., "Radiation Protection Guides and Constraints for Space - Mission and Vehicle - Design Studies Involving Nuclear Systems," National Academy of Sciences, 1970.

4. "Research and Applications Module (RAM) Phase B Study," Rep. GDCA-DDA71-004, Convair Aerospace Division of General Dynamics, San Diego, Calif., Contract NAS8-27539, Dec. 1971.

Table 1 - Performance Summary

Number of heat sources	Gross thermal power, Wt	Conditioned power to user, We	Efficiency
1	2400	550	0.23
2	4800	1260	.26
3	7200	1940	.27
4	9600	2670	.28

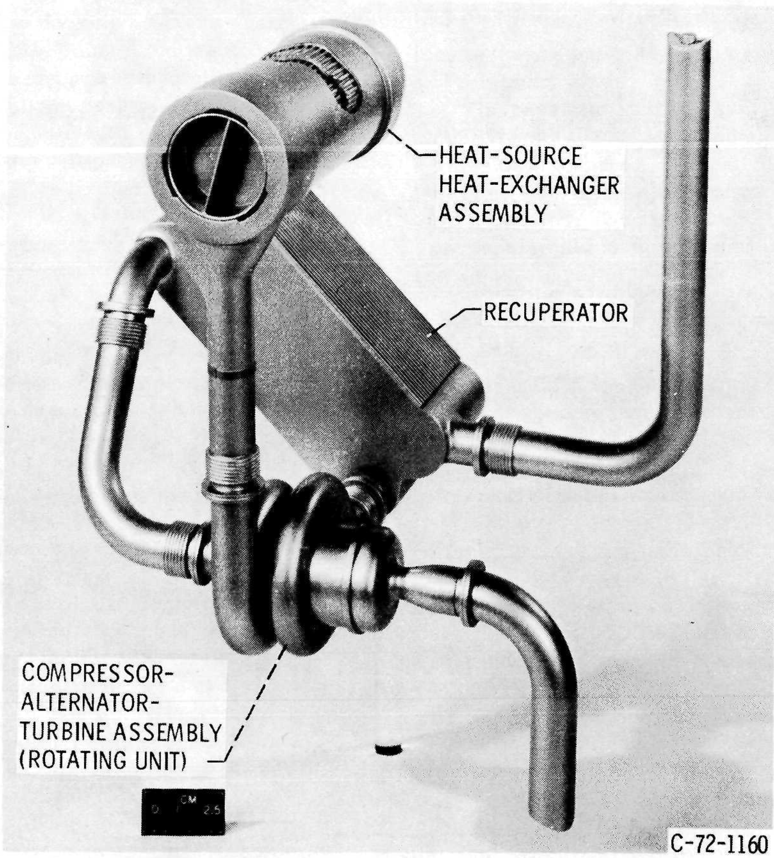

Figure 1. - Major components configuration.

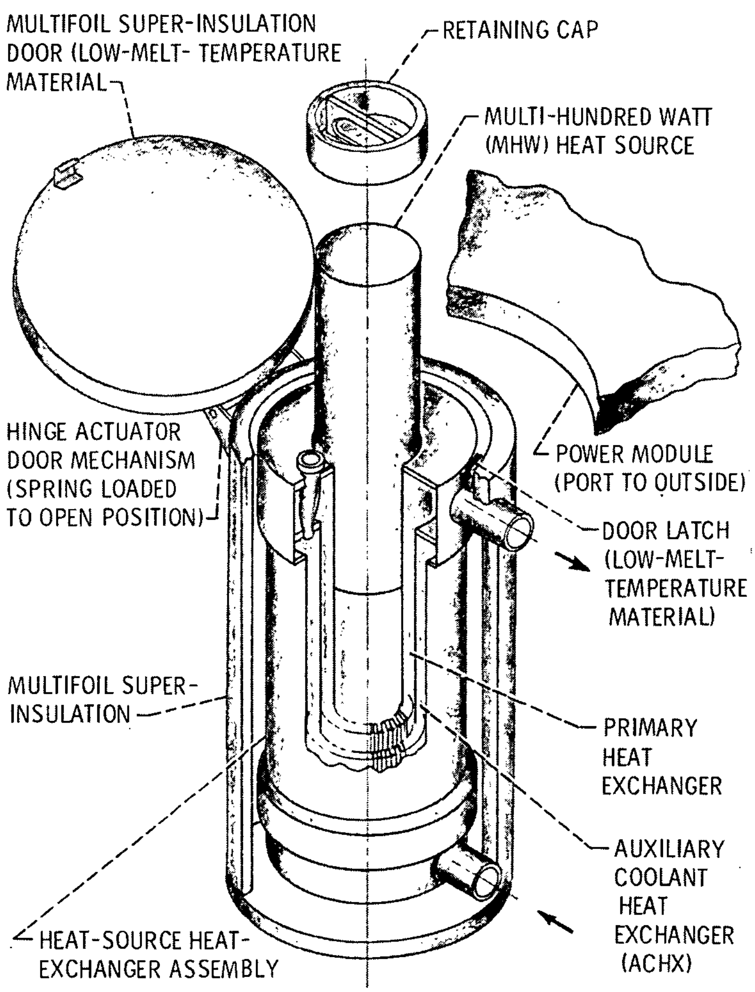

Figure 2. - Heat-source heat-exchanger assembly installed in a multifoil superinsulation system.

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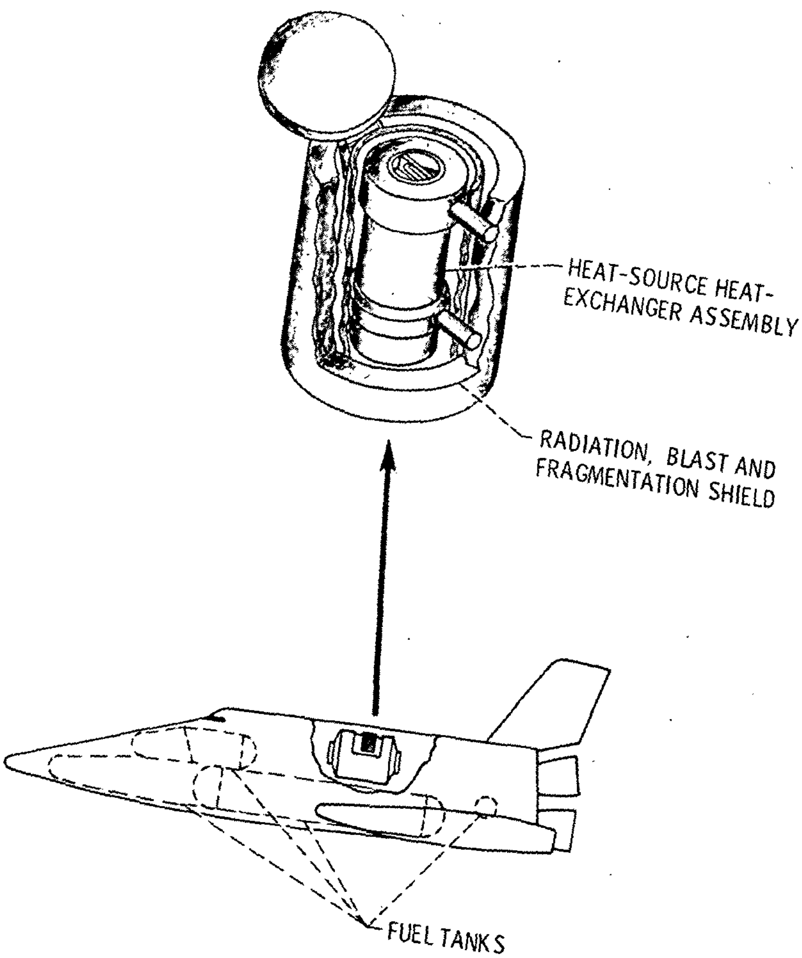
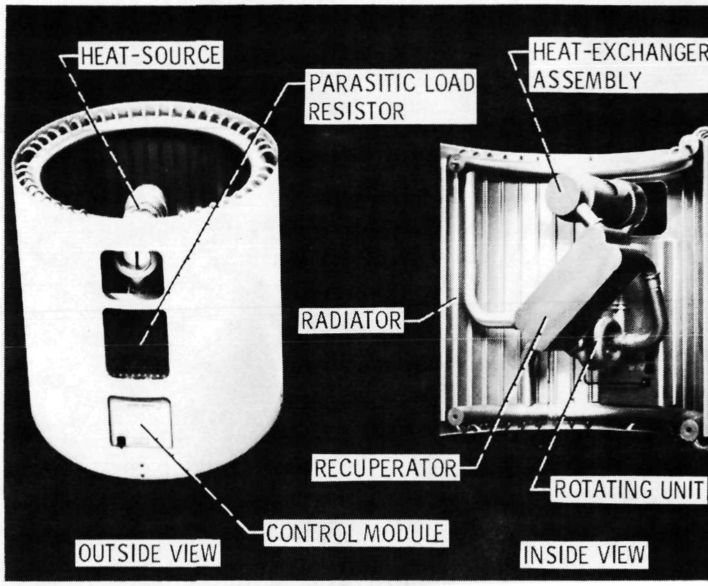


Figure 3. - Conceptual shield assembly.



(a) ORIGINAL CONCEPT.

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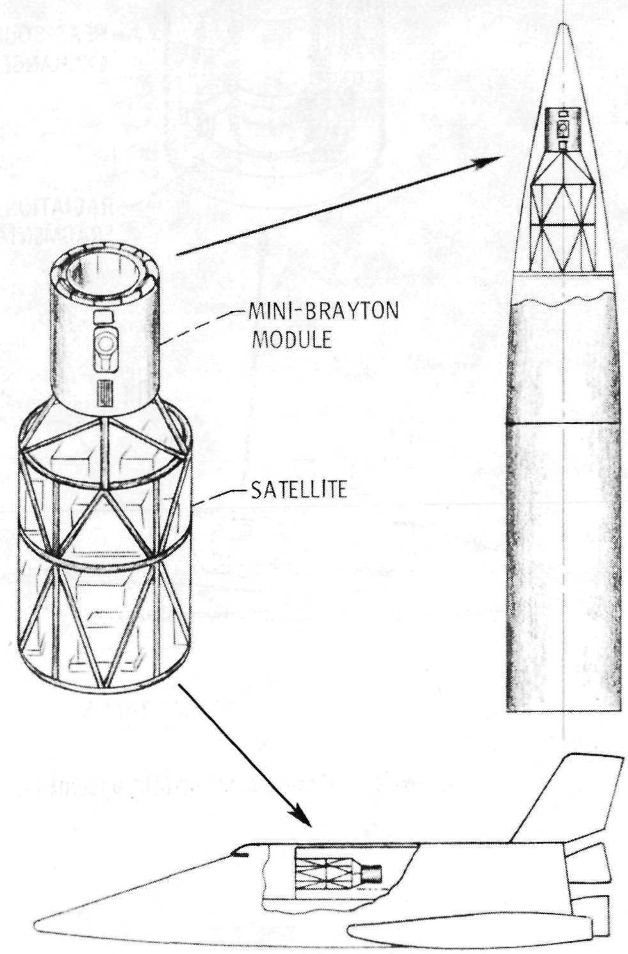

(b) APPLICATION

Figure 4. - Five-foot-diameter mini-Brayton configuration (550 We).

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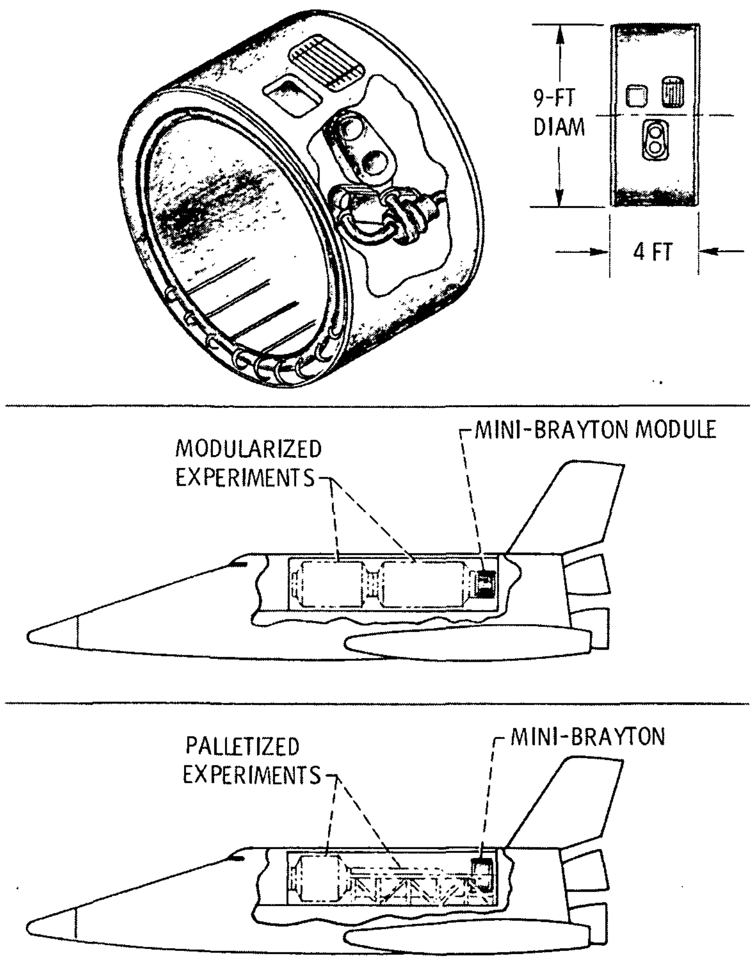

Figure 5. - Nine-foot-diameter mini-Brayton module (1260 We).

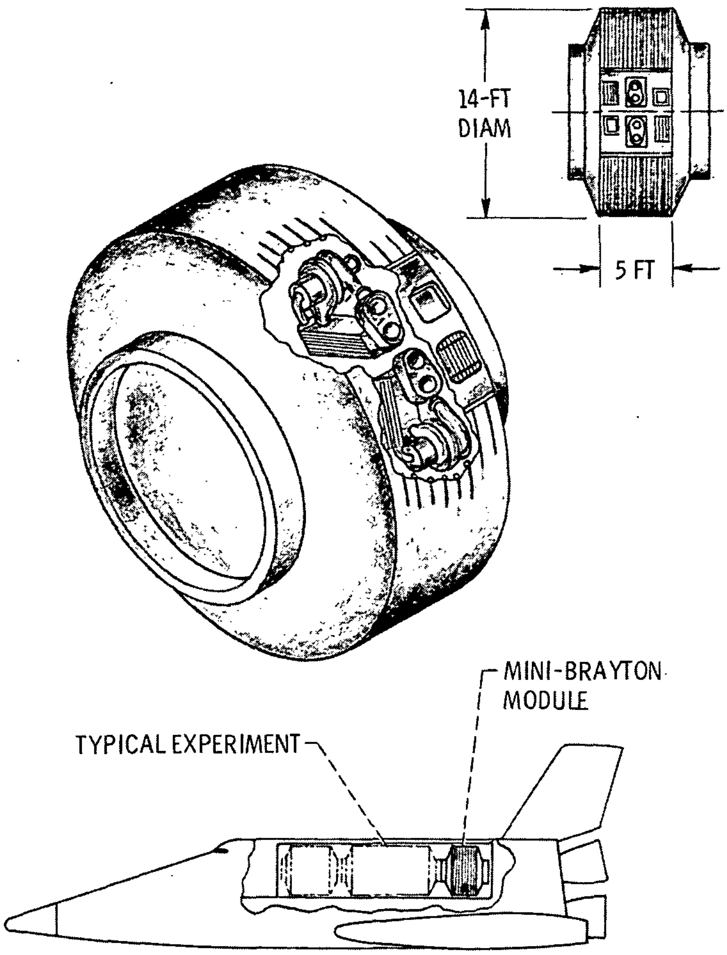

Figure 6. - Fourteen-foot-diameter mini-Brayton module (2500 We).

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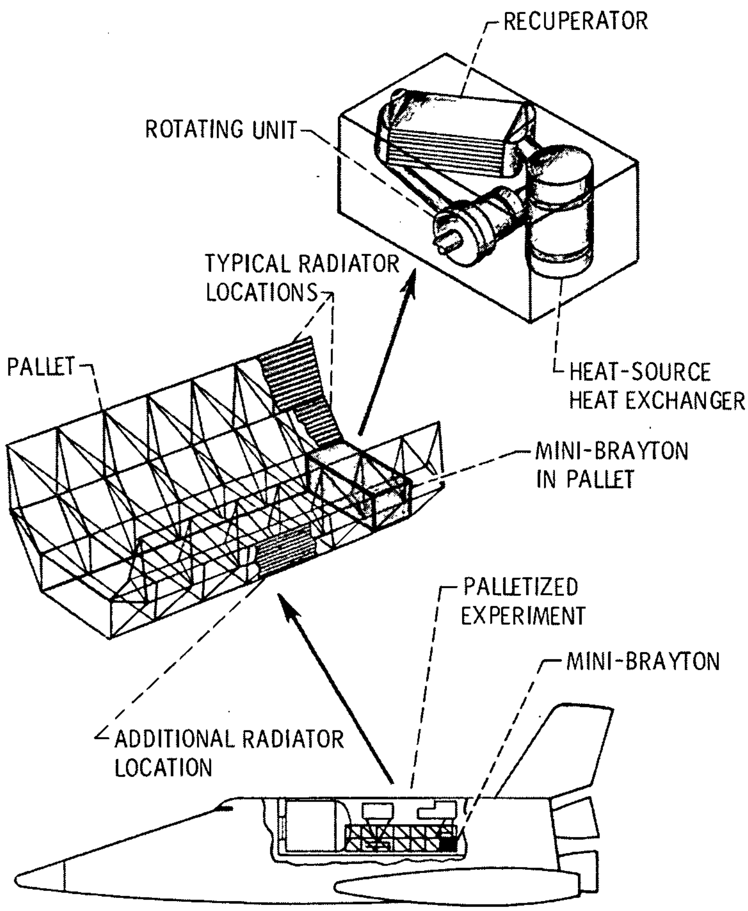

Figure 7. - Palletized mini-Brayton concept.