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ROTATING BUBBLE MEMBRANE RADIATOR FOR SPACE APPLICATIONS

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ABSTRACT

An advanced radiator concept for heat rejection in space is described which uses a two-phase working fluid to radiate waste heat. The development of new advanced materials and the large surface area per mass makes the Bubble Membrane Radiator an attractive alternative to both conventional heat pipes and liquid droplet radiators for mid to high temperature applications. A system description, a discussion of design requirements, and a mass comparison with heat pipes and liquid droplet radiators is provided.

INTRODUCTION

By the turn of the century, electrical power requirements for space activities will increase significantly as additional power is needed for orbiting space stations and platforms, electric propulsion systems, communication facilities, space based radars, and other proposed commercial and military applications. To meet this increased demand for power, solar dynamic and nuclear power systems, which operate on a closed heat engine cycle or use direct conversion of thermal to electric power, are being investigated for their significant reduction in size and mass over comparable photovoltaic systems. This reduction in power system mass and size may translate into reduced initial and life cycle costs as well as improved orbital operations in the areas of stability, control, and maintenance.

For any space-based activity, waste heat must ultimately be radiated to space. Spacecraft system studies by NASA and industry have shown that heat rejection radiator systems are a major weight and volume contributor to any power or thermal management system. The optimumal design and development of future power or thermal management systems will require advanced heat rejection concepts utilizing new and innovative approaches to reduce overall system mass and size, while increasing system efficiency and thermodynamic performance. These advanced heat rejection systems will be required to withstand the detrimental effects of meteoroid and space debris impact, radiation, and ionizing atoms, in addition to addressing such pertinent mission requirements as: reliability and maintainability, operation and control, system integration and life-cycle cost. Current research and development efforts are being focused on heat pipe and liquid droplet radiator technologies.

ROTATING BUBBLE MEMBRANE RADIATOR SYSTEM DESCRIPTION

An alternative approach to the problem of space-based heat rejection is the Rotating Bubble Membrane Radiator (RBMR). The RBMR is a hybrid radiator design which incorporates the high surface heat fluxes and isothermal operating characteristics of conventional heat pipes with the low system masses associated with liquid droplet radiators. The RBMR is designed to take full advantage of the microgravity environment of space through the integration and selection of components, and the elimination of mechanical phase separators.

The Rotating Bubble Membrane Radiator is an enclosed two-phase direct contact heat exchanger consisting of nine major components as shown in Figure 1. These components are: the attachment boom, rotation platform, central rotating shaft, central spray nozzle, thin film radiating surface, fluid collection troughs, return pumps, return piping and structure, and main feed/return lines.

Though the RBMR is capable of working with single-phase fluids by incorporation of a heat exchanger within its rotation platform, the operations discussion will be limited to a radiator system conceptualized for a two-phase working fluid. In this system, the two-phase working fluid enters the radiator via feed lines incorporated within the central axis of rotation. The working fluid is then ejected from the central spray nozzle as a combination of liquid droplets and vapor into the radiator envelope. Within this envelope, both convection and radiation heat transfer occurs between the droplets, the vapor and their cooler surroundings, with the dominant mode of heat transfer being radiation. As the droplets move radially outward, they grow in size by the condensation of vapor upon their surface and by collision with other droplets before striking the thin liquid film on the inner surface of the radiator. Once assimilated into the thin surface film, the working fluid begins to flow from the poles of the sphere toward the equator due to the rotationally induced artificial gravity. Heat transfer between the fluid and bubble radiator then becomes a combination of conduction and convec-

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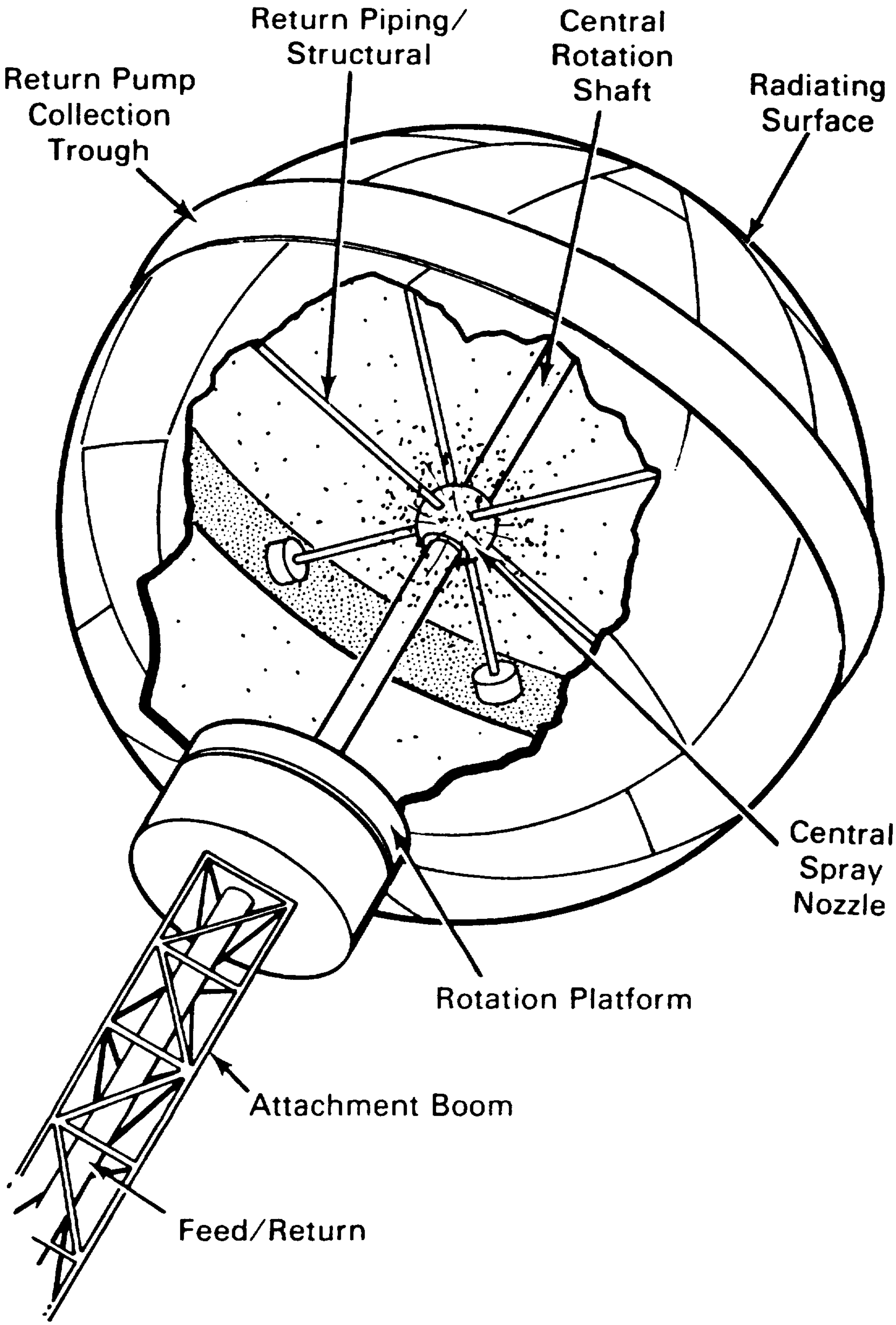


FIGURE 1
BOOM MOUNTED ROTATING BUBBLE MEMBRANE RADIATOR

tion. As the fluid reaches the equator of the sphere, it is collected in gravity wells (throughs) and pumped back to repeat the process.

To operate reliably in space, the RBMR will include design features to minimize tears and mitigate coolant losses that may result from meteoroid and space debris impacts. To minimize tearing of the radiator surface, structural support filaments will be incorporated into the radiator surface material. Coolant losses will be mitigated by incorporating self-sealing features which utilize system rotation. By developing self-sealing options substantial mass savings may be realized over other designs which provide protection against meteoroid impact by armoring the heat transfer surface.

Prime candidate materials for the thin film envelope include epoxy-carbon, zirconium and titanium alloys, and niobium-tungsten composites with final selection of the envelope material depended upon the radiator fluid and its intended operating temperature. Pump selection will also be determined by radiator fluid with EM pumps as possible candidates for liquid metal coolants, and mechanical or electric pumps favored for other applications.

RBMR SYSTEM ANALYSIS AND DESIGN CONSIDERATIONS

Primary design considerations for the RBMR were centered on the minimization of overall mass and payload volume and meteoroid survivability. Since all of these criteria are interrelated, a tradeoff study was performed based on current heat pipe and liquid droplet designs to determine the limitations and features of each type of radiator.

Heat pipe radiators, in general, consist of a circular pipe with a layer of wicking material covering the inner surface and leaving a central void region. The working fluid is added to this configuration and by capillary action per- meates the wicking material. When heat is added to the evaporator end of the pipe, the working fluid is vaporized and driven to the central void region. At the condenser end of the pipe, the vapor condenses back to liquid in the wicking material as heat is removed from the pipe structure via radiation to space. The liquid is then returned to the evaporator by capillary action through the wick.

The design review of the heat pipe radiator found that its design often incorporated armor plating to minimize the damage from meteoroid impact and that the orientation of the heat pipe during acceleration or deacceleration may directly affected its performance. The addition of this armor plating increases the overall system mass and the required payload volume. To compensate for the increase of mass due to the armor plating, efforts are underway to increase the operating temperature to minimize the mass to heat rejection ratio of the system. This in turn restricts the efficient usage of heat pipes from low temperature operations.

The liquid droplet radiator uses a stream of heated liquid droplets to radiate waste heat directly to space. A liquid droplet radiator consists of a droplet generating device, a collection device, makeup working fluid storage tanks, and return piping. The radiator fluid is typically heated by means of a heat exchanger and an additional working fluid. The radiator fluid is passed through a pressurized plenum, where it is ejected as jet streams into space towards a collector. Because of surface tension effects the fluid streams quickly break down into droplet form. The collector captures the droplets, pressurizes them, and returns them back to the heat exchanger.

The liquid droplet radiator was able to minimize its mass by spraying the radiator fluid directly to space. The design was found to require little payload volume and high meteoroid survivability, but it required extensive radiator fluid resupply for long-term continuous operations because of fluid losses to space. To reduce these losses, present research is focused on retention of radiator fluid by proper aiming of the droplet streams, minimizing evaporation, and efficient collection.

The ideal system, it was reasoned, would have as little structural mass as possible, be enclosed to reduce radiator fluid losses to space, have high surface heat fluxes, be self sealing, and self deployable. To achieve the high surface heat fluxes, a two-phase system was selected. Two-phase direct radiators offer higher surface heat fluxes then single phase indirect radiators, the overall system benefits from mass and volume savings. Initial estimates are that the RBMR is capable of heat rejection equivalent to a single-phase system, but with one-fourth the fluid mass and one-twentieth the mass flow requirements for the same operating temperatures.[1]

To reduce radiator fluid losses and structural mass and be self-deploying, a sphere or bubble type structure with support and return flow spokes was selected. To aid in the collection of the radiator fluid, artificial gravity was introduced into the system through rotation. Surface punctures could then be sealed by thin interior sheets that rely on pressure and gravity gradients to hold them in place.

The assumptions for the problem were:

Reactor Power (P)	1.11 MW
Waste Heat to Reject (Qr)	1.01 MW
Radiator Temperature (Tr)	775 K (935 F)
Temperature of Space (Ts)	0 K (-453 F)
Emissivity of Radiator	.9
Stefan-Boltzman Constant	$5.67\text{E-}8\ \text{W/m}^2\text{-K}^4$
Percent Error Introduced By Ignoring Solar and Earth Radiation (2)	5 %

The equation for finding the radiating surface required for the heat load is then:

$$\text{Area} = 1.05 * Qr/0.9 * 5.67\text{E-}8 * (Tr^4 - Ts^4) \text{ sq. meters}$$

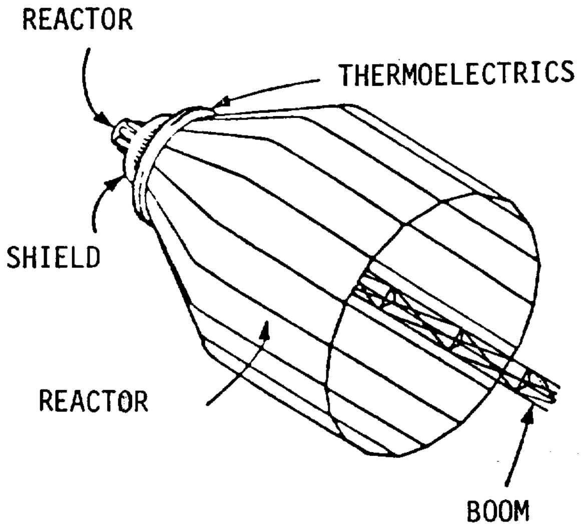
$$\text{Area} = 57.18 \text{ sq. meters}$$

This surface area then corresponds to a sphere with a radius of 2.13 meters (6.98 feet) to reject 1.01 MW of waste heat. The RBMR system mass, based on an 0.15 mm (0.006 in)-thick thin film envelope is then estimated to be approximately 91 to 137 kg (200 - 300 lbs) and is envisioned as being a small self-deployable unit.

MASS COMPARISON WITH OTHER HEAT REJECTION SYSTEMS

As a comparison of radiator system masses, the RBMR and the liquid droplet radiator have been directly substituted for the heat pipe radiator used for the 100 KWe Thermoelectric/SPAR Reactor (see Figure 2). A similar comparison previously made between the liquid droplet and heat pipe radiators was used as the basis of comparison of the RBMR.[2] A table of total system mass, estimated radiator masses, specific powers, and percent mass savings is given in Table 1.

The results of this comparison indicate that the RBMR is approximately four times lighter then today's heat pipe radiators while being four times heavier than a liquid droplet radiator with no operational coolant losses to space.



Source Temperature	1800 K
Hot Shoe Temperature	1400 K
Cold Shoe Temperature	775 K
Radiator Temperature	775 K
SPAR Reactor Power Rating	100 KWe
Total System Mass	1465 kg
Radiator Mass	455 kg
Specific Power with Heat Pipe Radiator	31 W(e)/lb

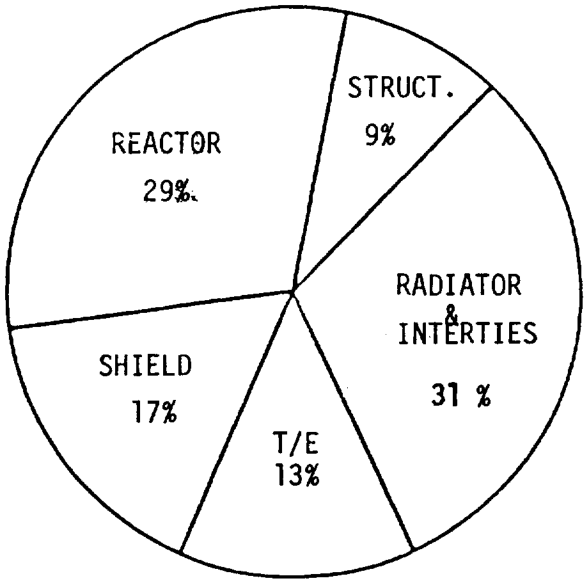


FIGURE 2. **Mass Distribution and Schematic for 100 kWe Thermoelectric/SPAR Reactor**

TABLE 1

SPAR REACTOR SYSTEM COMPARISON

Radiator Type:	Heat Pipes	RMBR	Liquid Droplet
Total System Mass	1465 kg (3226 lb)	1103-1148 kg (2426-2526 lb)	1033 kg * (2273 lb)
Radiator Mass	455 kg (1000 lb)	91-136 kg (200-300 lb)	21 kg (47 lb)
Specific Power (W(e)/lb)	31	39- 41	44
% Mass Savings	-	23	31

* Note: This value does not include system coolant mass estimates to compensate for coolant losses to space, since these are dependent upon the operating temperature, history and alignment of the system.

RBMR APPLICATIONS

As currently envisioned, the Rotating Bubble Membrane Radiator is capable of a broad range of space applications.

* As a thermal management device, the RBMR is suited to both high and low temperature applications through the proper selection of working fluid and radiator component materials.

* For power generation applications, the design can be modified by selection of materials to accommodate solar dynamic or nuclear two-phase systems.

* Using a boom-mounted configuration, the RBMR can be substituted for the type of heat pipe radiator panels currently envisioned for the NASA space station and orbital platforms. Because of its design, the boom-mounted RBMR need not require a gimbal attachment nor sensors for continuous alignment of the radiator to minimize solar heat input.

*The RBMR can be used as an integral part of advanced space apropulsion units (See Figure 3).

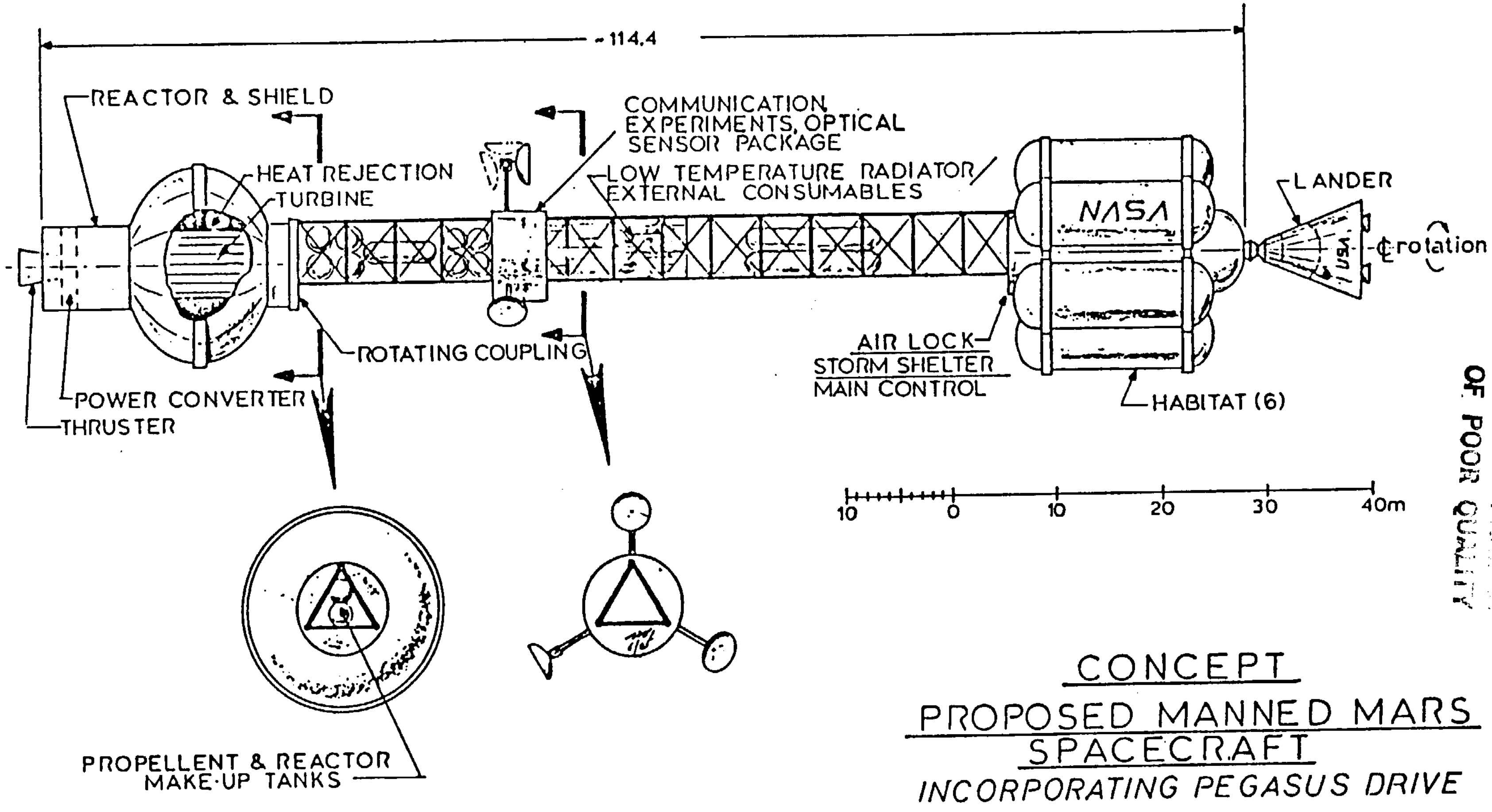


FIGURE 3. Rotating Bubble Membrane Radiator Incorporated in Spacecraft Design

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