Nov. 24, 1964 F. B. HUNTER, JR 3,158,198

SPACE RADIATOR AND METHOD FOR TRANSFERRING HEAT

Filed April 3, 1961 10 Sheets-Sheet 1

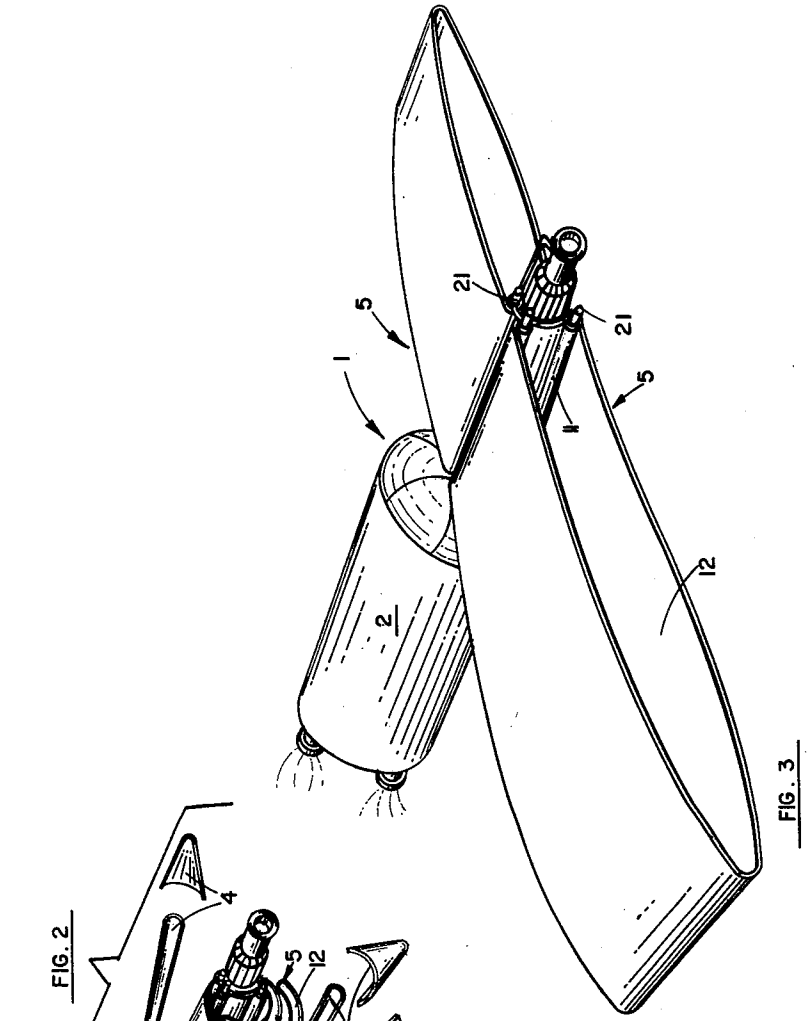


FIG. 3

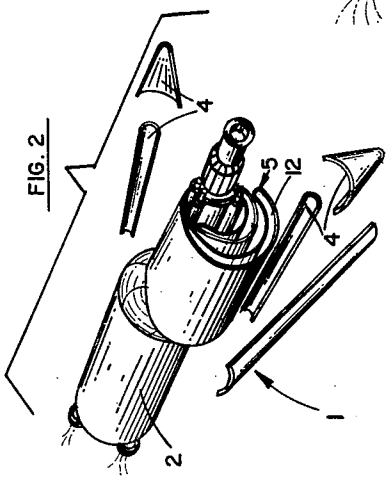


FIG. 2

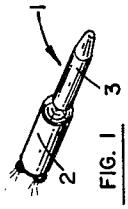


FIG. 1

INVENTOR.
FRANK B. HUNTER JR.
BY Thomas S. Macdonald

SPACE RADIATOR AND METHOD FOR TRANSFERRING HEAT

Filed April 3, 1961 10 Sheets-Sheet 2

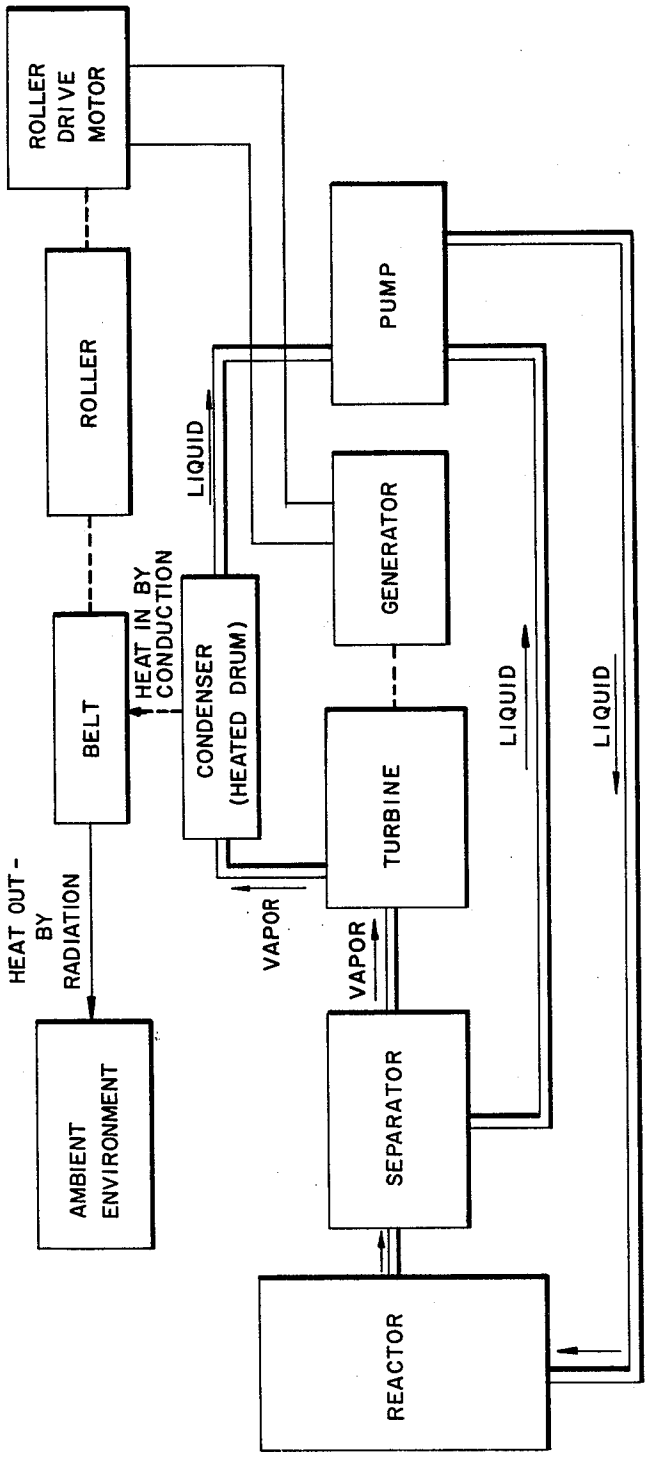


FIG. 4

INVENTOR.
FRANK B. HUNTER JR.
BY Thomas S. Macdonald
ATTORNEY

Nov. 24, 1964 F. B. HUNTER, JR 3,158,198

SPACE RADIATOR AND METHOD FOR TRANSFERRING HEAT

Filed April 3, 1961 10 Sheets-Sheet 3

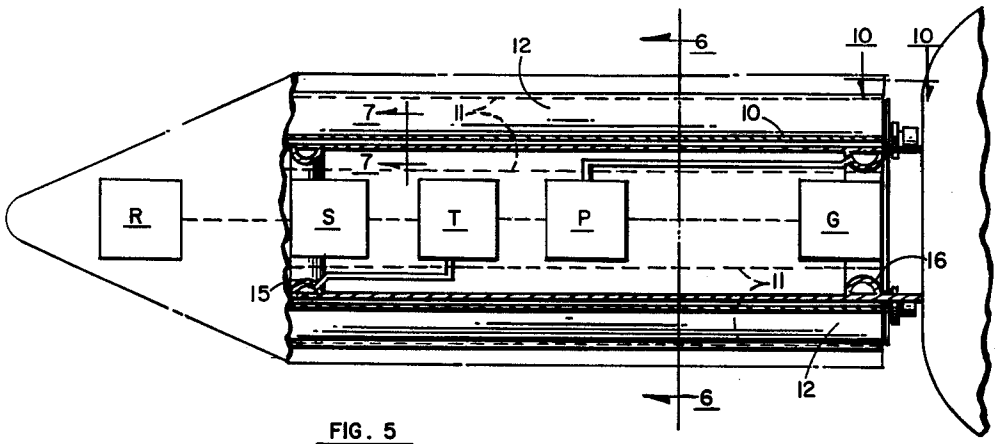


FIG. 5

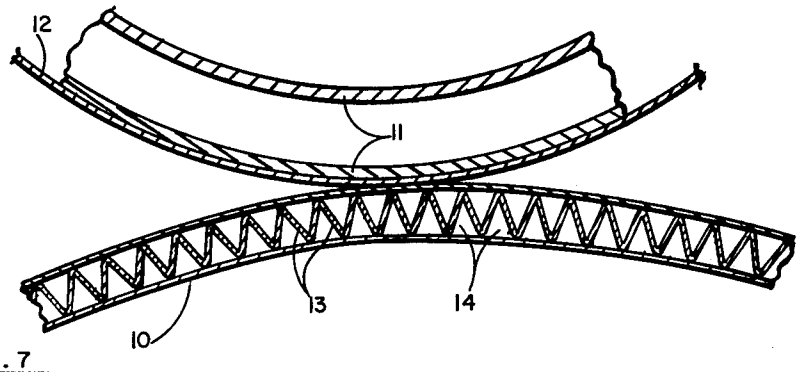


FIG. 7

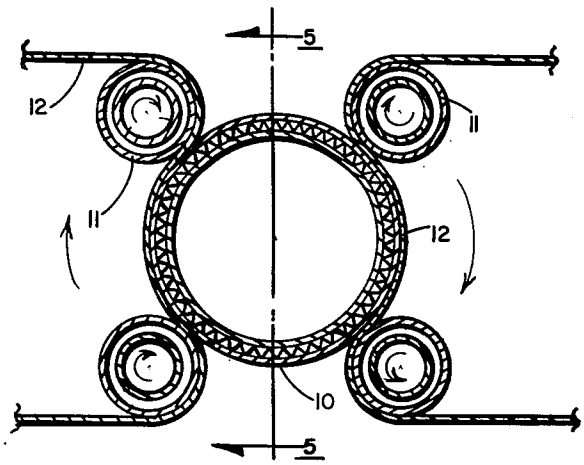


FIG. 6

INVENTOR.
FRANK B. HUNTER JR.
BY Thomas S. Macdonald
ATTORNEY

Nov. 24, 1964 F. B. HUNTER, JR 3,158,198

SPACE RADIATOR AND METHOD FOR TRANSFERRING HEAT

Filed April 3, 1961 10 Sheets-Sheet 4

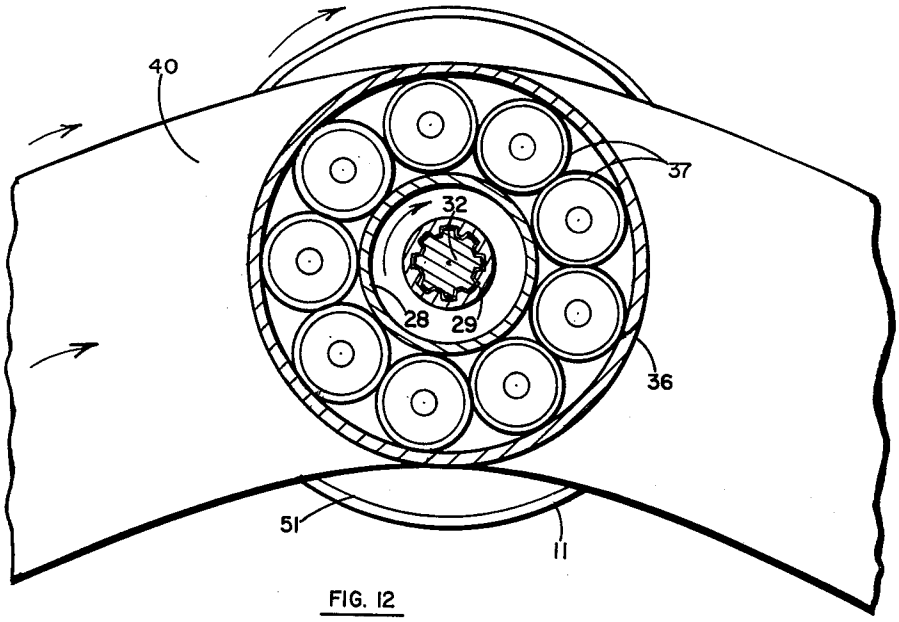


FIG. 12

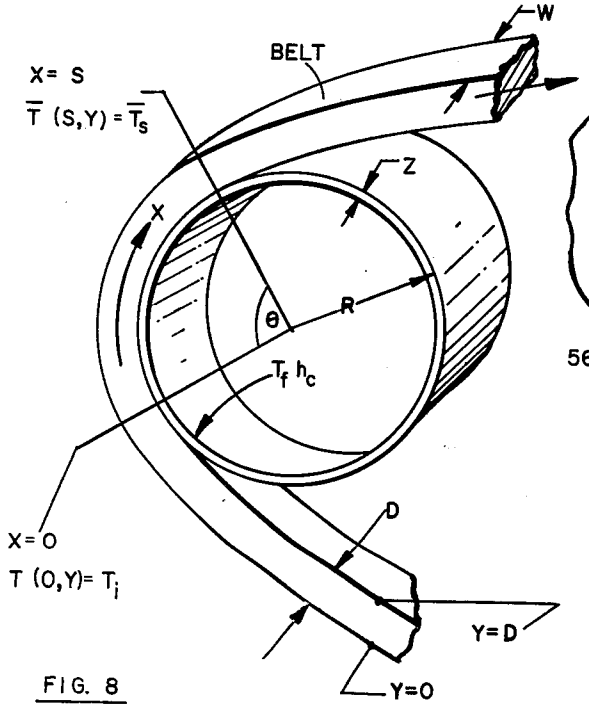


FIG. 8

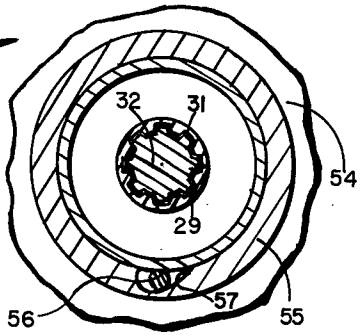


FIG. 13

INVENTOR.
FRANK B. HUNTER JR.
BY Thomas S. MacDonald
ATTORNEY

SPACE RADIATOR AND METHOD FOR TRANSFERRING HEAT

Filed April 3, 1961 10 Sheets-Sheet 5

$$\beta = \sum_{\lambda=1}^{\lambda=\infty} \left[\left(\frac{\sin^2 \phi_\lambda}{\phi_\lambda^2 - \phi_\lambda \sin\phi_\lambda \cos\phi_\lambda} \right) \left(1 - e^{-\phi_\lambda^2 \frac{\alpha S}{VD^2}} \right) \right]$$

WHERE $\phi_\lambda = (h_c D/K) \cot \phi_\lambda$

BELT PROPERTIES
A = THERMAL DIFFUSITY
C = SPECIFIC HEAT
D = THICKNESS
k = THERMAL CONDUCTIVITY
V = VELOCITY
S = CONTACT ARC LENGTH
W = WIDTH
ρ = DENSITY
h_c = CONTACT HEAT CONDUCTANCE

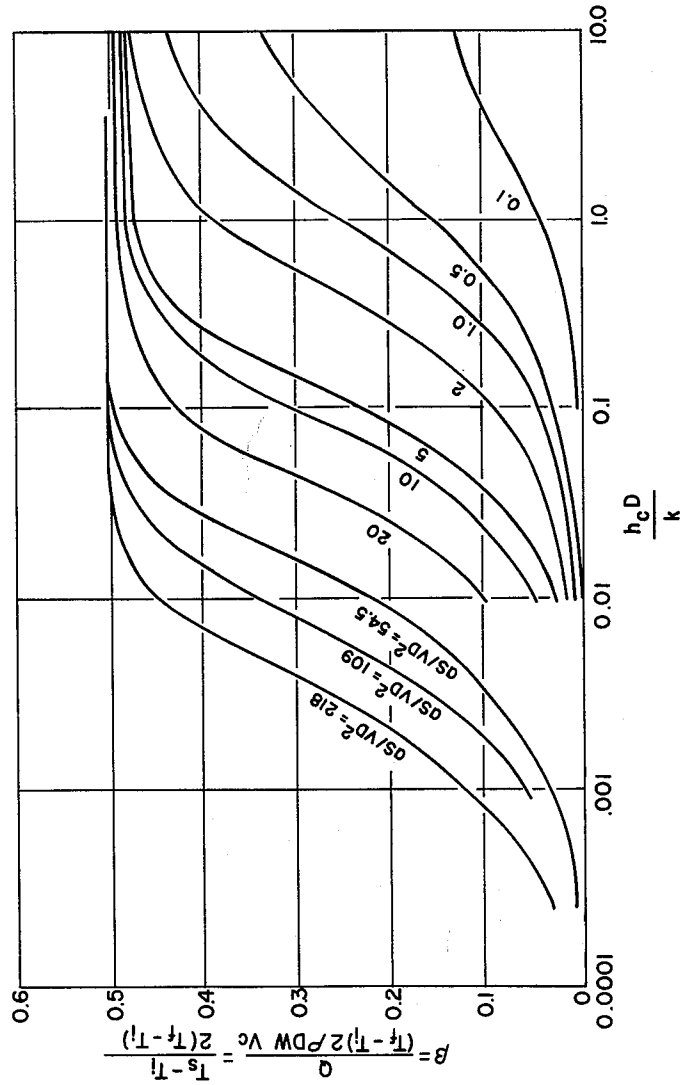


FIG. 9

INVENTOR.
FRANK B. HUNTER JR.

BY Thomas S. Macdonald

ATTORNEY

Nov. 24, 1964 F. B. HUNTER, JR 3,158,198

SPACE RADIATOR AND METHOD FOR TRANSFERRING HEAT

Filed April 3, 1961 10 Sheets-Sheet 6

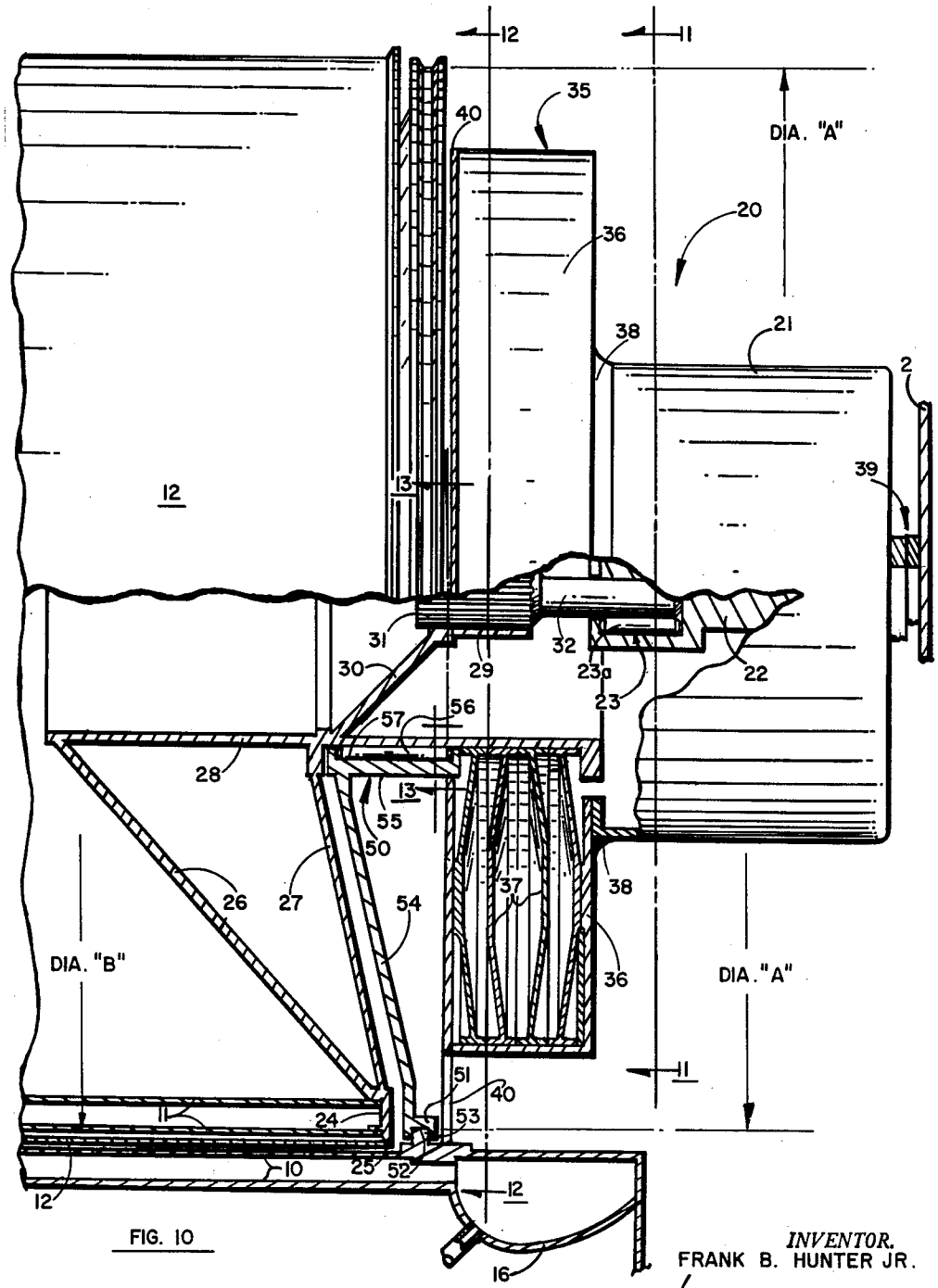


FIG. 10

INVENTOR.
FRANK B. HUNTER JR.

BY Thomas S. Macdonald

ATTORNEY

Nov. 24, 1964 F. B. HUNTER, JR 3,158,198

SPACE RADIATOR AND METHOD FOR TRANSFERRING HEAT

Filed April 3, 1961 10 Sheets-Sheet 7

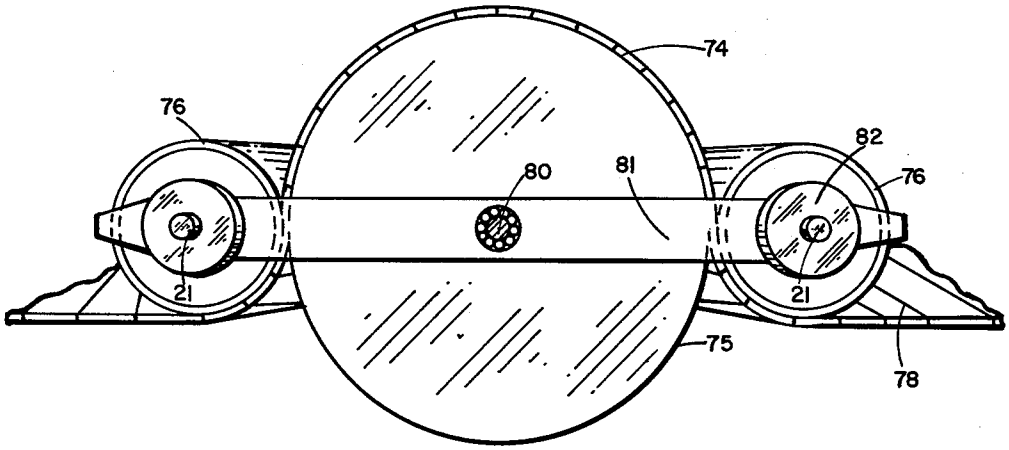


FIG. 21

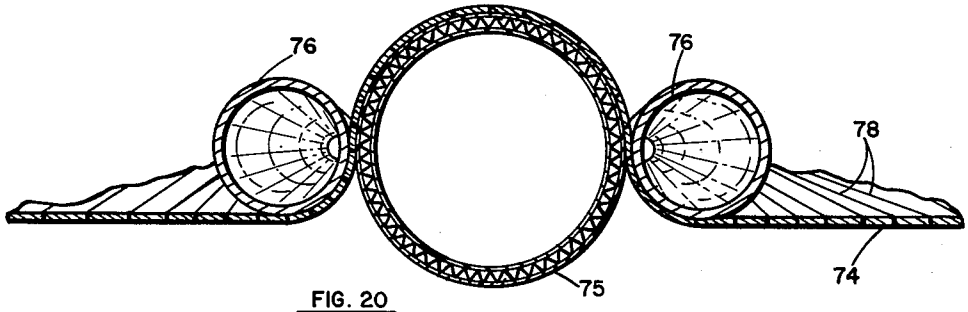


FIG. 20

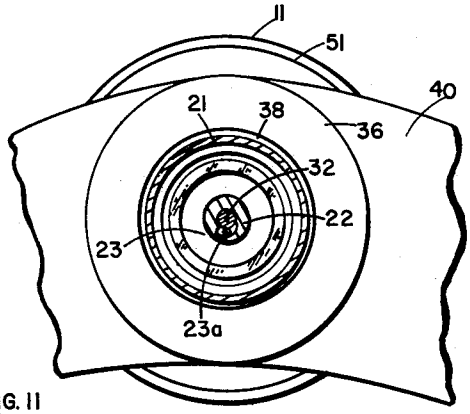


FIG. 11

INVENTOR.
FRANK B. HUNTER JR.

BY Thomas S. MacDonald

ATTORNEY

Nov. 24, 1964 F. B. HUNTER, JR 3,158,198

SPACE RADIATOR AND METHOD FOR TRANSFERRING HEAT

Filed April 3, 1961 10 Sheets-Sheet 8

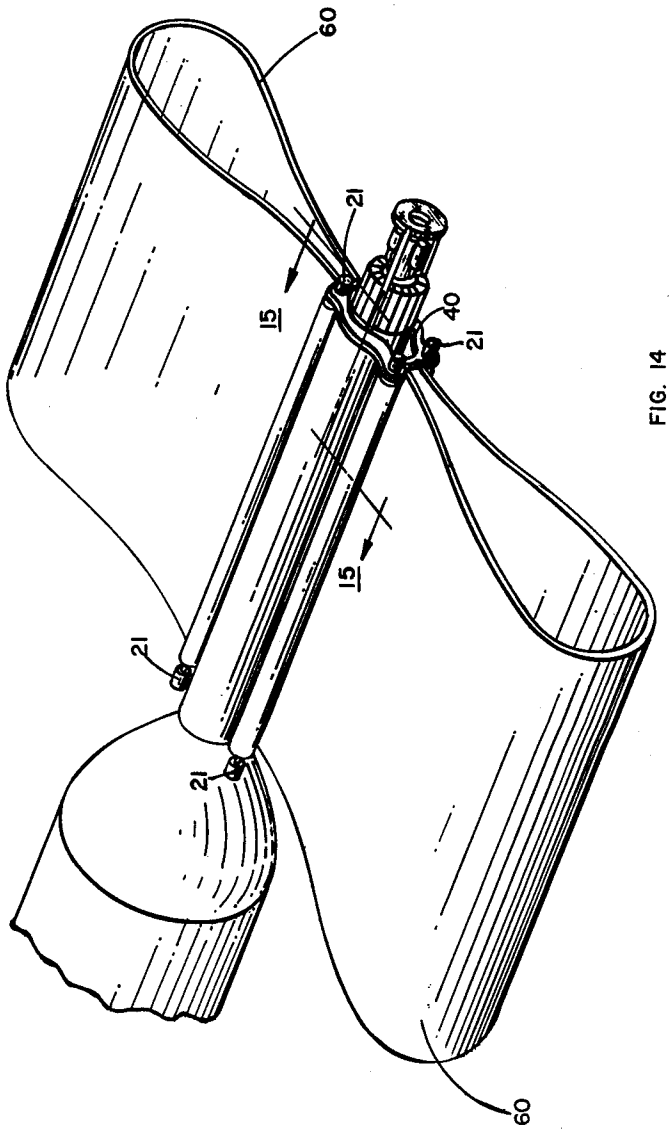


FIG. 14

INVENTOR.
FRANK B. HUNTER JR.

BY Thomas S. MacDonald

ATTORNEY

Nov. 24, 1964 F. B. HUNTER, JR 3,158,198

SPACE RADIATOR AND METHOD FOR TRANSFERRING HEAT

Filed April 3, 1961

10 Sheets-Sheet 9

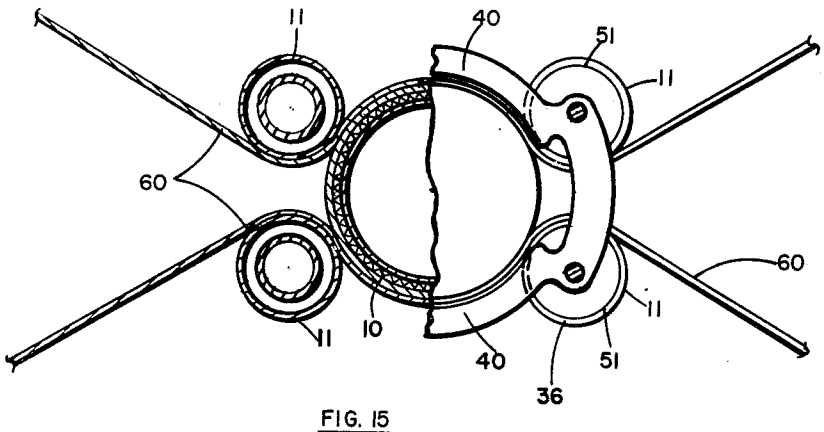


FIG. 15

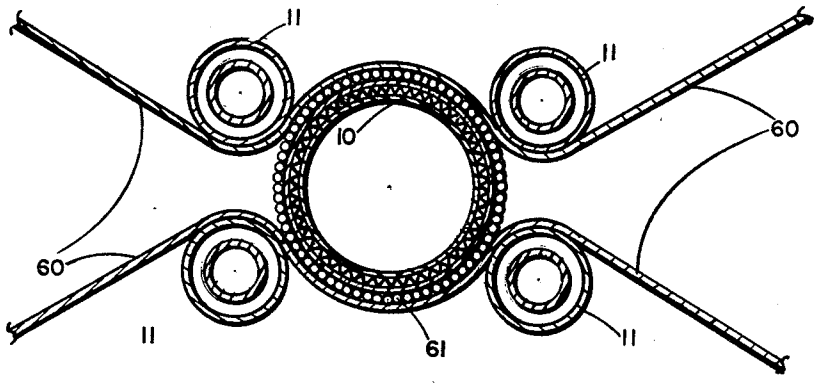


FIG. 17

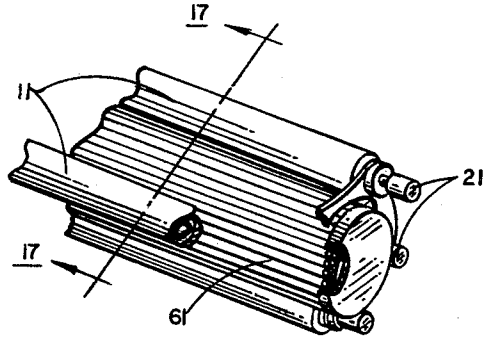


FIG. 16

INVENTOR.
FRANK B. HUNTER JR.

BY Thomas S. MacDonald

ATTORNEY

Nov. 24, 1964 F. B. HUNTER, JR 3,158,198

SPACE RADIATOR AND METHOD FOR TRANSFERRING HEAT

Filed April 3, 1961 10 Sheets-Sheet 10

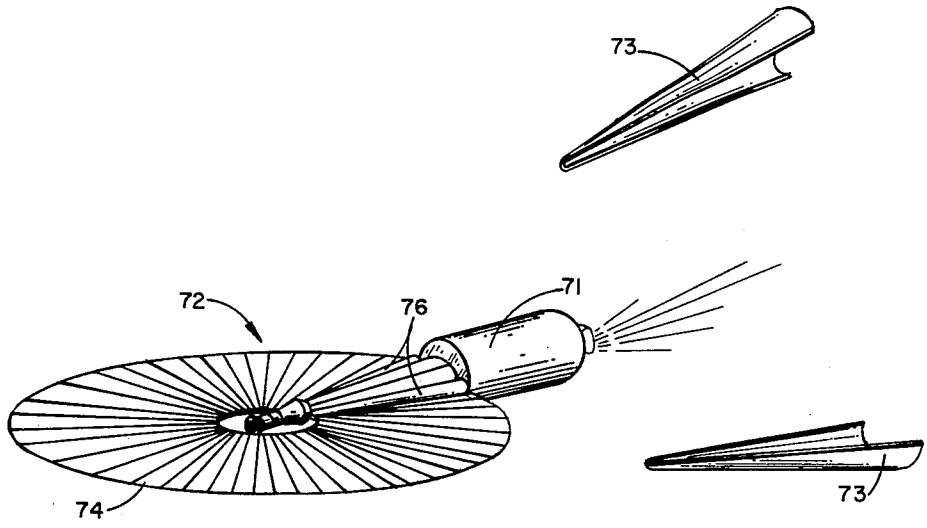


FIG. 18

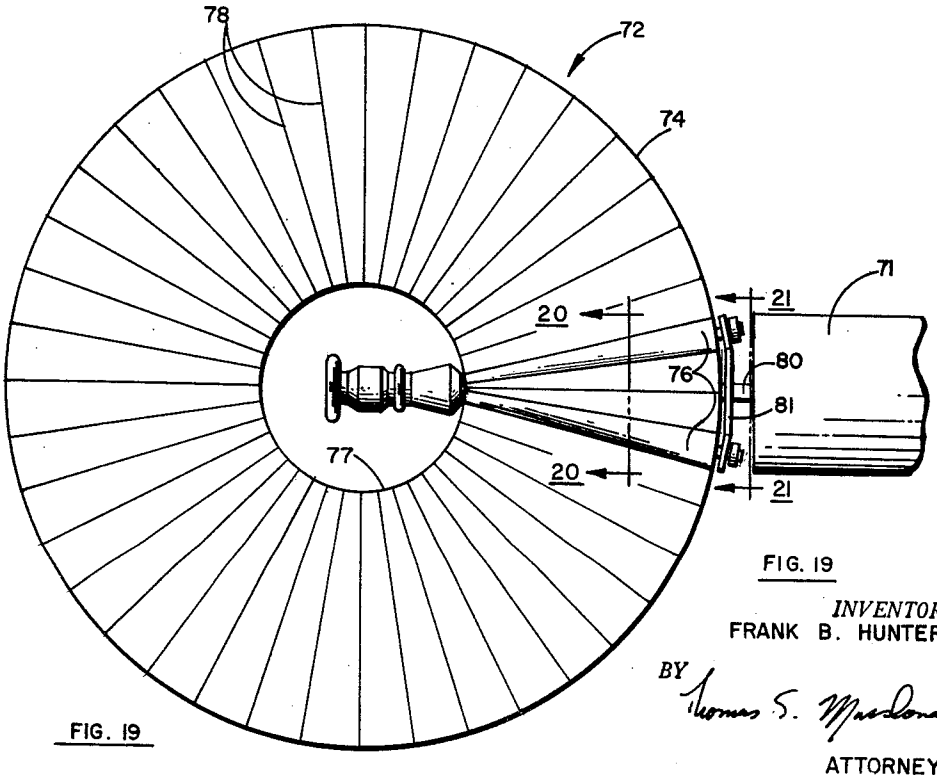


FIG. 19

FIG. 19

INVENTOR.
FRANK B. HUNTER JR.

BY Thomas S. Macdonald

ATTORNEY

United States Patent Office 3,158,198 Patented Nov. 24, 1964

3,158,198

SPACE RADIATOR AND METHOD FOR TRANSFERRING HEAT

Frank B. Hunter, Jr., Woodland Hills, Calif., assignor to North American Aviation, Inc.

Filed Apr. 3, 1961, Ser. No. 100,171
13 Claims. (Cl. 165—86)

This invention relates to a space radiator and method for transferring heat and more particularly relates to an endless belt capacitance type radiator concept particularly usable for rejecting heat from the interior of a craft adapted to fly through rarified environments. The term "rarified environment" should be herein understood to comprise a vacuum or near-vacuum type environment sparsely filled with a gaseous substance.

In closed-cycle powerplants, such as those used in modern day space craft, degraded heat energy which cannot be converted to work must be efficiently rejected so as to maintain such powerplants in operative condition. When such space crafts are flown through rarified environments, radiation comprises the only mode by which heat can be efficiently rejected from the closed-cycle systems employed therewith. Due to this limited mode of heat transfer, it is apparent that the independent variables controlling the design of such radiators are limited.

Such problems may be technically reiterated by stating that in any engine wherein heat is generated, only a partial conversion of the heat input energy to mechanical output energy is realized, the thermo-efficiency being limited to the Carnot cycle efficiency. Provisions must therefore be made to reject the degraded heat energy which cannot be converted to work. The required heat rejection rate is the output power multiplied by the quantity $(1/\eta-1)$, where η is the cycle efficiency. In space, or in any other rarified environment, the only effective method of rejecting heat is by thermo-radiation from a surface of the engine to the environment generally considered to be at very low temperatures. The radiation requirements are usually the controlling factors in the weight of a space heat rejection system regardless of whether the working fluid condenses, as in the Rankine cycle or is merely cooled as in the Brayton or Stirling cycles, for example. Thermionic and thermo-electric power conversion systems have similar requirements for rejecting heat.

Numerous studies have been made to optimize entire conversion systems employing space radiators. Such studies have generally recognized that two factors are of paramount importance in determining the weight of a radiator system: (1) the effective radiating area requirement, and (2) the necessity for protecting fluid systems against penetration by the meteoroids. With nuclear heat sources, for example, the radiator must also be shielded, resulting in an additional weight penalty. When the power levels increase the radiator becomes one of the heaviest components in the system and therefore, such a weight factor becomes very critical. Analyses such as there have shown that one can optimize radiator temperature for closed-cycle thermodynamic systems. This optimum varies between approximately 50 percent of the maximum cycle temperature for solar power systems to approximately 75 percent of the absolute maximum cycle temperature for nuclear systems.

Conventional radiators of the relatively stationary type which are adapted for use with modern day space craft and the like are generally excessively large and weighty in construction. In addition to these basic problems it is difficult to compactly store such devices in inoperative position during a boost phase of the space craft trajectory. Furthermore, the large support structures necessitated for such conventional type radiators must be constructed and arranged to withstand the extreme acceleration and aerodyanic loads imposed thereon.

The present invention has overcome many of the inherent inadequacies afforded by the state of the art radiator devices by providing an endless belt, capacitance type radiator concept particularly adapted for use in rarified environments. A driving means is operatively supported adjacent a heated wall portion and is constructed and arranged to continuously drive a relatively movable endless belt means there against. The endless belt means is constructed and arranged to have a portion thereof in constant abutting relation with said wall portion. Heat is received from said wall portion by conduction at that portion of the belt means which is in contact therewith and such heat is subsequently rejected by radiation when said belt portion moves out of abutting relationship with said wall portion.

A brief comparative summary with respect to conventional radiators suggested for use with modern space crafts, for example, would appear to disclose that the radiator comprising the novel concepts of this invention affords the following advantages thereover: (1) an effective radiating surface which is smaller by a factor of approximately ten; (2) a meteoroid reliability factor which is greater by a factor of approximately ten; (3) an increased mechanical reliability factor; (4) a simplified heat rejection speed control; (5) a self supporting and compactly stored radiator support structure; and (6) considerable weight savings.

An object of this invention is to provide a very efficient and low weight radiator which affords a high reliability factor.

Another object of this invention is to provide a highly efficient method for transferring heat, particularly in rarified environments.

Another object of this invention is to provide a radiator which has a ratio of weight per unit effective radiator surface area which is much lower than that afforded by conventional type radiators.

A further object of this invention is to provide a radiator affording maximum meteoroid protection primarily due to the alleviation of intimate contact between the working fluid and associated radiating surface.

A still further object of this invention is to provide a radiator which is not incapacitated when portions of the radiating surfaces thereof are punctured by meteoroids, for example.

A still further object of this invention is to provide a radiator wherein the heat rejection rate may be accurately controlled.

A still further object of this invention is to provide a radiator particularly adapted for use in a rarified environment, which radiator can be readily made part of the control system for the powerplant of the vehicle to which it is operatively connected.

A still further object of this invention is to provide a radiator which functions to diminish the dynamic problems of the powerplant control system to which it is operatively connected.

These and other objects of this invention will become apparent from the following description taken in connection with the accompanying drawings, in which:

FIG. 1 discloses a first of three successive operational stages of a missile employing a first preferred radiator embodiment therewith;

FIG. 2 discloses the second operational stage thereof wherein a furled radiator belt is exposed to an ambient environment;

FIG. 3 discloses the third operational stage thereof wherein the belt radiator of FIG. 2 is unfurled into operative position;

FIG. 4 discloses a flow diagram depicting a preferred operational sequence of a typical missile system employing the novel radiator belt concepts of this invention;

FIG. 5 is a longitudinal view partially in cross-section showing the fore section of the missile disclosed in FIGS. 1–3 inclusive;

FIG. 6 is a cross-sectional view taken on lines 6—6 in FIG. 5;

FIG. 7 is a partial cross-sectional view taken on lines 7—7 in FIG. 5;

FIG: 8 shows a set of drum-belt contact coordinates set forth for theoretical explanation purposes;

FIG. 9 is a graphical showing of the belt contact heat transfer factor;

FIG. 10 is a view, partially in section, taken in the direction of lines 10—10 in FIG. 5;

FIG. 11 is a cross-sectional view taken on lines 11—11 in FIG. 10;

FIG. 12 is a cross-sectional view taken on lines 12—12 in FIG. 10;

FIG. 13 is a cross-sectional view taken on lines 13—13 in FIG. 10;

FIG. 14 discloses a second preferred radiator embodiment employing the novel concepts of this invention;

FIG. 15 is a partial cross-sectional view taken on lines 15—15 in FIG. 14;

FIG. 16 is a slightly modified showing of the radiator embodiment of FIG. 14;

FIG. 17 is a cross-sectional view taken on lines 17—17 in FIG. 16;

FIG. 18 discloses a third preferred radiator embodiment employing the novel concepts of this invention;

FIG. 19 is a top plan view of the radiator embodiment disclosed in FIG. 17;

FIG. 20 is a cross-sectional view taken on lines 20—20 in FIG. 19; and

FIG. 21 is a cross-sectional view taken on lines 21—21 in FIG. 19.

The primary purpose of this invention is to provide a capacitance type radiator concept for use in combination with a craft adapted to fly in rarified environments. The craft has a wall means thereon generally in the shape of a drum, adapted to become heated at a first side thereof. A drive means is operatively supported adjacent said wall means and is adapted to continuously drive an endless belt means which is operatively associated therewith. Said endless belt means is constructed and arranged to have a portion thereof in constant abutting relation with a second side of said wall means whereby heat is picked up essentially by conduction, by said portion and subsequently rejected therefrom essentially by radiation when said belt means portion moves out of abutting relationship with said wall means.

FIGS. 1–3 inclusive disclose three successive operational stages of a missile generally noted at 1, employing a first preferred radiator embodiment therewith. FIG. 1 discloses the first operational stage wherein a missile 1 of the conventional type essentially comprising an aft payload and engine section 2 and a closed-cycle powerplant foresection 3 adapted to have the radiator contained therein, is shown as it would appear subsequent to the launching thereof. During the second stage of operation as shown in FIG. 2, upon a preselected command signal a plurality of aerodynamic shielding members 4 are jettisoned in the conventional manner to expose a radiator belt assembly generally noted at 5 which is shown in substantially stored or furled position. The specific details of such a jettisoning function do not comprise any of the novel aspects of this invention and may be achieved by means of conventional explosive type bolts, for example. The third stage of operation as shown in FIG. 3 discloses the first preferred radiator belt assembly as it would appear in unfurled and operative position.

FIG. 4 discloses a flow diagram depicting a preferred operational sequence of a typical missile system employing the novel radiator belt concepts of this invention. The

specific construction and arrangement of the hereinafter briefly described state-of-the-art closed powerplant type system per se does not comprise any of the novel aspects of this invention. A reactor of the conventional nuclear type, for example, is operatively connected to a separator which separator in turn selectively transmits an appropriate "working" vapor to a turbine and an appropriate "working" liquid to a liquid pump in the conventional manner. The liquid pump in turn boot-straps a desired liquid constituent back to the reactor. The liquid pump and turbine are operatively connected to an electrical generator which generator is adapted to supply power to the system and in particular to the individual roller drive motors which are adapted to drive the roller mechanisms of the hereinafter described novel radiator belt system. A condenser is operatively connected to the turbine to receive a constituent in vapor form and with the aid of the belt type radiator functions to condense such vapor into liquid form. The formed liquid is then transmitted to a liquid pump for return to the power system.

The condenser is operatively associated with the radiator type belt member which belt member functions to absorb heat from the condenser essentially by conduction and subsequently transmits such heat, essentially by radiation, to an ambient environment surrounding the system. The roller drive motor functions to continuously drive the endless-type belt against the condenser for the heat exchange function. With such a simplified system, and in particular due to the utilization of the endless belt-capacitance type radiator concept, heat may be very efficiently rejected from the interior of a craft which is adapted to fly through rarified environments. As hereinbefore stated, a typical closed-cycle type system such as that shown in FIG. 4, for example, demands that degraded heat energy which cannot be converted to work be efficiently rejected therefrom to maintain the powerplant in operative condition during all modes of missile flight.

FIGS. 5–10 inclusive more specifically discloses the structural make-up of the first radiator embodiment systematically disclosed in FIG. 1–4 inclusive.

FIG. 5 discloses a longitudinal view, partially in cross-section, more particularly showing the closed-cycle powerplant foresection 3 of the missile. The reactor (R) is preferably positioned at the foremost portion of the section whereas the separator (S), turbine (T), pump (P) and generator (G) are schematically represented as being constructed and arranged substantially within the radial confines of the condenser. As more clearly shown in the cross-sectional view of FIG. 6, the radiator system essentially comprises a condenser 10 in the form of a dual shell type drum member which is operatively associated with four drive rollers 11 and two endless type radiator belts 12.

A typical condenser wall cross-section is shown in FIG. 7 wherein the condenser 10 is constructed and arranged to provide a corrugated type inner layer 13 which is secured to the two shell members thereof to provide a plurality of longitudinally extending channels 14 which channels are utilized in the conventional manner to provide for the condensing function. As shown more clearly in FIG. 5, the vapors from the turbine are injected into the longitudinal passages 14 of the condenser by means of a circumferentially extending manifold 15. The vapors are then condensed to a liquid during their flow therethrough and such liquid is subsequently passed into a circumferentially extending manifold 16 which in turn transmits such condensed liquids to the pump of the closed-cycle powerplant. The specific construction and arrangement of the condenser and associated recirculation system are not further elucidated since such specific constructions do not in themselves comprise the novel concepts of this invention.

The broad novel concepts of this invention more particularly comprise the manner in which the radiator belt

12 is operatively associated with the heated condenser drum type member 10 so as to effect a cooling of the constituent contained in channels 14 thereof. In accordance therewith, the hereinafter stated analysis would appear advantageous in order to more fully explan the theoretical basis for such concepts.

Reference is now made to FIG. 8 wherein a set of drum-belt contact coordinates are set forth in order to briefly disclose a basic theoretical analysis of this invention and to also teach one skilled in the art how to efficiently construct such a device. In a space heat rejection system utilizing the moving belt concepts of this invention for dissipating heat from the working fluid to a sink in space, the heat must flow along at least four paths in series: (1) by convection from the working fluid to the inside surface of the drum; (2) by conduction across the drum wall; (3) by conduction from the outer surface of the drum to the belt; and (4) by radiation from the belt surfaces to space.

The resistance to heat flow must be minimized in all these paths, so that the resulting heat flow rate from the working fluid to the space sink is as large as possible while the dimensions and weight of the device are yet maintained as small as possible. Thus, a desired heat rejection rate may be attained with minimum radiator weight.

The heat flow rate will be primarily controlled by the highest thermal resistance of the four paths in series. The maximum ideal heat rejection rate is obtained when there is negligible thermal resistance in paths (1), (2) and (3) stated above, so that the mean belt temperature is close to the working fluid temperature. With this proposed condition, the dimensions and radiation properties of the belt surfaces control the heat flow rate. There are literally many finite thermal resistances in above paths (1), (2) and (3) which function to cause a temperature drop in each case, so that the mean belt temperature, and hence the radiator heat flow rate, are reduced. The measure of the ability to transfer heat in any mode is the "heat conductance" (h_c), which is the inverse of resistance.

Considering a typical liquid metal condensing system wherein the liquid-metals employed therewith have a condensing conductance in the order of 10,000 Btu/sq. ft.-hr./F.° units, the drum wall thickness (Z) will be small and the drum material thermal conductivity (k) will be large, so that, for example, with a wall thickness of 1/16 inch and a thermal conductivity of 10, the conductance (Z/k) for path (2), will be in the order of 2000. In a typical actual application, the first two conductances are, therefore, high and not likely to be critical in determining the heat flow rate (Q). This means that the drum outer surface temperature may effectively be taken as equal to the working fluid temperature (T_f). The limiting factor will then be either the contact drum-to-belt or the belt-to-space radiation heat transfer. The former will primarily depend on the contact time, which is dependent on belt speed (V) and contact arc (S), as well as the belt thickness (D), thermal diffusivity (a) and contact conductance (h_c).

The belt is subjected to heating at its contact surface over a contact length (S) from a constant drum wall temperature (T_f) and a given contact resistance (h_c), while moving with a constant velocity (V). The outer surface is assumed to comprise a near perfect insulation which insulation function is particularly true for the multiple belt-single drum configuration as disclosed in the embodiment of FIG. 6, for example. Furthermore, heat conduction inside the belt in the direction of motion is small enough to be ignored, since design belt speeds are in excess of the lateral heat conduction wave velocity in the belt (approximated by a/D) which approximates 1/4 foot per second. Practical belt velocities are approximately one to two orders of magnitude above such wave velocities.

With a constant V, x equals Vt, so that the normal transient heat conduction equation is:

$$\frac{\partial T'}{\partial t}=a\frac{\partial^2 T'}{\partial y^2} \tag{1}$$

wherein:

$T'=T-T_f$
T=Variable belt temperature
T_f=drum wall temperature at the cold side thereof
t=time
a=diffusity ($k/\rho C_p$)
k=conductivity
ρ=density
c_p=specific heat
y=distance from cold side of belt toward the heated contact side

From known data and by making the necessary obvious assumptions, the rate of heat input to the belt over the complete contact length may be expressed as follows:

$$Q=2(T_f-T_i)V_c DWC_p\rho\beta \tag{2}$$

wherein:

Q=heat rejection rate
T_i=uniform belt temperature at start of conduction portion
V_c=constant belt velocity
D=belt thickness
W=belt width (perpendicular to both D and S)
β=contact factor

Also, all the heat received by the belt from the drum results in a raising of the effective belt temperature from the uniform T_i at engagement to some mean $\overline{T}_S$ at disengagement, thus giving:

$$\frac{Q}{\rho DWV_c}=\overline{T}_s-T_i \tag{3}$$

Over the radiating loop of the belt, of length L, the assumption is made that the belt temperature is uniform at any cross-section, which permits integration of the four-power radiation law along the belt to give:

$$\frac{1}{T_i^3}-\frac{1}{\overline{T}_S^3}=\frac{3F\sigma\epsilon L}{DV_c} \tag{4}$$

and

$$T_m=\overline{T}_S\left[\frac{3\left(1-\frac{T_i}{\overline{T}_S}\right)}{\left(\frac{T_i}{\overline{T}_S}\right)^{-3}-1}\right] \tag{5}$$

where

T_m=mean belt temperature

From the above stated equations, it is apparent that compatible values for Q, T_i and $\overline{T}_S$ may be readily ascertained when a particular configuration is specified. Accordingly, T_m may be found from Eq. (5). Referring now to FIG. 9, it should be noted that when h_c approaches infinity, β approaches the value of 1/2, i.e., then $\overline{T}_S$ approaches T_f as would be expected.

It is also significant to note that an extremely high value of h_c is not required for a high β, i.e., Q. FIG. 5 further discloses that a value within 20% of the maximum attainable (β=0.4) may be obtained for h_c D/k values near 0.01, which for k=10 and D=0.003 inch (0.00025 foot) gives an h_c value of about 500. This implies a value (aS/VD^2) of about 150 with a V of 15 f.p.s. and a steel belt with S=3.5 feet. It should be further noted that from Equation 2, Q is directly proportional to $VD\beta$, where β itself is dependent on V and D. Varying V and D in order to get a change in β provides that when V or D is increased, β is decreased (thus, doubling V or D will increase Q, but not to the extent of doubling it) and also, that when the product VD is kept constant, Q remains fairly constant.

From the above discussion it is possible to draw the following conclusions: (1) the most effective method of increasing heat flow (Q), as more particularly shown in Eq. 2, is to increase belt width (W), specific heat (c), and density (ρ) since this will result in a linear increase of Q; (2) increases in belt velocity (V) or thickness (D) produce increases in Q, but at a less than linear rate. Q remains fairly constant for constant values of VD; (3) increasing Q by increasing belt length L is only effective up to a limit. This limit is independent of L; and (4) if contact conductance (h_c) is small, Q is also small, even with large belt widths and lengths. Intermediate h_c values, of the order of 500, are essentially the maximum required. Further increases in h_c do not improve over-all heat transfer because then the belt-to-space radiation becomes the limiting factor.

In order to efficiently design a belt radiator, a value for the contact conductance (h_c) is needed since this is a critical parameter in determining the heat flow particularly wherein heat conductance has to be evaluated for two hot surfaces, one rigid and one flexible, which are in rolling contact in a vacuum. The areas of primary concern are: (1) contact pressure between the surfaces; (2) vacuum or low pressure contained therearound; (3) high temperature of the surfaces; and (4) surface conditions (including hardness and yield).

It has been determined that for any given contact pressure (preferably 20 p.s.i. or less), the heat conductance increases as the r.m.s. of the surface roughness decreases. The effect of surface roughness is very significant since an increase in smoothness increases surface contact heat conductance by sizable amounts. For example, at 195 p.s.i. contact pressure, an increase in smoothness from 3320 microinches to 3 microinches increases the heat conductance from about 100 to 10,000 B.t.u./sq. ft.-hr.-° F. Control of surface finish (preferably approximating a "0" surface roughness value) and flexibility of the belt also contribute to a high h_c value at lower contact pressures.

It should be particularly noted that a belt-drum system operating without slippage is an example of pure rolling contact, in which the relative velocity between the belt and drum over the arc of contact is substantially zero. Therefore, only a normal force or a bona fide contact pressure between the surfaces exist. Further, it should be noted that the contact is of a surface nature, similar to a ball bearing which has rolling point contact or a roller bearing which has rolling line contact.

The hereinafter particular belt design provided for the improvement of contact heat transfer generally falls into two classes: (1) contact geometry and (2) surface coatings.

Since the belt type radiator has a curved rigid-flexible rather than a flat rigid-rigid contact, improved contact conductance is obviated. Moreover, it is then more important to control surface finish than actual dimensions. The drum may be out-of-round, but as long as all of the curved surfaces are parallel to each other, contact will not be impaired. Several surface designs suggest themselves so that such an intimate microscopic contact may be achieved. One is the mating of a relatively non-elastic type belt material with a relatively elastic type drum surface so that local contact areas of the drum are enlarged without the need for high contact pressure. Another possibility is the use of a belt having a relatively high elasticity, for example, a belt constructed of a woven material.

When the radiator is adapted for use in an environment having a temperature up to and including approximately 650° F., the belt material is preferably selected from the group comprising aluminum, aluminum alloys, magnesium and magnesium alloys. When the working temperatures comprise a range of approximately 650° F. to 1400° F., the belt material preferably comprises a stainless steel alloy selected from the SAE 300 series, a SAE 416 alloy etc. For the temperature range of 1400° F.–1800° F. the material may comprise columbium, zirconium, tantalum, molybdenum, etc. In the range of 1800° F.–4000° F. tungsten would comprise the most feasible material. One basic requirement is that the particular belt material employed should provide the desired "creep strength" (that stress which will cause the material to fail at a predetermined temperature and time period) during all modes of radiator operation. Knowing the range of temperatures and the time period through which the belt will be subjected provides a working basis whereby one of the above menticned materials, for example, may be selected.

The woven belt concept provides for better ability to follow drum surface imperfections; lower belt fatigue because the woven material has a higher elasticity, i.e., ability to return to the original shape after deformation, providing increased integrity and reliability for long periods of operation; increased tensile strength primarily due to the fact that relatively small wires may be used, thus, the desired crystal strength of the material could be approached; and enhanced contact points which would be discrete and more amenable to systematic variations based on mesh and wire size. The wire utilized to form such a woven belt structure may comprise any desired cross-section such as rectangular, round, half-round, etc. The woven belt structure also may be subjected to a colandering process if so desired. Such a process, wherein the woven belt structure is substantially flattened due to rolling pressures imparted to surfaces thereof, functions to increase the surface contact area. If round wires are used, the diameters of such employed wires preferably comprises those selected from the range of .001 in. to .008 in.

The belt material should preferably posses high specific heat, density, and surface emissivity. Metals generally provide high densities, but generally have relatively low specific heats (about 0.10 B.t.u./lb.-° F.). It may, therefore, be advisable to construct a composite belt material comprising a metallic portion in combination with another high-temperature resistant type material, such as graphite, for example (the specific heat of graphite approximates 0.40 B.t.u./lb.-° F.).

Also, it is possible to increase the desired conductivity by placing a small amount of a standard grease between the belt-drum contact surfaces. It is obvious that the maintenance of a fluid like material in the gap between the contacting surfaces provides for an increased heat conductance factor. Liquid-metal films, for example, when constructed and arranged on the juxtaposed drum and belt surfaces provide for a highly conducting bonding fluid. The principal requirements, apart from high thermal conductivity, are that the liquid-metal film wet the contact surfaces at all times and that the vapor pressure of the liquid-metal be very low so that the film is not removed before the operating period of the space powerplant is terminated. Furthermore, the liquid-metal constituent must be compatible with the materials of construction, i.e., they must not chemically react therewith, for example. The relatively high operating temperatures of the belt and the surrounding vacuumated environment would be conducive to the wetting of the contacting surfaces by a liquid-metal such as lead or bismuth, for example.

The heat transfer considerations above stated lead to the following significant conclusions: an efficient belt radiator system requires that the heat conductances in the entire heat flow path (fluid to drum inner wall, to belt to space) be maximized; and a detailed treatment of the heat flow into and within the belt over the contact area, combined with radiation heat outflow over the belt loop shows that the heat flow primarily depends on the parameters ($h_c D/k$), (aS/VD^2), ($\rho DWVc$) and ($F_c L/\rho DVc$) where the symbols have the meanings assigned previously. Simultaneous solution of the appropriate above stated equations provides a solution for a

complete heat transfer analysis. Such an analysis should particularly make cognizance of the following design considerations: that adequate contact pressure is needed for acceptable contact heat conductances between the contacting surface of the drum and the belt; contact heat conductance may be considerably improved by selecting a suitable belt-drum geometry (e.g. woven belt) and the application of a liquid-metal film or the like thereto; the convection of heat from a belt at a 50 f.p.s. linear speed, for example, is very small compared to the belt radiation even in a near perfect vacuum; and the free-molecule heat conduction across a contact gap of even 10^{-4} feet (applicable at less than 10^{-1} mm. mercury) only comprises a small percentage of the radiation across the gap. Together, these latter mentioned modes of heat transfer account for not more than 34 B.t.u./hr.-° F. per sq. ft. of gap surface. This may total approximately five percent of the contact heat conductance.

Having stated the basic analysis comprising the broad theoretical heat transfer concepts of this invention and the desired belt make-up, a specific application thereof will be hereinafter set forth. FIG. 10 is a partial cross-sectional view taken on lines 10—10 of FIG. 5. Since the roller drive assemblies, generally noted at 20 are identical, only one of such assemblies will be specifically explained. In most operational applications wherein four roller members 11 are utilized, it is desired to utilize eight such assemblies, each assembly being constructed and arranged at the respective ends of the four rollers. However, a lesser number may be employed, if so desired. For example, four such assemblies may be utilized with the individual assemblies with such assemblies being constructed and arranged at only one end of the four individual roller members 11.

A drive motor 21 of the conventional type comprises a drive shaft 22 extending therefrom and functions to drive the roller 11 by means of a conventional one-way overrunning type clutch assembly 23. It may be desired in many applications to utilize two such clutch assemblies 23 in each roller drive assembly 20 to avoid damage to the motor 21 in the event of a malfunction thereof. However, as hereinbefore stated in regards to the optional features of the roller drive assemblies 20, the relative number of clutch assemblies 23 which may be utilized is a matter of choice depending on the specific system design requirements. The belt drive roller 11 preferably comprises a cylindrically shaped inner and outer shell as shown, which shells are welded together in the conventional manner to an end abutment ring 24. The end abutment ring comprises a slightly champered surface 25 which functions to restrain the axial movements of the belt member 12.

Two dish shaped ring type members 26 and 27 are welded in the conventional manner to a cylindrically shaped drive roller shaft 28. The shaft 28 of the drum assembly is secured to a collar member 29 by means of dish shaped ring member 30. A standard spline type connection 31 operatively secures the collar member 29 to a stub shaft 32. The stub shaft 32 is in turn operatively engaged with the overrunning clutch assembly 23.

Referring now more particularly to FIG. 11, with such a construction and arrangement it is obvious that when the motor drive shaft 22 is rotated in a clockwise direction, for example, the roller member 23*a* of the overrunning clutch assembly functions to wedge in driving relationship between the drive shaft 22 and the driven stub shaft 32 in the conventional manner. Thus, a clockwise rotation is imparted to the stub shaft 32 and also the belt drive roller 11.

A belt guide and drive roller carriage assembly generally noted at 35 in FIG. 10, comprises a casing 36 which is adapted to house a plurality of dish shaped bearing rollers 37 of the free floating type. The casing 36 functions to positively support the roller drive motors 21 by means of a conventional weld bead 38. A sliding type contact generally noted at 39 may be conveniently provided to assure power from the generator of the closed-cycle powerplant to the drive motor 21 during all orbiting stages of the system. Such a contact illustrates one possible means of supplying electrical power to the drive motors 21.

As more clearly shown in FIG. 12, the belt guide and drive roller carriage assembly 35 additionally provides a circumferentially extending plate member 40 substantially formed in a flat plane which plate member functions to structurally connect the set of four bearing roller casings 36 which are constructed and arranged at one particular end of the roller assembly. Thus, it can be readily seen that orbital movement of one particular roller drive assembly 20 functions to drive the plate member 40 thus, simultaneously effecting an orbital movement of the other operatively connected assemblies 20.

FIG. 12 also more fully discloses the operational construction and arrangement of the free floating bearing type roller members 37. The bearing rollers are positioned in a planetary type arrangement around and in abutting relation with the roller drive shaft 28. Such rollers may be constructed of conventional type self-lubricating bearing materials. For example, a bronze or other low friction type bearing material may be used therefor. Since the bearing rollers are preferably of the free-floating type, when such rollers are subjected to wear they will automatically provide for a self centering function, i.e., the rollers will automatically assume and rotate around a new axis thereof.

As hereinbefore stated in connection with the three operational missile stages of FIGS. 1–3, when the closed-cycle powerplant is actuated into its first stage of operation, the belts 12 are prewrapped around the condenser 10 and rollers 11 and belts 12 will be protectively shielded from the surrounding environment by means of the disposable aerodynamic shields 4. At a predetermined position in space, and during the second illustrated stage of operation of FIG. 2, the aerodynamic shields 4 are selectively jettisoned away from the foresection 2 of the missile and the belts 12 begin to automatically unwrap due to the spring type action thereof, i.e., the belts are preferably constructed of a resilient type material. In order to efficiently effectuate the desired radiating functions it is necessary to orbit the rollers 11 around the preferably relatively stationary condenser drum 10. Such an orbiting function is primarily desired so that the radiator belt 12 does not move in sliding contact with the drum 10. During this latter stage of operation the friction created in the system is not sufficient to start the rollers 11 in their orbiting movement about the condenser drum 10.

To provide this orbiting function, a belt roller support and guide assembly generally noted at 50 is provided as more clearly shown in FIG. 10. Such an assembly comprises a circumferentially extending ring member 51 which has a recessed or grooved portion 52 formed on the periphery thereof which grooved portion is adapted to roll on a circumferentially extending track or ridge portion 53 formed on the condenser drum 10. The assembly further comprises a dish shaped ring member 54 which is fixedly secured between the member 51 and a cylindrically shaped hub member 55 by standard weldments or other conventional type fabrication techniques. A free wheeling roller member 56 is retained in an overrunning clutch groove 57. As more particularly disclosed in FIG. 13, such a conventional type overrunning one-way clutch means is constructed and arranged in a manner similar to the one-way clutch 23 which was hereinbefore discussed as being constructed and arranged between the drive shaft 22 of the motor 21 and the drum 11.

The diameter "A," as disclosed in FIG. 10, comprises that peripheral recessed portion 52 of the ring member 51 which abuts the radially extending track portion 53 formed on the periphery of the condenser drum 10. The

diameter of the drive roller 11 assumes the dimension "B," which diameter is slightly greater than diameter "A," as shown.

With such a construction and arrangement, at the start up of the variable speed drive motor 21 the reaction through the belt roller support and guide assembly 50 through its contact with the condenser drum 10 at track 53 (diameter "A") will function to cause the assembly 50 to revolve about the heat source carrying the associated radiator belt 12 with it. Attention is drawn to FIG. 11 wherein it should be noted that clockwise rotation of motor drive shaft 22, for example, functions to engage the clutch roller 23a therewith to thus drive the stub shaft 32 and drive rollers 11. When the friction occasioned by a predetermined amount of the centrifugal force imparted by the orbiting belts onto the drive rollers 11 and the condenser drum 10 reaches that amount which is required to drive the assembly 50, the free wheeling clutch assembly 50 will be over-driven by a difference in the diameters "A" and "B," thus, the rollers 11 will be subsequently driven directly by means of the drive motor 21. This method of initial selective orbital drive affords a simplified drive mechanism providing for minimum weight penalties and multiple start capabilities.

It should be particularly noted that the orbiting speed of the roller drive assemblies 20 relative to the heated condenser 10 primarily determine the temperature of the condenser, i.e., the rate of heat transfer from the condenser to the ambient environment may be accurately controlled by selectively varying the orbital speed of the assemblies. For example, variations in the amount of degraded heat energy generated during any particular flight regime requires that such variations be selectively compensated for by varying the orbiting speed of the assemblies. The particular radiator design considerations will largely determine what such orbital speeds will comprise for any particular flight regime.

Since the particular structural configurations of the device have been set forth, a brief discussion of the overall mechanism and operation follows. When the belt is initially exposed, as seen in FIG. 2, it does not immediately take the form as disclosed in FIG. 3. Actually, the belt 12 assumes a free form shape and is not regular in its initial configuration upon being deployed. It is only through the centrifugal force produced on the belt inherent in it being revolved that it becomes taut. Since the belt 12 is not stretched out or deployed, there is virtually little contact between it and the roller members 11 at this initial stage. At this initial stage, the rollers are caused to rotate, for example, in a clockwise direction about their own axis. This action, of course, is obtained through the utilization of the drive motor 21, driving the cylindrically-shaped drive roller shaft 28 which is in turn connected to the rollers member 11 as clearly shown in FIG. 10. At this stage, as previously mentioned, there is still very little contact between the roller 11 and belt 12 since the belt is not yet in a deployed taut condition and is not pulling outwardly away from the roller. In order to so-obtain the desired taut position for the belt, the four rollers, as shown in FIG. 6 for example, are caused to rotate about the center axis of the condenser 10 in addition to rotating about their individual axes. This, of course, affords an orbiting of the four rollers about the condenser. To effectuate this orbital condition, the drive assembly 50, as shown in FIG. 10, is connected to the drive roller shaft 28 by means of the clutch 56 so that it revolves with the drive roller shaft 28 causing the rollers 11 to orbit the condenser about the condenser track portion 53. Thus, as can be seen, in this initial condition the roller 11 is rotating clockwise about its own axis while at the same time rotating in a clockwise direction about the circumference of the condenser 10 on the track 53 as seen in FIG. 10. As soon as the rollers start orbiting about the condenser, more surface contact is made with the belt 12 and eventually the belt is deployed to a taut condition due to the centrifugal force exerted upon it as it is caused to rotate continuously about the center axis of the condenser 12, being rotated at the same time between adjacent rollers 11. Eventually, the static friction between the belt 12 and rollers 11 is such that at this point the guide assembly 50 which is rotating at a slower speed than the rollers 11 due to the difference in diameters A and B as seen in FIG. 10 will be overtaken by the effect of the motor 21 actuating the drive roller shaft 28 and rollers 11. The whole assembly will then start orbiting at a slightly faster rate than that of the guide assembly 50 which then serves virtually no function from that point on except as to guide the faster orbiting assembly about the condenser 12. This is apparent because of the larger diameter A of the roller drive member. With particular reference now to FIG. 12 the relative movement of the various components is illustrated by directional arrows. As can now be seen, the revolving drive roller shaft 28 is rotating in a clockwise direction while the roller member 12 is also moving in the same direction due to the rotation of the shaft 28. Additionally, the whole assembly including the motor actuating the drive shaft 28, the bearings 37 and associated constituents rotate in a clockwise direction with the circumferentially-extending plate member 40 about the center axis of the condenser. The previously-referred to static friction between the individual roller member and belt which friction is generated by the centrifugal force of the belt is not to be confused with sliding friction. This static friction is similar to that found between a conventional pulley and belt means and is of such a nature as to require no lubrication whatsoever since the parts are not at any time sliding against one another. Because of the fact that the four rollers shown in FIG. 6, for example, are rotating about the center axis of the condenser 12 while at the same time rotating about their own individual axes, the belt 12 in effect is being picked up and laid down or pushed against the condenser 12 rather than sliding against its surface. It is this feature which serves to exclude the necessity for lubricating the surfaces between the belt 12 and condenser 10 which lubrication is not feasible in outer space applications.

FIG. 14 discloses a second preferred embodiment of this invention employing a single radiator belt member 60. As more clearly shown in the cross-sectional view of FIG. 15 wherein parts have been deleted for clarity, the over-all actuating system is the same as that disclosed in connection with the first preferred embodiment of FIGS. 1–13 inclusive, except that a single radiator belt member 60 is utilized in lieu of the dual belt construction thereof.

FIGS. 16 and 17 disclose a radiator belt assembly similar to that disclosed in FIGS. 14 and 15. FIG. 16 has particular parts thereof sectioned and the belt 60 removed for clarification purposes. As shown, a plurality of free-floating, full complement type roller members 61 are constructed and arranged between the belt member 60 and the condenser drum member 10. This type of construction permits the belts to remain stationary relative to the heat source or condenser drum 10 during all modes of operation. Thus, the condenser drum 10 can be constructed and arranged to be selectively rotated if so desired, thus affording rolling line contact between the drum 10, the belt member 60 and the individual roller member 61, respectively.

FIGS. 18–21 disclose a third preferred embodiment employing the novel concepts of this invention. A missile is shown as comprising a payload section 71 and a closed-cycle powerplant section generally noted at 72 employing the novel radiator belt type concepts of this invention. The missile is shown in a second stage of operation similar to that shown in FIG. 2. The jettisonable type aerodynamic shieldings 73 are released therefrom to permit the fan shaped belt radiator member 74 to substantially function in the hereinbefore described radiating manner. It should be further noted that the belt member is constructed and arranged so that it may

also function as a radar antenna, if so desired. The condenser drum member 75 and the substantially diametrically opposed roller members 76 are preferably tapered as shown. The actuating means utilized to drive the roller members 76 are constructed and arranged in a maner similar to the at disclosed in the first preferred embodiment of FIGS. 1–13.

As more clearly shown in FIG. 19, the belt member 74 comprises a circularly shaped fan type member having a centrally constructed hole portion 77 formed therein. The radiator belt member 74 may have recesses or grooves 78 selectively formed therein if so desired so as to lend greater flexibility to the system. FIG. 19 also more clearly discloses the operative connection of the radiator belt system to the payload section 71 of the missile. A shaft 80 of any desired diameter depending on particular design considerations may be secured to a structural frame member (not shown) of the powerplant portion 72 of the system and is constructed and arranged to project into and be securely fastened (not shown) to the payload section 71. A belt roller support and guide assembly 81 is similar in construction to the carriage assembly 50 of the first preferred embodiment (FIGS. 1–13) and functions to carry the rollers 76 in orbital rotation about the tapered condenser drum 75.

Casing members 82 are provided for a function similar to that disclosed in connection with the casings 36 of FIG. 10. The drive motors 21 are constructed and arranged to drive through a cooperating driving mechanism identical to that disclosed in FIG. 10. Such actuating assemblies preferably total four, i.e., an assembly is constructed and arranged to drive each of the rollers 76 at both the fore and aft ends thereof.

With such a construction and arrangement it is obvious that upon selective actuation of the motors 21, the roller members 76 will be selectively rotated to orbit about the tapered condenser drum member 75 in much the same manner as hereinbefore explained in connection with the first disclosed preferred embodiment of FIGS. 1–10.

Although this invention has been described and illustrated in detail, it is to be understood that the same is by way of illustration and example only and is not to be taken by way of limitation, the spirit and scope of this invention being limited only by the terms of the appended claims.

I claim:

1. A capacitance type radiator in combination with a craft adapted to fly in a rarified environment, said craft having a wall portion thereon substantially circular in cross-section adapted to become heated at an inner surface thereof, said radiator comprising at least one rotatable roller member substantially circular in cross-section constructed and arranged adjacent an outer surface of said wall portion, drive means operatively connected to said rotatable roller member for causing a rotation thereof, a belt means constructed and arranged between said roller member and said wall portion to have at least one predetermined first portion thereof in abutting relation to said roller member and a predetermined second portion thereof in abutting relation to said wall portion, whereby when said roller member is rotated by said drive means the second portion of said belt means is moved out of abutting relation with the wall portion of said craft and into said rarified environment and means operatively connected to said roller member for orbiting said roller member about said cylindrically-shaped wall portion such that no sliding contact exists between said belt means and said wall portion.

2. The invention of claim 1 comprising a first and a second set of substantially diametrically opposed roller members.

3. The invention of claim 1 wherein said belt means comprises a first endless type belt member enveloping the first rollers of said first and second sets and a second endless type belt member enveloping the second rollers of said first and second sets.

4. The invention of claim 1 wherein said belt means comprises a single endless type belt member enveloping the wall portion of said craft.

5. A capacitance type radiator in combination with a craft adapted to fly in a rarified environment, said craft having an outer wall portion thereon substantially circular in cross-section adapted to become heated, said radiator comprising at least a first and a second rotatable roller member constructed and arranged adjacent the periphery of said outer wall portion, a belt means constructed and arranged to comprise a first portion thereof surrounding and in substantial abutting relation with that outer wall portion which is located between said roller members, said belt means further comprising second and third substantially diametrically opposed portions connected to said first portion and constructed and arranged in abutting relationship to said first and second roller members, respectively, whereby when the second portion of said belt means is moved toward said second roller in abutting relation to said wall portion, heat is absorbed therein essentially by conduction and when said second portion is moved away from said wall portion said heat is substantially rejected to said rarified environment essentially by radiation and means for orbiting said rotatable roller members around said outer wall portion such that no sliding contact exists between said belt means and said wall portion.

6. The invention of claim 5 wherein said belt means is constructed and arranged to comprise a single endless belt type member in substantial enveloping relationship to said roller members.

7. The invention of claim 5 wherein said belt means is constructed and arranged to comprise a single endless belt type member in substantial enveloping relationship to said outer wall portion.

8. The invention of claim 5 wherein said belt means formed in circular fashion to comprise a single endless belt type member with a fourth portion thereof connecting said second and third portions and substantially forming a frusto-conical fan shaped member therewith.

9. The invention of claim 8 wherein said roller members are substantially diametrically opposed relative to said outer wall portion.

10. The invention of claim 9 wherein the outer surfaces of the wall portions of said craft and said roller members are tapered with the juxtaposed surfaces thereof constructed and arranged in substantial parallel relationship.

11. A radiator in combination with a cylindrically shaped condenser adapted for use in a rarified environment comprising: a first and a second set of substantially diametrically opposed rollers having longitudinal axes constructed and arranged closely adjacent to said condenser; first and second endless type belt members enveloping a first roller of said first and second sets and a second roller of said first and second sets respectively, with portions of said first and second belt members constructed and arranged in abutting relation to said drum between said first and second rollers of said first and second sets, respectively; means operatively securing said rollers to each other for effecting simultaneous orbital movements thereof around said condenser; and drive means operatively connected to at least one of said rollers at a first end thereof for causing a rotation thereof about its axis and for beginning the orbital movement of said rollers about said condenser.

12. A radiator in combination with a heat source forming an outer wall portion adapted to become heated, said radiator comprising at least two rotatable roller members constructed and arranged radially of an closely adjacent to said outer wall portion; belt means constructed and arranged between said roller members for having a portion thereof constantly in contact with said outer wall

portion for absorbing heat therein; drive means operatively connected to said roller members for causing a rotation thereof; and means operatively connecting said roller members and said heat source for supportingly orbiting said roller members about the outer wall portion of said heat source.

13. A radiator in combination with a heat source having a circularly shaped outer surface portion comprising a first diameter, a radially extending flange portion formed on the periphery of said outer surface comprising a second diameter which is greater than said first diameter, said radiator comprising: at least one cylindrically shaped roller means constructed and arranged closely adjacent to the outer surface of said heat source; drive means operatively connected to said roller means by a first one-way overrunning clutch means operative to engage and rotatably drive said roller means in a first direction; a circularly shaped member rotatably mounted on said roller means and operatively connected thereto by a second one-way overrunning clutch means operative to engage and rotatably drive said member in said first direction when said variable drive means is actuated, a guide

means formed on the periphery of said cylindrically shaped member and constructed and arranged to engage the flange portion formed on said heat source to support said roller means thereon; and belt means constructed and arranged between the outer surface of said heat source to have at least one portion thereof in contact therewith during the actuation of said drive means, said portion operative to absorb heat essentially by conduction from said heat source and reject said heat when said variable drive means is actuated and said portion is moved out of contact with said heat source.

References Cited in the file of this patent

UNITED STATES PATENTS

2,010,180	De Ferranti	Aug. 6, 1935
2,408,867	McCollum	Oct. 8, 1946

FOREIGN PATENTS

448,381	Italy	May 16, 1949
468,047	Great Britain	Sept. 19, 1935
706,764	Great Britain	Apr. 7, 1954
765,384	Great Britain	Jan. 9, 1957