

[54] **MICROWAVE POWERED REUSABLE ORBITING SPACE TUG**

[76] Inventor: **Michael A. Minovitch**, 2832 St. George St., Los Angeles, Calif. 90027

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[51] Int. Cl. **B64g 1/00**

[58] Field of Search. **244/1 SS, 1 SA, 1 SB, 62, 244/73 R, 74; 60/203, 202; 318/16**

[56] **References Cited**

UNITED STATES PATENTS

3,083,528	4/1963	Brown.....	60/203
3,114,517	12/1963	Brown.....	244/1 SB
3,174,705	3/1965	Schiff et al.	244/1 SB
3,239,165	3/1966	Sohn.....	244/1 SA
3,540,048	11/1970	Clemens et al.	244/1 SS

OTHER PUBLICATIONS

Alexander, George, "Major Space Role Seen for Plasma Engine," Aviation Week and Space Technology, Nov. 27, 1961, pp. 75-76.

Primary Examiner—Trygve M. Blix
Assistant Examiner—Barry L. Kelmachter
Attorney, Agent, or Firm—Christie, Parker & Hale

[57] **ABSTRACT**

This space vehicle is used as a "tugboat" for propelling other space vehicles. The tug has a pair of propulsion nozzles to which a propulsion fluid is fed by way of an absorption chamber. A large microwave antenna is mounted on the space tug for receiving and concentrating a microwave beam which may come from the earth's surface. The nozzles and antenna are pivotable relative to each other. Large but short wave guides lead from the feed horn of the antenna through the pivot trunnions for conveying the concentrated microwave beam to the absorption chambers. The beam, which to this point has travelled through a vacuum, is nearly quantitatively absorbed by the propulsion fluid which is thereby heated to a plasma. The plasma is directed to the propulsion nozzle by a magnetic field. A single component propulsion fluid is contained in replaceable tanks and energy is imparted to the fluid by way of the microwave beam rather than by chemical reaction. A phased array of antennas permits focusing at high orbital altitudes.

10 Claims, 4 Drawing Figures

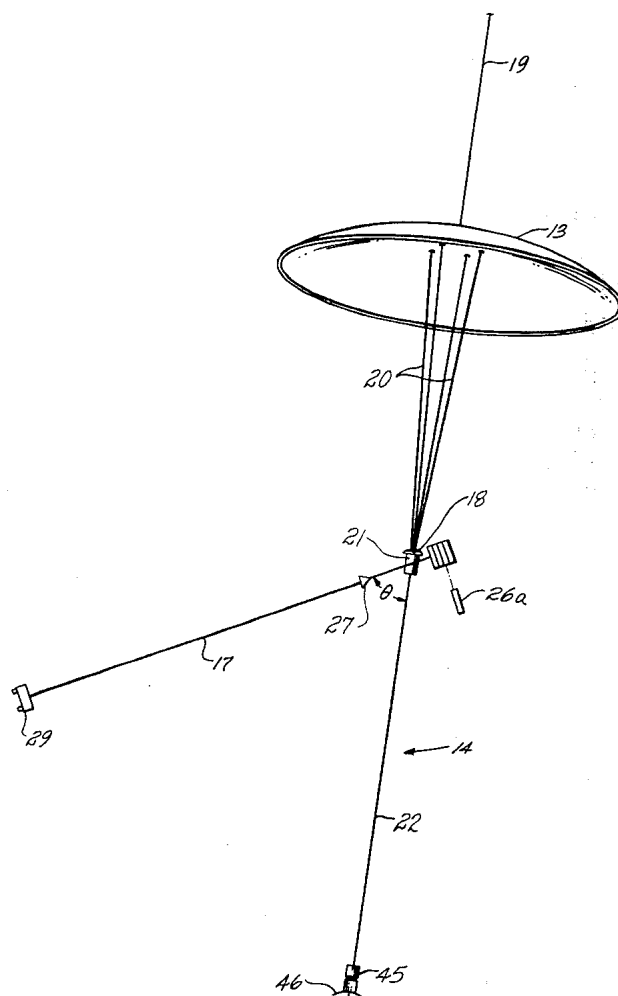


FIG. 1

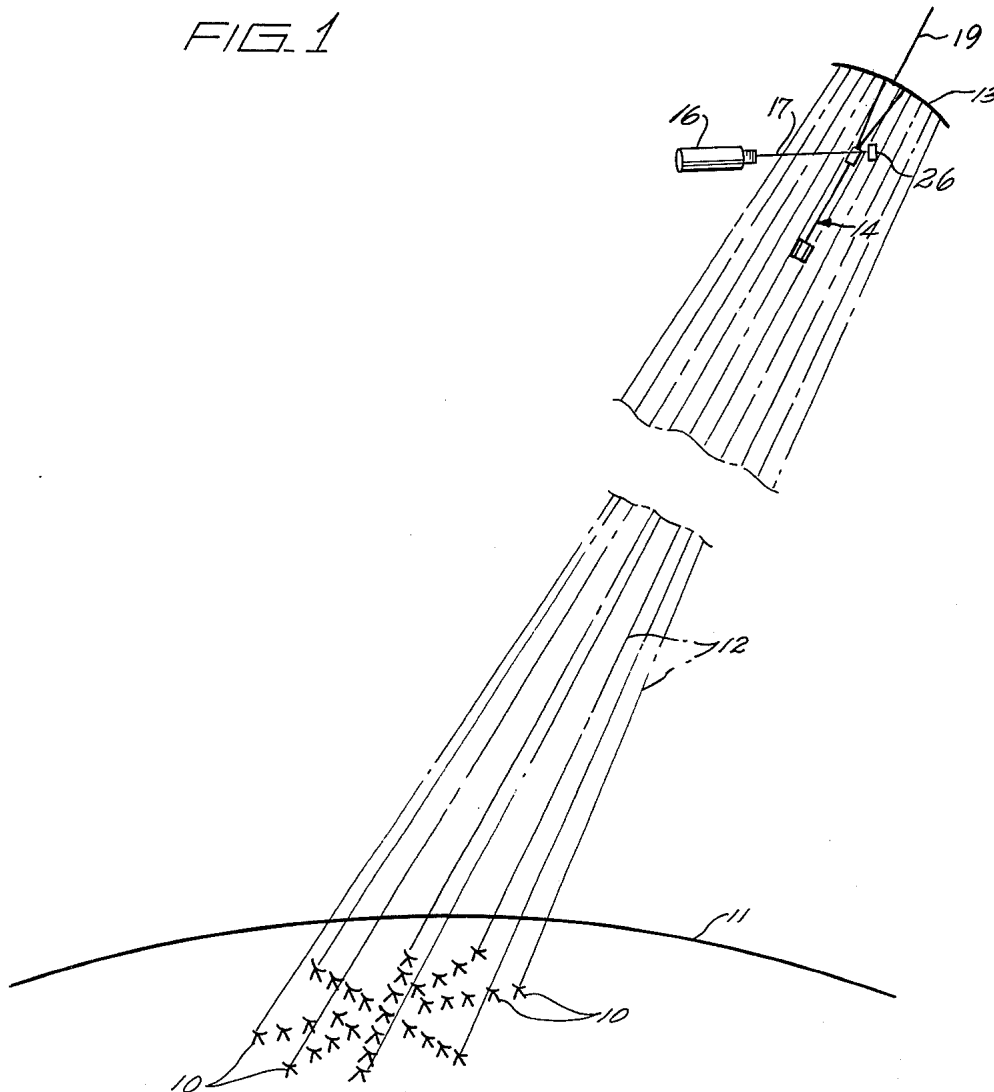
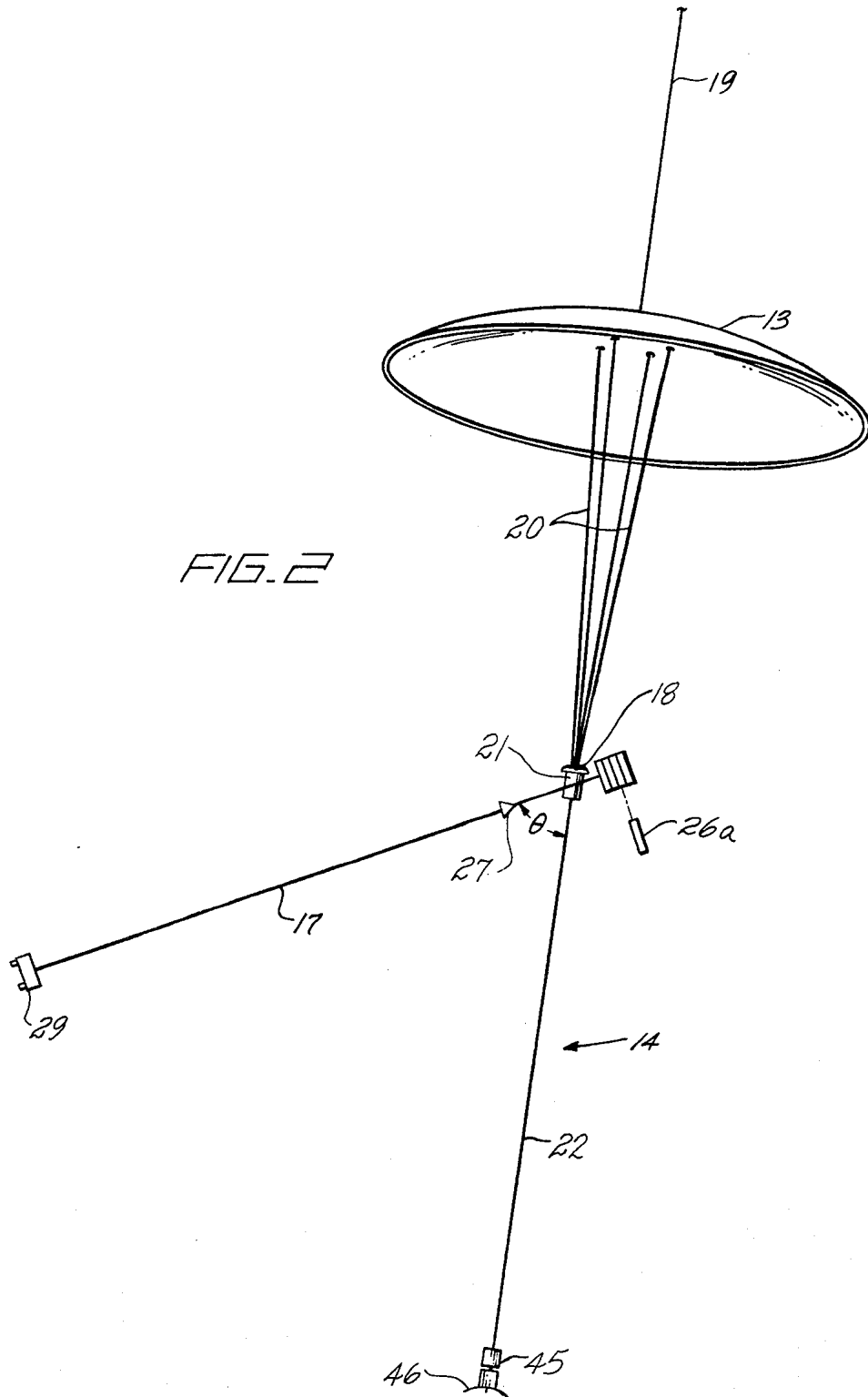
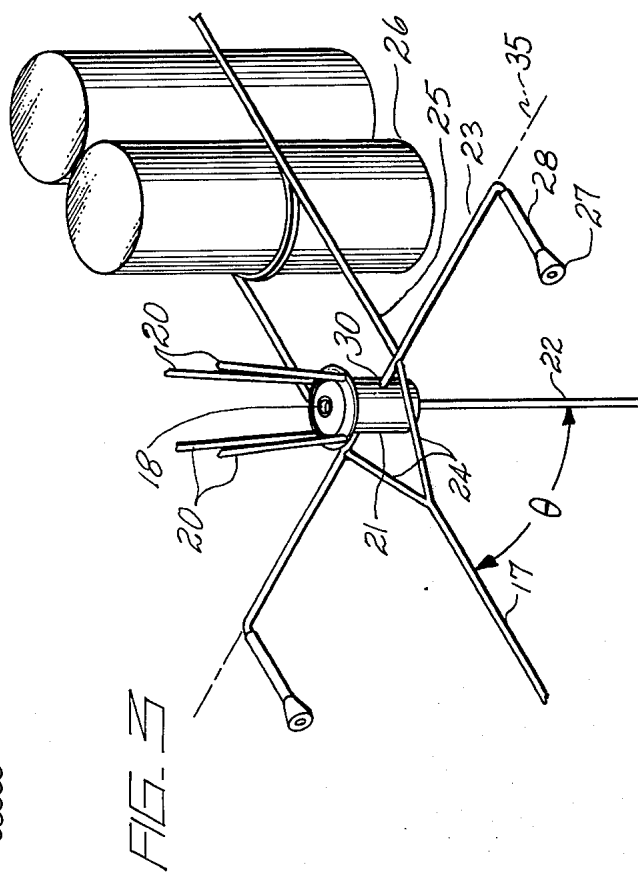
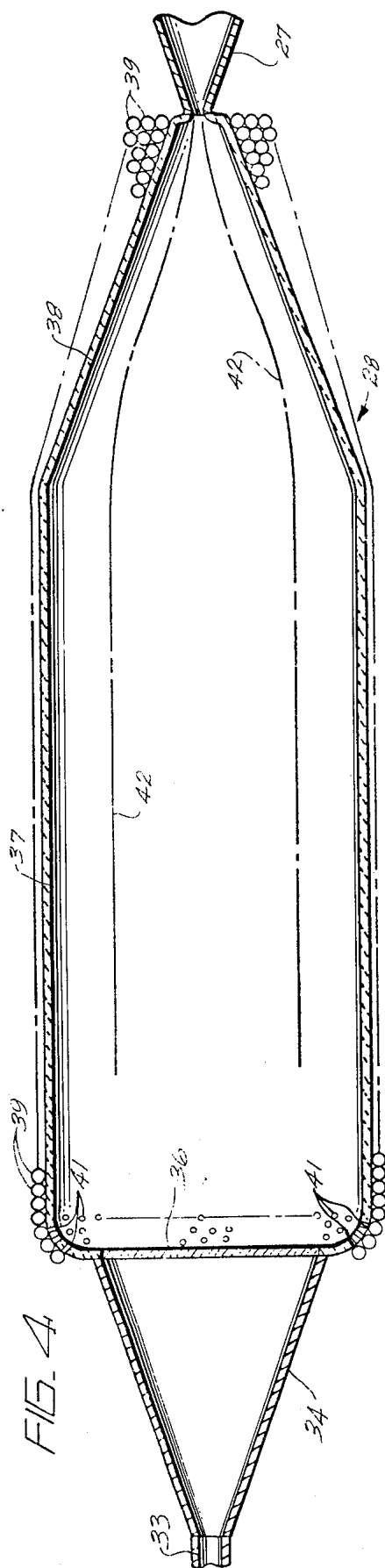


FIG. 2





MICROWAVE POWERED REUSABLE ORBITING SPACE TUG

BACKGROUND

In present space flight operations few, if any, components are reusable, although a reusable space shuttle is in development. Chemically powered rockets are used to boost payloads into earth orbit and these payloads are often boosted into escape trajectories by chemical propulsion. The escape trajectory boosters typically are lost into space and are not reusable. Presently, all orbital maneuvering is by chemical propulsion. Thus, the propulsion fluid and energy for heating it are put into orbit by chemically propelled boosters.

It is desirable to use a low molecular weight propulsion fluid such as hydrogen for high impulse, however, in chemical boosters, the hydrogen is typically combined with oxygen which has a significantly greater density and molecular weight. Energy can be supplied to an orbiting vehicle by an electro-magnetic beam, and this high energy beam used for heating a single propellant component, such as hydrogen, which can be used as the propulsion fluid without any chemical reactions.

It has been proposed to use beamed microwave power for space propulsion, thus, in a paper entitled "Microwave Powered Ferry Vehicles" in spaceflight (June 1966), page 217, M. I. Willinski proposes a microwave powered expendable upper stage vehicle with a 100 meter reflective dish and absorption of the focused microwave energy on a carbon absorber. Hydrogen is heated by contact with carbon absorber and fed to a gimballed nozzle for guiding the vehicle. The large dish antenna is connected to the payload by a system of wires and foam filled tubes. Microwave energy is beamed to the space vehicle by a phased array of high power antennas on the ground.

U.S. Pat. No. 3,114,517 describes a microwave powered vehicle that apparently is restricted to use within the earth's atmosphere. The vehicle uses the atmosphere as the propellant and the highest altitude mentioned is only 65,000 feet. U.S. Pat. No. 3,083,528 teaches a microwave engine for propulsion.

It is desirable to have a microwave powered space vehicle wherein the orientation of the receiving antenna and the vehicle thrust axis can be varied relative to each other. When this is done, the trajectory of the space vehicle can be relatively independent of the origin of the microwave beam. It is not necessary to orient the entire vehicle in order to maintain the antenna pointed properly at the ground station.

It is also desirable to have a microwave powered vehicle that can remain in orbit for a prolonged period to serve as a booster for other space vehicles. Such as "tugboat" in space can effect substantial economies since the same vehicle can be used for a number of missions.

BRIEF OF THE INVENTION

There is, therefore, provided in practice of this invention according to a presently preferred embodiment, a microwave powered space vehicle comprising a beam having means at one end for engaging another space vehicle and at least one propulsion nozzle mounted thereon. Propulsion fluid is fed from replaceable tanks to an absorption chamber adjacent the nozzle. A mi-

crowave antenna for receiving and concentrating a microwave beam is mounted for pivoting about an axis transverse to the longitudinal axis of the beam. A short wave guide from the feed horn of the antenna conveys a concentrated microwave beam through the pivot to the absorption chamber for absorption by the propulsion fluid.

DRAWINGS

These and other features and advantages of the present invention will be appreciated as the same becomes better understood by reference to the following detailed description of a presently preferred embodiment when considered in connection with the accompanying drawings wherein:

FIG. 1 illustrates schematically a space tug constructed according to principles of this invention as it is powered by a phased array of microwave antennas;

FIG. 2 is a perspective view of the microwave powered space vehicle;

FIG. 3 is a fragmentary view of the central support structure of the vehicle; and

FIG. 4 is a longitudinal cross section through an absorption chamber on the space vehicle.

DESCRIPTION

FIG. 1 illustrates schematically a technique for providing microwave power to an orbiting space vehicle. As illustrated in this arrangement, a plurality of conventional microwave antennas 10 are provided on the surface of the earth 11. These microwave antennas are in a large two-dimensional array and the microwave power applied to the several antennas is phase controlled for obtaining a focused microwave beam. Such phased arrays of microwave antennas are well known for high power radar installations. See for example, Theory and Analysis of Phased Array Antennas, John Wiley and Sons, Inc. (1972); or R. C. Hansen Microwave Scanning Antennas, Vol. III, Array Systems, Academic Press, (1966).

A phased array extending about 7 kilometers on the surface of the earth, permits focusing of a 10 gigahertz microwave beam on a 500 meter diameter receiving antenna at any range out to about 60,000 kilometers. The fill ratio of the phased array of 1000 16-meter dishes is about 1:190. If one is satisfied with a shorter range, that is, if one applies power to the microwave powered vehicle when it is relatively nearer the antennas, the base line of the phased array can be reduced. See for example, "Microwave Power Transmission from an Orbiting Solar Power Station," Journal of Microwave Power (December, 1970). Further, by providing a phased array of ground based antennas, very high power levels can be achieved since each antenna can run at a reasonable power level. A total power level of 500 megawatts is deemed suitable for substantially any contemplated mission. With the antennas each having a low power level, conventional components for microwave generation and antenna pointing can be employed. Almost any desired power level can be achieved by varying the power from each antenna or using more or fewer ground antennas without changing the width of the total antenna array. With the preferred sizes of phased array and antenna dish, the vehicle will receive about 90 percent of the transmitted power out to a range of about 60,000 kilometers.

The microwave beams 12 from the several antennas 10 are phase locked so as to focus on the receiving antenna 13 of a microwave powered space vehicle 14. As illustrated in FIG. 1, the space vehicle 14 has a beam 17 linked at one end to another space vehicle 16 for boosting it to a different trajectory. The general mode of operating the combined microwave powered space tug 14 and payload 16 is one of intermittently applying microwave power from the ground based antennas to the space vehicle. Typically, this microwave beam is applied as the vehicles approach periapsis and is continued through periapsis until the vehicles are near enough the horizon that the microwave antennas cannot properly focus on it. Relatively low accelerations such as 0.1g or less are used for minimizing distortion of the large vehicle structure.

With the long range provided by a long baseline phased antenna array, it is not necessary that periapsis be in proximity to the antenna array. Any reasonably close earth approach is satisfactory. Typically, power is applied periodically during a relatively short portion of certain orbits, separated by several complete orbits of unpowered flight. As each increment of power is applied to the combined vehicles, the apoapsis can be increased to reach higher and higher altitudes. Orbital circularization at a high altitude can then be obtained by applying power near apoapsis.

If an escape trajectory is desired, this can be imparted to the boosted vehicle 16 and, before the microwave powered vehicle leaves the range of the ground station, it is uncoupled from the boosted vehicle, rotated 180° so that its engines are pointed in the opposite direction, and braked by application of microwave power to a sufficient extent that it remains in earth orbit. It can then be further braked and its orbital trajectory adjusted for refueling, maintenance, or picking up another payload to be boosted.

A broad variety of such trajectories can be employed somewhat in the same manner as set forth in AIAA Paper Number 72-1095, entitled "Reactorless Nuclear Propulsion -- the Laser Rocket" by Michael A. Minovitch at AIAA/SAE 8th Joint Propulsion Specialist Conference, November 1972.

Referring now to FIG. 2, the microwave powered space vehicle 14 is seen in perspective. The vehicle includes a lightweight structural beam 17 connected to the structure of the microwave antenna. The antenna comprises a large, lightweight parabolic dish 13 about 500 meters in diameter with a short conventional microwave feed horn 18 at the focus of the dish. The antenna is a lightweight structure assembled or deployed in space. The parabolic dish reflector has a rigid mast 19 extending aft from its convex side. A plurality of rigid masts 20 extend from the concave side of the dish to the central structure 21 supporting the feed horn 18. If desired, a single mast can be used between the dish and central support structure. A second rigid mast 22 extends beyond the support structure 21 to mount guidance and navigation equipment, storage batteries, thermionic converters, communications transmitters, receivers and antennas, orientation propulsion rockets and the like designated schematically as elements 45. If need be, some dead weight may be provided at the end of the forward beam 22 for counterbalancing the weight of the dish 13 so that the center of mass of that portion of the vehicle rigidly connected to the dish is at the central support structure 21. The masts 19, 20

and 22 are connected to the antenna dish 13 by multiple guy cables which are not illustrated in the drawing to minimize confusion. The guy cables rigidify the beams and antenna and maintain them in tension for stabilizing the entire structure. The mast may be single hollow tubes or, if need be to enhance their buckling resistance, can be in the form of open trusses. Those masts and guy cables on the forward side of the antenna dish should in general, be made of nonconductive material to avoid disturbance of the incoming or reflected microwave beams. The general structure of such a large parabolic microwave antenna stiffened by masts and guy cables is shown and described by D. L. Pope, W. H. Hewitt, Jr., and J. G. Petz in *Journal of Spacecraft and Rockets*, Vol. 9, No. 5, May 1972, pp. 289 and 290, and as Paper Number 71-397 at the AAS-AIAA Variable Geometry and Expandable Structures Conference, April 21-23, 1971, available from AIAA.

The central support structure 21 and adjacent elements are illustrated in greater detail in FIG. 3. The feed horn 18 is rigidly mounted in the central structure 21 so that it is always aligned with the parabolic antenna dish 13. A pair of wave guides 23 extend laterally from the central support structure and are pivotally mounted relative thereto by a conventional hollow trunnion 30. Rotating pivots for conveying microwave beams are described in *Radar System Fundamentals*, NAVSHIPS 900,017, Navy Department (1944). A short Y-shaped link 24 provides a structural connection between the wave guides 23 and the beam 17. Short beams 25 extend in the opposite direction from the beam 17 and provide structural support for fuel tanks 26. Preferably, the fuel tanks 26 are in the form of a cluster of replaceable tanks, one of which (26a) is shown exploded from the cluster of tanks in FIG. 2. By using replaceable tanks, many of the problems of fuel transfer in vacuum and at high altitudes beyond the range of shuttle vehicles, can be avoided.

The wave guides 23 lead to propulsion nozzles 27 by way of absorption chambers 28 described in greater detail hereinafter.

It will be noted that the wave guides 23 with the propulsion nozzles 27 are rigidly connected to the links 24 and beam 17 and also the fuel tanks 26 by way of the short beams 25. This entire rigid structure is free to pivot around the central support structure 21 about an axis transverse to the mast 22, that is, transverse to the focal axis of the antenna. It will be recalled that the center of mass of the antenna system, including the masts and the accessory equipment 45, is located at the central support structure 21. The pivot axis of the wave guides 23 passes through this center of mass. The thrust axes of the propulsion nozzles 27 are parallel to the beam 17 or they may be canted at a slight angle outwardly relative to each other so that their integrated thrust is along the beam 17.

During powered flight the longitudinal axis of the dish 13 must be pointed at the transmitting antenna array on the ground. For maximum efficiency the vehicle's thrust vector should be aligned with the vehicle's instantaneous velocity vector. This is accomplished by slowly varying the tilt angle θ and slowly rotating the dish 13 about its longitudinal axis irrespective of the vehicle's trajectory. The propulsive thrust during these powered flight maneuvers is along the beam 17 and always passes through the center of mass of the entire vehicle irrespective of the payload mass, fuel load, or tilt

angle θ . The thrust, therefore, will never produce any unwanted torque on the vehicle. It will be noted that the antenna is spaced along the vehicle axis well away from other components so that there is minimum shielding of the antenna by other portions of the vehicle even when pivoted about a substantial angle relative to the vehicle axis. The thrust axis and the antenna axis can pivot relative to each other through angles θ of 30° to 150° or a total included angle of 120°. If a somewhat smaller angle is used, some construction constraints can be relaxed.

Docking latches 29 of a conventional type are provided at the end of the beam 17 for linking it to a payload to be boosted. (For example, the other space vehicle 16). A plurality of conventional chemical Vernier rockets (not shown) may be provided on the end of the beam and on the parabolic dish rim for assisting in controlling roll, pitch and yaw of the vehicle during space maneuvering. This enables trajectory adjustments and roll control to keep the antenna properly pointed as the vehicle is operated without undue oscillating motions building up.

Hydrogen or nitrogen propellant or working fluid is stored cryogenically in the replaceable propulsion tanks 26 and fixed sheaths may be left on the vehicle to provide thermal insulation and radiation protection. This latter is of appreciable importance when the microwave beam irradiates the portion of the vehicle where the hydrogen is stored, since a substantial thermal load may be applied during that period. It will be apparent that since one uniformly maintains the antenna pointing in the direction of the transmitting array during irradiation, radiation reflectors may be provided along that side for protecting parts of the vehicle structure from irradiation by the microwave beam.

It will be noted that the beam 17 extending between the supporting structure 21 and the payload 16 being boosted is in tension during acceleration. This permits a fairly long beam to keep the payload remote from the concentrated microwave beam irrespective of tilt angle relative to the antenna. It also keeps the payload remote from possible damaging effects from the rocket nozzle exhaust. Rocket exhaust is at a sufficiently high velocity that little if any impingement on the payload is encountered, particularly if the nozzles are skewed outwardly a few degrees. Since the payload and the fuel tanks swivel together and remain aligned with the thrust axis of the combined propulsion nozzles, vehicle performance is not dependent on a particular payload mass or propellant quantity. It can be used for accelerating large or small payloads and can operate with full or nearly empty propellant tanks without shift of the center of mass except in a direction along the thrust axis.

If desired the microwave powered space tug can be used to "push" a payload rather than pull it as in the preferred embodiment. In a pushing embodiment the location of fuel tanks and payload are, in effect, switched and a shorter beam to the payload is preferred to prevent buckling. If desired the payload can be forward of the fuel tanks without significant stability problems. With such an arrangement a propulsion nozzle on the thrust axis can be used without hazard of exhaust impingement on other structures.

When a microwave beam strikes the antenna dish 13, it is focused on the conventional feed horn 18. This concentrated beam is collected by the feed horn and

directed into the circular wave guides 23 which carry the concentrated beam transverse to the focal axis of the antenna. In this way the microwave beam is conducted through the hollow trunnions between the central antenna structure 21 and the laterally extending wave guides.

The circular wave guides are preferably operated in the TE-01 mode since the surface current losses are low. See, for example, Radar Electronic Fundamentals, NAVSHIPS 900,016, Navy Department (June 1944), Section 87, pages 368 to 370, in particular; or E. C. Okress, Microwave Power Engineering, Vol. I, (1968) Chapter 3. These surface currents yield a loss of about 0.003 db per meter in the wave guide. Since very high powers are being transmitted through the wave guides, forced cooling with the propulsion fluid is desirable and the cryogenic propulsion fluid is thereby pre-heated. The wave guides are preferably evacuated for low loss, and this is simply done by venting them to the hard vacuum of space. The circular wave guides are particularly advantageous for transmitting the microwave beam through the hollow trunnions 30 of the antenna. The wave guides are simply mounted along the trunnion axis and no complicated mechanisms are required.

The microwave beams may be divided as desired in wave guides external to the feed horn for leading to several absorption chambers 28 if additional propulsion nozzles 27 are desired. It will be recognized that the elements 23 identified in FIG. 3 as wave guides are in actuality also structural members for carrying the thrust of the propulsion system to the antenna portion of the vehicle, and include propulsion fluid transfer lines as well as the wave guides.

FIG. 4 illustrates in longitudinal cross-section one of the absorption chambers 28 connected to one of the rocket nozzles 27. A flared low reflection horn 34 connects the end of the circular wave guide 33 to the end of the absorption chamber. A suitable dielectric material such as beryllium oxide acts as a window 36 at the output end of the transition horn 34. The dielectric window 36 passes the microwave beam and separates the propulsion fluid in the absorption chamber 28 from the vacuum within the wave guide. See, for example, Harvey, Microwave Power, page 254.

The absorption chamber is about 2 meters long and formed of a dielectric material such as fused quartz. The chamber has a cylindrical portion 37 along most of its length and a conical portion 38 near its aft end where it is connected to the rocket nozzle 27. The entire absorption chamber is surrounded by coils of high conductivity copper tubing 39. The individual turns of tubing around the absorption chamber are electrically insulated from each other.

The working fluid or propellant is pumped through the tubing 39 and is injected into the absorption chamber through a plurality of orifices 41 around the forward end thereof. The working fluid then flows along the length of the absorption chamber and out through the nozzle 27 for propelling the vehicle. The microwave beam entering the absorption chamber is absorbed by the gas in the chamber. Since high energy levels are involved, the gas rapidly becomes a plasma which is electrically conductive and therefore highly absorbent of the microwave beam. Generation of such a plasma may be initiated by seeding the hydrogen propellant with a readily ionized material, such as cesium, where power is first applied.

A heavy electric current is passed through the propellant tubing 39 surrounding the absorption chamber. This current produces a "magnetic bottle" which forces the plasma into an envelope as indicated by the phantom lines 42 in FIG. 3.

The coils of tubing surrounding the cylindrical portion 37 of the dielectric absorption chamber are of substantially uniform spacing, and may be only one or two layers deep. In the conical portion 38 of the absorption chamber the coils gradually become more concentrated so that the magnetic field intensity in the conical portion of the absorption chamber is much higher. This increased magnetic flux is due to a greater number of coils and also due to the reduced cross section of the chamber. The increased magnetic field tends to "pinch" the plasma within the absorption chamber and direct the reduced cross section plasma through the throat of the nozzle 27 for obtaining very high exhaust velocities.

By forcing the plasma away from the walls of the absorption chamber, heating of the walls is substantially reduced. The walls are also kept cool by the propellant flowing through the tubes 39. It will be noted that with the copper tubes surrounding the absorption chamber it is in effect electrically conductive so that the microwave beam is entrapped therein. The highly absorbent plasma within the chamber absorbs most of the microwave energy and what little might escape appears as surface currents in the copper tubing and its heat is absorbed by the flowing propellant. Substantially quantitative absorption of the microwave energy and conversion to thermal energy is thereby effected. About the only losses occurring in such an arrangement are the minor reflections back into the input wave guide from the window 36 and the plasma. Although this absorption chamber is preferred, other structures for converting microwave radiation into heat for the working fluid may be used.

It turns out that about 92 percent of the power incident on the antenna is available for propulsion, less whatever additional losses may be encountered due to surface imperfections in the large parabolic reflector. Some of the total energy appears as heat that is absorbed by the propellant before it reaches the absorption chamber.

Electrical power for the magnetic coils on the absorption chamber is provided from storage batteries 45 at the end of the mast 22. These batteries are recharged by microwave powered thermionic generators that are energized during the powered flight periods. The microwave radiation used to power these thermionic generators is received by a second but much smaller parabolic antenna 46 mounted at the end of mast 22. The combined mass of these vehicle components (although low) will contribute towards shortening the length of the counter balancing torque arm 22. As an alternative to microwave powered thermionic generators one can generate electric power directly from the microwave beam by suitable rectennas located on any suitable portions of the vehicle. The antenna 46 may be a rectenna for converting some of the microwave beam directly into electric current rather than going through the intermediate thermal step of a thermionic generator. Rectennas have already exceeded an operational efficiency of 80 percent at 2 gigahertz. See, for example, "The Receiving Antenna and Microwave Power Rectification" Journal of Microwave Power, page 279 (De-

cember 1970). This eliminates the necessity for having thermionic generators. It will be noted that high electric currents are available only when the antenna is irradiated by microwave radiation. However, these are the only times that such heavy currents are required and, during intermediate periods during coast, power requirements can be satisfied by the on-board batteries which are recharged during the periods of irradiation by microwave beams.

In operation the reusable microwave powered space vehicle is boosted into low earth orbit by a conventional chemical booster or shuttle vehicle where it is assembled. Once assembled the microwave powered vehicle stays in orbit around the earth. The working fluid tanks can be provided by shuttle vehicle deliveries and these tanks 26 are placed in the mounting sheaths near the vehicle center of mass. The propulsion fluid is then fed to the absorption chambers 28 as required when microwave power is supplied.

A chemical powered shuttle vehicle launched from the earth's surface and carrying a payload designated for an orbit beyond its capability, rendezvouses with a microwave powered space tug. The payload is transferred and attached to the tug by docking latches 29. The tug and payload acceleration sequence then begins via an intermittent series of propulsive maneuvers. After the payload is boosted into its desired trajectory the microwave powered vehicle is rotated 180 degrees and the main propulsion rockets 27 used for braking the vehicle and retaining it in a suitable earth orbit. It will be noted that much less total energy is required for braking than for boosting, since by this time, the payload is disconnected and most of the propellant is expended so that the total vehicle mass is relatively low. When the vehicle is brought into a suitable orbit any empty working fluid tanks are removed and replaced from a space shuttle, thereby enabling the microwave powered vehicle to conduct another mission.

Microwave power is desirable for propelling a space vehicle since the energy can be provided from an earth station and only the propulsion fluid need be boosted into orbit. A higher specific impulse is obtainable from hydrogen than from the chemical fuels customarily used. Microwave power may be preferable to light from a laser station for several reasons. By using a phased array of microwave antennas the range of the system, that is the distance between the ground station and the space tug, can be quite large, as compared with a laser power source. By properly selecting the wave length to be used (e.g. about 3 cm.), the microwave system can be operated in any kind of weather whereas a laser system can not be operated in the presence of any overcast. The efficiency of generating microwave power by way of klystron tubes is in the range of 50 to 60 percent depending upon the power level and other operating conditions, which compares very favorably with a 20 percent efficiency in the best laser systems.

Although described hereinabove with respect to hydrogen propulsion, it will be noted that nitrogen propulsion also has certain distinct advantages. Nitrogen is about 11 times as dense as hydrogen and can be heated with microwave radiation with substantially the same efficiency. Because of the higher density, much less massive tanks are required and substantial vehicle and shuttle mass savings may accrue. In addition, the temperature of liquid nitrogen is significantly higher than that of liquid hydrogen and less sophisticated thermal

insulation can be employed. It will also be noted that liquid nitrogen is considerably less expensive than liquid hydrogen and it can be handled with greater ease and safety. Clearly, other propulsion fluids could be employed, but hydrogen or nitrogen are presently deemed preferable.

Although limited embodiments of a reusable microwave powered space vehicle have been described and illustrated herein, many modifications and variations will be apparent to one skilled in the art. It is, therefore, to be understood that within the scope of the appended claims the invention may be practiced otherwise than as specifically described.

What is claimed is:

1. A microwave powered reusable space tug comprising:
 - a structural beam;
 - means on one end of the structural beam for engaging and propelling another space vehicle;
 - propulsion nozzle means on the structural beam for propelling the tug;
 - an absorption chamber connected to the nozzle means;
 - tank means on the structural beam for containing a propulsion fluid;
 - means for conveying fluid from the tank means to the absorption chamber;
 - a microwave antenna for receiving and concentrating a microwave beam;
 - pivot means for interconnecting the antenna and the structural beam for pivoting about an axis transverse to the longitudinal axis of the beam and keeping the antenna pointed at the microwave beam independently of the direction of the propulsion nozzles; and
 - wave guide means for conveying a concentrated microwave beam from the antenna focus through the pivot means to the absorption chamber for absorption by the propulsion fluid.
2. A microwave powered space tug as defined in claim 1 wherein the antenna comprises a parabolic antenna dish and a feed horn; and wherein the pivot axis extends through the center of mass of the antenna and transverse to the focal axis of the antenna.
3. A microwave powered space tug as defined in claim 1 wherein the absorption chamber comprises:
 - a dielectric housing;
 - means for injecting propulsion fluid into the dielectric housing; and

a conductor coil around the housing for generating a magnetic field within the housing.

4. A microwave powered space tug as defined in claim 3 wherein the conductor coil comprises tubing and wherein the propulsion fluid is passed through the tubing prior to injection into the absorption chamber.

5. A microwave powered space tug as defined in claim 3 wherein the dielectric housing includes a pressure resistant dielectric window between the interior of the housing and the wave guide means.

6. A microwave powered space tug as defined in claim 3 wherein the tug further comprises a rectenna mounted thereon for generating electric power directly from a concentrated microwave beam.

7. A microwave powered space tug comprising:

- a structural beam;
- a propulsion nozzle on the beam;
- a microwave absorption chamber connected to the nozzle;
- means for injecting a propulsion fluid into the absorption chamber;
- a microwave antenna for receiving and concentrating a microwave beam;
- a pair of hollow trunnions for interconnecting the antenna and the structural beam for pivoting about an axis transverse to the longitudinal axis of the structural beam and to the focal axis of the antenna; and
- wave guide means for conveying a concentrated microwave beam from the antenna through the hollow trunnions to the absorption chamber for absorption by the propulsion fluid.

8. A microwave powered space tug as defined in claim 7 further comprising:

- means for replenishing fluid on the space tug while in space by interchanging cryogenic liquid fuel tanks.

9. A microwave powered space tug as defined in claim 7 wherein the absorption chamber comprises:

- means for containing a plasma within the chamber and for directing the plasma into the nozzle.

10. A microwave powered space tug as defined in claim 9 wherein the means for containing and directing a plasma comprises:

- electrically conductive coils surrounding the absorption chamber;
- means for passing a current through the coils for generating a magnetic field within the chamber; and
- means for circulating propulsion fluid through the coils prior to injection into the chamber.

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