March 3, 1964 R. D. SCHULTZ ETAL 3,122,882

PROPULSION MEANS

Filed Nov. 23, 1960 5 Sheets-Sheet 1

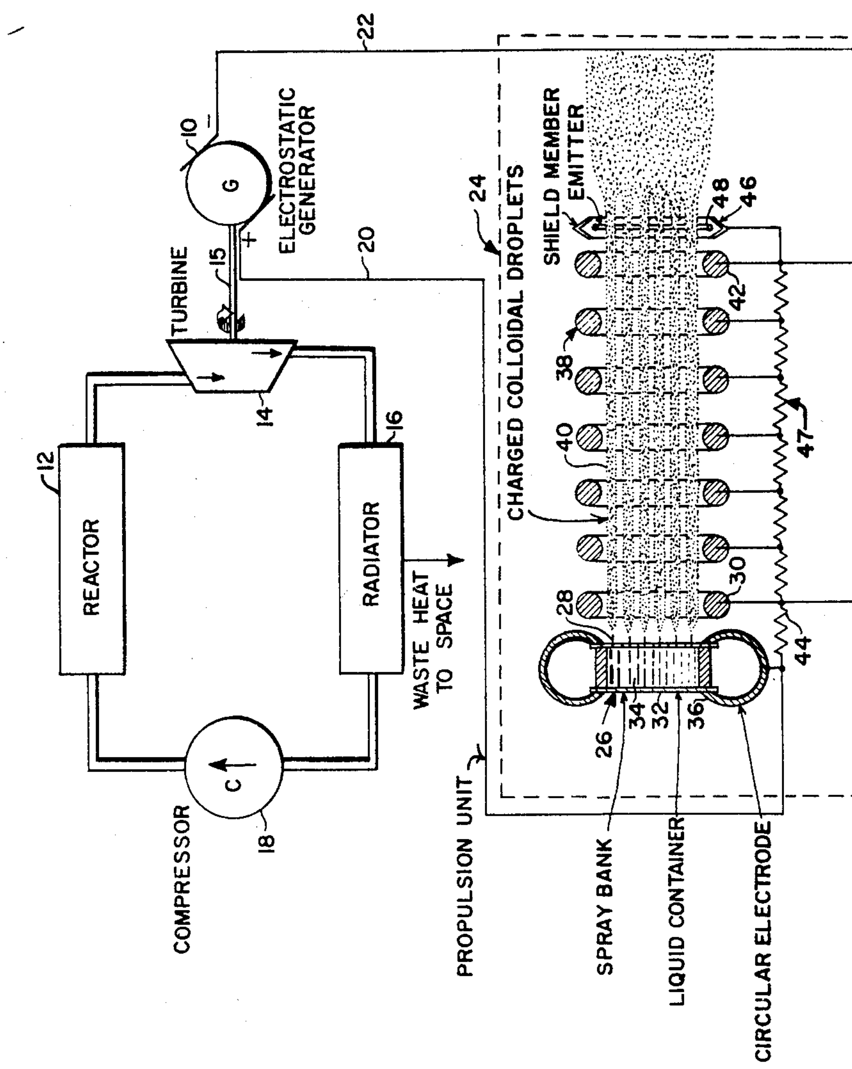

Fig. 1

INVENTORS.
ROBERT D. SCHULTZ
LANE K. BRANSON
ROBERT F. CHAIKEN
BY
ATTORNEY

PROPULSION MEANS

Filed Nov. 23, 1960 5 Sheets-Sheet 2

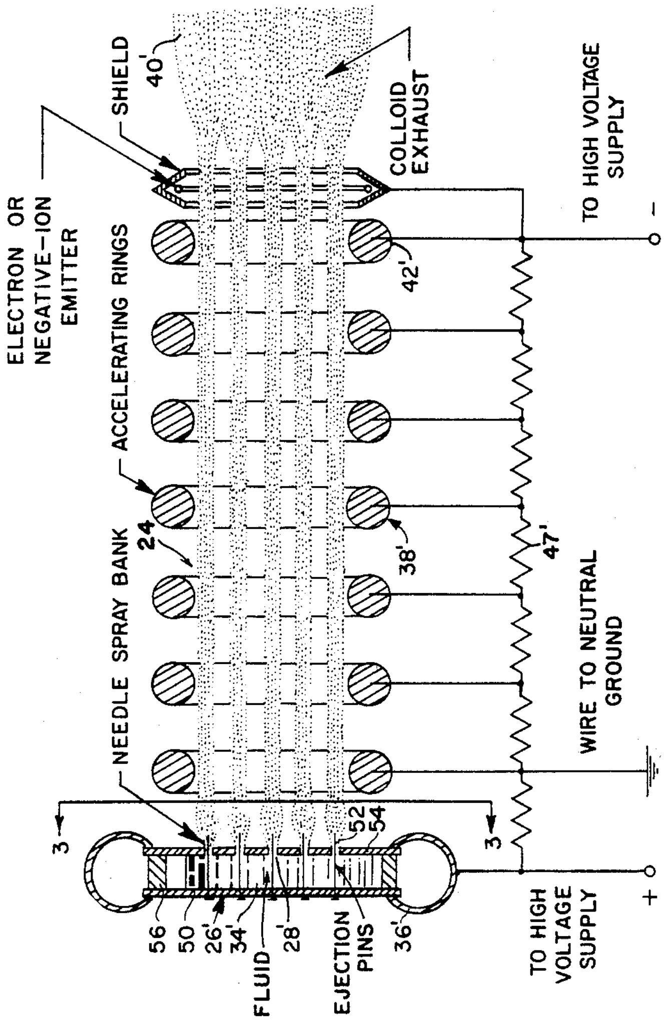

Fig-2

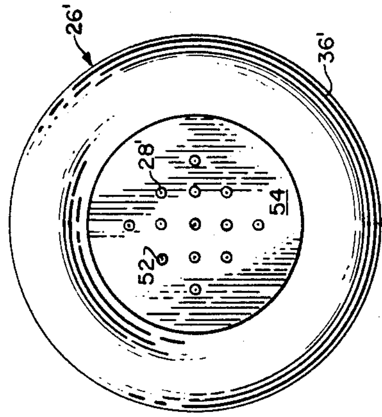

Fig-3.

INVENTOR.
ROBERT D. SCHULTZ
LANE K. BRANSON
ROBERT F. CHAIKEN

BY

ATTORNEY

PROPULSION MEANS

Filed Nov. 23, 1960 5 Sheets-Sheet 3

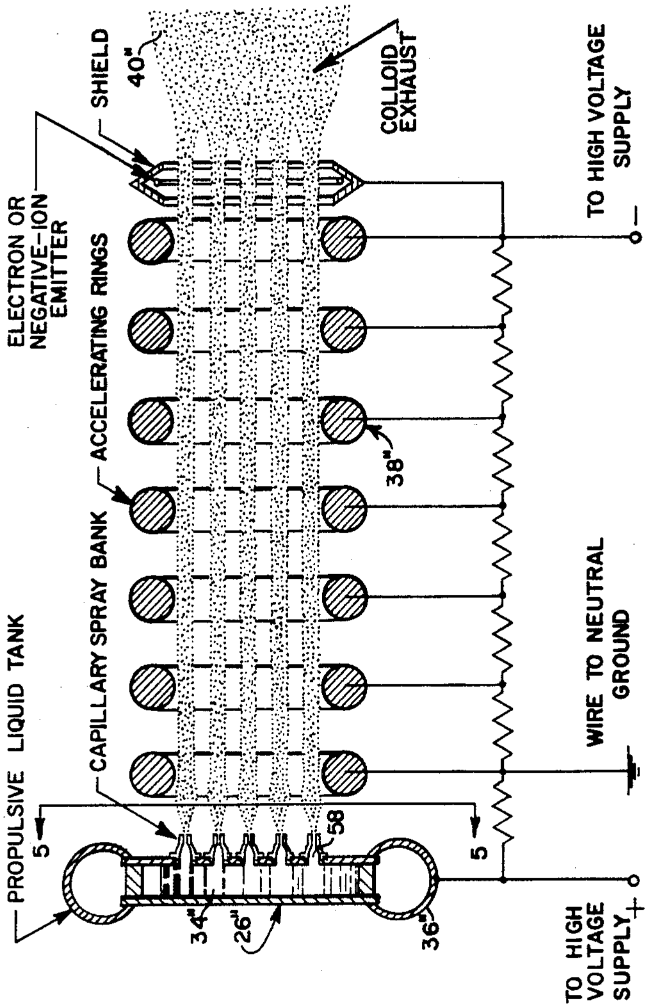

FIG. 4

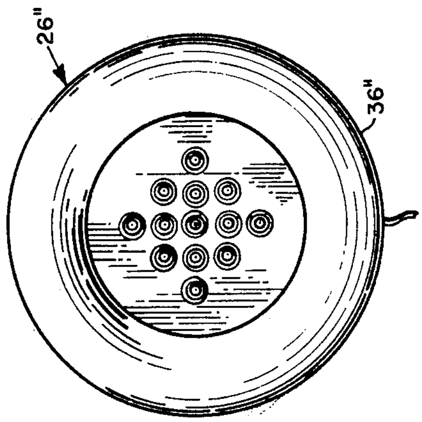

FIG. 5

INVENTOR.
ROBERT D. SCHULTZ
LANE K. BRANSON
BY ROBERT F. CHAIKEN

ATTORNEY

March 3, 1964 R. D. SCHULTZ ETAL 3,122,882

PROPULSION MEANS

Filed Nov. 23, 1960 5 Sheets-Sheet 4

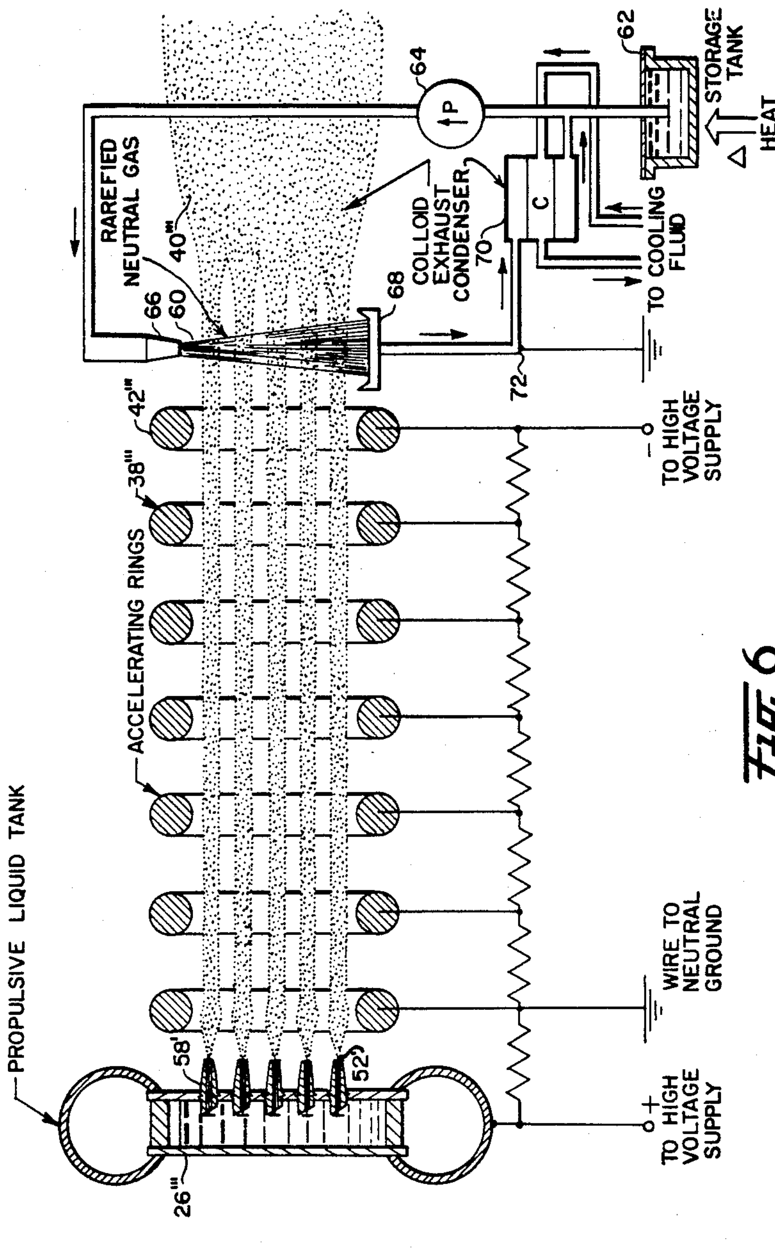

Fig. 6

INVENTOR.
ROBERT D. SCHULTZ
LANE K. BRANSON
BY ROBERT F. CHAIKEN

Robert C. Braun

ATTORNEY

PROPULSION MEANS

Filed Nov. 23, 1960 5 Sheets-Sheet 5

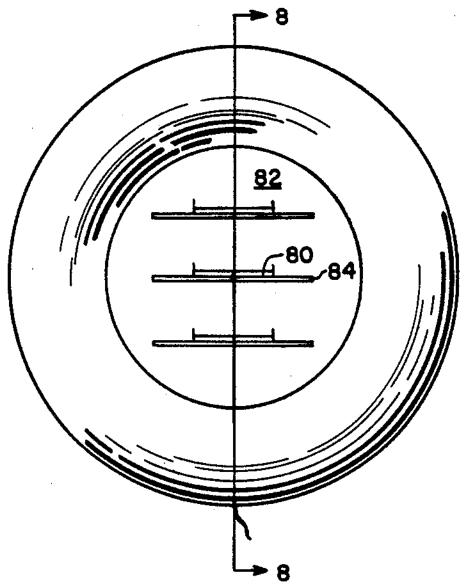

Fig. 7

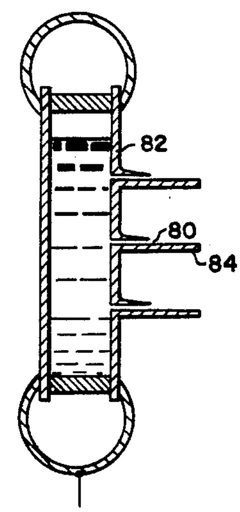

Fig. 8

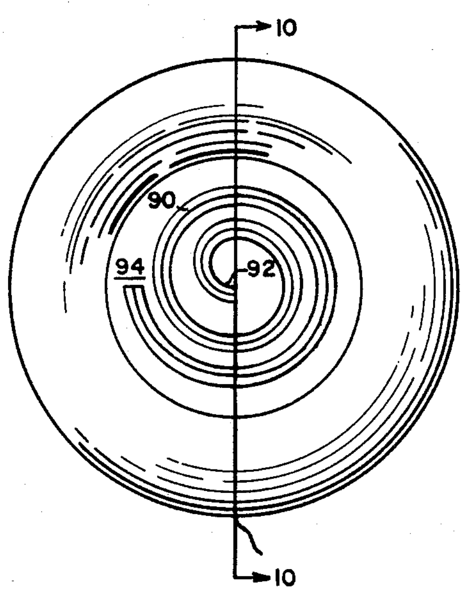

Fig. 9

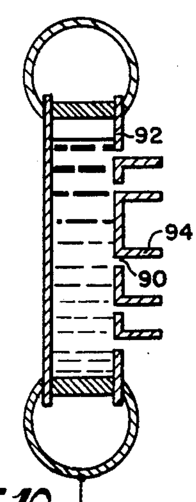

Fig. 10

INVENTOR.
ROBERT D. SCHULTZ
LANE K. BRANSON
ROBERT F. CHAIKEN
BY
ATTORNEY

United States Patent Office

3,122,882
Patented Mar. 3, 1964

3,122,882
PROPULSION MEANS

Robert D. Schultz, Whittier, Lane K. Branson, Pasadena, and Robert F. Chaiken, Covina, Calif., assignors to Aerojet-General Corporation, Azusa, Calif., a corporation of Ohio

Filed Nov. 23, 1960, Ser. No. 71,329
23 Claims. (Cl. 60—35.5)

This invention relates to a system for creating thrust under conditions of substantial vacuum generally, and to a system for propelling vehicles in outer space in particular.

Heretofore, a common method of creating thrust for purposes of propelling rockets or the like has involved the rapid creation of gases under pressure in a thrust chamber by burning chemical fuels therein. While this has proven the most common method used to obtain sufficient thrust for the propulsion of rockets within the earth's atmosphere and gravitational field, there are a number of disadvantages to the use of chemical fuels in outer space. Among them are the difficulty of carrying an adequate supply of fuel and oxidizer from earth and, when liquid propellants are used, the inherent danger of malfunction due to the unavoidably complex nature of liquid chemical propellant systems.

We have found that a jet of highly charged colloidal-sized droplets can be formed under vacuum from a liquid of suitable vapor pressure by subjecting a confined body of the liquid to a relatively large difference of electrical potential, said liquid being physically confined in a container having minute openings in the confining boundary. Hereinafter, a colloid shall be understood to mean a substnace in a state of fine division wherein its constituent particles range in diameter from about 0.2 to about 0.005 micron. By having such openings in the form of capillary tubes pointed at the outer ends, or arranging members having sharp edges or points in contiguity with the minute openings, it is found that the liquid will slowly migrate through the holes to the pointed ends of the capillary tubes or sharp edges or points of the contiguous members from whence it is ejected as charged atomized droplets of colloidal dimensions. By proper design and arrangement of the openings and capillary tubes or sharp edges or points, the streams of atomized and charged liquid droplets may be so positioned and distributed that they may be readily focused and accelerated to produce thrust in a given direction.

It is therefore the principal object of the present invention to provide a novel method of and improved means for reaction-propulsion of a space flight vehicle.

Another object of the present invention is to provide a novel method of and improved means for vernier control of the orbit of a military-communication, reconnaissance, or metreological-observation satellite.

In its principal aspect the invention comprises a unique propulsion unit operable within a substantial vacuum wherein colloidal size electrically charged liquid particles or droplets are ejected from points in contiguity with the liquid container. The charged particles are focused and accelerated through a gradient electrostatic field to produce thrust in a given direction. The charged particles may be directed to the ejection points through capillary tubes, or members in contiguity with the container having sharp edges or projections, or a combination of both may be employed.

These and other objects, aspects and features of this invention will be apparent to those skilled in the art from the following more detailed description taken together with the appended drawings wherein like or similar elements are afforded prime designations, and:

FIG. 1 shows a cross-sectional view of one embodiment of a propulsion unit according to this invention, together with a block and schematic diagram of the novel system in which it is incorporated;

FIG. 2 is a sectional view in detail of the propulsion unit of FIG. 1;

FIG. 3 is a plan view of the needle spray bank of the propulsion unit taken along section line 3—3 of FIG. 2;

FIG. 4 shows a sectional view of another embodiment of the propulsive unit of this invention which utilizes capillary tubes as a means for effecting escape of a liquid from confinement as charged atomized droplets;

FIG. 5 is a plan view of the capillary spray bank of the propulsion unit of FIG. 4 taken along section line 5—5 thereof;

FIG. 6 shows in section a combination needle-capillary tube spray bank which may be utilized in the propulsion unit of FIG. 1, together with an alternate means of neutralizing space charge tending to disrupt the colloid beam;

FIG. 7 illustrates a plan view of an alternate spray bank assembly in the form of a knife edge;

FIG. 8 shows a section view of the knife edge spray bank assembly taken along section line 8—8 of FIG. 7;

FIG. 9 discloses in a plan view yet another spray bank assembly in the form of a spiral knife edge for use in the propulsion unit of FIG. 1; and

FIG. 10 shows a section view of the spiral knife edge spray bank taken along section line 10—10 of FIG. 9.

The novel propulsion unit of the present invention embodied in a space propulsion system is illustrated in FIG. 1. High voltage electrical energy, necessary for the operation of the propulsion unit, is furnished by a high voltage generator **10**, shown to be driven from a closed turbine cycle. A nuclear reactor **12** heats working fluid which is directed to and expanded within a turbine **14**. The fluid exhaust from the turbine is cooled in a radiator **16**, the waste heat being directed to the ambient, and the cooled fluid then compressed in compressor **18** and fed back to the reactor **12** for reheating. The rotation of the turbine **14** drives the generator **10** thereby generating the electric power necessary for the operation of the propulsion unit. The closed-cycle thermal power plant described is not an absolute requirement of the present invention. The generator **10** could be driven by other means, such as by a turbine actuated by rocket exhaust gases. However, for true space flight it is contemplated that a solar or nuclear power source will be utilized, a thermonuclear source being preferable for extremely high power levels. The high voltage generator may be, preferably, an electrostatic generator capable of supplying an extremely high voltage and low current output, and may be of any type known to those skilled in the art such as, for example, a Van de Graaff generator.

The output lead **20**, **22** of the generator **10** are connected to the novel propulsion unit **24** of the present invention. A first lead **20** is connected to the positive terminal of the generator whereas the second power lead **22** is connected to the negative terminal of the generator, both leads being connected at their other end to the propulsion unit **24**, as will be later shown.

The propulsion unit itself **24** comprises a spray bank **26** and associated apparatus. Te spray bank **26** comprises a chamber or container **32** in which the propulsive liquid **34** is confined. This liquid is subjected to a high positive voltage by means of a circular electrode **36** which encompasses the container **32** and is connected to the first or positive power lead **20**. Openings **28** on one face of the confining chamber **32** are provided through which the liquid migrates under the influence of a force such as applied pressure or capillary attraction. The various types of spray banks and their associated components used by thte propulsion unit of this invention are shown in more detail in succeeding Figures. A drift tube assembly **38** is arranged adjacent the discharge openings **28** of the confined chamber **34**. The assembly **38** comprises drift tubes or accelerating rings spaced in a manner surrounding the proposed path of the charged colloidal droplet **40**. The drift tube **42** furthest in distance from the spray bank **26** is connected to the negative power lead **22** of the electrostatic generator **10**. The drift tube **30** closest to the spray bank **26** is connected to the positive power lead **20** of the generator **10** through a portion **44** of the voltage divider **47**. It is seen that the potential gradient between the fluid **34** in the spray bank assembly **26** and the furthest drift tube **42** is provided by the presence of a voltage divider **47**, the individual drift tubes achieving their potential from voltage taps intermediate the length of the voltage divider **47**. By this arrangement, an electric field is provided which has a potential gradient varying from a positive value at the spray bank **26**, neutral at the first drift tube **30**, to a high negative value at the furthest drift tube **42**. Adjacent the rearmost accelerating ring **42** is arranged a shield member **46** within which is located an electron or negative ion emitter **48**. The shield **46** is connected to be at the same high negative potential as the furthest ring **42**, and the emitter **48** is powered by a separate voltage source, not shown. It is the function of the emitter **48** to inject negative particles into the beam **40** of colloidal droplets to overcome the space-charge repulsion phenomena, while the shield **46** insures that the negative particles are confined to the vicinity of the beam **40**.

FIG. 2 shows in more detail a sectional view of the novel propulsion unit **24** of the present invention having a needle spray bank assembly. This unit provides a beam of charged colloidal particles **40'** having a net positiive or negative charge, depending upon the polarization of the exciting voltage. The beam has a large cross-section and may be modified to any desirable configuration. Operation for sustained length of time is possible because of the fluid reservoir feature and mechanism for supplying additional fluid to the reservoir from a larger supply may be provided. Pulsed operation is also possible.

The needle spray bank assembly **26'** comprises a first plate **50** to which are attached steel pins **52** of a small diameter, for example, in the neighborhood of .030 inch. The pins protrude through a similar pattern of holes **28'** which have a diameter of approximately .003 inch greater than the diameter of the pins, the holes being in a second plate **54**. Between the two plates **50, 54** is provided a reservoir for the fluid **34'** to be dispensed. The rounded configuration of the high voltage electrode **36'** is provided to prevent high voltage leakage from the sharp corners of the plate **50, 54**. FIG. 3 shows a plan view of the needle spray bank giving full details of its construction. A high positive voltage (for positively charged colloids), as shown here, or a high negative voltage (for negatively charged colloids) is applied to the high voltage electrode **36'**. This high voltage is transmitted to the points of the pins **52** and a spray **40'** of charged particles is produced. The fluid **34'** flows from the reservoir down the pins **52**, maintaining the spray **40'**. This flow is produced by gravity and capillary action, but could be produced by pressurizing the fluid **34'** in the reservoir, in the absence of a high gravitational field. A spacer **56** is provided between the plates **50, 54** to provide the proper chamber rigidity. An accelerating field for the colloid beam **40'** is provided by the drift tube assembly **38'** which is energized by the generator, the potential on each ring and the spray bank electrode **36'** being determined by taps off the voltage divider **47'**.

FIGS. 4 and 5 illustrate a capillary spray bank propulsion unit **26''** identical to that of FIGS. 2 and 3 with the exception that the liquid **34''** is caused to migrate through openings which are preferably capillary tubes **58** pointed at the outer ends and arranged in banks to yield colloid beam **40''** comprising a plurality of properly spaced streams of colloidal droplets. The liquid **34''** passes through the tubes **58** under the force of capillary attraction and is atomized from the pointed outer ends thereof. The reason for the atomization and dispersal of the liquid from the capillary tips as described can be attributed to the large electrostatic pressure developed by the repulsion of like charges at the surface of the liquid **34''**, and also to a partial electrical breakdown of the liquid subjected to the high electrostatic field at the capillary tip. By way of further explanation, when this electrostatic pressure exceeds the tensile strength of the liquid at the capillary tip, the liquid flies apart and forms the charged colloidal droplets.

In operation, the apparatus of our invention functions as follows: high voltage is supplied from a convenient source such as the electrostatic generator **10** and the voltage of positive polarity is applied to the liquid propellant material **34**. The liquid under high voltages migrates to the points of the needles **52** (FIGS. 2 and 3), or the ends of the capillary tubes **58** (FIGS. 4 and 5), from whence it is atomized as charged colloidal droplets. These droplets are immediately subjected to an electrostatic field of increasingly greater negative potential created by the drift tube assembly **38**. The electrostatic field focuses and accelerates the charged particles of the colloid beam **40** so that they travel along a fixed path at an accelerating rate to some predetermined exhaust velocity. The negative particles ejected by the emitter **48** into the colloid beam **40** as it emerges from the endmost drift tube ring **42** neutralize space-charge phenomena tending to attenuate the thrust produced by the beam. We have found that potential radiation from about +100 kilovolts at the spray bank electrode **36** to about −1000 kilovolts at the furthest drift tube **42** to be particularly suitable for the purposes of our novel propulsion system, although other voltage ranges may be employed.

Reference is made to FIG. 6 which shows in section a propulsion unit utilizing a combination needle-capillary tube spray bank which may be employed with the propulsion system of FIG. 1. An additional feature of this embodiment is a novel method of and means for neutralizing space charge tending to disrupt the colloid beam by passing the charged colloid beam through a rarefied neutral gas. As seen from the figure, the spray assembly **26'''** is a composite of the assemblies disclosed in the previous figures. Needles **52'** protrude through the hole openings at the end of capillary tubes **58'**. The spray bank assembly is similar in all other respects, and is utilized in conjunction with a drift tube assembly **38'''** energized in any manner previously described. Adjacent the rearmost accelerating ring **42'''** is arranged the improved neutralization means permitting passing the charged colloid beam **40'''** through a rarefied neutral gas **60** in a manner that corona discharge induced by voltage gradients on the charged colloidal particles occurs in the gas **60**. The electric charge on the rapidly moving colloidal droplets is thus transferred to the slower moving gas without materially effecting the velocity, hence thrust, of the colloidal particles in the beam **40'''**. To achieve this space charge neutralization, liquid capable of vaporization upon application of heat is arranged in a storage tank **62**. Heat is applied to the tank, as from the reactor **12** of FIG. 1 for example, and the resulting vapor is moved by a pump **64** to a discharge nozzle **66** in the vicinity of the furthest drift tube assembly ring **42'''**. The gas **60** is discharged from the nozzle **66** into the charged colloid beam **40'''**. The charges from the colloidal droplets are transferred to the gas particles, the gas particles being directed to gas receiving means **68** where they are channeled into condenser **70** and condensed to the liquid state and returned to the storage tank **62**, where the liquid is heated to repeat the cycle. The entire neutralization system is preferably kept at neutral or ground potential, as shown at point **72**. An ideal neutral gas is the material used in the colloid beam, for example, a low vapor pressure fusion pump oil such as dioctylphthalate. Removing the charge of the colloidal beam at the time ejection from the carrying vehicle is considered beneficial as "image forces" from the vehicle carrying the apparatus may render the colloidal stream ineffectual by either confining the stream to the vicinity of the vehicle or preventing the injection of further particles, thereby considerably attenuating the thrust from the unit.

FIGS. 7 and 8 show an alternate spray bank assembly in the form of a knife edge which may be used in the propulsion system of FIG. 1. As seen from the figures liquid is allowed to flow from the reservoir through minute slits **80** in one wall **82** of the assembly on to the knife edges **84** where it is discharged in the form of charged colloidal size droplets as previously explained.

FIGS. 9 and 10 show a variation of the knife edge spray bank wherein the ejection member **94** is in the form of a continuous spiral. The spiral plate **94** is secured to the outer face of one wall **92** and the liquid flows from the reservoir to the plate through a continuous minute slit **90** which is contiguous to the plate **94** and is also spiral in form.

The spray bank units shown in FIGS. 7–10 are similar in other respects to those disclosed in the previous figures, their distinction lying in the use of a sharp edge instead of a point to produce the high field gradient necessary to produce dispersion of the colloidal droplets.

The propulsive system of this invention is particularly useful for purposes of maneuvering vehicles, artificial satellites, and the like in space. For purposes of changing the direction of objects such as space vehicles substantially outside of the earth's enveloping atmosphere and sphere of strong gravitational force, a very small amount of thrust will suffice. A charged colloidal jet from our novel system is amply sufficient to supply the necessary amount of thrust for such purposes.

Although various liquids have been subjected to atomization in the past, such experiments have always been carried out at atmospheric pressure or, at any rate, at some pressure substantially above a vacuum. The essence of the present invention is our discovery that by means of the system described herein electrical atomization can be carried out at high vacuum or in an atmosphere in which the residual gas pressure is approximately 10^{-4} to 10^{-5} mm. Hg or less. Since high vacuum exists in space at altitudes greater than 190 kilometers, our propulsion system is particularly suitable for the propulsion of objects in outer space.

Liquids suitable for use as propellants in our charged colloid propulsion system are those having a vapor pressure of 10^{-5} mm. Hg or lower at 20° C. Use of a liquid having a low vapor pressure is important in practicing the present invention in order to prevent charge leakage from the colloidal particles by corona discharge. In addition, it is desirable, although not absolutely necessary, that the liquids have the following properties: an internal pressure greater than about 7×10^9 dynes per square centimeter; electrical conductivity greater than 6×10^{-8} mho/cm. but less than about 10^{-5} mho/cm.; a dielectric constant greater than 6; a density of about 1 to 1½ grams/cm.^{3}. A freezing point as low as possible, consistent with the above properties is also desirable. A liquid which we have found to be particularly suitable as a propellant for our novel system is dioctylphthalate, available commercially under the trade name of Octoil as a product of Consolidated Electrodynamics Corporation. Other suitable liquids are polypropylene-glycol, or glycerine.

Although it is preferred that the propulsive liquid be subjected to a high positive potential in the operation of our novel propulsion system, it is not essential that this be the case. The important factor is that there be a large potential difference between the charged colloidal droplets and the gradient electrostatic field through which they travel. Thus, it is within the scope of our invention to impress a high negative voltage on the liquid and accelerate the resulting charged particles through a gradient electrostatic field becoming more positive in potential. It is also within the scope of the invention to maintain the points of emission of the atomized droplets at ground potential while maintaining the accelerating units (grids or drift tubes) at high negative or positive voltage.

While we have illustrated and described many details of construction, alternatives and equivalents will occur to those skilled in the art which are within the scope and spirit of our invention; hence it is our desire that our protection be not limited to the details herein illustrated and described, but only by the proper scope of the appended claims.

We claim:

1. A reaction propulsion system for producing thrust in a substantial vacuum comprising: a body of liquid having a vapor pressure not greater than 10^{-5} mm. Hg at about 20° centigrade; means for confining said body of liquid, said confining means having minute openings in a portion of a surface thereof, through which the liquid may migrate; liquid dispersion means in contiguity with said minute openings; means for subjecting said confined liquid to a relatively high electric potential; means for creating and maintaining a gradient electrostatic field in a spaced relationship to said dispersion means, whereby charged droplets of the liquid are ejected from said dispersion means as the result of said high potential and are focused and accelerated in any desired direction, and means for injecting negative particles into said droplets after they have been focused and accelerated.

2. The reaction-propulsion system of claim 1 wherein said liquid is dioctyl phthalate.

3. The reaction-propulsion system of claim 1 wherein said liquid is polypropylene glycol.

4. The reaction-propulsion system of claim 1 wherein said liquid is glycerine.

5. The reaction-propulsion system of claim 1 wherein said dispersion means comprises capillary tubes.

6. The reaction-propulsion system of claim 1 wherein said dispersion means comprise a plurality of electrically conductive members having sharp projections which are arranged to project to the ambient through the minute openings in said surface of said confining means.

7. The reaction propulsion system of claim 1 wherein said dispersion means comprises a thin metallic plate having a thin edge.

8. The reaction propulsion system of claim 1 wherein said dispersion means comprises a thin metallic plate which is volute in form.

9. The reaction propulsion system of claim 1 wherein said dispersion means comprises a plurality of capillary tubes, each of which has an electrically conductive needle-like member centrally located therein.

10. The reaction-propulsion system of claim 1 wherein said high potential means furnishes approximately 100 kilovolts of one polarity and said means for creating and maintaining a gradient electrostatic field creates a field which varies from zero potential in the vicinity of said ejection means to a maximum potential of approximately 1,000 kilovolts of an opposite polarity at the point where the charged colloid beam leaves the propulsion system.

11. The reaction-propulsion system of claim 1 wherein said liquid has an electrical conductivity greater than 6×10^{-8} mho/cm., but less than about 10^{-5} mho/cm.

12. A reaction-propulsion system as described in claim 11 wherein said liquid has a dielectric constant greater than 6.

13. A reaction-propulsion system as in claim 12 wherein said liquid is of a density of about 1 to 1 and ½ g./cm.^{3}.

14. A reaction-propulsion system as in claim 13 wherein said liquid has an internal pressure greater than 7×10^9 dynes per square centimeter.

15. A propulsion system operable in a vacuum atmosphere comprising: a reservoir having a plurality of openings in a portion of a surface thereof; a body of liquid having a vapor pressure not greater than 10^{-5} mm.

Hg at about 20° centigrade arranged in said reservoir; fluid ejection means associated with said openings in said surface; means for applying electric potential to said fluid body in said reservoir; and electric focusing and accelerating means arranged in contiguity to said fluid ejection means.

16. A propulsion system as described in claim 15, and in addition, means for space charge neutralization, said neutralization means being associated with said focusing and acceleration means.

17. A system for creating thrust in a vacuum atmosphere comprising: a reservoir having a plurality of openings in a portion of a surface thereof; a body of liquid having a vapor pressure not greater than 10^{-5} mm. Hg at about 20° centigrade arranged in said reservoir; fluid ejection means associated with said openings in said surface; electrostatic focusing and accelerating means arranged in contiguity to said fluid ejection means; means for applying electric potential to said liquid body through said reservoir and said electrostatic focusing and accelerating means, a difference of potential existing between said reservoir and said electrostatic focusing and accelerating means whereby liquid particles of colloid size are ejected from said particle ejection means in a beam and said beam is focused and accelerated by said electrostatic focusing and accelerating means; and means associated with said electrostatic focusing and accelerating means for neutralizing the effect of space charge on said beam of particles.

18. A propulsion system as described in claim 17 wherein said neutralizing means comprises a negative particle emission source.

19. A propulsion system as described in claim 17 wherein said neutralizing means comprises a rarified neutral gas stream.

20. A propulsion system operable in a vacuum atmosphere comprising: a reservoir having a plurality of openings in a portion of a surface thereof; a body of liquid in said reservoir, said liquid having a vapor pressure not greater than 10^{-5} mm. Hg at about 20° centigrade, an internal pressure greater than about 7×10^9 dynes per square centimeter, an electric conductivity substantially between 6×10^{-8} and 10^{-5} mho/cm., a dielectric constant greater than 6, and a density substantially between 1 and 1½ grams/cm.^{3}; fluid ejection means associated with said openings in said surface; electrostatic focusing and accelerating means in spaced relation with said fluid ejection means; means for applying electric potential to said liquid body, said reservoir and said focusing and accelerating means, whereby the liquid body and reservoir are at a potential of approximately 100 kilovolts of one polarity and a gradient electric field is created which varies from zero in the vicinity of said ejection means to approximately 1000 kilovolts of an opposite polarity at the position of said focusing and accelerating means furthest extended from said fluid ejection means; and means associated with said focusing and accelerating means for neutralizing the effect of space charge, said neutralization means being juxtaposed with said focusing and accelerating means which is at a potential of approximately 1,000 kilovolts.

21. A method of creating thrust in a vacuum atmosphere comprising the steps of applying an electrical potential to a body of liquid having a vapor pressure not greater than 10^{-5} mm. Hg at about 20° centigrade which is confined in a means having minute openings in a portion of a surface thereof; directing said liquid to the extremities of dispersion means associated with said openings, whereby liquid particles of colloidal size and bearing an electric charge will be formed at said dispersion means extremities; ejecting said particles from said dispersion means in a beam; focusing and accelerating said beam particles; and, neutralizing the effect of space charge on said beam of particles.

22. A propulsion system operable in a vacuum atmosphere comprising: means for ejecting in a stream electrically charged atomized liquid droplets of colloidal dimensions, and electric focusing and acceleration means arranged in contiguity to said colloidal-sized fluid particle ejection means.

23. A device as described in claim 22 and, in addition, means for neutralizing the effect of space charge on said colloidal-sized fluid particle stream, said neutralizing means being associated with said electric focusing and acceleration means.

References Cited in the file of this patent

UNITED STATES PATENTS

2,880,337 Langmuir -------------- Mar. 31, 1959

OTHER REFERENCES

Reactors in Flight, Engineering, Feb. 28, 1958, vol. 185, No. 4799, pp. 268–270.

Nuclear Ion Rocket, SAE Journal, July 1959, vol. 67, pp. 40–42.