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De Broqueville

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[54] ELECTROMAGNETIC PROPULSION DEVICE FOR USE IN THE FORWARD PART OF A MOVING BODY

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[51] **Int. Cl.**....................**F03h 1/00,** F03h 5/00, H05h 11/00

[58] **Field of Search**.............60/202; 102/105, 49.3; 244/62, 244/130

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[57] **ABSTRACT**

At least two parallel annular electrodes are disposed on the outside dielectric surface of the body starting from the forward edge thereof, perpendicularly to the direction of the symmetry axis of a magnetic field around the body. A propulsion electromagnetic force field is produced around the body such as to substantially decrease the overpressure in front of said moving body while accelerating the surrounding fluid backward and aside from said body, thereby to reduce the shock wave due to said overpressure.

9 Claims, 10 Drawing Figures

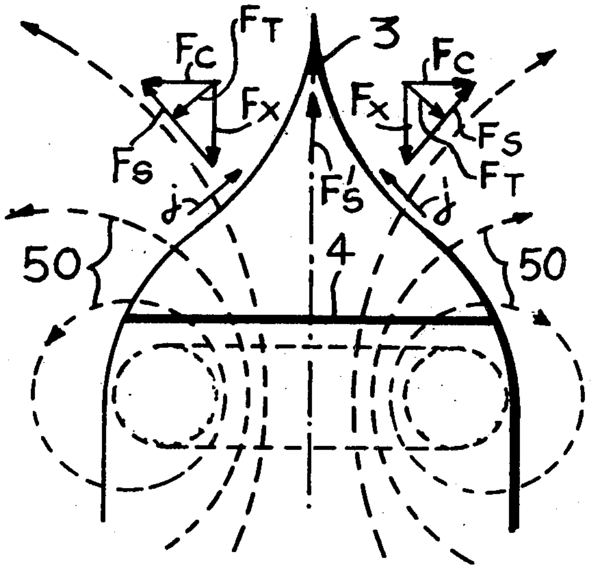


FIG_1

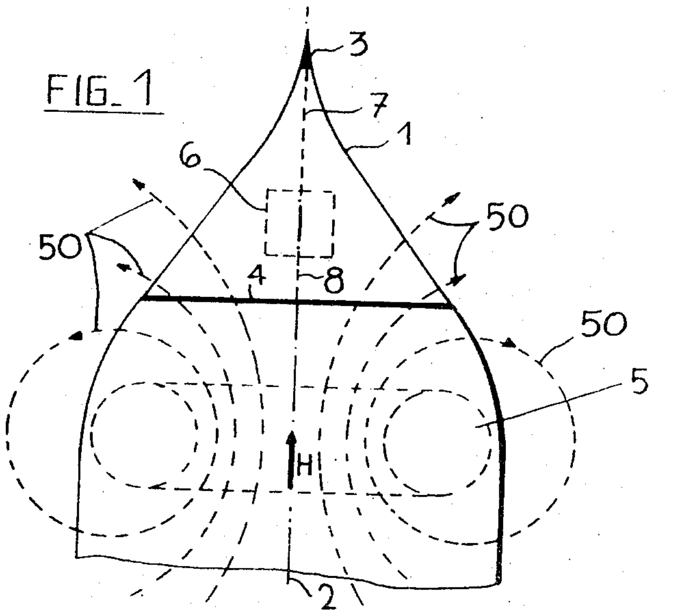


FIG_2

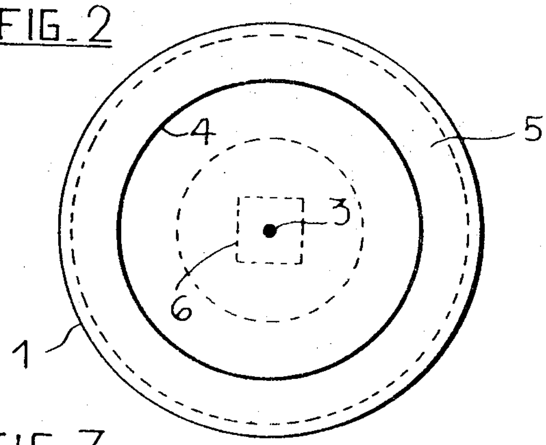


FIG_4

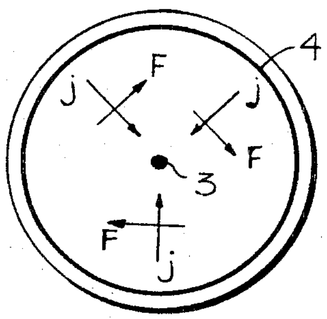


FIG_3

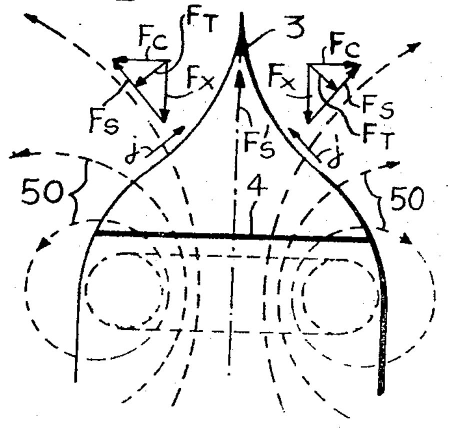


FIG. 7

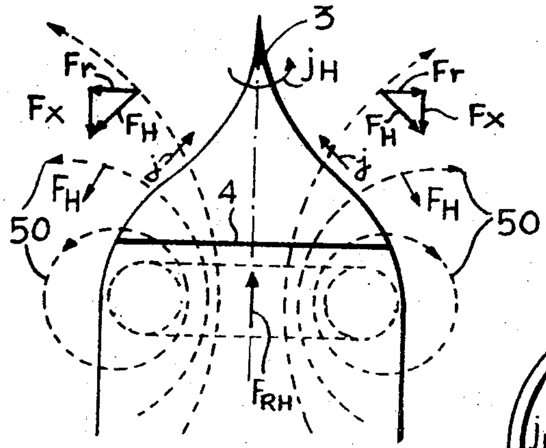


FIG. 8

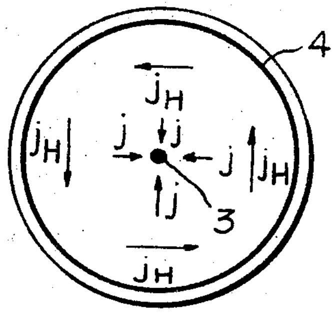


FIG. 5

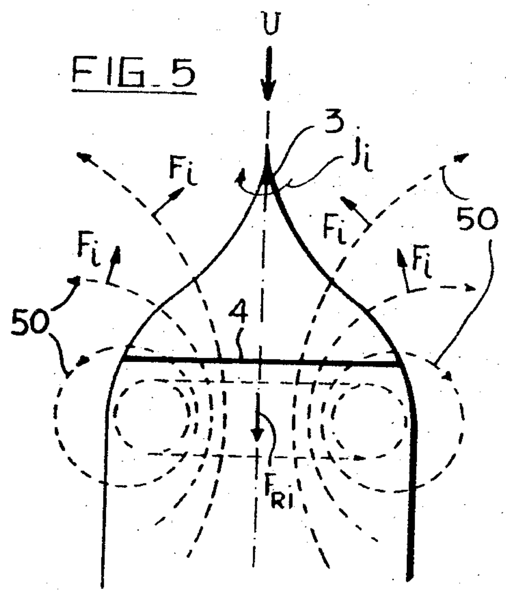


FIG. 6

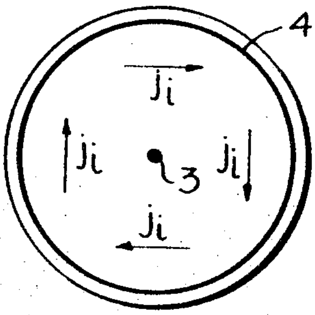


FIG_9

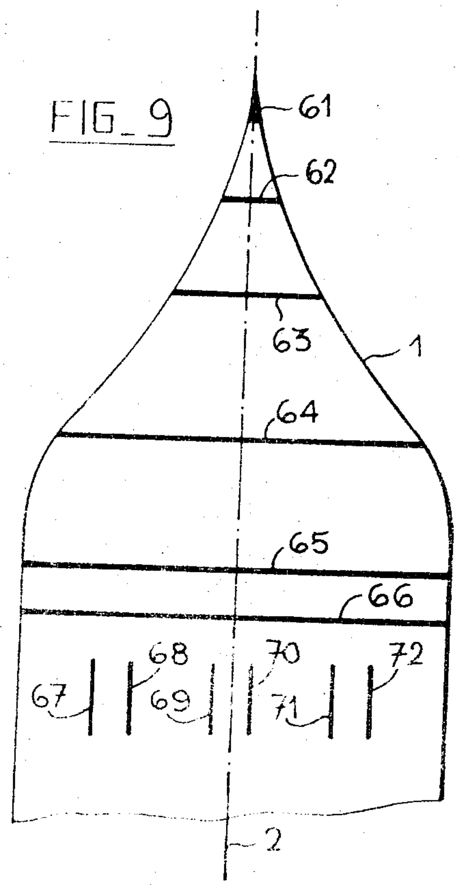
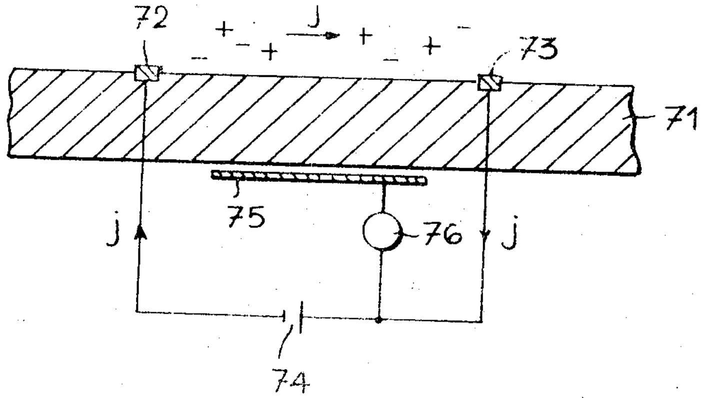


FIG_10



ELECTROMAGNETIC PROPULSION DEVICE FOR USE IN THE FORWARD PART OF A MOVING BODY

BACKGROUND OF THE INVENTION

The present invention relates to an electromagnetic propulsion device intended to be used in the forward part of a moving body and which creates in the surrounding flow medium, or fluid (such as air or water) an electromagnetic force field accelerating the fluid backward and expanding it aside from the body. Overpressure generated by the body motion in the fluid is reduced or suppressed. In case of a supersonic motion, the shock wave generated by that overpressure in front of the body can be minimized or suppressed.

Different electromagnetic propulsion devices acting upon the surrounding fluid outside of a vehicle are known. One was used in the electromagnetic submarine EMS–1 (experiment by Westinghouse in Santa Barbara in 1966) but the magnetic symmetry axis therein is substantially perpendicular to the direction of the body motion and the electric field not does not an axial symmetry. Consequently, an eventual reduction of the sonic boom is not possible all around the body.

Other similar electromagnetic devices have been studied in view of their application to re-entry-maneuvers of satellites into planetary atmospheres, but they are not propulsion devices; on the contrary they increase drag and shock wave intensity.

Electrostatic devices have been studied in connection with the reduction of the sonic boom in front of a supersonic vehicle, but their action is essentially based on a progressive deceleration of surrounding flow and not its acceleration. For that reason their effect is unstable and furthermore they have the very poor efficiency of any electrostatic device in the atmosphere.

Electro-magnetic propulsion devices having, some similarity with a Hall radial accelerator (as described in the report NASA TN D–3332, Mar. 1966) were suggested. The action of the latter is inside the vehicle and the fluid is not expanded but compressed by the Hall effect, and therefore it cannot suppress a shock wave.

SUMMARY OF THE INVENTION

The invention provides an electromagnetic propulsion device intended to be mounted in the forward part of a moving body, comprising an electromagnetic coil for generating a magnetic field around said body, the symmetry axis of said magnetic field having substantially the same direction as the relative motion between the body and the surrounding fluid, at least two annular electrodes placed on the outside dielectric surface of said body perpendicularly to the symmetry axis of said magnetic field, one of said electrodes being mounted at the forward end of said body, ionization means for the said fluid between said electrodes around said body, and a power generator having its terminals connected to said electrodes for generating between same an electric field and an electric current in the ionized fluid around said body, the action of said electric current in said magnetic field causing said fluid to rotate such as to produce a centrifugal force while at the same time the electric current due to the Hall effect produces an additional force effective to accelerate the ionized fluid backward and aside from the said body, thereby to increase the centrifugal force and produce a propulsion force acting on said body.

The basic effect of this propulsion device is that it does not only push the fluid aside from the body by centrifugal and Hall effects, but that it also accelerates the fluid backward (and does not decelerate the fluid forward as in other magnetic or electrostatic devices) such as to produce a propulsion effect simultaneously with a reduction of the drag due to the overpressure generated by the body motion relative to the fluid. In fact, thanks to the backward acceleration and in order to satisfy the conservation of mass condition, the fluid can be pushed aside from the body by the electromagnetic forces (and not by a pressure gradient as in ordinary flow) without or with a reduced increase of pressure such that the fluid is actually expanded aside from the body. Furthermore as the shock wave is only generated by compression flow, such a propulsion device also reduces drag and can suppress the shock wave generated in front of a supersonic body.

DESCRIPTION OF THE DRAWINGS

FIG. 1 is a schematic elevational view of a body nose incorporating a particular embodiment of the electromagnetic propulsion device according to the invention;

FIG. 2 is a horizontal view of the body of FIG. 1;

FIGS. 3, 4 through 8 show schematically in vertical projection (FIGS. 3, 5 and 7) and in horizontal projection (FIGS. 4, 6 and 8) the magnetic field configurations, the electric current lines and the resulting forces;

FIG. 9 is an elevational view of a body nose incorporating a variant of the propulsion device according to the invention;

FIG. 10 illustrates an ionization device according to the invention.

DETAILED DESCRIPTION:

FIGS. 1 and 2 show (in elevational and horizontal view respectively) the forward part of a body 1 which may be the nose of an aircraft having a general axial symmetry about longitudinal axis 2. In this case the propulsion device according to the invention is used for the aircraft propulsion or as an assist part of the aircraft propulsion system together with conventional propulsion devices, and acting at the same time to reduce or suppress the front shock wave, thereby to reduce drag and noise. It may also be used for the aircraft deceleration by inverting the force field as will be seen hereinafter.

The electromagnetic coil 5 generates a magnetic field having a symmetry axis that is illustratively coinciding with the aircraft axis 2. The field is a "poloidal magnetic field", in contrast to a "toroidal magnetic field". A toroidal magnetic field is a magnetic field which can be represented in cylindrical coordinates by the equation:

$\vec{H}_T = \vec{1}_z \times \vec{r}\, T$ where T is a scalar function. This equation means that the magnetic lines of force are annular or that the magnetic field is like a torus.

A poloidal magnetic field is a magnetic field which is not toroidal or whose magnetic lines of force are perpendicular to those of a toroidal magnetic field. Such a magnetic field is general and it can be represented in cylindrical coordinates by the equation:

$$H_p = V \times (\vec{1}_z \times \vec{r}\, P) \text{ where } P \text{ is a scalar function.}$$

Toroidal coils which produce approximately force-free magnetic fields are used. They provide a toroidal magnetic field inside a torus (including the coils) and a "poloidal" magnetic field outside the torus. The magnetic stresses of the toroidal magnetic field are opposite to the stresses of the poloidal magnetic field. Therefore the resulting stresses on the coils are strongly reduced or balanced. The poloidal magnetic fields are the most common magnetic fields, but the term "poloidal" has been introduced considering that only the poloidal component of the magnetic field would be outside the vehicle and consequently the only active component. This field is represented by vector H and has field lines 50 that go through the body envelope and have in the surrounding space a configuration as shown in FIGS. 1, 3, 5 and 7. The coil itself can advantageously be made of superconductors disposed inside a torus 5 (e.g. cooled by liquid Helium), the disposition of the conductors being such that the magnetic field approaches a "-force free" or "balanced" state, thereby reducing the magnetic stresses in the coil such that a dimensionally large (i.e. comparable with the body diameter) and powerful magnetic field can be generated.

A pair of parallel annular electrodes 3 and 4 are disposed on the aircraft dielectric outside surface 1 substantially perpendicularly to the symmetry axis of the magnetic field H. Electrode 3 is shown at the forward edge of the body while electrode 4 is shown close to the widest part thereof. The forward edge may be blunt or pointed and the shape of the electrode thereat can then be considered as the limit of the ring.

The power generator symbolized by box **6** is connected to the electrodes by the connections **7** and **8** with the appropriate polarity.It may comprise any current generator such as a dynamo driven by a gas turbine, etc. It can also advantageously use the magnetic field inside the vehicle and the necessary energy can be found in the magnetic field itself which then would serve as an energy source.

Means for ionizing the surrounding fluid may comprise any device such as a particle emitter, a high frequency electromagnetic field generator, etc. In the illustrative embodiment the ionization is assumed to be initiated by means (not shown) such as a spark generator, a device for applying an instantaneous high voltage between the electrodes, etc. In this case, the ionization is assumed to be maintained by the electric field generated by said power generator. Thus the power generator would produce a glow discharge (which must be close to an arc discharge at the atmospheric pressure). It is favored by the annular configuration and the transverse magnetic field such that it has a good efficiency with a small electrode corrosion. Furthermore the expanding and centrifugal forces reduce heat transfer with the dielectric outside surface. However devices may simultaneously be used for a better efficiency or to have ionization varying according to operating conditions.

The forces produced in the fluid by the device as described and their reaction applied to the vehicle through the magnetic coil may be divided into different species. Their action will be better understood by assuming three different operating conditions in which only one species is predominant, the other ones being then relatively negligible.

1st case (see FIGS. **3** and **4**) the body velocity is slow enough such that the induced electric current is negligible and the magnetic field strength and the fluid pressure are such that the Hall effect is negligible (since the Hall coefficient $C_H = \omega\,\tau$ is proportional to the electron cyclotron frequency ω which in turn is proportional to the magnetic field strength, and inversely proportional to the electron collision frequency $1/\tau$ which in turn is proportional to the pressure).

Under these conditions, the electric current j between electrodes **3** and **4** and its resulting force field F in the fluid are as sketched in FIGS. **3** and **4**; said force field causes the fluid to rotate and by reaction it induces an opposite couple to the body through the magnetic coil.

The air rotation produces underpressure due to the centrifugal force F_c and the underpressure in turn reacts with the body surface, accelerating the fluid backward (F_x) and inducing to the body through its surface a propulsion reaction F_S similar to the sucking effect in a cyclone. The vector relationship of the forces is seen in FIG. **3**. The centrifugal force F_c produced by the air rotation reacts with the body surface such that it can be divided into two components: F_s is perpendicular to the surface and F_T is tangent to the surface. The surrounding fluid is accelerated backward: due to the axial symmetry, F_S in turn can be divided into two components: F_c that is perpendicular to the symmetry axis and F_s' that is parallel to the symmetry axis, which gives the said propulsion reaction.

However if the body motion is not negligible, the underpressure will be balanced by an overpressure and the induced electric current will also increase the overpressure as it will be seen in the second case.

2nd case (FIGS. **5** and **6**) there is no applied electric field.

In pure aerodynamics, the fluid radial acceleration due to the body motion U is obtained by a pressure gradient, i.e. an overpressure which decelerates the fluid too, producing on the body a drag partially balanced at subsonic speed only by a similar overpressure in the back of the body.

As the surrounding fluid is ionized, the body motion U induces an azimuthal electric current j_i, as sketched in FIGS. **5** and **6**, generating a decelerating compressure force F_i as well as the reaction F_{Ri} thereof. This induced force increases the pressure gradient or overpressure in front of the body, increasing drag and shock stand-off distance as it was proposed to be used for the re-entry of satellites.

The device according to the invention is characterized by its capability of inverting said induced force thanks to the Hall effect as it will be seen in the third case.

3rd case (FIGS. **7** and **8**) the Hall effect is important as is the case at high altitude and with high magnetic field strength.

The Hall effect is the electric current tendency of going perpendicularly to the electric and magnetic field directions and therefore in this case the Hall current flows parallely to the electrodes, i.e. following an azimuthal direction.

Provided that the applied electric field is high enough and has the right polarity, the azimuthal Hall current j_H will be larger than and opposite to the induced electric current and their combined action F_H will be reversed, as sketched in FIGS. **7** and **8**, with a propulsion reaction F_{RH} applied to the body through the magnetic coil.

The transverse component j of the electric current causes the surrounding fluid to rotate, inducing a centrifugal force as in the first case, but, for a large Hall coefficient, i.e. at low pressure or high altitude, this action will be negligeable ($j << j_H$).

The Hall force F_H can be divided into two components, a radial force F_r, similar to the centrifugal force, and a backward acceleration force F_x, both of them being necessary in order to reduce or suppress the overpressure produced by the body motion. In fact, the pressure gradient can be replaced by the radial force F_r to curve the streamlines aside from the body, but the conservation of mass condition implies a similar backward acceleration of the surrounding fluid along those contracting streamlines which are progressively narrowing, by the F_x component.

Therefore it is only because the device according to the invention generates radial expansion simultaneously with a backward acceleration that it can actually suppress the overpressure generated by the body motion and, thanks to its axial symmetry, this is achieved in the whole surrounding flow.

The mechanism just described above can be analyzed using the magnetohydrodynamic equations which can be written, when neglecting dissipative effects and for axi-symmetric flow:

mass conservation:

$$\rho\left(\frac{\partial u}{\partial x}+\frac{\partial v}{\partial r}+\frac{v}{r}\right)+\left(u\,\frac{\partial \rho}{\partial x}+v\,\frac{\partial \rho}{\partial r}\right)=0$$

momentum conservation:

$$\rho\left(u\,\frac{\partial u}{\partial x}+v\,\frac{\partial u}{\partial r}\right)=-\frac{\partial p}{\partial x}-j_\theta B_r$$

$$\rho\left(u\,\frac{\partial v}{\partial x}+\frac{\partial v}{\partial r}\right)=-\frac{\partial p}{\partial r}+j_\theta B_x+\frac{\rho w^2}{r}$$

$$\rho\left(u\,\frac{\partial w}{\partial x}+v\,\frac{\partial w}{\partial r}\right)=(j_x B_r-j_r B_x)-\frac{\rho v w}{r}$$

with, deduced from the generalized Ohm's law:

$$j_\theta B=\overline{\sigma}\,[\,(uB_r-vB_x)B-C_H(E_xB_r-E_rB_x-wB^2)\,]$$

$$j_xB_r-j_rB_x=\overline{\sigma}\,[\,C_H(uB_r-vB_x)B+(E_xB_r-E_rB_x-wB^2)\,]$$

where $\overline{\sigma}=\sigma/(1+C_H^2)$ is the reduced conductivity.

It is possible to recognize in these flow equations:

the pressure gradient, $\partial p/\partial r$ and $\partial p/\partial r$, which must satisfy, in the forward part of the moving body, the conditions $\partial p/\partial x \leqslant 0$ and $\partial p/\partial r \geqslant 0$ in order to have no overpressure (it is interesting to note that such flows with $\partial p/\partial r \geqslant 0$ are not unstable as those created by electrostatic devices because of the condition $\partial p/\partial x \leqslant 0$ instead of $\partial p/\partial x > 0$ in the latter),

the electromagnetic backward force $-j_\theta B_r$ which must be positive or $j_\theta B_r < 0$, the electromagnetic radial force $j_\theta B_x$ which must be positive in order to replace the pressure gradient $\partial p/\partial r$ which is negative in ordinary flows,

the centrifugal force $\rho w^2/r$,

the rotation electromagnetic force $j_x B_r - j_r B_x$,

the Coriolis force $\rho wv/r$,

and, from the generalized Ohm's law, it can be seen that the Hall effect produces an apparent decrease of conductivity (corresponding to a proportional increase of Joule dissipation and electromagnetic work) and that C_H must be not negligeable in order to have the applied radial electromagnetic force larger than the induced one, proportional to $uB_r - vB_x$.

These equations are fully determined by the boundary conditions, determined themselves by the shape of the body, and by the electromagnetic configuration, determined itself by the Maxwell's equations and the electrode disposition. Therefore any body shape is not susceptible to satisfy the conditions $\partial p/\partial x \leq 0$ and $\partial p/\partial r \geq 0$ and, for that reason, although the device according to the invention will reduce the overpressure generated in front of a vehicle, it will actually completely suppress that overpressure only for a particular range of body shapes determined by constant pressure flow conditions, i.e. $\partial p/\partial r = 0$ and $\partial p/\partial x = 0$.

When pressure flows become constant (that is, do not increase) the least energy is required The study of shaped and flows was done by the applicant in a M.Sc. thesis.

As that condition suppresses one variable p, it was necessary to introduce other variables related with the body shape and electromagnetic configuration in order to make the flow equations compatible and a numerical approximate resolution method was established therefrom, proving that such flows were actually achievable. This method can be applied to the particular electromagnetic configurations according to the invention, although it needs new experimental data.

From that study, optimum body shapes relating to operating conditions can be found. However this device can be used independently from optimum conditions and more elaborated embodiments than those of FIGS. **1** and **2** can provide operating adaptability as will be disclosed hereinafter.

It will be necessary to note that the device according to the invention can work as a deceleration device when, for instance, the applied electric field is reversed or when $C_H(uB_r - vB_x)B$ is larger than $E_x B_r - E_r B_x - wB^2$ which is the condition for partially recovering the body kinetic energy. It is also possible to make the deceleration varying, thanks to the Hall effect, when varying the applied electric field.

The device according to the invention can also be used inside a channel in order to accelerate a fluid without large variations of the channel cross section and pressure. In this case the magnetic coil may be disposed outside of the channel and the device will work as an electromagnetic pump or accelerator. It will not be very different from a radial Hess accelerator, except for the magnetic field convergence. It can be used together with the outside fluid acceleration, using the same magnetic field, in order to increase the total thrust. In this case the nose of the body would be hollow.

In conclusion, it may be interesting to summarize the main properties and advantages of a device according to the invention.

It is firstly a propulsion device, reducing also the drag and noise generated by the front shock wave in case of a supersonic body. It can also be used for deceleration with body kinetic energy partial recovery, by increasing drag. In this case it will reduce heat transfer produced at hypersonic speed, by increasing shock stand-off distance.

It has a good efficiency for an electromagnetic propulsion device to be used in the atmosphere. In fact the electrical and mechanical efficiencies are increased because the usable cross section outside of a body or vehicle is larger than the one inside of the vehicle, allowing smaller electric current densities and smaller fluid acceleration for the same thrust. Furthermore the ionization is favored by the axial symmetry with transverse magnetic field. It can have as good an efficiency as similar annular glow or arc discharge with a reduced heat transfer and electrode corrosion.

The structure of the invention may be used with auxiliary devices for certain conditions of operation. Variable geometry, retractable wings, auxiliary propulsion devices, etc. . . may be used without objection.

To increase the effectiveness, further annular electrodes may be used, as shown in FIG. **9**, which illustrates a body **1** similar to that shown in FIG. **1**. Four electrodes **61** to **64** are shown similar to electrodes **3** and **4** in FIGS. **1** and **2**. It may also be advantageous to provide an additional pair of annular electrodes such as **65** and **66** where the body diameter is larger in order to suppress or modify the reaction couple applied to the vehicle.

Moreover, other electrodes such as electrodes **67** to **72**, substantially parallel to the direction of the fluid motion relative to the body, may also be used for modifying the motion direction or be used as auxiliary propulsion or deceleration device.

Ionization devices may also be used in order to modify locally or generally the surrounding fluid ionization. According to another aspect of the invention one illustrative embodiment of such a device is schematically shown in FIG. **10**. Electrodes such as **72** and **73**, e.g. of annular shape, are disposed on the outside surface of the dielectric body envelope **1**. Another electrode **75** is disposed on the inside surface of the body envelope. The electrodes **72** and **73** are connected to a DC voltage source **74** which may be constituted by the electric field generator. Electrode **75** is connected to an AC voltage source **76**. Ionizing alternative glow discharge is thus induced between the dielectric body surface **71** and the outside electrodes **72** and **73**. The frequency and voltage of source **76** are to be adjusted in term of the operating conditions.

In the foregoing the invention was described illustratively in its application to a body moving in an electrically non conducting surrounding fluid, e.g. in the atmosphere. However the invention is not limited thereto but it will be apparent that it is applicable to a body moving in an electrically conducting fluid as well such as the ionosphere or sea water. In that case provision of ionization means is not necessary for ionizing the surrounding fluid or initiate said ionization as explained hereabove. The operation of such a device is quite identical to that described in the foregoing.

What is claimed is:

1. Electromagnetic propulsion device to be mounted in the forward part of a body adapted to move in an ionizable fluid medium, comprising an electromagnetic coil for generating a poloidal magnetic field around said body, the symmetry axis of said magnetic field having substantially the same direction as the relative motion between the body and the surrounding fluid; at least two annular electrodes placed on the outside dielectric surface of said body perpendicularly to the symmetry axis of said magnetic field, one of said electrodes being mounted at the forward end of said body; and a power generator having its terminals connected to said electrodes for generating between same an electric field sufficient to provide for ionization of the fluid and an electric current in the ionized fluid around said body, the combined action of said electric current in the fluid subjected to said magnetic field causing said fluid to rotate such as to produce a centrifugal force, the electric current due to the Hall effect producing simultaneously an additional force effective to accelerate the ionized fluid backward and radially aside from the said body to increase the centrifugal force and produce a propulsion force acting on said body.

2. The electromagnetic propulsion device of claim **1**, comprising means for changing the applied electric field strength and polarity to adapt the device to operating conditions and for reversing the force field direction in order to produce a deceleration effect with a body kinetic energy partial recovery.

3. The electromagnetic propulsion device of claim **1**, further comprising a pair of annular parallel electrodes disposed on the outside surface of said body perpendicularly to the symmetry axis of said magnetic field thereby to modify or suppress the reaction rotation couple applied to said body.

4. The electromagnetic propulsion device of claim 1 further comprising at least two electrodes disposed on the outside surface of said body substantially parallel to the fluid relative motion, for changing the direction of motion and for increasing thrust or deceleration.

5. The electromagnetic propulsion device of claim 1, wherein the ionization means comprise at least one device for producing an ionizing alternative glow discharge between the said electrodes and the body dielectric surface, thereby to modify the ionization of the fluid around said body.

6. Electromagnetic propulsion device to be mounted in the forward part of a moving body surrounded by an electrically conducting fluid, comprising an electromagnetic coil for generating a magnetic field around said body, the symmetry axis of said magnetic field having substantially the same direction as the relative motion between the body and the surrounding fluid; at least two annular electrodes placed on the outside dielectric surface of said body perpendicularly to the symmetry axis of said magnetic field, one of said electrodes being mounted at the forward end of said body; and a power generator having its terminals connected to said electrodes to produce an electric current between said electrodes in the electrically conducting fluid surrounding said body, the action of said electric current in said magnetic field causing said fluid to rotate and to produce a centrifugal force while at the same time the electric current, due to the Hall effect, produces an additional force effective to accelerate the ionized fluid backward and laterally aside from the said body to increase the centrifugal force and produce a propulsion force acting on said body.

7. The electromagnetic propulsion device of claim 6 comprising means for changing the applied electric field strength and polarity to adopt the device to operating conditions and for reversing the force field direction in order to produce a deceleration effect with a body kinetic energy partial recovery.

8. The electromagnetic propulsion device of claim 6, comprising a pair of annular parallel electrodes disposed on the body external surface perpendicularly to the symmetry axis of said magnetic field, thereby to modify or suppress the reaction rotation couple applied to said body.

9. The electromagnetic propulsion device of claim 6, comprising at least two electrodes disposed on the outside surface of said body, substantially parallel to the fluid relative motion, for changing the direction of motion and for increasing thrust or deceleration.

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