<u>SUPPLEMENT A</u>

To Develop Practical Military, Space, and Research Applications of

ELECTROHYDRODYNAMICS

As Related To:

SPACE PROPULSION. . . . . .Electrical

ENERGY CONVERSION. . . . . .Electrical to Mechanical

FLUID PUMPING . . . . .No Moving Parts

HARD VACUUM PUMP . . . . .10^{-9} mm. of Hg or Better

CONTINUOUS PARTICLE GUN. . . . . .100,000 fps meteorite simulator

ELECTRIC POWER GENERATOR. . . . . .Flame-Jet Generator

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March 4, 190

ELECTROHYDRODYNAMICS

I EHD DEFINITION

Electrohydrodynamics (EHD) is the study of electric field phenomena and their relationship to dielectric media and ion plasma.

II OUTLINE

This proposal consists essentially of:

(a) A review of experimental work performed to date and empirical results obtained thereby;

(b) A discussion of known theory and possible further theoretical development;

(c) A series of project outlines aimed at developing practical design criteria for the exploitation of EHD phenomena.

III EHD GENERAL DESCRIPTION

In essence, EHD is the study of high-intensity electric field phenomena and their influence on non-conducting (dielectric) media. It is in many respects analogous to the study of magnetic field phenomena and their influence on conducting media and electric currents-through which we have developed the host of electromagnetic devices we enjoy today.

There is a fundamental difference, however: Magnetic fields influence or are influenced by certain conductors, electric currents, etc. In contrast, high-intensity electric fields interact with dielectric media, including gases such as air and, according to the fundamental laws of electricity and magnetism, a vacuum. Even as a magnetic field can be "shaped" by the geometric design of the field-producing components, so can electric fields be shaped by paying careful attention to the geometric design of the electrodes. In fact, in this way it has been possible to establish a considerable differential force between the device-essentially a condenser-and its dielectric environment.

The establishment of such a force with respect to air, a vacuum, or any other dielectric medium results in thrust being imparted to the device with respect to its ambient medium. If the device is held fixed, the medium moves and the effect of a pump is achieved. If the device is free to move, it accelerates in the direction of the force according to Newton's Third Law of Motion, and the effect of propulsion is achieved. It is towards the exploitation of these potentials that this proposal is primarily directed.

IV QUALIFYING CONSIDERATIONS

Empirical data developed through years of privately financed research indicate that:

(a) Proposed applications of EHD should result in energy conversion efficiencies greater by many orders of magnitude than those now possible or contemplated from any other competitive technology.

(b) The validity of the claims made for EHD can be reconfirmed by a relatively small expenditure of research and development funds.

(c) Development of fundamental design criteria for the construction of full-scale devices can be programmed into a series of relatively inexpensive projects.

(d) Construction of full-scale equipment will result in a major break-through in space vehicle propulsion, pumping, particle acceleration, etc.

(e) Development of full-scale equipment is not contingent on a complete theoretical explanation of the phenomena involved.

(f) Full theoretical justification of EHD phenomena may provide the basis for a new appreciation of fundamental physical laws in the area of field-energy/mass relationships.

V EHD PROJECT OBJECTIVES

The proposed end-result objectives of any research and development effort in EHD are as follows:

(a) An electrically-powered space vehicle propulsion system with a specific impulse reckoned in millions of seconds, the life of which would be limited only by the duration of its electric power source-i.e., a propulsion system that requires no expendable working fluid.

Laboratory devices weighing 100 grams (~ 3.5 ounces) less power source have produced a thrust of 110 grams, for an electrical power expenditure of 5OO watts (250,000 volts @ 2.0 milliamperes). This experiment was performed in air (1 atmosphere). Supplementary research indicates much greater efficiency (same thrust for less power input) results when operated in a vacuum (10^{-4} mm. Hg. or better), when the current drops to about 2.0 microamperes.

This performance compares with the ion propulsion unit being operated at NASA's Lewis Research Center, which weighs several pounds (kilograms) and produces 28.35 grams of thrust for a power input of 1,200 watts (10,000 volts @ 120 milliamps). It produced these results in a 10^{-8} mm. Hg vacuum.

Even disregarding the disadvantage it suffers due to its environment (air @ 1 atmosphere), the EHD device shows an energy conversion efficiency many times that of the ion unit.

(b) Direct translation of electrical energy into mechanical (rotary) energy has been achieved in a simple demonstration turbine. This EHD plasma turbine is about 10 inches in diameter, and when energized with a 50,000 volt power supply it accelerates to something over 100 revolutions per minute. Current used is of the order of 0.5 milliamperes.

(c) Effective pumps for dielectric fluids-including cryogenic liquids, gases, etc.-containing no moving parts have been built and demonstrated. One of these about 18 inches long and six inches in diameter pumps air through a one-half-inch diameter pipe at a rate of 250 feet per minute for a power consumption of 38,000 volts and less than one milliampere. Efficiency of this device improves materially at fluid working pressures above one atmosphere and below 10^{-3} mm. of Hg. In the region between, the glow discharge causes high-to-prohibitive ohmic losses.

(d) A high vacuum pump is readily visualized as a special application of (c). This should be capable of producing a vacuum on the order of 10^{-9} mm. of Hg or better - thus enabling the hard vacuum of outer space to be simulated in the laboratory.

(e) A meteorite simulator is yet another special application of (c). The same pump principle can be utilized to accelerate sand (or other dielectric particles) in a continuous stream to velocities of 100,000 feet per second or better. This compares to 18,000 feet per second now achieved through the use of light gas guns such as those employed by NASA's Ames Research Center.

(f) Electric Power Generation-particularly of very high voltages (several million)-is essentially the converse of the thrust production principle. The name for the device is Flame-Jet Generator. ln this instance a shaped electrostatic field constricts and excites a high-velocity powered flow of a medium, as from a jet flame. This results in high free electron density which increases along the length of the flame jet. When this electron concentration is picked off by specially designed electrodes, the structure acts as an electric power generator.

A flame jet generator has yet to be built. However, empirical data supports its feasibility. The main problem would be the selection of materials of construction with adequate electrical and high-temperature properties, though it seems likely that a satisfactory solution to this problem could be found in current development work in the refractory metals (tungsten, columbium, etc.), graphite and certain of the ceramics (such as silicon nitride which has excellent electrical, chemical, and mechanical high temperature properties).

VI EHD THEORETICAL DISCUSSION

The theory behind observed EHD phenomena is not entirely clear, but appears to be related to the laws governing electrostatic fields. These include:

Electrophoresis - the force exerted on a charged particle in the presence of electric fields (Coulomb force), and which is proportional to the electric charge and the field strength.

Dielectrophoresis - the force exerted on dielectric materials in non-uniform electric fields. This force is approximately proportional to the dielectric constant, field strength, and field gradient, with the force tending to move the dielectric in the direction of increasing field strength.

Stress Systems in Dielectric Media- (First formulated by Helmholtz). As outlined by Sir James Jeans "The Mathematical Theory of Electricity and Magnetism" (Cambridge University Press, 1951, Page 177) these consist of:

A Tension ___ per unit area in the direction of the lines of force;

A Pressure ___ per unit area perpendicular to the lines of force;

A Hydrostatic Pressure ____ acting in all directions.

(Where K = dielectric constant, R = electric field density, and ___ = density of the dielectric medium.)

No serious effort has been made to equate these theories and formulae to observed EHD phenomena. However, it seems feasible that careful vector, analysis of the interrelated field/ dielectric forces and stresses may in part at least explain the observed results.

Among the observations are these:

Device thrust (EHD force) increases directly as K (dielectric constant of the medium).

Device thrust (EHD force) increases as the square of the voltage (in some special cases this has been observed to be a cubic function), starting with a minimum observable effect thought to be at about 10,000 volts. Thrust and current in air are found to vary with pressure according to the following relationship: (See graph)

Note that with a moderate reduction in pressure below one atmosphere, current rises catastrophically and thrust terminates. This is the region of so-called "glow-discharge" in which the air ionizes and becomes a conductor, virtually "shorting" the electrodes.

A significant feature of the curves is that ' except for this limitation, thrust remains constant with the reduction in pressure down to 10^{-6} mm. of Hg, while current consumption falls off sharply demonstrating the system's improved efficiency as a hard vacuum is approached.

An additional consideration in the development of EHD theory is the effect of so-called "ion winds"-plasmas accelerated by the electric field. In the operation of EHD lift devices, a toroidal flow of the medium (air, for example, or dielectric oil) is clearly evident.

Though procedures have been developed to calculate thrust purely on the basis of ion wind, their validity has neither been proved nor disproved. They appear to be generally reliable under the limiting condition of an appreciable atmosphere from which a plasma can be generated, but fail to explain the continuing constancy of thrust at very low pressures-such as 10^{-6} mm. of Hg, which is the lowest pressure at which measurements have been taken.

For this reason the strong indication remains that thrust results primarily from electrostatic field stresses - rather than plasma flow. Thus EHD may prove more efficient in a hard vacuum (10^{-12} mm. of Hg) than in air, where the induced plasma actually seems to result in unnecessary power consumption. It seems certain that fundamental EHD theory will become clearer with further experimentation.