ADVANCES IN ASTRONAUTICAL PROPULSION

PROCEEDINGS OF A SEMINAR HELD IN MILAN
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INTRODUCTORY REMARKS ON SPACE PROPULSION PROBLEMS

RIASSUNTO - L'Autore, considerate le enormi distanze da percorrere in un viaggio interplanetario e la limitatezza delle velocità raggiungibili alla partenza, per mezzo degli attuali razzi a propellenti chimici, presenta brevemente alcuni nuovi tipi di propulsori in bassa spinta ma di funzionamento abbastanza lungo per permettere il raggiungimento graduale invece che quasi impulsivo, delle velocità necessarie.

ABSTRACT - The Autor, looking to the enormous distances that involves an interplanetary flight and to the limited velocities now attainable by conventional chemical rockets,shortly introduces some new kinds of propulsion charaterized by lower thrust but much higher specific impulse, which would permit the gradual attainement of the necessary velocities.

RÉSUMÉ - L'Auteur, après avoir souligné la limitation des vitesses qu'on peut attaindre à présent par des fusées à propulsion chimique, par rapport aux enormes distances propres de voyages interplanetaires, présente brièvement des nouveaux types de propulseurs caractérisés par une poussée très faible mais ausssi par une impulsion specifique extrèmement elevée, qui pourraient lentement accélerer le navire spatial jusqu'aux vitesses nécessaires.

When we talk of astronautics in our lifetime and in the lifetime of the next few generations, we really mean interplanetary flight. According to Dr. ZWICKY, the nearest fixed star (Proxima Centauri) is located at a distance of 4.29 lightyears from us. Dr. TSU of the Westinghouse laboratories, has calculated that, with our present means of propulsion, a round trip to this nearest fixed star would require a time period of 500 years. Only if we can use vehicles with a velocity comparable to the velocity of light, for example, vehicles accelerated by photon rockets, or by nuclear-electric rockets with very low spe-

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cific weights, can we consider that such a trip may be undertaken in a reasonable time period.

The outer frontier of interplanetary travel is well defined by the trajectories of the planets belonging to our solar system; the transition from the atmosphere of our globe to outer space is somewhat arbitrary but the altitude of the atmosphere is very small in comparison with the distances we have to deal with in interplanetary space missions.

If we consider a definite space mission, we may define an « equivalent velocity » as the initial velocity which enables us to carry out the mission without subsequent acceleration, using auxiliary devices only for the task of guidance.

Table 1 contains a list of space missions indicating the equivalent velocities corresponding to the individual missions.

It is evident that if we exclude additional propulsion along the trajectory, most of the interplanetary space missions require initial velocities which we are unable to realize by the use of chemical rockets. It may be possible in the future to use nuclear rockets to reach such velocities. It is known that serious work is

TABLE 1

Equivalent velocities for space missions, feet per second

500 Nautical mile orbit	27,000
Escape from Earth	37,000
Earth to Moon and Return . .	83,000
Earth to Mars Orbit and Return	100,000

done in the U.S.A. on several methods of nuclear rocket propulsion. Performance data for solid-core and gas-core nuclear rockets are shown in Fig. 1. In most of the projects, one has to face material problems connected with the high temperatures occurring in the nuclear reactors to be used for rocket purposes. An interesting attempt to use nuclear energy for high accelerations, without extraordinarily high temperatures (except for short intervals at the base of an accelerating platform), is represented by the Orion project. The fundamental idea of Orion is to use a large number of small fission bombs, which create a successive sequence of blasts each acting on a surface during an extremely short time and creating in this way a practically continuous thrust.

The great advantage of chemical boosters is a favorable thrust/weight ratio. Fortunately, the time necessary for most of the space missions allows the use of propulsion devices with a relatively unfavorable thrust/weight ratio; in other words, after an initial boost through the atmosphere, against air resistance and gravitational forces, we can use propulsion systems which are rather heavy and bulky and create only a small thrust over a very long time period. Required

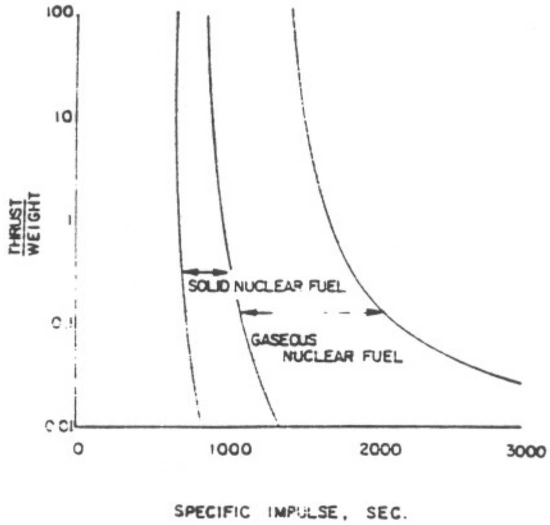

Fig. 1. — Nuclear rockets.

thrust to weight ratios for various space missions are summarized in Table 2.

In the following lines, we give a short review of various ideas and experimental hardware projects relating to space propulsion. Furthermore, we shall

TABLE 2

Thrust/weigt ratios for space missions

Takeoff from Erth	3×10^{-4}
Fast transfer from Earth orbit to Moon orbit	10^{-3}
Fast transfer from Earth orbit to orbit of Mars or Venus	10^{-2}
Fast transfer from Earth orbit to orbit of outer planets	1.5

consider briefly the possibilites to win energy for such thrust devices by conversion of energy that is either available in space or else easily stored in our vehicles.

First, we should mention the various ideas which are based on the use of an electric field to produce thrust. Such devices can be divided into electrostatic and electromagnetic thrust-producing devices.

a) The *electrostatic rockets* use an electric field for the acceleration of ion or colloidal particles. The specific impulses realized with colloidal particles are smaller than those obtained with ion rockets. Development of the ionic rocket involves at least two major problems: first, how to produce ions without requiring very high temperatures at surfaces where the atoms are ionized and to remove the electrons without producing a strong negative charge at the electrode; second, how to accelerate the ions and neutralize them at high speeds. There are several ionic rockets at an advanced stage of development. Schematic diagrams showing how the ions may be produced are shown in Fig. 2.

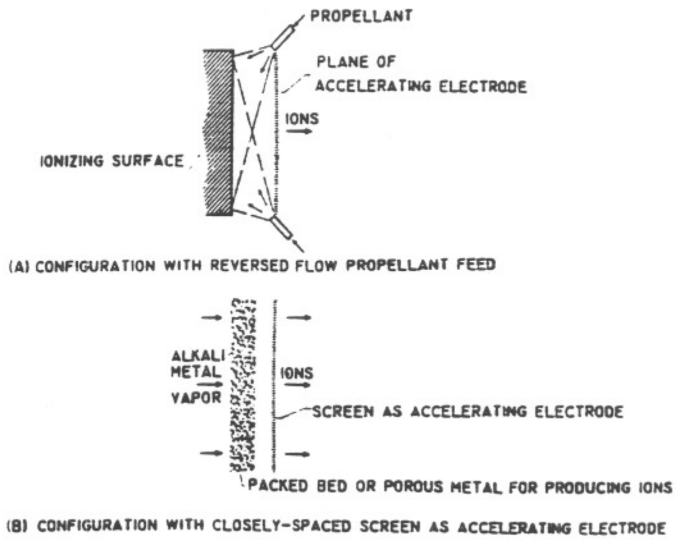

Fig. 2 — Ion rockets.

b) The *electromagnetic rockets* are based on the use of the principles of magneto-fluid-dynamics (MFD), a branch of science and technology also called mag-

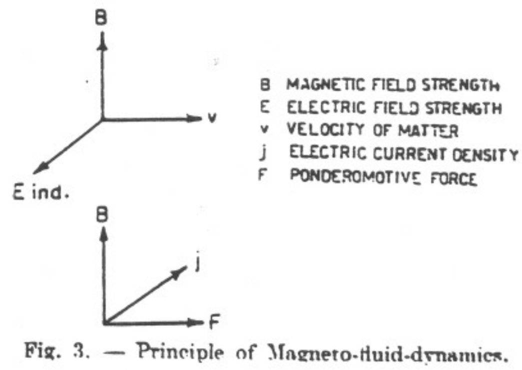

Fig. 3. — Principle of Magneto-fluid-dynamics.

neto-hydro-dynamics (MHD). The Figs. 3 and 4 provide simple illustrations of the basic phenomena used in thrust-producing devices. The upper diagram in Fig. 3 shows qualitatively the induction of an electric field E by moving a conductive medium (plasma) with the velocity v perpendicularly to a magnetic field B, the lower diagram in the same figure shows how a ponderomotive force is produced by an electric current j perpendicular to the magnetic field B. Now let us look at the Fig. 4. It is evident that in order to obtain an acceler-

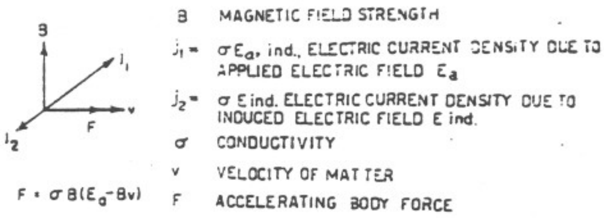

Fig. 4. — Principle of Magneto-fluid-dynamics.

ating force acting on the conductive medium we need an electric current j_1 which is larger than the electric current j_2 induced by the motion of the plasma through the magnetic field. The accelerating body force will be equal to

$$F = \sigma B (E_a - B v)$$

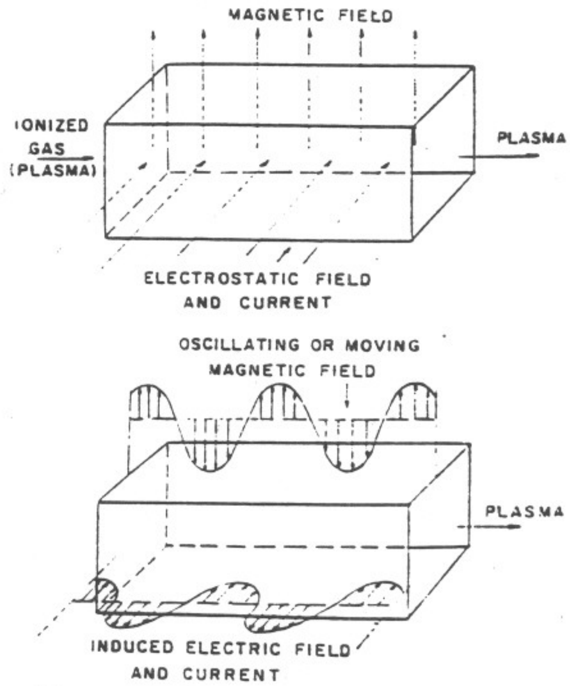

Fig. 5 — Applications of Magneto-fluid-dynamics.

where σ is the electric conductivity of the plasma, E_o designates the electric field which has to be imposed to the system and $\sigma B^2 v$ is the electric current induced by the motion. We may consider the production of acceleration by using either a direct or an alternating current and using either a steady or a traveling magnetic filed. The flow and acceleration of a plasma through combined electric and magnetic fileds is shown in Fig. 5.

As projects promising success in the not too distant future, we may mention:

1. the T-type shock-tube accelerator (see Fig. 6) developed by the General Electric Company;

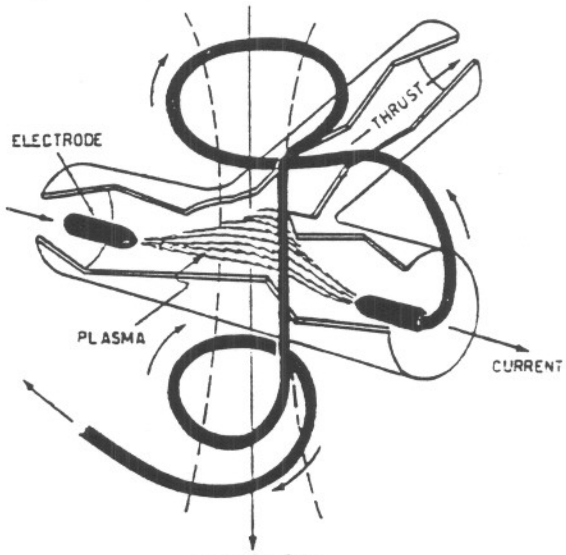

Fig. 6 — Acceleration of plasma T-type shock tube GE.

2. the magnetic annular shock-tube accelerator (see Fig. 7) proposed and developed by AVCO;

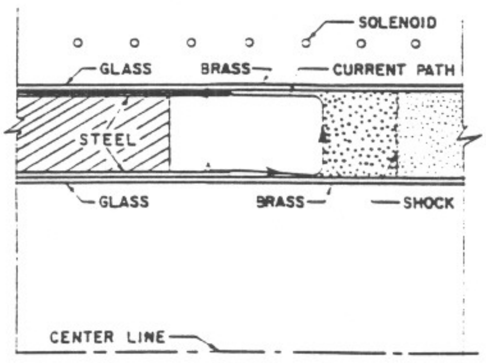

Fig. 7. — AVCO accelerator.

3. the so-called « pinch accelerator » of Republic Aviation. It is evident that the pinch-effect, i.e. keeping away the accelerated hot plasma from the walls of the device by magnetic forces, would be an ideal method to be applied in accelerators. Unfortunately the instability of the pinch means serious limitations.

All of the nuclear-electric propulsion devices would profit greatly by any progress made in the direction of reducing the weight of machinery producing magnetic fields (see Fig. 8). Perhaps radical progress will be possible in this field, as happened, for example, in the case of reduction of the weight of gas turbines in the last decades.

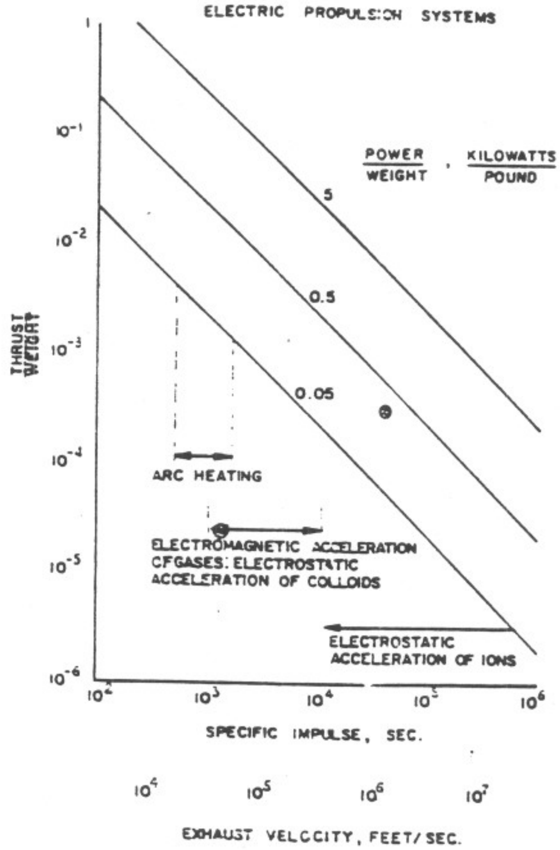

Fig. 8. — Comparison of electric propulsion methods.

Concerning the conversion of energy into propulsive force, we note the following developments:

1) *Direct conversion* of heat into electricity either by:

a) the thermoelectric effect (known for more than 150 years as the Seebeck Effect);

b) the thermoionic effect, which leads to devices of much lower weight but requires higher temperatures for operation (above 1500° Kelvin).

2) *Fuel cells* producing electric energy from electrochemical processes.

3) *MFD generators*, i.e. a kind of rotating machinery using the magneto-fluid-dynamic phenomena for thrust production.

All of these methods can be used for the conversion of solar energy received by appropriate devices; some allow the exploitation of magnetic and electric fields existing in space.

I hope that these brief remarks will help to classify and clarify the ideas dis cussed by different authors in the following chapters of this volume.