Scientists propose fusion rockets for Mars mission

More than three years after LaRouche insisted that a Mars colonization program would have to use fusion-powered rockets, new research is eyeing the plasma focus. Charles B. Stevens reports.

At least in formal terms, the recently released NASA "Report of the Synthesis Group on America's Space Exploration Initiative" has acknowledged the argument of Lyndon LaRouche against the feasibility of manned flight to Mars using chemical rockets and therefore traveling a ballistic route. Presidential candidate LaRouche, in his 1988 national television broadcast "The Woman on Mars," stated that his policy as President would be to develop rapidly fusion rockets as a precondition to colonization of Mars within a 40-50 year period. At that time, as well as in various earlier published locations, Mr. LaRouche called for establishing a permanent colony on Mars of more than 100,000 people "by approximately the year A.D. 2027." He further specified that that goal could only be realized through the development of superhigh-power, high-impluse nuclear fusion rockets capable of making the 60 million mile trip to Mars in a couple of days. One such fusion rocket would have a power output equal to 10 times the current rate of world energy consumption and would have a thrust sufficient to maintain the equivalent of one Earth gravity (1 g) throughout its flight. As LaRouche emphasized in his proposals, such new, high-power technologies would give an immense boost to the U.S. and world economies.

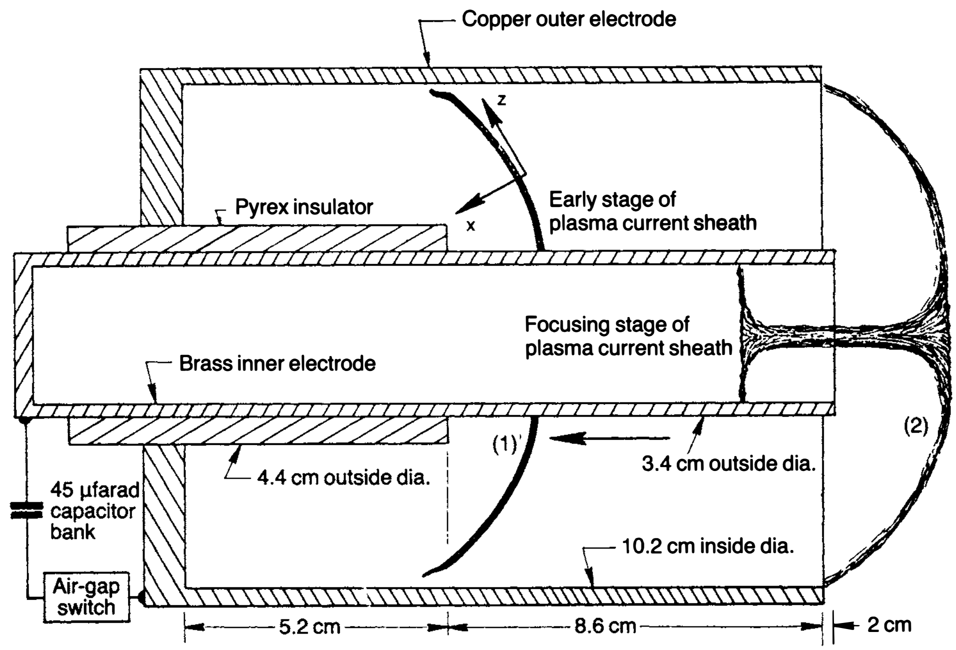
When LaRouche first made his "technical" proposals for colonizing Mars, more traditional agencies involved in long-term space planning, such as the NASA Paine Commission, were focused upon existing chemical rocket technologies, which would take upwards of a year to make the trip to Mars. Now, leading scientists, such as Dr. George Miley of the University of Illinois, Dr. Edward Teller of Lawrence Livermore National Laboratory, and the U.S. government's own Synthesis Group, headed by retired astronaut Lt. Gen. Thomas P. Stafford, are putting forward the need for faster nuclear rockets and the fact that the technology required can be demonstrated over the coming decades. Clearly such a project orientation would have important defense implications.

The March 18 issue of *Aviation Week & Space Technology* magazine, in an article entitled "Nuclear Rockets Gain Support For Propelling Mars Mission," reported: "The Synthesis Group emphasis on nuclear propulsion is sparking a flurry of activity inside and outside the U.S. space agency. Increasingly, nuclear rockets are seen as the most practical means of sending explorers to Mars and the only possible vehicles for visiting other planets." *Aviation Week* quotes astronaut Franklin Chang-Diaz, "If we're going to be serious about exploring space, we're going to have to come up with something better than chemical rockets."

While clearly the Bush administration's economic policy is diametrically opposite to that of LaRouche, whose focus is upon infrastructure development and rapid infusions of productivity into the economy, in order to make the United States a technology-exporting country, nonetheless certain circles in Washington see fission and fusion power development as essential to their more limited aims. In fact, where LaRouche emphasizes the need to rapidly introduce the most advanced technologies to the Third World, Bush is seeking to bar technology transfer to the misnamed "developing" sector, while engaging in trade war with Europe and Japan. This said, the present discussion of fission- and fusion-powered rockets is of real interest.

For example, we note the discussion of potential economic spinoffs of a nuclear rocket-powered colonization of Mars in the *Aviation Week* report: "The new emphasis on nuclear propulsion for manned space exploration is seen as a way to

FIGURE 1
Schematic cross section of plasma focus



The plasma focus consists of two cylindrical electrodes, one placed inside the other. In the schematic, a cross section of the outer copper electrode and inner hollow center brass electrode are indicated. These two "coaxial" electrodes are separated by a Pyrex insulator. The entire assembly is placed within a vacuum chamber, which is not shown in the diagram. A current pulse is switched into the plasma focus from a capacitor bank. This leads to the formation of annular plasma sheath near the Pyrex insulator end, which is marked (1) in the diagram and shown in cross section. This sheath accelerates down the length of the space between the electrodes—left to right in the diagram—and forms a plasma pinch at the righthand, open end of the machine, which is marked (2) in the diagram.

Source: Winston Bostick, "The Morphology of the Electron," *International Journal of Fusion Energy,* January 1985.

accelerate critical industrial technologies. Although not often articulated, that goal—advancing U.S. economic competitiveness—underlies much of the Bush administration's interest in lunar and Mars missions."

In his Mars colonization proposal, LaRouche emphasized that the kind of program he advocated, which would entail a thousandfold increase in available energy per capita here on Earth in order to realize the infrastructure necessary to build and maintain a city on Mars, would pay for itself long before it was completed. The payback is generated in the form of new technologies which spill over from the project into other areas of the general economy. The Kennedy Apollo program paid the U.S. back many times over in just this way: first, through a generous supply of credit at low borrowing costs to those investing in use of the Moon project technologies, and second, through investment tax credit incentives, to encourage concentration of job-creating high-technology investments in U.S. industries. In a United States vectored toward being an international force fostering development, these same policies would be essential to rescue the country from the present economic debacle which is sending it into a rapid collapse of its physical economy as well as its financial superstructure.

The key economic feature of the Mars project is associated with measuring the increases in energy-density and energy-flux densities of employed technologies in terms of orders of magnitude on an exponential scale. For example, in the Mars project, we are moving from production of energy in generating units on the scale of gigawatts, to units on the scale of terawatts—a thousandfold or greater increase in the energy-density per capita for new space technologies, as compared with the most advanced Earth-based technologies of today. Also the energy-flux density at the point of production and application will increase even more dramatically, approaching levels congruent with the energetics of controlled "matter-antimatter" reactions.

Nuclear fusion rocket technology

There are two distinct types of fusion rockets that have been scoped out in some detail and approach the requirements specified by LaRouche. The first is that type which would be propelled by laser fusion. That is, intense laser pulses would be utilized to ignite small pellets of fusion fuel. The resulting microexplosion would then be channeled by a magnetic nozzle to produce the rocket thrust. Such a system is reviewed in some detail in the March 20, 1987 *EIR* article, "Powered Flight to Mars in Less than Two Days," by Heinz Horeis, and in the *EIR Quarterly Economic Report,* First Quarter

1987 (see References).

An alternative fusion-based approach was recently reviewed by Prof. George Miley and his collaborators from the University of Illinois Fusion Studies Laboratory, in a paper presented to the June 1991 Plasma Science Conference of the Institute for Electrical and Electronic Engineers at William and Mary College in Virginia. The paper, "Computer Model for Space Propulsion Using the Plasma Focus," was completed as part of ongoing research supported under contract with Edwards Air Force Base in California.

The printed abstract notes: "A generalized power flow model has been developed to study use of a fusion source to provide thrust and electrical power for a spacecraft. At present, a Dense Plasma Focus (DPF) is modeled as the fusion reactor. Theoretical scaling laws are used, but they will be further benchmarked as data become available from the University of Illinois' DPF. In that experiment, a special electrode design is used to optimize thrust production and direct measurements are in progress. The DPF model evaluates the thrust produced from electromagnetic acceleration of plasma by J×B (rundown), and calculates the average fusion power produced in the pinch per pulse. The overall system model calculates the power required by the reactor and magnetic nozzle, and sets propellant flow to obtain a desired thrust/specific power ratio. Input parameters include: plasma focus electrode dimensions, capacitor bank voltage, turbine-generator efficiency, effectiveness of magnetic nozzle, material temperature limitations, etc. Component masses are calculated and propulsion performance is given in terms of: thrust, I, thrust-to-weight, jet power, α, initial payload mass fraction, and ΔV." (See Technical Appendix.)

The late Winston Bostick, formerly of the Stevens Institute in New Jersey, was the leading advocate and a leading pioneer of plasma focus research, as well as a close collaborator and friend of LaRouche. As described in scores of articles appearing over the past decade and a half in the Fusion Energy Foundation's *Fusion* magazine, *EIR*, and more recently, in *21st Century Science & Technology*, the plasma focus is the almost ideal energy compresser and transformer. The plasma focus efficiently transforms low-voltage electricity into extremely dense, high-velocity fusion plasmas. As emphasized in the Miley presentation, the plasma focus is almost an ideal system for "electromagnetic acceleration of plasma."

In fact, the growing interest in the Dense Plasma Focus as a potential fusion rocket is by no means surprising, if one simply examines its close relationship to the configuration of current designs of high-specific-impulse rocket engines.

Advanced rocket designs

In general, rocket performance is measured in terms of specific rocket thrust—acceleration—and propellant exhaust velocity. Both of these parameters are determined by the specific rocket power—the rocket engine power in watts divided by the rocket's mass. And this can be determined in the first approximation by the energy produced per kilogram of rocket fuel.

Near-term advanced rocket designs are primarily directed toward providing the most efficient means to lift satellites from low Earth orbit to geosynchronous orbit, with the minimum expenditure of propellant mass. This is achieved with low-thrust, high exhaust-velocity systems.

The first type, which is scheduled to be deployed by the mid-1990s, is that of the arcjet. The simplest concept is electrothermal, which uses electrical resistance heating of the propellant (resistojet) or arc heating in the same manner (arcjet). Next are the electrostatic devices that accelerate ionized gas plasma, using a high-voltage grid like that of a vacuum tube which is closely related to z-pinch gas puff systems and plasma guns. If the propellant consists of the atoms of a single element, such as cesium or mercury, it is an ion rocket. If very small particles (groups of molecules) are used, it is a colloid rocket. The advantages of the last two rockets compared with chemical types is that ionized particles can be accelerated to very high velocities, which translate into high performance (high specific impulse).

A more advanced type are magnetoplasmadynamic (MPD) arcjets and pulsed plasma accelerators, which are propulsion devices that derive thrust from the application of electromagnetic body forces. These forces result from the interaction of internal and external magnetic fields with currents that are passed through the propellant gas (plasma). MPD arcjets tend to be mechanically simpler than the electrostatic thrusters, but the physics is more complex. A high thrust-per-unit exhaust area (10,000 times that of the ion engine) makes such thrusters desirable. The MPD is scheduled to be developed by about the year 2000.

The plasma focus actually looks exactly like the most advanced form of the MPD (see **Figure 1**). And the operation of the MPD follows exactly along the same lines as the plasma focus in that the "plasma" is accelerated to high velocities to form the propellant stream of the rocket by the interaction of electric currents (J) with the magnetic fields (B), as discussed in the Miley abstract. In the case of dense magnetic plasmas, these interactions are highly nonlinear. (Just look at the example of electromagnetic pulses [EMP] from high-altitude nuclear explosions. Viewing the magnetosphere plasma as consisting of electrons and ions leads to an electric dipole model for EMP generation which only ranges over a few hundred miles at relatively low intensities. In actuality, the magnetosphere organizes itself into plasma filaments, like those in the plasma focus described below. These plasma filaments lead to magnetic dipole generation of EMP. This was discovered accidentally in the case of the U.S. when the "lights went off" in Hawaii due to very intense EMP, thousands of miles from the nuclear weapon test site over Johnson Island.)

As we shall see, these nonlinear processes in dense magnetic plasmas not only lead to much more efficient electromagnetic forms of interaction, but even generate entirely new forms of matter-energy, such as plasma superclusters consisting of bubbles made up of billions of electrons and ions which act like single atoms. (Many scientists believe that these plasma focus-generated superclusters are actually a form of ball lightning.)

Miley's projections

Professor Miley's study of the plasma focus is designed to provide the most conservative projections which come closest to matching the existing outputs of his small experimental plasma focus facility. Even given these constraints, the plasma focus rocket he projects demonstrates significant capabilities well beyond those projected for standard nuclear fission designs. Other studies indicate that by scaling up the system by a factor of 100 to 1,000 in terms of specific rocket power, rocket performance approaching the specifications of LaRouche for rockets capable of constant accelerations of 1 gravity could be achieved with the plasma focus.

The Miley rocket is projected to have a 100,000 kilogram payload. The maximum fusion power output is about 5 billion watts. This fusion power produces a rocket propellant power (or "jet power") on the same order, about 4 billion watts. The specific rocket power would then be 50 kilowatts per kilogram. The maximum thrust would approach 1 million newtons, which is about equal to the weight of the payload. The maximum ΔV of our V_f projected is on the order of 30-40,000 meters per second—or 3,000-4,000 seconds specific impulse. The projected maximum ratio of the payload to the takeoff mass (M_p/M_o) is 0.15.

The Teller proposal

In a paper, "Space Propulsion by Fusion in a Magnetic Dipole," presented to the First International A.D. Sakharov Conference on Physics, in Moscow May 27-31, Dr. Edward Teller of the Lawrence Livermore National Laboratory proposed that rockets powered by magnetic fusion reactors be developed for missions to Mars and for deep space probes: "A conceptual design is discussed for a fusion rocket propulsion system based on the magnetic dipole configuration. The dipole is found to have features well suited to space applications. Example parameters are presented for a system producing a specific power of 1 kilowatt per kilogram, capable of interplanetary flights to Mars in 90 days and to Jupiter in a year, and of extra-Solar System flights to 1,000 astronomical units (the Tau mission) in 20 years. This is about 10 times better specific power performance than fission systems. Possibilities to further increase the specific power toward 10 kilowatts per kilogram are discussed, as is an approach to implementing the concept through proof-testing on the Moon."

Dr. Teller's coauthors are A.J. Glass and T.K. Fowler of Livermore, J.F. Santarius of the University of Wisconsin Fusion Technology Institute and A. Hasegawa, who is currently at Bell Labs and is one of Japan's leading laser fusion scientists.

The plama focus: an energy-compressing transformer

What makes the plasma focus such an experimental powerhouse is the fact that it functions like an ideal energy compression and storage transforming device with no moving parts—except the plasma which it generates. Depending on its initial setup mode, the plasma focus can efficiently generate intense, high-energy clustered-ion and electron beams, microwaves, x-rays, and neutrons. More recently it has shown that it can produce copious heavy ion fusion—a result which directly bears on its capacity for short-lived radioisotope production.

In general, the plasma focus's versatility and compactness derive from its ability to compress and transform energy. In terms of its basic operation, the laboratory plasma focus looks like a large radio tube. It consists of two electrodes, both shaped like hollow cylinders, with one placed inside the other as shown in Figure 1.

The motive power for the device consists of a pulse of electrical current which is generated by a bank of capacitors. Capacitor banks provide an initial means of compressing energy. They can be charged up in a low-voltage circuit utilizing a commercial power line input. Once brought up to full capacity, the bank can be discharged in a relatively short pulse through the use of fast-acting circuit switches which reconfigure the bank into a high-voltage circuit. The resulting compressed current pulse is simultaneously switched into one of the plasma focus electrodes.

The plasma focus vacuum chamber, in which the two cylindrical electrodes are located, is usually filled with a small quantity of hydrogen gas, though alternative materials such as oxygen, nitrogen, and carbon can be utilized.

Within the few billionths of a second that the current pulse takes to arrive at the electrodes, a large electric field is generated between the electrodes. This field causes the fill gas to "break down." That is, free electrons in the gas are accelerated to high velocities, and they cause gas molecules to become ionized through collisions. Within a few billionths of a second, the gas is transformed into an ionized plasma. This takes place at the end of the plasma focus where the two electrodes are mechanically connected together with an intervening layer of insulator. This breakdown plasma has a high electrical conductivity and thus permits the flow of electric current between the electrodes—the current is driven by the electric field. In fact, as is shown in the accompanying box, an annular sheet of conducting plasma rapidly forms between the electrodes.

In order to comprehend how the plasma focus compresses, stores, and transforms the energy input, it is essential to examine the fine microscopic plasma structures that are formed by this annular plasma sheath. But to give an immediate overview, what happens is as follows: The current flowing through the plasma current sheath interacts with the ambient magnetic field and generates a force which accelerates the plasma sheath laterally away from the insulator end of the focus toward its open end. (The ambient magnetic field is generated by lateral current flows in the cylindrical electrodes.)

While the plasma sheath undergoes acceleration toward the open end, it gathers up more mass deriving from the background gas fill. It also absorbs a significant fraction of the electrical current passing through it and stores this energy input in the form of intense magnetic fields within the plasma sheath.

Once the sheath reaches the open end of the two cylindrical electrodes, a plasma pinch is generated. As this compressed plasma is formed, the stored magnetic energy is transformed back into intense electric fields and kinetic energy of the plasma electrons and ions. Small nodules of dense plasma form within the pinch plasma. These dense plasma nodules sustain energy densities trillions of times greater than that of the capacitor bank. Intense, relativistic electron and ion beams are generated together with bursts of x-rays. The ambient densities and temperatures are sufficient to support copious thermonuclear reactions with resulting neutron outputs.

In other words, the plasma focus "focuses" the energy of the input current pulse both in time and space. It also transforms the energy up to much greater voltages in the process. What allows this to take place is the emergence of highly organized plasma structures which can withstand energy densities trillions of times greater than ordinary materials. These highly organized plasma structures are actually "force-free" Beltrami vortex filaments, as shown in the box.

Plasma superclusters

In fact, scientists working at the New Jersey Stevens Institute of Technology report discovering a new state of matter. The new form of matter acts macroscopically like one atom, but is made up of what would ordinarily be called billions of atoms. Also, the new form of matter is generated under what appears to be high-temperature plasma conditions. Researchers also term this configuration a plasma supercluster.

The superclusters are either formed within the pinch plasma as the Bostick nodules of the plasma focus, or by the combination of the electron and ion beams emission of the pinch plasma. In any case, the superclusters can be separated from the plasma focus pinch by sticking a glass tube near the pinch to permit a route along which the supercluster can travel.

The supercluster consists of millions of electrons and ions that are organized in the most unusual fashion. They form a spherical bubble with virtually all of the material being on the surface of the sphere. There are extremely high magnetic fields in the bubble—hundreds of megagauss in strength. (These fields may be sufficiently intense to generate matter-antimatter reactions.) The bubble is highly resilient and will bounce many times on the film before breaking up.

When the superclusters break up, the components come out with very high energies, like those found in a particle accelerator. Also the energy of the component electrons and ions is very coherent—monoenergetic. As a result of these measurements, it is found that the supercluster is acting like one big atom or "quantum" system. Furthermore, the density of the bubble surface is near that of solid materials.

The supercluster bubbles are described as having a "negative temperature." This means that the supercluster will always transfer energy to matter with positive temperatures, no matter how high that temperature may be. Furthermore, this means that the supercluster bubble will not absorb electromagnetic radiation. (It is like the electromagnetic "shields" which are so often described in science fiction movies.) The bubbles are therefore negentropic relative to the observations of closed systems of ordinary matter-energy.

These results indicate that the "virtual neutron," or hydron, formation which has recently been hypothesized in cold fusion research, could be taking place in these plasma focus-generated superclusters. And rather than resulting from pair-wise particle interactions, the hydron in effect derives from the more general circumstance of this new state of matter, a sort of macro-quantum state. In fact the original hypothesis for the formation of hydrons was derived from work on high-density plasma cluster fusion research.

These new physical states open up prospects for the plasma focus to provide the energy densities needed to access matter-antimatter reactions. Experiments to explore these possibilities are now being designed.

The results from plasma focus experiments over the past several decades demonstrate that this compact device has among the best scalings for producing fusion.

If nothing else, the Synthesis Group report demonstrates that LaRouche was technically on the mark. And despite the failure to implement LaRouche's science-driver programs, such as his Strategic Defense Initiative and Mars colonization proposals, continuing research advances demonstrate that fusion is best for space propulsion. As Dr. Gerald Kulcinski of the University of Wisconsin Fusion Technology Institute informed a recent Princeton conference: "Fusion will be to space propulsion what fission is to the submarine."