Abstract

This paper introduces novel propulsion and/or on-board superconducting high-temperature superconducting power plants suitable for aerospace planes and space vehicles. The propulsion thrust is provided by electro-magnetically accelerating and expelling ingested or stored, ionized gases at high velocities. Take-off and short duration maneuvering thrusts for aerospace plane applications are provided by proton-antiproton reaction. The power for the electro-magnetic accelerators and for the on-board production of the antiprotons is supplied by "third generation" inertial confinement type fusion power plants. The ignition temperature and pressure for the fusion is achieved by appropriately shaped beams of antiprotons from storage synchrotrons. Alternatively, two fuel pellets may be brought to ignition temperature and pressure for the fusion by appropriately shaped beams of antiprotons from storage synchrotrons. In order to establish a truly routine confinement, presently under development, will be too complicated, too heavy and cumbersome for vehicle applications. The inertia confinement of pellets of the tandem pellet accelerators may be used to transmute one element into another, and its single accelerator configuration may be adapted to launch payloads into space.

1.0 Introduction

In order to establish a truly routine access to space, we have to develop alternatives to the present inefficient rocket propulsion systems and the RAM/SCRAM jet propulsion systems considered for the aero-space planes. Instead of accelerating large amount of gasses to the relatively low velocities obtainable by chemical processes, we have to accelerate small amount of gasses to very high exit velocities. Since the propulsive power of an exhaust gas stream is a square function of the exhaust velocity and the efficiency of the propulsive system increases exponentially with that velocity, a propulsion plant utilizing on-board fusion power source and means to accelerate gasses to very high velocities will make space travel more affordable and more cost effective.

One way to achieve essentially unlimited exit velocities is by accelerating ionized gasses (plasma) by electro-magnetic means. Another way is to heat the propulsive gasses by the tremendous energy released through antimatter annihilation.

This paper proposes unique, integrated propulsion/power plants based on one of the so-called "third generation" fusion reactions power plasma accelerators and/or on-board superconducting synchrotrons producing antiprotons for the proton-antiproton accelerators. The propulsive systems are "air-breathing", thus the accelerated gas does not add to the take-off weight of the vehicle, further increasing its thrust-to-weight ratio and its "specific impulse". The proposed propulsion plants can be used for aerospace planes as well as for space vehicles. Apart from the superconducting turbo-generators and the pellet feeding mechanisms of the fusion power source, the propulsion systems have no moving parts, thus they are inherently reliable, safe and offer low maintenance requirements and long life.

2.0 The Power Plant

It is a safe bet that the power source of the future aerospace planes and space vehicles will be one of the nuclear fusion processes. This has long been agreed and decided upon by the science fiction writers, whether from North America, Sri Lanka or Poland. Just like the submarines "came to age" through nuclear propulsion, the true Space Age will be ushered in by electro-magnetic plasma accelerators or matter/antimatter propulsion systems powered by fusion reactors.

2.1 Third Generation Fusion Process.

It is my belief that the so-called "first generation" fusion reactors, utilizing the fusion of deuterium/tritium and magnetic confinement, presently under development, will be too complicated, too heavy and cumbersome for vehicle applications. The inertia confinement of pellets of the above-mentioned light elements/isotopes by laser or ion beams would perhaps be more feasible. Since most of the fusion reactions of the deuterium/tritium/lithium group are accompanied by harmful radiations of neutrons and/or gamma rays, and since the abundance and ready availability of the fuel is not as pressing for aero-space applications as for large-scale commercial power generation, I propose the development of the boron-proton fusion process which is sometimes referred to as "third generation", for space propulsion. The result of the B-p reaction is three helium nuclei and energy - without harmful radiation.

The B-p reaction occurs when boron 11 is bombarded by fast protons: \( ^{11}B + p \rightarrow ^{4}He + ^{7}Li + \gamma \)
resulting in a spectacular explosion of the compound nucleus - three alpha particles are ejected, all in the same plane to conserve momentum. The energy gain is 8.7 Mev; about 50% of it in the form of electro-magnetic radiation, 50% as the kinetic energy of the alphas. No neutrons!

To achieve useable power output from the reaction, it is necessary to compress and heat a suitable compound of B and H (such as Decaborane: B₁₀H₁₄, for example) to thermonuclear "ignition" condition; i.e. to a condition where the protons have sufficiently high kinetic energies to overcome the potential barrier of electrostatic repulsion as well as enough chance to eventually bore into and explode the boron nuclei. The physical size of the pellet and the essential parameters of the process are chosen to ensure that practically the whole pellet undergoes fusion in an explosion resembling a miniature thermonuclear bomb. The electromagnetic radiation and the kinetic energy of the alphas are converted into thermal energy in the reaction chamber. This thermal energy is converted into electrical power by a closed-cycle gas turbine driving a superconducting generator.

Compressing and heating of the fuel pellets may be accomplished by several ways, three of which are presented here:

- ignition of a single pellet by antiproton beams
- ignition by colliding two pellets at high speed. The pellets are accelerated and heated by antiproton beams
- ignition by collision; accelerating and heating by microwaves and by laser beams

2.1.1 Ignition by Antiprotons.

Referring now to the center part of Figure 2, the spherical reactor chamber (1) has cooling passages (2) in its walls for the working medium of the gas turbine (3). The working medium may be an appropriate inert gas, such as helium (since the product of the reaction is He, it can be obtained by periodically "scrubbing" the reactor). After the thermal energy, carried by the helium, is converted into mechanical power in the gas turbine, the gas passes through a condenser (4) and returns to the cooling passages of the reactor. To achieve compactness and light weight, the gas turbine shall be of the high speed, high temperature type with ceramic blades and magnetic or gas bearings, and the generator (5) of the superconducting type. The condenser may be a suitably cooled surface of the craft.

The spherical fuel pellet (6) is shown in the center of the chamber (the feeding mechanism is omitted for clarity). The Decaborane (or similar compound) is encased in a solid boron (or material with high boron content) shell. The outer surface of the spherical shell is coated with layers of suitable "pusher" and "ablator" materials. The "ablator" layer, a hydrogen compound, when hit by the antiprotons, will explode outward, while the "pusher" shell will drive inward, compressing and heating the fuel to fusion.

The antiprotons utilized to trigger the fusion are stored in "cross-belt" shaped storage synchrotrons (7). (See more about synchrotrons under the heading "The Integrated Plant"). The moment the pellet reaches the center of the reactor, four small "puffs" of antiprotons are released from storage by the "kick-out" magnets (8). The beams of antiprotons are shaped on their way to the chamber into spherical "cups" by electro-magnetic circuits depicted at (9). This "shaping" assures that the triggering antiprotons fit over the outer surface of the pellet and that they arrive to their destination at the same instant.

2.1.2 Ignition by Colliding Two Pellets

2.1.2.1 Acceleration and Heating by Antiprotons

This arrangement, depicted at Figure 3 on the following page, is suitable for larger aero-space crafts. Here the reactor (1) is located between two long pellet accelerator assemblies (10). The two pellets (5) are introduced into the accelerators by feeding mechanisms (11). The pellets in this case are cylindrical, the "ablator" and "pusher" materials being applied at their receding-end surfaces.

At the appropriate moment, short pulses of antiprotons, having slightly higher velocities than the final design velocity of the pellets, are introduced simultaneously into the accelerator tubes from the storage synchrotron (7) by the "kick-out" magnets (8). As the pellets race toward the center of the chamber,
Note that the combined velocities of the pellets at impact is $2v$; and 46 km/sec certainly can contribute significantly toward achieving ignition conditions.

2.1.2.2 Accelerating and Heating by Microwaves and Laser Beams.

The pellets can also be accelerated by microwaves and laser beams as indicated in Figure 5. Here, a "race-track" shaped electron storage synchrotron (12) surrounds the reactor chamber and the pellet accelerators (10) and feeders (11). Parts of the straight sections of the "race-track" are equipped with wiggler/undulator magnets (13) of an

**Figure 3**

they acquire large kinetic energies, which at the moment of their head-on collision, are converted instantly into pressure and heat, contributing a sizeable % of the energy required for ignition. The cylindrically shaped "tail ends" of the antiproton beams give the final coup de grace for the fusion reaction.

Although detailed numerical analyses are beyond the scope of a symposium paper, it is worthwhile to look briefly at the velocities obtainable by a pellet accelerator described above. Assuming a pellet geometry and physical properties depicted on Figure 4, and an accelerator length of 10 meters and utilizing elementary formulas from mechanics:

![Figure 4](Image)

we come up with a final pellet velocity of $v=23$ km/sec

and travel time of $T=.0008$ sec.

**Figure 5**
appropriate strength and spacings, suitable for the productions of microwaves as the electron beam, having a velocity close to the speed of light, passes through the magnets. Different straight sections (14) are designed to produce high power laser beams (free electron laser) and flights in the lower atmosphere.

The laser beams also produce high density plasmas near vertical takeoffs and landings. These plasmas are then accelerated in the direction of the pellets' motion by the microwaves, contributing to their accelerating pressure/force.

In this arrangement the reactor chamber has transparent ports (19) through which different branches of the split original laser beams are directed by mirrors (20) to complete the ignition when the pellets collide in the center.

3.0 The Propulsion Plants

3.1 Plasma Acceleration by Microwaves

Referring again to Figure 5, the long, tubular elements (21) on either side of the "race-track" represent the main propulsion plasma accelerators. The propulsive gas (22), in liquid form in most cases, enters the tubes through nozzles (23) and get ionized by X-rays emitted in small, conical angle beams (24) from curving sections of the "cross-belt" type auxiliary electron storage synchrotron (25). All along the length of the plasma accelerator tubes "resonant cavities" are placed (not shown in the illustration) increasing the velocity of the plasma and allowing the radio frequency resonant forces which provide the thrust for the craft. The length of the accelerator tubes can be considerable; 20 - 30 meters for a large scale, of course.

The power for the acceleration is provided by electro-magnetic radiation (microwaves), generated in the straight sections (26) of the main, "race-track" type electron storage synchrotron in a similar manner as discussed for the pellet accelerator - albeit on a much larger scale, of course.

3.2 Antiproton Propulsion

As indicated on Figures 2 and 3, minute amounts of antiprotons can be diverted at the required time from the stored proton beam (free electron laser) by the "kick-off" magnets (26) into appropriate expansion chambers (27). Here, after their encounter with an equal number of protons, their combined annihilation energy heats the propulsive gasses. The gasses expand and exit at high velocities, producing the thrust for the craft. These short and stubby expander can be swivelled around for vertical, or near vertical takeoffs and landings.

A good % of the generated fusion power will have to be devoted to the onboard production of antiprotons during takeoffs and flights in the atmosphere.

Storing large amounts of antiprotons onboard would be as dangerous (and as foolish) as sitting atop a six-story high tank filled with liquid hydrogen and oxygen.

Antiprotons can be produced by bombarding a suitable metal target with high energy protons. Such protons are stored in a large diameter circular proton synchrotron indicated schematically at (28). Some of these protons are diverted by magnets (29) into a high-gain linear accelerator (30), where their energies are boosted to the required level of 5+ Gev. Note the large diameter of the proton synchrotron (28); even with high power superconducting bending magnets (not shown on the illustrations), these high energy particles have to be handled gingerly!

The boosted protons emerging from the linear accelerator (30) hit the target at (31) and undergo a reaction, during which antiprotons are also produced. The antiprotons are then separated, "cooled" and tamed so they can be channeled through the transfer lines (32) to the antiproton storage synchrotrons (7). Here they are corralled at a relatively modest speed and kinetic energy by bending magnets (33) and focusing magnets (not shown on Figures 2 and 3) - until they are called upon to ignite the fuel pellets or produce thrust for propelling and steering the craft.

4.0 The Integrated Plants

The main objective of this paper is to propose means by which the power source and the propulsion components of an aerospace craft could be integrated. Even as we looked at the fusion power plants and then at the propulsion systems separately, common components had to be referred to: the "race-track" electron storage synchrotron for the production of microwaves and laser beams, for example - or the "cross-belt" antiproton storage rings on which both the fusion reactor and the propulsion "expanders" depend.

Although only the barest minimum of details can be presented in a brief symposium paper, it is still necessary to say a few words about the "synchrotrons" so often referred to herein. Synchrotrons are one class of particle accelerators, usually consisting of an alternating pattern of bending and focusing magnets and accelerator cavities (the last two illustrations in this paper), arranged, most often, in a circle. They also have means to insert and divert out the accelerated (or stored) particles. The cross sections and weight of these machines are being steadily reduced. With the development of the new, "high temperature" superconductors, their size and weight will further be reduced to a point where their aerospace application will be practical.

Superconductors at liquid nitrogen
temperature would be ideal, since the propulsive gas in the plasma accelerators will, most likely, be nitrogen, which is easy to ionize and safe to store in liquid form. Nitrogen for the portion of the flight outside the atmosphere could be collected, cooled and compressed during the vehicle's flight through the atmosphere.1

For their ability to produce copious amounts of electromagnetic radiation of different wavelengths (including laser beams - "free electron lasers"), electron storage synchrotrons will soon be common in many branches of the manufacturing and service industries.3,4

Summary and Conclusions

This paper has introduced several integrated aerospace propulsion plants utilizing the latest emerging technologies in physics and engineering. It was not my intention to present an exhaustive, encyclopedic account of the possible alternatives - many more arrangements are, of course, possible. The combination of antimatter and electromagnetic plasma propulsion plants (combining Figures 1 and 4, with the fusion reaction triggered by antiprotons, for example) seems quite attractive. I realize that we are still a long way from air and spaceborne synchrotrons and particle storage rings; (They are still buried in underground tunnels) - maybe as far away as the steam locomotives were from the present day jet engines. But I believe that the existing pace of research and development, and the reality of international cooperation so much in evidence here, will shrink that hundred year span by a factor of ten.

Laser or antimatter? One of the earlier laser fusion apparatus in Livermore, California, was named after Shiva, the Hindu god of love and destruction. They thought the name apt, because of the many "arms" bringing the laser beams to the reactor chamber, and also because Shiva had the ability to emit "annihilating radiation" from his third eye.5

But we may consider this radiation energy originated from the annihilation of protons and antiprotons; a 1,000 times stronger than the most powerful laser they could produce in those days. And we don't need the "arms" which filled a whole 2-story building!

Lasers or antiprotons? Like my fellow countryman, Dr. Teller says, we'll have the pleasure of making all those delicious mistakes still ahead of us. He also said, by the way, in connection with fusion power: "those who know the least about the subject are the ones who talk the most about it!"5

A few words have to be said about the non-aerospace applications of the fusion power plants discussed here. It goes without saying that a terrestrial version of the reactors presented here will end mankind's long quest for practical fusion power, bringing the fire of the stars down to earth. For large-scale power generation, where the radiation shielding and hardening of the reactor will not be a problem, the "first and second generation" reactions of the deuterium-tritium-lithium cycles can, of course, be utilized.

Similarly, the colliding pellets version of the reactors (Figures 2 and 4) may find some non-power applications: two pellets of a certain element (such as lead) could be slammed together with velocities high enough to transmute that element into another (gold?). Thus we might be on the verge of becoming a "Category Six" Civilization, which, according to Arthur C. Clarke, is characterized by the ability to transmute one element into another "on a commercial scale".6

In a somewhat altered configuration wherein only one pellet accelerator is used, the system could be utilized to accelerate payloads into orbit.

A prominent feature of the future aero-space crafts will probably be the large diameter proton storage ring for antiproton production. It is likely that the general appearance of these crafts will also follow that circular shape. This shape will enable us to spin the craft for artificial gravity during coasting.

At last we will have entered the age of the flying saucers!

References