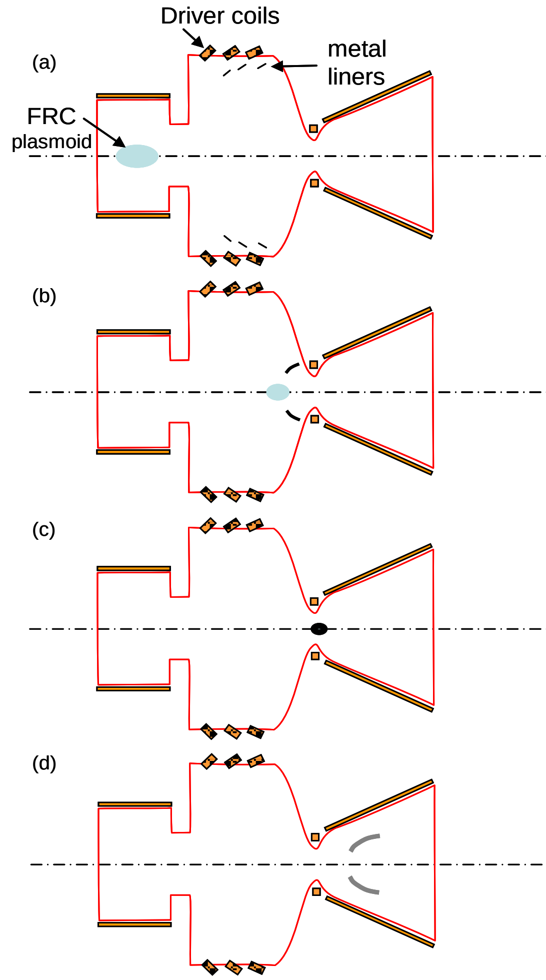
**THE FUSION DRIVEN ROCKET: NUCLEAR PROPULSION THROUGH DIRECT CONVERSION OF FUSION ENERGY.** John Slough[1] Anthony Pancotti, David Kirtley and George Votroubek[2], [1]University of Washington, Plasma Dynamics Laboratory, 15125 NE 90th St. Redmond, WA 98052, sloughj@UW.edu, [2] MSNW LLC 8551 154th Avenue NE, Redmond, WA 98052.




The future of manned space exploration and development of space depends critically on the creation of dramatically more efficient propulsion architecture for in-space transportation. A very persuasive reason for investigating the applicability of nuclear power in rockets is the vast energy density gain of nuclear fuel when compared to chemical combustion energy. The combustion of hydrogen and oxygen has an energy release of 13 MJ/kg, whereas the fission of $^{235}$U yields approximately 8 x $10^7$ MJ/kg and the fusion of deuterium and tritium has a 3.6 x $10^8$ MJ/kg yield. Not as well recognized is the need for high power, high Isp propulsion in Low Earth Orbit (LEO) as it relates to several unmanned orbital maneuvers that are quite costly or not feasible with current chemical propulsion rockets. Of particular value to both military and commercial interests would be a high power orbital tug that can shuttle numerous payloads of several metric tons from LEO to GEO. In addition to the tug, other important in-orbit, high power, high Isp missions from the DoD perspective would include the rapid repositioning of large space assets. These include high ΔV maneuvers such as large plane changes (inclination changes) and phase changes for rendezvous with other space assets, or rapid repositioning of assets over areas of interest.

The Fusion Driven rocket (FDR) represents a revolutionary approach to fusion propulsion where the power source releases its energy directly into the propellant, not requiring conversion to electricity. It employs a solid lithium propellant that requires no significant tankage mass. The propellant is rapidly heated, ionized and accelerated to high exhaust velocity (> 30 km/s) by high gain fusion reactions. This is accomplished with no significant physical interaction with the spacecraft, thereby limiting the thermal heat load to the spacecraft and the need for large radiator mass. The key to achieving this stems from research at MSNW and the UW on the magnetically driven implosion of metal foils onto a magnetized plasma target. In this approach to magnetic fusion, thin bands of lithium metal, initially at large radius, are driven radially and axially inward to provide the convergence and inertial mass required to produce and sustain fusion conditions in a magnetized plasma. A logical extension of this work leads to a method that utilizes these metal liners to not only achieve fusion conditions, but to have the liner serve as the propellant as well (see figure).

The lowest mass system by which magnetic fusion can be achieved, and the one to be employed here, is based on the very compact, high energy density FRC. It is of paramount advantage to employ a closed field line plasma that has intrinsically high $\beta$ (plasma/magnetic pressure ratio), and that can be readily translated and compressed, for the primary target plasma. Only the FRC plasmoid has the linear geometry and sufficient closed field confinement required for liner fusion at high energy density. Most importantly, the FRC has already demonstrated both translatability over large distances as well as the confinement scaling with size and density required to assure sufficient lifetime to survive the compression timescale required. For a sufficiently magnetized target plasmoid like the FRC, the fusion alphas will also be confined providing for fusion ignition as well. The direction of the bands for convergent motion is controlled by appropriately fashioned coils. Virtually all of the radiant, neutron and particle energy from the plasma is intercepted by the encapsulating, thick metal blanket formed during convergence thereby isolating the reactor walls from the fusion process. The absorption of these energies, along with the intense Ohmic heating at peak magnetic field compression, is more than sufficient to vaporize and ionize the lithium blanket. On expansion this lithium plasma drives the magnetic field, introduced into the chamber for driving the initial liner implosion, radially back toward the reactor wall while at the same time protecting the wall from direct plasma impingement. For propulsion, a conically shaped wall is employed (see figure) for conversion of thermal plasma motion into directed energy. The nozzle flux compression can also be employed to derive electrical energy directly from the back emf induced in the driver coils. The energy from the fusion process, along with the waste heat, is thus utilized at very high efficiency.

It is possible to test most of the critical elements in smaller scale laboratory experiments. To that end a full-scale, Aluminum liner compression test facility has been assembled at the University of Washington's Plasma Dynamics Laboratory with sufficient liner kinetic energy (~ 0.5 MJ) to reach fusion breakeven conditions. The two year effort funded by NASA's Innovative Advanced concepts program (NIAC) is focused on advancing the three key areas required to move the Fusion Driven Rocket forward for further development: (1) the physics of the FDR needs to be elucidated and experimentally validated, (2) the design and technology development for the FDR required for its implementation in space fully characterized, and (3) an analysis of the rocket design and spacecraft integration, as well as mission architectures enabled by the FDR should be carried out. Results from the initial liner compression experiments with Aluminum will be presented. The initial spacecraft design, as well as the outcome from a study of several mission architectures and destinations for which this fusion propulsion system would be critical or enabling, will also be presented. In particular a rapid, single launch manned Mars mission will be discussed.