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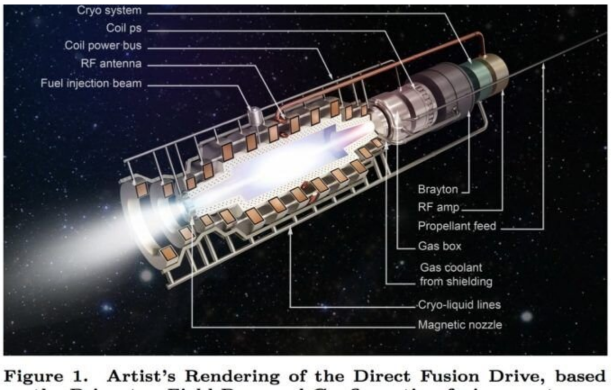
Spacecraft design could get to Titan in only 2 years using a direct fusion drive

19 October 2020, by Andy Tomaswick



Artist conception of the Direct Fusion Drive. Credit: Princeton Satellite Systems

Fusion power is the technology that is 30 years away, and always will be, according to skeptics, at least. Despite its difficult transition into a reliable power source, the nuclear reactions that power the sun have a wide variety of uses in other fields. The most obvious is in weapons; hydrogen bombs are to this day the most powerful weapons we have ever produced. But there's another use case that is much less destructive and could prove much more interesting—space drives.

The concept fusion drive, called a direct fusion drive (or DFD), is in development at the Princeton Plasma Physics Laboratory (PPPL). Scientists and Engineers there, led by Dr. Samuel Cohen, are currently working on the second iteration of it, known as the Princeton field reversed configuration-2 (PFRC-2). Eventually, the system's developers hope to launch it into space to test, and eventually become the primary drive system of spacecraft traveling throughout the solar system.

There's already one particularly interesting target in the outer solar system that is similar to Earth in many ways—Titan. Its liquid cycles and potential to harbor life have fascinated scientists since they first started collecting data on it. And if we properly used the DFD, we could send a probe there in a little under two years, according to research done by a team of aerospace engineers at the Physics Department of the New York City College of Technology, led by Professor Roman Kezerashvili and joined by two fellows from the Politecnico di Torino in Italy—Paolo Aime and Marco Gajeri.

Though still under development, the engine itself exploits many of the advantages of aneutronic fusion, most notably an extremely high power-to-weight ratio. The fuel for a DFD drive can vary slightly in mass and contains deuterium and a helium-3 isotope. Even with relatively small amounts of extremely powerful fuel, the DFD can outperform the chemical or electric propulsion methods that are commonly used today. The specific impulse of the system, which is a measure of how effectively an engine uses fuel, is estimated to be comparable to electrical engines, the most efficient currently available. In addition, the DFD engine would provide 4-5 N of thrust in low power mode, only slightly less than what a chemical rocket would output over long periods of time. Essentially, the DFD takes the excellent specific impulse of electric propulsion systems and combines it with the excellent thrust of chemical rockets, for a combination that melds the best of both flight systems.

All of those improved specifications are great, but in order to be useful, they actually have to get a spacecraft somewhere. The paper's authors picked Titan, largely because it's relatively far away, but also extremely interesting due to its liquid cycles and abundant organic molecules. In order to map the best route to Saturn's biggest moon, the Italian team collaborated with the DFD's developers at PPPL and were granted access to performance data from the test engine. They then pulled some additional data on planetary alignments and started working on orbital mechanics. This resulted in two different potential paths, one where constant thrust was only applied at the beginning and the end of the journey (called a thrust-coast-thrust—TCT—profile) and one in which the thrust was constant for the duration of the journey.

Both journeys involved switching the direction of thrust to slow the spacecraft down to enter into the Saturnian system. Providing constant thrust would put the journey at a little less than two years, while the TCT profile would result in a total trip duration of 2.6 years for a spacecraft much larger than Cassini. Both of those paths would not require any gravity assists, which spacecraft traveling to the outer planets have regularly benefited from.

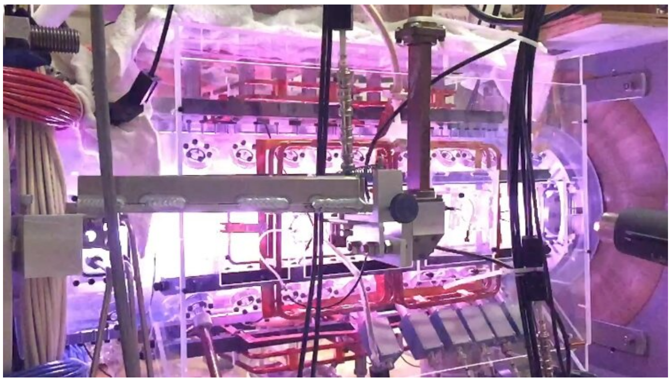


Image of the PFRC-2 DFD Drive at work. Credit: Wikipedia user Cswancmu / PPPL

Cassini, the last famous mission to visit the Saturnian system, used a series of gravity assists between Venus and Earth to reach its destination, a journey which took almost seven years. One important thing to note, says Marco Gajeri, the paper's corresponding author, is that the window that makes these short-trip durations the most efficient opens up around 2046. While not quite 30 years from now, it does give the team at PPPL a lot more time to improve upon their current design.

Other challenges arise once a DFD-enabled probe reaches that Saturnian system, however. Orbiting around the second-biggest planet in the solar system is relatively easy. Transferring orbits to its largest moon is much more difficult. Solving that problem requires tackling the three-body problem, a notoriously difficult orbital mechanics problem that involves solving the orbits of three different orbital bodies (i.e., the spacecraft, Saturn and Titan).

With all the orbital mechanics out of the way and the spacecraft safely in Titan's orbit, it can begin to take advantage of another of the DFD's benefits—it can provide direct power to the spacecraft's systems. Most outer solar system missions rely on radioisotope thermal generators (RTGs) for their power source. But a DFD is, in fact, a power source in addition to being a source of thrust. If designed correctly, it could provide all the power a spacecraft needs for an extended mission lifespan.

That extended mission life span means that the DFD could be useful in a wide array of missions. The authors that studied the mission to Titan also looked at the potential for a mission to the trans-Neptuian objects, which so far have only been visited by New Horizons, which took nine years to reach Pluto. Needless to say, a DFD would dramatically decrease the time needed to make that journey. And if it happens to be operational in the next 30 years, it can start serving as the driving force for all kinds of new exploration missions.

More information: Trajectory design for a Titan mission using the Direct Fusion Drive: webthesis.biblio.polito.it/15184/1/tesi.pdf

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