Fusion-Enabled Pluto Orbiter and Lander

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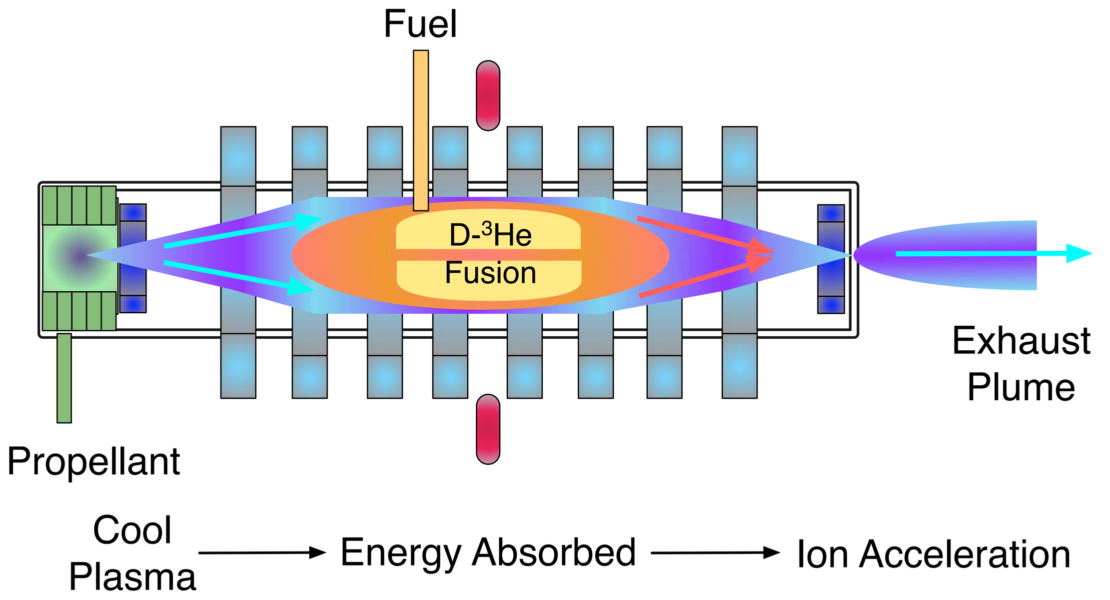
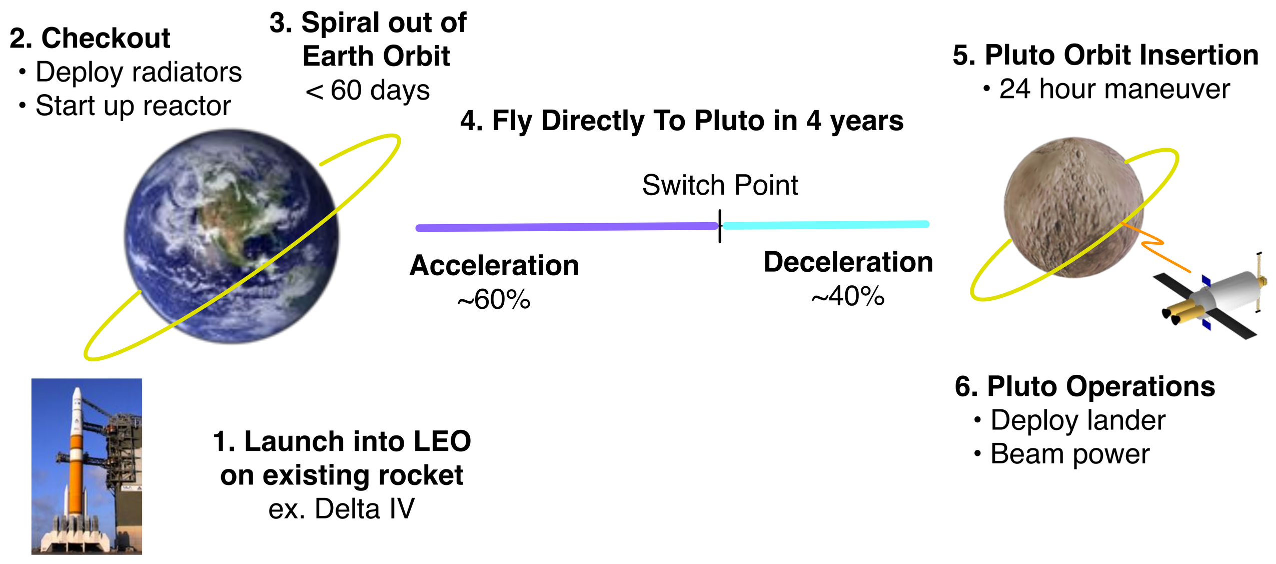
Fusion Rocket

A linear reactor configuration allows power and propulsion from a single integrated device. This would enable new and exciting human and robotic missions in the solar system and beyond.



Mission Concept: Pluto Explorer

Deliver an orbiter and lander in 4-5 years and power the lander from orbit.

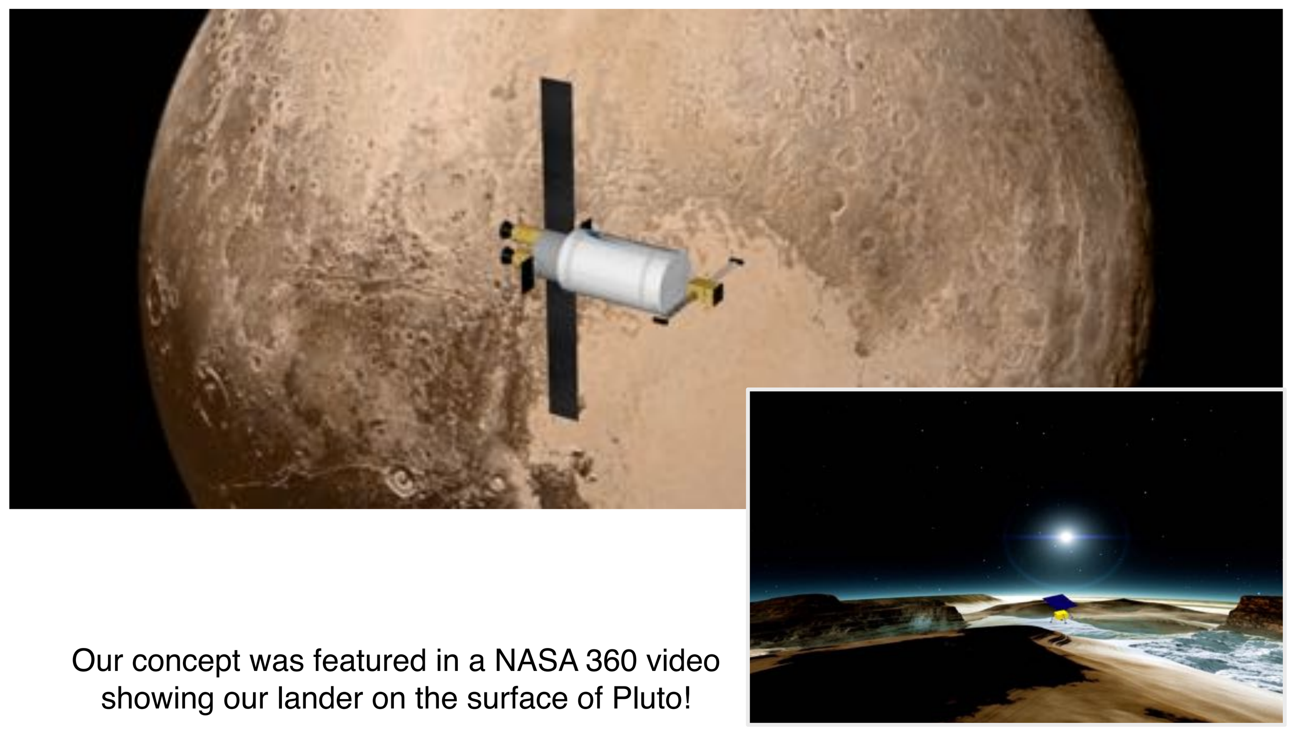


Imagine delivering a payload of 1000 kg to Pluto in only four years, and providing 1 MW of power to the spacecraft on arrival. With this engine, such a mission can fit on a Delta IV - no assembly in space, just launch, start up, and go! The extremely low neutron production of the reactor requires only a modest amount of shielding to achieve multi-year component lifetimes. The megawatt power levels can support high-definition video via optical communication and still provide 30 kW of power to a lander on the surface by beaming power with a laser.

Technology Highlights

This engine provides game-changing levels of power and thrust in a compact package.

- Provide 5-50 N thrust ***AND*** 1-10 MW power per engine
- Fit on a Delta IV launch vehicle
- Fast trip times reduce cost of deep space missions
- No radioactive fuel to launch



Our concept was featured in a NASA 360 video showing our lander on the surface of Pluto!

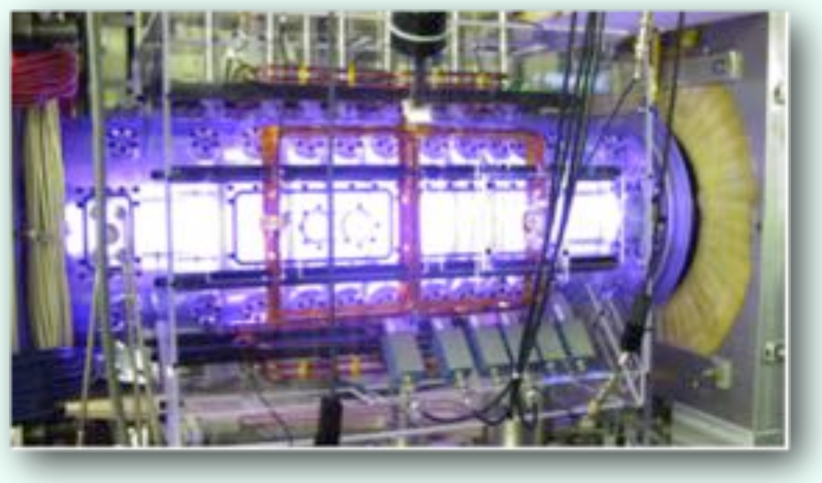
Creating a Small, Clean Reactor

The Princeton Field-Reversed Configuration (PFRC) reactor is a magnetic plasma-confinement device that uses a novel RF heating method.

- Linear solenoid geometry
- Steady-state operation
- Superconducting coils
- Plasma radius of 20-30 cm
- Estimated fusion power levels of 1-10 MW

2nd generation research machine in operation (Princeton Plasma Physics Laboratory).

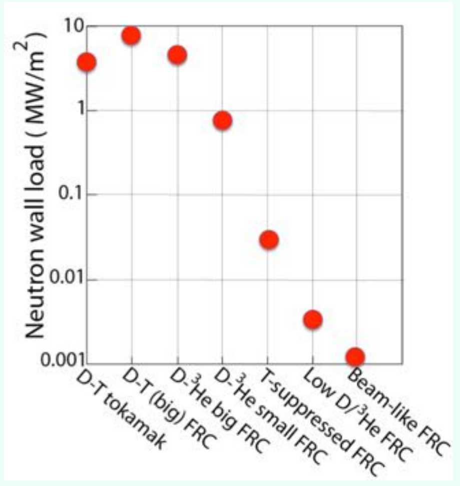
Pulse length: 300 ms
Duty factor: 1%
Field strength: 400* -1500** G
Plasma temperature:
500* - 1000** eV
* achieved ** machine goal

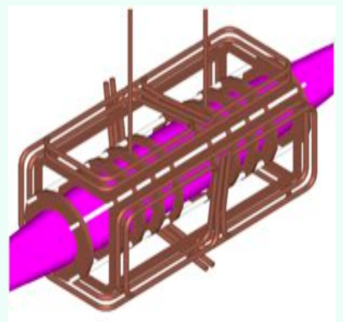


Neutrons are reduced through choice of fuels (D-^{3}He), fuel ratio (D:^{3}He = 1:3), and machine size. Tritium, a byproduct of D-D fusion, is exhausted before it can fuse.

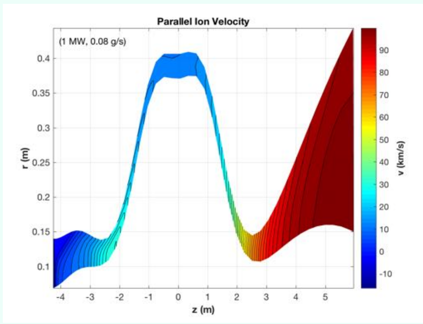
$^2D + {}^3He \rightarrow {}^4He$ (3.6 MeV) + ^1p (14.7 MeV)

$^2D + {}^2D \rightarrow {}^3T$ (1.01 MeV) + ^1p (3.01 MeV)
$^2D + {}^2D \rightarrow {}^3He$ (0.82 MeV) + ^1n (2.45 MeV)
~~$^2D + {}^3T \rightarrow {}^4He$ (3.5 MeV) + ^1n (14.1 MeV)~~

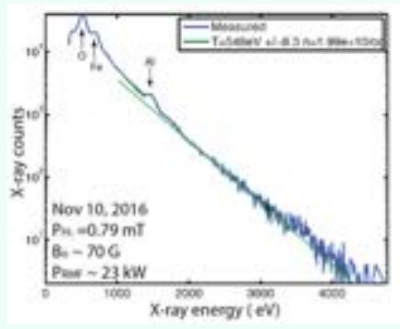




RF frequency power (0.2 to 4 MHz) is applied by antennas outside the plasma vessel.



Propellant heating is modeled by the UEDGE fluid code to study thrust and specific impulse of rocket operation.



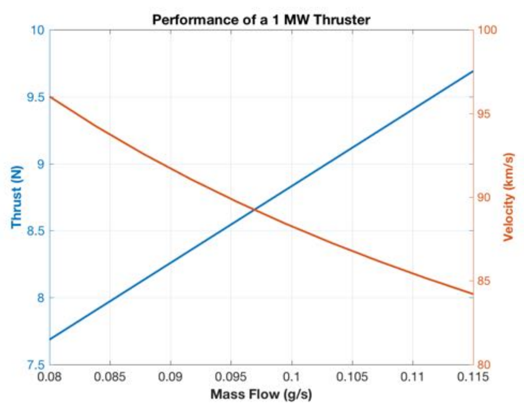
X-ray spectra on the experiment indicate electron temperatures exceeding 500 eV with 20 kW input power

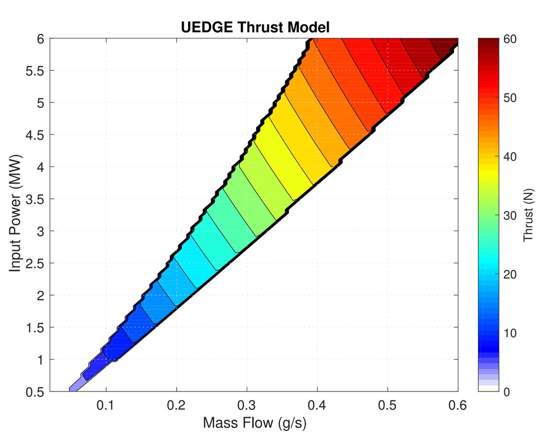
Thrust Augmentation

Increasing the propellant flow rate generates higher thrust.

- Add and ionize more H or D in gas box
- Fusion products primarily heat electrons in SOL
- Magnetic nozzle transfers energy from electrons to ions
- Exhaust velocities from 50 to 150 km/s

We use the UEDGE multi-fluid code (Rognlein) to study formation, heating, acceleration and exhaust of the propellant stream. Propellant (H_2 or D_2) is added to the gas box and ionized there; ions and electrons then flow along the SOL magnetic field, from left to right. As this plasma passes the fusion region, its electrons are heated by the MeV fusion products to 10-150 eV. The warmed plasma proceeds through the magnetic nozzle and the electron thermal energy is converted to directed ion kinetic energy, hence thrust. New results indicate 5-10 N thrust per MW of power into the SOL and Isp of about 10,000 s. About 80% of the power flow into the SOL exits as thrust and 20% is deposited into the walls and gas box.

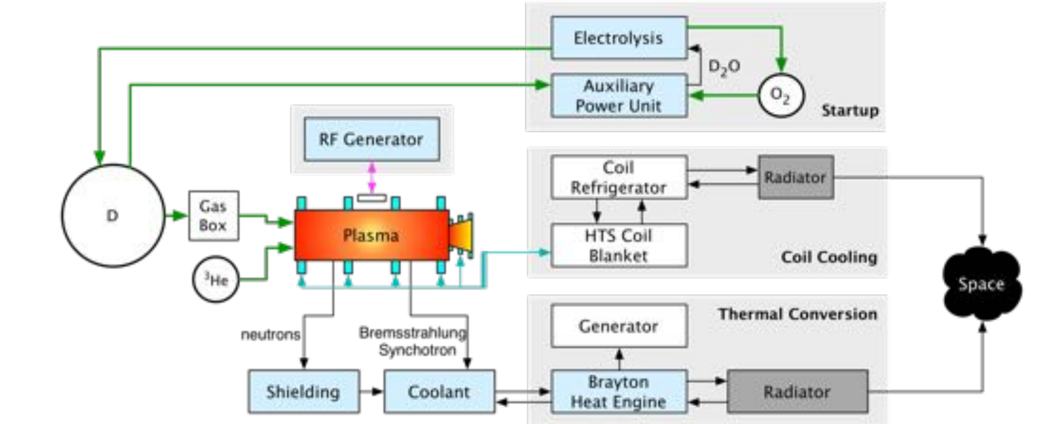


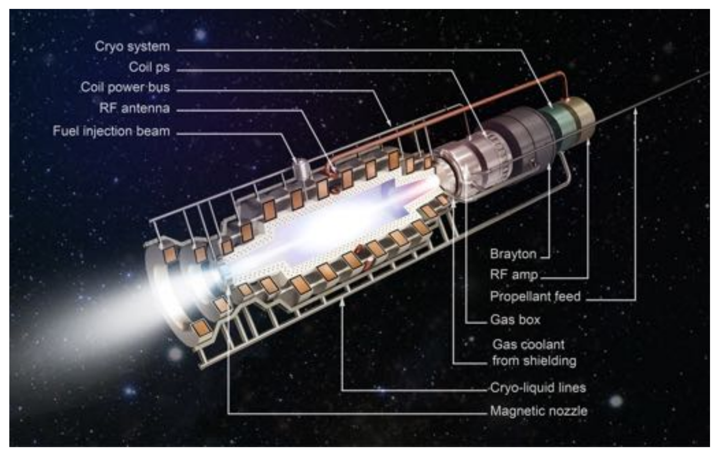


Engine Development

In Phase II, we are analyzing the engine subsystems component by component to develop a detailed mass model. All engine subsystems are based on high TRL technology.

Block diagram of the engine subsystems including the startup engine and the thermal conversion system

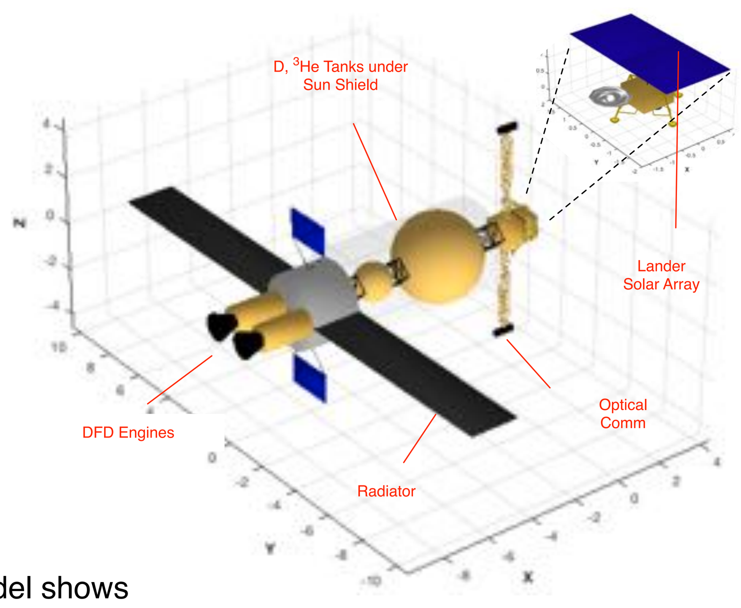




The key metric for evaluating the engine feasibility is the specific power, or power produced per the mass of the engine - including *all* the subsystems and shielding.

Spacecraft Design

Our reference spacecraft has two 1 MW engines, small solar arrays for on-orbit checkout and startup, and large radiators. Deuterium is stored as a cryogenic liquid and the Helium-3 can be stored as a gas.



The MATLAB model shows estimated sizes for the fuel tanks, radiators, and lander solar array for receiving power.

Our point mission design uses a thrust of 6 N and an Isp of 10,000 s, resulting in a 4 year trip time. We used the delta-V to size the fuel tanks. This amount of Helium 3 can be bought off the shelf today!

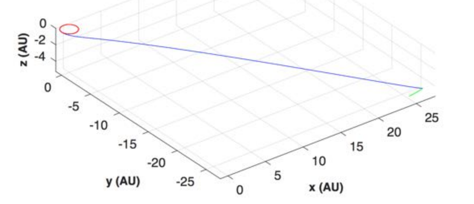
Point Mission Design

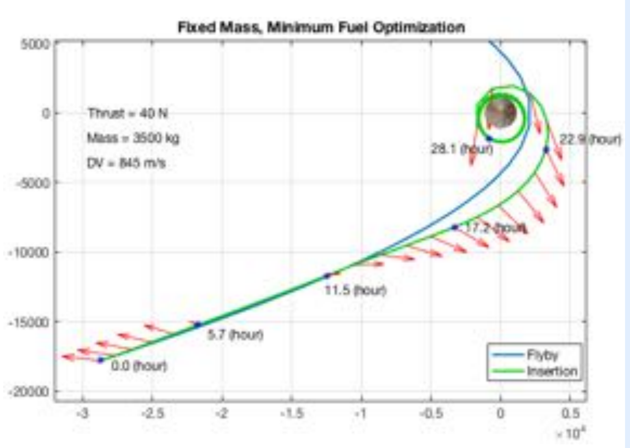
Payload	1000 kg
Thrust	6 N
Isp	10,000 s
Power	1 MW
Specific Power	0.74 kW/kg
Thrust Efficiency	0.4
Lander Power	30 kW
Total ΔV	140 km/s
Total Mass	10000 kg
Engine Mass	1350 kg
Total Trip Time	4 years
Mass ^{3}He	0.5 kg

Trajectory Analysis

Transfer and Insertion into Pluto Orbit

The trajectory to Pluto is essentially a straight line. The spacecraft spirals out of Earth orbit after on-orbit checkout. The deceleration burn leaves the spacecraft in a hyperbolic trajectory, and the powered insertion to Pluto, shown at right, occurs during the final few days of the approach.





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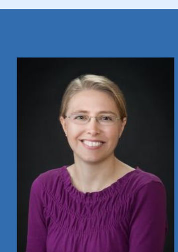

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