Fuel Element for a Centrifugal Nuclear Thermal Rocket

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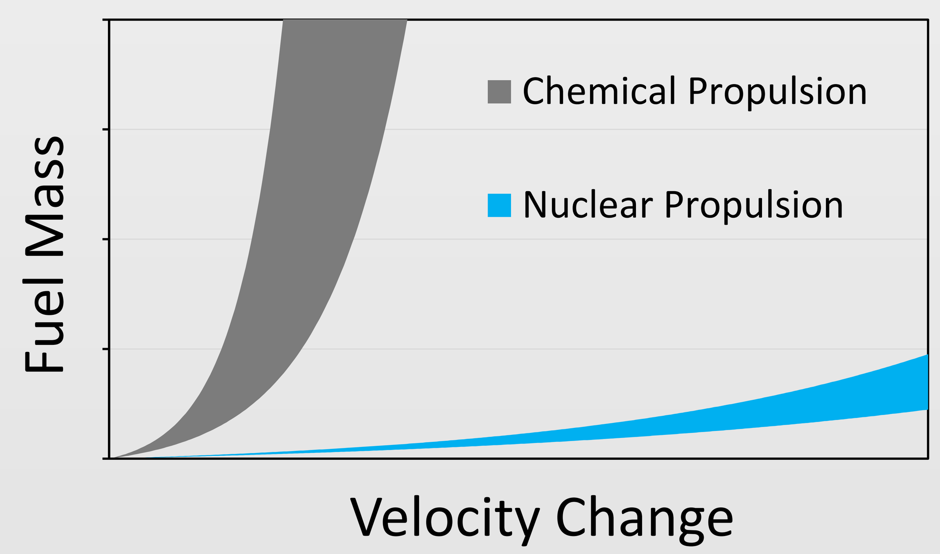
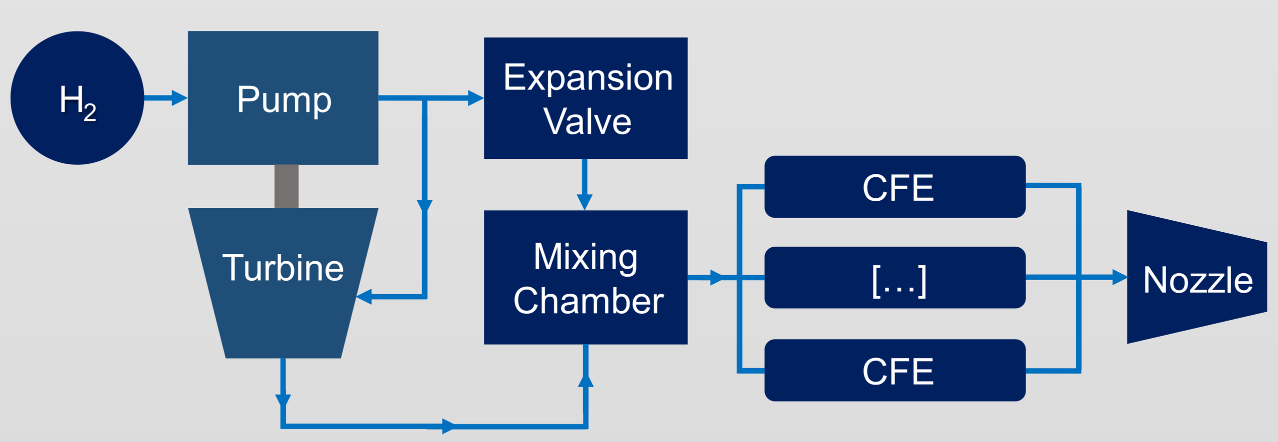
Why Nuclear?

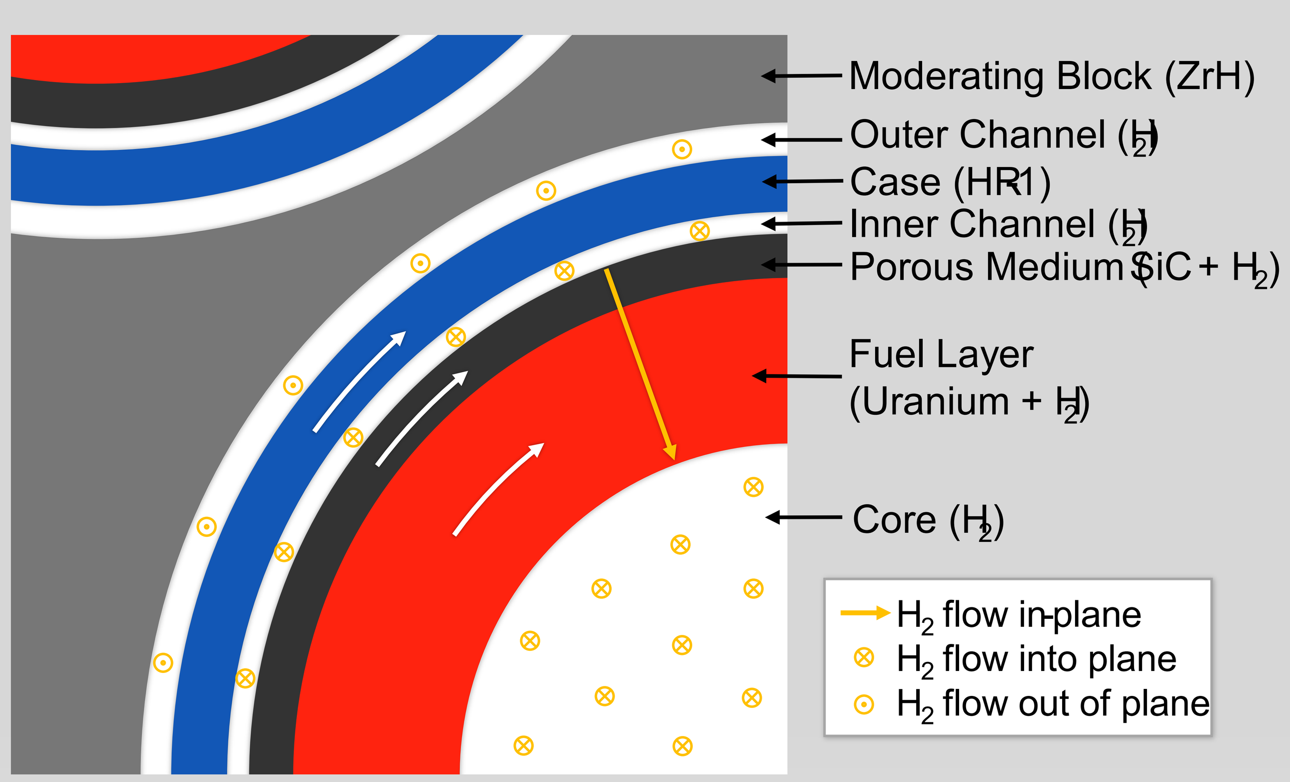
The Centrifugal Nuclear Thermal Rocket (CNTR) is an advanced nuclear propulsion engine proposed by NASA. The CNTR could achieve a specific impulse of ~1800 s compared to ~250 s using chemical rockets and enable round-trip interplanetary flight.



CNTR Design



The CNTR contains 19 centrifugal fuel elements (CFEs) within a shared moderating block. Within each cylindrical CFE, hydrogen propellant is heated by bubbling through a layer of molten uranium. A turbine spins each CFE at 7,000 RPM to generate centrifugal force. This keeps the uranium against the outer CFE wall while hydrogen is ejected out into space.



Goal

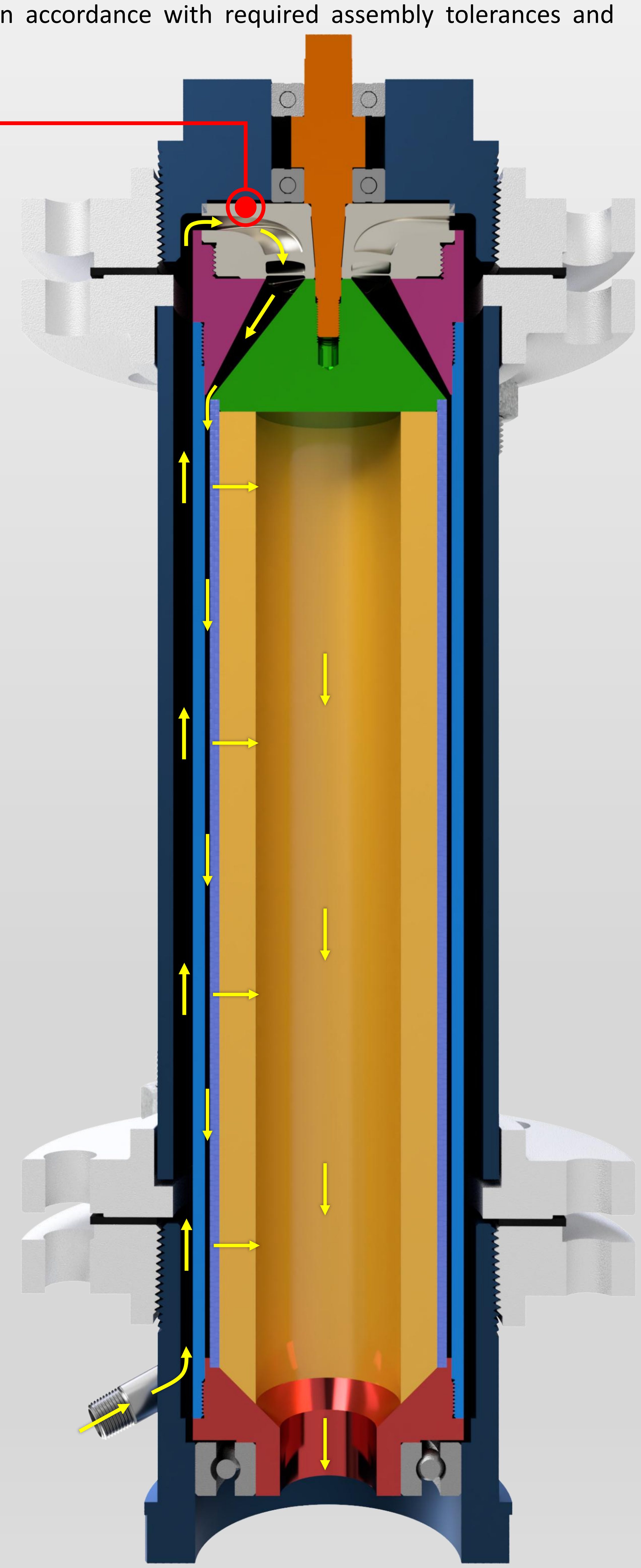
This project aims to design, build, and test a non-nuclear prototype CFE. The baseline configuration for the design point and first-order prototype will be determined from fluid and structural analysis results. The performance parameters will be validated with a test apparatus.

Methods

Thermodynamic, fluid, structural, vibrational, and heat transfer models were used to determine design requirements, validate performance, and develop a prototype geometry. Manufacturing drawings were made in accordance with required assembly tolerances and used for machining and 3D printing.

Turbine

The turbine will be used to spin the CFE as the propellant passes across it. Extensive analysis was done to develop the required blade geometry for optimal flow conditions.



Assembly

The critical components will be assembled via a combination of transition press fits and threaded interfaces. Calculations regarding required torque transfer are used to inform degree of interference and length of thread engagement. Labyrinth seals are strategically placed to control the mass flow of air through the desired channels.

Flow Path

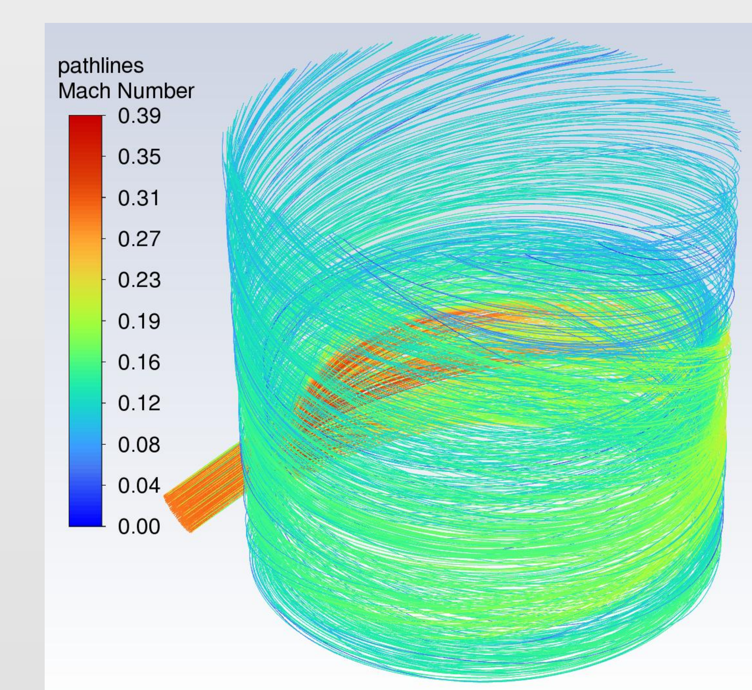
For the prototype, air will replace hydrogen as the propellant, entering the CFE through an inlet pipe and will travel up a channel to spin the turbine. Air will exit the turbine, accelerate through a crossover section, and travel down an intermediary channel between the Case and the Porous Medium. Air will diffuse through the Porous Medium into the core chamber where it will pass through the rotating liquid fuel and be ejected out of the nozzle.

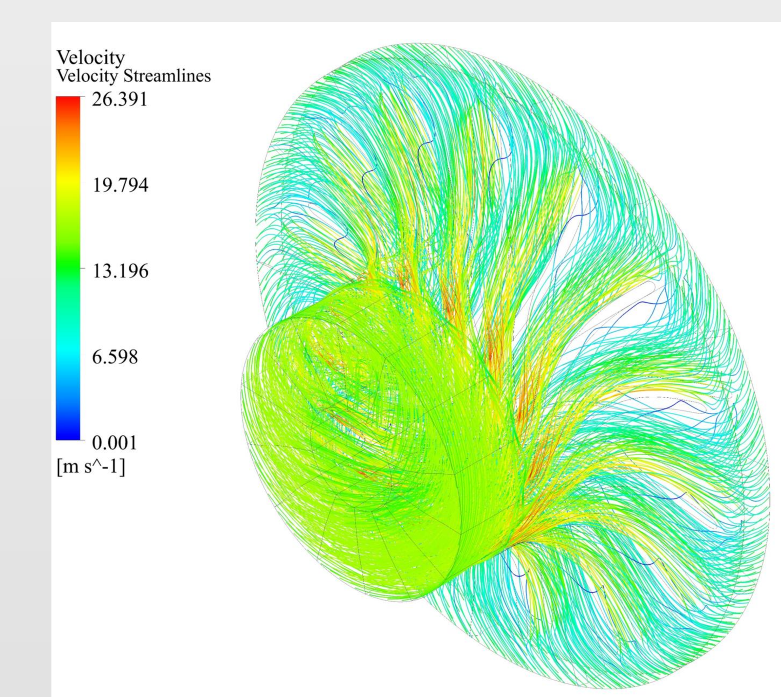
Manufacturing

The components for the prototype will be manufactured through a combination of metal 3D printing, CNC milling, and manual turning. Some components will require tight tolerances to enable the required transition fits and smooth interlocking between threaded interfaces.

Simulation Results

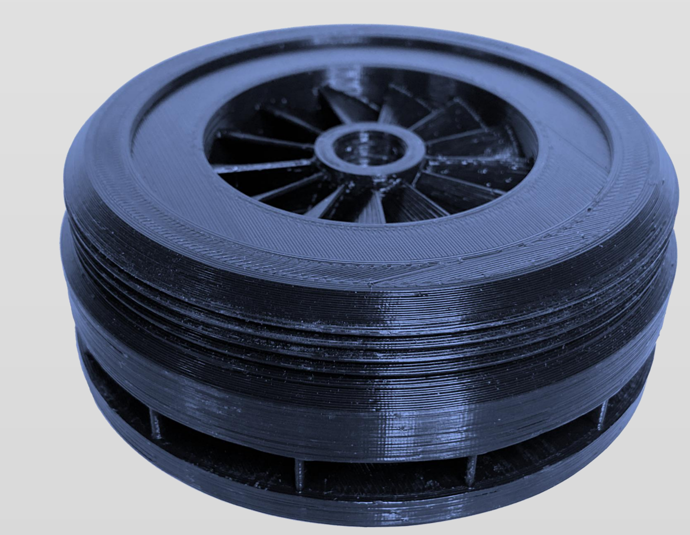
CFE properties and geometry requirements were calculated across 400 different possible engine configurations. After selecting a configuration from these results, computational fluid dynamics were used to validate performance of the turbine and CFE under both the operating conditions of the prototype and of space. Rotordynamic and modal analyses were performed on the system to ensure adequate strength of each component.

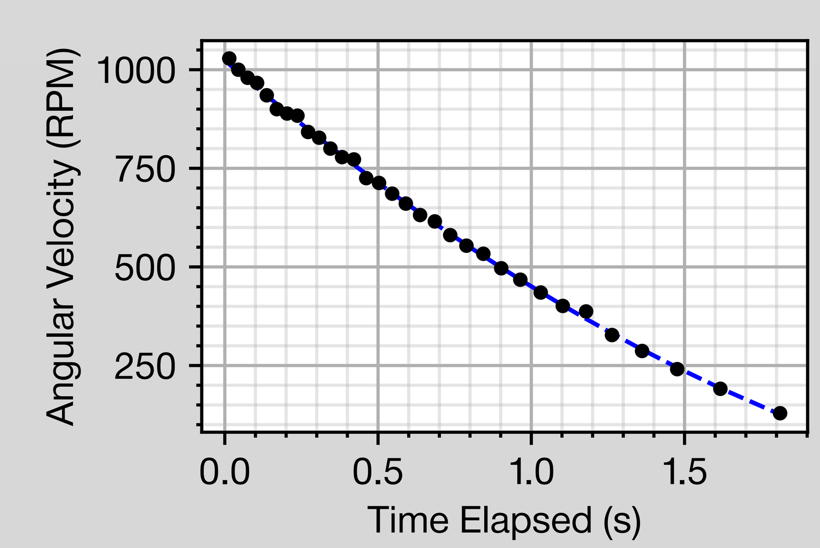


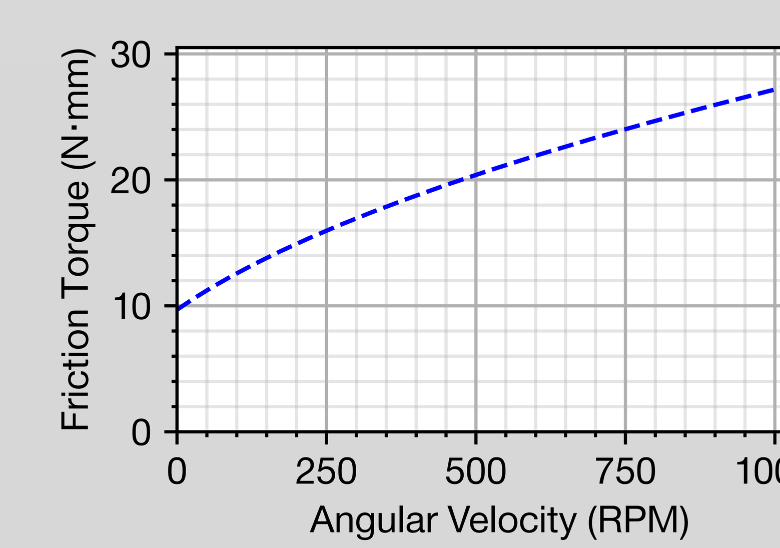


Prototyping Results

Using FDM 3D printing, an initial polymer prototype was manufactured at a modified scale for visualization and assembly validation purposes. A high-speed camera was used to record the spinning bearings and determine frictional torque across different rotation rates.







Next Steps

The next phase of the project will be to construct a metal prototype at Marshall Space Flight Center in Huntsville, AL. The team has corresponded with subject matter experts and machinists to provide technical feedback and manufacturing services. The prototype will also be tested in a lab to validate the design and the selected operating parameters.

Acknowledgements

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