Design and Initial Testing of a Novel Benchtop CNTP Model

Department of Mechanical Engineering, University of Nevada Las Vegas
By: Thomas Miller, Daniel Gadaleta, Dr. Vince Wang, Dr. Yi-tung Chen*, and Dr. Huang Chen*
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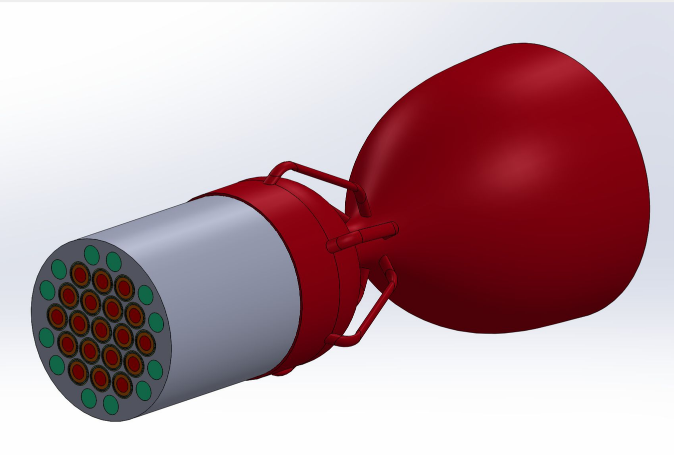
Overview

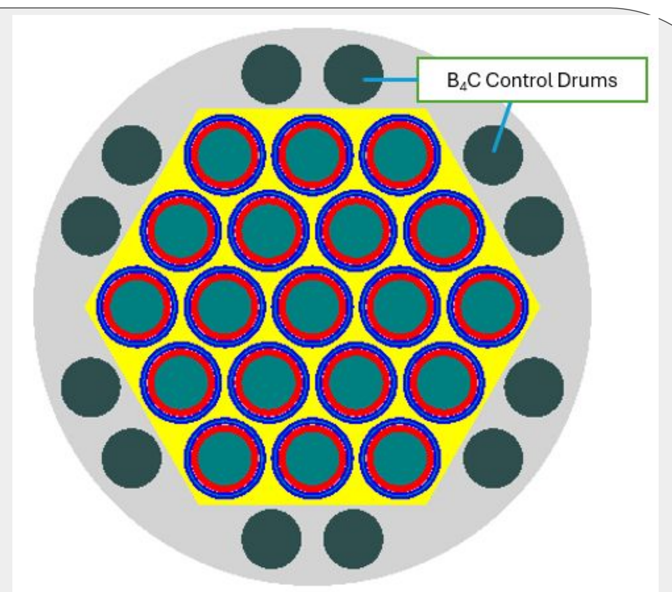
- Centrifugal Nuclear Thermal Propulsion (CNTP) is a novel propulsion system for future deep-space missions.
- CNTP confines molten uranium fuel in a fast-rotating cylindrical reactor to increase the operating temperature, and the resulting specific impulse of the engine.
- This work used an experimental setup and photovelcoimetry to study the patterns and fluctuations of the fluid flow within a rotating cylinder.
- Results will be validated by thermal-fluids simulations with OpenFOAM.
- Findings used to contribute to improving CNTP specific impulse, advancing nuclear propulsion for space exploration, and understanding the underlying physics of the CNTP engine.

Background and Purpose

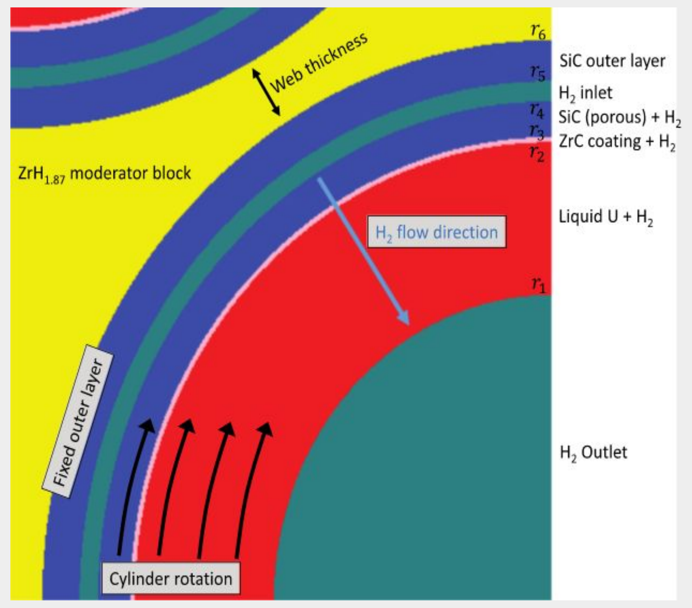
- In the 1950's and 1960's NASA created a program called NERVA which had the goal of making a nuclear powered rocket engine.
- NERVA succeeded in creating an engine that could sustain a specific impulse of 800 seconds by significantly increasing the temperature of the fuel.
- One of the main problems with NERVA and previous CNTP designs is that the flow patterns of the hydrogen through the liquid uranium is unknown, thus making the heat transfer unknown.
- The primary purpose of this study is to determine whether or not centrifugal nuclear thermal propulsion is a viable option for increasing space travel speed and whether or not it is a viable option for long space flights.



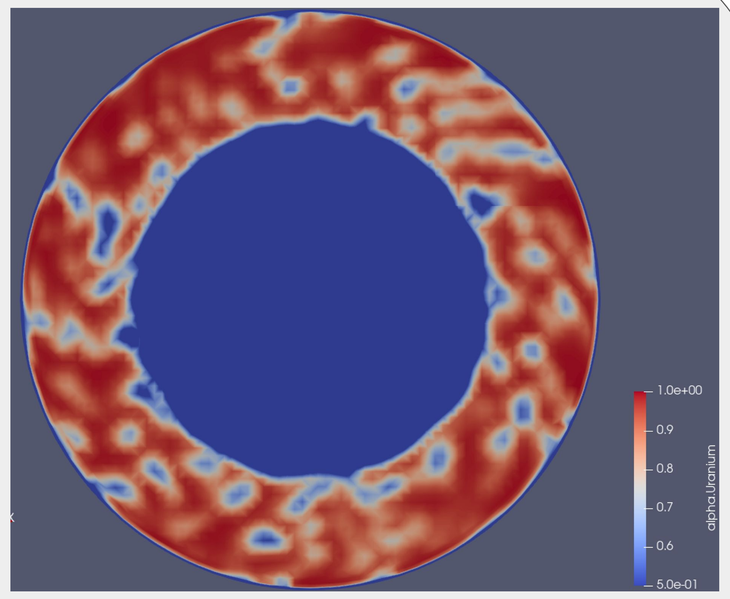
CNTP reactor attached to a theoretical nozzle showing what a fully built rocket engine would look like.



CNTP geometry with the added B4C control drums to be able to control criticality.

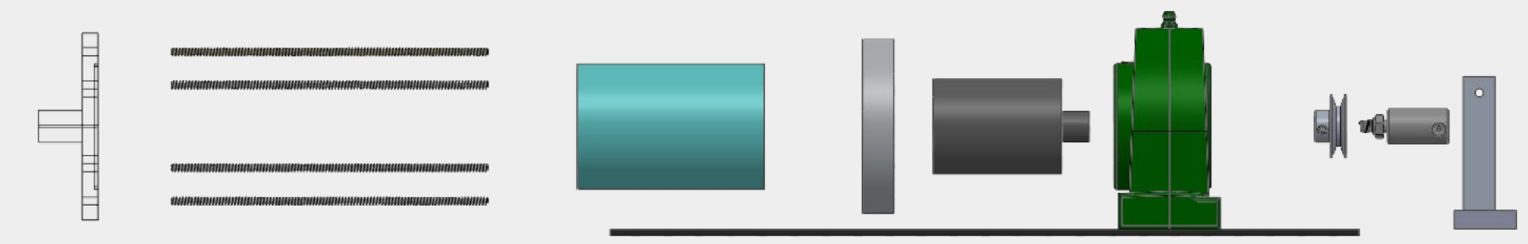


Conceptual cross sectional view of an individual CNTR fuel element.



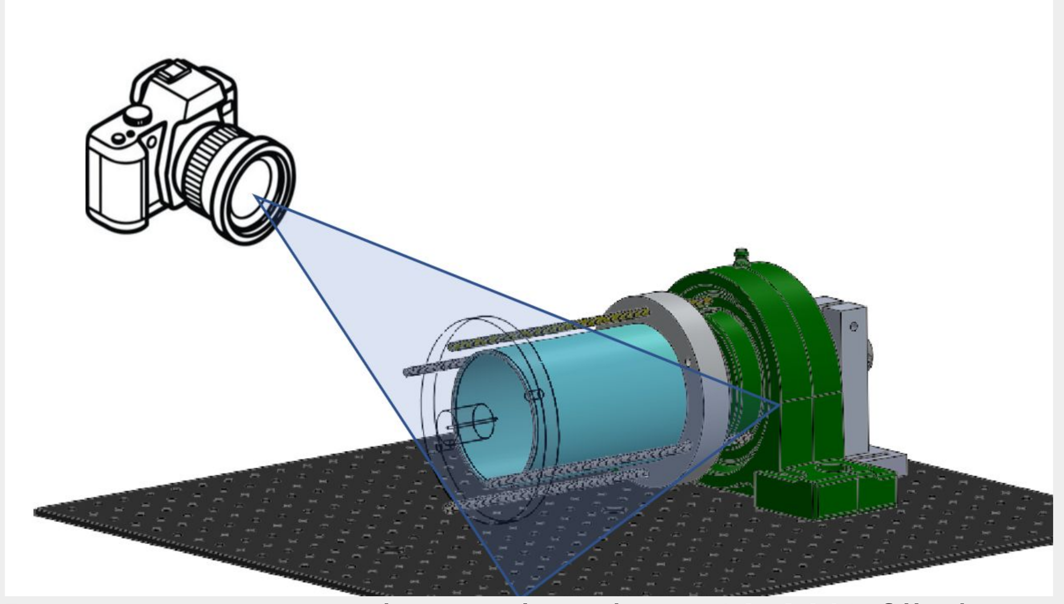
H_2 bubbles rise within a rotating CNTR fuel element. Data obtained from a combined neutronics-CFD simulation.

Experimental Setup



An explosion view of the experimental setup

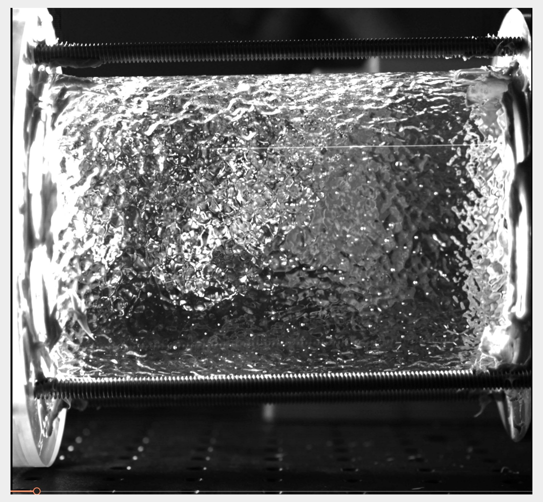
Top view of the experimental setup where the motor on the left turns the acrylic tube containing water. An LED light on the right is used to illuminate the flow with in the cylinder.

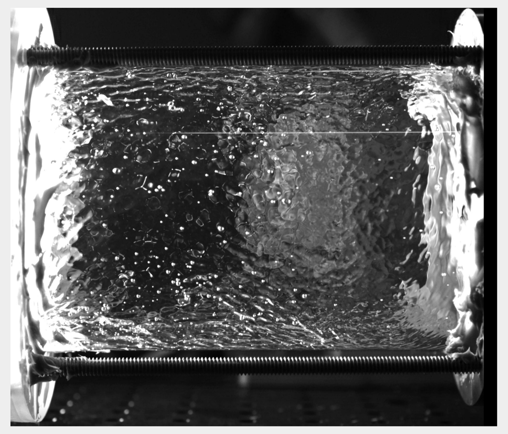


During experiment the acrylic tube is 10-20% filled with water and is then spun up to 700 RPM, 1,000 RPM, and 1,300 RPM for 3 seconds to analyze how the fluid flows, and how long it takes to reach steady state that shows a clean free surface. A high speed camera working at 12,800 frames per second recorded the view from axial and radial directions.

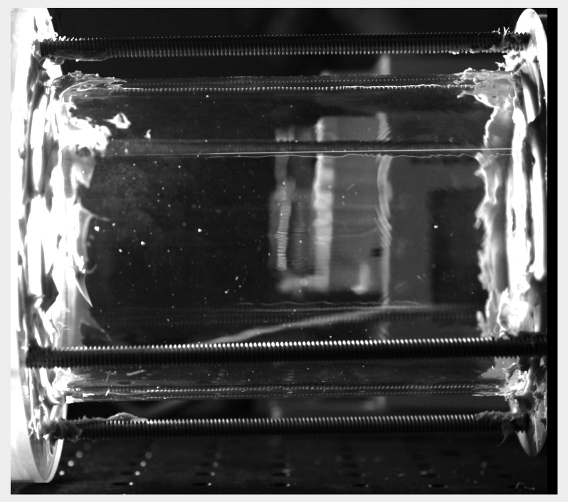
Results - 700 RPM axial

Initial start up





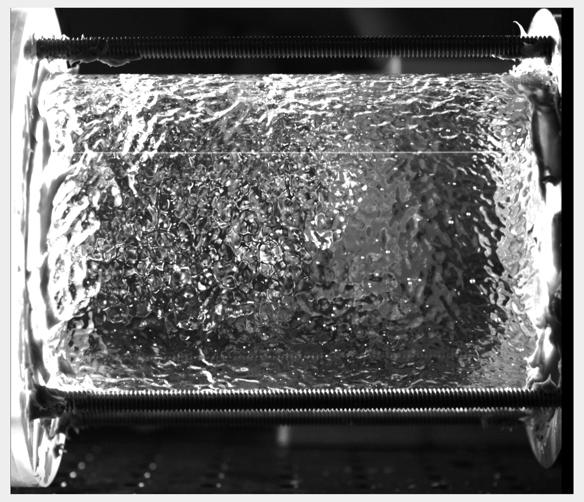
Steady State

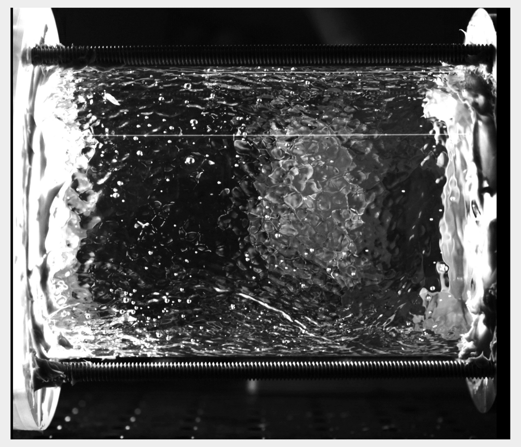


2.8 seconds

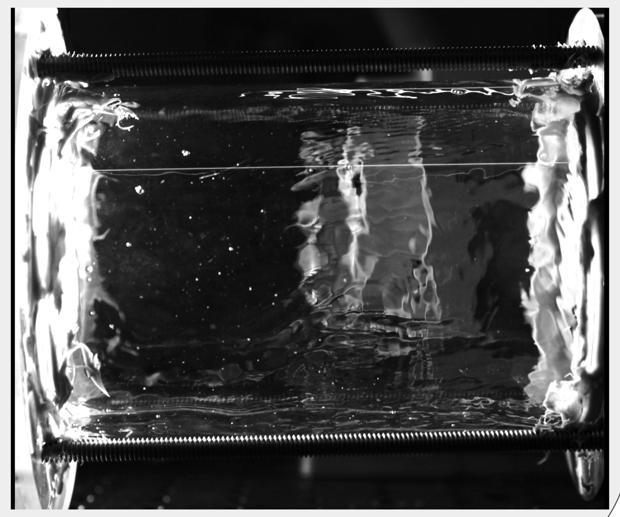
Results – 1,300 RPM Axial

Initial start up



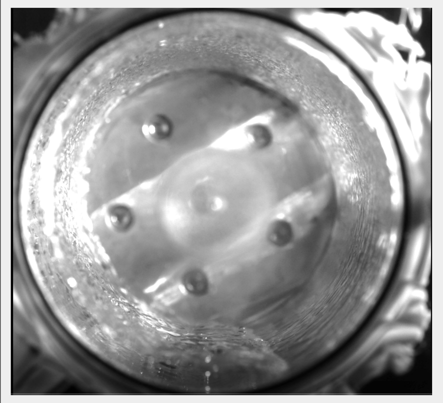


Steady State



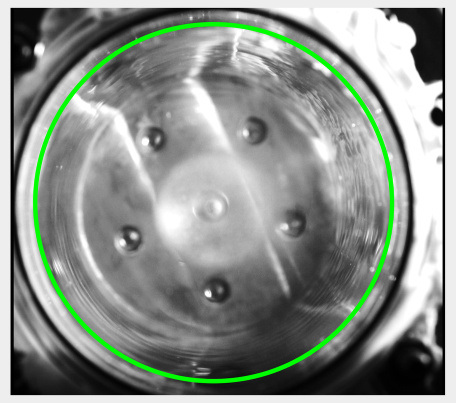
1.28 seconds

Results – 700 RPM Radial



0.5 Seconds

1.5 seconds

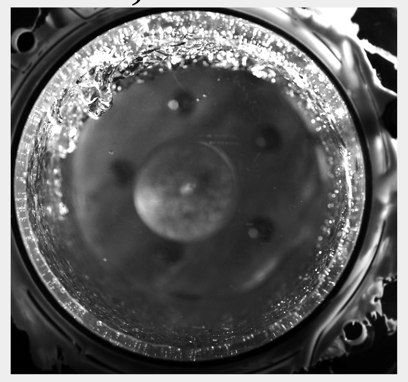


2.8 seconds

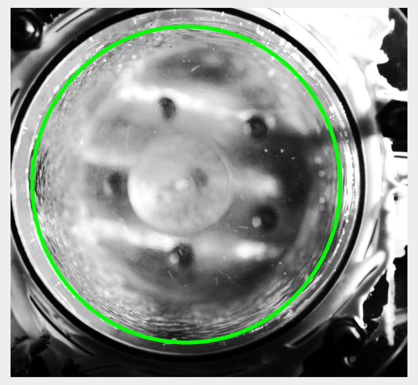
At 700 RPM it takes 2.8 seconds for the rotating liquid to reach a steady state condition and form a free surface as shown by the green circle.

Results – 1,300 RPM Radial

0.2 seconds



0.7 seconds



1.28 seconds

At 1,300 RPM it takes 1.28 seconds for the rotating liquid to reach a steady state condition and form a free surface as indicated by the green circle.

Conclusions

- Continued on our successful work of building a model of the CNTR fuel element that can be used to model the fluid flow within the CNTP engine, we have designed and built an experimental CNTP apparatus to study the bubble dynamics in a fast rotating cylinder.
- Images were recorded at 12,800 frames per second for the cylinder rotating at 700- 1,300RPM.
- Initial results show that a stable free surface can be formed seconds after startup even at 700 RPM.
- The imaging step up was able to clearing capture the flow within the fast rotating cylinder, setting up stage for next phase of experiments.

Future Work

- **(Computational) Liquid Gas Interface Analysis:** Analyzing the path, radius, and forces acting on the bubbles as they pass through the rotating liquid.
- **(Experimental) Bubble Dynamics in CNTR:** Increase the speed of the current setup to a realistic operating RPM of the CNTP. Inject bubbles from the side of the wall and study the bubble dynamics as they rise through water.
- **(Combined) Thermal Neutronic Optimization:** Integrating the experimental results into the neutronic simulation to analyze the power density.

References

[1] Rodgar M, Scolan H, Marié J-L, Doppler D, Matas J-P. Bubble behaviour in a horizontal high-speed solid-body rotating flow. *Journal of Fluid Mechanics*. 2021;925:A34. doi:10.1017/jfm.2021.683
[2] William J. Walters (2023) *Neutronic Evaluation and Optimization of the Centrifugal Nuclear Thermal Rocket Concept*, Nuclear Science and Engineering, 197:8, 2150-2160, DOI: 10.1080/00295639.2022.2161805

Acknowledgements

Thanh Nguyen