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Author: Mr. Mitchell Schroll
Propulsion Research Center, University of Alabama in Huntsville, United States, ms0246@uah.edu

SYSTEM DESIGN OPTIMIZATION FOR A CENTRIFUGAL NUCLEAR THERMAL ROCKET

Abstract

A Centrifugal Nuclear Thermal Rocket (CNTR) is a high-performance engine concept utilizing a liquid uranium fuel to achieve a theoretical specific impulse of 1800 seconds. The design is a modification of traditional Nuclear Thermal Propulsion (NTP) in that it utilizes a high energy density uranium reactor to heat a propellant gas, eliminating the need for mass hungry oxidizers. While the concept of a CNTR dates back to the early 60's and 70's in work conducted by Nelson, Grey, and Williams, no significant advancement has been made in the modeling of the system since then. Research conducted in the interim based the system design around the work by Nelson, utilizing the same geometry and system performance assumptions since deemed the baseline design. Recently, efforts by Keese et al. have shown that this initial baseline design had erroneous assumptions and the newly calculated values show a significantly reduced performance of the engine than previously thought, giving rise to the need to determine the optimum design configuration for future work.

A comprehensive systems model was developed incorporating the propellent tanks, turbomachinery, regenerative cooling systems, centrifugal fuel element turbines, core fluid dynamics, nucleonics, and nozzle dynamics. The systems model was then overlain with a thermodynamics module allowing for various propellent and materials properties to be considered. Finally, a multidisciplinary design optimization framework was implemented within the code to iteratively solve the optimum geometry and operating conditions for various use cases, such as: long duration loiter, deep space scientific missions, and manned planetary missions.

The results from the optimization study found that each use case has similar geometries but differing operating conditions. This result was expected since the main difference between the cases is the propellent used and therefore a function of their thermodynamic properties as they relate to the gas dynamics and turbomachinery and less so their nucleonic heating profiles. The new optimized designs improve upon the existing work done by Nelson et al. by using higher fidelity models and more modern techniques, reducing the need for high level assumptions previous models used as well as increased confidence in the design configuration. These new configurations can now serve as a baseline for future work into further design improvements and mission trade studies with significantly improved fidelity.