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EVALUATION OF MINIMALLY-INTRUSIVE POWER GENERATION SYSTEM (MIPS) DESIGN ALTERNATIVES FOR NUCLEAR THERMAL PROPULSION

Abstract

NASA's current Nuclear Thermal Propulsion Project has advanced further than any American effort since the original NERVA program in the 1950s. Nevertheless, several design challenges remain. Among these concerns is mid-band corrosion and embrittlement of the fuel elements, long-term cryogenic hydrogen storage, and reactor shutdown and cooling operations. Bimodal or dual-mode configurations, which are designed to optimize the reactor's megawatts of thermal energy for both propulsion and electrical power generation, may be able to address these issues. However, each of the previously proposed designs have required substantial modifications to the reactor and almost halved the engine's efficiency. Instead, a system that is optimized for minimum impact to the baseline mission configuration rather than maximum power generation may simultaneously address all of these technical challenges. If possible, implementation of such a Minimally-Intrusive Power generation System (MIPS) could be fundamentally enabling for a Mars 2030 mission.

In order to achieve this a series of alternative designs were considered, evaluated for their high-level feasibility, and traded. Three potential solutions considered were 1) closing the propulsion loop and redirecting the post-reactor hot hydrogen through a heat exchanger, 2) adding thermoelectric converters to the outside of the pressure vessel, and 3) regeneratively cooling the pressure vessel in addition to the nozzle. These options were compared in regards to their total mass savings, impact to engine propulsive performance, technology readiness level, cost, specific power, and total power generation. This work was performed with the Cameo Model-Based Systems Engineering tool and MATLAB for feasibility and physics-based analysis. Ideally, the results of this trade study will be identification of any feasible MIPS designs and selection of the configuration that best meets the stated design requirements. This option will then be further refined and validated in future works.

The "holy grail" within nuclear thermal propulsion (NTP) research has always been the bimodal or dual-mode configuration, yet its unique design and impact to propulsive performance limited its support. Still, NASA's Nuclear Thermal Propulsion Project will require some form of active thermal control in order to mitigate fuel loss and maintain reactor cool down temperatures, thus the most desirable option would be to convert any excess heat into electrical power. Investigations into nuclear power generation with the objective of minimum "intrusion" to a baseline nuclear thermal propulsion mission have yet to be performed. This work serves as the first step towards a formalized approach for investigating such versatile design solutions.