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Changing the World's Energy Future

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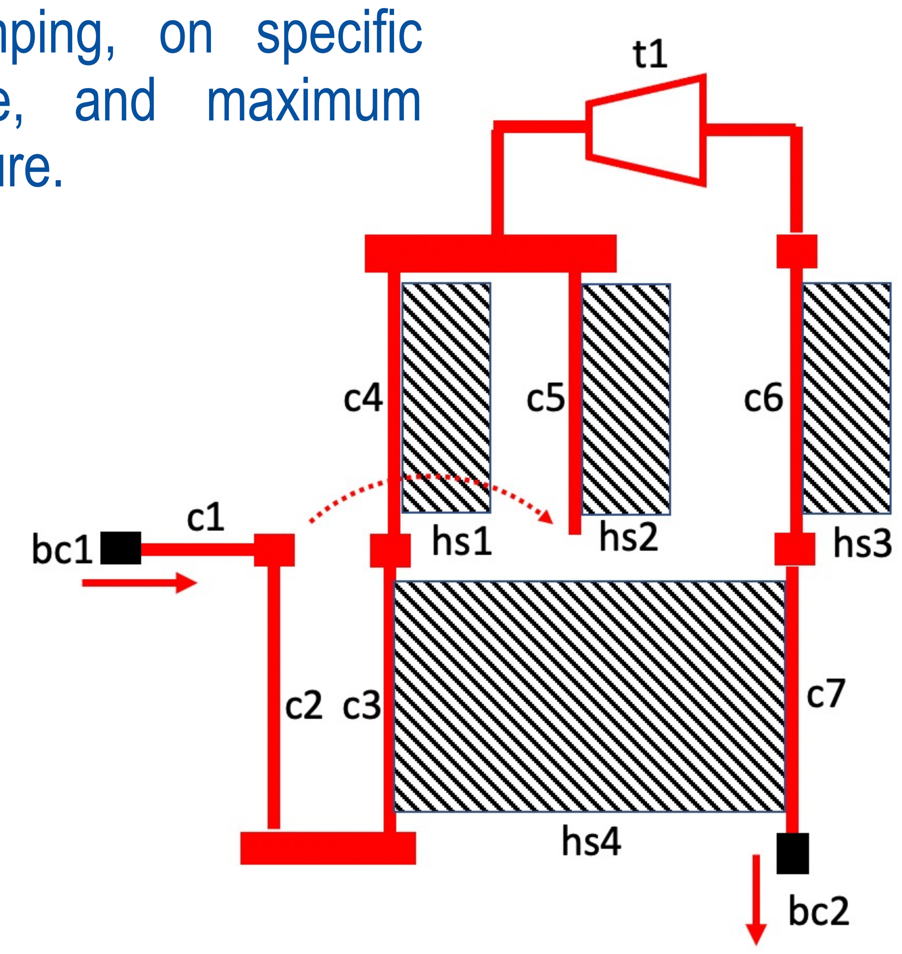
Modeling Nuclear Thermal Propulsion Startup Transients

Motivation

- NASA has the goal of a manned mission to Mars within the decade of the 2030's **[1]**.
- Nuclear thermal propulsion (NTP) is a type of rocket propulsion which uses hydrogen heated by a nuclear reactor as propellant.
- An important advantage to NTP over conventional rocketry is its higher specific impulse (I_{sp}), a measurement of propellant efficiency.
- Rapid, efficient startup is a requirement for a Mars mission.
- NTP therefore appears to be a promising candidate for a manned mission to Mars.
- This work looks to improve our understanding of NTP reactor startup and to provide guidance on startup sequencing.

Model

- A multiphysics model has been developed coupling reactor point kinetics from Griffin with 1D fluid flow and 2D heat transfer from RELAP-7.
- Heat transfer characteristics were calibrated to match those of a 3D finite-element reference model.
- Feedback effects from fuel temperature and hydrogen density inside fuel and moderator channels contribute to the reactivity.
- The model can perform startup transient simulations and has been used to investigate the effects of startup sequencing, specifically of reactivity insertion ramping and hydrogen mass flow rate (MFR) ramping, on specific impulse, startup time, and maximum transient fuel temperature.



[1] SPACE NUCLEAR PROPULSION TECHNOLOGIES COMMITTEE, "Space Nuclear Propulsion for Human Mars Exploration," Tech. rep., National Academies of Sciences, Engineering, and Medicine (2021).

Results

- The model successfully performed 58 startup transients ending at an impulse of 6376Ns. Each line represents a different reactivity insertion ramp duration.
- The effects on specific impulse, time to reach the given impulse (approximate startup time), and maximum transient temperature were all studied.
- The following trends were discovered:
  - Longer MFR ramp durations generally improve propellant efficiency. However, they slow startup and render the core's power Doppler feedback-bound.
  - Startup speed is maximized by lowering both ramping durations. This prevents the core's power from being feedback-limited.
  - Reactivity insertion ramping duration impacts specific impulse more strongly than MFR ramping duration.
  - Maximum transient fuel temperature varies by only ~2% in all tests, so it may be left out of a trade off study when considering startup sequencing.
    - Fast MFR ramps cool the core rapidly, while slow ramps cause Doppler feedback to limit power.

Conclusions

- Using this multiphysics model, transient simulation work has begun optimizing startup sequencing for an NTP system.
- The most efficient and fastest startups require a rapid reactivity insertion to counteract Doppler feedback effects.
- MFR ramping duration has a more variable effect and should be considered more closely during any trade off study.

Credits

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