Progress Towards LES of Multiphase CHT in a Hypervapotron

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MOTIVATION

Challenge: *Tokamak operation requires managing extreme heat fluxes.*

Solution: *Hypervapotrons are devices which enhance heat transfer via cavity-induced mixing, with three distinct regimes of operation: **convective**, **nucleate boiling**, and **critical heat flux**.*

Modelling gap: *Most simulations have relied on **RANS** turbulence models, which struggle with separated, unsteady cavity flows, leading to uncertain predictions. Large-eddy simulation (**LES**) offers higher fidelity but has been applied mainly to single-phase convection regime.*

This work: *validates a conjugate heat transfer **(CHT)** framework for single-phase hypervapotron simulations, benchmarking **RANS vs. LES** against experimental data as a foundation for future multiphase studies.*

COMPUTATIONAL TOOLS

Cardinal

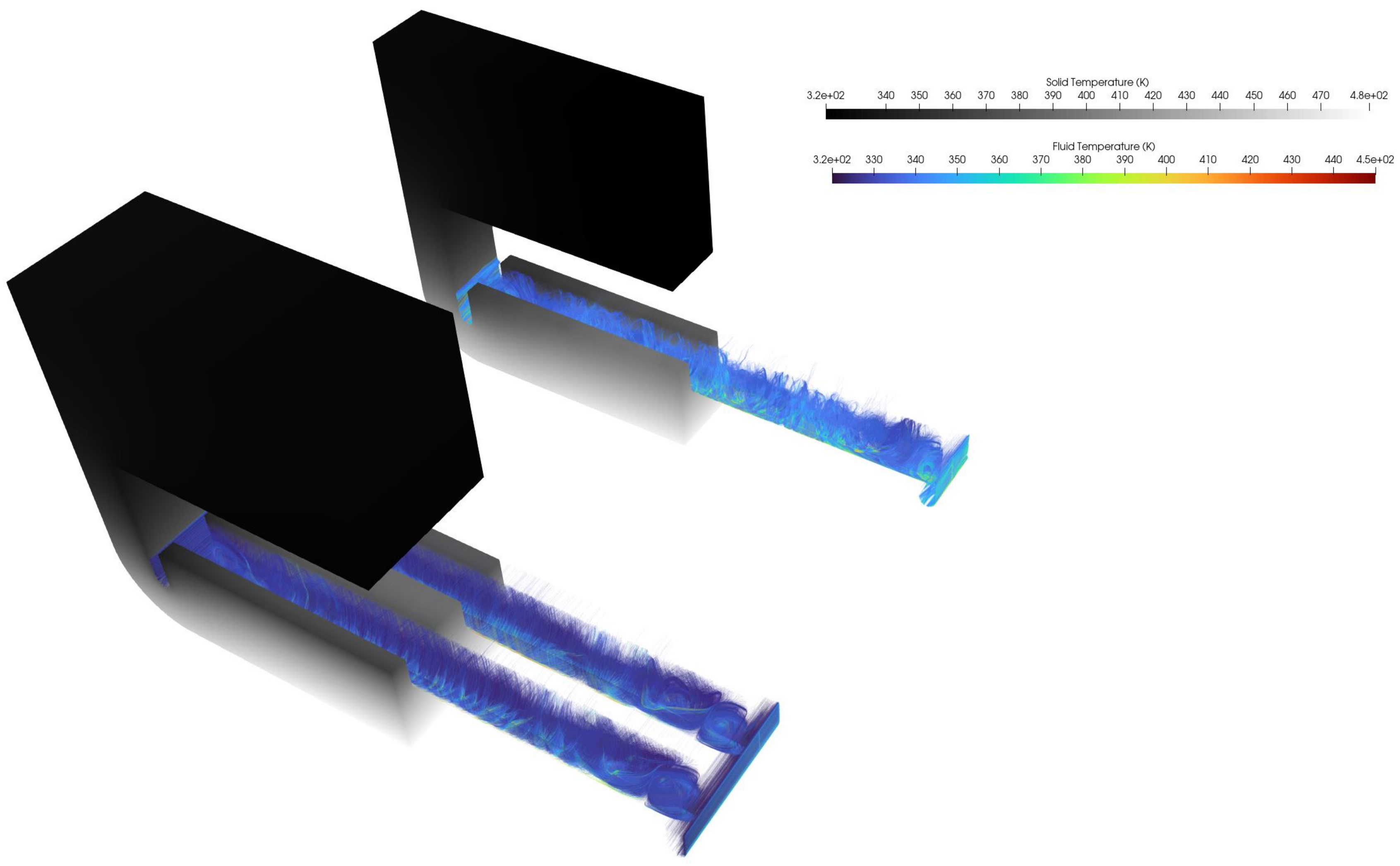
*Built on the **MOOSE** framework, couples the **NekRS** CFD solver with the **MOOSE** heat conduction module to perform **CHT** simulations. Fluid–solid interaction is handled with a **flux-forward/HTC-forward temperature-back strategy**, enabling stable and efficient thermal–hydraulic modelling.*

MOOSE

*The **M**ultiphysics **O**bject **O**riented **S**imulation **E**nvironment framework is a scalable **finite element framework** that offers a broad suite of **physics modules**. We employ the **heat conduction module** to solve the transient heat conduction equation, accounting for **thermal storage** and **conduction**.*

nekRS

*NekRS is an **incompressible flow solver** that is based on a **spectral element method** and simulates **turbulent** flows using either the **k–τ RANS** model or an explicit **LES high-pass filter model**.*



Fluid–solid solution: RANS (foreground) and LES (background).

MODEL VALIDATION

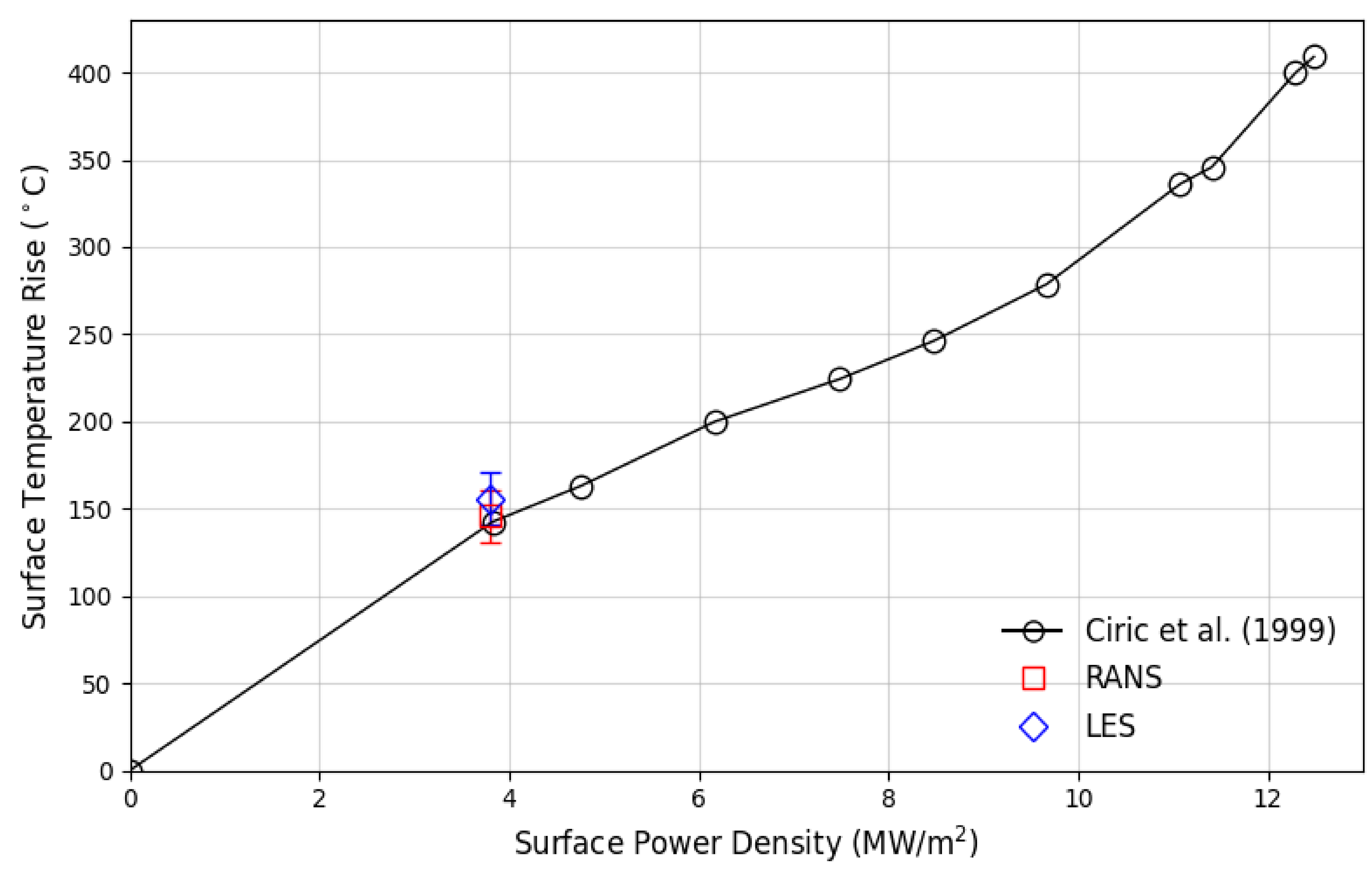
Model validation: *Preliminary **validation** focused on **predicting temperature distribution** in a hypervapotron with **prescribed surface heat** flux operating in **single-phase convective regime** with **water** as the coolant.*

Reference experiment: *Simulations replicate the **JET Neutral Beam Test Bed** campaign of **Ciric et al. (1999)**, using **low power density** (3.8 MW m^{-2}) and cooling velocity (U = 4.0 m s^{-1}) near the **single-phase limit.***

RANS and LES setups: *RANS followed the setup by **Milnes (2010)** simulating a **double cavity** subsection and employing an **inlet** boundary with **approximate mid-length condition** and an **outlet** boundary; **LES** used a **single cavity** with **periodic inlet/outlet** and **initialised** the **temperature field** with the **approximate mid-length condition**; both **coupled** to **solid walls** under the imposed heat flux.*

Comparison with data: *Both **RANS** and **LES matched experimental surface temperature rise** within uncertainty of the initial solid temperature (20–50 ° C).*

Key observations: *Fluid regions **reached boiling point**, suggesting multiphase effects could **lower heat transfer**; **LES** predicting **slightly higher wall temperatures**, as expected due to the bulk flow heating due to periodic boundary modelling.*



FUTURE WORK

- *Complete **grid convergence** study for the results presented.*
- *Implement **multiphase** solver + **boiling** phase-change **model** in **NekRS.***
- ***Validate** model **across all power densities** reported by Ciric et al. (1999).*
- ***Benchmark RANS** model **against LES** model to better **understand limitations** of **RANS modelling** for **hypervapotrons**.*

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