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Development of a heat transfer surrogate model to predict convective heat transfer coefficient from CFD simulation in a multi-input, multi-output cooling system

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ABSTRACT

In many industrial processes, such as high-pressure die casting, the presence of temperature hot spots can result in product defects and shorten the equipment's lifespan. Conventional cooling systems generally lack the ability to locally adjust cooling rate, making it difficult to address these hot spots. To overcome this limitation, Lamarre and Raymond [1] patented a thermal management system that actively controls the Nusselt number profile in space and time. Their approach uses an array of round impinging jets operating at varying flow rates and in which jets can dynamically switch from inlets to outlets (and vice-versa).

While flexible, the potential of the technology depends on a temperature control strategy. Developing and evaluating such strategies is challenging due to the complex interactions between the jets. In this work, we develop a surrogate model that relates the arrangement (inlet/outlet/closed state of individual nozzles) to the Nusselt number profiles. We aim to use this model for model-based control, allowing dynamic adjustments of inlet flow rates and nozzle state (inlet/outlet/closed) in thermal management systems.

The surrogate model is built using computational fluid dynamics (CFD) simulations performed with Lethe [2], an open-source implicit large-eddy simulation (ILES) software. First, a mesh sensitivity analysis is conducted to establish the cost of simulations under real operating conditions (Re=20,000). To address computing limitations, we train a feedforward neural network using CFD simulations at a lower Reynolds number. Using correlation-based strategies, we then scale the Nusselt number profiles to Reynolds numbers up to 20,000. This scaling approach reduces the computational cost of the training while capturing important features of the flow. Predictions of the model for the heat transfer coefficients are validated using transient simulation (Re=20,000) and the root mean squared error as a criterion.

This surrogate provides a more reliable approach to predict the heat transfer coefficients compared to existing correlations [3] since it captures the jet-to-jet interactions as well as the positioning of the outlets while maintaining a small computational cost.

References

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