Multi-objective optimisation of additive manufactured heat exchangers with lattice-like topology for aeronautical applications

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Abstract

In this thesis, a novel framework for the multi-scale simulation, optimisation, and validation of *Additive Manufactured* (AM) *Heat Exchangers* (HX) with lattice-like topology is presented. The work focuses on *Micro Channel Heat Exchangers* (MCHX) based on *Triply Periodic Minimal Surface* (TPMS) lattices, and introduces a surrogate modelling strategy that enables fast and accurate full-scale simulations within realistic industrial timelines. By treating the TPMS lattice as an equivalent porous medium, the approach avoids high-resolution meshing and computationally demanding *High-Fidelity* (HF) *Computational Fluid Dynamics* (CFD), while still capturing the essential physics governing momentum and heat transfer.

Micro- and meso-scale effects are accounted for through variable permeability K, Forchheimer C_F, and heat transfer $h_{(sf)}$ coefficients, modelled as non-linear functions of local flow conditions and lattice geometry. These closure relationships are inferred using a *Multi-Fidelity* (MF) *Machine Learning* (ML) framework trained on a combination of low- and high-fidelity CFD data. This strategy allows the surrogate model to implicitly capture small-scale flow phenomena, such as boundary effects and head losses, without explicitly resolving the lattice geometry. The resulting model provides a favourable balance between accuracy and computational cost, making it suitable for large-scale design exploration and optimisation.

The proposed methodology is applied to the multi-objective optimisation of a TPMS-based HX developed for the thermal management of high-power electronics in aeronautical applications at Rolls-Royce Plc. The MF surrogate enables the efficient exploration of the design space and the extraction of a Pareto front accounting for competing objectives. Three representative configurations are selected, respectively optimised for maximum heat transfer, minimum pressure drop, and a balanced trade-off, demonstrating the flexibility of the framework in addressing different industrial design priorities.

Finally, the predictive capability of the MF model is assessed through a validation against both HF *Conjugate Heat Transfer* (CHT) simulations and experimental data. HF CHT runs performed in ANSYS Fluent are used as a numerical benchmark, while experiments are performed on a series of AM gyroid-based HXs, tested under controlled thermal loads, at different mass flow rates. The comparison with experimental data shows an excellent agreement for temperature values. A qualitative

comparison with experimental measurements indicates that also the pressure drop predicted by the MF model is consistent with the experimental observations. The MF model is able to correctly capture the order of magnitude of the pressure drop and the overall trend with respect to the inlet mass flow rate. These results confirm the predictive accuracy of the MF surrogate model and demonstrate that the proposed pipeline provides a reliable and computationally efficient tool for the simulation and optimisation of TPMS-based lattice HXs.