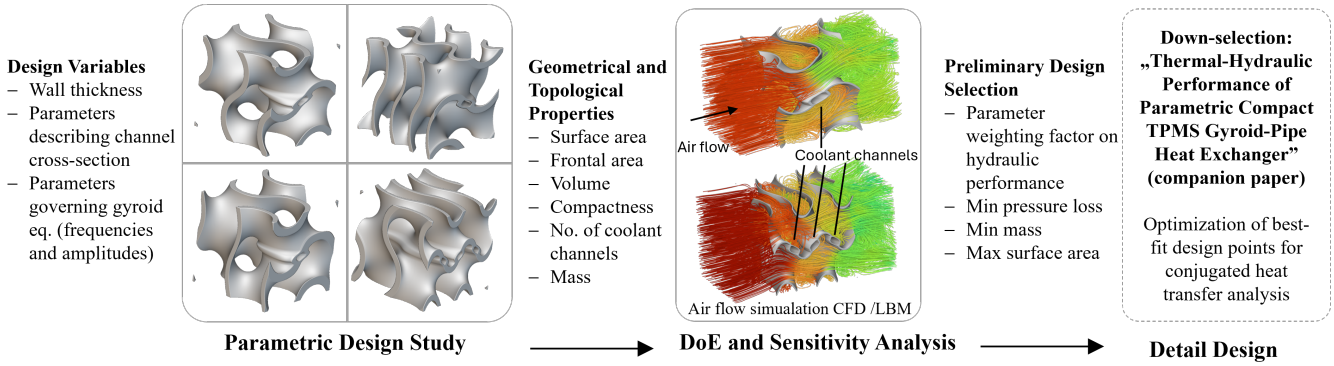
Preliminary Parametric Design of Compact Gyroid-Pipe Heat Exchangers for Electrified Aero Engines

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The increasing demand for lightweight and highly efficient thermal management in next-generation hydrogen-electric aviation propulsion systems is driven by the need to reduce emissions. Compact heat exchangers (HEs) are crucial components, offering effective thermal load management while minimizing weight and volume. Triply Periodic Minimal Surfaces (TPMS), such as gyroids, are particularly attractive due to their lightweight nature, high design flexibility, and large specific surface area, which enable enhanced heat transfer performance and structural efficiency. However, TPMS HEs can induce increased air pressure drops, affecting engine performance. Designing a lightweight TPMS HE that delivers improved heat transfer performance while inducing a considerably small air pressure drop, remains a challenging and open field of research.

This work presents a preliminary parametric design study of compact gyroid-pipe HEs. We design a fully parametrised gyroid HE with embedded coolant channels integrated into its conventional wall structures. The liquid coolant, responsible for thermal regulation of battery and fuel cell systems to minimize efficiency loss, is then cooled by the engine's inlet air flow. The objective of this preliminary design study is to investigate how predefined design parameters affect air pressure drop, mass, and geometrical and topological properties. Thereby, it provides a foundation for our subsequent detailed design study, which aims to optimize the design to achieve a balance between minimizing air pressure drop, maximizing heat transfer, while ensuring structural integrity.



From our parametric model, we devise several different designs for our gyroid-pipe HEs with varying parameters. We explore our design variables, including wall thickness, channel cross-section, and the amplitude and frequency parameters governing the gyroid equation, and compute geometrical and topological properties for each design. We then perform incompressible transient CFD simulations using the Lattice Boltzmann Method (LBM) to compute the average pressure drop. To systematically explore the design space and identify the most promising HE configurations, we apply design of experiments (DoE). Our preliminary results suggest that the parameters of the gyroid equation (frequencies f_x and f_y) and the wall thickness have a significant impact on pressure drop, with certain combinations of parameters leading to a 50% reduction. This integrated approach enables a rapid identification and selection of the best set of design parameters, allowing us to efficiently transition to high-fidelity thermal-hydraulic performance calculations (in our companion paper submitted simultaneously) and thereby, assisting the development of efficient, compact heat exchangers.

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