Thermal-Hydraulic Performance of Parametric Compact TPMS Gyroid-Pipe Heat Exchanger

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ABSTRACT

The future of aviation, as outlined in Flightpath 2050, is to achieve low emissions through all-electric aircraft propulsion using carbon-free fuels. Fuel cell-powered aircraft propulsion using hydrogen gas is a proven technology for small demonstration aircraft. Among the various subsystems required, a lightweight and compact thermal management system with high mass-specific performance is essential. Excess heat from the fuel cell stack must be dissipated for the system to function properly. The challenge lies in developing lightweight and compact heat exchangers (CHE) with high heat transfer capability, low pressure losses, a small frontal area to reduce blockage and drag, and a small volume to enable safe integration into the propulsion system. This paper presents a design for a gyroid-pipe CHE using Triply Periodic Minimal Surface (TPMS) geometries with embedded coolant channels. An aero-thermal coupled analysis of the best-fit design points was identified in an earlier preliminary study. The pitch, amplitude, and thickness of the TPMS gyroid surfaces were varied in three directions. The optimal geometries are prototyped using additive manufacturing methods and aero-thermal tests are performed. Experimental results are used to validate the CFD simulation methodology and results.

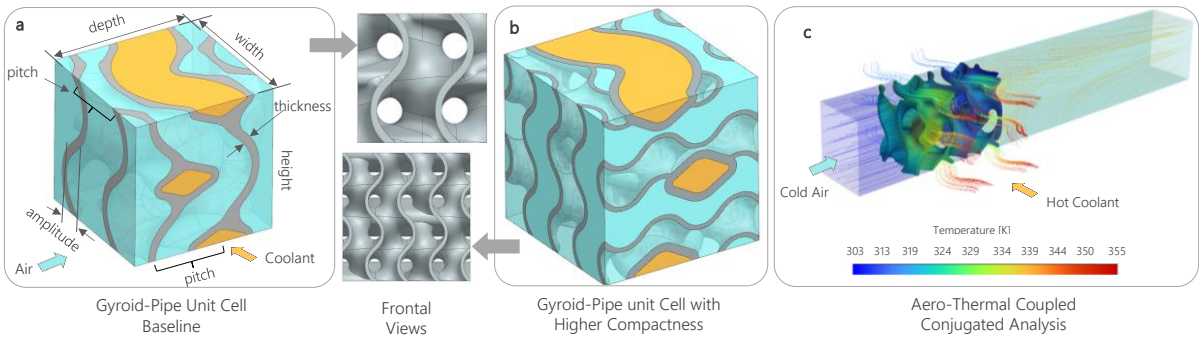


Figure 1: Gyroid-pipe CHE unit cell, a) baseline, b) design point with higher compactness, c) aero-thermal coupled conjugated CFD simulation.

Aero-thermal coupled conjugated CFD analysis shows that increasing the gyroid pitch along the width increases the heat transfer surface area, thereby improving convective heat transfer on the air side, while reducing pressure loss. However, due to the highly curved coolant channels, regions of local reverse flow are generated which result in a reduction in the overall aero-thermal performance. Conversely, this reduces the free flow frontal area for air acting to increase the aerodynamic drag. Increasing the gyroid pitch along the unit cell depth shows a larger reduction in pressure loss and causes no change in the frontal area relative to pitch variation along the width. As a result, number of coolant channels in cross-flow to the air increases. This causes higher convective heat transfer between the hot coolant and the structure but the frictional losses on the air side increases. The full paper describes the weighted effect of the selected design parameters on the heat transfer rate relative to the power required to overcome the aerodynamic losses in fluid domains.

KEYWORDS: Compact heat exchanger, TPMS structures, gyroid design, coupled conjugated CFD, heat transfer.