# Design Assessment and Test of Compact Gyroid-TPMS Heat Exchanger with Embedded Coolant Channels for LTPEM Fuel Cell Powered Regional Aircraft

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The Flightpath 2050 and Waypoint 2050 strategies aim for low-emission flights, which can be achieved through all-electric aircraft propulsion powered by carbon-free fuels such as hydrogen gas. Low Temperature Polymer Electrolyte Membrane Fuel Cells (LTPEMFC) are considered a key enabling technology, using hydrogen gas and air to generate the electrical power required for propulsion. Although an LTPEMFC propulsion system would produce lower emissions than a conventional gas turbine engine, regional flights with 70-90 passengers are not yet feasible with current mass-specific power densities of the propulsion system as it would require megawatt levels of power generation and heat removal. To make such a system feasible, large component such as compressors and heat exchangers (HEXs), which are an essential part of the thermal management system, need to be made lighter, more compact and more efficient. To meet this challenge, the Triple Periodic Minimal Surface (TPMS) Gyroid HEX geometry is chosen for its high heat transfer efficiency and compactness due to its complex flow path. This research deals with the design and testing of a compact Gyroid-Pipe TPMS HEX with integrated coolant channels. This paper briefly describes the functions of the LTPEM-powered all-electric propulsion topology and the role of the compact heat exchangers as part of the thermal management. A brief overview of the methodology for HEX design, aero-thermal and structural calculations is presented. Simulation results are obtained using a single repeating unit cell of the HEX and are compared with the test measurements in terms of pressure drop, heat transfer capability and structural strength. Three variations are developed with increasing ratio of their length in air direction to constant width, called as aspect ratio (AR) of 1, 1.5 and 2, as shown in Figure 1.

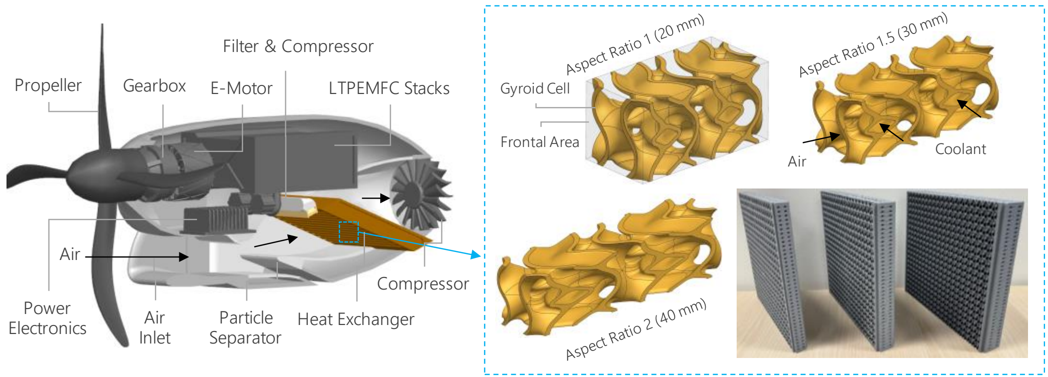


Fig. 1: LTPEM-powered all-electric propulsion topology and design variation of TPMS Gyroid-Pipe heat exchanger.

The effects of increasing the ARs are quantified by solving the conjugate heat transfer using CFD and validated by aero-thermal testing for air velocities from 5 m/s to 30 m/s. The test prototypes, with a frontal cross-section of 200 mm x 200 mm, are developed using additive manufacturing. The test results show a reduction in air-side pressure drop of 10% and 16% with AR 1.5 and 2, respectively, compared to AR 1, resulting in a reduction in air compressor pumping power. On the other hand, higher aspect ratios stretch the coolant channels, intensifying local secondary flows and internal temperature, resulting in a reduction of the heat transfer coefficient of 17% with AR 1.5 and 29% with AR 2 compared to AR 1. Additionally, thermo-mechanical analysis and mechanical simulation tests, namely tension, compression and three-point bending analyses, are calculated and tested on all three unit cell variants. Primary results from the thermal conductivity tensor indicate that AR 2 has almost 20% higher principal thermal conductivity in the y-direction, while still exhibiting only slightly lower thermal conductivities in the x- and z- principal directions compared to the other two geometries. A similar result has been observed for the stiffness matrix tensor, where the elasticity modulus of AR 2 is up to 40% greater than the other geometries in the y-direction, while exhibiting relatively similar values for other coefficients. The results show that AR 2 is more resistant to tensile and compressive loads and to higher values of compressive loads. A detailed description of the numerical and test results, together with the applied methodologies is presented in full paper.