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Parametric study of coolant-injection flow through different pore geometrical patterns for injection flow control in hypersonic flow

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The control of the flow injected from the porous surface is crucial in transpiration cooling applications suitable for thermal protection systems (TPS) of hypersonic vehicles, where the features of the coolant flow entering the boundary layer can significantly affect the transition to turbulence as well as the turbulent mixing and the wall cooling effectiveness (Cerminara et al., 2020, 2021). The geometry of the porous structure determines the characteristics of the flow through the porous medium as well as those of the flow injected at the surface. As such this work parametrically investigates the flow patterns through the regular porous structure of a triply periodic minimal surface (TPMS) configuration using computational fluid dynamics (CFD) considering key geometrical parameters of the inner pore cells. In particular, a Schwartz-P type TPMS is considered as reference structure, as it was shown to maximise the permeability (and hence the blowing ratio) for a given porosity, due to its lower specific surface in comparison to other TPMS structures, in the study of Jung and Torquato (2005). Deflection angles of the pore channels at the pore intakes are varied to obtain specified values of the velocity components of the outflow at the porous surface. Three different injection directions are considered, namely (i) uniform flow injection at 45-deg inclination angle in the spanwise direction, (ii) flow injection at alternate +/- 45-deg inclination angle (in the spanwise direction) between adjacent pores, iii) conventional straight 90-deg flow injection. The flow is injected at the same assigned pressure drop for all the configurations. CFD simulations of the internal laminar flow within the periodic porous structure are conducted for the three above-mentioned configurations, considering the same level of porosity (40%), and an analysis of the injected flow features at the surface is conducted, including blowing ratio and injection velocity profiles. Ultimately, the results of this CFD study will inform a model of surface porous injection in high-resolution direct numerical simulations (DNS) of hypersonic turbulent flow over a porous flat plate. This, in turn, will enable accurate analysis of the boundary-layer flow behaviour as well as assessment of the cooling effectiveness for the different configurations, and will inform the additive manufacturing process of porous structures (Arjunan et al., 2020) for TPS applications.

References

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