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DIRECT NUMERICAL SIMULATION OF HYPERSONIC FLOW THROUGH REGULAR AND IRREGULAR POROUS SURFACES

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Flow at hypersonic speeds is characterised by severe heat loads at the wall that can lead to the failure of the vehicle structure. Most passive-cooling thermal protection systems (TPS) make use of a low-density porous material to decrease the thermal conductivity and the heat transfer in the inner structure. Porosity plays in turn an important role in active-cooling systems, allowing the coolant gas to be injected into the hot boundary layer, as in the case of transpiration cooling. Thus, the correct design of a TPS requires advanced numerical techniques, for the modeling and meshing of the porous structure as well as for accurate simulation of the flow in the boundary layer and within the pores. In the present work, direct numerical simulations of the Navier-Stokes equations are performed to study a Mach 6 flow over two different surface configurations, namely i) a flat plate with periodic regular pores, and ii) a flat plate with a slot of inner irregular porosity. The simulations are performed through a high-resolution hybrid method, consisting of a 6th order central differencing scheme for the smooth regions of the flow, and a 6th order weighted essentially non-oscillatory (WENO) scheme switched on only in the sharp flow regions. The hybridization minimizes the numerical dissipation while providing numerical stability and computational cost reduction. Moreover, a structured adaptive mesh refinement (SAMR) methodology is used, which dynamically refines the grid by adding consecutive finer grid levels in the local flow regions where sharp gradients are encountered. The SAMR approach, in particular, is crucial for the accurate resolution of the different scales of the flow within the boundary layer and inside the inner porosity layer. A comparison of the main flow features between the case of periodic regular pores and the case of irregular pores is presented, with focus on the radiation of acoustic disturbances in the external field and on the flow characteristics inside and outside the porosity layer. These results demonstrate the code capabilities in perfmorming multiscale DNS simulations of hypersonic flow, resolving both the boundary layer and the flow within the porous layer. As such they provide a basis for future simulations of more complex porous geometries in the context of transpiration-cooling system design for new-generation hypersonic vehicles.

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