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DNS of turbulent ribbed channel flow with heat transfer and comparison with current RANS capabilities

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Abstract

The innovative production of additively manufactured components has given renewed importance to the study of rough surfaces; in the past great effort has been put in the evaluation of the momentum loss near the wall, but little to no importance was given to the influence on the heat exchange, which results of paramount importance in the frame of liquid-rocket-engines (LREs) cooling channels.
In this paper Direct-Numerical-Simulation (DNS) is performed for rectangular channels with one or two walls covered by a row of riblets, and high Reynolds number is imposed, to simulate the conditions of the flow in LREs, up to 10^5. The solver is firstly validated against a channel-flow benchmark result and used afterwards to elucidate the effects of roughness on the statistical quantities in the velocity and thermal fields by varying the width, the height and the spacing of the riblets, which have been used as parameters to replicate the same statistical characteristics of roughness due to additive manufacturing. The Kolmogorov length scale is considered for the correctness of the mesh and >200 timesteps are used for the evaluation of time-averaged quantities. The computational-time has been reduced by introducing an artificial turbulence at the inlet of the channel, whose statistical parameters have been tuned and validated in a previous paper, [1]. The Nusselt number is used to evaluate the heat enhancement due to the rough surface with respect to the smooth walls and the Reynolds stress tensor components are evaluated and compared with smooth-wall results.
It is found that turbulent mixing is promoted by the ribs, the distributions of mean velocity and temperature become markedly asymmetric due to the heat transfer enhancement of the rough wall, and systematic variations of secondary flow patterns between ribs are clearly identified. Empirical laws based on one single geometrical parameter fail in predicting the roughness function $\Delta U+$, or the sand-grain parameter k_s, at high roughness-Reynolds number, following in inaccurate results when applied to RANS models. The DNS time averaged results are compared with Reynolds-Stress models, in order to quantify the error given by the inaccurate prediction of the sand-grain parameter and by the wall functions approach, in order to improve the RANS calculation of the friction factor and the heat transfer coefficient.

References

[1] D. Martinez-Sanchis, A. Sternin, D. Sternin and O.J.Haidn, "Analysis of periodic synthetic turbulence generation and development for direct numerical simulation applications," *Physics of Fluids,* vol. 33, p. 125130, 2021.