Direct numerical simulations of high-speed turbulent boundary layers over rough surfaces

M. Bernardini*, M. Cogo†, D. Modesti‡ and F. Picano§†

The study of supersonic and hypersonic boundary layers is essential to determine drag and heat transfer on flight vehicles, but the predicted flow dynamics is vulnerable to the onset of surface roughness. For example, thermal protection systems (TPSs), which are typically required to endure high-temperature conditions, present gaps between the tiles that can be though as a structured roughness pattern. Regular or irregular roughness topologies can also arise from random pitting, spallation or ablation[1].

At the present time only experimental studies have tackled this problem for turbulent boundary layers (TBLs), while a few numerical studies have been recently performed for turbulent channels[2]. In this context, the study of TBLs is essential to characterize the streamwise development of the flow statistics, which can be heavily influenced by roughness-generated shock waves[3] .

In this work, we use the solver STREAmS[4] to perform Direct Numerical Simulations of turbulent boundary layers over cubical roughness elements at Mach 2 and friction Reynolds number in the range of $Re_\tau = 300 - 400$. The roughness elements are resolved using the immersed boundary method, similarly to Modesti et al.[2].

Figure 1 shows an instantaneous slice of temperature T/T_∞ in the wall-normal plane, where the boundary layer interacts with roughness emanating a pattern of subsequent acoustic disturbances to the far field.

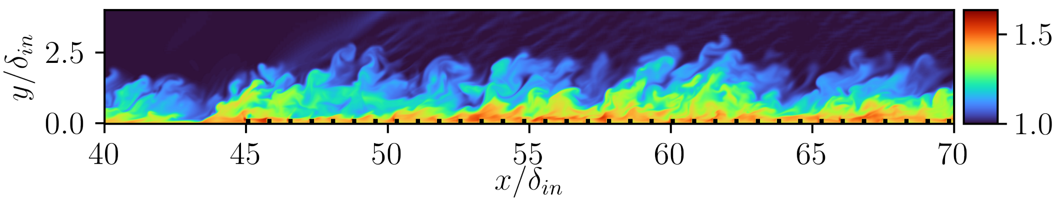

Figure 1: Contours of the instantaneous temperature T/T_∞ in a longitudinal plane. Roughness is visible with black squares starting at $x = 45\delta_{in}$.

*Dep. of Mechanical and Aerospace Engineering, Sapienza University of Rome, via Eudossiana 18, 00184 Rome, Italy

†Centro di Ateneo di Studi e Attività Spaziali "Giuseppe Colombo", Via Venezia 15, 35131 Padova, Italy

‡Faculty of Aerospace Engineering, Delft University of Technology, 2629 HS, Delft, Netherlands

§Department of Industrial Engineering, Università degli Studi di Padova, Via Venezia 1, 35131 Padova, Italy

[1]Bowersox, *37th AIAA Fluid Dynamics Conference and Exhibt*, 3998 (2007).

[2]Modesti et al., *J. Fluid Mech.* **942**, A44 (2022).

[3]Kocher et al., *AIAA J.* **60**, 9 (2022).

[4]Bernardini et al., *Comp. Phys. Comm.* **263**, 107906 (2021).