Direct numerical simulation of supersonic turbulent skin-friction reduction via the boundary-layer combustion

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Reduction of the turbulent skin friction inside the supersonic combustor is a key challenge in the development of future hypersonic vehicules. For the extreme operating condition of supersonic combustors, a more suitable drag reduction technology is to inject a hydrogen film near the combustor wall to induce combustion in the turbulent boundary layer[1]. This work aims to understand the detailed turbulent drag reduction mechanisms of boundary-layer combustion with means of direct numerical simulations. The corresponding flow model is chosen as a non-premixed hydrogen-air flame ignited in a 3d supersonic turbulent flat-plate boundary layer at $Ma = 2.44$. Calculations with frozen chemistry and a finite-rate model of 9 species and 19 reactions are illustrated in Fig. 1(a,b), respectively. The inlet flow is set to be preheated air in the mainstream and a hydrogen film injected close to the isothermal cold wall. The turbulence is generated by blow and suction at the surface, inducing the turbulent mixing and auto-ignition of flame in the boundary layer. For the prescribed flow parameters, a reduction of the skin-friction coefficient around 20% is obtained for the ignited case with respect to the frozen-chemistry case, as shown in Fig. 1(c). The contribution of Reynolds shear stress to the skin friction is evaluated based on a skin-friction decomposition formula extended to the compressible flow[2]. It is found that Reynolds shear stress is reduced in the ignited case mainly through the decrease of mean density in the boundary layer. The viscosity variation across the boundary layer is found to have a non-negligible contribution to the skin friction. A skin-friction prediction model for boundary-layer combustion based on the Kármán momentum integral is evaluated[3]. It is found that the model gives qualitative predictions, with quantitative congruence not achieved.

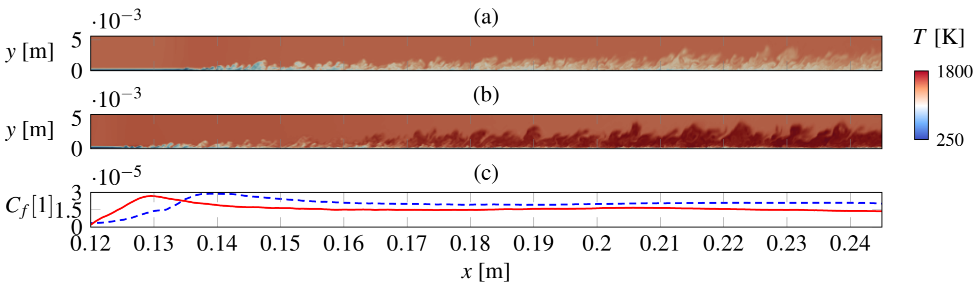

Figure 1: Figures (a,b) show the instantaneous temperature fields of frozen-chemistry and ignited flows, respectively. Figure (c) shows the associated skin-friction coefficients C_f of frozen-chemistry (blue) and ignited (red) flows.

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[2]Gomez et al., *Phys. Rev. E* **79** 035301, (2009).
[3]Stalker, *J. Spacecr. Rockets* **42**(4) 577, (2005).