Compressible turbulent boundary layers with heat transfer and pressure gradients

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The results and analysis of multiple direct numerical simulations (DNS) of compressible turbulent boundary layers with pressure gradients and heat transfer are presented. The pressure gradient and wall temperature distributions were designed to achieve self-similarity of the outer layer as in Gibis et al.[1]. First, ideas are discussed on how to classify the behaviour and compare cases with heat transfer to other super- and hypersonic cases. The idea for this is derived from the results of the integral analysis of Wenzel et al.[2], where it is suggested that an Ec number defined as $Ec = U_e^2/(h_w - h_r)$ gives similar behaviour regardless of whether M_∞ or the wall temperature is changed. Here U_e is the edge velocity, h_r is the recovery enthalpy and h_w is the enthalpy at the wall. Secondly, the combined effects of heat transfer and pressure gradients are discussed. Do the results for adiabatic flow of the self-similarity analysis change and to what extent does the theoretical modelling, in particular the strong Reynolds analogy, still work? In Fig. 1 for example shows the inner scaled root mean square of the temperature fluctuation including reference data[3] showing the effect of strong cooling (a) and pressure gradients (b).

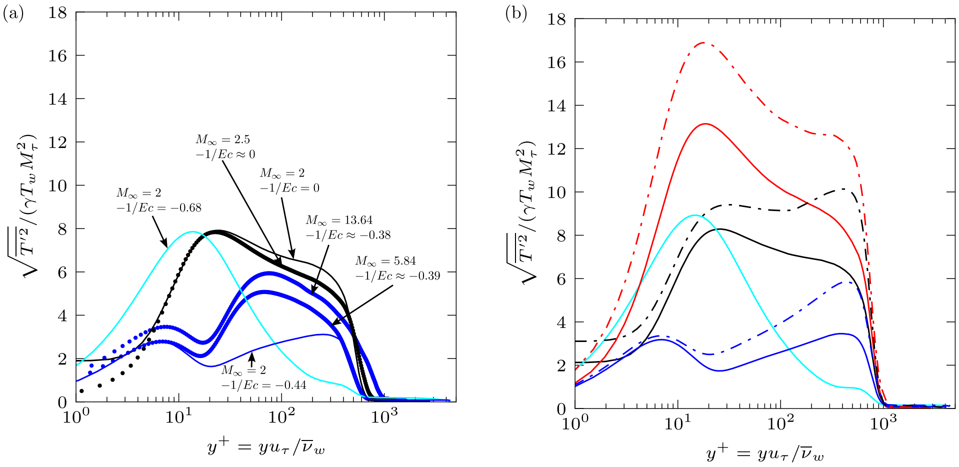

Figure 1: Temperature fluctuations root mean square in inner scaling of (a) the strongly cooled and adiabatic cases without pressure gradients at $Re_\tau \approx 450$ (except for the case $M_\infty \approx 14$), and (b) for the zero (solid lines) and adverse pressure gradients (dashed lines) at $M_\infty \approx 2$ at $Re_\tau = 700$ for different heating conditions. Red: heated, black: adiabatic, Blue: cooled, cyan: heavily cooled.

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[1] Gibis et al., *J. Fluid Mech.* **880**, 284-325 (2019).

[2] Wenzel et al., *J. Fluid Mech.* **930**, A1 (2022).

[3] Zhang et al., *AIAA Journal* **56**, 11 (2018).