TURBULENT DRAG REDUCTION FOR A WALL WITH A BUMP

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This work investigates the effects of turbulent skin-friction drag reduction techniques applied over non-planar walls, with a view to understanding the relationship between skin-friction drag reduction and changes in the total drag.

The existing proofs of concept for skin-friction drag reduction are mostly limited to (i) low-Reynolds number, and (ii) very simple geometries, such as flat plates. Recently, [1] showed that limitation (i) does not preclude spanwise forcing techniques from obtaining large amount of drag reduction, even at flight Re. In order address limitation (ii), [2] recently assessed via a RANS-based calculation the effects of riblets on the total aerodynamic drag of an airplane in transonic flight. They observed a total drag reduction higher than expected due to secondary effect on the pressure drag.

The present contribution intends to confirm this result, by employing more reliable prediction tools (DNS instead of RANS), and by considering a skin-friction reduction technique capable to provide larger and clearer effects than riblets.

DNS simulations are carried out for a turbulent flow in a channel at $Re_b = 3173$, where one wall possesses a small-height bump. The computational domain has dimensions of (L_x, L_y, L_z) = $(24.56h, \pi h, 2h)$ in the streamwise, spanwise and wall-normal directions respectively, being h the half-width of the channel in the flat sections. Around 9×10^7 grid points are used. The considered skin-friction reduction technique is the streamwise-travelling wave (STW) of spanwise velocity [3].

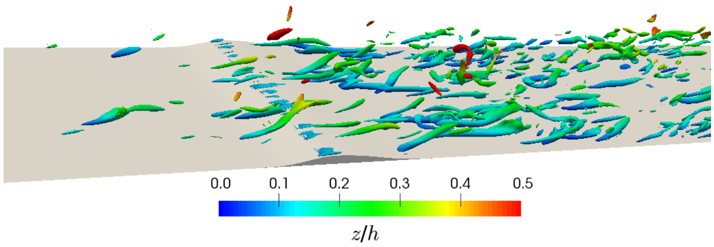

Figure 1. Isosurfaces of λ_2 in an instantaneous snapshot of the turbulent flow over a bump.

Figure 1 shows isosurfaces of the intermediate eigenvalue λ_2 of the velocity gradient tensor and shows the local increase of turbulent activity due to the bump. To investigate the effect of STW on total drag, we plot in fig. 2 and 3 the streamwise distribution of the friction coefficient ($C_f(x) = 2\tau_w/\rho U_b$) and the pressure coefficient ($C_p(x) = 2p/\rho U_b$). In both reference and controlled case, the bump induces flow separation, where friction becomes negative: the separation bubble is extended by STW. Figure also plots the local friction reduction ($R(x) = (C_f - C_{f,stw})/C_f$), which far from the bump takes the expected value of 45% for the indefinite channel flow.

Pressure in the reference case increases before the bump, then a minimum is reached at its tip, followed by a recompression. The effect of STW is non-trivial. The positive pressure peak before the bump is noticeably reduced, and with it, the pressure drag associated to the anterior part of the bump. Also, the pressure minimum near the bump top is decreased by STW.

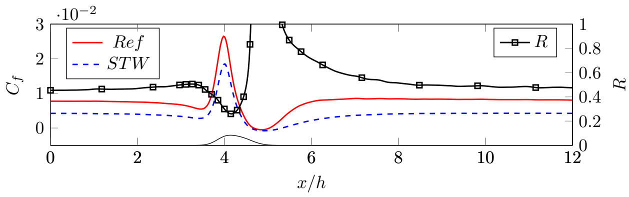

Figure 2. Comparison of C_f. Bump geometry on the bottom.

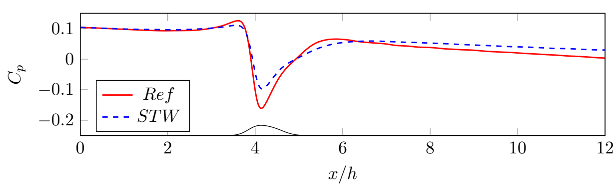

Figure 3. Comparison of C_p. Bump geometry on the bottom.

Overall, the changes in the pressure distribution, once translated into drag changes by accounting for the geometry of the bump, result in an additional 10% of pressure drag reduction. Qualitative changes are also observed in several turbulent statistics, which will be presented at the conference.

References

[1] D. Gatti and M. Quadrio. Reynolds-number dependence of turbulent skin-friction drag reduction induced by spanwise forcing. *J. Fluid Mech.*, **802**:553–58, 2016.

[2] B. Mele, R. Tognaccini, and P. Catalano. Performance assessment of a transonic wing-body configuration with riblets installed. *J. Aircr.*, **53**(1):129–140, 2016.

[3] M. Quadrio, P. Ricco, and C. Viotti. Streamwise-traveling waves of spanwise wall velocity for turbulent drag reduction. *J. Fluid Mech.*, **627**:161–178, 2009.