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Imperial College London

Department of Aeronautics

Active research area

Modelling turbulent skin-friction control using linearised Navier-Stokes equations

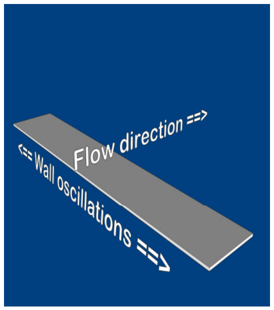

Fig.1. Directions of the flow and of the wall oscillations

Turbulent skin friction can be significantly (almost by 50%) reduced by the spanwise oscillations of the wall (Fig. 1). More importantly, the power required to move the wall might be not so large, so that in an ideal case almost 20% of fuel spent on overcoming skin-friction drag can be saved. For this, however, the wall motion has to be quite complicated, with the spanwise wall velocity forming a wave travelling in the main flow direction:

$$V_{wall} = A \, \Re \left(e^{\mathbf{i}(\kappa_x x - \omega t)} \right)$$

It is hard to imagine an aircraft wing surface performing such a complicated motion. In order to make this method practical one needs to understand the phenomenon, and then to use this understanding for finding a simpler method of actuation.

Linearised Navier-Stokes equations (LNSE) has already proved to be a useful tool in predicting near-wall structures in turbulent flows. Importantly, when developed turbulence is concerned, using LNSE is not based on the assumption of small magnitude of perturbations, as it is usual in other applications of LNSE. In developed turbulence, LNSE arise as a result of rearranging the full nonlinear equations with the LNSE terms on one side all the other terms on the other side. It turns out that as far as many (but not all) properties of the solution are concerned LNSE acts as a filter, so that its output is relatively independent of the form of the input, as far as the input is sufficiently broadband, which is of course the case in turbulent flows. In application to the drag reduction by spanwise oscillations, linearization is done about the phase-averaged mean profile of the turbulent flow. Since LNSE are much simpler than the full equations, they are much easier to understand.

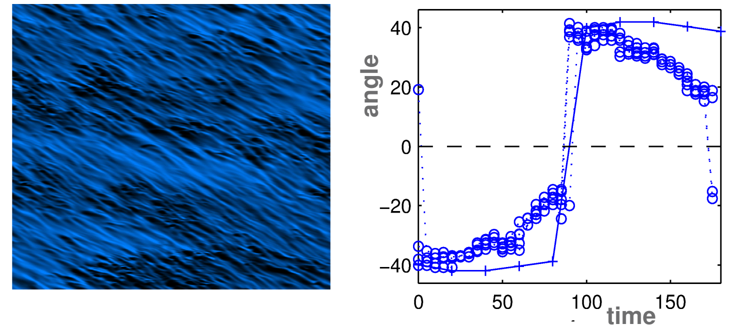

Fig.2. Oblique streaks calculated numerically and the dependence of their angle on time compared with LNSE predictions

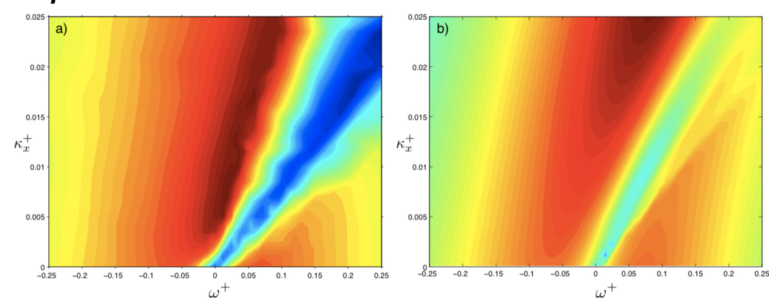

Fig. 3 Contour plots over actuation parameter space (ω, κ_x) of: a) drag reduction as calculated by Quadrio et. al. (2009); b) Percentage change in streak amplification as calculated from LNSE.

More information: contact Prof. S.I. Chernyshenko or any of his co-workers, whose results are mentioned here:

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Streaks, the most important near-wall structures, become oblique near a spanwise-oscillating wall, and their angle varies with time discontinuously. This phenomenon was explained on the basis of LNSE (Fig.2). Fig. 3 shows the comparison of the drag reduction obtained numerically and predicted on the basis of LNSE. These results give a hope that actuation methods that are easier to implement in a real aircraft might be developed based on the progress made so far.