European Drag Reduction and Flow Control Meeting – EDRFCM 2017
April 3–6, 2017, Rome, Italy

DRAG REDUCTION OF A WHOLE-AIRCRAFT CONFIGURATION VIA SPANWISE FORCING

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MOTIVATION

In the last decades, several numerical and experimental studies have been devoted to the understanding and furthering of the potential of aerodynamic drag reduction systems. Nevertheless, so far most of these techniques are still far from being applied in the aeronautical sector.

One of the most promising skin-friction drag reduction techniques is based on wall-based spanwise forcing. In particular, the streamwise-travelling waves of spanwise wall velocity, introduced by Quadrio et al. [6], are a technique which has been experimentally validated [2] and offer interesting energetic performance. Contrary to a widespread belief, recent work of Gatti and Quadrio [4] indicates that the amount of friction drag reduction remains remarkable even at Reynolds number typical of practical applications (e.g. of the order of 25% at Reynolds number characteristic of the airplane at cruising speed).

The long-term goal of the present work is to assess the potential benefits of such techniques in the context of an aerodynamic analysis of the whole aircraft, and to try and quantify their effect on the global energy budget.

PRESENT WORK

Numerical simulations of the compressible Reynolds-averaged Navier–Stokes equations are carried out for an aircraft at Mach number $M_\infty = 0.75$ and Reynolds number $Re_\infty = 3 \times 10^6$. Spanwise forcing is taken into account through modeling of its local effects. The spanwise-travelling waves produce an upward shift of the logarithmic portion of the mean velocity profile [4] that, when properly measured, remains constant as Re is increased. This is used to enforce a boundary condition that mimics the drag reduction effects while avoiding the need for a detailed description of the small-scale, unsteady forcing technique. The considered aircraft is the complex wing-body configuration DLR-F6, which has been analysed in the Second AIAA CFD Drag Prediction Workshop [1]. The test case is specifically designed to check the capabilities of RANS solvers in the prediction of the flow around a typical aircraft, where both compressible and viscous effects are significant. The employed flow solver is AeroX [3], a GPU-accelerated compressible RANS solver whose performances are analysed. The computational efficiency of AeroX it such that a 10-points polar of the whole-aircraft configuration over a computational grid of 2×10^6 cells has been obtained in 6 hours time by using a single personal computer. Our preliminary results in transonic conditions show how the use of drag reduction systems through spanwise forcing can significantly reduce the global drag of the aircraft.

RESULTS

For the case of aircraft with no forcing, our results, obtained with AeroX in conjunction with a Spalart-Allmaras turbulence model, are in good agreement with the reference solution. When spanwise forcing is added, our results are coherent with the observation, already put forward by Mele et al. [5] in their recent work, that the beneficial effect may be larger than expected. We notice that the present work and [5] arrive at the same qualitative conclusion with substantially different methodology: the RANS solvers are different, the specific turbulence model is different, the drag reduction technique is different, and drag reduction is modelled following a different strategy. Moreover, the present calculations employ the wall-functions concept, while wall functions were not used in [5]. Hence, the main message is that the global drag reduction of the wing-body configuration might be something more that the expected friction reduction weighted by the share of friction drag in the overall drag of the airplane. This unexpected global effect will be discussed at the workshop in order to understand the basic phenomena behind this result.

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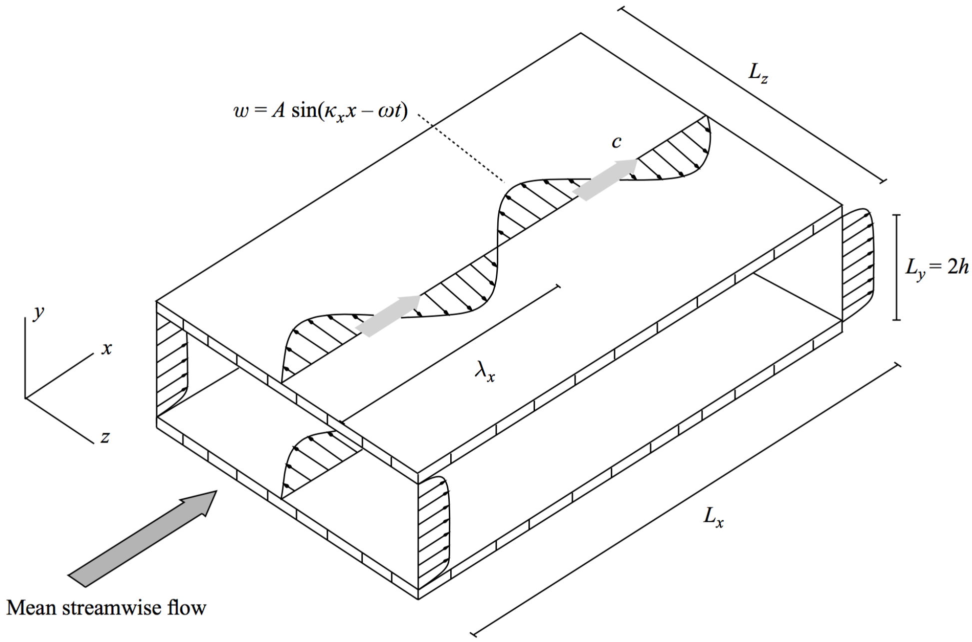

Figure 1: Sketch of a turbulent channel flow with wall streamwise-travelling waves [6].

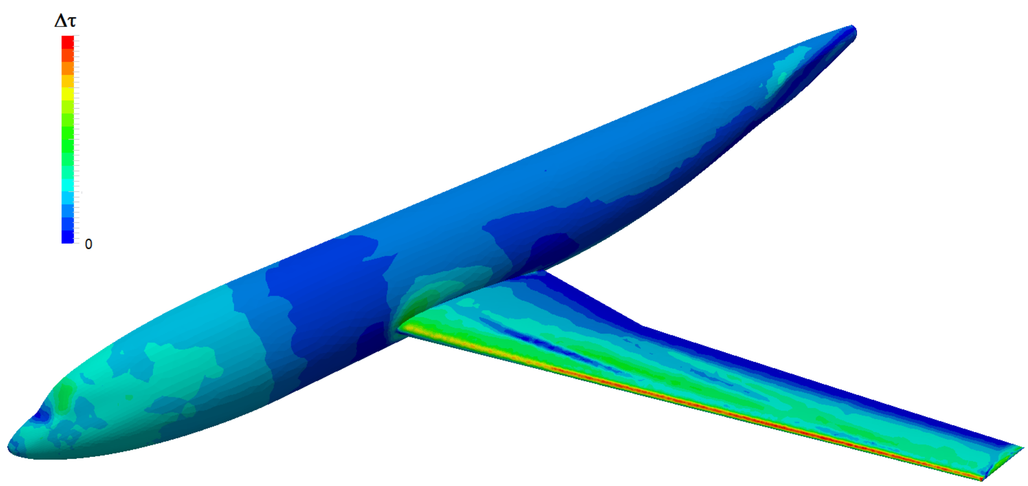

Figure 2: Distribution of the wall shear stress reduction due to the flow control technique over the DLR-F6 geometry.