DESIGN CONSIDERATIONS FOR THE FLOW CONDITIONS AROUND A WING MODEL INSIDE A WIND TUNNEL

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The development and behavior of turbulent boundary layers (TBLs) under high pressure gradients as appearing on wing surfaces are still open research topics. Recent advancements in high-performance computing have allowed for the study of such TBLs through highly resolved numerical simulations. For the present study, we chose the NACA 4412 profile that has been a benchmark airfoil in the study of the development of boundary layers over wings, mainly due to its pressure-gradient distribution being quite independent of Reynolds number (Re), as well as having benign stall properties. Recently, well-resolved large-eddy simulations (LES) [1] have been performed at moderate but yet relevant Reynolds numbers over this profile, allowing to obtain accurate boundary layer data and high-order statistics. However, the experimental data is limited to the pioneering work by Wadcock and Coles [2,3] from the 1970s and 80s. Thus, we aim at providing high quality experimental data with recent advanced measurement techniques, and in guidance of the numerical work performed within the Linné FLOW Centre, new – more detailed – experiments are planned in the Minimum Turbulence Level (MTL) wind tunnel at KTH Mechanics. Corresponding preliminary experimental results are being described in a companion abstract.

The test wing model is designed with a chord length of 0.5 m in order to achieve a similar Reynolds-number range as Wadcock [3]. This leads to a blockage ratio of around 8% and 14% for angles of attack of 5 and 12 degrees, respectively, in the MTL wind tunnel (a test section of 1.2×0.8 m^2). In order to mitigate the blockage effect, the use of wall liners on the side walls of the MTL was pursued. The present work summarises the design process and effect on the flow inside the wind tunnel of such inserts.

The main goal of these liners is to reduce the interference from the wind-tunnel walls so that the flow around the wing resembles that of a free flight case. To achieve this, 2D Reynolds-Averaged Navier–Stokes (RANS) simulations using the $k-\omega$ shear-stress transport (SST) model were performed for each angle of attack (α) and Reynolds number (based on chord length and free-stream velocity) of interest (α = 5, 10, 12 degrees; $Re = 400 \times 10^3$, 10^6 and 1.64×10^6), both for the wing in free-flight conditions and inside the wind tunnel. Due to the development of the boundary layer around the wind-tunnel wall liners, an iterative process was followed in order to obtain a proper insert geometry. This iterative process was performed until the shape of the displacement thickness (δ_1) profile around the top and bottom inserts matched a streamline of the free-flight case within a 0.5 mm margin.

Especially, for the higher angle of attacks (10 and 12 degrees), larger differences between the wind-tunnel and free-flight simulations are observed: the wake is deflected up and the separation region near the trailing edge begins earlier for the wind-tunnel case. The early separation is certainly not desirable, since the focus of this experimental campaign is to obtain accurate boundary-layer measurements. By introducing the wall liners, this effect is mitigated substantially, as it can be seen in the skin-friction coefficient distribution around the wing, reported in Figure 1.

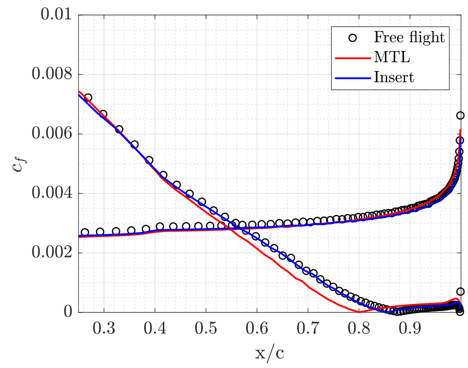

Figure 1: Friction coefficient c_f around the wing for (black circles) free-flight conditions, (red lines) original wind tunnel and (blue lines) wind tunnel with liners, at $\alpha = 12$ degrees and $Re = 10^6$.

$$c_f = \frac{\tau_{wall}}{\frac{1}{2}\rho U_\infty^2} \quad (1)$$

The full presentation will detail different liner designs and preliminary measurements to cross-validate their effectiveness in the setup to achieve the desired flow conditions.

References

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