Coherent structures of the flow over a multi-element high-lift airfoil

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Introduction

A series of 3D numerical investigations of the incompressible flow over a 30P30N high-lift airfoil with a span of 20% of stowed chord length, c, are performed at low Reynolds number ($Re_c \sim O(10^4)$) at an angle of attack α = 4°. A well-resolved direct numerical simulation is implemented via **NEK5000**[1] which is an open-source code based upon a high-order spectral element method. The present study focuses on Re_c = 0.832 $\times 10^4$ and 1.270 $\times 10^4$, aiming to understand the instability mechanisms that fundamentally govern the transition route to turbulence over the high-lift airfoil.

Flow configuration

- A total of **332,050** elements
- a 7^{th}−polynomial order in space & 3^{rd}−order accuracy in time

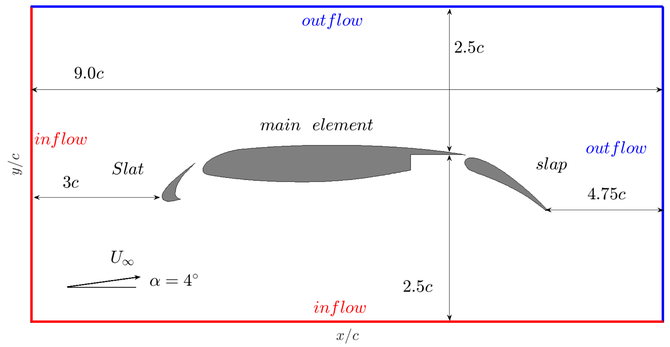

Figure 1. Sketch of the computational domain used for the calculation.

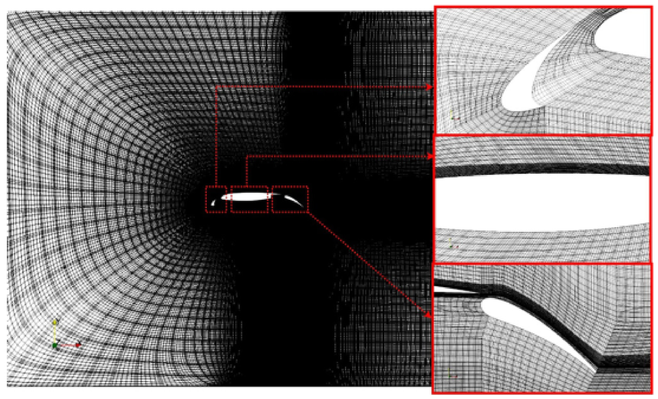

Figure 2. Grid mesh around the airfoil [2].

Coherent structures

Counter-rotating Görtler vortices, characteristic of centrifugal instability, are observed in the streamwise direction shortly downstream of the main-airfoil-element leading edge for Re_c = 0.832 $\times 10^4$ and 1.27×10^4. This phenomenon, however, is unexpected over a convex surface. The appearance of Görtler vortices is likely caused by a curved shear layer emanating from the slat cove, just above the leading edge of the main-airfoil-element, as posited by Wang et al. [3]. The present work looks into this phenomenon more closely. As the flow evolves further downstream and starts to separate, Kelvin-Helmholtz (K-H) instability takes over and leads to the formation of quasi two-dimensional (2D) vortices. While propagating downstream, these quasi-2D coherent structures get distorted and reoriented towards the streamwise direction prior to the occurrence of more complex structures in the separation region. **One question this study attempts to answer** is whether the Görtler vortices extend sufficiently far downstream such that they start to interact with the K-H instability.

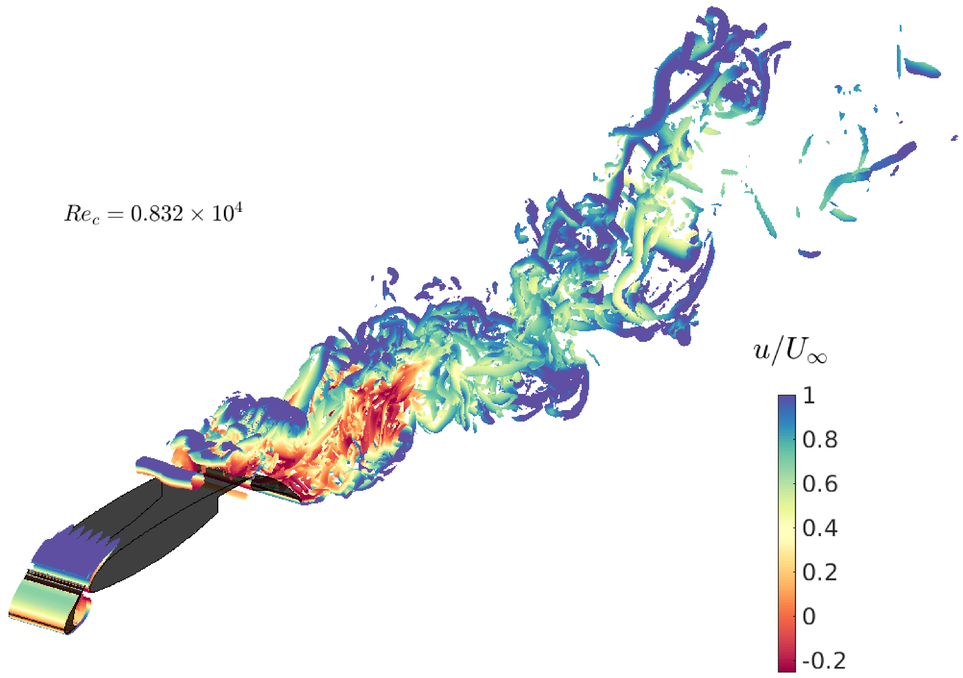

Figure 3. Iso-surfaces of λ_2 ($\lambda_2 = -50.0$), coloured by the magnitude of streamwise velocity, at $t/c = 8.96$

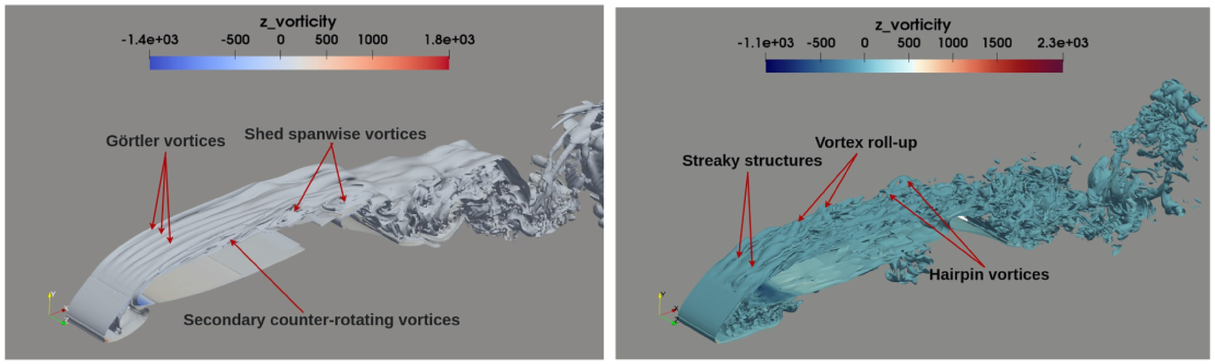

Figure 4. Instantaneous spanwise vorticity for (LEFT) $Re_c = 1.27 \times 10^4$ and (RIGHT) $Re_c = 1.83 \times 10^4$ [2]

References

[1] P. F. Fischer, J. W. Lottes, and S. G. Kerkemeier. NEK5000. https://nek5000.mcs.anl.gov, 2008.

[2] M Vadsola, GG Agbaglah, and C Mavriplis. Slat cove dynamics of low reynolds number flow past a 30p30n high lift configuration. *Physics of Fluids*, 33(3):033607, 2021.

[3] Jiang-Sheng Wang, Li-Hao Feng, Jin-jun Wang, and Tian Li. Görtler vortices in low-reynolds-number flow over multi-element airfoil. *Journal of Fluid Mechanics*, 835:898–935, 2018.

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