High Order Direct Numerical Simulation of an Iced NLF-0414 Airfoil

François Lepage[1] and Catherine Mavriplis[2]
Department of Mechanical Engineering, University of Ottawa

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Introduction

Ice accretion can largely affect the aerodynamic profile of an airfoil and has a negative consequence on the total lift. In many cases ice accretion cannot be prevented but knowing its affects can increase flight safety. Experimental data for iced airfoils is largely available but are case specific and are usually done on small scale replicas. The proposed paper aims to observe and compare results obtained by a two-dimensional direct numerical simulation (DNS) with experimental data.

Methodology

The iced airfoil being studied is the one found in run Case 606 which is one of many run cases performed on a NLF-0414 airfoil in a NASA technical publication [1]. Case 606 was performed with wind speeds of 93.0 m/s or chord Reynolds number of $5x10^6$ resulting in the iced surface in Figure 1. Differences of 10-20% are measured even for moderate angles of attack (AoA) for lift and drag. The solver Nek5000 [2], a high order DNS solver that uses the spectral element method (SEM) to solve the incompressible Navier-Stokes equations is used to compute the flow. Gmsh [3], an open source three-dimensional finite element mesh generator was used to generate the mesh. After generating the mesh, gmsh2nek [4] was used to convert from the Gmsh mesh output to a file readable by Nek5000. The initial iced domain is decomposed into 45,924 elements with a larger concentration of elements found at the leading edge of the airfoil, seen in Figure 2c, as well as in the wake. The solution is approximated using tensor products of Legendre polynomial Lagrangian interpolants. In the present paper a polynomial of order N = 5 is used for velocity as well as for pressure calculations for a total of 1,148,100 points. A clean NLF-0414 with 1,243,550 points (49,742 elements with order N = 5 polynomials) will be used for comparison. Refer to Figure 2 for the clean and iced airfoil mesh comparison.

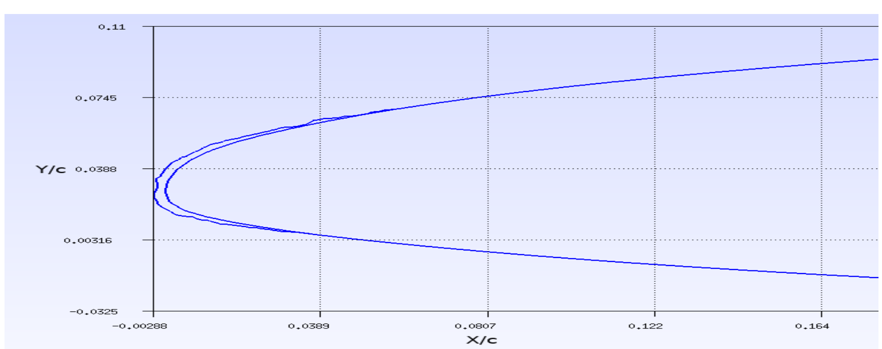
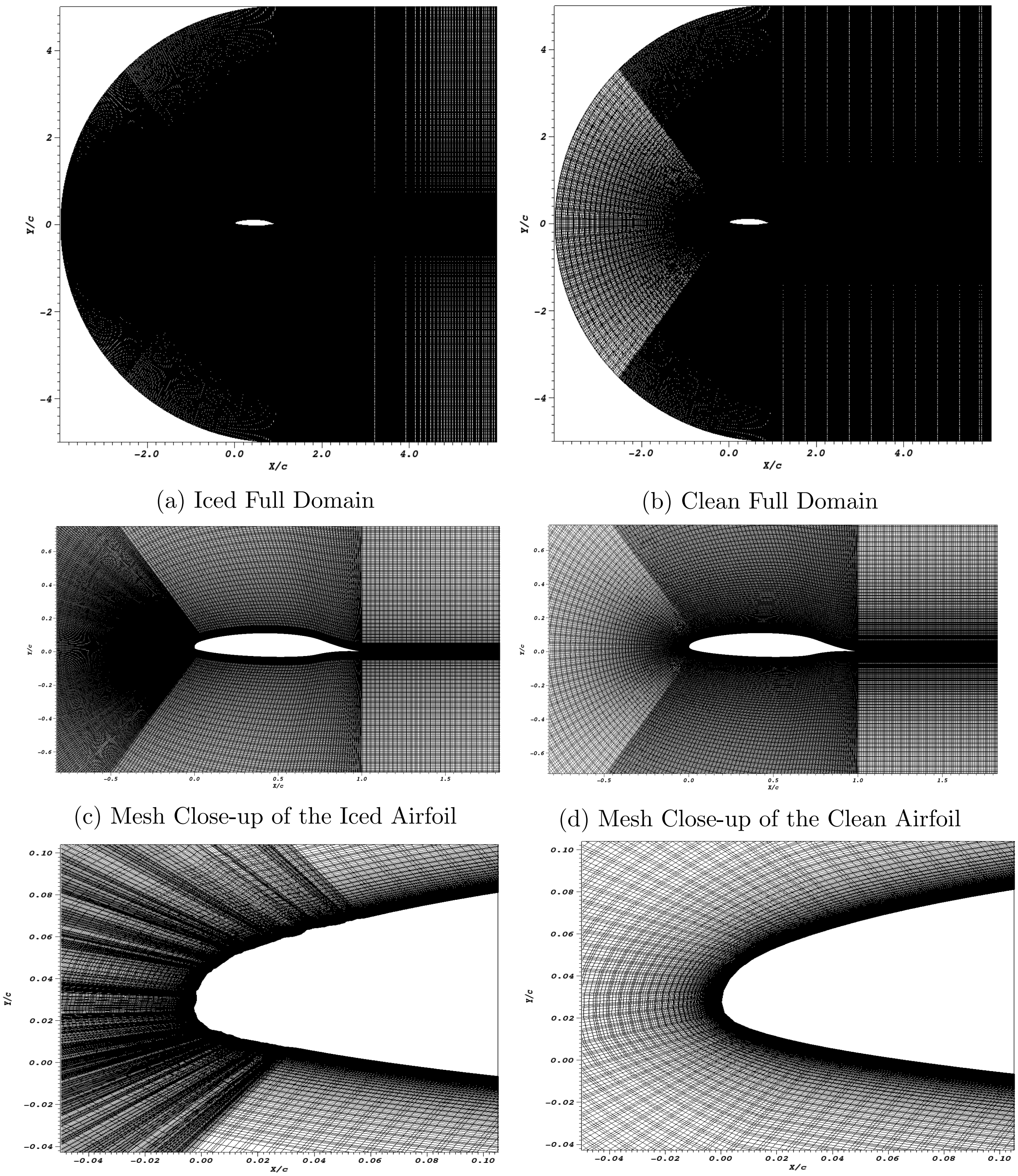


Figure 1: Run Case 606 Iced profile of a NLF-0414 Airfoil

[1]Graduate Student: flepa015@uottawa.ca
[2]AFCASI



(a) Iced Full Domain

(b) Clean Full Domain

(c) Mesh Close-up of the Iced Airfoil

(d) Mesh Close-up of the Clean Airfoil

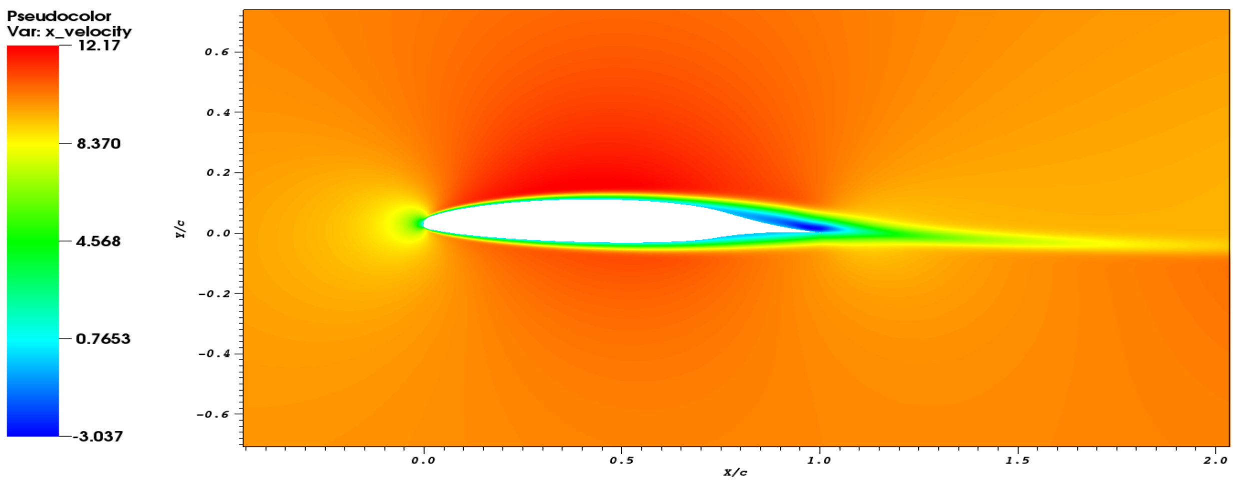
(e) Iced Leading Edge

(f) Clean Leading Edge

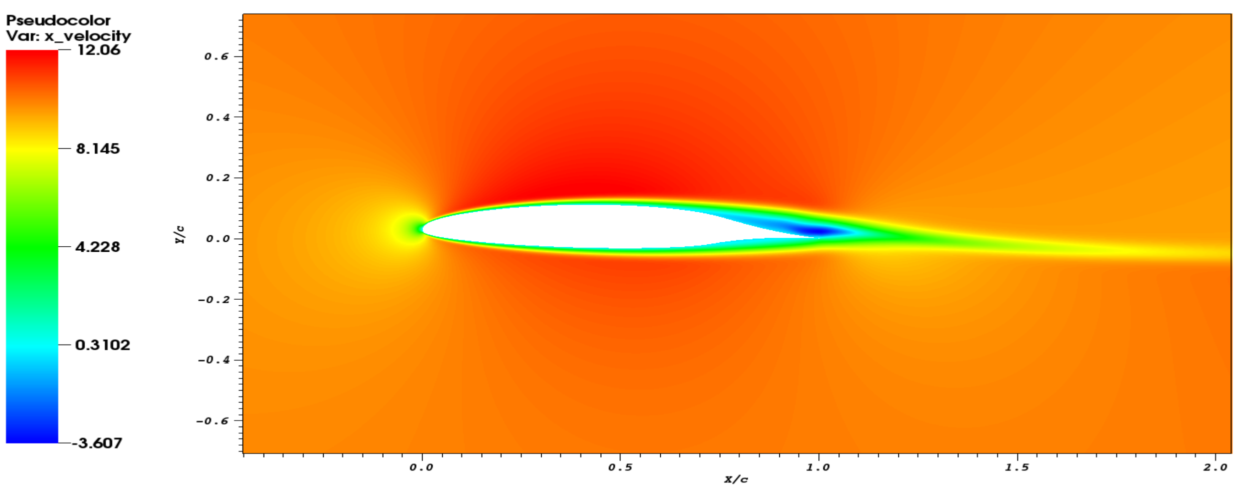
Figure 2: Meshing of the Clean and Iced NLF-0414 airfoil

Preliminary Results

To check the mesh for appropriate capture of the flow as well as to get preliminary results that can be used to initialize higher speed investigations, a low Re = 5000 case is utilized here. Figure 3 shows the x-velocity over the iced and clean airfoil at a Re = 5000 and zero angle of attack. Some differences can be seen between the iced and clean airfoil simulation, notably at the trailing edge and in the acceleration over the leading edge.



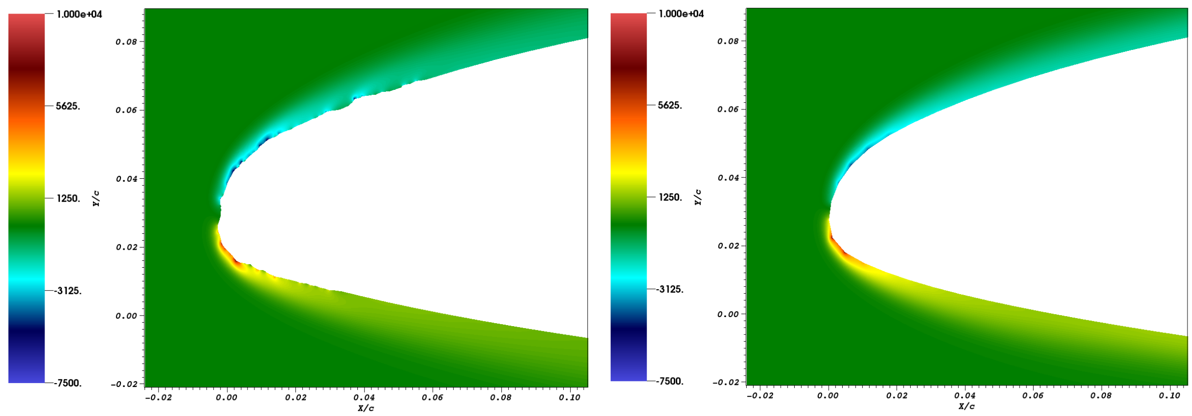
(a) X-Velocity over the Iced NLF-0414



(b) X-Velocity over the Clean NLF-0414

Figure 3: Velocity Comparison of Iced and Non-Iced NLF-0414 for Re = 5000

Figure 4 shows a leading edge comparison of the clean and iced airfoil. Figure 4a shows a large amount of localized vorticity at the sharp edges caused by the irregular iced surface. Figure 4b displays a small amount of localized vorticity but these are caused by the rectilinear (rather than curved) surface of the non-iced airfoil. This can be corrected by introducing splined-based curved elements at the leading edge of the airfoil. Nevertheless, the effect of the iced surface is clearly seen through the comparison: the boundary layer is thicker in the iced case, which will affect the drag and lift. We expect at higher Reynolds numbers that this vorticity will induce a faster transition to turbulence which will also negatively impact the drag.



(a) Vorticity of Iced Leading Edge

(b) Vorticity of Clean Leading Edge

Figure 4: Vorticity Comparison at Leading Edge for Re = 5000 and Zero Angle of Attack

Conclusion

A proof of concept has been demonstrated for using high order DNS for iced airfoils. Grid generation is challenging for the irregular iced surfaces but high resolution can be achieved with high order functions to define the geometry and provide high accuracy of the Navier-Stokes calculations. Vorticity generated by the rough iced surface is certain to negatively impact the aerodynamic performance of airfoils designed for laminar flow such as the NLF-0414. The oral presentation will include more detailed analysis of this Re = 5000 flow as we work towards simulating more realistic Reynolds numbers.

References

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