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NUMERICAL SIMULATION OF ACTIVE FLOW CONTROL BASED ON STREAMWISE VORTICES FOR A BLUNT TRAILING EDGE AIRFOIL

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1 INTRODUCTION

Previous studies have shown that three-dimensional features of the wake behind blunt trailing edge objects with different forebody geometries can be manipulated to dislocate and mitigate von Kármán vortices, and thereby reduce fluctuating lift and drag forces. Bearman and Tombazis [1,2] achieved a 34% decrease in drag by using a passive control technique which involved spanwise periodical protrusions at the trailing edge of blunt trailing edge profiles. The drag reduction associated with mitigation of vortex shedding was related to the development of three dimensional structures in the shear layer. Darekar and Sherwin [3] numerically explored the effects of the amplitude and the spanwise periodicity of the sinusoidal protrusions for low Reynolds numbers. Dobre and Hangan [4] experimentally identified the three dimensional wake flow topology at a relatively high Reynolds number of 10^4. Following these findings, Dobre, Hangan, and Vickery [5] showed that the best control efficiency in terms of vortex shedding mitigation is achieved when the near wake is excited by sinusoidal perturbations spaced at a wavelength corresponding to the statistical spanwise location of streamwise vortices. The wavelength λ_z, was found to be $2.4d$ in their case, where d is thickness of the blunt trailing edge profile. Moreover, El-Gammal and Hangan [6] extended these topological findings to the case of blunt and divergent trailing edge airfoils. The spacing of perturbations was fixed in all passive flow control schemes mentioned above. Therefore, the passive control schemes were limited to the single Reynolds number and possibly inlet conditions for which they had been designed.

However, numerical simulations carried out in the present study indicate that the streamwise vortices have a dynamic nature. They change in strength and shift in the spanwise direction overtime, while maintaining a spacing close to λ_z. This fact is the principal motivation for the present study, which aims at developing an active flow control system, to sense the instantaneous location of streamwise vortices, and excite them accordingly, in order to achieve the target of mitigation of vortex shedding more effectively in a broader range of flow conditions.

2 BASELINE GEOMETRY

The baseline geometry over which active flow control is simulated is similar to the one used by Tombazis and Bearman in [7]. It is a flat plate airfoil consisting of an elliptical nose, followed by a rectangular section (Fig. 1). This geometric configuration is popular in the wake control literature, because it provides the desired upstream boundary layer velocity profile at the trailing edge, without the uncontrollable effects of forced separation-reattachment associated with sharp leading edge corners. The geometric model has a span of 457.2mm, a chord of 321.5mm, a semi-major axis length of 65.5mm for the elliptical section, and a total thickness of 29.4mm. These dimensions are selected in accordance with the requirements of future wind tunnel tests, and to facilitate comparison of the results with the experimental data obtained by Doddipatla et al. [8].

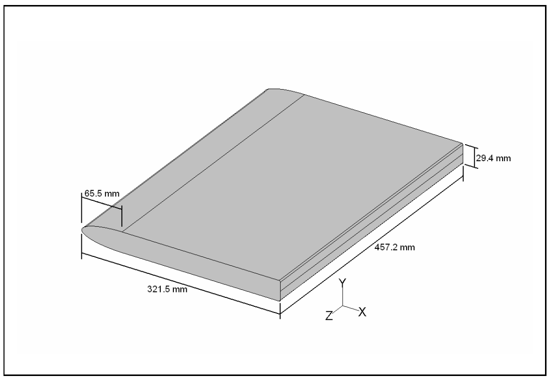

Figure 1- Geometry of the flat plate airfoil

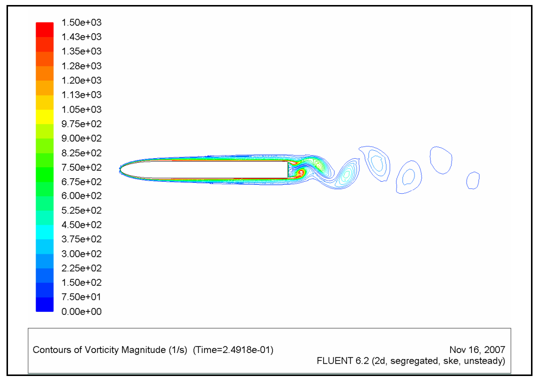

Figure 2- Vorticity distribution in the wake of the airfoil, showing the von Kármán vortex street

3 WAKE CHARACTERISTICS

Results of numerical simulations of turbulent flow around the baseline geometry indicate existence of a von Kármán vortex street in the wake (Fig. 2). For a freestream velocity of $U_\infty = 10 m/s$, which corresponds to a Reynolds number of 2×10^4 based on airfoil thickness, vortex shedding Strouhal number is 0.215.

Three dimensional numerical simulations are carried out to investigate the three dimensional wake vortex interactions. The solution domain extends 6 chord lengths behind, 2 chord lengths in front, and 2 chord lengths from the upper and lower surfaces of the airfoil. The domain is descretized using a combination of a structured, boundary layer type grid in the vicinity of the airfoil, and an unstructured grid in the surrounding areas, with a total of 1.05 million cells. Results of the simulations indicate that formation of the von Kármán vortex street is accompanied counter rotating streamwise vortices, also known as ribs. (Fig. 3). A study of the effect of the streamwise vortices on spanwise pressure and vorticity distributions (Fig. 4) reveals that the streamwise vortices occur periodically in the spanwise direction, with an average instantaneous wavelength of $\lambda_z = 2.14d$, which is close to the wavelength of three dimensional wake instabilities reported in the previously mentioned studies.

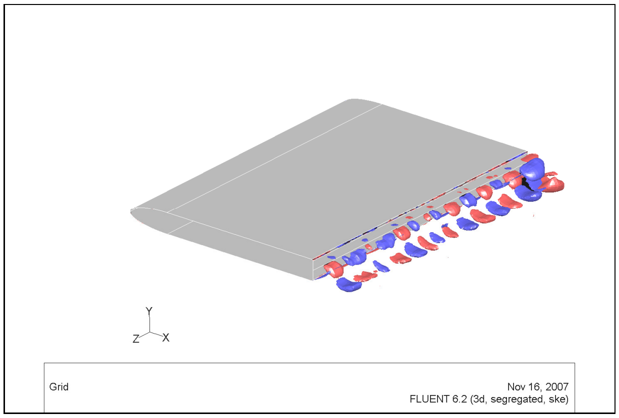

Figure 3- Isosurfaces of streamwise vorticity, showing counter rotating vortices (blue: ω_x=−20, red: ω_x = 20)

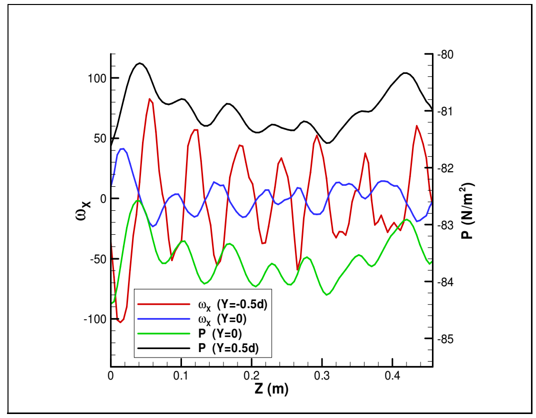

Figure 4- Spanwise distribution of static pressure and streamwise vorticity at a distance of 1d from the trailing edge

4 THE ACTIVE FLOW CONTROL MECHANISM

Based on these observations, an active flow control system consisting of a series of injection holes is designed. By injecting a secondary flow at the desired locations at the trailing edge of the airfoil, the control system produces vorticity that can amplify the streamwise vortices, and therefore disorganize and attenuate the von Kármán vortex street. The system consists of 5 rows of injection holes, each having 17 injection holes spaced at a distance of $0.1\lambda_Z$, covering a total spanwise domain equal to $1.6\lambda_z$ (Fig. 5). The upper and lower rows are placed as close as possible to the upper and lower corners of the trailing edge where vortices originate, in order to attain maximum control efficiency. Placing the injection holes closer to the corners results in a design that will be difficult to implement in practice, considering manufacturing restrictions.

To make the control system even more efficient and independent of external sources of energy, the idea of conveying the high pressure air from the high pressure area at the nose stagnation region, to the injection holes located at the relatively low pressure area of the trailing edge, is studied. Numerical simulations have been conducted to determine the amount of mass flow rate available for injection by such a design (Fig. 6). The resulting mass flow rates determine the available control budget, if no external source of controlling flow is to be used.

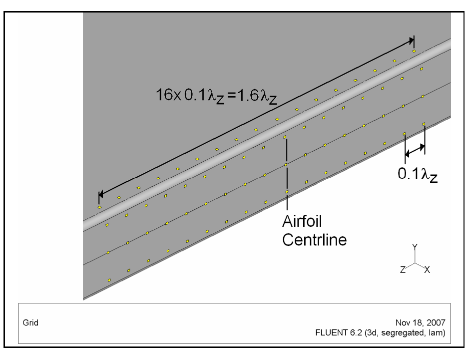

Figure 5- Arrangement of injection holes at the trailing edge

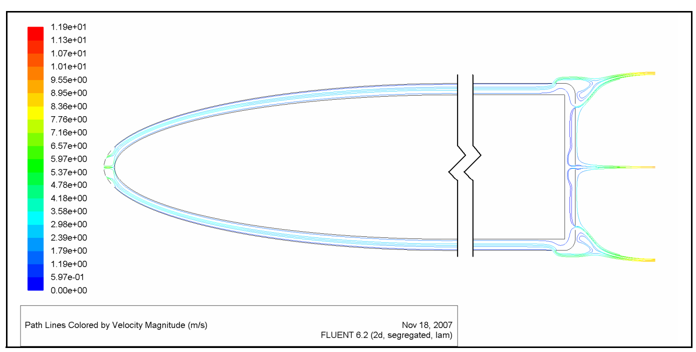

Figure 6- Pathlines and velocity distribution throughout a channel extending from the nose to the injection holes

Following the determination of the flow rates available for injection, the numerical simulations are extended to investigate three dimensional features of wake vortices in presence of the active control mechanism, using a computational grid of 1.5 million cells. Preliminary results of simulations indicate that due to the careful spacing of the holes, even the small mass flow rates achievable by the above mentioned design can significantly amplify three dimensional disturbances, and disorganize the spanwise vortices in the vicinity of the injection holes. Fig. 7 shows an example of this effect, achieved using constant injection rate from all holes.

Based on the promising preliminary results achieved, control efficiency can be further improved by using an active control trigger parameter related to the instantaneous location of streamwise vortices, and injecting the secondary flow selectively to amplify the vortices. Results of application of this control method in terms of the effect of selective injection on spanwise vortices, and consequently on the oscillating aerodynamic forces, will be presented in the final manuscript.

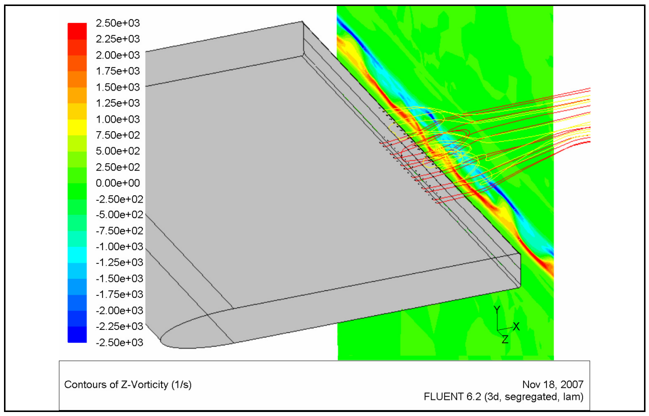

Figure 7- Effect of injection from the holes on distribution of spanwise vorticity at a distance of 1d from the trailing edge

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