Numerical simulation of flow past a flat plate with anti-singing trailing edge

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Abstract. Aerofoil with anti-singing trailing edge has been seen as the treatment to eliminate singing. The present study numerically investigates the bevel and chamfer anti-singing trailing edges with rounded ones in flat plates. The effects of 25°, 45°, 10° bevel and 15°, 45° chamfer angles provided at the trailing edge of the flat plate on the aerodynamic characteristics are systematically compared with rounded ones at a Reynolds number of 1.5x10⁵ and 25°, 30° and 45° angle of attack. The substantial reduction of primary vortex shedding frequency is observed in 25°, 45°, 10° bevel and 15°, 45° chamfer trailing edges as compared to the rounded one. Also, the presence of broader wake profile indicates higher drag in rounded trailing edge geometry as compared to anti-singing trailing edges. Thus, the present study demonstrates that the 45° and 10° bevel trailing edge could provide better anti-singing behavior and aerodynamic performance in comparison with 25° bevel, 15°, 45° chamfer and rounded trailing edge.

Keywords Vortex shedding, Wake, Trailing edge, Lift, Drag, Singing

1. Introduction

When vortex shedding frequency coincides with one of the natural frequency of aerofoil a high pitched noise is generated referred to as singing and the vibration amplitude is amplified. Under this condition, premature cracks and fatigue failure of the aerofoil may occur. The interaction between two separating shear layers from the trailing edge is the origin of vortex sheet formation. Once the vortex is produced it grows and fed by circulation from its associated shear layer. As the vortex get to be sufficiently strong, it draws the restricting shear layer across the near wake. As a result, further circulation to the growing vortex is cut off by vorticity of opposite sign and the vortex is then shed downstream. If the shear layers come closer to each other than the interaction between the shear layers is increased and the time period is reduced as the result the frequency of vortex shedding also increase (ROSHKO 1954) [1]. Von Karman stated that two parallel rows of isolated, equal, point vortices in a non-viscous fluid is stable if the vortex arrangement is asymmetrical and the ratio between lateral (b) and longitudinal (a) spacing between vortices is equal to 0.28 due to this stable vortex street a well-behaved system of alternating eddies and forces is established as shown in Figure 1. and when it resonates with natural structural frequency, results in the audible sound of singing and harmful structural vibrations.

The velocity of the vortex can be determined as:

\[ U_{Karan} = \frac{\Gamma}{2c} \tanh \left( \frac{\pi d}{c} \right) \]  (1)
For an inclined plate vortex shedding occur from the two edges, leading edge and trailing edge it was found that at an angle of attack 30° wake is dominated by vortices shed from trailing edge of the plate and vortex from leading edge detached completely from the plate and started its convection in the wake at a location near the trailing edge (Lam and Leung, 2005)[2] and for angle of attack from 30 to 90 flat plate have approximately constant value of Stourhal number 0.148 (A. Fage and F. C. Johansen, 1927)[3]. A rounded trailing edge acts like a circular body due to which a well-mannered system of alternating vortices and forces is established as shown in Figure 2, resulting in *singing* (HydroComp Technical Report, Report 138) [4]. Therefore, an *Anti-singing* trailing edge – a bevelling or chamfering of the trailing edge on suction side as shown in Figure 3. reduced vortex induced excitation considerably and used as a treatment to avoid singing. Trailing edges with asymmetric bevels and chamfering effectively thicken the trailing edge points and change the correlation scale of the vortex, therefore the frequency of vortex excitation shifts away from the natural frequency of the aerofoil (BLAKE, W. K. 1983)[5]. Early detachment occurs in the region where aspect ratio is more than 1.5 due larger vortex diameter (Nathan Phillips et al, 2015)[7]. Trailing edge noise reduction and changes in boundary layer thickness are noticed due to the leading edge serrations (P. Chaitanya et al, 2015) [8].

2. Computational domain and Grid sensitivity study
The computational domain used in the present study has length and width of 300 cm and 150 cm respectively, where flat plate is situated at an angle of attack $30^\circ$ at the x-axis such that length of a domain is 210 cm behind the center of the flat plate. No slip condition is applied at wall and fluid was considered as incompressible ideal gas. Air enters the computational domain with velocity 20 m/s and the outlet of the domain is set to pressure outlet as shown in Figure 4. The computational grid with varying mesh size is used, the fine grids are used in the regions of vortex shedding and coarse grids are used in those regions where flow effects are absent.

To check the sensitivity of computational domain four different no. of grid elements 120118, 134063, 150407 and 175959 were implemented and after comparison of the coefficient of pressure ($C_p$) along the normalized position ($x/c$) on the flat plate as shown in Figure 5. it was found that result after 120118 number of grid elements did not have significant variations, hence the grid with 125000 elements are chosen as the grid independence solution.

3. Validation

In order to establish that the predictions are right, the mean pressure coefficient $\bar{C}_p$ along the plate surface on the pressure side and suction side from the present numerical simulation is compared with
the results of Dan Yang et al [6], at angle of attack $30^\circ$ as shown in Figure 6. After comparing the plots, it is clearly seen that the almost constant pressure in the suction side is measured by experiment and simulations done in the present case.

4. Results and discussions

Numerical simulation of flow past over a flat plate with different trailing edge (a) $25^\circ$ bevel trailing edge (b) $45^\circ$ bevel trailing edge (c) $10^\circ$ bevel trailing edge (d) $45^\circ$ chamfer trailing edge (e) $15^\circ$ chamfer trailing edge (f) rounded trailing edge. as shown in Figure 4.1 is done in the present study at three different angles of attacks $25^\circ$, $30^\circ$, $45^\circ$.

![Different trailing edge geometries of flat plate.](image)

4.1 Variation of Lift and Drag Coefficient with Time

In the present case when aerodynamic characteristics like lift coefficient and drag coefficient are compared for different trailing edge geometries at different angles of attack.

4.1.1 At $25^\circ$ angle of attack

$25^\circ$ bevel and $45^\circ$ bevel trailing edge geometries are compared with rounded ones as shown in Figure 8 a,b, fractional decrease in lift and drag coefficient has been noticed for anti-singing trailing edges as compare to rounded trailing edge flat plate.

4.1.2 At $30^\circ$ angle of attack

$25^\circ$ bevel and $45^\circ$ bevel, $10^\circ$ bevel, $45^\circ$ chamfer, $15^\circ$ chamfer trailing edge geometries are compared with rounded ones as shown in Figure 8 c,d. Least drag is found for $10^\circ$ bevel trailing edge and other anti-singing trailing edges on flat plate shows considerable decrease in lift and drag coefficient as compare to rounded trailing edge flat plate.

4.1.3 At $45^\circ$ angle of attack

At high AOA $45^\circ$ flat plate behaves like bluff body and when $25^\circ$ bevel and $45^\circ$ bevel trailing edge geometries are compared with rounded trailing edge geometries as shown in Figure 8 e,f, increase in lift and drag coefficient has been noticed for anti-singing trailing edges as compare to rounded trailing edge flat plate.

4.1.4 Comparison between different angle of attacks.

Numerical simulation of flat plate plate at different angle of attacks shows more drag coefficient
in case of 45° angle of attack and less drag coefficient for 25° angle of attack whereas at an angle of attack of 25° more lift coefficient is appeared in comparison with 45° angle of attack as shown in Figure 9. This shows as we increase angle of attack drag for the flat plate increases and lift decreases.

Figure 8. AOA 25° (a) Drag coefficient vs Time (b)Lift coefficient vs Time, AOA 30° (c) Drag coefficient vs Time (d)Lift coefficient vs Time, AOA 45° (e) Drag coefficient vs Time (f)Lift coefficient vs Time
4.2 Power Spectral Density

4.2.1 At 25° angle of attack

The frequency spectra of the drag coefficient fluctuation over the top surface of the plate for different trailing edge geometry are shown in the Figure 10 (a). For rounded trailing edge a single peak is observed with more energy as compared to 25° and 45° bevel trailing edges and the considerable decrease in primary vortex shedding frequency in 25° bevel and 45° bevel is observed as compared to rounded trailing edge which indicates that 25° and 45° bevel trailing edges are proven to behave like anti-singing trailing edges. The increase of energy in the rounded trailing edge as compared to anti-singing trailing edges represents broader wake and higher drag which is discussed in the next section.

4.2.2 At 30° angle of attack

The power spectral density is estimated for flat plate with 25° bevel, 10° bevel, 45° chamfer and rounded trailing edges from the raw data samples using FFT-techniques as shown in Figure 10 (b) which require samples that are equally spaced in time. 25° bevel resulted in least primary vortex shedding frequency in comparison with others and rounded trailing edge high peak which means that it has more energy.

4.2.3 At 45° angle of attack

Again the flat plate with rounded trailing edge encountered to has highest peak in the FFT in comparison with anti-singing trailing edges (25° bevel, 45° bevel) Figure 10 (c). which shows anti-singing trailing edges continues to maintain their anti-singing nature at different angle of attacks.

4.3 Wake velocity profile

The variation of wake profile showing velocity deficit for rounded, 25° bevel and 45° bevel is shown in Figure 11. at AOA 30°. It is observed that the velocity deficit is more for a rounded trailing edge as compared to 25° bevel and 45° bevel trailing edge which indicates more drag in the rounded
trailing edge. This is further confirmed by determining the wake width, the width of the wake (W) is found more in rounded (W3) than in 25° bevel (W2) and least in 45° bevel trailing edge (W1). The presence of broader wake in the rounded geometry represents that it generates higher drag as compared to the 25° and 45° bevel trailing edges.

![Figure 10. FFT for Drag coefficient - PSD vs Frequency (a) AOA 30°, (b) AOA 25°, (c) AOA 45°](image)

Figure 11. Normalized mean stream velocity across the wake at position x/c =1.13
4.4 Effect of leading and trailing edge shape on vortex formation

With respect to Figure 12. It is seen that a set of counter rotating vortices are formed from leading and trailing edges of the flat plate. The size of the vortex generated from the leading edge is large compared to those generated from the trailing edge. It is seen that vortex from leading edge detached completely from the plate and started its convection in the wake at a location near the trailing edge.

![Figure 12. Velocity vectors showing vortex shedding](image)

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