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Numerical Investigation of Flow Induced Sound Around a Square Cylinder at Various Incidence Angles

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1-Introduction

Flow around bluff bodies such as cylinders in cross-flow is intrinsically unstable. Flow instability leads to fluctuations in the aerodynamic forces. In most cases this phenomenon is dominated by periodic vortex shedding which produces a whistling sound. Design of mitigation measures for noise generated by these bluff bodies requires fundamental understanding of the mechanism of sound generation.

Numerical simulation of turbulent flow is complicated and there is a relation between turbulent flow and acoustic field. The literatures contains few numerical studies reporting solving the details of the turbulent flow and the effect of angle of attack on the sound generated from flow around bluff bodies, specially square cylinder. In the present study flow characteristics and sound pressure level in the acoustical far field and also on the surface of a square cylinder at incidence are investigated for six angles of attack.

2- Geometry and Computational grid

The schematic of 3-D geometry and computational domain are shown in Fig. 1. Parameter D is rod width. The boundary conditions include the no-slip wall conditions on the edges of the cylinder and a uniform inlet velocity from the left face of the domain and zero gauge pressure at exit and up and down faces.

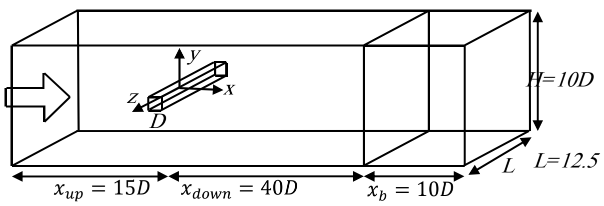

Fig.1. Computational domain

3- Results

The time averaged velocity magnitude in face z = 0 for 13° angle of attack shows that flow separation occurs on the front edges and reattachment of the flow occurs on the lower face of the rod. Due to flow separation and reattachment at 13° angle of attack, this angle is named critical angle. (Fig. 2)

When vortex shedding occurs; the acoustic noise originated by lift and drag fluctuations. The *rms* value of the lift coefficient variation at different angle of attack for three Reynolds numbers shows that it follows the same trend as the mean lift coefficient and drag coefficient. The *rms* of the lift coefficient decreases from a high initial value at 0° angle of attack to minimum value for critical angle of attack. The *rms* of the lift coefficient decreases from a high initial value at 0° angle of attack to minimum value for critical angle of attack and increases afterward.

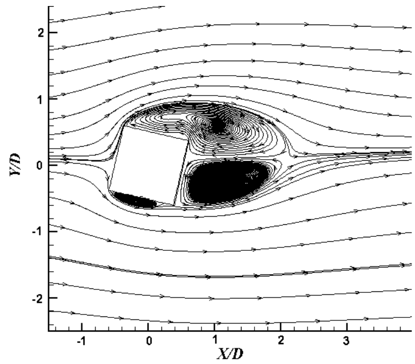

Fig2. The time averaged velocity magnitude in face z = 0 for 13° angle of attack

According to results obtained in this study and previous ones, the Strouhal number depends on the angle of attack. The behaviour of Strouhal number as a function of angle of attack show the same trend as *rms* value of lift coefficient for all Reynolds numbers. The Strouhal number increases with angle of attack from 0° to 13°. The maximum value of Strouhal number is occurred in 13° angle of attack and decreases as angle of attack increase from 13° to 45°.

The sound generated by air flow around the square cylinder shown in Fig. 1 is measured by two receivers. The Receivers positions are (0.21m, 0.55m, 0m) and (0.21m, −0.55m, 0m). It follows the same trend as the lift fluctuations. Sound pressure level *(SPL)*, at various angles of attack for three Reynolds numbers is shown in figure 3.

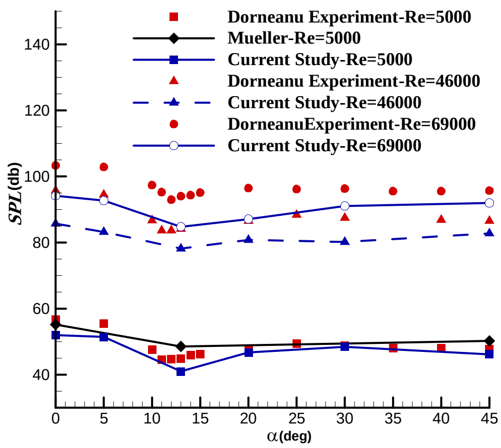

Fig.3. Far field sound pressure level for different angles of attack

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The SPL directivity patterns investigations show that for 0° angle of attack the sound pressure level has maximum value at the 0° and 180° directions and minimum at the 90° and 270°. The sound pressure field is shaped by the Aeolian tones that is related strongly to the lift fluctuations of the bluff body. For sound field that is generated by the lift, the sound waves radiates at ±90 directions in respect to the free stream. The sound pressure level originated due to the lift fluctuation at three values of far field distance and for Reynolds number of 5000 and 45° angle of attack is plotted in Figure 4.

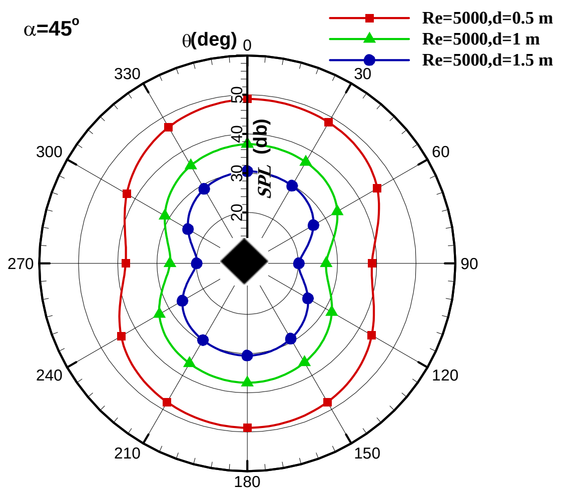

Fig.4. directivity patterns for Re=5000 at 45° angle of attack

Sound pressure level on the surface of a square cylinder at incidence are also investigated for six angles of attack. The results show that the *SPL* on the surface is not so correlated with the Reynolds number. The minimum sound pressure level on the surface occurs at 13° angle of attack, the same as the sound pressure level in the acoustical far field. Fig.5 shows the Sound pressure level on the rod surface for Reynolds numbers of 46000 and 69000 for 13° angle of attack.

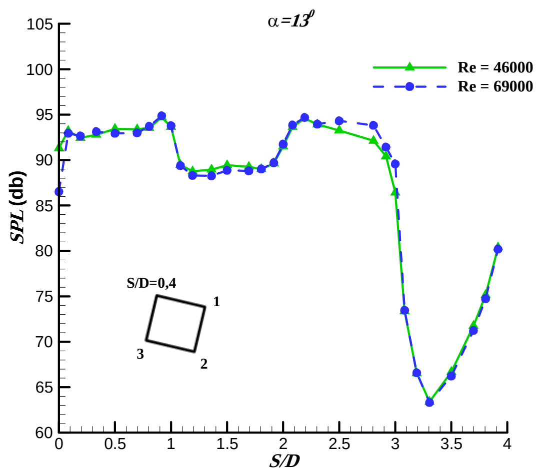

Fig.5. Sound pressure level on the rod surface for Reynolds numbers 46000 and 69000 at Angle of attack 13°

4- Conclusion

In the present study flow characteristics and *SPL* in the acoustical far field and on the surface of a square cylinder at incidence are investigated for six angles of attack. Flow around square cylinder is modelled using large eddy simulation method. The flow simulation is conducted using Fluent commercial software. The results of drag coefficient, mean and root mean squared (*rms*) value of lift coefficient, and sound pressure level in acoustical far field compared with the numerical and experimental results data from the literature. The results of the present study show good agreement with the available experimental and numerical results. The trend of SPL variation was in agreement with the other investigations and minimum of both *rms* of lift coefficient and SPL occurred at critical angle of attack.

It is noticed in the present study that Fluent commercial software cannot correctly evaluate the sound pressure level over the surface of a solid body. Hence, by capturing the pressure fluctuations on the surface, sound pressure level in the near field could be calculated by different equations which is used in Fluent. Numerical simulations showed a good trend of variation for sound pressure level (SPL) in acoustical far field. The sound pressure level predicted by numerical simulations has less than 10% difference with the published experimental results. The minimum of sound pressure level occurred at 13° angle of attack which is consistent with the fluctuating lift force acting on the rod which in turn generates the acoustic field. The turbulence level of the flow depends on Reynolds number. By increasing the Reynolds number, the sound pressure level also increases. Although the cost of this numerical simulations by LES (Large Eddy Simulation) is considerably higher than RANS (Reynolds Averaged Navier-Stokes) methods, but its predicted flow characteristics as well as far field SPL agree well with the available experimental results.