

Reduction of Aeroacoustic Sound and Aerodynamic Drag using Porous Cover

Alexander M, Karthik K, Jeyakumar S



Abstract: *The application of a porous media on square cylinders to reduce drag in cross-flow is an active research area. Be that as it may, the related stream incited sound in the encompassing flow likewise experiences decrease, an angle which has gotten less consideration. This paper exhibits a numerical strategy for coupled streamlined and aero acoustic estimations for low Mach number flow current pass a square cylinder with permeable cover. Computations are performed at a subcritical Re of 54,800 using URANS technique and FW-H acoustic analogy. The cylinder without porous cover is subjected to an incoming flow is considered for validation against measurements. A significant drag reduction and sound reduction is observed with the presence of the porous layer. Comparisons are made among the modified cylinder and its unmodified counterpart.*

Keywords: *Aero acoustics, Aerodynamics, CFD, Passive control*

I. INTRODUCTION

The interaction of high-speed flow past a solid body generates unsteady fluid dynamic loads, which in turn produces flow-induced noise, also called aeroacoustic sound (Rienstra and Sijtsma, 2018). Aerodynamic loads and the associated aero acoustic sound emitted from the bluff bodies are of concern for many applications, such as landing gear, automobiles, etc. (Kaviani and Nejat, 2017; Talotte, 2000; Vilela de Abreu et al., 2016). The numerical computation of aerodynamic and aero acoustic characteristics of rigid bluff bodies have received extensive attention (Kurbatskii and Mankbadi, 2004; Tam, 2006; Wang et al., 2006).

The development of aerodynamics led to streamlined structures which have decreased aerodynamic drag and self-induced noise in comparison to bluff bodies (Devinant et al., 2002; Moreau et al., 2014). But most structures encountered in the engineering applications are bluff bodies which include bridge piers, buildings, vehicles, chimneys, cooling towers, heat exchanger tubes, flame- holders, aircraft undercarriage during landing, pipelines and re-entry vehicles, to mention a few. Hence studying the aerodynamics and aero acoustics of bluff bodies, has been the field of interest of

several numerical and experimental (Casalino and Jacob, 2003; Cox et al., 1998; Gloerfelt et al., 2005; Guo et al., 2016; Inoue and Hatakeyama, 2002; Karthik et al., 2018a; Khalighi et al., 2010; King and Pfizenmaier, 2009; Moreau and Doolan, 2013). From the literature survey, it is observed that most of the analysis is concentrated on circular cylinders and a few reported investigations are found on the study of aerodynamic drag and flow-induced noise on flows over the square cylinder (Chauhan et al., 2018; King and Pfizenmaier, 2009; Latorre Iglesias et al., 2016; Purohit et al., 2014; Samion et al., 2016; Sukri Mat Ali et al., 2011).

Be that as it may, the related stream incited sound in the encompassing flow likewise experiences a decrease, an angle which has gotten less consideration. This paper exhibits a numerical strategy for coupled streamline and aero acoustic estimations for low Mach number wind current pass a square cylinder with permeable cover (Anirudh and Dhinakaran, 2018; Babu and Narasimhan, 2010; Bhattacharyya and Singh, 2011; Bruneau and Mortazavi, 2008, 2004; De and Ghosh, 1989; Geyer and Sarradj, 2016;

Jue, 2004; Liu et al., 2013; Naito and Fukagata, 2012; Rong et al., 2011; Salimi et al., 2015; Sueki et al., 2010; Yu et al., 2010; Zhao and Cheng, 2010). However, only a few studies have been performed for computing both the aerodynamic drag and aero acoustic sound of cylinders with a porous cover.

II. GEOMETRY AND FLOW CONDITION

In this work, a rigid square cylinder covered with porous media of porosity (ϵ) 0.95 is considered. All simulations in this paper are carried out at $Re = \rho U D / \mu = 54800$. The flow Re and the associated properties in this paper are consistent with the experimental values (Latorre Iglesias et al., 2016).

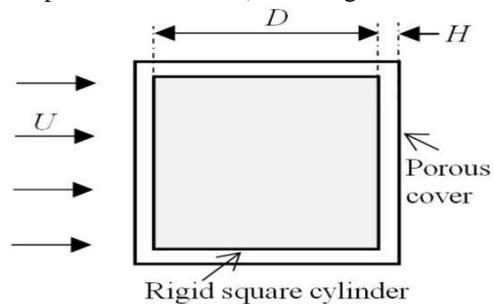


Figure 1: Definition sketch

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III. COMPUTATIONAL METHODOLOGY

The turbulent air flow field over the cylinder is computed by utilizing the two-dimensional URANS technique (Samion et al., 2016), where the numerical model simultaneously solves the mass and momentum conservation equations. Even though the flow field in this problem is 3D in nature, the 2D method can, however, obtain the significant aerodynamic and aero acoustic characteristics (Cox., 1998; Liu., 2015; Samion., 2016) at a cheap computational expense and is a more appropriate technique for a parametric study (Khorrami et al., 2007). The $k-\omega$ SST model (Menter, 1994; Wilcox, 2006) is employed to provide closure to the system of equations formed by URANS. The FVM with the QUICK (Leonard, 1979) is used for the spatial discretization, while a 1st order discretization is utilized for transient discretization. The SIMPLE calculation is used for the weight speed coupling. For efficient flow control, the dimensionless permeability is defined as Darcy number, $Da = 7.86 \times 10^{-3}$ and $\varepsilon = 0.95$ (Naito and Fukagata, 2012). (Karthik et al., 2018b). To compute the aerodynamic drag coefficient and acoustic pressure signals, the unsteady information is collected, once the fluid flow attains the statistically steady-state. The flow-induced sound is calculated using the FW-H acoustic analogy (Williams and Hawkings, 1969) with the 2D URANS results as input by using a "correlation length" method (Cox et al., 1998; Liu et al., 2015). The "correlation length" technique presumes that the vortex shedding is totally related over a specific length of the cylinder in the lengthwise course (Casalino and Jacob, 2003). The correlation length that is required in this method can be found experimentally by determining the surface static pressure along the length of the cylinder. In this paper, a correlation length of $6D$ is adopted based on the previous experimental data (Porteous et al., 2017; Vickery, 1966). Detailed explanations of the fluid governing equations, acoustic analogy, and correlation length model may be found in previous studies (Casalino and Jacob, 2003; Karthik et al., 2018a; Samion et al., 2016). The CFD simulations have been carried out by implementing the cylinder models in the commercial flow solver ANSYS Fluent (Ansys, 2011), and a MATLAB code (MatLab, 2012) was developed for processing the acoustic pressure data.

IV. RESULTS AND DISCUSSIONS

The dimensions of the computational domain around the 2D square cylinder are shown in Fig. 2. The uniform fluid stream is normal to the inlet boundary „AB“, i.e. x-axis is parallel to the incoming velocity U . The origin (0, 0) of the coordinate system is positioned at the midpoint of the cylinder. The boundaries „BC“ and „have zero shear pressure and uniform speed. The outlet limit 'CD' has a zero gauge pressure. The no-slip (wall) condition is assigned on the cylinder surface. The computational domain size is chosen as $31.5D \times 21D$ (Samion et al., 2016).

A near wall resolution of $y^+ = 1$ has been protected close to the surface for completely resolving the laminar sublayer. Along the peripheral surface of the cylinder, the cells are being spaced equally at $0.02D (= \Delta s)$ apart. For numerical calculations, the tempestuous flow trench ought to accomplish a statistically steady state and this happens at around 0.1 s. In all computations, the entire simulation time is

1.1 s and the final 0.9 s (i.e. = T; from 0.2 s to 1.1 s) of time history information is utilized in computing the fluid and acoustic outcomes.

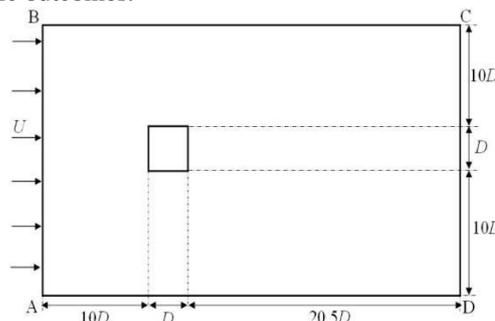


Figure 2: Schematic diagram of the computational domain (not to scale).

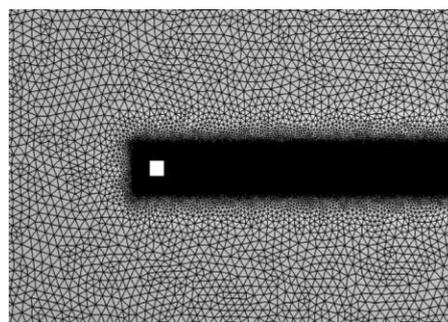


Figure 3 Computational Mesh

The exactness of the SPL computations essentially depends on the precision of the URANS. To validate this solution, the mean aerodynamic drag coefficient ($C_{D,mean}$), rms lift coefficient ($C_{L,rms}$) and Strouhal number (St) corresponding to the dominant vortex shedding frequency, computed numerically, are compared with previous studies (Table 1). The $C_{D,mean}$, $C_{L,rms}$ and St of the cylinder acquired from CFD are in great concurrence with the past investigations (Bosch and Rodi, 1998; Murakami and Mochida, 1995; Park, 1995; Samion et al., 2016; Shimada and Ishihara, 2002; Sohankar, 2006; Tian et al., 2013; Vickery, 1966)

Table 1: comparison of the numerical solution with the literature

Method (Author)	$C_{D,mean}$	$C_{L,rms}$	St
$k-\omega$ SST (Present)	2.181	1.485	0.118
$k-\omega$ SST (Tian et al., 2013)	2.06	1.492	0.138
$k-\omega$ SST (Samion et al., 2016)	2.1	1.43	0.126
$k-\varepsilon$ (Bosch and Rodi, 1998)	2.108	1.012	0.146
$k-\varepsilon$ (Shimada and Ishihara, 2002)	2.05	1.43	0.141
LES (Murakami and Mochida, 1995)	.09	1.6	0.132
LES (Sohankar, 2006)	2.19	1.433	0.118

Experiment (Park, 1995)	2.1	-	0.13
Experiment (Vickery, 1966)	2.044	1.299	0.12
Empirical; Circular cylinder (Norberg, 2003)	-	0.5	0.188

To assess the precision of the far-field acoustic investigation, the figured flow actuated sound information are approved utilizing trial results (Latorre Iglesias et al., 2016) at $Re = 54,800$. The sound estimations were led in an echo-free wind tunnel on a square cylinder. The PSD of the calculated sound pressure at the receiver location (0, 87.5D, 0) has been obtained using Welch technique (Dumitran, 2014) adopting Hann window with 50% overlap of 3 data segments (Oppenheim, 1987).

Figure 4 shows the examination of the registered SPL range with test information (Latorre Iglesias et al., 2016). The figured range concurs with the exploratory range at the important districts and demonstrates a satisfactory match elsewhere. The most essential qualities of this range, explicitly, tonal Strouhal number (for example the Strouhal number related with the pinnacle recurrence of the range, spoken to by St) and the tonal SPL at this recurrence (spoken to by SPL_T in dB) coordinate exactly with test results as appeared Table 2. This implies the URANS and FW-H strategy used in this examination is fit to foresee the essential highlights of the aero acoustic sound and furthermore has the ability to display extra knowledge through a parametric report. To make clear the sound decrease levels at the recipient area, the OASPL, which is a gauge of the all-out sound vitality of the SPL range is used in this paper.

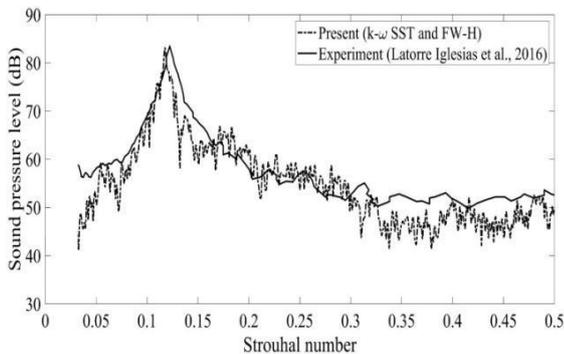


Figure 4: Comparison of the numerical SPL spectrum with the experimental result.

Table 2: Comparison of the calculated sound parameters with experimental results.

Acoustic parameters	Exp.	Num.
St_T	0.122	0.118
SPL_T (dB)	83.48	83.06

Table 3: $C_{D,mean}$ and OASPL of a cylinder with and without porous cover.

H/D	$C_{D,mean}$		OASPL	
	CFD	Reduction (%)	CFD	Reduction (dB)
0	2.181	-	96.89	-
0.1	1.452	33.43	93.51	3.38
0.15	1.399	35.86	91.65	5.24
0.2	1.361	37.62	90.02	6.87
0.25	1.318	39.57	89.33	7.56
0.3	1.281	41.25	88.74	8.15
0.35	1.340	38.54	87.47	9.42
0.4	1.379	36.79	87.53	9.36

With regards to enhancement, a response surface for both OASPL and C_D , mean width permeable thickness as the variable was built. The built RSA models are as per the following:

$$OASPL \text{ (dB)} = (0.15809 \times L6) + (0.85074 \times L5) - (0.11494 \times L4) - (2.2725 \times L3) + (0.2507 \times L2) - (0.93467 \times L) + 89.33 \tag{11}$$

$$C_D, \text{ mean} = (-0.057872 \times L6) - (0.045085 \times L5) + (0.15275 \times L4) + (0.13232 \times L3) - (0.030074 \times L2) - (0.11269 \times L) + 1.3 \tag{12}$$

$$\text{Where } L = (H/D - 0.25) / 0.10801 \tag{13}$$

Comparing the St (see Table 2) with the St (see Table 1), it is clear that the peak sound frequency takes place at around the dominant vortex shedding frequency, which means the dominant role of vortex shedding on aero acoustic sound generation. So, by amending the vortical flow structures in the cylinder wake, the sound production can be controlled (You et al., 1998) and this is what a cylinder with a porous cover does (Bruneau and Mortazavi, 2004).

The R-square and RMSE for these sixth-degree polynomials (Eq. 11 and 12) are given in Table 4. The knee point of the Pareto optimal front (Fig. 6) is found to be $H/D = 0.3201$

In the present work, a square cylinder with a porous cover of non-dimensional thickness 0.1D to 0.4D with intervals of 0.05D is simulated numerically. The instantaneous drag force and flow-induced sound pressure of all the models were numerically computed. Table 3 records the values of C_D , mean and OASPL for all cases. It can be noticed that the mean drag force (C_D , mean) and flow-induced sound (represented by OASPL) of cylinders with porous are significantly suppressed, with respect to the unmodified cylinder.

This is due to the increased base pressure of the modified cylinder compared to the unmodified one (Naito and Fukagata, 2012; Zhao and Cheng, 2010) (Fig. 7). The presence of porous cover shows the way to a considerable decrease of the vorticity magnitude (Bruneau and Mortazavi, 2008, 2004), and in turn, reduce flow-induced sound (Liu et al., 2015) (Fig. 8). When a porous cover of $H = 0.35D$ is connected to the barrel, the sound outflow and drag constrain lessens by about 9.42 dB and 38.54 % individually. So also, when a permeable front of $H = 0.3D$ is connected to the cylinder sound emanation and drag drive diminish by about 8.15 dB and 41.25 % individually. Further increment in the H ($> 0.35D$) results in higher C_D , mean and OASPL. The variety of C_D , mean and OASPL with and the corresponding results are given in Table 5.

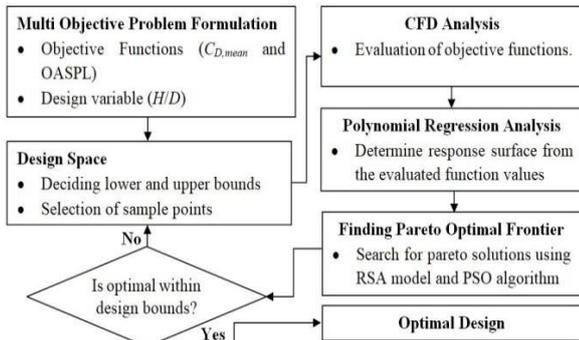


Figure 5: Design methodology

Table 4: Statistical parameters of the RSA model
 Goodness-of-Fit Statistics C_D , mean OASPL
 R-square 0.99 0.99

Goodness-of-Fit Statistics	$C_{D,mean}$	OASPL
R-square	0.99	0.99

Root mean squared error (RMSE) 9.4405×10^{-6} ,
 8.8329×10^{-5}

Table 5: Results for the ideal setup of the cylinder

H/D	OASPL	$C_{D,mean}$
0	96.89	2.181
0.3201 (Optimum)	88.30	1.268
Reduction	8.59 dB	41.86 %

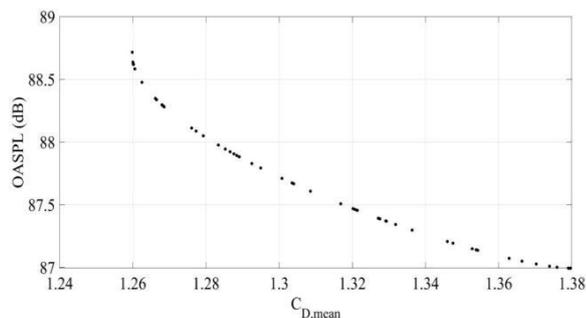


Figure 6: Pareto optimal front

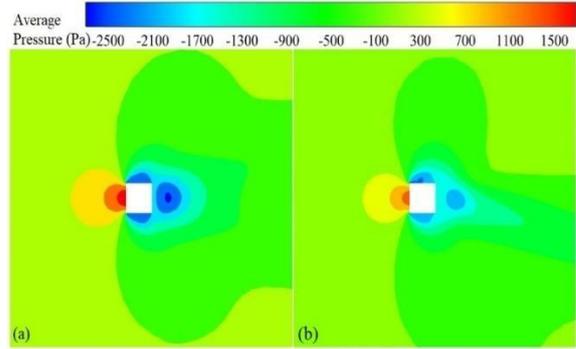


Figure 7: The mean static pressure distributions around square cylinders (a) without and (b) with an optimal porous cover

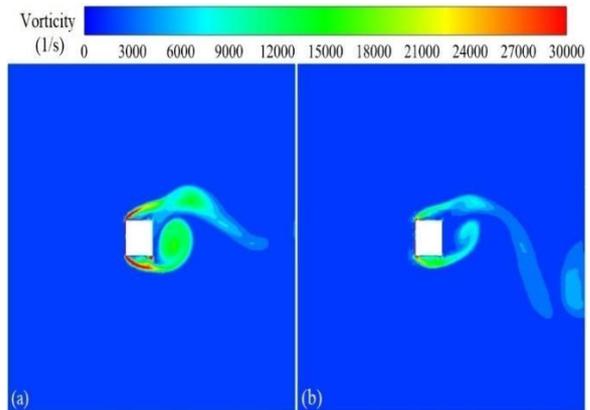


Figure 8: The instantaneous vortices distributions around square cylinders (a) without and (b) with an optimal porous cover.

V. CONCLUSION

The use of a square cylinder covered with porous media as a means to reduce drag force in cross-flow is an active area of research. However, the sound that is induced by such flows and the associated sound emission levels has not received much attention. This paper studies aerodynamic and aero acoustic behavior of square cylinders attached with porous cover numerically. The incoming flow field at $Re = 54,800$ has been resolved using the URANS technique, and the far-field acoustic results are computed by means of the FW-H acoustic analogy. The considered cylinder model of optimal porous thickness $H/D = 0.3201$ show significant drag and sound mitigation. The drag and OASPL reduce by 41.86 % and 8.59 dB, respectively compared to the unmodified cylinder.

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