

THE NEAR-WALL INFLUENCE ON THE FLOW AROUND A SINGLE SQUARE CYLINDER.

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***Abstract**. The* flow around a solid body is very influenced by a wall placed at close distance, due to the strong interaction between the boundary layer on the wall and the vortex shedding behind the cylinder. The intensity of this iteration depends on the displacement between the wall and the body, characterized by the critical gap, where the vortex shedding loses its periodicity. In order to simulate this problem, a numerical code was developed in FORTRAN employing the Finite Volume technique, and the Large Eddy Simulation (LES) for turbulence modeling. A set of different displacements and Reynolds numbers were performed, aiming to better understand the phenomena involved

Keywords. square cylinder, numerical simulation, near-wall, vortex shedding, LES.

1. Introduction

The capability of maintaining a constant vortex shedding frequency is a very important characteristic for many applications, such as vortex shedding flowmeters and electronic devices cooling systems. Furthermore, the proximity of walls and other obstacles, the flow free stream turbulence level, the flow regime and the velocity distribution could have strong influence on the vortex shedding frequency. In this work, numerical simulations of a square cylinder close to a wall, and immersed in a 2D, incompressible, turbulent flow, were performed in order to reproduce the critical gap encountered in the experimental tests.

For a square cylinder, having the side dimension B and at distance y from a plane wall, the critical gap is the ratio y/B where there is no regular vortex shedding. However, this critical gap may vary accordingly to the shape of the body and its distance from the boundary layer. In cases where the boundary layer thickness is large enough, or the distance from the body to the plane wall is too close, the vortex street may come in contact with it, suppressing the vortex shedding regular pattern – the Von Karman street.

It is expected that the break-up in the regular vortex shedding frequency would be due the interaction between the separated shear layer, behind the cylinder, and the boundary layer developed on the plane wall. The high turbulence intensity presented in the boundary layer is injected into the recirculation zone, avoiding the inversion in the velocity profile as an effect of the shear layer.

In order to better reproduce the experimental results found in literature (Durão *et al.*, 1991), several numerical simulations were performed for different Reynolds number, ranging from 2000 to 18000, and three y/B ratios: 0.25, 0.35, and 0.55 were tested. Due to the high Re regime, in some cases a Large Eddy Simulation turbulence methodology were employed. For this flow regime and square cylinders, the critical gap was found to be around y/B < 0.35 (Durão *et al.*, 1991). The Reynolds number is given by:

$$Re = \frac{\rho\, U_\infty B}{\mu} \qquad (1)$$

It is worth noting that no free stream turbulence intensity was introduced in the numerical simulation, as well as no wall friction effect was modeled, such as presented in the experimental tests (Durão *et al.*, 1991). In that experimental work, a high free stream turbulence intensity - about 6% - was found due to the lack of screens and honeycombs, and the skin friction was evaluated to be $C_f = 0.0046$. Furthermore, in both experimental and numerical tests, no blockage correction had been done.

2. Numerical method

An unsteady, incompressible, and isothermal flow of a Newtonian fluid can be modeled by the Navier-Stokes equations associated with the continuity equation. These equations are stated, respectively, as follows:

$$\frac{\partial}{\partial t}\left(u_i\right)+\frac{\partial}{\partial x_j}\left(u_i u_j\right)=-\frac{1}{\rho}\frac{\partial p}{\partial x_i}+\frac{\partial}{\partial x_j}\left[\nu\left(\frac{\partial u_i}{\partial x_j}+\frac{\partial u_j}{\partial x_i}\right)\right]+Sc_i\,, \qquad (2)$$

$$\frac{\partial}{\partial x_j}\left(u_j\right)=0\,. \qquad (3)$$

The numerical simulations were performed over a non-uniform regular orthogonal mesh and an example for an y/B = 0.35 configuration is depicted in Fig. (1). Due to the high Reynolds numbers, a highly density of cells around the cylinder line was needed in order to capture the smaller scales vortexes. The mesh generation had been done using the pre-processing routines of the simulation software. The Large Eddy Simulation methodology was used with the Smagorinsky sub-grid model (Smagorinsky, 1963).

The advective terms were interpolated by the Consistent QUICK scheme (Hayase *et al.*, 1992) and the pressure-velocity coupling algorithm were solved by the SIMPLEC scheme (Patankar, 1980) in fully implicit first order time discretization. In order to solve the linear system generated by the Eq. (2) and Eq. (3) discretization, a TDMA algorithm was employed.

The domain dimension has been changed for each configuration. In the Fig. (2), the dimensions for y/B = 0.35 configuration is depicted as well as the boundary conditions employed for all configurations.

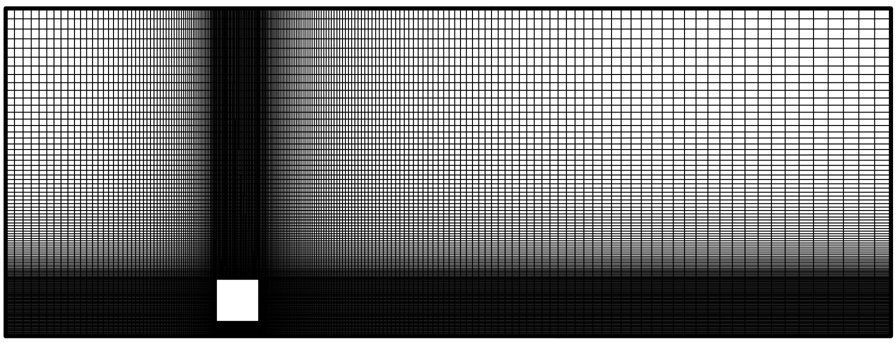

Figure 1. Numerical mesh (228x135 cells) for y/B = 0.35 configuration.

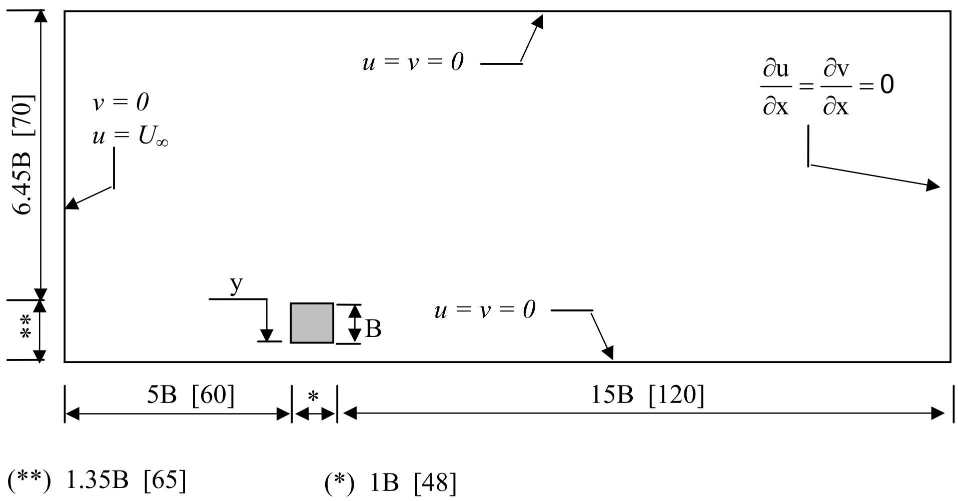

Figure 2. Domain dimensions and boundary conditions.

Numerical probes were employed in order to capture the velocity oscillations caused by the vortex emissions. The power spectrum analysis of this signals helps to evaluate the regular vortex shedding frequency break-up in the critical gap. A more detailed description about the numerical simulation software can be found in Campregher (2002).

As stated above, the main goal was to reproduce the experimental data, given by Durão *et al*. (1991). The dimensions used in this present work were the same as that employed by Durão *et al*. (1991), i.e., the numerical square cylinder had B = 20mm, and the domain was 420 x 156 mm.

3. Results and discussion

The tests were performed for three different gaps – distance y, see Figure (2 – and, for each gap, several Reynolds numbers and Smagorinsky constant (Cs). The Smagorinsky constant was adjusted to the numerical code. The isovorticity contours and their related spectral density power for Re = 8500 are presented in Fig (3).

For the first geometric configuration, y/B = 0.55, the power spectrum shows a well-defined peak, representing the main vortex shedding frequency. Furthermore, there is no secondary peak coming up in any other frequency. This scenario is very interesting and shows that the wake behind the cylinder had suffered no interference from the wall. Hence, some authors had reported that the critical gap increases as the boundary layer height increases. In the isovorticity contours lines, one can see several well-defined vortices shed behind the cylinders. The accelerated flow below the cylinder pushes down the boundary layer, decreasing its height in that region.

The second configuration simulated, y/B = 0.35, had presented the interaction between the boundary layer and the vortex street behind the cylinder. As expected, this contact had produced some interference in the vortex shedding pattern, suppressing the fundamental frequency. At the same time, more turbulence is injected into the shear layer. As the gap becomes smaller, the boundary layer faces some resistance in flowing throughout it. In the isovorticity contours, in the Fig (3) right column, it is possible to see the stagnation region before the cylinder, as a consequence of the boundary layer detachment.

In the third configuration, y/B = 0.25, one can see that the stagnation point in front of the cylinder has increased its height. This was expected due to the narrow gap between the cylinder and the wall. One can see that upwind the cylinder, the boundary layer had detached.

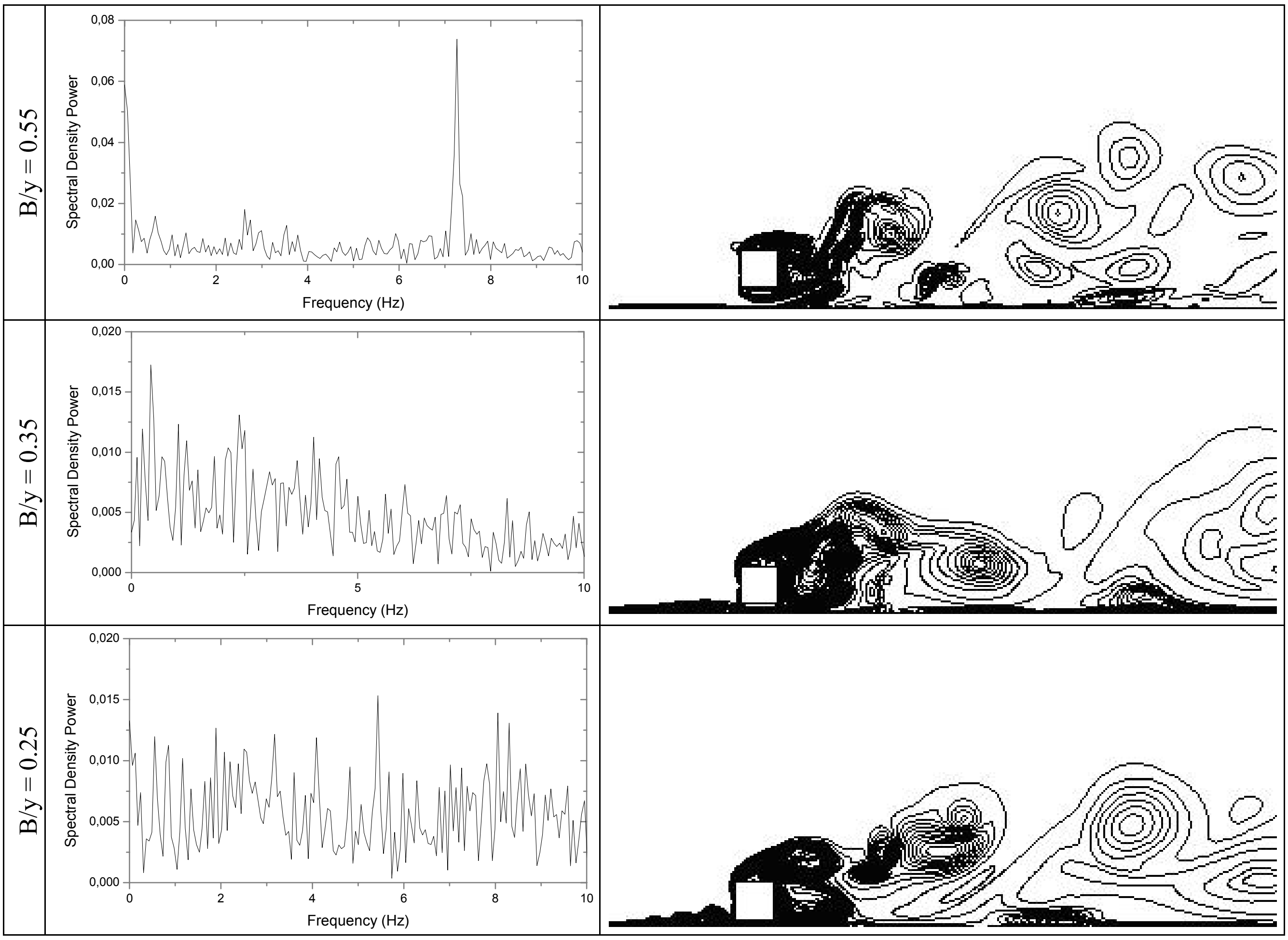

Figure 3. Spectral density power (left) and vorticity contours for the three configurations tested.

The Figure (4) depicts the flow behavior around the cylinder in more details for the three configurations and the early detachment of the boundary layer. One can see that the velocity vectors have deviated almost symmetrically around the cylinder front face in the y/B = 0.55 configuration. This characteristic tends to make the shear layer in both upper and lower sides of the cylinder to present the same pattern as the encountered in the cylinder immersed in a wall free stream. In the other configurations, the pictures reinforce the presence of a stagnation region in front of the obstacle and the lower face vortex break-up due to the fluid injection from the boundary layer.

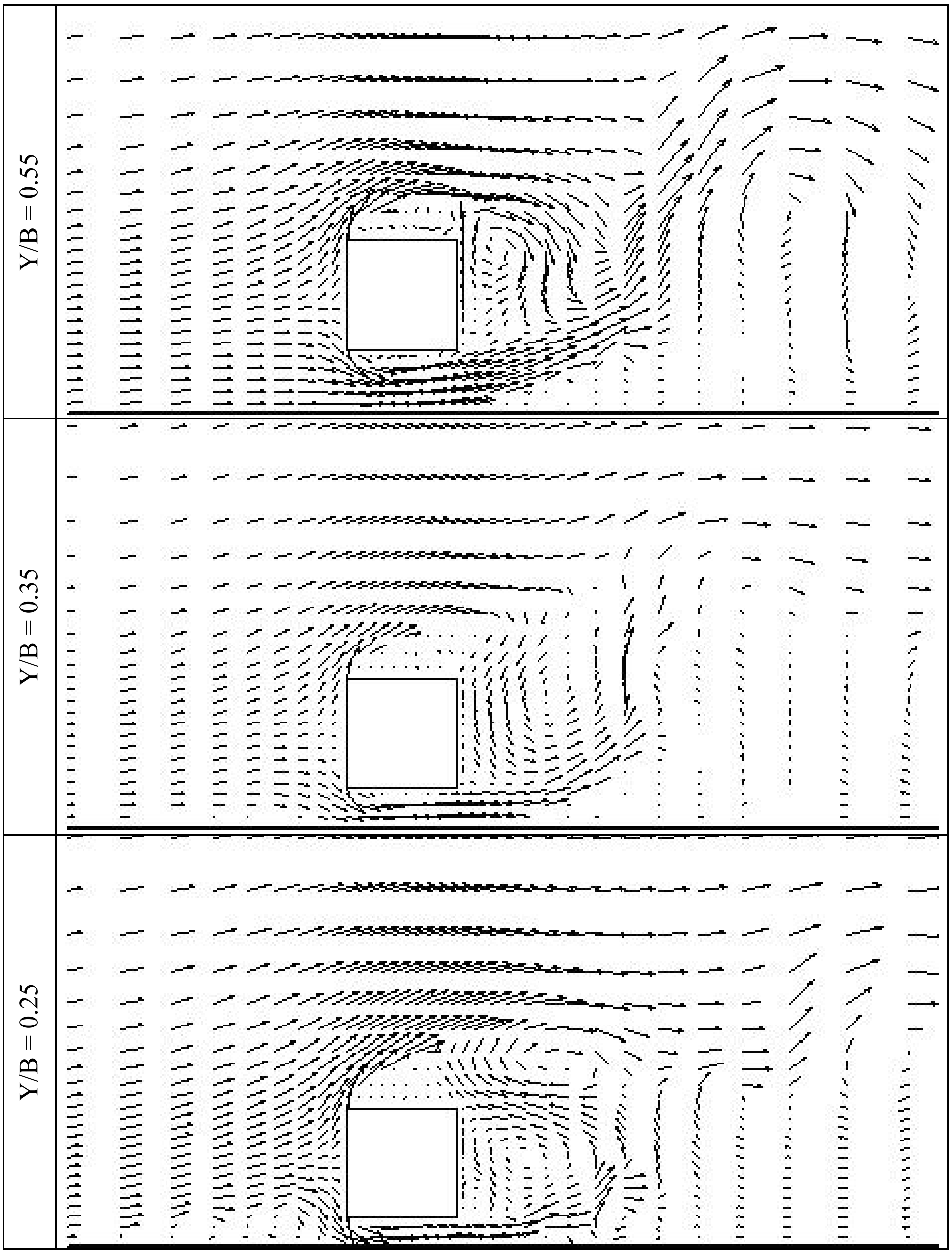

Figure 4. Velocity vectors for the different gap configurations.

The frequency results for different configurations are compared against the experimental data from Durão *et al.* (1991) and depicted in the Figure (5). One can see in the Figure that the frequency and, as a consequence, the Strouhal number, behave in a similar manner for both experimental and numerical tests. In both works, the frequency value increases in a linear behavior as a function of Reynolds number, although the error stays around 20%. Furthermore, it is possible to realize that, the Smagorinsky constant (Cs) of 0.10 has presented almost the same error as for Cs = 0.15. It is important to mention that the calculation is two-dimension and the measure was performed in a three-dimensional flow.

Finally, it is worth noting that the results for the critical gap, in this work, have presented a good agreement with the experimental results.

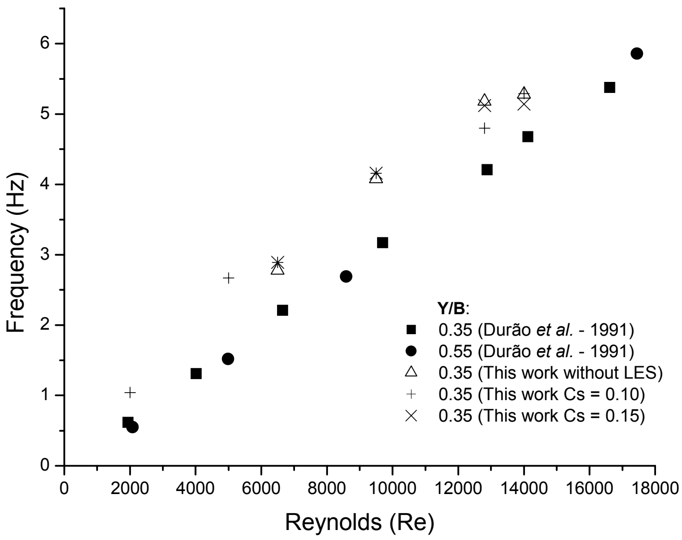

Figure 5. Vortex shedding frequency *versus* Reynolds number for numerical and experimental tests.

4. Conclusions

The fairly large differences, especially for the main vortex shedding frequency, obtained between the two approaches, numerical and experimental, could be related to several characteristics of the numerical simulation. Among them could be cited the bi-dimensional domain, which is well known as inapt of getting the cross-flow influence behind the cylinder. The cross-flow is a great responsible for the onset of the transition effects.

It worth noting that no wall treatment was employed in the simulation. The wall treatment could influence on the boundary layer height, influencing directly on the critical gap value and on the vortex shedding frequency. Accordingly to the results presented above, the value of the former seemed not be influenced at all – there was great concordance with the experimental data.

Despite the differences presented in this preliminary analysis, the results are promising, that encourages performing additional tests in order to explore the phenomena in more details.

5. References

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