

COBEM2019-2089

SHEDDING VORTEX IN THE NEAR WAKE OF A CYLINDER ARE ANALYZED FROM THE NUMBER OF STROUHAL CHANGING THE METHODS OF NUMERICAL DISCRETIZATION

E. A. Freitas
L.F.R Castelo Branco
E. O. do Nascimento
A. V. C. Araujo
E. F. Lins

Federal University of Para, Campus Belem, Street Augusto 01, Guama, Belem
elcilaneaf@gmail.com, leticia.branco@maraba.ufpa.br, oliveira94n@gmail.com, andrecoستا@ufpa.br, erb@ufpa.br

Abstract. Problems involving flow past cylindrical structures are common, physical phenomena concern from the formation of permanent vortices to turbulent vortices, passing through vortices formed in the Reynolds laminar region, forming the Von Karman vortex. The description of these vortices can be performed by numerical analysis using the finite volume method. However, several algorithms are modeling the phenomenon, being necessary to compare them with experimental results and to evaluate what is best suited to each case. Thus, a numerical flow model was developed past a cylinder using the PISO and SIMPLE pressure-velocity coupling methods and the second-order Upwind spatial discretization schemes and the third-order MUSCL, the results were compared with experimental results existing in the specialized literature. Shedding vortex is simulated lift and drag coefficients are also verified (CL and CD), with a turbulent flow for $Re = 150$. The frequencies of the lift oscillations obtained in the reviewed literature agree well with experimental results simulated from the calculated Strouhal number. It was observed that the methods give very approximate results, but with different processing times.

Keywords: Von Karman vortex, Strouhal number, Upwind second-order, Third-order MUSCL. . .

1. INTRODUCTION

The flow around cylinders is a well-known problem in the mechanics of fluids, since many are the practical applications involving the physical phenomena, such as, flow through submarines, offshore structures, submarine pipelines, etc. Depending on the range of the Reynolds number, the flow presents several different behaviors. According to Sumer (1997), the flow field around a circular cylinder is symmetric at low Reynolds number values. As Reynolds increases, there is separation of the flow, forming laminar vortices ($40 < Re < 200$) and configuring a transient phenomenon. The transition region is observed in $200 < Re < 300$. As for the subcritical region, equivalent to the wake around the circular cylinder becomes completely turbulent.

Chong *et al.* (1980) described the properties of the vortices formed by the flow past a cylinder, analyzing the vortices near the cylinder and the distant vortices of the cylinder. Figure 1 shows the formation of vortices and streamlines.

Numerical analysis was performed for transient flow past a cylinder with Reynolds number of 150 to observe the formed vortices (Von Karman track), using the velocity-pressure coupling algorithms Semi-implicit Method for Pressure Linked Equation (SIMPLE) and Pressure-Implicit with Splitting of Operators (PISO) in order to observe the effects on the solution. Strouhal number values were compared with experimental data shown by Lienhard *et al.* (1966).

2. PHYSICAL AND NUMERIC MODEL

As can be seen in Figure 2, there is a domain configuration for flow past a cylinder, cf. Rahman *et al.* (2007), considering a Reynolds number of 150. The flow presents a complex region as it passes through the cylinder, namely: the wake region immediately after separation of the boundary layer with the immersed body, with ordered structures, initially laminar, and the formation of vortices (see Jamal and Azmi (2018) and Sumer (1997)). The analysis of the flow around a cylinder will be made through the fields of velocity and pressure. The geometry of interest is two-dimensional in order to simplify the analysis of the flow.

The average flow along the mat was obtained from numerical simulations of the Navier-Stokes equations using Fluent software. The boundary conditions were defined as the cylinder walls according to the non-slip condition, that is, $u = 0$

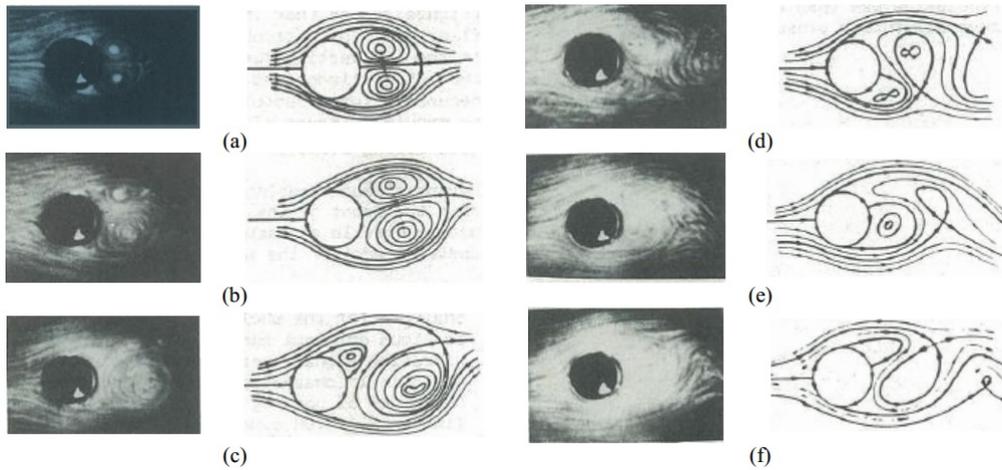


Figure 1. Flow around a cylinder from rest. The sequence of events begins at (a) and ends at (f)

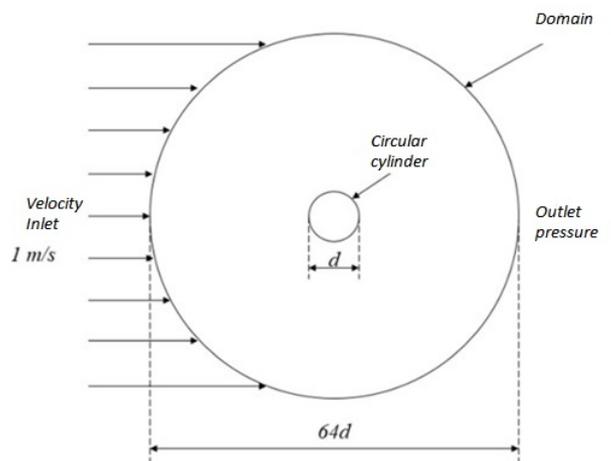


Figure 2. Schematic drawing of the flow field around a cylinder

and $v = 0$. It was defined that in the domain, there is a free current with uniform speed $U_{\infty} = 1 \text{ m / s}$, applied at the inlet. The fluid outlet is treated as outlet pressure. The dynamic viscosity was adjusted to $0.00666 \text{ kg / (m.s)}$, according to the chosen Reynolds. The created mesh has 18624 nodes, 36480 faces and 18432 quadrilateral cells. More elements are generated in the intermediations near the study of cylinder to satisfy the visualization in the region near-wake, (see Figure 3 b).

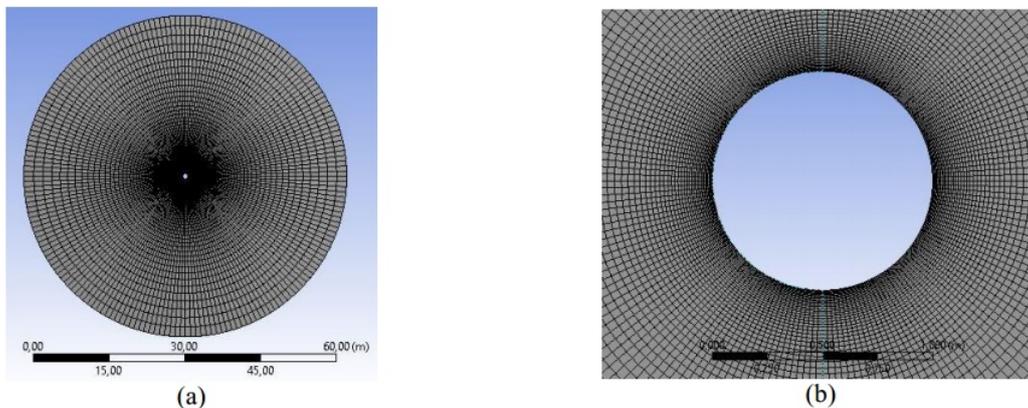


Figure 3. (a) mesh computational domain (b) refined mesh near the cylinder wall.

3. MATHEMATICAL MODELING

In a transient flow with incompressible fluid, where it passes through a circular cylinder, the classical continuity and momentum equation are considered in Eq. 1 and Eq. 2.

$$\nabla \cdot \vec{u} = 0 \quad (1)$$

$$\frac{\partial(u)}{\partial t} + u \nabla \cdot \vec{u} = \frac{1}{2} \nabla \cdot (\Gamma \nabla u) \quad (2)$$

The lift coefficient and pressure coefficient are calculated according to Eq 3 and Eq. 4, respectively:

$$C_L = \frac{L}{0,5\rho U^2_\infty d} \quad (3)$$

$$C_P = (P - P_\infty) \frac{1}{2} \rho U^2 d \quad (4)$$

Where L is the holding force and P is the pressure. The Reynolds number is given by . The dimensionless number of Strouhal is expressed by Eq. 5:

$$S_t = \frac{fd}{U_\infty} \quad (5)$$

Where f is the frequency of the vortex, d is the diameter of the cylinder and U_∞ is the velocity of the flow.

4. RESULTS

The simulations involving the transient flow around a cylinder were made in $Re = 150$ using the SIMPLE and PISO coupling schemes. The processing times of the schemes were 6803.75 seconds of PISO and 5621.86 seconds of SIMPLE, that is, a difference of 1181.89 s. It is natural that the PISO algorithm takes longer processing time, since it performs more calculations than the SIMPLE and is used for transient flows. Figure 4 shows the vortex formation obtained with the SIMPLE discretization method and MUSCL resolution.

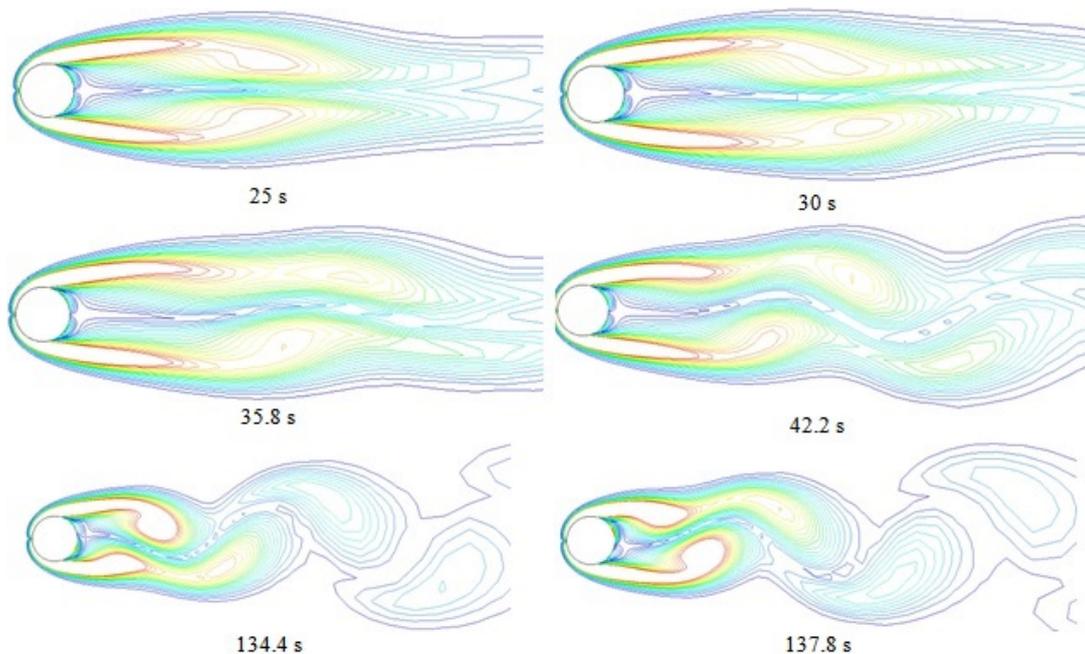


Figure 4. Formation of the vortices, with beginning of the shedding in 35.8 s

Figure 5 represents the lift coefficient comparing the simulations using second order Upwind and MUSCL. It is observed that the beginning of vortex formation in both schemes is 35.8 s. After the complete formation of the vortices, the shedding period observed in the Upwind scheme is 6.84 s and frequency of 0.146 Hz, for the MUSCL scheme, the shedding is faster, with a period equal to 6.4 s if the frequency is equal to 0.156 Hz. Figure 6 shows the number of

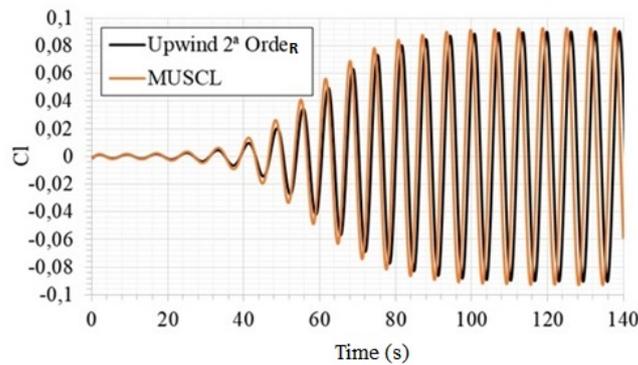


Figure 5. Simulation result to Lift coefficient

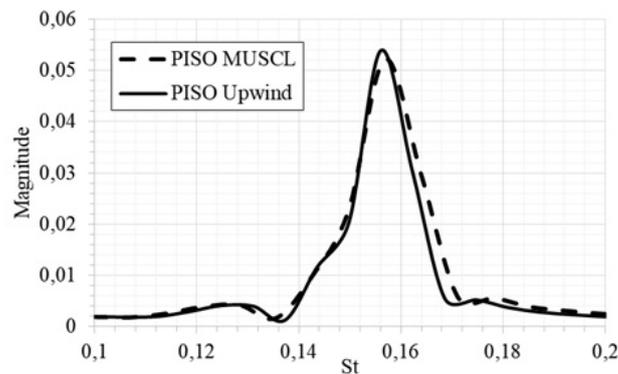


Figure 6. Comparison between St

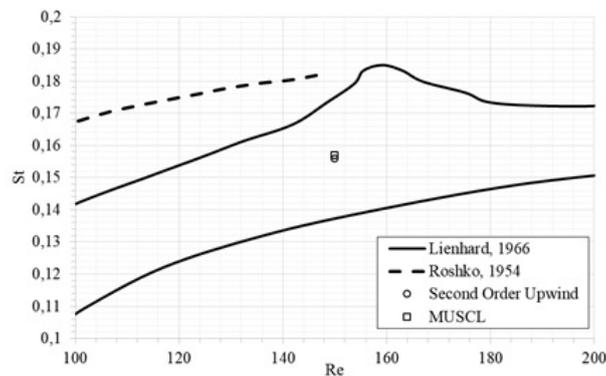


Figure 7. Comparison between St obtained in $Re = 150$ and experimental results. The upper and lower lines indicate a St range of experimental data.

Strouhal (St) obtained for the flow with $Re = 150$, and a small variation of the value between the second order Upwind spatial discretization schemes and third order MUSCL, the values of St obtained were 0.156 and 0.157, respectively.

Experimental results show that for $Re = 100$, St is in the range of 0.164 to 0.165 (Tritton, 1959 apud Rahman *et al.* (2007)). Applying the finite volume method, Rahman *et al.* (2007) obtained the $St = 0.164$ for $Re = 100$, furthermore, Lienhard *et al.* (1966) presents the data obtained for St from several experiments. Comparing the analyzes cited with the results of St obtained (Figure 7), it is seen that the values of St are in the range presented by Lienhard *et al.* (1966).

5. CONCLUSIONS

A numerical analysis of the laminar flow around a cylinder was carried out, from which the formation of the vortices, the Strouhal number and data related to the processing time were obtained.

Von Karman's vortex resemble those presented in experimental results, with periodic formation of structures. The longest processing time of the PISO algorithm was verified, although the results obtained with the two algorithms are

similar. If only processing time is considered, SIMPLE appears to be the best choice for simulation.

However, although the lift coefficient and consequently the Strouhal number for SIMPLE and PISO algorithms are equal, as there is an approximation of the results when using the second-order Upwind and MUSCL schemes, it is verified that despite the computational mesh not be refined enough that it can accurately state that any combination of coupling methods and discretization scheme used will lead to the result obtained. The St value obtained is in the range described by Lienhard *et al.* (1966).

6. ACKNOWLEDGEMENTS

We thank CAPES for granting the scholarship to carry out and encourage this work.

7. REFERENCES

- Chong, M., Lim, T., Perry, A. *et al.*, 1980. "The vortex shedding process behind a circular cylinder". *7th Australasian Conference on Hydraulics and Fluid Mechanics 1980: Preprints of Papers*, p. 330.
- Jamal, M.H.M. and Azmi, A.M., 2018. "Flow past two interlocking squares cylinder at low Reynolds number". *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences*, Vol. 44, No. 1, pp. 140–148.
- Lienhard, J.H. *et al.*, 1966. "Synopsis of lift, drag, and vortex frequency data for rigid circular cylinders". *Journal of Naval Architecture and Marine Engineering*, Vol. 300.
- Rahman, M.M., Karim, M.M. and Alim, M.A., 2007. "Numerical investigation of unsteady flow past a circular cylinder using 2-d finite volume method". *Journal of Naval Architecture and Marine Engineering*, Vol. 4, No. 1, pp. 27–42.
- Sumer, B.M., 1997. "Hydrodynamics around cylindrical structures". *World Scientific, Singapore*, Vol. 26.

8. RESPONSIBILITY NOTICE

The following text, properly adapted to the number of authors, must be included in the last section of the paper:
The author(s) is (are) the only responsible for the printed material included in this paper.