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EXPERIMENTAL AND NUMERICAL ANALYSIS OF THE FLOW AROUND PRISMATIC BODIES IN VORTEX METERS

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Abstract: *The flow where vortexes are shed meet several applications in many Engineering fields, like aerodynamics and hydrodynamics. The present work studies, numerically and experimentally, the vortexes generation and the shedding phenomenon in a flow around prismatic bodies having trapezoidal cross section. The experimental tests were obtained in a low turbulence vertical hydrodynamic tunnel for Reynolds number up to 500. The vortexes trail images were gathered employing the dye wash technique. The trail velocity measurements, that were probed by hot film anemometry, allowed to evaluate the vortexes shedding frequency. The numerical solution of Navier-Stokes equations, with no turbulence modeling, was evaluated employing the volume finite technique with orthogonal non-structured grid. The comparison between experimental and numerical results has shown fairly good agreement.*

Keywords: *Flow visualization, hot film anemometry, numerical simulation, bluff bodies, Strouhal number.*

1. INTRODUCTION

The flow around bluff bodies generates, in most of the time, vortexes due the boundary layer separation. In some conditions, the vortexes are shed alternately, in both sides of the body, producing the well known von Kármán vortex street. The vortexes shedding frequency (f) is directly related to the free stream velocity (V) and the characteristic body diameter (D), and is represented by a non-dimensional parameter known as Strouhal number, that is defined by:

$$Sr = \frac{f\ D}{V} \tag{1}$$

Nowadays, many studies based on theoretical and experimental analysis are performed, showing the close relation among the Strouhal number, the geometry of the body, and the flow regime, as some examples, one can cite Okajima(1982), who studied Square base cylinders with several shape factors in aerodynamic and hydrodynamic tunnels, exploring a wide range of the Reynolds number; Kawakita & Silvares (1993), employed ten different prismatic bodies geometry, having high blockage ratio (around 30%); Vieira *et al.* (1997a,b), who studied elliptic and circular cylinders, and Mansur *et al.* (1996), who studied rectangular cylinders.

The primary idea of build a vortex meter based on the Strouhal number variation due the Reynolds number (*Re*) is from Anatol Roshko (1953) who, in 1953 studied the vortex shedding phenomenon on circular cylinder and established the relation between (*Sr*) and (*Re*) with accuracity enough to be used as air speed measurement system – Ower & Pankhurst (1977). Roshko stated that, supported by a huge number of observations, for a circular cylinder placed orthogonally in the main stream, the following relation:

$$Sr = 0.212\left(1 - \frac{C}{\mathrm{Re}}\right) \tag{2}$$

where (C) has the value 21,2 or 12,7 for Reynolds between $50-150$ and $300-2000$, respectively.

The equation (2) can be changed in order to express the free stream velocity (*V*) and the vortex shedding frequency (*f*).

$$V = 4{,}72 \cdot f \cdot D \ + \ \frac{C \cdot m}{D \cdot r} \tag{3}$$

Accordingly with Roshko(1953), these results can be used to measure the flow velocity employing the following procedure: a circular cylinder is placed inside the flow and the vortex shedding frequency (*f*) is evaluated by different experimental methods, like those discussed by Gonçalves & Vieira (1999). The velocity (*V*) can be obtained by equation (3), since the Reynolds number still within the range specified by Roshko, i.e.,50–150 or 300–2000.

Nowadays the vortex flowmeters, are used in many industrial, commercial, and aeronautical applications and have been, for about two decades, proved to be reliable and precise devices. Actually, vortex flowmeters have very simple configuration, high accuracy, wide range, weak dependence on fluid viscosity, and no moving parts exposed to wear so, they are very reliable – Yokoi & Kamemoto (1994) and Unal & Rockwell (1988).

Due this advantages, a better understanding of the influences caused by the several different cylinder bodies geometry on the vortexes shedding are highly desirable. Os vortex flowmeters are excellent devices for volumetric and/or mass flow rate measurements, but their design is quite complex due the many different characteristics that might influence the vortex shedding phenomenon. Obviously, the main factor is the vortex generator geometry of the shedder, because the continuous and discrete vortex shedding capability has strong dependence of the geometry employed – Pankanin & Krystkowicz (1995). Different prismatic bodies of different cross section geometry are tested by the flowmeters manufacturers, aiming stable frequency curves.

In this work, two trapezoidal cross section bodies were tested, for Reynolds number up to 500 employing both numerical and experimental methods, focusing on vortex meters application.

2. EXPERIMENTAL APPARATUS AND PROCEDURES

2.1. Hydrodynamic Tunnel

The tests were performed in a low turbulence hydrodynamic tunnel driven only by gravitational effects, having test section of 146×146×500 mm, schematically depicted in Fig. 1 and detailed by Vieira (1997a.,b).

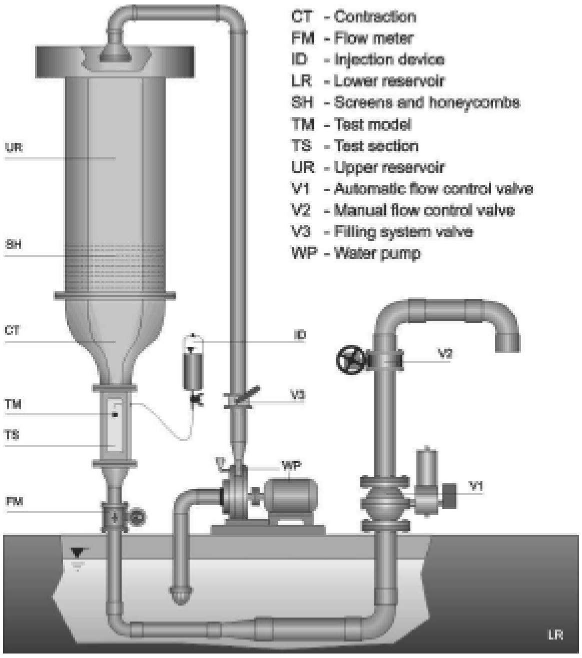


Figure 1. Low turbulence hydrodynamic tunnel

The vortex shedding frequency was evaluated from spectral analysis, utilizing the Fast Fourier Transform (FFT) on velocity signal, probed at a pre-established point in the vortex shedding street, by a 3-channels Dantec Streamline 90N10 constant temperature anemometry system with digital data acquisition. A 2μm hot-film 55R11 probe were used at constant temperature of 150°C and the acquisition data frequency up to 30kHz.

2.2. Test Bodies

The Fig. 2 shows, schematically, the test bodies geometry used. The two tested models were tooled in aeronautic aluminum polished, with sharp edges, and controlled dimensional deviation. The Table 1 represents their dimensions.

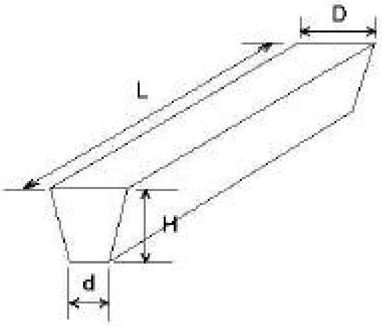


Figure 2: Test bodies sketch.

Table 1. test bodies dimensions

Test body	D (mm)	d (mm)	L (mm)	H (mm)
TB1	8	4	146	8
TB2	8	6	146	8

2.3 – Flow Visualization

The vortex shedding street visualization was obtained using the dye wash technique. The dye – a mixture of PVA pigments, alcohol ethylic, and water – was injected upstream the body helped by a 0,7 mm OD long hypodermic needle. For further details of this technique, please see Lindquist (2000).

The images were captured using a Nikon F4s SLR photographic camera that takes 5,7 photos per second and has a 60 mm f.1:2.8 macro objective. The film was a color Kodak Ultra ISO 400 and the illumination was supplied by eight 150W Photo Flood GE incandescent bulbs.

3. NUMERICAL MODELING

A unsteady, incompressible and isothermal flow of Newtonian fluid around cylindrical bodies can be fairly good represented by the numerical solutions of the Navier-Stokes Equations in association with the Continuity equation. In this work, the equations have been solved considering, additionally, a two dimensional flow of constant properties. The momentum equations were discretized by the volume finite technique. Furthermore, pressure-velocity coupling algorithm was the SIMPLEC (Patankar & Spalding –1972), and the advective terms was the QUICK scheme (Leonard -1979). No turbulence modeling was employed due the fairly low Reynolds number of the current simulation. The Fig. 4 depicts the computational non-uniform orthogonal mesh, with finer grids near the side wall and the downstream the body, as shown in Fig. 5.

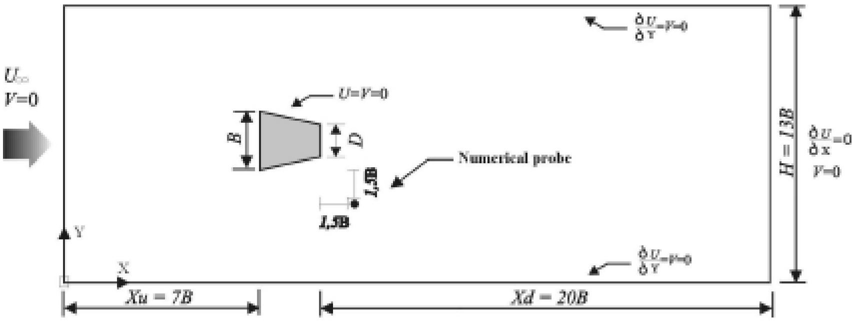


Figure 4. Computational domain

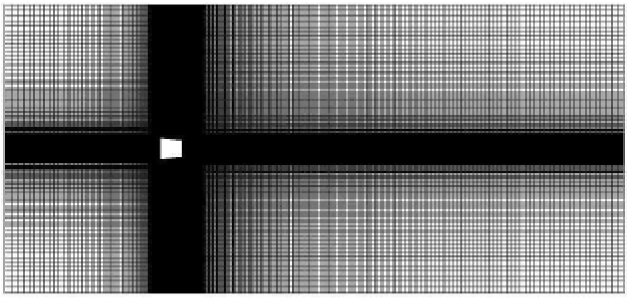


Figure 5. Numerical mesh

In every simulations, the following boundary conditions had been set: uniform velocity profile inlet the domain, $U = 1$ and $V = 0$; von Neumann outlet the domain, i.e., completely developed flow; symmetry for the up and bottom boundaries, $V = \partial U/\partial y = 0$. Furthermore, the cylinder walls were considered as non-porous non-slip conditions , that implies $U = V = 0$. The fully implicit time discretization was used set with a time step of 0,01, where τ has the relation with the real time t, by:

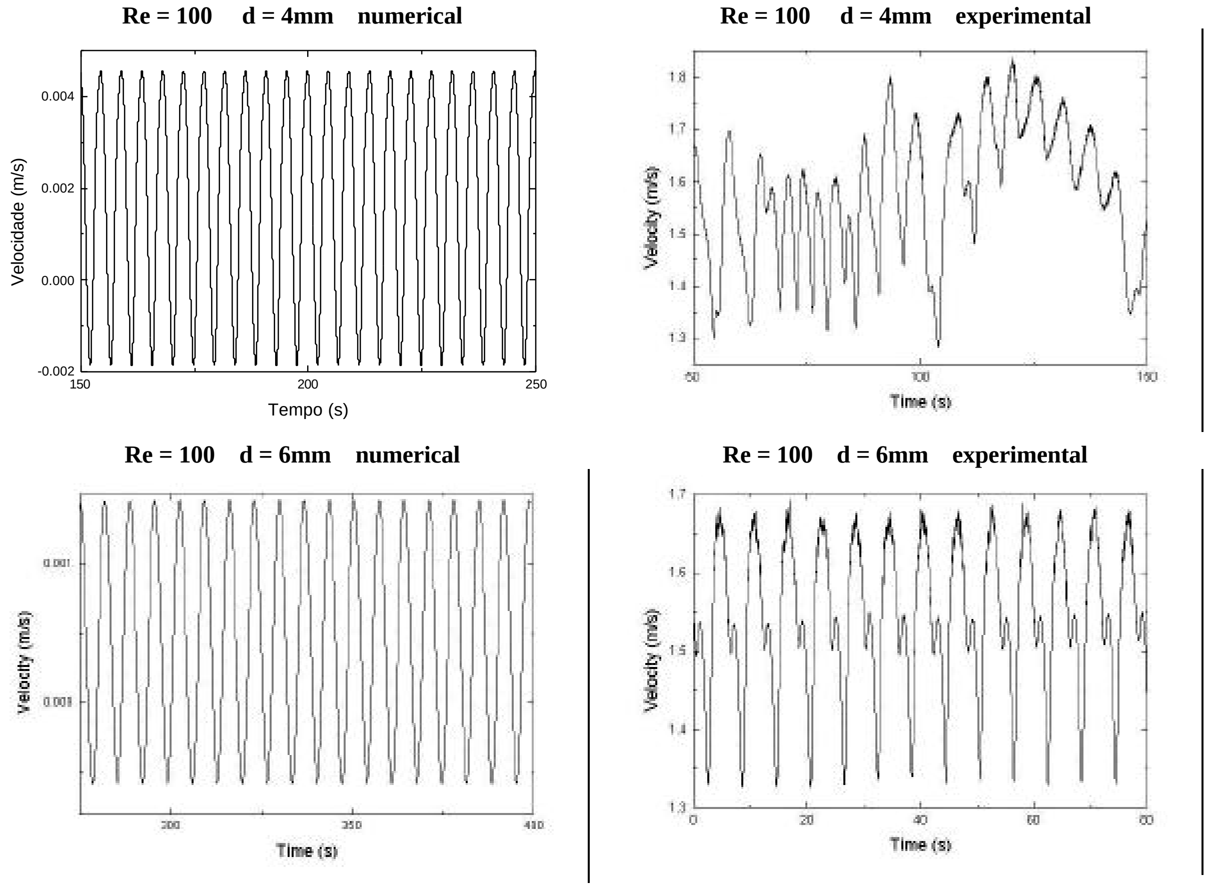
$$\tau = t \,.U_\infty / B \tag{4}$$

The simulation were performed until a statistically developed flow regime, characterized by a periodically variation of the flow mean properties in the cylinder wake.

4 – RESULTS AND DISCUSSION

4.1 – Signal probed on the wake

The Fig. 6 shows the comparison between the signal probed experimentally and obtained numerically, for Reynolds number equal to 100. The signal obtained experimentally is not calibrated, since vortex shedding frequency evaluated by a FFT, this is dispensable.


Re = 100 d = 4mm numerical

Re = 100 d = 4mm experimental

Re = 100 d = 6mm numerical

Re = 100 d = 6mm experimental

Figure 6. Numerical and experimental signals processed.

4.2 –Strouhal number

The Fig. 7 depicts the Strouhal *vs* Reynolds number curves of the studied cases. For the experimental case, the Strouhal number was evaluated from the non-calibrated signal probed in the wake. For the numerical one, the signal registered was the (y) velocity component. Both signals were pos-processed via FFT by a Matlab® software, in order to obtain the main vortex shedding frequency (f) .

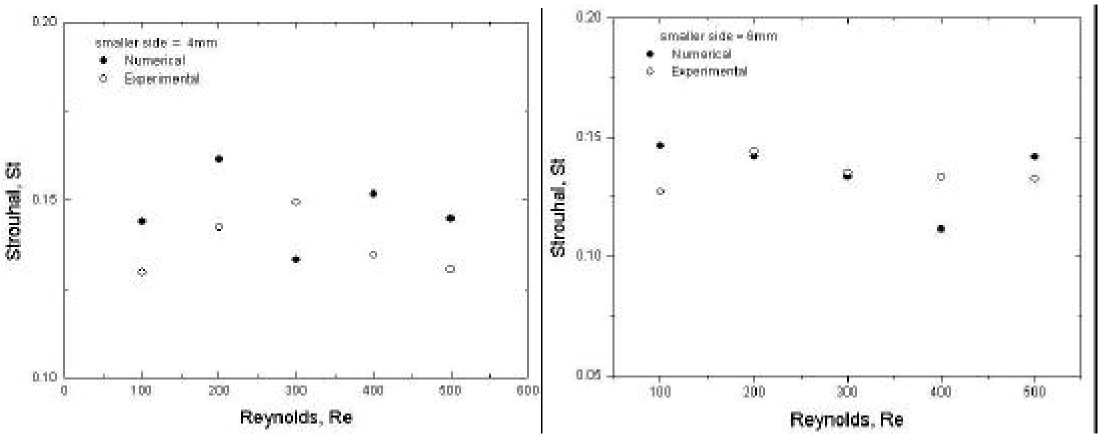


Figure 7. Strouhal × Reynolds Curves

4.3 – Images of the wake

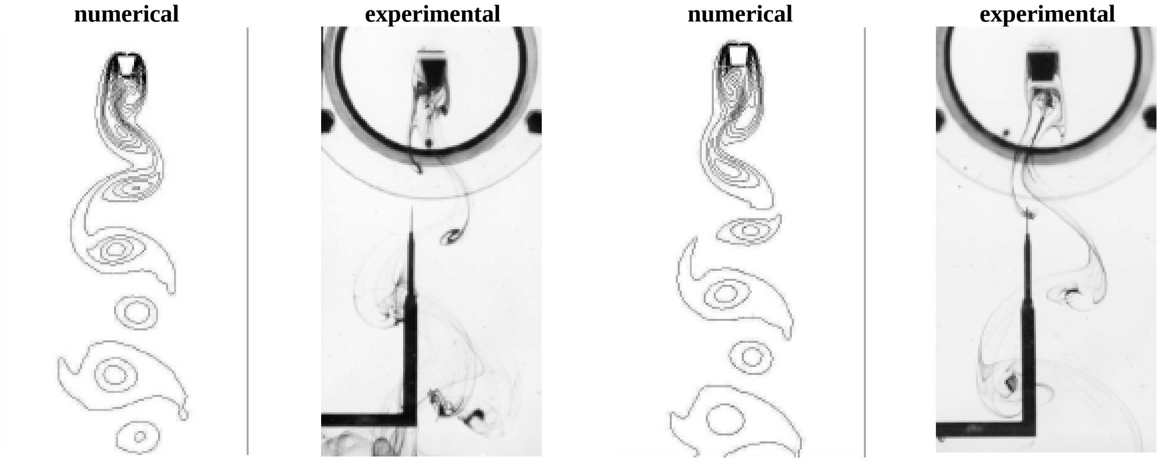
The Fig. 8 depicts the wake visualization at Reynolds from 100 to 500 for both tested bodies.

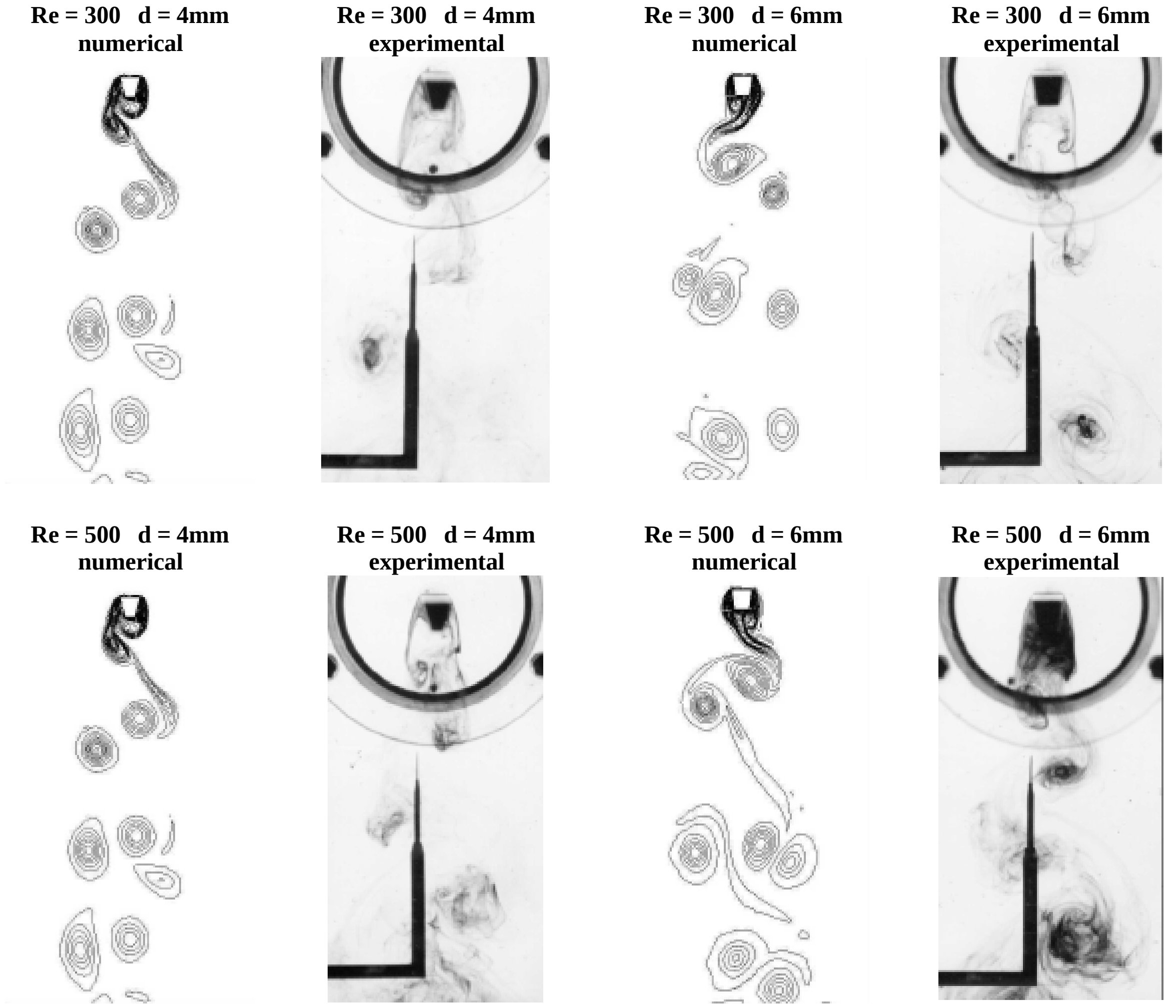
5 – CONCLUSION

The use of vortex flowmeters has significantly increasing during the last 30 years due theirs high applicability, reliability, and accuracy. These advantages coupled with the resources of the modern electronics, this kind of meter has high cost-effective characteristics when compared with another devices. Even though, the manufacturers greatest challenge is to design a shedder with a geometry that could keep a wake shedding discrete and regular vortexes at the lowest Reynolds number as possible. In this work the relationship between the non-dimensional Reynolds and Strouhal numbers was evaluated using both experimental and numerical techniques. The numerical and experimental results seemed good agreement between them.

The wake generated by the trapezoidal cross sectional area body of d = 4 mm presented more unstable, having less discrete vortexes and more difficult to be noted, and also, with suddenly changes in shedding pattern, producing strong effects on the tridimensional component of the wake, when compared to the d = 6 mm body. This effects can explain, not all, the better agreement between the experimental and numerical results observed in the Fig. 6 for the d = 6 mm body.

Re = 100 d = 4mm numerical **Re = 100 d = 4mm experimental** **Re = 100 d = 6mm numerical** **Re = 100 d = 6mm experimental**





Re = 300 d = 4mm numerical

Re = 300 d = 4mm experimental

Re = 300 d = 6mm numerical

Re = 300 d = 6mm experimental

Re = 500 d = 4mm numerical

Re = 500 d = 4mm experimental

Re = 500 d = 6mm numerical

Re = 500 d = 6mm experimental

Figure 8. Cylinder wake images

6. AKNOWLEDGEMENT

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