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FLOW AROUND PRISMATICS BLUFF-BODIES

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Resume. *Flow visualization is a powerful tool, very useful to promote the understanding the complex phenomena associated with the fluid motion. The present work links this important experimental technique with the image processing in order to investigate qualitatively and quantitatively the vortex shedding phenomena occurring downstream a prismatic body with trapezoidal cross section. The tests have been carried out in a low turbulence vertical hydrodynamic tunnel operated by gravitational effect, especially conceived to flow visualization proposes, with 146x146x500 mm of test section. Has been utilized the direct injection of liquid ink technique in order to turn the flow visible. The vortex shedding frequency has been determined utilizing the analysis of the visualized flow images recorded in a magnetic tape. The observation frame by frame of the flow images makes possible to determinate the vortex shedding frequency and shows a simple and low cost experimental technique of easy implementation, when compared with others experimental technique usually employed in research laboratories as laser Doppler anemometry, hot-wire anemometry or particle image velocimetry.*

Keywords: *flow visualization, hidrodynamic tunnel, vortex shedding, Strouhal number, vortex flowmeter*.

1. INTRODUCTION

In many human activities a very large number of physical data is usually manipulated. Satellite orbits, astronomic data analysis, spacecraft design, geophysical and meteorological studies, and many engineering projects are good examples. The human brain is unable of to interpret adequately those information if the data have been pictured exclusively in numerical format. In other side, a single image can condense millions of data and allows to facilitate enormously the correct interpretation of physical, medical, biological and meteorological information. The methodology that transforms numerical data in visual information, i.e., the technique utilized to generate and to interpret images is known as visualization and it offers a form of interpretation and communication of large number of data. In other words, visualization is the transformation of physical variables in geometric symbols. Approximately 50% of the human brain neurons are devoted to vision sense. Visual communication is, without doubts, the quickest way of communication and interpretation of the information. For example, scientific computation applied to image processing in medicine have been carried out to new solutions in medical diagnostics, surgical planning, orthopedic prosthesis and medical treatment involving radiation.

Image processing finds several applications in various engineering fields. For example, infrared photography is useful to evaluate heat generation and power loss in electrical plants, high-speed photography is intensely utilized in vehicles crash test and particle image velocimetry (PIV) is a modern technique that uses the image to evaluate the flow field velocity.

The use of images is traditional in fluid mechanics research, it can be performed either by an experimental or numerical approaches, but in both cases the use of flow visualization is a very important tool. Experimental flow visualization employs images in hundreds of techniques and they allows to obtain qualitative and quantitative data. Computational flow visualization (CFD) is the data processing obtained by a numerical solution of Navier-Stokes equations, then beautiful and realistic flow images are produced.

In this effort of work the flow around prismatic bluff-bodies with pentagonal cross-section is visualized utilizing a hydrodynamic tunnel. The images have been recorded in magnetic tape or in photographic film, accordingly to the test performed. The adimensional vortex shedding frequency (Strouhal number) has been evaluated for Reynolds number up to 600.

2. EXPERIMENTAL FLOW VISUALIZATION

In early days, fluid mechanics researchers could only employ the flow visualization to theirs discoveries and reflections about the flow motion. Some great names of the past like Da Vinci, Galileu, Bernoulli and Pascal, utilized intensely the visualization, and in more recent days Reynolds, Mach, Prandtl, Roshko and von Kármán also made use of flow images. Nowadays, flow visualization remains a useful tool for interpretation of complex phenomena and the knowledge generation in the fluid dynamics field.

Employed, traditionally, as a source of qualitative information, the experimental flow visualization is generally coupled with extensive experimental measurements in order to supply the quantitative information about the flow studied. Recently the impressive software and hardware development has opening several new frontiers addressed to direct quantification of flow fields by the flow images processing.

Nowadays, despite the new methods and techniques of flow analysis, the flow visualization remain occupying a prominent role in the study of the problems associated with mass, momentum and energy transport. The new flow visualization experimental techniques have come up in several technical publications involving many levels of sophistication and, additionally, even the traditional techniques have been developed year after year. Consequently, flow visualization reviews are tremendous.

The Merzkirch's book (1987) covering nearly all fields of flow and the handbook edited by Yang (1989), presenting a comprehensive account of many different flow visualization applications are good examples of reviews. Others available text like Mueller (1983), Settles (1986) and Freymuth (1993) describe several aspects and techniques of flow visualization comprehensively explained.

3. FLOW AROUND CYLINDRICAL BLUFF-BODIES

The flow around prismatic non-aerodynamics bodies have found a wide range of applications in several engineering fields. Buildings, monuments, bridges, and civil engineering constructions are frequently submitted to wind as well as electrical cables and towers. Bridge pillars, offshore platform structures and petroleum risers are submitted to efforts of maritime or fluvial streams. Several components of hydraulics turbo machines, heat exchanges and other fluid mechanic systems are also submitted to interactions between the fluid and the structure. In all those cases there is a strong interest in the correct identification and analysis of every force actuating on the solid body. More specifically, the vortex generation and shedding in the wake of cylindrical bluff-bodies, nowadays, several phenomenological aspects remain obscures, and justification the effort of researchers.

The flow around cylinders placed in cross flow shows some complexity due the simultaneous interaction among the several shear zones presented in the flow. In this flow, shear layers are shed from the solid body sides and extend toward the wake direction. Since the inner shear layer, in contact with the wake, has a lower velocity than the outer layer, which is in contact with the free stream, tend to roll over themselves generating discrete vortices. This dynamic pattern generates the several flow structures.

Figure (1) depicts the main flow behavior founded at downstream a circular cylinder in cross flow. In Reynolds number less than one, the flow contours perfectly the body, producing no sensible boundary layer detachment, and the wake is fore and aft symmetric and remain time independent, as can be seeing in the Fig. (1a). For higher Reynolds number, the boundary layer separation can occurs, producing twin symmetric eddies downstream the circular cylinder named recirculation bubbles, Fig.(1b). These bubbles are stables at Reynolds number less 30-40. Increasing the Reynolds number comes up an incipient von Kármán range, the wake is laminar, but the first instabilities are present, deforming the wake, Fig.(1c). For Reynolds between 80-90 to 150-300 there is a pure von Kármán range, the vortex wake street is already established. Augmenting this Reynolds, one can observe the subcritical regime (up to approximately Re 10^5), where the flow is characterized by a laminar near-wake with vortex street instabilities and the separation occurs in a fixed point, independently of the Reynolds, near 80°, Fig. (1d). For a more complete explanation about the flow regimes around circular cylinders, see Gersten (1983) and Coutanceau & Defaye (1991).

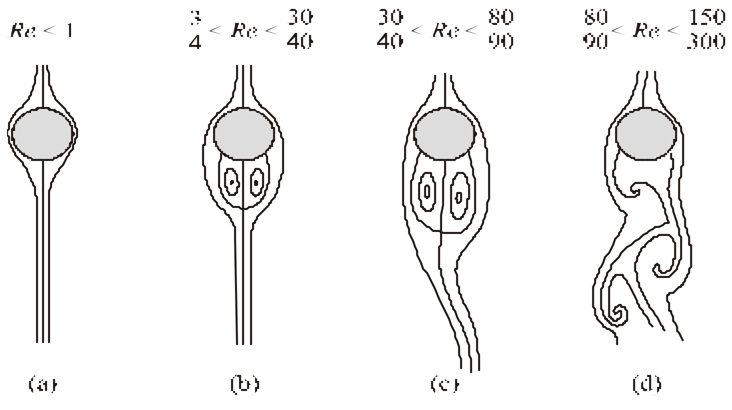


Figure 1. Flow structures around a circular cylinder (Gersten, 1983).

For the vortex shedding regime, the vortex frequency relationship (f), the free stream velocity (V), and the body characteristic length (D) is known as Strouhal number (S_t), and is defined by:

$$S_t = \frac{f\,D}{V} \tag{1}$$

This adimensional parameter remain strict relation between the Reynolds number and the body geometry, accordingly to Kawakita & Silvares (1993). Many other numerical and experimental works have devoted to study the Strouhal-Reynolds relation for several geometries. Lindquist et al (1999), for moderate Reynolds (less than 10^3) studied square cylinders in several attack angle configurations and Esfahani (1998), who employed a numerical approach for rectangular cylinders, are examples of the recent interest on the study of the Strouhal number behavior.

The knowledge of the Strouhal –Reynolds relation found application in the design of vortex shedding flowmeters. Vortex flowmeter measuring mass or volume flow, are used in steady flow in several industrial applications for over two decades and have proven themselves to be accurate and reliable. Vortex meter is a flowmeter with a simple configuration, high accuracy, linearity, wide dynamic range, weak dependency of fluid viscosity and containing no moving parts submitted to deterioration, it is in fact high reliability – Gonçalves & Vieira (1999).

In this work has been carried out an experimental study, utilizing exclusively flow visualization tools of the flow around trapezoidal cylinders. Flow images have been captured and the Strouhal number behavior in relation to the Reynolds number is determined for Reynolds up to 900.

4. EXPERIMENTAL APPARATUS

The tests have been carried out in a vertical low turbulence hydrodynamic tunnel operated by gravitational effects having 146 x 146 x 500 mm of test section. This device has been especially designed for flow visualization proposes – Fig. (2) and detailed information about this operation and dimension is obtained in the work of Vieira (1997). Recently, several modifications have been carried out, described by Lindquist (2000), and permit the operation in continuous or in blow-down modes, with relatively low level of turbulence inside the test section.

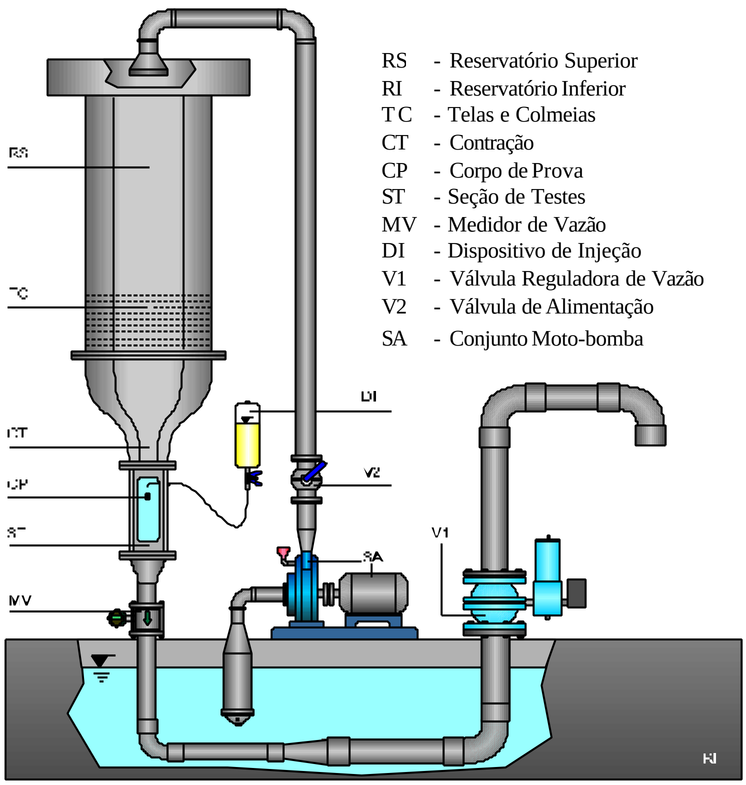


Figure 2. Pilot hydrodynamic tunnel.

Figure (3) shows a velocity profile and the relative turbulence level, evaluated by a hot-film anemometer, for three operation velocities, obtained in the centerline of the test section in the same position where the prismatic body of test is placed.

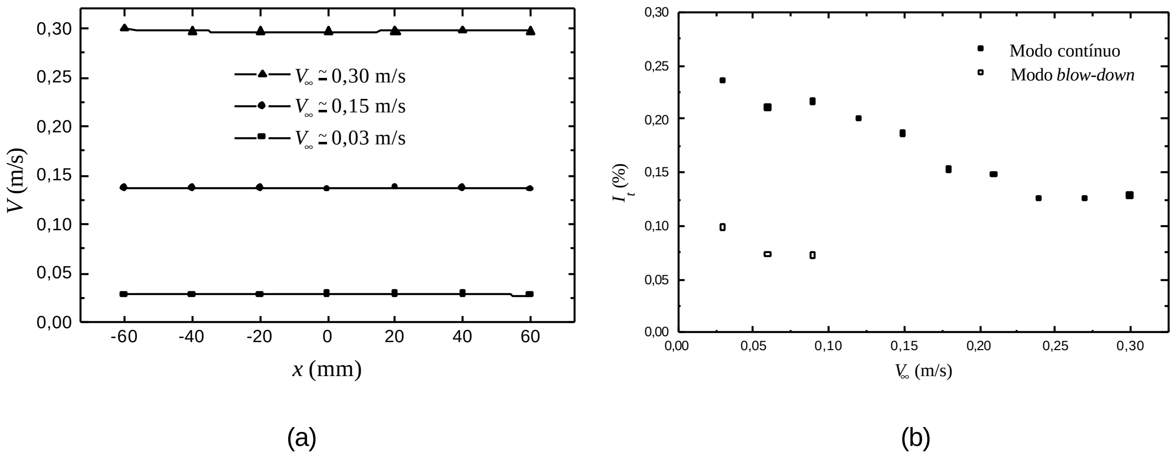
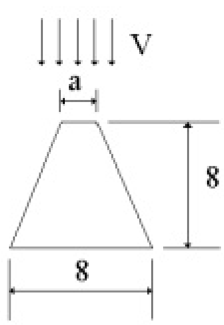


Figure 3. Hydrodynamic tunnel average velocity profiles (a) and relative turbulence level (b).

All test have been carried out utilizing the direct injection of liquid dye or hydrogen bubble flow visualization techniques. The liquid dye, a blend of opaque black PVA pigments dilute in ethyl alcohol, has been injected in the free stream, upstream to the test model, by means of a long hypodermic needle. For more details about the dye wash technique employed, please see the work of Gonçalves & Vieira (2000). Still flow images have been captured too utilizing the micro hydrogen bubble technique. The micro bubble have been produced utilizing a tungsten wire (Φ = 0,025 mm) where is applied about 100 VDC. A comprehensible explanation about the hydrogen bubble technique and the tedious work to capture the images is available in the work of Hirai et al (1999).

5. RESULTS

All test have been carried out utilizing the vertical hydrodynamic tunnel operated in continuous mode. The flow images captured, at 30 frames per second, in a broadcasting video tape with a 3 CCD high resolution video camera, have been analyzed in slow motion with controlled velocity. The image observation of the precise instant of the vortex shedding has been registered due to a time-code board inserted in the VCR. The basic geometry of the five test bodies (TB) is depicted in the Fig. (4).

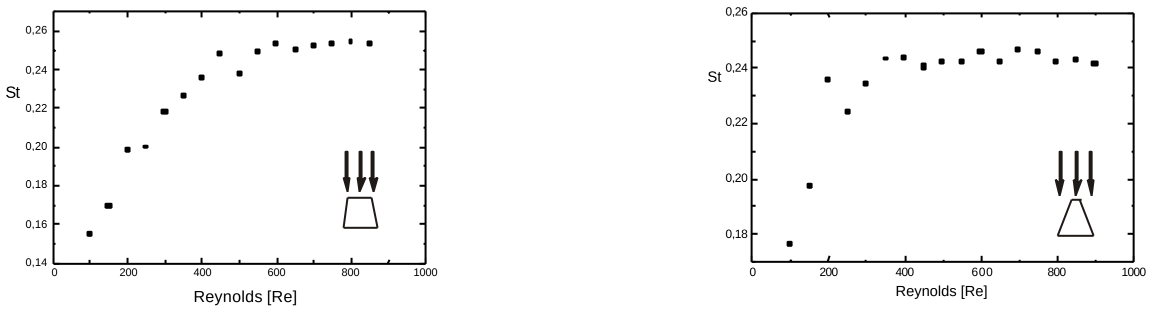


TB # 1	a = 8 mm
TB # 2	a = 6 mm
TB # 3	a = 4 mm
TB # 4	a = 2 mm
TB # 5	a = 0 mm

Dimensions in millimeters

Figure 4. Dimensions of the test bodies.

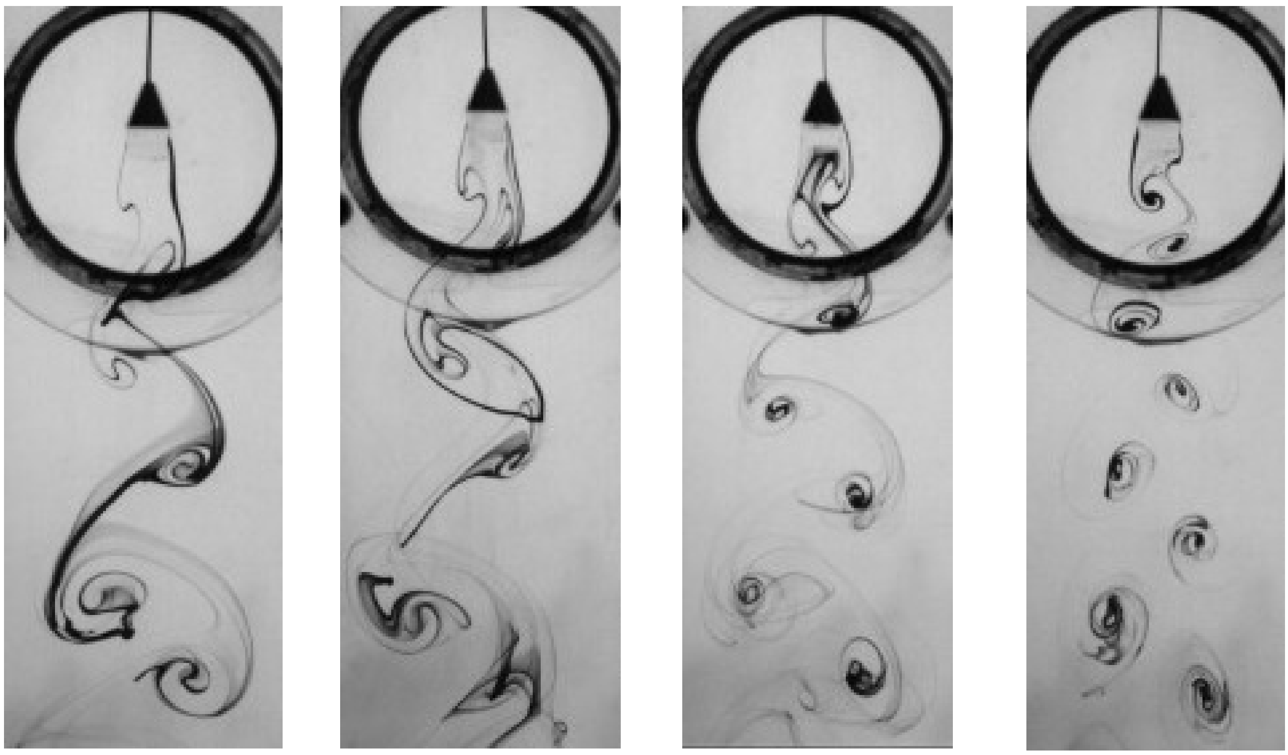
Figure 5 shows, as a example, two Reynolds versus Strouhal curves to test body # 4 and 2, respectively.



TB # 2 TB # 4

Figure 5. Strouhal–Reynolds behavior for TB # 4 and 2.

The Fig. (6) pictures a wake images for several different Reynolds for TB # 4, captured with help of the injection of a continuos fillet of liquid dye.



Re = 65 Re = 86 Re = 97 Re = 297

Figure 6. Wake of the prismatic cylinder TB # 4.

In accord to Fig. (6) is observed that the von Kármán street is fully established in Re = 65, the vortices are produced alternately in both cylinder sides. Gradually increasing the Reynolds number, no significant alteration of the flow regime is verified.

For the test body TB # 2, the wake images are showed in the Fig. (7). In this case, for low Reynolds (Re = 46 and 65) has been utilized the dye wash technique – the solution of opaque black dye is emitted intermittently. For other Reynolds values the injection of a continuous dye fillet technique was used.

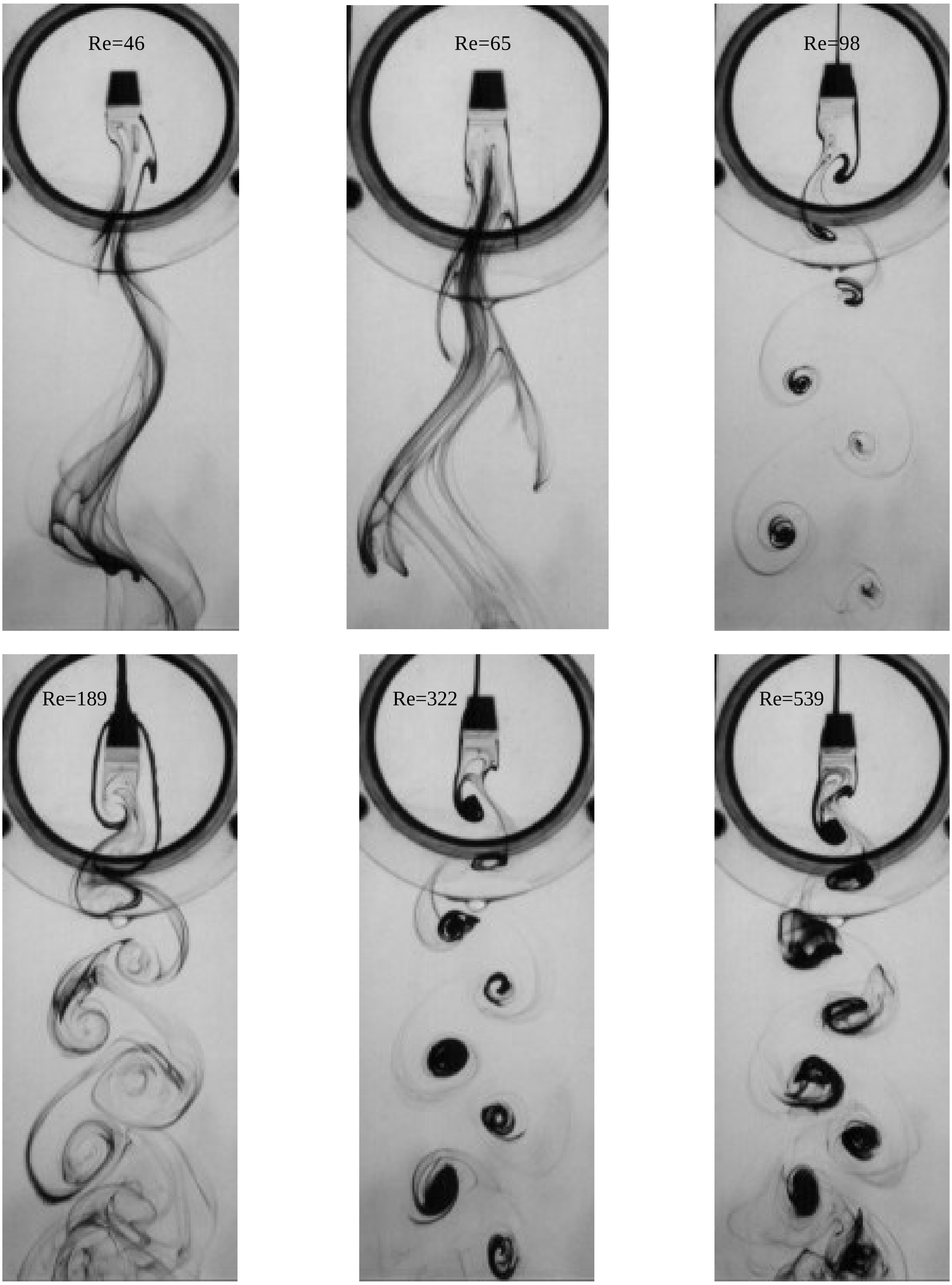


Figure 7. Flow wake images for CP # 2.

In Fig. (7) for Re = 46, the flow instabilities act provoking the coming up of severe oscillations in the wake. For Reynolds 65, the vortex wake is incipient, but to Re = 98 is fully configured. For Re=322 and 539 the vortices are shedding alternately and discretely. Additional tests have been carried out and they are condensed in the Fig. (8), this curve are fitted utilizing a four grade polynomial curve, with a error less than 3 %.

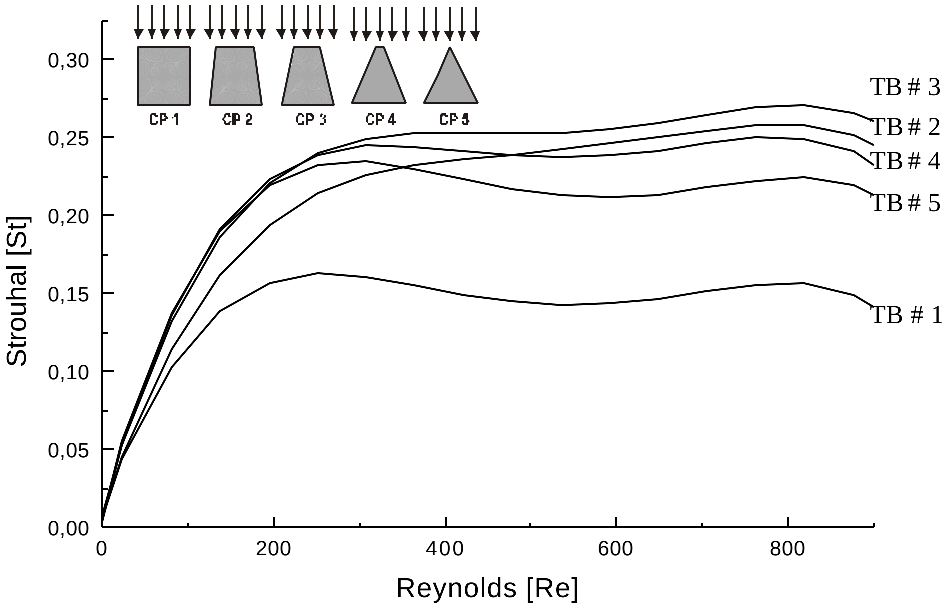
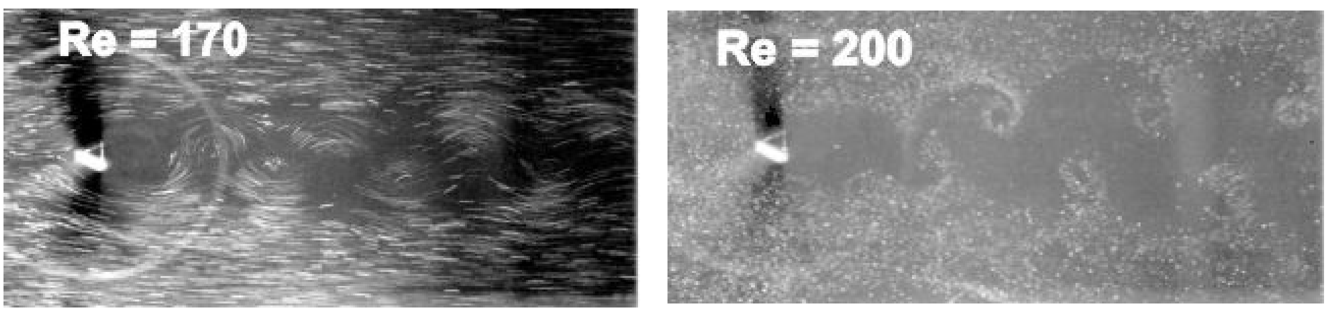


Figure 8. Reynolds *versus* Strouhal for different bodies.

Figure (8) shows a high interference degree provoked by the superior face on the flow and how much it intensifies the mechanism of vortex generating and shedding. The non perturbed flow velocity was determined with help of a electromagnetical flowmeter Yokogawa with less than ±3 % of max error. The vortex shedding frequency determined by analysis of the frames recorded in magnetic tape shows 4% of error.

Finally, for the TB # 5 (triangular cylinder) several test utilizing hydrogen bubble have been carried out. This tests, depicted in Fig. (9), achieved in this work aim to compare the two visualization techniques. Dye injection is an easy to implement technique and good for qualitative results. In other way, hydrogen bubble technique permits also a quantitative analysis employing the particle image velocimetry techniques. An implementation of a PIV system utilizing a hydrogen micro-bubbles is a next stage of this work.



(a) (b)

Figure 9. Hydrogen bubbles images (a)long exposure time (1/8s) (b)short exposure time (1/125s).

5. CONCLUSION

The technique of frame-to-frame analysis of the visualized flow in order to identify the vortex shedding frequency shows a cheap and quick technique when compared with other techniques applied in fluid dynamics laboratory. Although, the slow motion analysis of the images recorded in tape is a slow process due the visual identification dependence for each vortex, and a single measure can involve dozens of vortex. In this work the images have been captured in 30 fps, restricting the test to Re = 900. The use of high-speed video camera will become this Reynolds number range wider.

An extensive number of works related to the study of Strouhal number of square and rectangular cylinders is found in the technical literature showing how the lateral sides of the rectangular (and particularly the square) cylinder produce a strong effect on the vortex frequency. In this present effort of work, the results for Strouhal number for trapezoidal cylinder has been compared with the results for square and triangular cylinders. An analysis of the Fig. (8) shows a strong difference in the Strouhal number between the square cylinder and the another cylinders tested, showing a influence of the frontal and lateral faces in the complex vortex generation and shedding process.

Finally, the liquid dye injection technique compared to the hydrogen bubble technique has several advantages, mainly the low cost, the easily implementation and the quick results obtaining. By the other hand, the hydrogen bubble technique permits see the tracking of the displacement of each individual particle.

At least, that main distortion in the results in due Lindquist (2000) who, in same situations, refers to the tridimensional characteristics of the wake. Employing end-plates devices might diminish these non-desirable effects.

6. ACKNOWLEDGEMENT

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