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FLOW VISUALIZATION INSIDE A CHANNEL WITH SQUARE ROUGHNESS

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Abstract. : *For years the very flow visualization has been an important tool to aid the understanding of the phenomenology of the behavior of fluids. Thus the present study was used water as a working fluid in a hydrodynamic tunnel vertical, and experimental techniques for the visualization, liquid dyes were used to generate qualitative information regarding the behavior of a fluid flowing in a rectangular channel with two protuberances square on one of the inner walls. The experiments were performed for Reynolds number up to 1,000.*

Keywords. *Flow visualization, Hydrodynamic tunnel, liquid dyes, vortex shedding, channel flow*

1. INTRODUCTION

The study of the complex phenomena associated with fluid movement arouses the attention of researchers for many centuries. Thus, the search for tools of analysis becomes absolutely necessary.

Most of this effort was experimental, though scholars also directed their research to find mathematical solutions for the movement of fluids, a consequence of this attitude were the Navier-Stokes equations, which allow to obtain analytical solutions for some cases. But it was from numerical methods (CFD - Computational Fluids Dynamics) has become possible to obtain solutions to complex problems.

Despite their importance in many engineering situations, work on the flow in channels with parietal protuberance, are few in the literature, mainly for moderate Reynolds numbers.

In Tovbich work [1] was developed experiments to visualize flow in a rectangular channel containing an obstacle near the wall using dyes, aluminum powder and photography, to obtain images of the flow. The results are in all cases evaluated vorticais structures due to the presence of the protuberance arranged on the wall.

Martinuzzi & Tropea [2] performed tests on a prismatic channel with obstacles of rectangular cross section, varying the characteristic length of the body. The techniques employed were: laser blade, oil film, crystal violet, and even injection of smoke. In this work effort, there is an evident difference between the two-dimensional flow and tridimensioal around the solid obstacle.

Onur & Baydar [3] investigated flowing through a flow channel which contains a protuberance, being a cylinder attached to a square base walls. In this experimental study using air as the working fluid identified five regions circulations in different locations within the channel.

Vieira's works [4] and Lohász [5] present a study using two-dimensional numerical simulation of a flow in a channel containing a bulge along the wall, using the Reynolds numbers of the order of 104 and shows the complexity of this type of flow.

Thus, the flow in a channel with parietal protuberance, various turbulent structures can be observed, such as recirculation, stagnation, vortices and detachments.

2. PURPOSE

In this context, this paper proposes to evaluate the behavior of a Newtonian fluid flowing in steady state, in a rectangular channel with three lumps, illustrated in Fig. 1, where the arrow indicates the direction of flow of the fluid and the gray color is the solid region.

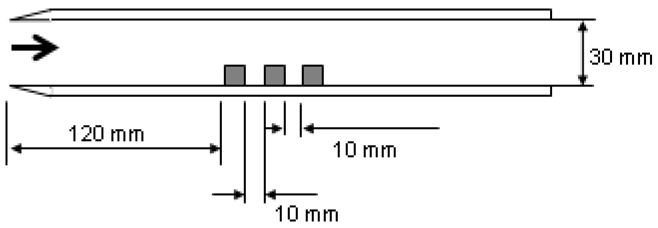

Figure 1. Channel with rectangular protuberances - geometry of the problem studied.

The area is isolated and no mass flow in horizontal walls of Fig. 1, with only flow in vertical walls (input and output). The flow is incompressible, isothermal and steady state occurs. This study was through the visualization techniques of experimental hydrodynamic flow in a vertical tunnel.

3. EXPERIMENTAL METHODOLOGY

Hydrodynamic tunnels along with other types of devices such as wind tunnels and water channels, are tools with fundamental importance in fluid mechanics.

All tests here in this study were performed using a tunnel vertical hydrodynamic low turbulence, provided a test section, whose, dimensions are 146 × 146 × 500 mm, in the center of this section is inserted in the channel study measuring 146 × 30 × 340 mm and the square roughness with dimensions 146 × 10 × 10 mm. The technique used to observe the current lines in this experimental research, was the use of liquid dye PVA pigments, which has great hiding power and low cost, added to a small amount of ethyl alcohol, to make the mixture density closer to that of water, and to avoid convection in the tests a very low Reynolds number.

In the views made throughout this work was used a retractable needle, allowing inject the dye on the test model, and soon after, it was taken to the wall of the test section. This method is known as "dye wash", which consists of injecting a large amount of dye liquid on the model test, for a period. Excess dye is removed rapidly by the flow in regions of high velocity remains longer in areas of high velocity less, particularly at the base of the body, making it possible to display the whole area of the wake. The procedure of the use of retractable needle is essential to avoid the influence of the wake produced by the needle on the flow, such influence can cause a significant deformation of the velocity profile of the free stream, which focuses on the model tests.

The experimental apparatus is located in Flow Visualization Lab on the campus of UNESP-Universidade Estadual Paulista, in the town of Ilha Solteira, the recently rebuilt this equipment outlined schematically in Fig. 2.

4 EXPERIMENTAL APPARATUS

4.1 THE HYDRODINAMIC TUNNEL

The tunnel presents also a 146 × 146 × 500 mm test section with octagonal cross section but with more than 6 m of height, representing a sensible increase of the total water mass stocked internal the tunnel. The increase of the water mass internal the tunnel permitted to extend the blow-down run time of operation several times. Obviously, the increase in the tunnel size forced a new design of all tunnel components. In a water tunnel all walls and parts need to be not flexible and enough rigid in order to no provoke flow oscillations. Fig. 2(a) depicts a sketch of the vertical hydrodynamic tunnel showing the principal parts. An external subterraneous water tank (LR) with a capacity of 9.8 m^3, careful protected against dust and possible contaminants, provides the water for the experiments. In the old tunnel the lower reservoir was installed internal the laboratory, and frequently occurred the water contamination forcing frequent experiment interruption. The construction of an external sealed tank with large dimensions shows a good solution in order to remain clear the water along the experiments avoid frequent water changes. A membrane filter and a small pump (both no showed in Fig. 2) remove up to 10µm particles of the water. The water pump (PP) is a KSB pump model Megachem 32-200 type of 5,5 KW of power all constructed in stainless steel to fit out in a level below of the reservoir level. In the old facility, the water pump was positioned above reservoir level and frequently the restart of the pump was difficult because the air bubble formation inside the pump. Air ingestion occurs when the reservoir presents limited dimensions because the vortex formation in the tube entrance if the flow rate is high or due to fall in the check valve. The pump installation bellow the reservoir level eliminates the check valve. The pump is installed in a subterraneous power-house, external the laboratory room, careful to fit up on vibration isolated supports in order to minimize the vibration transmission to the tunnel. A 75 mm nominal diameter PVC tube with 5 mm of wall thickness positioned in the exhaust of the pump discharge the flow to the upper of the tunnel. All valves are made in stainless

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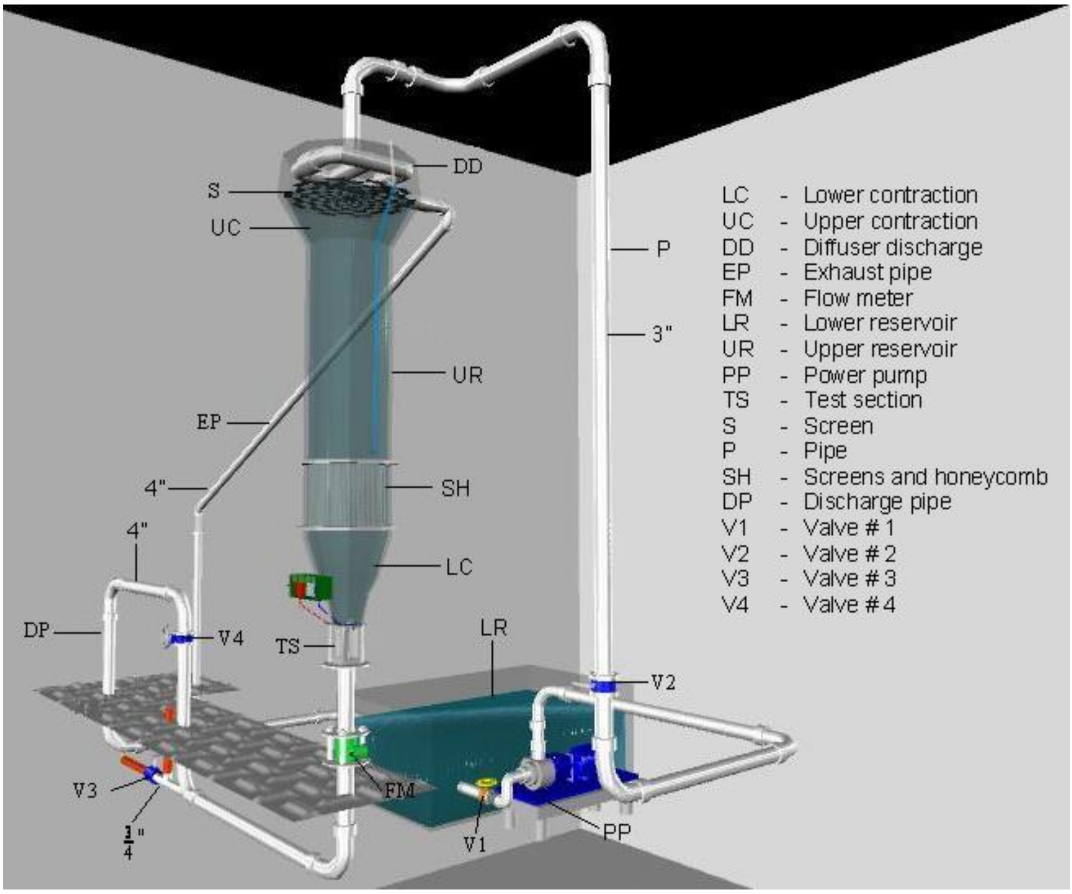
steel except to valve #3. All valves showed in Fig. 2(a) are of manual operating. An automatic sphere valve pneumatically powered and electrically driver, no showed in Fig. 2(a), should be mounted in order to remote control the flow. Use of sphere valve also permits to control the flow rate adequately. Unfortunately, sphere and butterfly valves utilized in chemical industry applications are expensive because the rigid security norms. The valve #2, is a butterfly valve installed in order to manually control the flow inlet the tunnel. This valve type mounted after the pump in a high pressure line and operated only by one quarter of lap need be slowly moved in order to avoid the sudden flow interruption causing undesirable hydraulic ham effect.

The tunnel stagnation section (the upper part of the tunnel) is composed by an upper reservoir (UR), an upper contraction (UC), screens (S), honeycombs (SH) and a discharge diffuser. Discharge diffuser, contraction and screens are needed in order to introduce the flow field with a minimal turbulence in stagnation section. The work of Vogt (1983) discusses the problem due to residual turbulence internal the stagnation section in vertical hydrodynamic tunnel. The honeycombs with hexagonal cells of 6 mm and 280 mm of thickness are made of fine sheet of alloy 3003 aluminium. The discharge diffuser shows 614 small holes of 3 mm of diameter proportionally distributed order to delivery uniformly the flow inside the stagnation section producing a minimal perturbation, principally in continuous mode operation.

The maximum water level internal the upper reservoir in controlled by an exhaust PVC pipe of 100 mm nominal diameter. The contraction (LC) has a short length and a contraction ratio of 1:16. The test section (TS) was made of aeronautical aluminium 4050 with windows of optical Plexiglas with 10 mm of thickness. The average velocity at the test section has been determined from the water flow rate measured by an electromagnetic flowmeter (FM). This practice of determination of the average velocity in the test section measuring the downstream bulk flow rate is recommended by several authors, and currently used in many water tunnel facilities. The non-perturbed velocity, upstream the test model has been obtained, in this work, using an AXF100G model *Yokogawa* electromagnetic flow meter mounted downstream the test section. An assessment of the uncertain associated to free stream velocity shown less than 4%, when compared with data obtained by hot film anemometer (*Dantec CTA Streamline*).

The tunnel structural support was entirely constructed of NPS 6 Schedule 40 steel pipes with 150 mm of nominal diameter and 7 mm of wall thickness for a rigid structure with minimal vibrations. Seamless Schedule pipes provide a high quality tube for structural application. The tunnel structure need be to place careful in an adequate foundation bases in order to isolate external vibration conducted by the ground. Fig. 2(b) a detail view of the test section.



(a). The vertical hydrodynamic tunnel of the Flow Visualization Laboratory.

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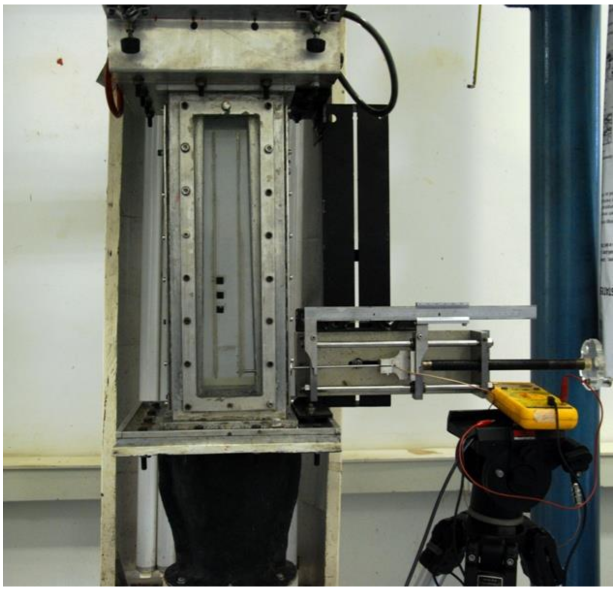

(b) Test section.

Figure 2. The vertical hydrodynamic tunnel.

The flow image has been illuminated by eight (150 W) *G.E. Photo Flood* tungsten lamps placed in line with the camera and shielded by white velvet-like translucent paper to provide a uniformly diffuse bright background against which the dye patterns were photographed. *Photo Flood* is a low-cost lamp, and supplies white light with relative high color temperature. Unfortunately, *Photo Flood* is an incandescent lamp that emits a high heat flux, requiring an efficient air-cooling system in order to avoid convection in the experiment. New cold illumination by means of fluorescent lamps with high color temperature but minimal heat emission has been adapted in the new tunnel permitting sharp and well defined images. The use of Rosco color illuminating filter Cinegel#3308 converts daylight fluorescent lamps to 5 500 K and a diffuser Cinegel#3007, a slight filter with less density softens edge and provides a good illumination for still and video image capture.

Still images are also captured using a 12.3 megapixel *Nikon* D 90 DSLR single lens reflex camera equipped with a special *Nikkor* medical macro lens with 120 mm and f/1:4. The pictures have been obtained in f/1:11 and 1/250 s for ISO 100. The very expensive medical Nikkor macro lens was designed for application in full frame (24 ×36 mm) chemical 35 mm roll film cameras generating very good macro photography ideal to image capture in medical surgery.

The average velocity at the test section has been determined from the water flow rate measured by an electromagnetic flowmeter. This practice of determination of the average velocity in the test section measuring the downstream bulk flow rate is recommended by several authors, and currently used in many water tunnel facilities. The non-perturbed velocity, upstream the test model has been obtained, in this work, using a *Yokogawa* electromagnetic flowmeter AXF100G model mounted downstream the test section (FM). The free flow velocity has been determined by measuring the mass flow during the experiments; the uncertainty in the free flow velocity determination is estimated in ±5%.

The water tunnel is operated by gravitational action, and can be used in continuous or blow-down mode. Blow-down mode have been used in this work, due to its lower turbulence level, although in this mode, the free stream mean velocity decreases noticeably with the water level inside the upper reservoir. To account for that, it has been estimated that, for a period up to 15 seconds, the effects of decreasing free stream mean velocity are overshadowed by turbulence.

5 RESULTS

Qualitative results are concerning to the capture of flow visualized images of the flow around squares protuberances positioned in tunnel walls in Reynolds numbers up to 1 000. The images obtained allow to identify several structures of the flow, as Kelvin-Helmoltz instabilities and recirculating zones, as shown in Fig. 3.

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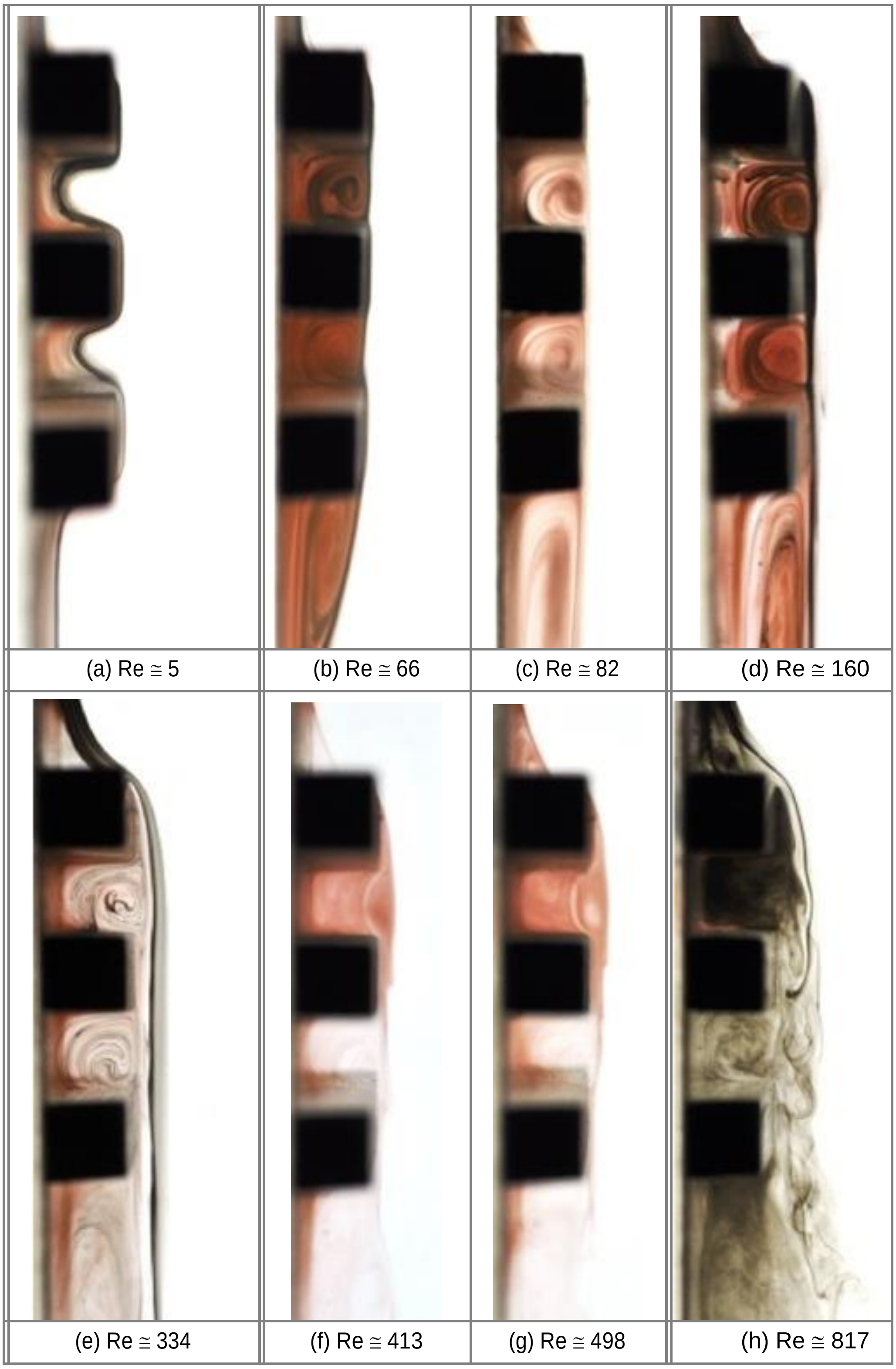

(a) Re ≅ 5 (b) Re ≅ 66 (c) Re ≅ 82 (d) Re ≅ 160

(e) Re ≅ 334 (f) Re ≅ 413 (g) Re ≅ 498 (h) Re ≅ 817

Figure 3. Experimental result for different number of Re.

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6 DISCUSSION

Figure 3 (a) (Re ≅ 5) shows the flow with relatively low Reynolds number for which the dye practically follows the contour of the square roughness._However, for (Re ≅ 66), Fig. 3 (b) shows a detailed picture of the recirculation zone between the cavities between the protrusions and as noted, the dye undergoes detachment of the rear edge protrusions but is recola easily on the upper face of the next edge.

It is observed details of the recirculating region between the protuberances – Fig. 3 (c), (Re ≅ 82). In Fig. 3 (d) (Re ≅ 160) for this flow regime, it is relatively large as the recirculation region that occurs downstream of the third protuberance that extends out of the field of view of the image up to the limits of the walls of the channel. Also noticeable is the first evidence of a mild detachment occurring in the anterior edge of the first protuberance.

However, for a significantly higher Reynolds (Re ≅ 334) Fig. 3 (e), there is a drastic change in the existing recirculating region after the third protuberance with the occurrence of a turbulent process significantly deforming the recirculating bubble.

In Fig. 3 (f), (Re ≅ 413), there is a unique structure in the form lenticular occurring above the region bounded by the first and second protuberance The structure may also be observed in Fig. 3 (g) to Reynolds equal to 498. This is a structure of interest in the study because of its unique shape and position.In this case, the availability of large facilities that accommodate large models facilitate the visualization of fine details of the flow and understanding of this topology. Successive observations of this phenomenon allow reporting that the white line which bypasses the formation of lenticular the protuberances its proximal part is formed by working fluid without colorant therefore clean water, that is from the space between the second and third protuberance Therefore, the lenticular formation is caused by the detachment which occurs on the first front edge of the protuberance.

In Fig. 3 (h) to Reynolds equal to 817, the strong diffusion effects are apparent image hindering capture a sharp image with the visualization technique employed.

7 CONCLUSIONS

The protuberance in the inside wall of the flow channel changes significantly by producing a turbulent wake sensitive to change in the heat transfer coefficients and drag. Thus, this type of flow has important applications involving the design of turbo machinery or even cooling of electronic components.

In this paper a study of the flow inside a canal with three protrusions on the wall, was conducted using experimental tools for visualization of flows, allowing to identify different topological structures thereof.

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9 RESPONSIBILITY NOTICE

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