FLOW STRUCTURE AROUND A SQUARED SECTION CYLINDRICAL PROTUBERANCE MOUNTED ON A SMOOTH FLAT PLATE

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Abstract: In this work, vortex shedding phenomenon produced by a square protuberance placed on a smooth flat wall is experimentally studied by means of flow visualization and hot-film anemometry. Qualitative and quantitative information have been obtained for Reynolds numbers up to 610.

Keywords: Fluid dynamics, vortex shedding, Strouhal number.

1. INTRODUCTION

The flow around a cylindrical obstacle placed inside a channel has been intensively studied by several authors in the last decades. On the other hand, the problem of the flow over a single rib transversally mounted on a smooth flat surface has been less well investigated, despite of its recognized practical importance in terms of engineering [5]. In this case, the flow field on the plate is strongly affected by the presence of a protuberance. The turbulence level increases, modifying heat transfer and drag coefficients. So, detailed knowledge of the flow field is necessary to improve design of different types of equipment, like discussed in [1].

Different experimental tools have been employed to study this kind of problem. Flow visualization has allowed putting in evidence the complex topology of vortical structures generated in the protuberance vicinity [2]. Measurements using hot-film or hot-wire anemometer have permitted to obtain quantitative information about velocity gradients and turbulent properties of the flow field. Combination of these two techniques is a very good way to investigate complex flows, as demonstrated by Freymuth et al. [4].

In the present work, combination of these two tools is done in order to investigate the isothermal incompressible flow past a smooth flat plate containing a squared section cylindrical protuberance mounted on it, as showed in Fig. 1. By means of flow visualization, recirculation, boundary layer detachment, vortex shedding, and other complex mechanisms inherent to such a flow are identified. Measurements with a hot-film anemometer are made to obtain the flow velocity signal and vortex shedding frequency behind protuberance.

2. EXPERIMENTAL FACILITY AND PROCEDURE

The experiments have been performed for Reynolds numbers up to 610 in a low turbulence hydrodynamic tunnel with a test section of 146 × 146 × 500 mm. As described in [2], the tunnel is operated by gravitational action in blow-down mode producing a low turbulence level (less than 0.2%).

The volumetric flow rate in the tunnel has been determined utilizing a Yokogawa electromagnetic flowmeter. The uncertainty in the free stream velocity is less than 4%, in more adverse case, producing a maximum uncertainty less than 5% in the Reynolds number (based in the protuberance height, i.e. 10 mm). Fig. 2 shows the non perturbed free stream velocity and the turbulence level produced in the test section.

The flow visualization technique applied in the present work is the direct injection of opaque liquid dye in non-perturbed flow by means a rake of long hypodermic needles of 0.7 mm O.D. A solution of PVA pigments, tap water and ethyl alcohol have been used as dye. Strong amount of this colored dye has been injected directly in the non perturbed stream, sufficient to color the entire flow field. Subtly, the injection dye is stopped and the clean water flow wash the entire flow field, except in the cylinder wake, because in that region the flow speed is significantly small than in other ones. This procedure permits to see, for some few seconds, the re-circulating bubble and the wake downstream the protuberance.
Vortex Shedding in a Square Protuberance

Fig. 2. Free stream velocity and turbulence level in the test section.

All still images have been captured using a D 90 Nikon DSLR 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 resulting in a good depth of field. The very expensive medical Nikkor macro lens was designed for application in full frame (24 × 36 mm) chemical 35 mm roll film cameras and adequately adapted for a half frame (23.6×15.8 mm) digital camera resulted in an excellent optical device for capture close up images.

Cold illumination by means of fluorescent lamps with high color temperature, but minimal heat emission, has been adapted in the tunnel allowing sharp and well defined images. A Rosco color illuminating filter Cinegel#3308 converts daylight fluorescent lamps to 5,500 K, while a diffuser Cinegel#3007, a slight filter with less density softens edge, provides a good illumination for still and video image capture.

Velocity measurements have been performed with a 55R11 fiber-film probe made by Dantec Measurement Technology, with 70 µm diameter quartz fiber coated with 2 µm nickel film and with an overall length of 3 mm. This is a straight general-purpose type sensor which permits a wide measurement range in water medium. For very small velocities (up to 0.10 m/s) several special cares could be adopted in order to reduce the convection effect around the probe. Indeed, a hot-wire probe immersed in recirculation zones can produce a high level of thermal convection interfering in the measurements, like discussed by [3]. A Dantec StreamLine 90C10 frame with 3 CTA modules 90C10 permits simultaneously measurements in 3 channels. An A/D board NI-DAQmx 8.7.1 (16 bits), made by National Instrument, has been utilized in order to record the output voltage signal. Single element hot-film measurement downstream the protuberance were employed to obtain temporal flow velocity fluctuations. Data acquired by hot-film probe have been processed to obtain a frequency spectrum with a FFT - Fast Fourier Transform.

3. RESULTS

Results include several flow visualized images of vortex produced by a square rib. A small stable re-circulating zone upstream the protuberance was observed in all the tests. Fig. 3 shows a close up image of this re-circulating bubble in clockwise motion in Reynolds equal to 610.

Fig. 3. Clockwise circulating zone upstream the protuberance.

Flow visualized images of the turbulent wake are depicted in Fig. 4 for different Reynolds numbers, showing the vortex shedding phenomenon.

Fig. 4. Vortex shedding in a square protuberance in a flat wall.
Figure 5 shows a temporal signal of velocity obtained at $Re = 300$ with the hot-film probe positioned downstream the protuberance. By using a FFT algorithm, this signal has been transposed to the frequency domain. The spectrum frequency presented in Fig. 6 indicate that the shedding vortex frequency is about 0.12 Hz.

![Fig. 5. Flow velocity obtained downstream the protuberance, $Re = 300$.](image)

![Fig. 6. Frequency spectrum for, $Re = 300$.](image)

The flow velocity is also depicted in Fig. 7, 9 and 11 for Reynolds numbers equals to 400, 500 and 600 respectively.

![Fig. 7. Flow velocity downstream the protuberance, $Re = 400$.](image)

![Fig. 9. Flow velocity downstream the protuberance, $Re = 500$.](image)

![Fig. 10. Frequency spectrum for, $Re = 500$.](image)

![Fig. 11. Flow velocity downstream the protuberance, $Re = 600$.](image)
3. CONCLUSION

In this work, flow visualization by direct liquid injection and hot-film measurements have been performed to obtain qualitative and quantitative information about a flow around a square rib transversally positioned in a flat wall. Vortex shedding phenomenon has been qualitatively visualized by means of still images, while vortex shedding frequencies have been determined by hot-film measurements.

For moderate and low Reynolds numbers, the correct probe positioning downstream protuberance is a very important factor to obtain a good noise to signal ratio. In this sense, flow visualization is an excellent tool, helping in the tedious work to position adequately the hot-film probes in the flow.

The injection of liquid colored dye permits easily to visualize the vortex. Because the relative low vortex frequency, a use of an image processing technique can be alternatively applied in a video image in order to determine the vortex shedding frequency.

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REFERENCES


