Vortex Shedding in Turbulent Flow

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Figure 1: Final Image

1 Introduction

The image shown in figure 1 was taken for the second team assignment in the MCEN-5151 Flow Visualization course at CU Boulder. The purpose of this team assignment was to observe another real world flow and photograph its effects during experimentation. For this assignment, our group decided to capture the effect of dyes travelling through a flow channel and colliding with a cylindrical pipe. The intent of this image was to capture the Strouhal instability in a two phase flow and observe the resulting vortex shedding effect.

2 Flow Apparatus setup

The flow apparatus in figure 2, was the Armfield C4 Tilting Flume equipped with the Hydraulics Test Bench, which uses a long channel and clear acrylic walls to observe a controlled flow. The tilting flume has channel dimensions of 0.076 meter wide and a maximum height of 0.25 meters. The total length of the channel is 2.5 meters and can also be adjusted between a -1 to 3 percent grade of slope. The hydraulic bench was filled with enough water to submerge the pump for ideal flow and set to a flow rate of 96 liters per minute with the water at a height of 0.22 meters to prevent overflow in the channel. The object being observed was a 0.048 meter diameter PVC pipe placed in the channel in the middle of the water level height as show in figure 2a.

(a) Setup (b) Armfield Apparatus

Figure 2: Apparatus and Setup

The flow from this experiment is described by the following actions. First, the water flowing at a rate of 96 $\frac{L}{min}$ with a calculated velocity of 0.09569 $\frac{m}{s}$, equation 1, collides with the cylinder. Second, a mixture of dyes were added to the channel and injected using scientific syringes placed near the front surface of the cylinder, which dispersed into the turbulent flow. The green dye was placed above the yellow dye to allow the dyes to separate in opposite directions, resulting in mixing during collision from the oscillations. The Reynolds number of the flow was calculated in equation 2 to be 5160.81 where ρ is the density of water, D is the diameter of the cylinder, V is the velocity of the water, and μ is the viscosity of water [2].

$$V = \frac{Q}{A} = \frac{0.0016\frac{m^3}{s}}{(0.22m)(0.076m)} = 0.09569\frac{m}{s} \tag{1}$$

$$R_e = \frac{(\rho)(D)(v)}{\mu} = \frac{(1000\frac{kg}{m^3})(0.048m)(0.09569\frac{m}{s})}{8.9 * 10^{-4}\frac{kg}{ms}} = 5160.81 \tag{2}$$

A laminar flow occurs when the Reynolds number is below 2300, turbulent if greater than 4000, and transient if in between. For this experiment, the flow was found to be turbulent since the Reynolds number was above 4000. The Reynolds number agrees with the patterns depicted in figure 1 since through empirical evidence, “regular vortex shedding occurs most strongly in the range of Reynolds number from about 60 to 5000” [2]. Perpendicular to the stream motion, in the vertical direction, a vortex stream developed and caused an oscillatory lifting force to be exerted on the cylinder. Using food dyes in this experiment was very useful for visualizing the oscillation patterns since it provided color in the transparent water. The Strouhal number, equation 3, is the dimensionless frequency of vortex shedding and measures the ratio of the local acceleration of the flow to the inertial forces caused by velocity changes across multiple points in the flow field [2].

$$S_t = \frac{fD}{v} = \frac{(0.85\frac{1}{s})(0.048m)}{0.09569\frac{m}{s}} = 0.427 \tag{3}$$

In equation 3, the vortex shedding frequency of motion, f, was found to be 0.85 Hz since it took 1.17 seconds for one cycle to occur, resulting in a Strouhal number of 0.427. Evidently an increase in velocity is proportional to an increase in the rate at which vortices shed from the wake of the cylinder. The geometry of the cylinder also has an effect on the separation angle of the flow into the vortex such that a larger departure angle will result in an earlier separation and a smaller angle will result in a later separation. It is theorized that these vortices continue to grow from circulation of the shear layers until the opposite layers become strong enough to pull the associated layers across the wake [1]. The Reynolds number is directly proportional to velocity and has a huge effect on the development of these alternating vortices such that when velocity is increased, “the drag coefficient becomes almost independent of the velocity, and we can observe a regular pattern of alternating vortices” [3].

3 Visualization Technique

The visualization technique was created by using McCormick green and yellow food dye. The food dye was important for visualizing the flow since the water is transparent and the movement inside of the channel cannot be naturally seen. A white background was placed on the back channel wall to maintain consistency of color behind the dyes that would be travelling in front of it, as featured in figure 2a. A pair of commercial halogen lights were placed behind the white background to help illuminate the setup in addition to the halogen room lights on the ceiling. The lights on the front side of the flow apparatus were turned off in order to reduce the glare on the acrylic that was present while capturing images. As the water was flowing in the left direction through the channel, the green and yellow food dye were injected using the syringes aligned horizontally with the middle of the cylinder on the right side. After testing many trials, the dye injection was toned in and the instability forming from the impact of the flow against the cylinder became visibly apparent.

4 Photographic Technique

Figure 3: Original Image

To photograph this phenomenon, a digital Nikon D3400 DSLR equipped with a 18-55mm lens, was used to capture a 6000 by 4000 pixel image in RAW format, figure 3, which was later edited down to 5771 by 2279 pixel image to focus in on the Strouhal instability. The photographic technique for this composition involved first focusing on a small object in the mid-plane of the channel and manually changing the camera settings, which are shown in table 1. Typically an increase in ISO value results in a grainier photo, although the image did not seem much effected by the higher ISO setting. An aperture of 4.5 best suited the light environment along with a shutter speed of 1/250 second to reduce motion blur. The distance from the lens to the channel wall was about 24 inches at a focal length of 24mm. The photo was edited in Photoshop by using a skew transform to change the perspective of the image and crop out miscellaneous parts of the flow apparatus. The colors were then inverted to produce a more interesting color mapping and leveled to highlight the key points of the vortex shedding. The shadow and black levels were decreased to values of -80 whereas the highlight and white levels were increased to 40. Additionally, the contrast was increased to 22, which also helped draw focus to the white swirls featured in figure 1.

ISO	3200
Focal Length	24mm
EV	1
Aperture	4.5
Shutter Speed	1/125 s
Mode	Manual

Table 1: Nikon D3400 Camera Settings

5 Image Revelation

The most appealing aspect of this image is the swirls of instability that result as the dyes interact with the cylinder. More interesting results could be produced by varying the flow rate to obtain either a more laminar or turbulent flow and by changing the height of the cylinder in the channel. Another possibility is to add another cylinder into the flow channel at a set horizontal distance which could produce a different visible instability in the flow channel. Another improvement could be to increase the amount of dye and method of injecting into the channel since it proved to be difficult without obstructing the flow too much. This image overall reveals the interesting phenomenon of Strouhal instability and the presence of vortex shedding in a flow channel.

References

[1] Alex Mendonça Bimbato, Luiz Antonio Alcântara Pereira, and Miguel Hiroo Hirata. "Study of the vortex shedding flow around a body near a moving ground". In: *Journal of Wind Engineering and Industrial Aerodynamics* 99.1 (2011), pp. 7–17. ISSN: 0167-6105. DOI: `https://doi.org/10.1016/j.jweia.2010.10.003`. URL: `http://www.sciencedirect.com/science/article/pii/S0167610510001029`.

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