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von Karman Vortex Street Visualized in Rheoscopic Fluid

A von Karman vortex street is a well-known phenomenon that can be seen in the wake of different shaped objects, especially cylindrical objects. The vortex street is a visualization of interesting fluid flow events, including vortices, and also provides an aesthetically appealing image. von Karman vortex streets are so common, in fact, that satellites have captured images of naturally occurring vortex streets in the wake large objects on Earth. Figure 1 below shows a vortex street captured by NASA's Multi-angle Imaging SpectroRadiometer satellite. This image occurred over Jan Mayen Island of Norway. The island is home to a volcano that rises 2.2 km, providing a significant impediment to wind flow[1].

Figure 1:von Karman vortex street seen visualized in the clouds in the wake of Jan Mayen island[1].

It is also believed that insects take advantage of the energy from the vortices of the von Karman vortex streets that form around their wings during flight. Insects rotate their wings before beginning the return stroke so that their wings are at an angle from 45° to 90° (perpendicular) to the vortex and are lifted by the eddies of air [2]. Vortices usually just create drag (i.e. in the wake of a racecar); however, this method used by insects can recapture some of the energy and use it to improve speed and maneuverability[3].

For this experiment we would observe the flow in a fish tank. The media shack in the ITLL was used because of its ease to control the surroundings. The first step was to clean the fish tank to remove any unwanted particles in the tank from its previous uses. Next, the 10 gallon tank was filled with ¾ inch of water. After that, the Kalliroscope solution, a fish scales solution, was added to raise level in the tank to 7/8ths of an inch. Subsequently, the water and Kalliroscope solution was mixed thoroughly. The fish tank was placed on a black velvet sheet to eliminate background distractions. A set of 1000 Watt work lights were placed at the side of the fish tank to better light the fluid flow, as shown in a top view on the left side of Figure 2. The angles of the lighting and camera are shown on the right side of Figure 2. To create the fluid flow phenomena, a piece of all-thread, with a nut on the end, was dragged through the fluid at a rate of 0.2 meters per second.

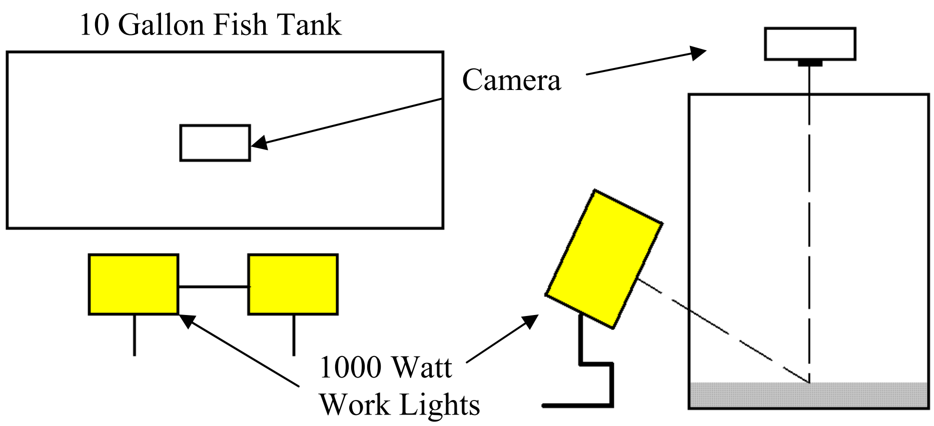

Figure 2: Left - Top View Right - Side View

The von Karman vortex streets are characterized by the Navier-Stokes equations as well as by the Reynolds number. The rheoscopic fluid used for this visualization consists of greater than 99% water and, because a very thin layer of the fluid was used, the fluid can be assumed incompressible. With this assumption, the Navier-Stokes equations simplify to Equation 1, where ν is the kinematic viscosity, **u** is the velocity of the fluid, **P** is the pressure, and $\boldsymbol{\rho}$ is the fluid density[4].

$$\frac{\partial \mathbf{u}}{\partial t} + \mathbf{u} \cdot \nabla \mathbf{u} = -\frac{\nabla P}{\rho} + \nu \nabla^2 \mathbf{u},$$

Equation 1

$$\text{Re} = \frac{u \cdot D}{\nu}$$

Equation 2

$$St = \frac{f_v D}{u}$$

Equation 3

Equation 2 shows the calculation for the Reynolds number for flow over a bluff body, where **u** is the free stream velocity of the fluid, **D** is the diameter of the bluff body, and **υ** is the kinematic viscosity of the fluid. For water at 20 C, **υ** = 1.0e-6 m^2/s[5]. The other parameters for our flow are a free stream velocity of 0.2 m/s, and a cylinder diameter of 2 cm. With these conditions, the Reynolds number calculated using Equation 2 above for the flow in this experiment is around 4,000. A Reynolds number of this value corresponds to turbulent flow (for flow over a bluff body)[5]. This turbulence (mixing) can be seen in the vortex street images created in this experiment. The Strouhal number (Equation 3) is another important characteristic for determining the frequency of vortex shedding in the von Karman vortex street. For a Reynolds number of 4,000, studies have shown that the Strouhal number is about 0.18 for flow over a cylinder [6]. Based on this number, the frequency of vortex shedding off the trail end of the cylinder is 1.8 vortices/second.

Figure 3: Final Image

The photographic technique for this case relied on the use of a Sony DSC-P92 Cyber-shot 5 Mega Pixels digital camera and some slight Photoshop processing. The image, shown in Figure 3 was taken approximately 0.6 meters above the object with a focal length of 8 mm. The ISO was set at 100 while the shutter speed was 1/200 of a second. The aperture was set at a value of 2.8. The size of the field of view was 0.28 m x 0.15 m, 0.042 square meters. The pixilation of the image is 2592 x 1944 pixels. The spatial resolution of the image found from the field of view and the pixilation is 9 pixels/mm. Based on the estimated flow speed of 0.2 m/s and the shutter speed previously mentioned, the flow will move 1 mm in the exposure, corresponding to a motion blur across 9 pixels. This blur can be seen in the photograph, but is not significant. A few Photoshop processes were needed for this image. The contrast/levels were slightly adjusted. The most drastic process was to crop and Photoshop out the reflection of the over head fluorescent lights.

The image in Figure 3 shows a distinct von Karman vortex street. One can clearly see the vortices and even see how the vortices develop as the all-thread was dragged from the left to the right. We believe that our attempt to produce the von Karman vortex streets have been a success. In the future, we might have tried to add more work lights to try and make the image brighter to show even more details of this fluid phenomenon. Overall, the image is interesting, has impact, and clearly illustrates the von Karman vortex streets fluid phenomenon.

References

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