MCEN 5151, Team #2 Report, April 4th, 2011

Vortex Shedding with Incense Smoke at Low Reynolds Number Flow: a failed attempt at creating a Kármán vortex street

By P. A. C. MOUNTFORD

MCEN 5151 – Flow Visualization, Spring 2011
Prof. J. Hertzberg

School of Engineering and Applied Science, The University of Colorado, Boulder, Boulder, Colorado US

Introduction

The first step in executing and capturing a flow visualization picture is the brain storming. This is the easiest part because one can let their mind wander and think of the endless possibilities for capturing an image. The next part of the process is executing the setup and procedure so that you can produce an ideal image. Although this image is referred to as a team project, I worked alone to capture it. After brainstorming for this project, I decided to try and capture a low Reynolds Number Kármán vortex street. These vortex streets occur in nature as well as laboratories. They occur when the flow's parameters are at a specific value so that the Reynolds number is just right. After many attempts at trying to create this phenomenon, it was not executed and captured. This is simply because the Reynolds Number of the flow did not meet the conditions for vortex shedding to occur.

It is noticed in research that no result is still a result. The same thing can be applied to capturing flow visualization images. Although a Kármán vortex street was not captured on film using incense smoke as the working fluid, there was still a type of flow captured. Looking to the flow around the annulus in the image, it is seen that the incense smoke detaches from the surface of the annulus in a definable way. The physics of the Kármán vortex street and the apparent smoke trail in the image will be further discussed in the report. Although capturing the Kármán vortex street was unsuccessful, there was still some good physics salvaged from the image.

Physics Background

To understand what image was trying to be captured, the physics of the ideal image must be first presented and understood. Kármán vortex streets were discovered by engineer Dr. Theodore von Karman, co-founder of NASA's Jet Propulsion Laboratories.[1] Fig.1 provides a visual representation of a Kármán vortex street seen in nature. After reviewing Fig.1, it is noticed that vortices are being formed periodically on both sides of the island (cylinder) and are offset by a constant reoccurring distance. Although the pattern captured is a Kármán vortex street, the physics that creates the eddy street is referred to as the Strouhal instability.[3] The Strouhal instability is responsible for creating a succession of eddies close to a annulus or cylinder that break away alternatively from both sides of the cylinder.[3] This instability is shown in Fig.2.

Like all instabilities in nature, the Strouhal instability only produces a Kármán vortex street when the conditions are right. Kármán vortex streets are found when:

$$40 < R_e < 80 \qquad (1), [4]$$

Eqn.1. presents the Reynolds number for a Kármán vortex street formation. In order to achieve this type of flow, the Reynolds number needs to be examined.

$$R_e = \frac{Vd}{\nu} \qquad (2), [4]$$

In Eqn.2. "V" represents the velocity of the steady flow upstream of the cylinder, "d" represents the diameter of the cylinder being used to disturb the steady flow, and "ν" is the kinematic viscosity of the fluid flowing past the cylinder.[4] Knowing that a Kármán vortex street is created by a Strouhal instability around a cylinder at a Reynolds Number of 40 can help one determine a necessary setup to produce the desired phenomenon.

Procedure

To capture a good image of incense smoke traveling past a cylinder, a certain type of lighting is needed. To make the smoke jump out at the viewer, light needs to be concentrated on the smoke while everything else in the image is kept dark. To do this, some kind of shading material (cardboard for this image) must be placed in between the light source and the area being photographed. Then, respective to a project, a hole must be cut in the shading material so that light can be directed towards the photographed object as desired. It should be realized that the incense smoke is going to be rising past the cylinder driven by natural convection. This means that the cylinder must be suspended above the incense smoke. For this project, the cylinder was suspended by tying dental floss to the shading material above. A visual representation of this set up can be seen in Fig.3.

Camera Setup

Camera – Canon EOS DIGITAL REBEL XSi
Distance from focus to lens – Approximately 660mm, holding camera
Focal Length – 35mm
Exposure Time – 1/13sec.
Aperture – 4.375
F-Stop – f/5
Sensitivity – ISO-1600
Image dimensions – 2304 x 3648
Field of View – Approximately 23x36"
Flash – No Flash

Discussion

After reviewing the image on the first page, the fundamental physics of what is going on in the image, and the project setup, the question of "What is actually happening in the image?" needs to be answered.

It is know that the Kármán vortex street only occurs when the flow is under specified conditions (refer to Eqn.1.). The Reynolds Number for the flow in the picture needs to be calculated in order to determine what was wrong with the experimental setup. The Reynolds number is defined by Eqn.2. The variables from that equation were obtained by assuming that the working fluid is the incense smoke. The variables are defined as:

$$V = 0.5\frac{m}{s}, \qquad d = 0.0762m\ (3"), \qquad v = \ 1.56E^{-5}\frac{m^2}{s} \qquad (3), [5]$$

In Eqn.3., the kinematic viscosity is defined for air at 55 degrees Fahrenheit. The variables above give the following Reynolds Number seen in Eqn.4.

$$R_e = \frac{\left(0.1\frac{m}{s} * 0.0762m\right)}{1.56E^{-5}\frac{m^2}{s}} = 488 \qquad (4)$$

The result from Eqn.4. was actually the opposite of what was originally thought to be occurring. Originally, it was thought that the Kármán vortex street wasn't being produced because the Reynolds number of the flow was too low, but after calculating the Reynolds number for the setup and referring to Eqn.1, it is seen that the Reynolds number of the Flow is too high. This means that there should be a turbulent wake being formed on the side of the cylinder that is opposite from the oncoming flow.[4] This isn't apparent in the image taken. Looking to Fig.4, you can see the types of disturbances a cylinder can create for forced flow.

Looking to Fig.4, it is noted that the incense smoke should be departing at 82 degrees from the horizontal of the cylinder and the flow. This also isn't occurring in the image taken above. Upon reviewing over all of Fig.4, it is determined that the flow in the image above closely represents the flow for a Reynolds Number greater than 4 and less than 40. This means that either some of the parameters used for determining the actual Reynolds number are incorrect, or this method of trying to create a Kármán vortex street using natural convection is invalid. I have chosen the latter. It has been determined that a natural convection flow does not represent the same fluid mechanics as a forced convection flow. Due to the fact that Strouhal instability has only been seen for larger scale forced convection flows, I have concluded that a Kármán vortex street cannot be produced at this scale using a natural convection flow. It is probable that a natural convection flow could produce a Kármán vortex street at either a much larger or much smaller scale of setup. Regardless, I think I obtained a cool picture from the experience.

Image Processing

The image was cropped and the contrast was enhanced so that the smoke from the incense sticks would be more easily seen by the viewer.

References

[1] Theodore von Kármán, "Aerodynamics". McGraw-Hill (1963)

[2] "Kármán vortex seen in nature." http://www.wired.com/wiredscience/tag/von-karman-vortex-street/ , April 4th, 2011

[3] "Strouhal Instability." http://hmf.enseeiht.fr/travaux/CD0102/travaux/optmfn/gpfmho/01-02/grp1/presenta.htm , April 4th, 2011

[4] Kundu, Pijush K., and Ira M. Cohen. Fluid mechanics. 4th ed. Amsterdam: Academic P, 2008 pp. (369-373)

[5] "Kinematic Viscosity of air" http://www.engineeringtoolbox.com/air-absolute-kinematic-viscosity-d_601.html , April 4th, 2011

Figures

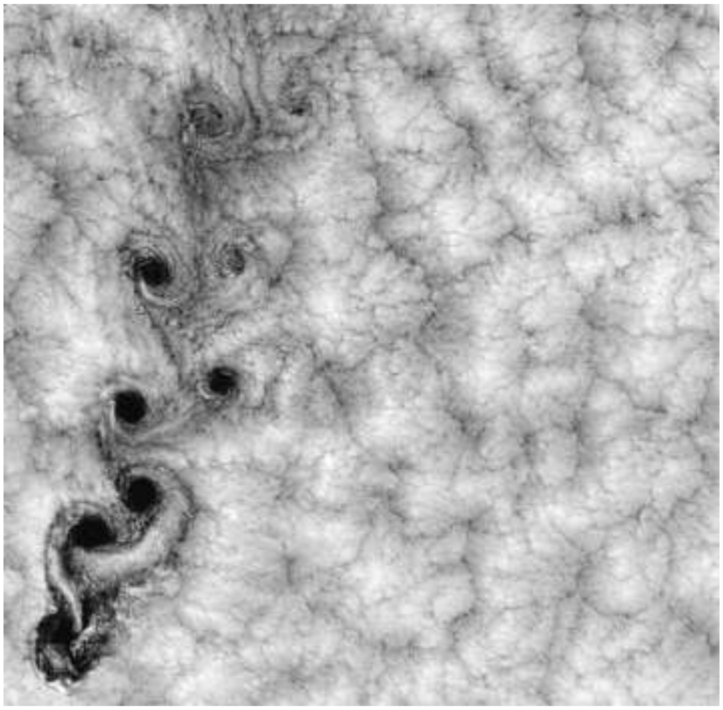

Figure 1: Visual representation of a Kármán vortex street occurring in nature. Effect is caused by an island disturbing the steady flow of clouds.[2]

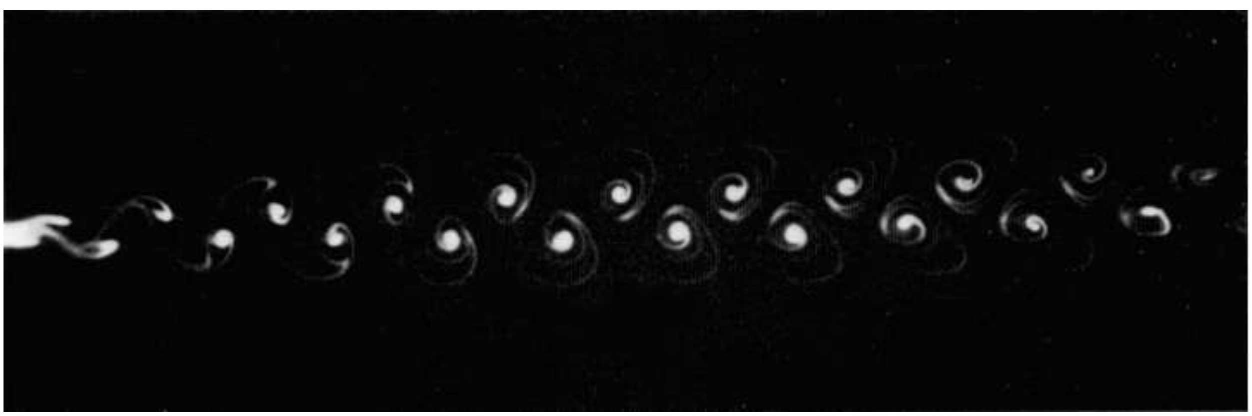

Figure 2: Kármán vortex street produce in a lab as a result of the Strouhal instability.[4]

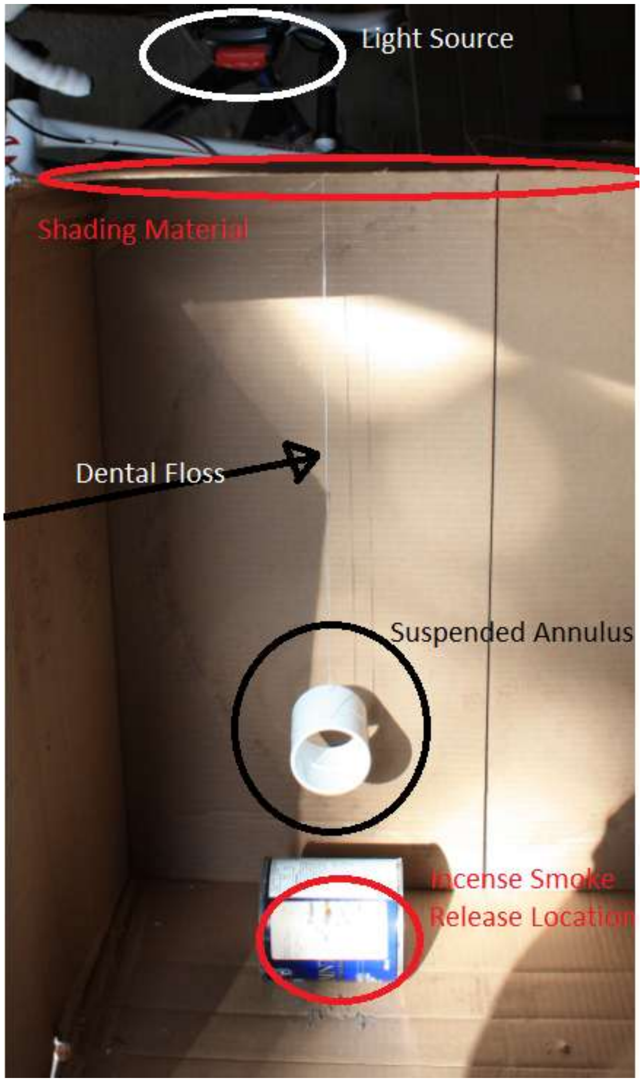

Figure 3: Visual representation of experimental setup for the captured image.

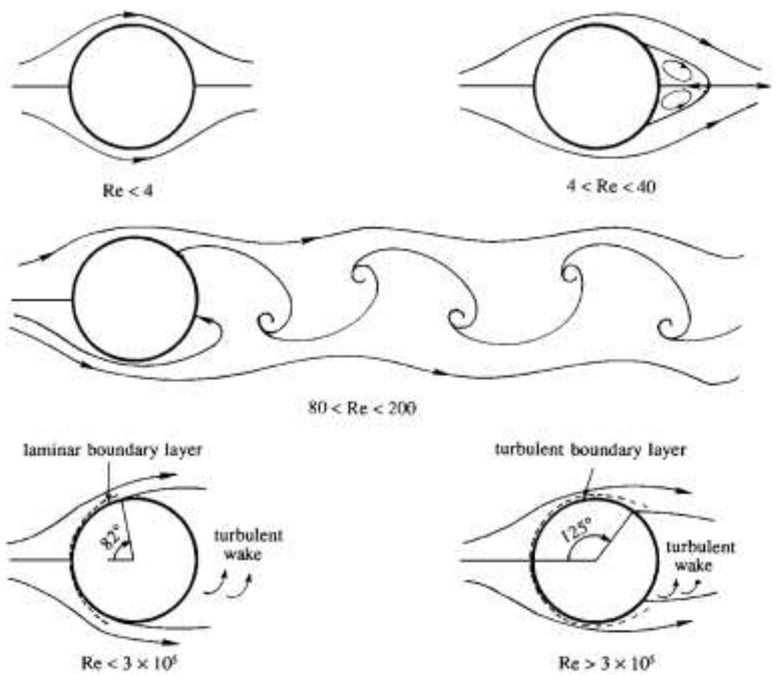

Figure 4: Different types of flow caused by a cylinder disturbing the flow at various Reynolds Numbers.[4]