Group Project #3

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1. Introduction

The purpose of this report is to describe the physics behind a flow phenomena, visualization techniques, and photographic techniques for the third group flow visualization project. For this assignment wake formation from ocean water flowing around a round rock was used as the flow phenomena, and achieved by placing a medium sized rock in the outgoing tide of the Pacific Ocean. The following text describes the physics behind wake formation, how the flow was achieved, and photographic techniques used to achieve the best possible picture. Initially the goal of the project was to capture an ocean wave cresting, but the turbulent conditions of the ocean that day made it difficult to get a clean wave picture, as seen in figure 1.1. The goal of the project then changed to capturing the wake patterns the outgoing waves made in the sand after walking by a large post and seeing the patterns in the sand. It was discovered that by placing a rock in an undisturbed section of sand the wake patterns were clearer and more distinct as see in the cover photograph. Figure 1.2 shows an example of when the rock was placed in a section that was already disturbed by another rocks wake pattern.

Figure 1.1 Ocean Wave

Figure 1.2 Disturbed Section of Sand

2.0 Experimental Setup

For this project the Pacific Ocean and sand were used to visualize wake patterns of a fluid flowing around an object. The section of sand at Great Highway and Sloat Blvd on San Francisco's Ocean Beach had a black film on the top layer of sand that provided a nice contrast to the brown and gray sand. The black film had a lower density than the sand and was easily washed away by outgoing waves, especially where the flow was turbulent, or settled on top of the brown sand. The black film could possibly be soot from nearby bonfires, but actual density and origin are unknown. Care was taken to find a section of beach that didn't have any rocks or other objects, in order to get a clean slate for creating a wake pattern, and had a relatively small slope of 15 degrees. A medium sized rock roughly 5 inches across was placed on a clean section of sand while a wave was going out. If the rock was placed while the wave was coming in it often times got swept up by the incoming wave a carried to a new location that was difficult to track. The photographer was standing in the ocean roughly 6 feet from the rock as the wave went out in order to make sure no shadows were in the photograph. The time of day was roughly 11:30am PDT so the sun was almost directly overhead, but attempts at standing on the beach produced unwanted shadows in the photographic area. Figure 2.1 shows a diagram of the experimental setup.

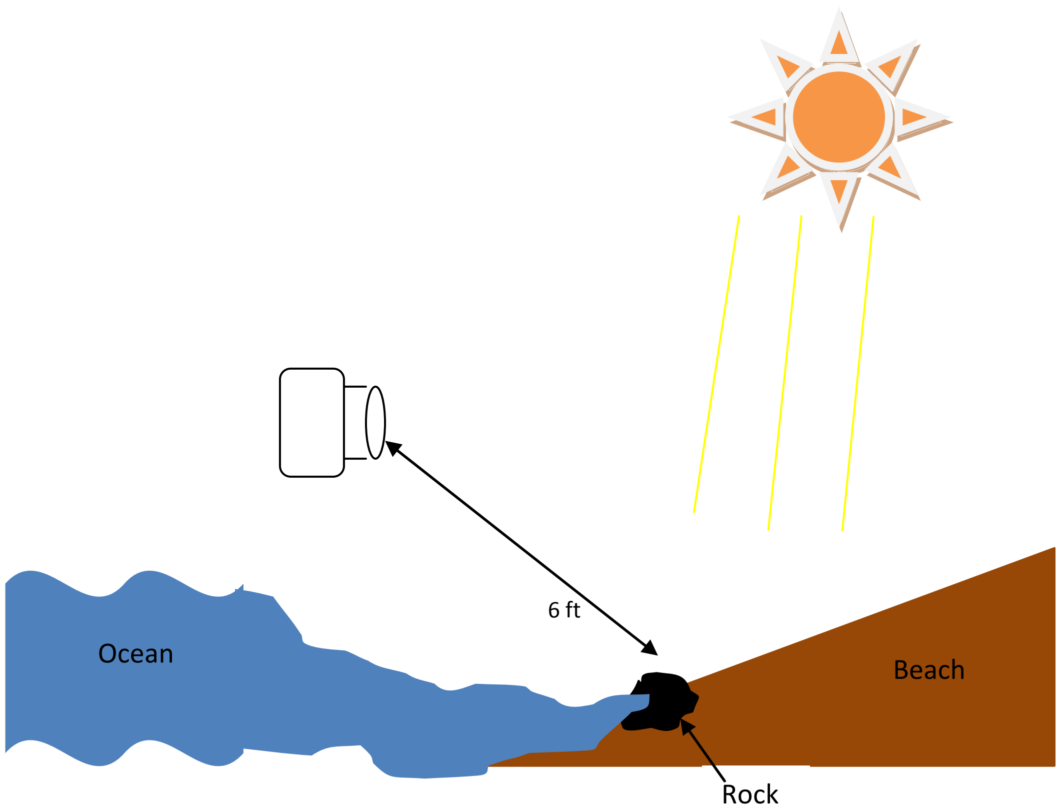

Figure 2.1 Experimental Setup

3.0 Description of Flow Physics

For incompressible fluids, such as water in this experiment, wakes can form when an object moves through a fluid, or in this case a fluid moves around an object with great enough velocity. When an incompressible fluid encounters an object it must be displaced around an object[1]. The path the fluid takes around the object is governed by two forces, inertial force and frictional forces around the boundary layer of the object. If frictional forces dominate the fluid will flow around the object without separating. If inertial forces dominate the fluid will be thrown from its path by perpendicular acceleration [3]. The relationship between the frictional and inertial forces is the Reynolds number given by equation 3.1.

$$Re = \frac{U_{drop} * R_{drop}}{\nu_{drop}} \quad \text{eq. 3.1}$$

For Reynolds number less than 1 the flow is dominated by frictional forces and the flow remains laminar around the object. As the Reynolds number increases the boundary layer begins to separate behind the object creating a vortex pair. If the Reynolds number is high enough, typically

75-350, a wake forms [2]. The waves formed in the wake dissipate energy outward forming the wedge shape that can be seen in the cover photograph. The angle of the wake is given by equation 3.2, where c is the phase velocity of the wave and v is the velocity of the fluid. In order for wakes to form v has to be greater than c.

$$\theta = \arcsin\left(\frac{c}{v}\right) \quad \text{eq. 3.2}$$

In order to calculate the Reynolds number the velocity of the water flow was estimated at roughly 0.004 ft/s by marking the sand and counting how long it took the wave to move 1 foot as it went back out to sea. The ocean water was approximately 40°F giving a dynamic viscosity of $1.664*10^{-5}$ ft^2/s. The diameter of the rock was roughly 5 inches. The Reynolds number of the water flowing into the rock is calculated as:

$$Re = \frac{0.008\frac{ft}{s} * 0.208\, ft}{1.664 * 10^{-5} ft^2/s} = 100$$

This Re is large enough that the flow around the rock is turbulent and the condition for wake formation is met.

4.0 Photographic Technique

A Nikon D5100 SLR 16.2 MP camera was utilized for this photograph. The 18-52 mm lens was used, and the field of view of the photograph was roughly 5' x 4' and the camera was held roughly 5' from the rock. The focus mode was set to automatic with a focal length of 18 mm. Aperture was set to F/5.6. The shutter speed was 1/1250s and the ISO was 400. Figure 4.1 shows the before and after gimp processing photograph. Post processing in gimp included cropping the wave out of the photograph so that the focus remained on the wake pattern drawn in the sand. The photo was converted to grayscale and contrast was increased to make the lines of the black sand stand out more against the brown sand making the wake pattern and wave pattern of the sand more visible.

Figure 4.1 Pre and Post Processing Photograph

5.0 Conclusion

This image shows the distinctive V-pattern that a fluid makes as it flows around an object with high enough velocity. The flow showed high enough velocity to create a wake and the different colors and density of sand marked the shape of the wake after the water moved past the object. The biggest issue with this assignment was not collecting enough information about the density of the different sands. I feel that with a better idea of what information should have been collected while the experiment was taking place could have lead to more precise calculations and insight into the patterns seen on the sand. For the original intention of capturing well defined waves, a zoon lens would have been helpful taking photographs of waves further out that were not as churned up as the waves closer to shore. I feel that despite missing the original intention of the photo shoot the wake patterns on the sand provided a great second thought experiment that produced great photographs that had not been done before in this class.

6.0 References

1. http://en.wikipedia.org/wiki/Wake

2. B.E. Stewart, T. Leweke, K. Hourigan, and M.C. Thompson,"Wake Formation Behind a Rolling Sphere," Physics of Fluids, No. 20 (2008).

3. http://www.es.flinders.edu.au/~mattom/ShelfCoast/chapter07.html

4. C.C. Epifanio, R. Rotunno, "The Dynamics of Orographic Wake Formation in Flows with Upstream Blocking," American Meteorological Society, Vol. 62 (2005).