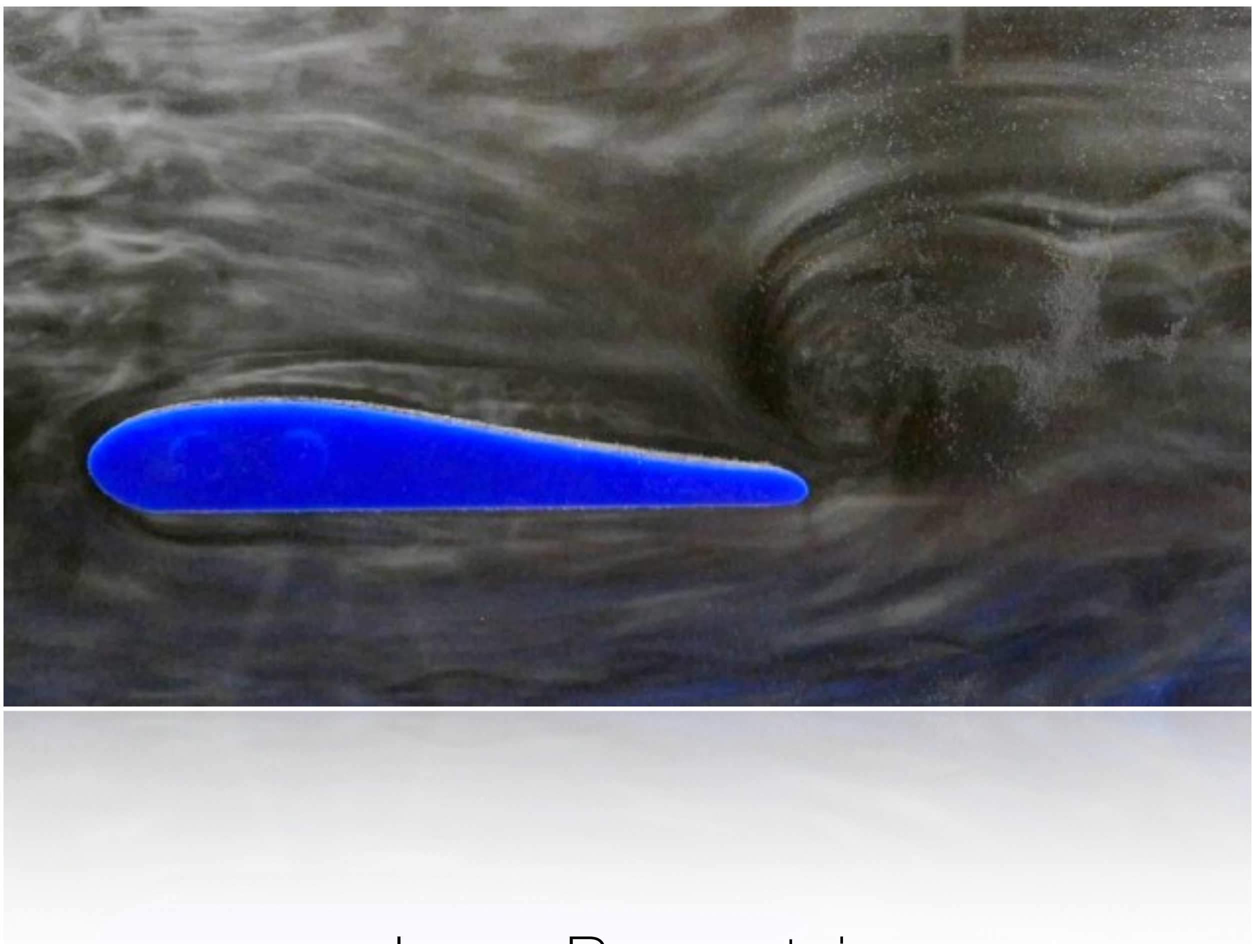
WAKE AND TURBULENT REGIONS ON BLUFF BODIES



Jason Brownstein

In accordance with:

Eric Fauble

TEAM IMAGE 2

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Purpose:

A fluid dynamics course will teach the basics of boundary layers behind bluff bodies and their corresponding wake regions. It is easy to understand these concepts with the photographs that are shown during a fluid dynamics class. The only issue is these videos and images were taken about 40 years ago. It is time for a update for the visualization of fluid flow around bluff bodies. This experiment was conducted with the intent to visualize these boundary layer and wake regions behind several different types of bluff bodies. Initially the flume in the ITLL was used due to ease of use and it was an existing set up. This set up did not work because the flow rate was far to high and not nearly laminar enough. A new set up was built for this experiment and is now available for later classes to use.

Flow Set-Up:

To accurately capture this flow phenomena a new set up had to be created. This set up is depicted in Figure 1. It consists of a 55 gallon fish tank with a vertical divider in it to isolate part of the tank. This divider is the region of interest in the flow visualization set up. On the left side of the tank PVC pipes carry water into the fish tank. On the right side of the tank, water is carried out of the system via PVC pipes and a pump then returns the water to the left side of the tank, circulating the water around the tank.

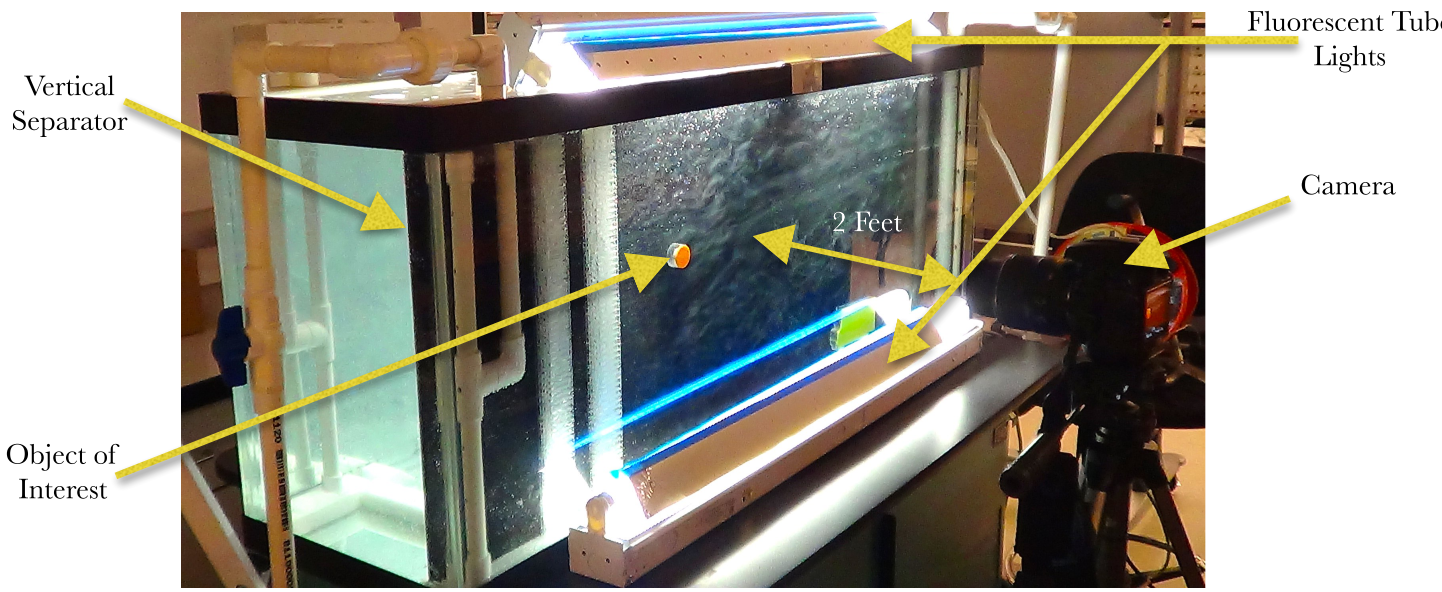

Figure 1: Flow Set-Up

This pump is capable of five liters per minute which provides a relatively slow flow through the fish tank. It is important to try to achieve a laminar flow through the region of interest. If the flow is laminar there will be minimal mixing by just the fluid and streamlines will be easier to create. A streamline is visualized with a refracting fluid that contains crushed up fish scales. This fluid works well in a set up like this because it will “shine” in the water and provide contrast against the black vertical separator.

Manifolds are then placed in between the front of the glass and the vertical separator (approx. 1.5” wide) to aid in straightening the flow and making the fluid more laminar through our area of interest. After the manifold a bluff body was placed and is approximately the same depth as the manifold to attempt to ensure all flow goes around the object instead of between it and the glass. These bluff bodies have magnets in them, so an opposing magnet is placed on the opposite side of the vertical separator to keep it suspended in the flow. The camera was placed two feet away from the fish tank and two fluorescent tube lights were place above and below the fish tank. This provided extra shine to the fish scale fluid to increase the chance of capturing the flow phenomena.

Flow Physics:

A boundary layer is defined as a, “thin layer of fluid near the surface in which the velocity changes from zero at the surface to the free stream value away from the surface.”[1] This moment of instantaneous zero velocity at the surface of an object is called the no slip condition. Given this condition a typical flow velocity profile will take on a parabolic shape. Starting at zero and increasing in x until the velocity has reached the free stream. In a paper by Kehro et al. the turbulence intensity over an airfoil is studied. Figure 2 shows the experimental results of a velocity profile, which takes on the parabolic shape as mentioned above.[2]

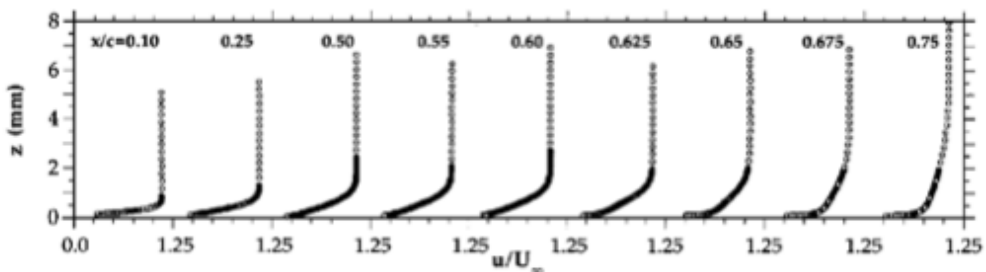

Figure 2: Velocity Profile Over an Airfoil

Further into the experimental results of the study Kehro et al. attempts to visualize the turbulence that can occur over the airfoil at different Reynolds number. Which is defined as the ratio between the inertial forces and the viscous forces in the fluid.[3] It is shown in Figure 3 as the reynolds number increases the turbulence intensity does as well, as does the point at which the boundary layer trips into turbulence. This result can be illustrated with a snippet from the video of the flow visualization at hand. Figure 4 shows the initial laminar boundary layer then further along the layer trips into turbulence just like the experiment shown in Figure 3. A

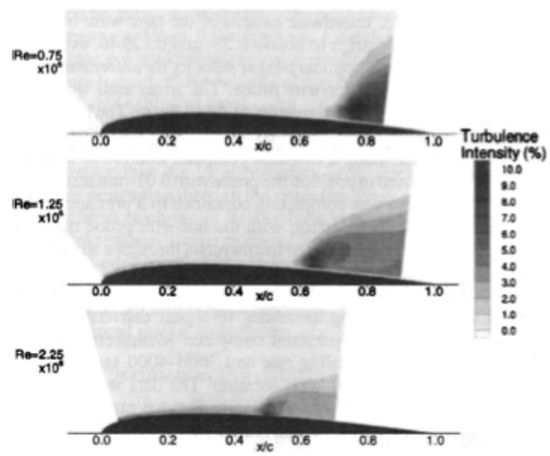

Figure 3: Turbulence Intensity Experiment

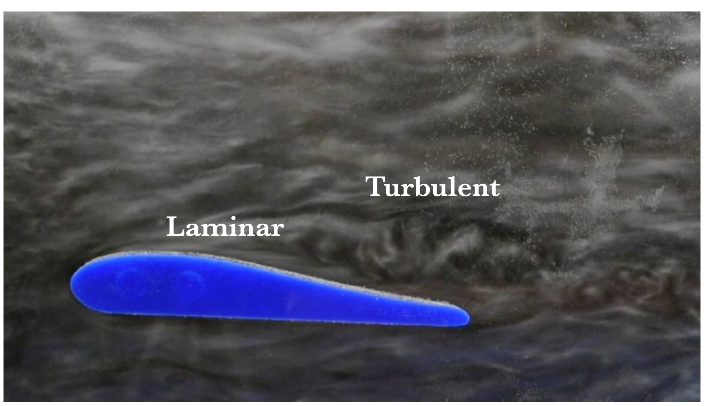

Figure 4: Project Experiment Flow

boundary layer forms around a sphere in the same way that it forms around the airfoil. In this case there are some unique properties that occur in the wake behind a sphere because of the geometry. As the Reynolds number is increased in the flow distinct changes occur around the wake of the sphere. Some of the values in which these changes take place are still a point of contention but typically used as a decent guideline.[4] For a Reynolds number of .2 or below the flow remains laminar and no separation occurs behind the sphere. Re = 12 The flow begins to separate directly behind the sphere and retains a symmetrical pattern. Re = 120 the wake begins to separate further and generate an oscillating wake or Karmen vortex sheet. This phenomena is shown in the video visualization and it can be estimated that the Reynolds number of the flow is roughly 30,000 because the flow will go between being a wide turbulent wake and an oscillating vortex sheet. At Re = 30,000 the oscillation ceases and the wake becomes wide and turbulent. Then as the number increases further the turbulent region starts to narrow, Re = 500,000. Figure 5 shows the difference in wake behind a sphere for different Reynolds numbers.

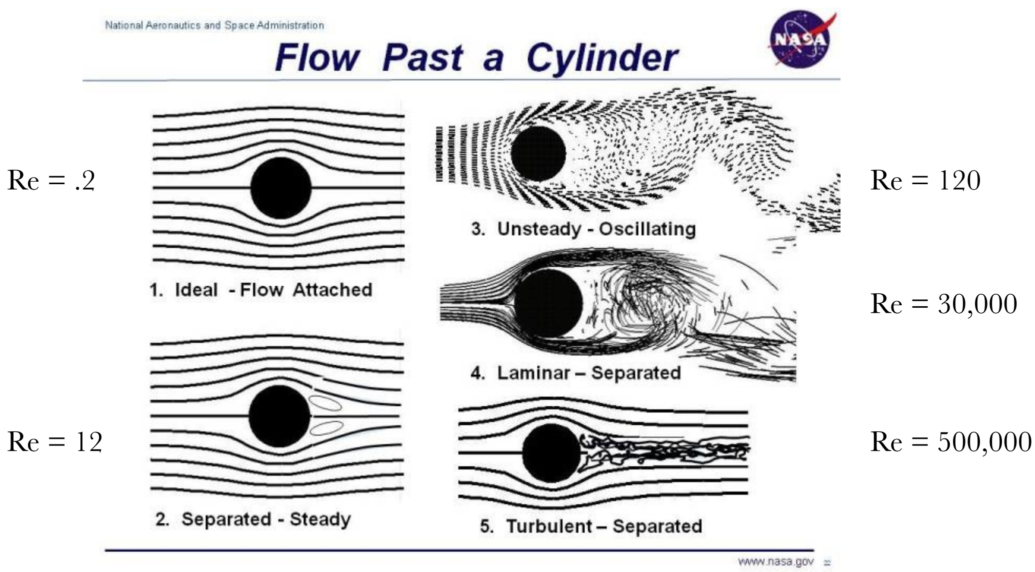

Figure 5: Wake Behind a Sphere at Different Re

Photographic Technique:

This image was taken with a Nikon D5000 equipped with a 18-55mm focal length lens. The lens was adjusted to a focal length of 55mm in this image to result in an image size of roughly a foot by a foot. Positioning the camera two feet away from the subject and zooming in resulted in the least amount of glare. A shutter speed of 1/13 of a second was used with a corresponding aperture of *f*/6.3. This combination allowed for the use of an ISO of 400. A tripod was used to ensure that there was no motion distortion as the video was filming. The resolution of the D5000 video camera mode is 720p (1280x720) at 24 fps. This capability allowed for the capturing of the complete fluid phenomena in high resolution.

After the video was taken it was complied into iMovie to generate a movie. In iMovie the videos were adjusted to increase the saturation of the image by a slider of +20. Each video was then put into the timeline to create the video and titles were added on top of the video. Music was then added to the video to add another dimension of entertainment. For the airfoil stock airplane sounds were used because it seemed fitting to have such ambient sounds as the airfoil moved around in the fish tank. Then piano music was used to be a bit off beat from the previous music.

Conclusion:

This experiment turned out much better than was expected and a validation of textbook pictures was nice to achieve. It was shown that the illustrations in textbooks could be recreated using a homemade set up and some reflective fluid. From this visualization it was was to identify a Reynolds number based off of the characteristics of a flow around a cylinder. Reception to the video was good and the overlaid music was enjoyable. In the next iteration of this video it would be nice to attempt to remove more of the air bubbles from the fish tank before starting the experiment. These bubbles became distracting when they would mix with the fluid or be overlapping with the bluff body in the tank. An attempt to make the fluid more laminar could be attempted by reducing the flow rate of the pump even further but this may cause issues of the fish scale reflective fluid may settle out fast than it is transported across the fish tank.

References:

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2. Kerho, Michael F., and Michael B. Bragg. "Airfoil boundary-layer development and transition with large leading-edge roughness." *AIAA journal* 35.1 (1997): 75-84.

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