Turbulence in a Flow Tunnel

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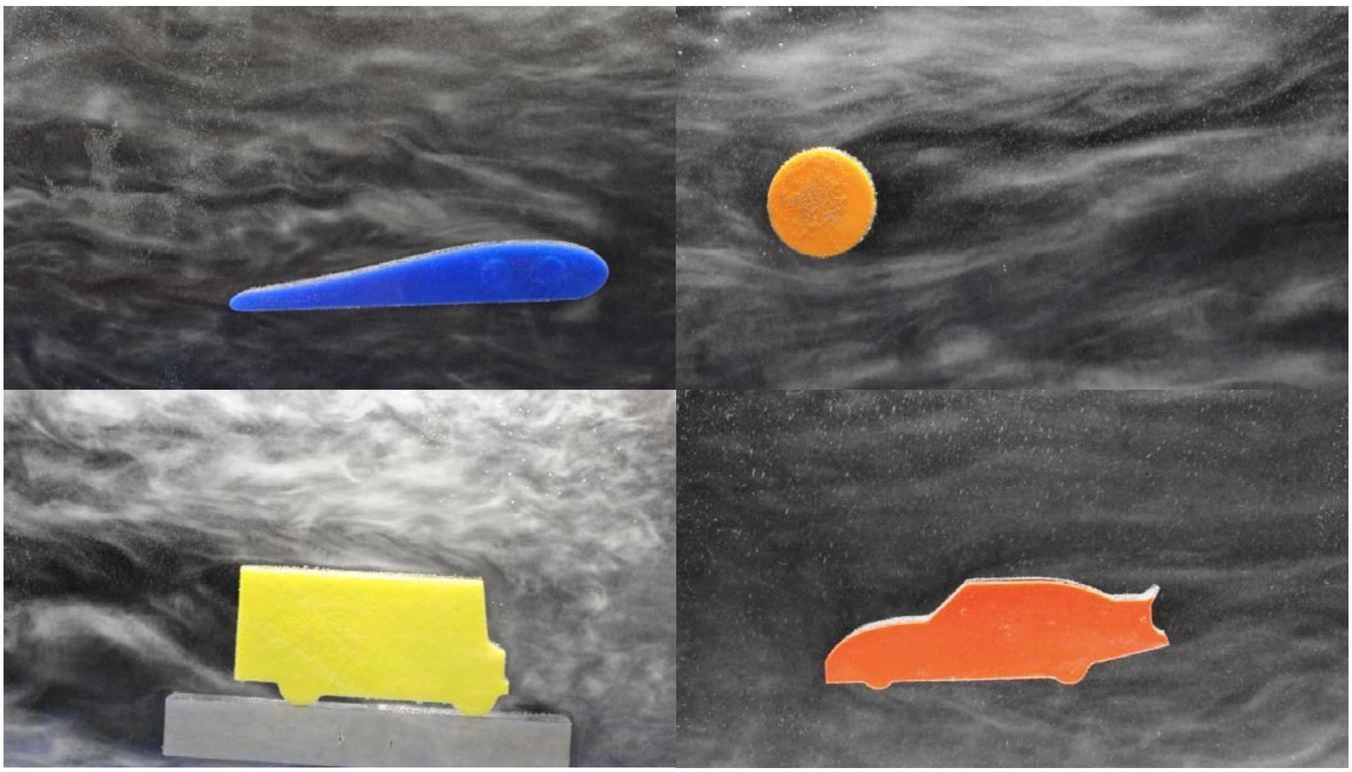
MCEN 5151



Rheoscopic Fluid in Laminar Flow

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Purpose

This video was an attempt to capture the laminar and turbulent boundary layers formed on various shapes. Four shapes, a red sports car, a yellow truck, an orange cylinder, and a blue air foil were placed in in a fish tank with “close to” laminar water flowing over them. The water contained a rheoscopic fluid to provide reflective elements in order to capture the fluid physics that developed as the flow interacted with the four shapes. This video was conducted with the intention of visualizing the boundary layers so commonly studied in the classroom, and the results were surprisingly similar to the pictures found in most fluid dynamics text books.

Flow Set-Up:

To accurately capture the formation of laminar and turbulent boundary layers, a fairly sophisticated set-up was required. The set-up (seen in figure 1) consisted of a 55 gallon fish tank, a vertical divider, laminar manifolds, two fluorescent light, rheoscopic fluid, four magnetic objects, PVC piping, and a pump.

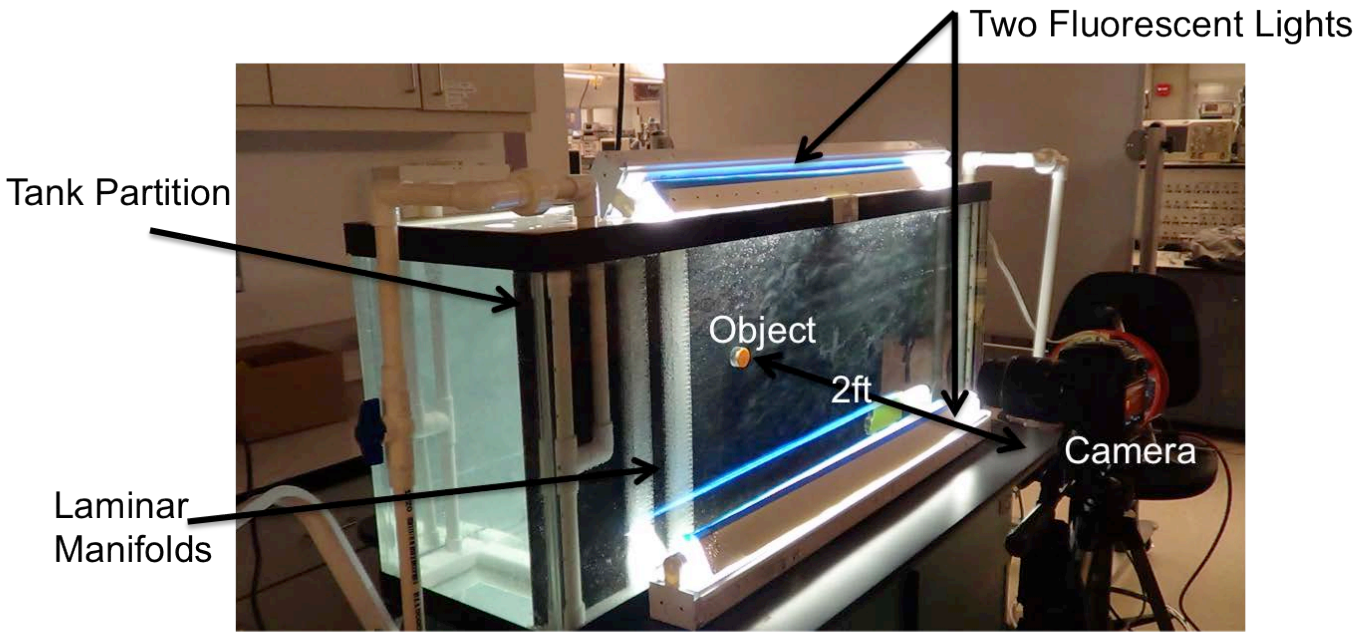

Figure 1: Setup consisting of water light box, camera on a tripod and a bowl of milk

Vertical Divider: The vertical divider confined the volume of flow to the size of the objects, which was roughly 1.5’’ in depth. This was important in limiting the flow to two dimensions.

Laminar Manifolds: Two manifolds approximately 1.5’’ wide at the left of the tank took the turbulent flow from the pump and “straightened” it to be laminar. Another manifold located at the right of the tank helped ensure that the flow would maintain its laminarity throughout the length of the tank before being sucked back into the pump

Lights: Two fluorescent lights were used to evenly light the set-up from top and bottom. The even light eliminated shadows allowing for the rheoscopic fluid to accurately portray the fluid physics occurring.

Rheoscopic Fluid: The name rheoscopic comes from the greek words rheo – to flow and scope – to watch.[1] The particular fluid used in this set up was from Kalliroscope Corporation. This fluid consisted of crushed up fish scales.

Pump: This system consisted of a recycling pump system. A pump with the ability to pump 5L a minute pumped water into the left side of the tank and pulled water out from the right side of the tank.

Fluid Physics:

A boundary layer is defined as a thin layer of fluid near the surface in which the velocity goes from zero to 0.99 the velocity of the free stream velocity. The height of the boundary layer, referred to as δ, is determined by the Reynolds number and the distance travel along the object in the direction of flow.[2] The existence of a zero velocity at the surface of the object is called the no-slip condition, and given this condition the velocity profile that exist as you move away from an object is parabolic.[3]

Boundary layers may either be laminar, or turbulent depending on the value of the Reynolds number. (The Reynolds number is the ratio between inertial and viscous forces).[3] Lower Reynolds number yield laminar boundary layers while higher Reynolds numbers yield turbulent boundary layers.

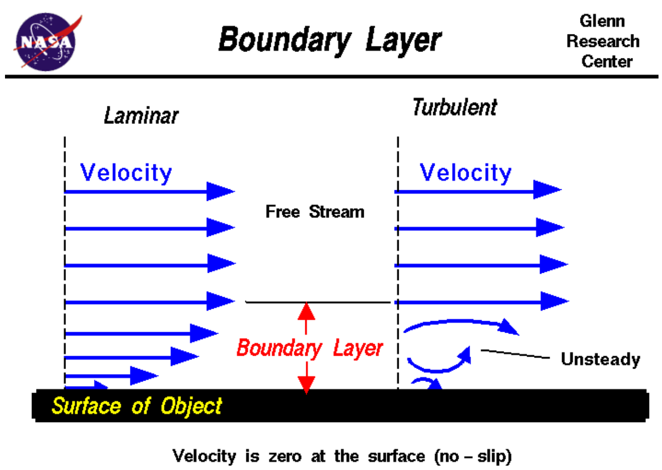

Figure 2: Laminar and Turbulent boundary layers[2]

Figure 3 shows a frame from the footage taken during the experiment. This frame illustrates both a laminar and turbulent boundary layer created on the airfoil. It should be noted that the turbulent boundary layer grows to be significantly taller than the laminar boundary layer.

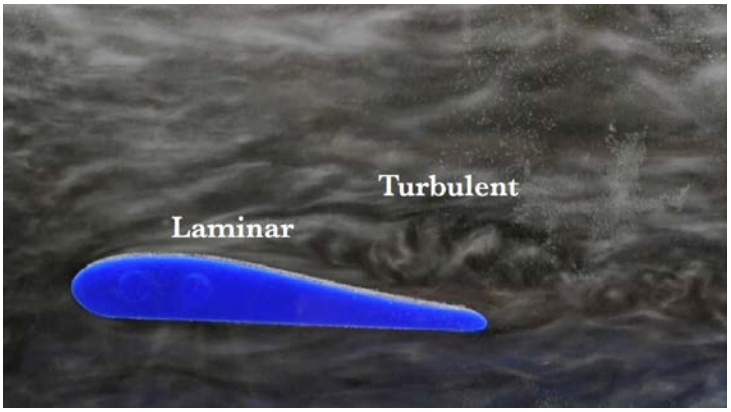

Figure 3: Laminar and Turbulent boundary layers on an airfoil

Like an airfoil, boundary layers also form around cylinders, and just like and airfoil the flow past a cylinder changes with regards to the Reynolds number. Figure 4 provides an illustration of the various physical phenomenon that occur at various Reynolds number. If you compare Figure 4 with the footage in the video you can see that the orange cylinder is oscillating and shedding vortices. This phenomenon is known as a Karmen Vortex sheet.[4]

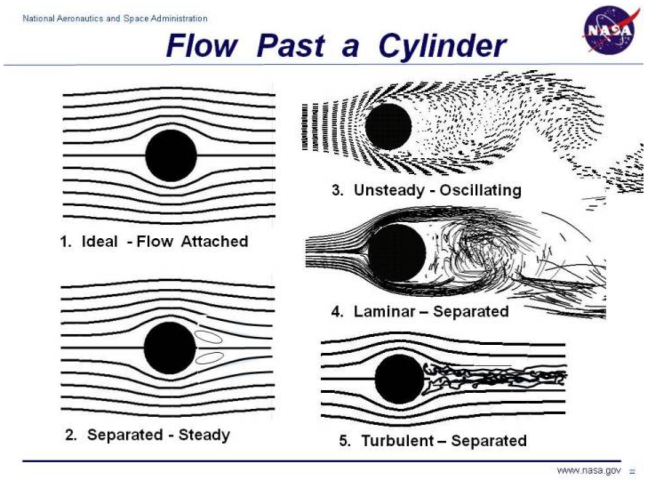

Figure 4: Flow past a cylinder at various Re numbers[4]

Figure 5: Snap shot from footage of Karmen Vortex sheet

Photographic Technique

Camera Settings

This video was taken with a Nikon D500 equipped with an 18-55mm focal length lens. The focus of the video was set to 55mm. The field of view in this video is roughly 12’’x12’’ with the objects approximately 6’’ in length. The camera was positioned about two feet away from the glass of the fish tank, and then zoomed in to reduce the effects of glare on the glass. The resolution of the D500 in video mode is 720p (1280x720) at 24fps. The camera was mounted on a tripod to ensure there was no hand held motion blur. Luckily, the speed at which the fluid was flowing was also slow enough to ensure that there was also no motion blur, which allowed for the boundary layers to be completely captured in high resolution.

Post Processing:

The video was compiled and edited in iMovie. The initial three scenes where you can see the rheocopic fluid encroaching upon the objects is shown in real speed. The following footage where the laminar and turbulent boundary layers are clearly present were sped up either 200% or 400%. The footage of the orange cylinder was sped up to 400% in order to clearly illustrate the oscillation shedding of vortices. No music was chosen for this video because I thought the images themselves were powerful enough, and I wanted to keep a scientific feel to the video.

Reflection

I found myself pleasantly surprised at the quality of footage that my group was able to capture. I really enjoyed being able to see for myself the boundary layers that I had so commonly studied in fluid dynamics. I was also very happy to utilize the fluid flow setup that I had design and manufactured during the summer of my sophomore year. If I was to revisit this setup I would attempt to eliminate all 3D flow by improving the vertical divider. I would also attempt to fix the problem of bubble generation in the pump that occasionally produce distracting bubbles that clung to the glass.

Bibliography

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[2] "Boundary Layer." *Boundary Layer*. N.p., n.d. Web. 06 May 2014. <http://www.grc.nasa.gov/WWW/k-12/airplane/boundlay.html>

[3] Young, Donald F. *Student Solutions Manual to Accompany A Brief Introduction to Fluid Mechanics, Fourth Ed*. Hoboken, NJ: Wiley, 2008. Print.

[4] "Drag of a Sphere." *Drag of a Sphere*. N.p., n.d. Web. 06 May 2014. <http://www.grc.nasa.gov/WWW/k-12/airplane/dragsphere.html>

[4] Dyke, Milton Van. *An Album of Fluid Motion*. Stanford, CA: Parabolic, 1982. Print.