A demonstration of Kelvin-Helmholtz instability.

Team Project 1

MCEN 5151 – Flow Vis

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This image came as a result of the first group project. Our original intent was to capture the fluid physics displayed by Kelvin-Helmholtz (KH) instability. In order to realize this intent, we decided to build a wide and thin acrylic box. We originally wanted to build a box that was much larger, but due to the limitation of the equipment available, we were only able to construct a box 22" in length. By filling the box equally with two liquids of different densities, we hoped to achieve this certain instability at the interface between them. When the box is tilted side to side along the longest axis, the liquids move at different velocities creating an instability.

The box was designed so that it could be easily tilted back and forth creating instabilities at the fluid interface. The following image shows the dimensions and layout of the box that was designed and built.

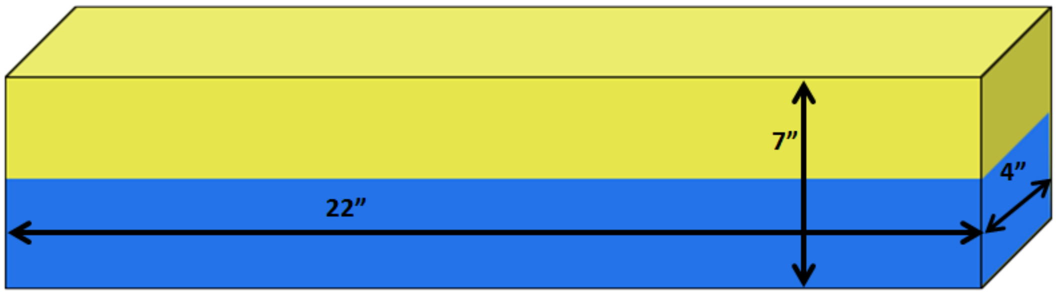

Figure 1: Acrylic Box

The yellow indicates the vegetable oil floating on top of the dyed blue water. We attempted to demonstrate KH instability, but it proved to be more difficult than we were expecting. KH instability is described as an instability of the basic flow of incompressible inviscid fluids in two parallel infinite streams of different velocities and densities.[1] Considering the air pressure of Colorado, both of these fluids are deemed to be incompressible. The two main factors of speed and density dictate to what extent instabilities will be observed. When the box is simply tilted back and forth, the velocities of the two liquids seemed to be too similar to really create any dramatic instability. After some experimentation, we decided that since we couldn't change the densities of these two fluids, we needed to change the speed at which they interact. By rotating the box 90 degrees clockwise we took advantage of the force of gravity. This motion created a situation with two fluids which were parallel to one another instead of one on top of the other. The increased velocity created very interesting but not well defined KH waves. Halfway down the box, when the water had rushed mostly towards the bottom, a very interesting wave was created which is shown here. The photo editing techniques used to create these colors are described below. This wave lasted for less than a second so it was quite difficult to capture. The dynamics of KH instability are described by the Taylor-Goldstein equation. This equation is an ordinary differential equation based on factors such as the Brunt-Vaisala frequency, the perturbation velocity, and the wave speed. This equation can be solved to determine if the waves

Figure 2: KH Wave

are stable or not. The bubbles seen in the image were created by continual mixing of the two fluids. There are water bubbles in the oil and oil bubbles in the water. The bubbles actually play a role in the dynamics and stabilization of the wave. The presence of bubbles in the fluid permits energy from the wave formations to be transformed into the energy of radial oscillations of these bubbles.[2] While this is not exactly applicable in the final image, since gravity and density difference are the greatest contributors to stability, it is still one way in which bubbles can affect stability.

The box was filled with vegetable oil and water. To create an affect that would be aesthetically pleasing we dyed the water blue to complement the yellow/gold colored vegetable oil. The entire volume of the box is roughly 10 liters, with half of that being filled with water. There were roughly 10-15 drops of food dye added to the water. To create the affect seen in the final image, the box was resting horizontally then quickly rotated clockwise 90 degrees. This created a moment in time in which the blue water resided on the left side of the box and the oil on the right side. The oil has a lower density, so it naturally and quickly moved upwards while the water rushed downwards. At the interface, half way up the box, a Kelvin Helmholtz instability formed creating an interaction in the form of a wave. Due to the high speed and short time life of this event, a high shutter speed was used to freeze the flow. In order to use a fast shutter speed, a flash was used to create the necessary light to complement a fast shutter speed. There were regular overhead lights from the ceiling, but the camera flash dominated the lighting.

When the box was tipped vertically, the width was 7 inches. The image was taken such that this width covered the entire field of view. The focus point was at the very middle of the box, with a field width of 7 inches give or take. The image was taken roughly 24-36 inches away from the box. At this distance, the focal length was maxed out at 55 mm. The shooting mode of the camera was set to aperture priority. The f-stop was set to F/9.5. The flash was enabled which generally defaults the shutter speed to 1/60 seconds. Since the lighting condition was decent from the flash, the ISO was set to 400 to prevent any sort of grainy image. The image was taken using a Pentax K2000 Digital SLR. The camera shoots at 10.2 megapixels (MP) creating an original image that was 3896 x 2616 pixels. After cropping the image to make the "wave" the centerpiece of the image, the final resolution was 2538 x 1824 pixels. Cropping was the first alteration to occur, but it was followed by several color manipulations using GIMP (GNU Image Manipulation Program). The curves tool was used some to enhance the contrast but the main tool used was the levels tool. By adjusting the levels of the R, G, and B, I was able to remove the yellow color from the oil. No edge definition was lost by this color transformation, but it did increase the contrast between the oil and the water. The water ended up being a deeper, richer blue, and the oil was clear in the end. The color editing techniques enhanced the original by demonstrating the flow more clearly.

I like that the image clearly reveals the separations of these two different liquids and how they interact given the external disturbance. Unfortunately, the multitude of bubbles created was a bit of a nuisance. Without the bubbles, the image would be very clean looking. After several attempts at trying to figure out what worked best to illustrate the flow, the bubbles were unavoidable. The way in which the two fluids interacted was not what we initially anticipated. We were hoping to tilt the box from side to side and be able to clearly see Kelvin-Helmholtz Instability. This was not the case. It would be interesting to find out what two liquids work better. Water was free and the vegetable was relatively inexpensive for the cause. If it is found that there are other liquids that definitely work better, then perhaps the box will be emptied and refilled. Overall I am satisfied with the image that was produced. It just looks like a big blue wave crashing down.

References

[1] Danforth, Charles. "Kelvin-Helmholtz Instability." *CASA*. 24 Mar. 1999. Web. 13 Mar. 2011. <http://casa.colorado.edu/~danforth/science/cloudshock/node5.html>.

[2] Gavrilyuk, S.L., H. Gouin, and V.M. Teshukov. "Bubble Effect on Kelvin-Helmholtz Instability." *Continuum Mechanics and Thermodynamics* 16 (2004): 31-42. Print.