Team Third Report: Kelvin-Helmholtz Instability

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Introduction

This video was for Group 11's Team 3rd Lab. Our goal was to capture Kelvin-Helmholtz instability inside a fluid. I will go into the explicit fluid phenomenon in the following section, but the gist is a turbulence layer being instigated by a shear force between two layers of a similar fluid but with different densities. This lab was created

Flow Apparatus

Kelvin-Helmholtz Instability is a unique phenomenon. It is primary observed in clouds in the upper atmosphere, where the conditions to create such a flow are well documented. However, it has been "observed from 500 m deep in the oceans on Earth to the Orion molecular cloud[1]." Sheer forces (such as wind) and slight density variations in a similar fluid (ie temperature differences in air which in turn change the density) are ever present in air streams. When clouds are present, they give us particles suspended in air to be viewed by the naked eye, showing those of us looking up what exactly is going on in the skies above.

Imagine two sections of air – one on top of the other. As the top section blows over the other creating a shear force, the bottom layer becomes disrupted. Tiny perturbations form at the boundary layer between the two fluids. As the top, less dense layer blows over the heavier one on the bottom, it starts to push those bumps and swells. As this phenomenon continues, the bumps get bigger and bigger, getting rolled over themselves in the direction of the upper flow. This is what creates the famous rolled waves we see in the clouds[2].

This is a highly turbulent system. What begins in the lower realms of Reynolds numbers $Re = \frac{\rho V L}{\mu} < \sim 2000$ aka laminar flow. As this begins to transition, the Reynolds number increases. Above 4000, we can say this flow is turbulent.

Methods

To achieve this same effect in lab, we used a clear water tank. Instead of using temperature differences – as that would quickly dissipate over time – we got the density variations using salt water. Since salt water is slightly more dense than fresh water, we were able to achieve a very thin boundary layer between the two fluids. To distinguish one from the other, our team dyed the salt water blue and the fresh water red. The salt water was 9 percent salinity, which was chosen specifically for this lab. We filled a tank with the water. The tank was appx. 96" long, 6" high, and 1" wide. We began by filling the tank halfway with the fresh water. We then slowly, over the course of an hour, filled the tank with the remaining salt water. We had to go slow to prevent any mixing of the two waters. Once the tank was full and no air bubbles remained, we sealed it off and let it settle another few minutes. Once our cameras and lighting were in position, we lifted the tank quickly off the ground to a heigh of appx. 48".

Our lighting technique for this lab required additional lights. We sourced industrial halogen bulbs from the University. These lights provided wide angle, bright, direct, and indirect lighting. This allowed our team to control the lights and shadows across the water and tank, rather than using the lab ceiling lights.

For this shot, we took videos recording on iPhones. One camera was recording in slow motion and the other in real time. The slow motion video that was used in the final project was shot at 26mm, f/1.5, 60 fps, and with an unknown ISO (as iPhone does not record that data). Our field of view was appx. 6' x 4' at around 3' to the subject. Image size is 1920x1280 which comes to 25 pixels per in. The temporal resolution is about 1/4 in per frame. My video was resolved in Movavi. There was not much editing done to the video itself except some size cropping, cutting, reversing, and music added in.

Discussion

This lab was amazing to produce. Our group could not have imagined the final flow that we captured. To be able to create such a complex visual and video is well enough to see the minute details involved is what makes me so happy to be able to take this class. The video shows in great detail how the KHI begins through sheer forces, small random turbulations, and then the waves get bigger and bigger. Our group agreed that we did well, but would love to fine-tune this lab to get the perfect time scales between the waves, wave sizes, and more. It takes a long time to setup but the results are worth it. I am very very happy with this lab.

References

[1]Masson, A., Nykyri, K. Kelvin–Helmholtz Instability: Lessons Learned and Ways Forward. *Space Sci Rev* **214**, 71 (2018). https://doi.org/10.1007/s11214-018-0505-6

[2]Hendrix, T., and R. Keppens. "Effect of Dust on Kelvin-Helmholtz Instabilities." *Astronomy & Astrophysics* 562 (February 2014): A114. https://doi.org/10.1051/0004-6361/201322322.