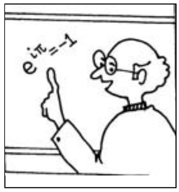

In this section of *Resonance*, we invite readers to pose questions likely to be raised in a classroom situation. We may suggest strategies for dealing with them, or invite responses, or both. "Classroom" is equally a forum for raising broader issues and sharing personal experiences and viewpoints on matters related to teaching and learning science.

The Inveterate Tinkerer
8. Kelvin–Helmholtz Instability

Chirag Kalelkar
Department of Mechanical Engineering,
IIT Kharagpur, Kharagpur
West Bengal 721 302, India.
kalelkar@mech.iitkgp.ernet.in

In this series of articles, the authors discuss various phenomena in fluid dynamics, which may be investigated *via* tabletop experiments using low-cost or home-made instruments. The eighth article in this series explores and demonstrates Kelvin–Helmholtz instability

Background

Kelvin–Helmholtz (KH) instability [1, 2] is a fluid instability that occurs at the interface of two sheared, incompressible fluids. The base flow comprises horizontal parallel streams, one above the other, with different velocities and densities or a single continuous fluid with an internal velocity shear. Kelvin [1] assumed that the two fluids were unbounded, incompressible, inviscid, immiscible, irrotational (*i.e.*, with zero vorticity) and the lower fluid had a higher density to avoid considering the Rayleigh–Taylor instability (see [3] for an elementary discussion of fluid instabilities). When the relative speed of the fluids exceeds a critical value determined by the densities of the fluids (ρ_1, ρ_2), the acceleration due to gravity (g), the interfacial tension (γ), and the wavenumber of the perturbed interface, the interface becomes unstable. The physical parameters mentioned above may be used to construct a length scale, which is called the 'capillary length' (L_c):

Keywords
Kelvin–Helmholtz instability, capillary length, shear, Karman vortices.

$$L_c \equiv \sqrt{\gamma/[(\rho_1 - \rho_2)g]} \tag{1}$$

KH instability is occasionally rendered visible by clouds in the upper atmosphere and has also been observed in the planetary atmosphere near Jupiter's Red Spot.

The instability is typically manifest when wind blows over a water surface beyond a relative speed that depends on a critical wavenumber for the perturbation given by $2\pi/L_c$. The instability is occasionally rendered visible by clouds in the upper atmosphere and has also been observed in the planetary atmosphere near Jupiter's Red Spot.

Materials Required

The experimental setup (see *Figure* 1) comprises a plexiglass cell with dimensions $120\times5\times10$ cm^3 (a fluid volume of 6 L) which is mounted on a pivot above a pyramidal steel support. We prepared 5 L of dyed brine solution by mixing 320 g of sodium chloride and a few milliliters of Taral Alta (Rose Bengal) dye with 5 L of water. Note that the setup has a stopcock at both ends. We keep the stopcock at the top right of the cell open at all times during the liquid-filling stage and block this outlet only when the filling nears completion. This step is critically important during the liquid filling stage, as it allows the air within the cell to exit. We attached a submersible pump (Zolta Khaitan, 18 W, 1.6 m head) to the inlet on the bottom left of the cell *via* a plastic tube and filled the setup with 3 L of water. The submersible pump was then placed inside a bucket containing 5 L of dyed brine solution. The cell was inclined at an angle of 8 degrees, and the brine solution was dripped into the cell through a flow regulator on the inlet pipe (see *Figure* 2). This liquid filling must be carried out at a slow flow rate, taking care to avoid vibrating the setup. The brine solution entering the cell slowly displaces the water layer upwards. It takes ~2.5 hours to fill 3 L of dyed brine solution. If the filling time exceeds 3 hours, the interface is found to be diffuse, and the resulting KH instability not clearly discernible.

When the water level reaches the upper surface of the cell, the submersible pump is switched off and both the stopcocks are closed. The cell is then made horizontal using the pivot. This

Figure 1. Experimental setup for demonstrating Kelvin–Helmholtz instability.

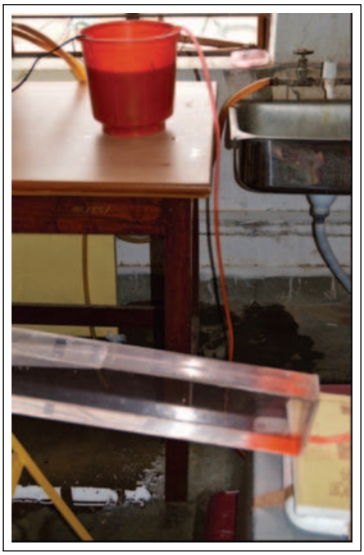

Figure 2. Filling the plexiglass cell with dyed brine *via* a submersible pump placed inside the bucket.

process is also carried out slowly to avoid fluid mixing near the interface. A final check for horizontal leveling is carried out using an inclinometer. We wait 5 minutes for any residual fluid motion in the cell to dissipate. A DSLR camera with macro lens is focused on the mid-section of the cell, with a white backdrop for contrast. The cell is rapidly tilted to an angle of about 8 degrees and held at this inclination. The heavier brine solution descends rapidly, while the water layer at the top slides upwards creating a shear layer at the interface. The interface becomes unstable and

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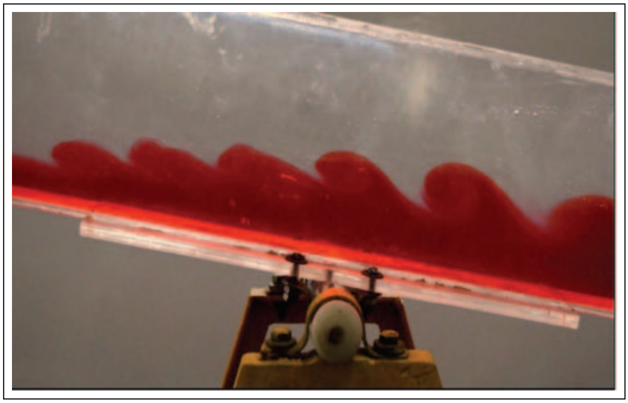

Figure 3. Kelvin–Helmholtz vortices at the interface of dyed brine (below) and water (above).

for a few seconds, approximately seven vortices may be seen at the interface (see *Figure* 3). The flow undergoes a transition to turbulence and rapid mixing ensues at the interface.

A video of the KH instability may be viewed here: `youtube.com/watch?v=kSsIQjr1Tt0`

Suggestions for Further Work

1. *Transition to Turbulence in a Smoke Jet*: A vertical smoke jet was created by burning incense. To reduce the effect of air currents in the vicinity of the jet, the burning incense was covered on three sides by a piece of cardboard (with black paper pasted on it for contrast). A video of the resulting KH instability was taken with a DSLR camera and macro lens, which may be viewed here (rotated clockwise by 90°): `youtube.com/watch?v=E7l6r6amilw`

2. *Mixing Layer in a Rectangular Channel*: A plexiglass rectangular channel of dimensions $24.5 \times 4 \times 1$ cm^3 was placed on a white paper. The channel has a splitter plate along the centreline, attached to one wall of the channel with two holes drilled through the same wall on opposite sides of the splitter plate (see *Figure* 4). Aqueous corn syrup flows through the inlet holes *via* a submersible pump and the two fluid streams meet at the end of the splitter plate. A 10 ml syringe was used to inject methylene blue dye at the end of the plate, which is used to visualize KH

Figure 4. Plexiglass rectangular channel with splitter plate and two inlet holes.

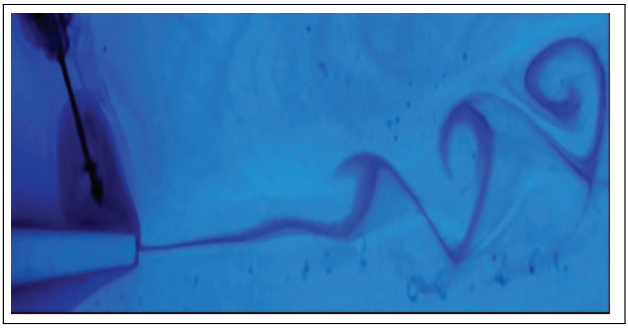

Figure 5. Kelvin–Helmholtz vortices in a rectangular channel at the interface of two parallel streams of aqueous corn-syrup.

vortices at the interface. See *Figure* 5 taken with a DSLR camera and macro lens. A video of the experiment may be viewed here: `youtube.com/watch?v=Z5rZrro4Cms`

3. ***Karman Vortices Behind a Moving Cylinder*****:** The plexiglass rectangular channel mentioned above was filled with water, after plugging the inlet and outlet holes. A small amount of lycopodium powder was sprayed on the surface of the water. A steel rod of 8 mm diameter was translated through the channel, showing Karman vortices in the wake. A video of the experiment may be viewed here: `youtube.com/watch?v=Hd3bzFtV724`

Acknowledgment

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Suggested Reading

[1] W Thompson (Lord Kelvin), The Influence of Wind on Waves in Water Supposed frictionless, *Phil. Mag*., Vol.42, p.368, 1871.

[2] S Thorpe, Experiments on the Instability of Stratified Shear Flows: Miscible Fluids, *J. Fluid Mech*., Vol.46, p.299, 1971.

[3] E Guyon, J Hulin, L Petit and C Mitescu, *Physical Hydrodynamics*, Oxford University Press, 2nd ed., 2015.

[4] G Brown and A Roshko, Coherent structures were visualised at the interface of plane turbulent streams of two different gases behind a splitter plate using shadowgraphy in a highly-cited paper: On Density Effects and Large Structure in Turbulent Mixing Layers, *J. Fluid Mech*., Vol.64, p.775, 1974.

[5] KH vortices at the edge of an axisymmetric free jet of high-velocity air from a nozzle into surrounding stagnant air may be seen in the video: `youtube.com/watch?v=ELaZ2x42dkU`

[6] KH and buckling instabilities in a free jet of viscoelastic fluid may be seen in the video: `youtube.com/watch?v=XPlm1Wsz_tE`

[7] Vortex shedding in the wake of a stationary cylinder in a vertically flowing soap film may be seen in the video: `youtube.com/watch?v=Mtobb9Ss4OA`

[8] View the the video 'Flow Instabilities' which is part of the series produced by the National Committee for Fluid Mechanics Films (United States) available online at: `web.mit.edu/hml/ncfmf.html`