Physics 3920 Laboratory

Vortex dipoles II. Electromagnetic method.

Objective:

To study the dynamics of fluid flows generated by a force applied in a small area of fluid.

Apparatus

The same as in Vortex dipoles I (Physics 3900) plus DC Power supply, graphite electrodes and rare earth permanent magnet.

Background

A force applied locally to a layer of fluid generates a flow in the form of a vortex dipole. Vortex dipole is a two-dimensional analog of a vortex ring. It performs translational motion and can therefore be characterized by its net linear momentum. For more background on vortex dipoles, their dynamics and examples in nature see Refs (1-3). In this experiment the Lorentz force is used to generate the flow. This force acts on ions moving in a magnetic field. Experimental apparatus is shown in Figure 1. The container is filled with two layers of water of depth 0.5 cm each. The lower layer is salt water of concentration 250 g/ l while the top layer is fresh water. Two layers are used to minimize the vertical component of velocity, providing the two-dimensionality of the flow. The flow is forced electromagnetically by imposing an electric current of magnitude j = 0–3 A in the horizontal direction. A rare earth permanent magnet of diameter 0.5 cm was placed flush with the bottom of the container. The magnet produces a magnetic field with a vertical component of ~ 0.09 T. The interaction of the magnetic field with the electric current results in a horizontal force exerted locally on the fluid in the direction perpendicular to the electric current. This localized force generates a vortex dipole (Fig. 2) and the magnitude of the force can be controlled by varying the current.

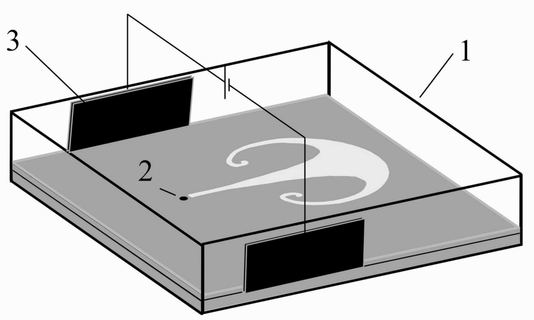

Figure 1. Experimental apparatus: 1- Plexiglas container, 2- permanent magnet and 3- electrodes.

Procedure

Create the stratified fluid in the tank (see Ref.1 on how to do this but note that the depth of the layers is different in this experiment). Inject a few drops of dyed water of intermediate density (half salt/half fresh) over the magnet. Switch on the current and observe the dipoles. Record videos of the dipole evolution using a PC camera. Repeat this experiment for different magnitudes of the current. Use the videos to measure the length L of the flow for different times.

Plot the length of the dipole L versus time t in logarithmic scale. Compare with theoretical dependence (eqs 10 in Ref. 2):

$$L(t) = \left(\frac{3J}{4\pi}\right)^{1/3} t^{2/3}. \qquad (1)$$

Here the momentum source (force) starts acting at time $t = 0$ and thereafter exerts on the fluid the kinematic momentum flux (force per unit mass and unit depth) equal to J = const. The dimensions of J are $[J]=\mathrm{Length}^3\mathrm{Time}^{-2}$, where Length and Time are the units of length and time (e.g. cm and s). The distance L is measured from the center of the magnet to the front of the dipole.

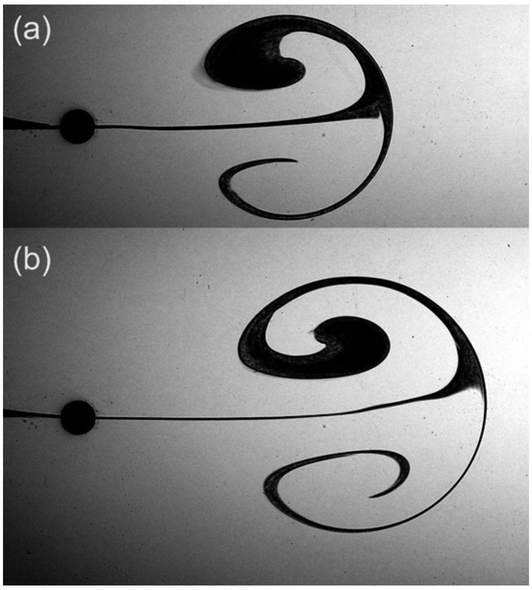

Figure 2. Typical view of the developing vortex dipole in the laboratory experiment. Current 0.3 A, t = 15 s (a) and 18 s (b). Black circle is the magnet of diameter 0.5 cm.

The momentum flux J remains undetermined so far. To measure the velocity field and then derive this parameter we use the PIV method. Create the density stratification again. (Note that it can be used for a time period of about one hour. The stratification is eventually destroyed by the diffusion of salt across the interface between the layers.) Illuminate the interface using a slide projector from the side (for PIV procedure see Ref 1). Insert polyamid particles at the interface. The particles should cover uniformly the area where the flow is observed. Take video sequences of the flow for different magnitudes of the current. Process the pairs of images from the video sequences to obtain the velocity fields. The profiles of the x-component of the velocity across the jet region of the dipole where the flow is established after the frontal part of the flow has passed can then be integrated to obtain the values of momentum flux in the jet. The values of the flux should be approximately equal for different sections of the jet along the x-axis which confirms the fact that the flow is steady in this region. These measurements allows you to obtain the values of the control parameter J for different values of electric current in the tank. The linear relation can found of the form

$$J = cj, \qquad (2)$$

where J is in $\mathrm{cm}^3/\mathrm{s}^2$, j is in A and c is the coefficient measured in the experiment. Here we assume that the flow is approximately uniform in the vertical direction along the depth of the layer (except in the thin boundary layer at the bottom). Use (2) to estimate J in your previous experiment where L was measured.

Questions:

Prove that the Lorentz force acting on the fluid in this experiment does not depend on the motion of fluid above the magnet.

Can you try and estimate the value of the Lorentz force using the geometry of the electrodes, the value of the electric current and the value of the magnetic field?

References:

1. Vortex Dipoles I (Physics 3900) http://www.physics.mun.ca/~yakov/P3900_PIV.PDF
2. Y.D. Afanasyev, V.N. Korabel: Starting vortex dipoles in a viscous fluid: asymptotic theory, numerical simulations and laboratory experiments, **Phys Fluids,** 2004 **16** (11), 3850-3858. click for full text PDF (http://www.physics.mun.ca/~yakov/paper_AK_PhysFluids.pdf)
3. S.I.Voropayev and Ya.D.Afanasyev. Vortex Structures in a Stratified Fluid: Order from Chaos. **Chapman and Hall.** London 1994.
4. A.M.Fincham and G.R.Spedding. Low cost, high resolution DPIV for measurement of turbulent fluid flow. *Exp. in Fluids*, 23, 449-462