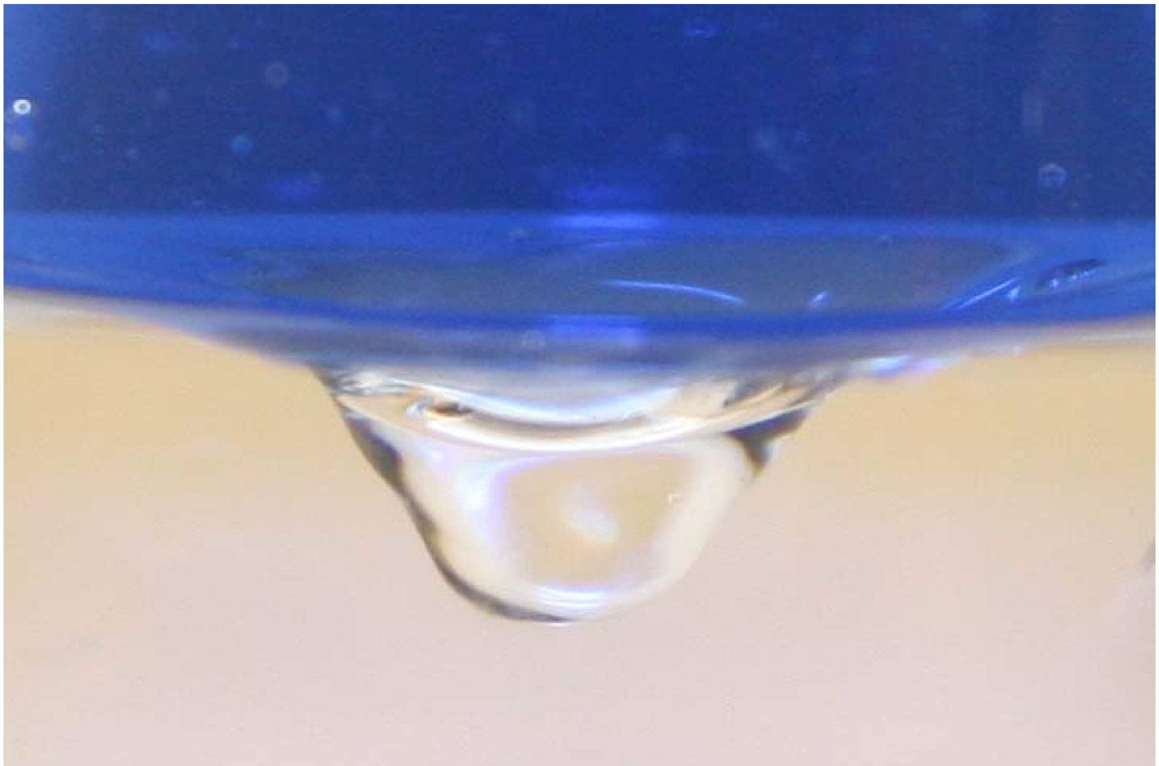
Assignment 1 – "Get Wet"

Brian A. Larsen, 9/26/2007



1 Objective

The objective of the image was to visualize the fluid dynamics of a vortex propagating through immiscible fluids. This was accomplished by overlaying equal volumes of three immiscible liquids with the intent of creating a vortex through three discrete strata. This proved to be unattainable, but a vortex at the interface of two immiscible liquids was created and the interaction of the two liquids was visualized in laminar flow conditions.

2 Methods

2.1 Flow apparatus

The experimental setup consisted of a 20 mL glass scintillation vial, a magnetic stir bar, and a magnetic stirring plate (Figure 1). Approximately 5 mL of each of the following liquids were used, listed with decreasing density: Fluorinert FC-77 (3M), deionized water with trypan blue stain, and toluene (Sigma). The three liquids possess distinct molecular structures that render them completely immiscible with each other. Fluorinert is a perfluorocarbon with an alkane backbone, water is a polar molecule capable of forming hydrogen bonding networks, and toluene is a non-polar molecule with a six-member ring structure.

The stir bar created a vortex in the densest liquid, Fluorinert, by generating flow normal to the stir bar rotation, increasing proportionally with distance from the rotational axis. An appropriate non-dimensional parameter to characterize the flow regime is the "spin" Reynolds number (Equation 1), as defined by Czarny *et al* in similar rotationally induced vortex conditions [1].

The calculated Re_{spin} for the flow visualized in the image was approximately 1.3, using the parameters from Table 1. Based on the calculated Re_{spin}, the flow conditions are undoubtedly laminar and this is qualitatively affirmed by the well defined interface between Fluorinert and water. Turbulent flow conditions would cause mixing at the interface and would be visible by light scattering and refraction. The flow occurring within the water layer is likely cylindrical Couette flow, which this experimental setup is not intended to visualize.

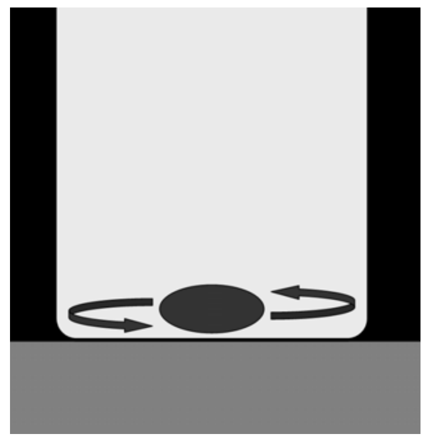


Figure 1 – Magnetic stirring plate, magnetic stir bar, and glass scintillation vial

$$Re_{spin} = \frac{\rho \cdot \omega \cdot r \cdot h}{\mu}$$

Equation 1 – "Spin" Reynolds number where "ρ" is the liquid density, "ω" is the stir bar angular velocity, "r" is the stir bar radius, "h" is the gap from the stir bar to the water-Fluorinert interface, and "μ" is the Fluorinert viscosity

Parameter	Value	Units
ρ	1.78	$g\cdot ml^{-1}$
ω	125.7	$rad\cdot s^{-1}$
r	0.5	cm
h	1.5	cm
μ	130	$g\cdot cm^{-1}\cdot s^{-1}$

Table 1 – Parameters used in to calculate Re_{spin} of the visualized flow

2.2 Visualization technique

To visualize the flow, trypan blue stain was added to the deionized water to create contrast with the colorless Fluorinert liquid. Trypan blue is a hydrophilic stain used for biological cell staining and is immiscible in completely immiscible in Fluorinert. The interface was visualized without modification due to the different refractive indices of water and Fluorinert.

The lighting for the image was fluorescent ambient lighting combined with diffuse flash lighting. Briefly, the flash lighting source was the camera flash and was diffused by double reflectance using distressed aluminum foil. The flash light source was first reflected away and then back towards subject, minimizing flash reflections from the glass vial.

2.3 Photographic technique

The field of view of the image is approximately 0.75” X 0.5” at a distance of 12“ from the lens. The lens focal length was 55 mm and the exposure settings were f4.0 and 1/60th of a second. The camera used was a digital SLR (Canon Rebel XT) with a 3456 X 2304 pixel CCD set at ISO 400. Except for image cropping, no image manipulation was performed.

3 Discussion

The image provided flow visualization of a vortex at a liquid-liquid interface of two immiscible liquids. Interestingly, the fluid flow of the Fluorinert is not transmitted to the water at the interface. Rather, the water is almost completely unaffected by the Fluorinert vortex, influenced mainly by the precessing motion caused by the instability of the vortex. This is likely due to the inability of the Fluorinert to form strong intermolecular bonds with water. Fluorinert is a fully fluorinated alkane, thus lacking hydrogens and carbonyls to form hydrogen bonds with water. Furthermore, Fluorinert is extremely non-polar, eliminating any permanent dipole intermolecular bonding. Even at maximum stir bar angular velocity, the vortex had a low Re_{spin}, disallowing the generation of additional interesting vortex phenomena, such as Gortler vortices and instabilities with polyhedral profiles [2].

Beyond the physics of the image, several aesthetic aspects are appealing. The simplistic contrast of sky blue and sandy yellow is vaguely reminiscent of an ocean beach. In addition, the dark upper liquid and clear liquid is somewhat uncommon, due to the prevalent use of aqueous dyes denser than water overlayed with uncolored oil layers. The composition of the image could use improvement, such as the camera being off-level and image editing to remove foreground/background dirt on the glass vial. Overall, this image is much more technical than artistic.

4 References

1. Czarny, O.; Iacovides, H.; Launder, B. E., Precessing vortex structures in turbulent flow within rotor-stator disc cavities. *Flow Turbulence and Combustion* **2002,** 69, (1), 51-61.

2. Jansson, T. R. N.; Haspang, M. P.; Jensen, K. H.; Hersen, P.; Bohr, T., Polygons on a rotating fluid surface. *Physical Review Letters* **2006,** 96, (17).