Get Wet Report: Stable Spins

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Figure 1: The final image 'Stable Spins'

1 Introduction

The image 'Stable Spins' was created as a result of the prompt 'Get Wet' ; the initial assignment of FlowVis. In this image, I wanted to capture the interesting structure of fluids under rotation. The phenomenon captured here is known as convective rings in the literature and is a snapshot of the structures that can evolve in rotating fluid systems. [1, 3]

2 Flow Physics

The basic layout of the setup used is illustrated by Figure 2. The final photo was taken from the front view depicted. The setup consists of a record player with a cylindrical glass tank filled with tap water centered on the spin plate. The tank had 15 cm of water and a radius of 4.25 cm. The conditions of this flow were created by setting the record player to spin at 78 revolutions per minute starting from rest. This is the fastest rotation available on most consumer record players and is equivalent to 8.2 rad/sec or 1.3 hz.

The flows going on in this image are very interesting and largely governed by the Taylor-Proud theorem. The dyed ring structures show the area where we have some convection downward. These areas are where the flow is allowed to change along the axis of rotation. These layers are very thin

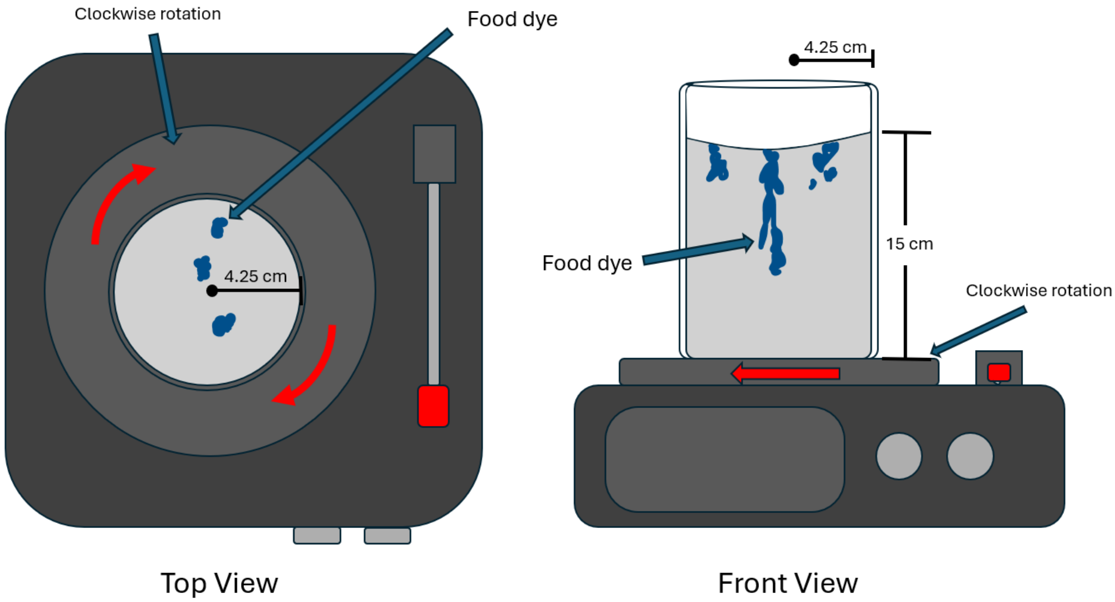

Figure 2: This diagram depicts the placement and basic dimensions of the record player and cylindrical tank of water. Both the top and front views show the initial placement of the food dye before the formation of the convective rings.

because the bulk of the fluid wants to travel at the same speed as the fluid above and below it.[1, 2] How thin these layers tend to be can be characterized by the non-dimensional Ekmanns number.

$$E = \frac{\nu}{\Omega L^2} = \frac{(1 * 10^{-6} m^2/s)}{(8.2 rad/s)(0.15m)^2} = 5.4 * 10^{-6}$$

Where ν is the kinematic viscosity, Ω is the angular velocity, and L is the height of the fluid in the tank. Since the the Ekmanns number is much less than 1 in this system we would expect very thin Ekmann layers which we do observe. We can also calculate the spin up time scale of this system into solid body rotation. For this we calculate $t_{spin} = L/\sqrt{\nu\Omega} \approx 52s$ So when the dye was introduced it was quickly contained to a few 2D planes perpendicular to the rotation. The dye is then able to slowly diffuse downward with time, but it still does not diffuse outside of its circular ring structures.

We can also calculate the Reynolds number which tells us about the balance of the inertial and viscous forces which can give us insight into if we expect the flow to be laminar or turbulent. For this expression we use many of the same values but now we have a radius R term.

$$Re = \frac{\Delta\Omega R L}{\nu} = \frac{(8.2 rad/s)(0.0425m)(0.15m)}{(1 * 10^-6)} = 5.2 * 10^4$$

This is a large Reynolds number where we would expect the flow to transition into some kind of turbulence. This would explain the evolution of convection rings into vortex grid patterns, which has been studied. [1, 3]

3 Visualization

The visualization technique I used consisted of seeding the tank with McCormick blue food dye, which is mainly composed of water and propylene glycol, into the water a few seconds after the turntable was accelerated from rest. Once in the tank, the food dye was traced around in the convective rings showing how the flows move in these thin 2D sheets that are aligned along the axis of rotation. The lighting and framing of this image was achieved by lighting a white poster-board behind the tank with a led lamp from the left side. For this setup I used the warmer colored lighting setting from the led lamp. This gave the background a more yellow color.

4 Photo Details

The original image was taken with a Nikon D3100 held by hand from about 30 cm away with a Nikon DX SWM VR aspherical lens. This image was captured with a 55 mm focal length, f/5.6 with an exposure of 3/10 s and iso 100. The original image is 4644 x 3084 pixels. I cropped the final image to be 3197 x 1780 pixels, focusing on the lower part of the tank where the flows were more transparent. I also increased the contrast of the image making the different semi-transparent layer edges more distinct.

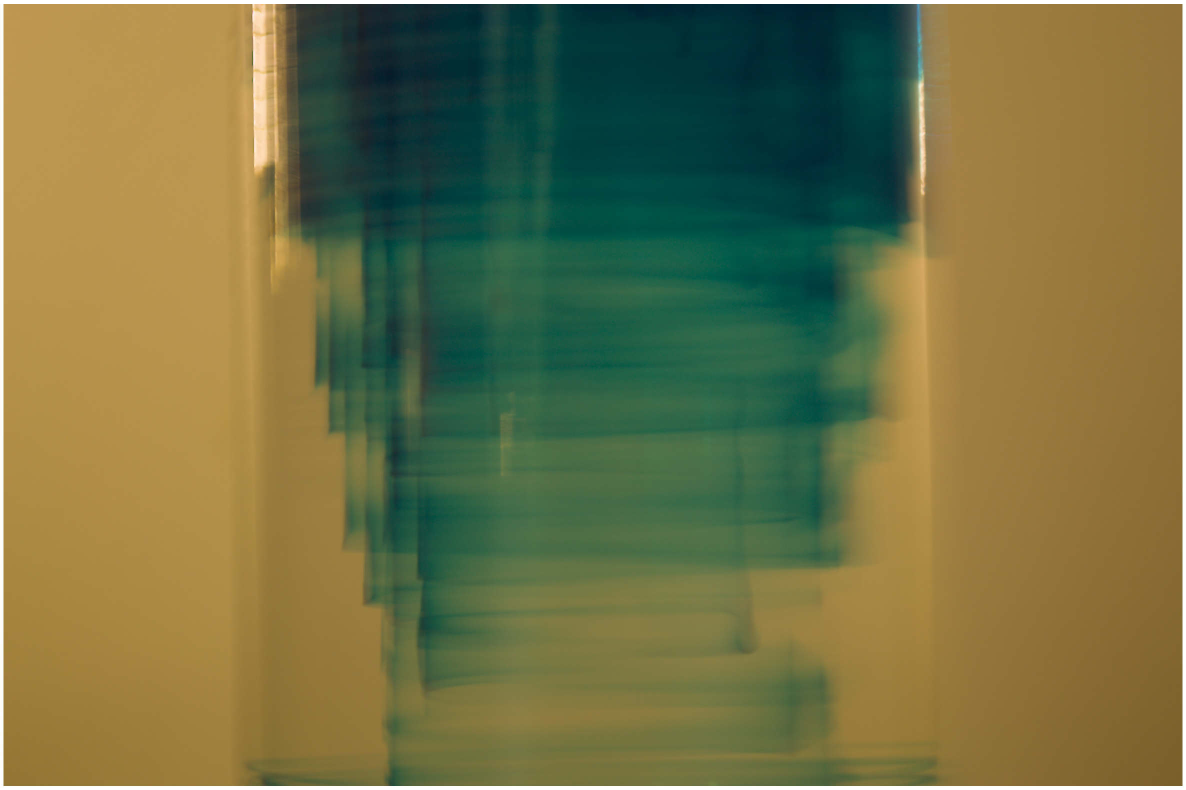

Figure 3: An unedited version of 'Stable Spins'

5 Reflection

What I like about this image is the depth you can see with the overlapping layers. This was one of the main reasons it became my chosen image to work with. For being a single image it gives the viewer a detailed look into the flows at work. Getting more examples of this phenomena as seen from the top would be a great addition to help highlight the structure of this phenomenon. One aspect of this image that I may want to address in the future is the glare that can be seen on part the glass toward the center. This could be addressed through some careful editing or by trying to replicate this image in the future with a more controlled lighting setup.

References

[1] B. M. Boubnov and G. S. Golitsyn. Experimental study of convective structures in rotating fluids. 167:503–531.

[2] L. N. Howard. Fundamentals of the Theory of Rotating Fluids. 30(4):481–485.

[3] J.-Q. Zhong, M. D. Patterson, and J. S. Wettlaufer. Streaks to Rings to Vortex Grids: Generic Patterns in Transient Convective Spin Up of an Evaporating Fluid. 105(4):044504.