Tennis Ball Galaxy

Team Image 3, MCEN 4151, Flow Visualization

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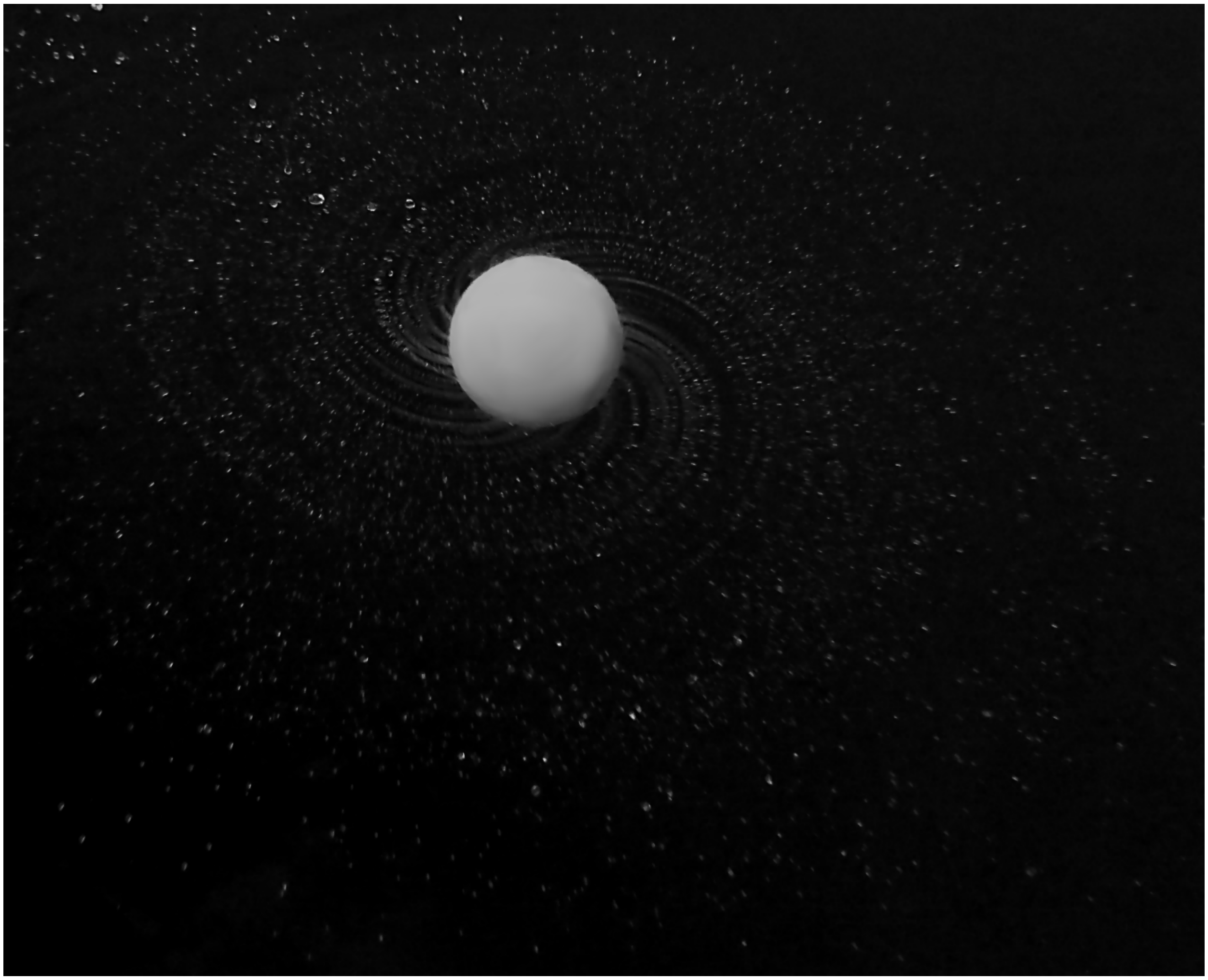

Introduction

This image is for the third and final team assignment in Flow Visualization. I worked with Kristopher Tierney to image the spray from a wet, rotating tennis ball. We were motivated to create this image after seeing a similar one on the internet.[1] There was a beautiful symmetry in the spiral patterns in the spray, but it lasted for only a fraction of a second. The spiral pattern reminds me of a galaxy, so the image was edited to appear more like a galaxy. In addition to being beautiful, the fluid flow off a rotating surface and the subsequent breakup into droplets has practical applications in rotary atomization. Rotary atomization is a processed used in the chemical manufacturing industry today to produce small droplets of a liquid.[2]

Experiment and Flow Description

To capture an image of the spiral spray, a black backdrop was placed on the ground outside. Then, a tennis ball was submerged in a bucket of tap water for a few seconds. The exact time submerged was not important as long as the tennis ball was completely wet. The tennis ball was then held over the black backdrop and released. When it was released, it was given a fast rotation about its vertical axis. As it fell and rotated, the water on the surface of the tennis ball was flung off in a beautiful spiral pattern. See Figure 1 and Figure 2 below for an image and a sketch of the experiment. All light in this experiment came from natural sunlight. Since it was cloudy, it was well lit, but there were no shadows.

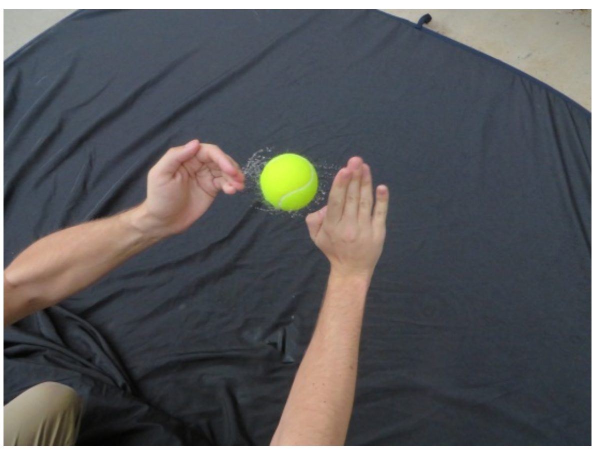

Figure 1: Experimental Set Up

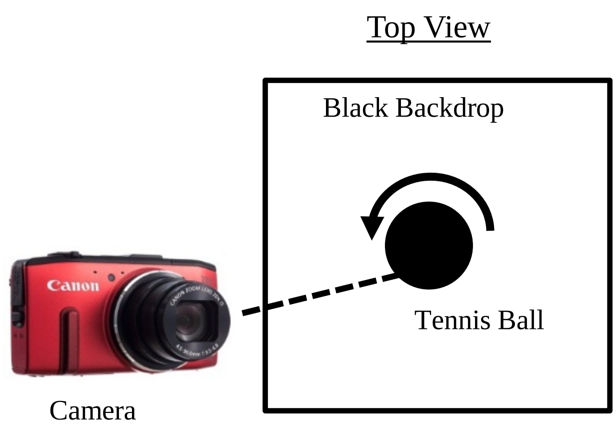

Figure 2: Experimental Sketch

The camera was located about 1 meter above the tennis ball above and at a slight angle from the vertical axis of rotation. This position yielded the clearest images of the spiral spray. The experimental set up picture shown in Figure 1 was taken from this position.

The spiral droplet pattern is formed from a complex interaction between surface tension, density, rotational speed, and several other parameters. Initially, the surface of the tennis ball is completely covered with water. As the tennis ball rotates, the water is drawn to the widest portion, or the "equator" of the ball. The "equator" has the largest diameter, and since the entire tennis ball must rotate at the same angular velocity, a point on the equator has a higher linear velocity a point anywhere else on the tennis ball. The rotational motion of the tennis ball is so large, that it overcomes the surface tension between the water and the water breaks away from the surface along the "equator".

The physics governing how the water breaks away from the surface has been studied over the years. In general, there are three modes for how the water breaks away: direct drop formation, ligament formation, and sheet formation.[3] In direct drop formation, free droplets are generated at surface. In ligament formation, a narrow "fingers" of fluid extend from the surface, and the droplets are formed at the end of these "fingers". Sheet formation is characterized by a sheet of fluid extending out from the surface. Fingered ligaments appear at the edge of the sheet, and the water droplets are created at the ends of the fingers.[4] A. R. Frost describes several equations for these modes.[5] However, not enough information was gathered in this experiment to evaluate the droplet formation numerically from the tennis ball. Filming the wet tennis ball in high speed as it rotates would yield valuable information about the rotational speed and droplet formation frequency that could be used in Frost's equations. From the images of each mode provided in Frost's work, the primary mode present in the tennis ball image is the ligament formation mode.

From the spiral drop pattern in the image, it appears as if the drops are moving opposite from the tennis ball's rotation, but this is an illusion. A velocity diagram for a point on the surface is shown below in Figure 3.[6]

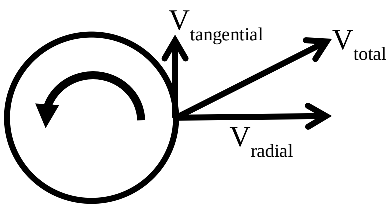

Figure 3: Velocity diagram on the surface

Once the droplet breaks free from the surface the only forces acting on it are gravity and air resistance. Figure 3 is a top down view, and gravity acts into the page. Therefore, gravity does not significantly influence the spiral pattern. By definition, air resistance acts opposite the droplet's total velocity. Since this force is always 180 degrees from the droplet's motion, it will not cause the droplet to curve, but it will decrease its velocity as it moves farther from the tennis ball. From this analysis, it is concluded that all of the drops move forward in the direction of rotation from their point of origin on the surface. This is confirmed in the image, and under close inspection, all drops lie along a line that leads back to the surface of the tennis ball. This is illustrated in Figure 4 below in a portion of the original image. The drop that lies on the line leads back to the surface of the tennis ball.

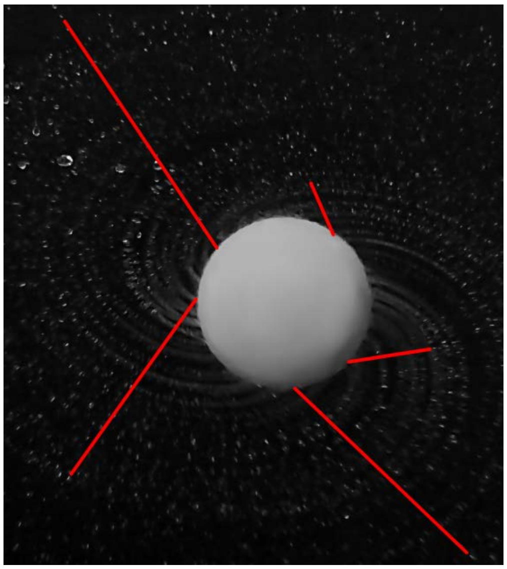

Figure 4: Drops lead back to the surface

The spiral pattern in the droplets is another interesting phenomenon that results from the forces presents in the image. The pattern is beautiful, and it was the primary motivation for this image. The spiral is approximately described as a golden spiral, where the growth per turn is based on the golden ration (approximately 1.61). Spirals similar to this are frequently found in nature from plants to galaxies.

Visualization Technique

The spiral sheet is visualized by water droplets in the air. This is an index of refraction technique, because the natural sunlight refracts off the water droplets and into the camera lens.[7] The change in direction of the light is due to a difference in the index of refraction between air and water. While few of the individual water drops are clear and in focus, the droplet's position can be seen by their refraction of the light. All of the light in this image came from natural sunlight on a cloud day. The clouds diffused the light, and there were no shadows. No flash was used.

Photographic Technique

A Canon PowerShot SX280 HS Digital Camera with 12.1 megapixels was used to take this image. The camera lens has a 4.5 - 90.0 mm focal length with a 20 times optical zoom, and it supports image stabilization. The lens can produce an aperture between 1:3.5 and 1:6.8 and an ISO from 80 to 6400.

Originally, the image was 4000 pixels by 3,000 pixels with a bit depth of 24. The field of view was about 50 cm, and the lens was about 1 m from the tennis ball. The focal length was 8 mm. Since the tennis ball was rotating so quickly, a fast shutter speed of 1/1600 seconds was used. The fast shutter speed limited the amount of light entering the lens, so a wider aperture was used. The F Number was 6.3, and the ISO was 1600. The relatively high ISO also compensated for the fast shutter speed.

This image was manipulated extensively with GIMP 2.8 to enhance the light in each water droplet and to make the spiral pattern appear more like a galaxy in space. First, the image was cropped slightly to 3703 pixels by 3000 pixels and converted to black and white with the luminosity setting in the desaturate tool. The stamp tool and the smudge tool were then used to convert the tennis ball into a uniform light color and remove the printing on it. This gave the image the appearance of a bright star in the center of a galaxy. The unsharp mask filter was used to sharpen the image and bring out the reflections in the droplets. The original image also had some noise in the background due to the high ISO. By adjusting the contrast with the curves tool, the blacks were made darker and more uniform, and the highlights were accentuated. Noise was still visible in the background after this, so the selective gaussian blur tool was used to smooth the background. The original image is shown below in Figure 5.

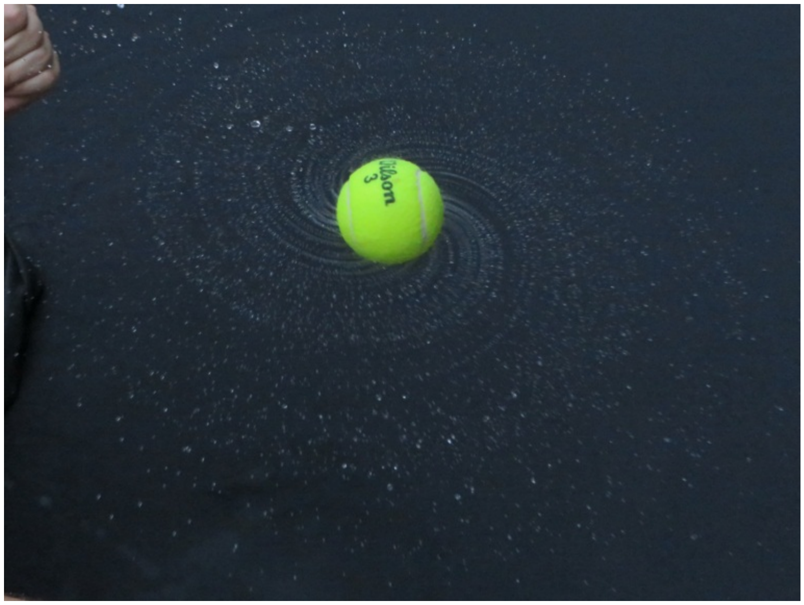

Figure 5: Original Image

Image Results

I had a great time making this image, and I was surprised at how easy it was to create the beautiful spirals. All you need is a wet tennis ball, but capturing an image of it is more challenging. I would not have imagined that something this complex would exist in such a short time frame before disappearing when the tennis ball hit the ground. I like how the refracted light clearly shows the location of the water droplets despite the fact that they are not well resolved. This image would benefit from additional light sources. The natural sunlight was good, but it was not bright enough to expose the image properly. To compensate for this, I used a higher ISO, but that created noise in the background. Additional light source would brighten the image and allow for a lower ISO with less noise. This would also reveal even more water drops, because the additional light would refract on more droplets.

References

[1] Gupta, Nishant. "Tennis Ball Galaxy." *500px.com*. 5 Nov. 2013. Web. 26 Apr. 2014.

[2] Glahn, A., S. Busam, M. F. Blair, K. L. Allard, and S. Wittig. "Droplet Generation by Disintegration of Oil Films at the Rim of a Rotating Disk." *Journal of Engineering for Gas Turbines and Power* 124.1 (2002): 117. Print.

[3] Frost, A. R. "Rotary Atomization in the Ligament Formation Mode." *Journal of Agricultural Engineering Research* 26.1 (1981): 63-78. Print.

[4] Frost, A. R. "Rotary Atomization in the Ligament Formation Mode." *Journal of Agricultural Engineering Research* 26.1 (1981): 63-78. Print.

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[5] Frost, A. R. "Rotary Atomization in the Ligament Formation Mode." *Journal of Agricultural Engineering Research* 26.1 (1981): 63-78. Print.

[6] Glahn, A., S. Busam, M. F. Blair, K. L. Allard, and S. Wittig. "Droplet Generation by Disintegration of Oil Films at the Rim of a Rotating Disk." *Journal of Engineering for Gas Turbines and Power* 124.1 (2002): 117. Print.

[7] Luzy, R. "Difference Between Reflection and Refraction." *DifferenceBetween.net*. 18 Dec. 2009. Web. 26 Apr. 2014.