# Water Wheel

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Figure 1: Water flung from a bicycle tire

## Context and Purpose

For the Team First assignment, we created a visualization involving water spinning off of a bicycle tire to involve the popular outdoors activity of cycling. I chose the bicycle with pink tires to add some color that would contrast with the brown background. We knew that water being spun off of a rotating object would create a beautiful visualization of streaklines. Furthermore, we could display the concepts of adhesive forces, centripetal acceleration, and aerodynamic drag. The experiment involved wetting a bicycle tire on a stand and spinning it to move the water droplets.

Special thanks to my teammates, Bryce Pfuetze and Gavin Lopez, for their part in creating and executing our experiment.

## Flow Apparatus and Physics

The flow apparatus was a bicycle mounted on a stand to allow the tires to spin freely. A hose was mounted over the right side of the tire pointing downwards. The water originates from this point and adheres to the tire until flow separation occurs.

In fluid mechanics, A streakline is defined as the set of points all fluid particles pass through that originate from the same spatial origin. A pathline is the path traced out by a single particle as it moves through a flow in time. A streamline is the curve made by the tangent vectors of a velocity field [1]. This image captures streaklines because the flow involves multiple droplets originating from the same point.

The water experiences adhesive and cohesive forces that govern how well it sticks to the tire. Water molecules have a strong attraction to each other because they are polar. The interactions between the hydrogen and oxygen atoms creates a cohesive force. The molecules at the surface are pulled inward and act to minimize the droplets' surface area. Adhesive forces are the electrostatic forces that cause molecules to stick to different surfaces [2]. However, rubber is a known hydrophobic substance and does not bond well with water. Therefore, water molecules are dominated by cohesive forces and are easily separated from the rubber tire. However, the flow adheres enough for the tire to transfer it kinetic energy and drive it upwards.

Centripetal acceleration is the driving force behind the flow visualization. This is calculated as $a_c = \frac{V_t^2}{r}$ where V is the tangential velocity and r is the radius. The radius of the tire is 0.351 meters and it's angular velocity $\omega$ is 960 degrees per second, or 16.8 radians per second. Tangential velocity is derived from angular velocity and radius as $V_t = \omega * r$. Therefore the centripetal acceleration the flow experiences is $a_c = r * \omega^2 = 98.5$ meters per second squared.

The water is ultimately separated into droplets because of surface tension and drag. After being spun of the tire, the pressure the air exerts on the flow balances with the cohesive force of water to create droplets of a certain size. The cohesive force of water fails at a diameter of 4 to 6 millimeters according to a NASA study [3] on the shape of raindrops. Similar values are expected for this experiment since the droplets are not exceeding the terminal velocity of rain. This is why sections of the flow break up into lines of droplets in the experiment.

The Weber number is the ratio of inertial forces to surface tension in a fluid. It is calculated as $We = \frac{\rho * l * V^2}{\sigma}$ where $\rho$ is density, $l$ is characteristic length, V is velocity, and $\sigma$ is the surface tension. The density of water is 1,000 kilograms per meter cubed, the characteristic length is 4 millimeters, the velocity is $V_t = \omega * r = 5.9$ meters per second, and the surface tension of water is 72 millinewtons per meter at 20 degrees Celcius [4]. Thus, the Weber number for this flow is 1808.



Figure 2: Picture of the flow apparatus

## Visualization Technique

Our experiment involved visualizing streaklines by freezing a flow of water over a spinning tire. We set a bicycle on a stand and fixed a hose over the 3 o'clock position. We spun the tire counter-clockwise to move the flow over the top of the tire. The camera faced west in mid afternoon. I manually focused the camera with an external flash kit. The lighting from the sun is classified at white light and the flash kit emits an electronic xenon flash that mimics white light.

## Photographic Technique

My camera is a Canon Rebel T3i DSLR camera. I took pictures from about two feet away from the experiment. The field of view was about 28.7 degrees diagonally for my camera. The settings of my camera were 55mm focal length, f/5.6 aperture, 1/200 shutter speed, ISO 200, and a Godox VING V860 II external flash kit. The original image has a size of 5202 x 3464 pixels and the final image was cropped to 4011 x 2083.

The radius of the tire was 0.351 meters. We took slow motion videos of the tires spinning to calculate their angular velocity. The period of rotation was 0.375 seconds. The angular velocity is therefore 960 degrees per second. With a shutter speed of 0.005 seconds, the tire would have rotated through an angle of 4.8 seconds. However, the flash kit served to effectively reduce the shutter speed. The flash time is about $\frac{1}{5{,}600}$ seconds at $\frac{1}{8}$ power. Therefore, the tire actually rotated through 0.17 degrees and was effectively frozen.

The original image is below. I cropped the image in postprocessing. The final image can be seen at the start of the report.



Figure 3: Original image before adjustments

## Discussion

The image reveals water droplets being flung off the tire in a repeating pattern. The droplets separate from the tire in methodical lines due to the physics of the flow described above. I find the visualization in the image appealing, but I do not like the background. The brown color and dark lighting contrast well with the foreground but are unpleasant. The droplets are in focus, but they reflect light from the flash in such a way that they look blurred and leave streaks in the image. Overall, I am satisfied with how this image captures the flow phenomenon. If I were to repeat

this experiment I would use a different background and try to mitigate the reflected streaks with different shooting angles and flash kit settings. I would also like to try this with different circular surfaces to see how this changes the separation pattern.

## References


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