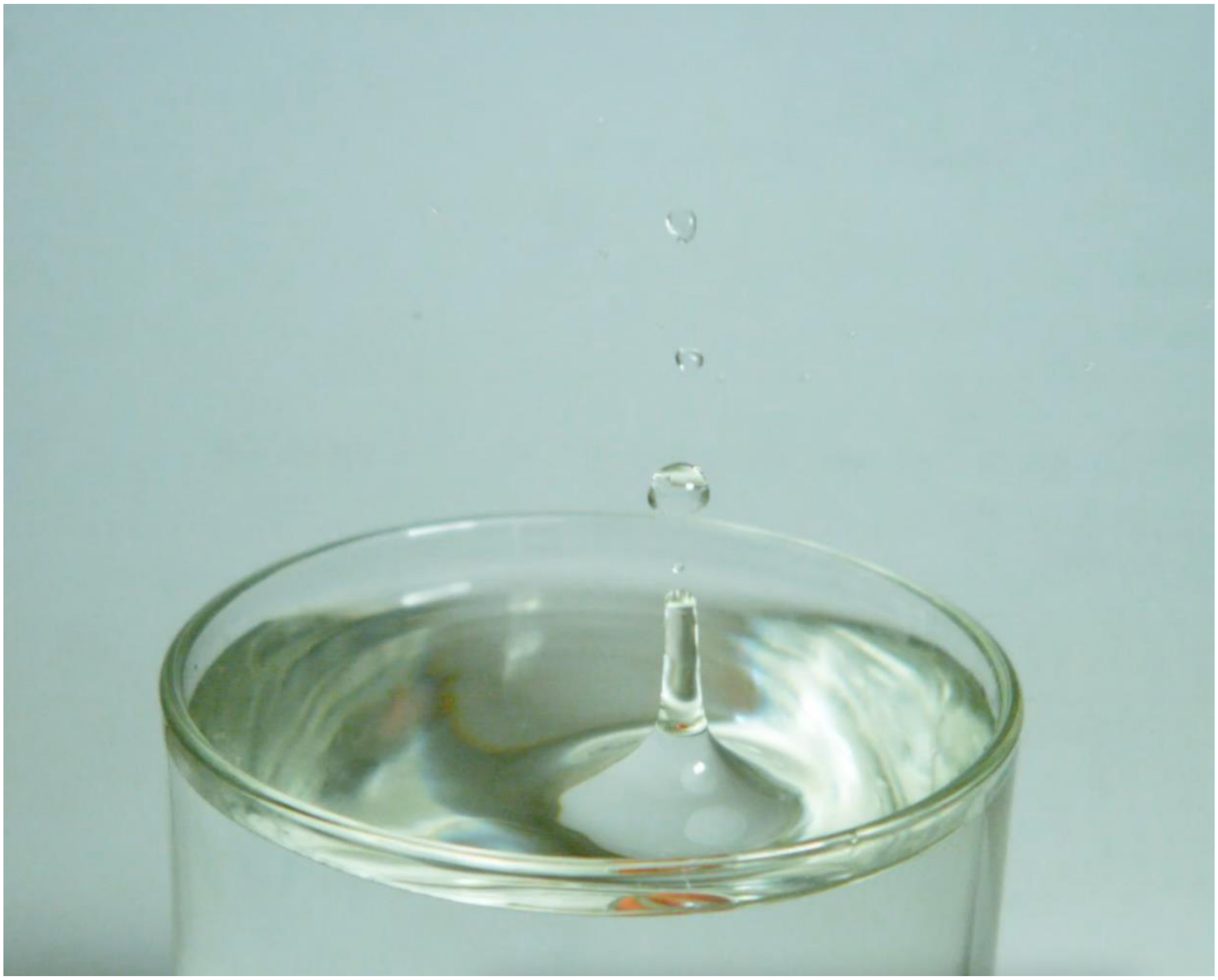
IV3 Report:

Using a High-Speed Camera to Document Water Jets



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Introduction:

For this project, I worked with Alex Kelling, Ben Carnicelli, and Nathan Gallagher to explore the Worthington Jet phenomenon, using a high-speed camera. Components required for the experiment include: a vessel filled with water, a dense object to drop into the vessel, a strong light source, and a high-speed camera. High-speed cameras can be incredibly finnicky, so be prepared for several false starts as you calibrate resolution, framerate, focus, and lighting. It took us several tries to eventually set up a shooting system, but we found the following order of operations worked best:

1. Choose shooting location based on where your field of view is
2. Place camera and calibrate focus based on your field of view
3. Place object in field of view
4. Introduce lighting source
5. Take practice videos to calibrate entire system
    a. It's going to take several tries, but following this procedure will drastically reduce setup time

In order to document the Worthington Jet phenomenon, you will need a deep enough vessel so that whatever you drop into the fluid produces a noticeable jet. We found a circular Tupperware, about 2" in diameter and 4" in depth, was voluminous enough to give us the desired results.

Flow Description:

For this experiment, we pursued the following process to document the Worthington Jet phenomenon.

1. Fill the vessel with water, leaving enough room so it won't spill
2. Have one individual standby with the high-speed camera, while another waits to drop the object into the vessel
3. Fire the camera trigger while dropping the object into the vessel, ideally into the center of the fluid pool

These steps are further displayed in *Appendix A*. As mentioned, the vessel was approximately 2" in diameter, and 4" in depth. This volume was conveniently small, and suitably large to visualize the jet after dropping the object in it. The documentation method is further elaborated upon in *Experimental Procedure* and *Camera Settings*.

The phenomena being visualized here is a jet flow. The characteristics of the flow are easily measured from still images, based on the flows' relative lengths to the vessel.

A great way to understand the flow behavior is to calculate the Reynold's number. This dimensionless number indicates whether the flow is laminar or turbulent. Based on Tinh (2010), the Reynold's number can be calculated using the velocity of the fluid (V), the characteristic length of the flow (L), and the kinematic viscosity of the fluid (v). If the kinematic viscosity is unavailable, this variable can be replaced with the fluid density (ρ) over the dynamic viscosity (μ)[1]. These are derived below in Eq. 1.

$$Re = \frac{VL}{v} = \frac{\rho VL}{\mu} \tag{1}$$

For our experiment, we can make several assumptions about the density of medium, velocity, characteristic length, and dynamic viscosity. The velocity of each vertex was about 0.5 m/s, the density of the water in the vessel was approximately 997.5 kg/m^3 [2], the characteristic length of the ring was about 0.05 m, and the dynamic viscosity is 2.034e-5[3].

$$Re = \frac{\rho VL}{\mu} = \frac{(997.5)(0.05)(0.05)}{(0.00002034)} = 122{,}603$$

The resultant Reynold's number is 122,603 implying a highly turbulent flow.

Experimental Procedure:

After assembling the camera and field of view correctly, we had to decide how to proceed experimentally. For my particular submission, this involved a coordination between triggering the camera, and dropping the object into the water at the correct time, in the correct location. We had two specific aesthetic expectations we were looking to meet: it was important to drop the object into the middle of the glass, and to trigger the camera at the correct time. We wanted to document object entering the water, the jet formation, and the ultimate return to equilibrium.

Lighting control was tricky, because of the saturation required by the camera's sensor to create a legible video. We shot a field of view with white walls, ceilings, and backdrops, in order to reflect as much light as possible into the shot. Additionally, the location was directly beneath a large window, which introduced a sizeable amount of clear afternoon light into the room. Lastly, we placed a study lamp 45 degrees above the vessel, in order to front-top light the shot. With this combination of light sources and reflective conditions, we had just enough illumination in the field of view to receive legible videos in the camera's sensor.

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[1] Trinh, T. (2010). On The Critical Reynolds Number for Transition From Laminar To Turbulent Flow

[2] Engineers Edge, L. L. C. (n.d.). Water density, viscosity, and specific weight table, equations and calculator. Engineers Edge - Engineering, Design and Manufacturing Solutions. https://www.engineersedge.com/physics/water__density_viscosity_specific_weight_13146.htm#:~:text=The%20dynamic%20viscosity%20of%20water,centipoise%20at%2020%20%C2%B0C.

Camera Settings:

For this experiment, we used the Phantom Miro C110 camera, loaned out from the Integrated Teaching and Learning Laboratory (ITLL). The Miro C110 specs were sourced online, and can be found in *Table 1* below[3].

Spec	Description
Camera Type	Phantom Miro C110
Field of View	6” x 4”
Distance from Object to Lens	5’
Focal Length	18mm
Frames per Second	1,200
Video Resolution	1024 x 768

Table 1: Camera settings and lens specs

The Miro C110 is capable of shooting up to 12,000 frames per second. However, frames per second and video resolution are inversely proportional, meaning the higher the resolution the lower the available frames per second and vice versa. We found that a resolution of 1024 x 768 combined with a frame rate of 1,200 frames per second afforded us the image clarity and frame control balance that we wanted.

I edited this video in Adobe Premiere Pro, as it is available for a reduced fee through CU’s division of IT. The only material revision made in Premiere Pro was a title slide added at the beginning of the video. The original video remained otherwise untouched.

Conclusions:

I feel this was a successful project, especially considering no one in the group had ever used a high-speed camera before. The amount of setup and calibration required left us feeling a little unnerved, but ultimately the videos came out well, and accurately displayed the flow phenomenon we were looking for.

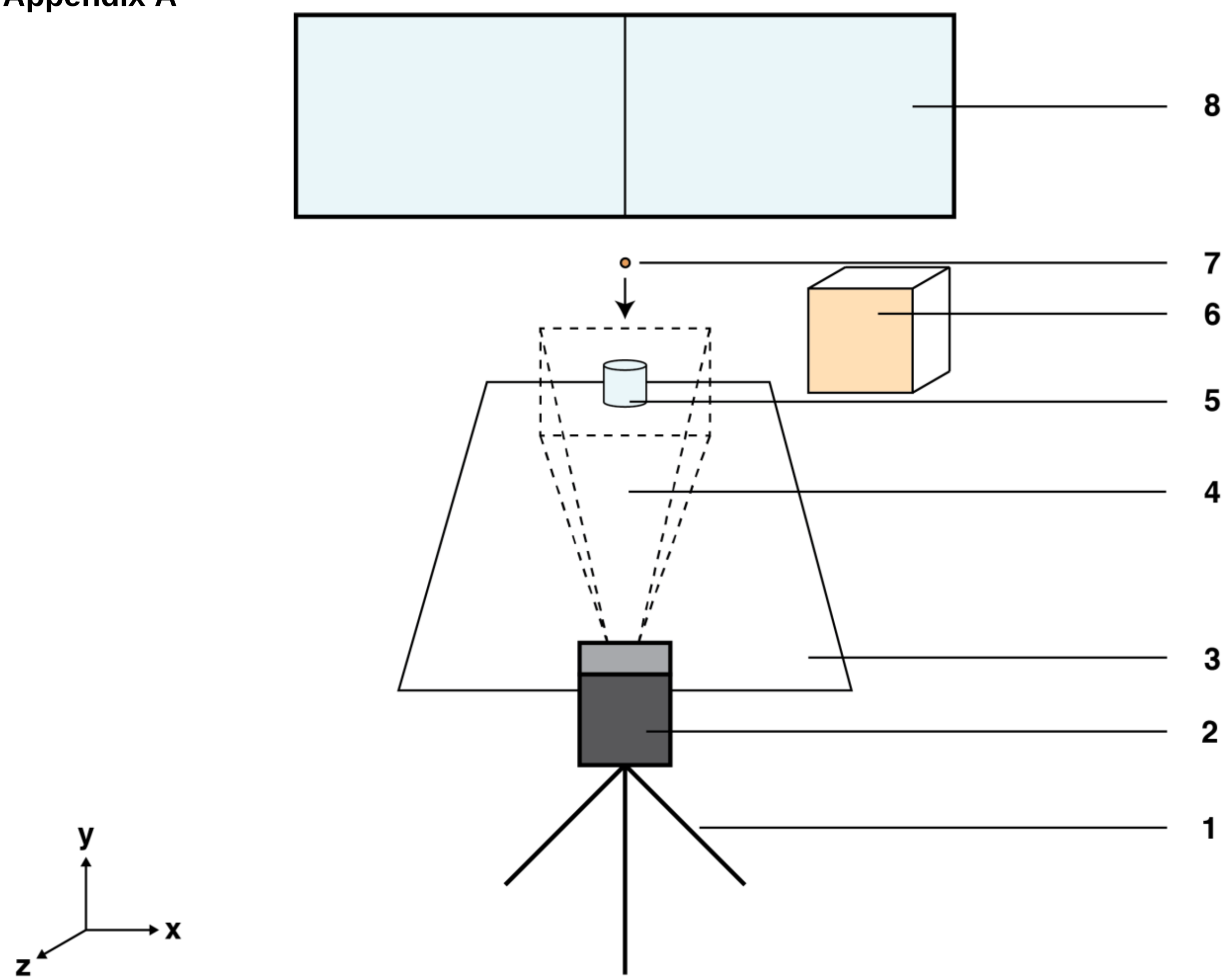
The video itself holds some interesting information as well. Normally Worthington jets are single, connected, conical jets, that rebound out of the body of fluid they originate from. In the video I took, however, the jet is broken into 4 separate sections. I believe this occurred because of the small volume of the vessel, and the size of the object being dropped into it (in this case, a marble).

Overall, I feel the flow effect is documented quite clearly. The formation, and dissolution, of the jet is clearly visible because of the high frame rate produced by the camera. There are areas that could be improved if conducted again, and unclear aspects of the experiment. Firstly, we could have experimented with outdoor, natural light in addition to the indoor, artificially lit setup we used. The clarity and intensity of the natural light may have produced a field of view more advantageous than the one we had. We also could have experimented a little more with the frame rate/resolution relationship I mentioned

[3] Phantom Miro C110 high-speed camera. Darwin Microfluidics. (n.d.). Retrieved November 8, 2022, from https://darwin-microfluidics.com/products/phantom-miro-c110-high-speed-camera?variant=37445731680420

earlier. While we were firmly satisfied with the combination chosen for this project, we never pushed further for a higher frame rate, as we would have had to continually change the entire experimental apparatus to meet the needs of the new, constrained field of view. Overall, I am happy with this experiment, and feel we achieved the flow visualization goals we defined in our problem statement.

Appendix A



Component Ref.	Description
1	Tripod
2	Camera
3	Table
4	Constrained field of view
5	Vessel
6	Light
7	Dense object used to create jet
8	Window