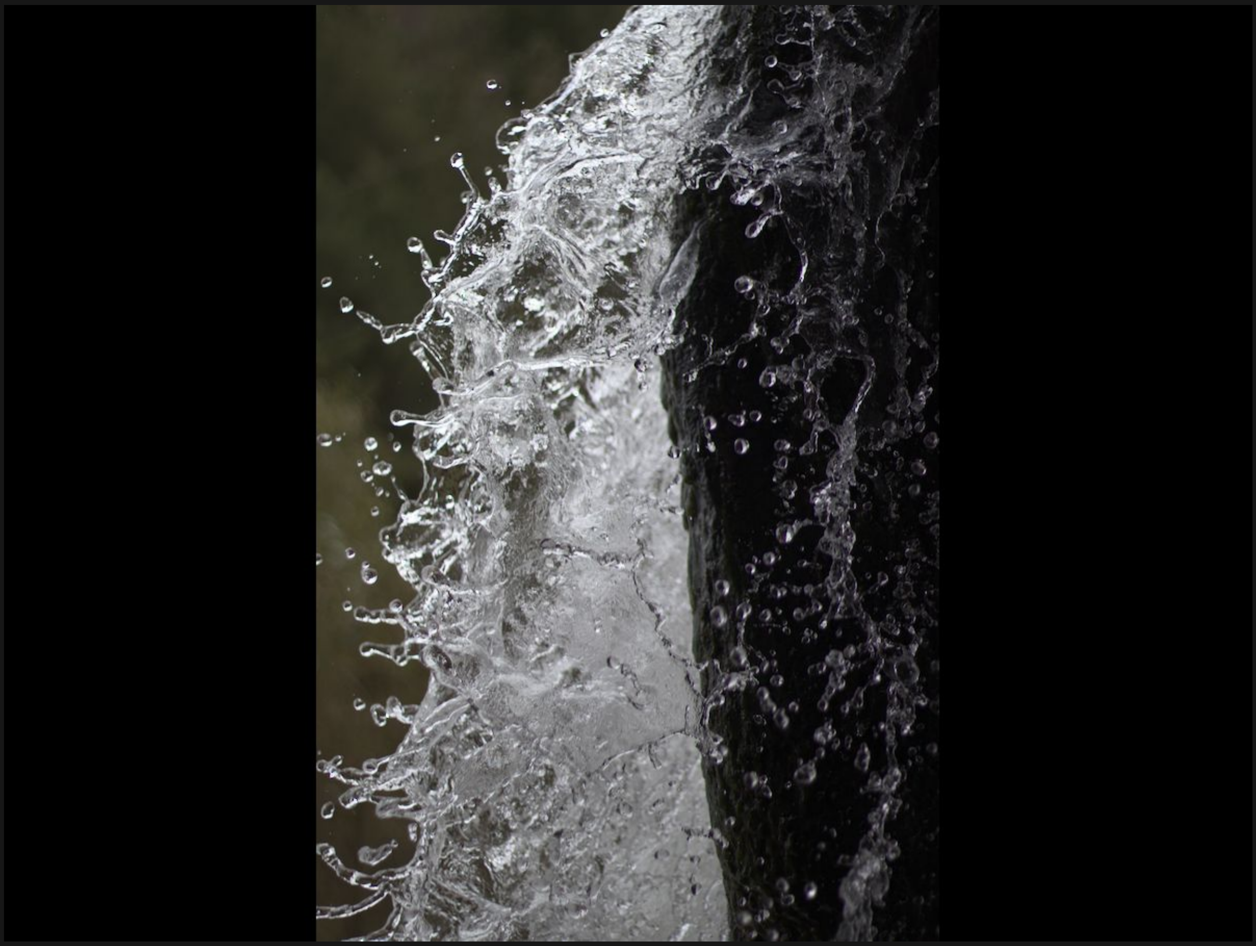
CVEN 5153 Flow Visualization Report
Get Wet Project

Luke Parker, 18 SEPT 2026
https://www.flowvis.org/2026/08/30/luke-parker/



This image was taken of a waterfall as it was flowing in Eldorado Canyon State Park outside of Boulder, Colorado. The intent of the image was to capture the very interesting effects present between various layers of the flow: solid rock, water, and air, and to do so in a way that was visually exciting and also true to the physics of the flow. (Please visit FlowVis.org for the full resolution image).

As previously mentioned, the flow apparatus used in the image was a natural waterfall. Water from a spring and various watersheds collects into a river in the bottom of Eldorado Canyon, and at the point imaged here flows over a very large set of submerged boulders. This results in a large ($\approx$ 1m wide) main plume that fully separates from the rock face, as well as several smaller side plumes such as the one captured in the image that do not fully separate from the rock face but rather remain attached until contact with the pool beneath them. The flow loses about 2.5 meters of height between flowing over the top edge of the boulder and hitting the top surface of the pool below.

The prevailing two forces causing the fluid to behave as it does in the image are gravity and shear force. Gravity exchanges the potential energy of the fluid for kinetic energy as it looses height, causing the fluid to accelerate in a downward motion. Boundary layer and surface tension effects feed into shear force which causes the formation of the sheets, droplets, and spikes that are present.

To quantify the effects of turbulence, we will lean on the Reynolds number. We can obtain fluid flow data from the

Colorado Department of Water Resources website [1], where for 28 August 2026 at 2:30PM, data shows that the air temperature was 85°F and flow rate was 8 cubic feet per second. To find velocity, we can estimate the cross-sectional area of the top of the waterfall as $0.2m \cdot 1m = 0.6m^2$, and with a little unit conversion arrive at a horizontal velocity component of about $V_x = 1.13\frac{m}{s}$. This would do for an estimate at the top of the flow, but the image was taken at about 0.5m down from the top of the waterfall so we must include the additional velocity from gravitational acceleration in our estimate: $V_z = 2g\Delta z = 2 \cdot 9.81\frac{m}{s^2} \cdot 0.5m = 9.81\frac{m}{s}$. Adding these two vector components together, we get a velocity magnitude estimate of $|\vec{V}| = 9.87\frac{m}{s}$. The total height of the imaged flow (≈ 0.5 m) was used as the characteristic length L, and the kinematic viscosity of water at an estimated 85°F (equal to the air temperature) was collected from the Engineering Toolbox [2].

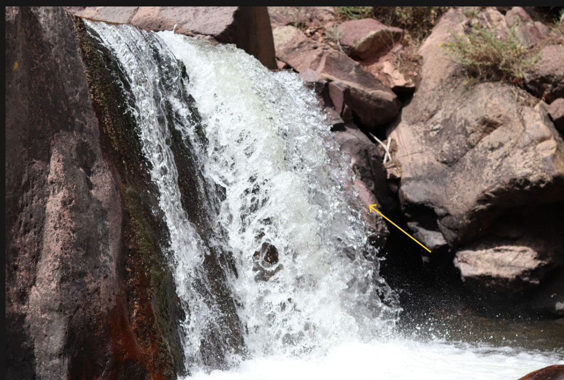
$$Re = \frac{VL}{\nu} = \frac{9.87\frac{m}{s} \cdot 0.5m}{8.099 \cdot 10^{-7}\frac{m^2}{s}} = 6.09 \cdot 10^6 \tag{1}$$

This value is well within the turbulent regime, which is a result that aligns with the highly turbulent behavior observed in the image. Additionally, it corresponds fairly well to the Reynolds numbers observed by Nakagawa and Nezu's 1987 paper [3], where they found values on the order of $2 \cdot 10^4$ with a much smaller and much smoother experimental setup. Unfortunately their work is published in Japanese and the author of this paper is illiterate in that language, and so only the glimmer of enlightenment which can be teased from their mathematics can be gained from the paper. Manson and Pender

A second phenomenon that is clearly visible though much more difficult to quantitatively describe is that the droplets appear to be all of the same size. This is observable only because the time resolution of the image is so small: a shutter speed of $\frac{1}{4000}s$ was used, and so with the estimated flow velocity from above it can be estimated that the bulk mass moved only 2.5mm. Given the highly turbulent nature of the flow, the velocity field is of course wildly varied from this value, and (although to do so ventures disconcertingly close to heuristics) since the flow in the image is experiencing significant drag from its boundary layer with the rock, it would be reasonable to reduce the estimated movement across the exposure by a factor of at least 10 to 0.25mm. Whether this is done or not, it remains that very clear, fairly homogeneously-sized droplets are resolved in the image especially on the right portion. Since homogeneity of any property, much less physical dimension, is not usually associated with such highly turbulent flows, this is surprising phenomenon.

Mansard, Mecca, et. al. [4] provide some excellent insight into why this might be the case in their 2016 paper on multi-jet Rayleigh-Plateau instability. While their experimental setup was in the microfluidics regime, their result seems to hold on the macro scale, at least for the flow being considered in this report. What they found was that due to interdependent physics effects, jets of different sizes in the same flow tended to produce droplets of homogeneous sizes, as well as having similar wavelengths of Rayleigh-Plateau instability prior to breakup. The second portion of their result is somewhat more difficult to observe in the image here, however, it could potentially be identified in the uniform lengths between droplet and jet for those droplets that have separated from their parent jet. However, such a conclusion is likely the result of hopefulness since there is such a great quantity of turbulent mixing occurring that jets as clear as those in Mansard, Mecca, et. al.'s experiment are simply not present.

No physical changes were made to the flow in order to visualize it, in small part due to the logistical difficulty of modifying a flow at the scale of a river and mostly due to the unthinkable environmental impact that almost any technique would have. The image was taken at approximately 2:30 PM MST in late August, on a day without clouds. Because of this (and with the help of a convenient small cave behind the waterfall), the flow was able to be positioned between the sun and the camera such that an incredibly fast shutter speed could be used while maintaining a very low ISO. More numerical camera details will follow, but the key point is that the angle and lighting allowed for the fluid motion to be crisply frozen. See the below images of the area, with an annotation in yellow indicating the point and direction from which the project image was captured.

The photographic parameters used were chosen in alignment with the goal of a capturing a crisply defined segment of waterfall, as large as possible, and with as little motion across the flow as possible. The image was shot on a Canon EOS T7i with a Canon EF 50mm f/1.8 STM lens. The image was taken from as far back as the natural rock formation allowed in order to capture as large an area of flow as possible, unfortunately, this distance was limited to about five feet. The field of view is 17° degrees horizontal by 26° degrees vertical, (the camera was held in portrait orientation to better capture the vertical nature of the flow), and the focal length used was 50mm since the largest-aperture lens available to the author was a fixed-focal-length 50mm lens. The aperture used was the maximum aperture the lens supported at f/1.8, which was chosen in order to let as much light into the sensor in as short a time as possible, with the goal of being able to use the fastest possible shutter speed supported by the camera. This was achieved, with a shutter speed of $\frac{1}{4000}s$ used. Fortunately, the lighting conditions were such that even at this incredibly fast speed, a very low ISO of 100 produced a well-exposed image and so the potential noise found in higher ISO images could be avoided. The raw image was 4020x6024 pixels wxh, and it was edited in Darktable to fine-tune the contrast, crop, and add solid padding to the sides to produce a landscape-oriented file.

The image discussed in this report, along with supporting images, calculations, and writing, are the sole work of Luke Parker. No collaborators, human or otherwise, participated in their production in any way whatsoever.

References

[1] Colorado Division of Water Resources, "Flow Monitoring Station Data," , 2026. URL `https://dwr.state.co.us/Tools/Stations/BOCELSCO?params=DISCHRG,GAGE_HT,AIRTEMP`.

[2] The Engineering ToolBox, "Water - Dynamic and Kinematic Viscosity at Various Temperatures and Pressures." , 2004. URL `https://www.engineeringtoolbox.com/water-dynamic-kinematic-viscosity-d_596.html`.

[3] Nakagawa, H., and Nezu, I., "Experimental investigation on turbulent structure of backward-facing step flow in an open channel," *Journal of Hydraulic Research*, Vol. 25, No. 1, 1987, pp. 67–88. https://doi.org/10.1080/00221688709499289, URL https://doi.org/10.1080/00221688709499289.

[4] Mansard, M. J. M. D. D. L. M. D. T. C. J., Vincent, and Squires, T. M., "Collective Rayleigh-Plateau Instability: A Mimic of Droplet Breakup in High Internal Phase Emulsion," *Langmuir*, Vol. 32, 2016, pp. 2549, 2555. https://doi.org/10.1021/acs.langmuir.5b04727.