CVEN 5153 Flow Visualization Report
Team Second Project

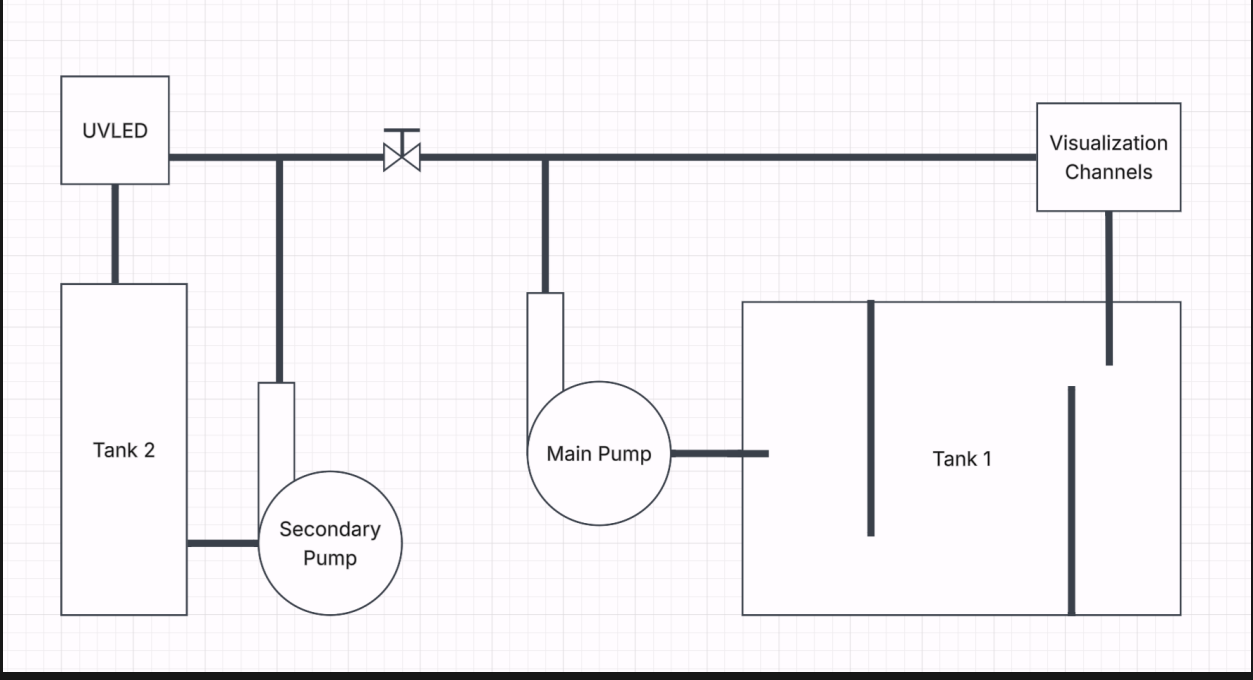
Luke Parker, 1 NOV 2026
https://www.flowvis.org/2026/10/06/luke-parker-2026-team-second/

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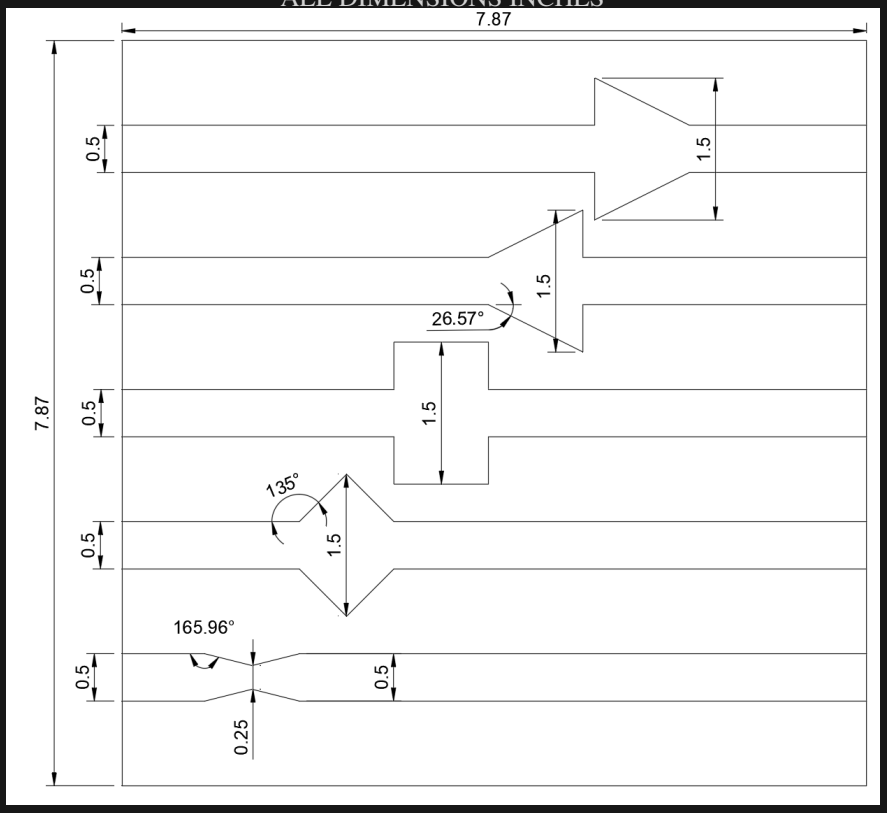
This video was created for the Flow Visualization Team Second project. The artistic intent was to create an inverse of the classic "Coefficients of drag of solid bodies" picture where streamlines are shown around various shapes in a freestream and the corresponding coefficients of drag are indicated, by creating a visualization of streamlines in a flow through channels that have various shapes cut out of them. The scientific intent was to investigate the effect of different rates of change of cross-sectional area on streamlines in the flow.

The flow apparatus used for this project was fairly straightforward. At the heart of the system was a 3D printed set of flow channels, a sketch of which is shown below, into which water and self-luminous particles were pumped through a 3D printed diffuser. The set of channels was placed such that the outlets drained into a bucket filled with water, which was used as a settling pool. The main pump inlet was placed on the opposite end of this settling pool from the channel outlets, and tape was used to create baffles such that the main pump was not intaking particles. A second pump was set up to continuously circulate a much smaller container, such that the high-density solution of particles inside was homogenously mixed at all times. The outlet tube of the second pump was fed through a small enclosure containing high-power UV LEDs which ensured that the particles were glowing as bright as possible. The outlet of this second pump was also joined through a tee and a needle valve to the tube from the main pump feeding the flow channels, such that the quantity of particles injected into the stream was controllable.

A diagram of the plumbing setup and a mechanical sketch of the flow channels follow. All dimensions are in inches. CAD is available upon request.



ALL DIMENSIONS INCHES



The basic flow being observed is turbulent flow through a channel. As shown in the sketch above, the channels are each 0.5 inches across. Four of the channels increase in area to 1.5 inches and one channel decreases to 0.25 inches. The channels are 7.8 inches long, which was the maximum size achievable with the available 3D printers.

To calculate theoretical maximum spatial resolution, the following still image was taken with bright ambient lighting:



From this image and the reference CAD, it can be determined that there are 0.00188" per pixel in the X direction and 0.00185" per pixel in the Y direction. Therefore, the smallest resolvable 3-pixel feature is theoretically 0.0055", which is about 140 times larger than the particle size. Therefore, individual particles are not resolvable in the final

video, appearing instead as a glowing haze.

As far as temporal resolution, the video was filmed at 60 frames per second so the fastest resolvable motion is $7.87\frac{in}{frame} \cdot 60\ fps = 472\frac{in}{s} = 11.99\frac{m}{s}$, or about 12 meters per second. The pump was estimated to be flowing about 2 quarts per minute, which converts to about 1.925 cubic inches per second. Assuming that this divided evenly across the channels (an assumption backed by observation), this means that about 0.385 cubic inches per second was flowing through each channel. At the measured flow depth of 0.125 inches, a velocity of 6.16 inches per second or 0.1564 meters per second. Therefore, the temporal resolution is solidly three orders of magnitude larger than the bulk fluid motion, so we can say that the flow is well temporally resolved.

The last component of resolution, and the component with the most impact on final visualization quality, is measurand resolution. Even at the highest available ISO, the amount of light emitted by the particles was so small that in order to have the flow appear, a small amount of overall grain in the video had to be accepted. Because of this lack of light, the measurand resolution can be said to be very very poor. Nonetheless, there are still interesting insights which can be gained. Given that the whole artistic and scientific idea was around replicating a common coefficient-of-drag diagram, we can make some estimates of what the coefficient of drag is for our channels via the Bejan number, which is a dimensionless pressure drop. Through some fantastic mathematical rearranging, we can then use the Bejan number to find the coefficient of drag in the channel. As always in fluid dynamics, we end up needing the Reynolds number, so we will find that first. Below, ρ is density, V is water bulk velocity, L is the characteristic length which here is the channel length, μ is dynamic viscosity, d is the width of the channel, A_{wet} is the wetted channel area, and A_{front} is the stream frontal area.

$$Re = \frac{\rho V L}{\mu} = \frac{1000\frac{kg}{m^3}0.156\frac{m}{s}0.2\ m}{0.0010518\frac{Ns}{m^2}} = 29663.4 \tag{1}$$

$$Be = \frac{32ReL^3}{d^3} = \frac{32 \cdot 29663.4 \cdot (0.2m)^3}{(0.0127m)^3} = 3.707 \cdot 10^9 \tag{2}$$

$$C_d = 2\frac{A_{wet}}{A_{front}}\frac{Be}{Re^2} = 2\frac{0.2m \cdot 0.0127m}{0.0127m \cdot 0.003175m}\frac{3.707 \cdot 10^9}{29663.4^2} = 530.79 \tag{3}$$

(Properties of water were collected from the Engineering Toolbox [1])
This is a huge coefficient of drag. However, since the flow is very thin, the effect of the no-slip condition and subsequent boundary layer drag on the flow is enormous, so it makes sense. Something interesting to note is that the Reynolds number calculated here is an order of magnitude larger than the turbulent cutoff for open channel flow. The high turbulence is likely a contributor to the homogeneity of particulate distribution within the streams, as the turbulence allows the particles to disperse evenly rather than maintaining clean boundary lines as is seen in more laminar flows. However, the actual drag may in fact be somewhat lower than what is suggested by this coefficient of drag. A paper in the Journal of Hydraulic Research suggests that flows with suspended sediment (such as the particles in this experiment) are similar to flows with entrained microbubbles, and that such flows have reduced drag due to smaller friction losses. [2]

A second phenomenon of interest is the deposition of particles at certain places over others. A paper by Tang et al [3] explores the correlation between sediment deposition and Froude number around boulders in mountain streams. For the flow discussed in this report, the Froude number is as follows, with V being bulk velocity, g being gravitational acceleration, and H being water depth)

$$Fr = \frac{V}{(gH)^{0.5}} = \frac{0.156}{(9.81 \cdot 0.003175)^{0.5}} = 0.88393 \tag{4}$$

This puts our flow in the "small Fr" region, for which the paper indicates that sediment should accumulate favorably upstream of flow disturbances such as boulders. This matches with our experimental result, where particles would build up in a thicker layer ahead of the geometry changes. It is somewhat difficult to see in the final video due to the above-discussed poor measurand resolution, but it does show up as a stronger-glowing region to the right of each area disturbance.

The technique used to visualize this flow was the injection of light-emitting particles. Specifically, a slurry of 5 micron Europium-doped Strontium Aluminate particles suspended in water was charged with a small UV light enclosure,

to activate the long self-luminous glow time characteristic of these particles. The dilution ratio was quite large - at the peak flow in the video, the injection rate of particles was only about 2 grams per second. However, their extremely small size allowed them to mix very well with the flow, and thereby differentially illuminate regions with more water-mass flux over regions with less water-mass flux as time progressed across the visualization. No external lighting was used, which is likely the first thing that should be changed in a follow-on experiment. As it was, the only lighting in the setup was the light emitted by the particles themselves, as all other lights in the room were turned off. Because the self-luminosity of the particles was so very low, there was not enough light for the camera to properly pick up the fluid motion, especially filming at high speed. In the future, the whole apparatus could be illuminated with a large UV lamp and the fluorescent nature of the particles could be exploited to provide much more light to the camera sensor.

The camera parameters used to generate the visualization were heavily constrained by how little light the particles emitted. The following table contains the relevant parameters:

Camera	Canon T7i
Lens	Canon 50mm f/1.8 EF-STM
Original video size	1900x1080px
Post-editing video size	1080x1080 px
FPS shot	60
FPS played back	30
ISO	12800
Aperture	f/1.8
Shutter speed	1/200 s
FOV size (post-crop)	7.87" wide x 7.87" high
FOV angle (post-crop)	31°x31°
Object-lens distance (measured)	28.25"

Originally, the intent had been to film at an even higher framerate than 60fps. The setup was tested with a 240fps phone camera, with the intent of playing back a short segment at 30fps to be able to very clearly see individual particle motion in the flow. However, the minute size of the particles and the difficulties presented by filming dim things at high speed forced a pivot to a slower framerate and larger-sensor setup with a DLSR camera. In post-processing, the video was cropped to the square flow-channel region, and the playback speed was slowed to 30fps to give the viewer more time to analyze the flow patterns as well as to enhance the artistic impact. Additionally, contrast was increased globally via an RGB curve such that the glowing regions were more visible. Using the RGB curve instead of a contrast tool allowed the walls between the channels to not acquire enormous amounts of noise, which they otherwise would have due to the very high ISO that the video was shot at.

Aperture Shutter speed

Overall, the video reveals interesting patterns around sediment deposition and transport that are consistent across a variety of geometry disturbances. The author would have preferred a final visualization that more clearly shows individual particle movement, as the minuscule well-mixed particles somewhat obscure the single-particle-level physics. However, the artistic and scientific intent of the experiment were still fulfilled, even if there is significant room to improve via better choice of particle and better use of lighting. Strategies for further development are discussed above in the body of the report, but the fastest and potentially most impactful would be to acquire a UV lamp and use it to activate the fluorescent modes of the particles, rather than relying on their self-luminance.

The video discussed in this report, along with supporting images, calculations, and writing, are the sole work of Luke Parker. Reid Benfield and Cutler Connaughton gave invaluable insight during the ideation phase, and no other collaborators, human or otherwise, participated in the production of any of the above work in any way whatsoever.

References

[1] 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.

[2] Chanson, H., "Drag reduction in open channel flow by aeration and suspended load," *Journal of Hydraulic Research*, Vol. 32, No. 1, 1994, pp. 87–101. https://doi.org/10.1080/00221689409498791, URL https://doi.org/10.1080/00221689409498791.

[3] Tang, Z., Stoesser, T., Huang, L., Liu, Y., and Fang, H., "Drag and Lift Forces on Bed Sediments in Open-Channel Flow Through Boulders at Various Froude Numbers," *Journal of Geophysical Research: Earth Surface*, Vol. 130, No. 8, 2025, p. e2024JF008069. https://doi.org/https://doi.org/10.1029/2024JF008069, URL https://agupubs.onlinelibrary.wiley.com/doi/abs/10.1029/2024JF008069, e2024JF008069 2024JF008069.