Flow Visualization and Scaling

Kieran Neath '22, Pierrette Umwaliwase '22, Marcus Mashanda '22, Professor Clayton Byers
Trinity College Department of Engineering

Background

Fluid flows take on many forms with different governing forces that induce changes in their behavior. This project was inspired by kitchen flows; steam from a kettle, emulsion and suspension, non-Newtonian and complex flows all of which have a flow phenomenon associated with them. Particularly this investigation seeks to describe and characterize fluids poured from a spout; a patterned behavior is observed when fluids are poured from a spout like a water filter of jug. This patterned behavior described as 'chain-link' perpendicular features have some similar geometry and form a steady-state flow.

This investigation was conducted using 3D printing and modelling to emulate spout forms, an apparatus comprised of a water pump, piping and flow restriction to sustain the flow, imaging tools to capture flow detail and MATLAB post processing to analyze captured data. By use of non-dimensional numbers and scaling the behavior of poured fluids and their surface patterns can be determined.

There is an applicable relevance in that describing this patterned behavior can lead to scaling to large fluid flow systems where the same governing forces and parameters may arise such as free surface flows in weirs and other forms of hydraulic structures.

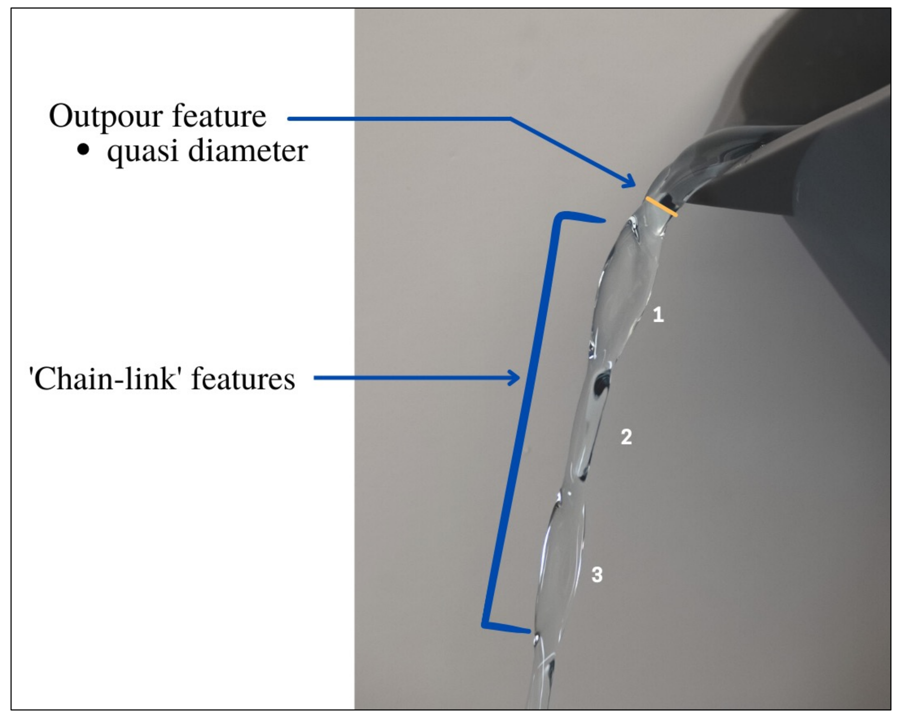


Figure 1. Flow features (3) of partnered behavior

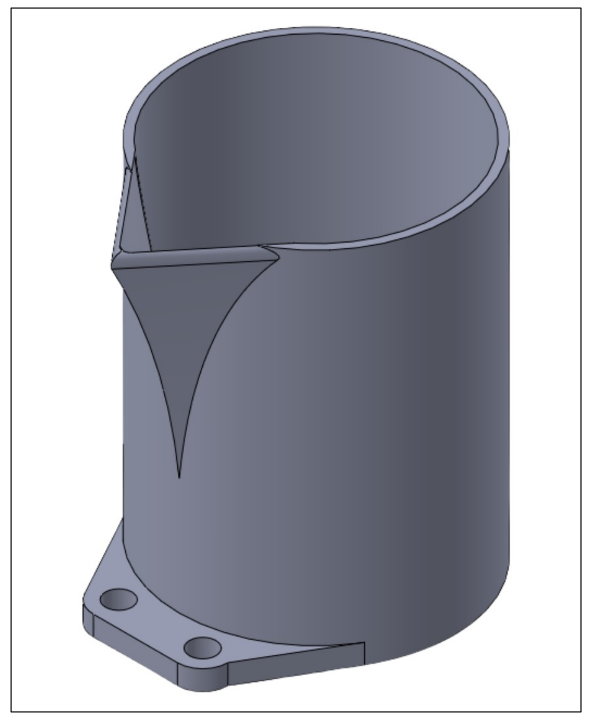


Figure 2. Spout design from SOLIDWORKS™ (isometric view)

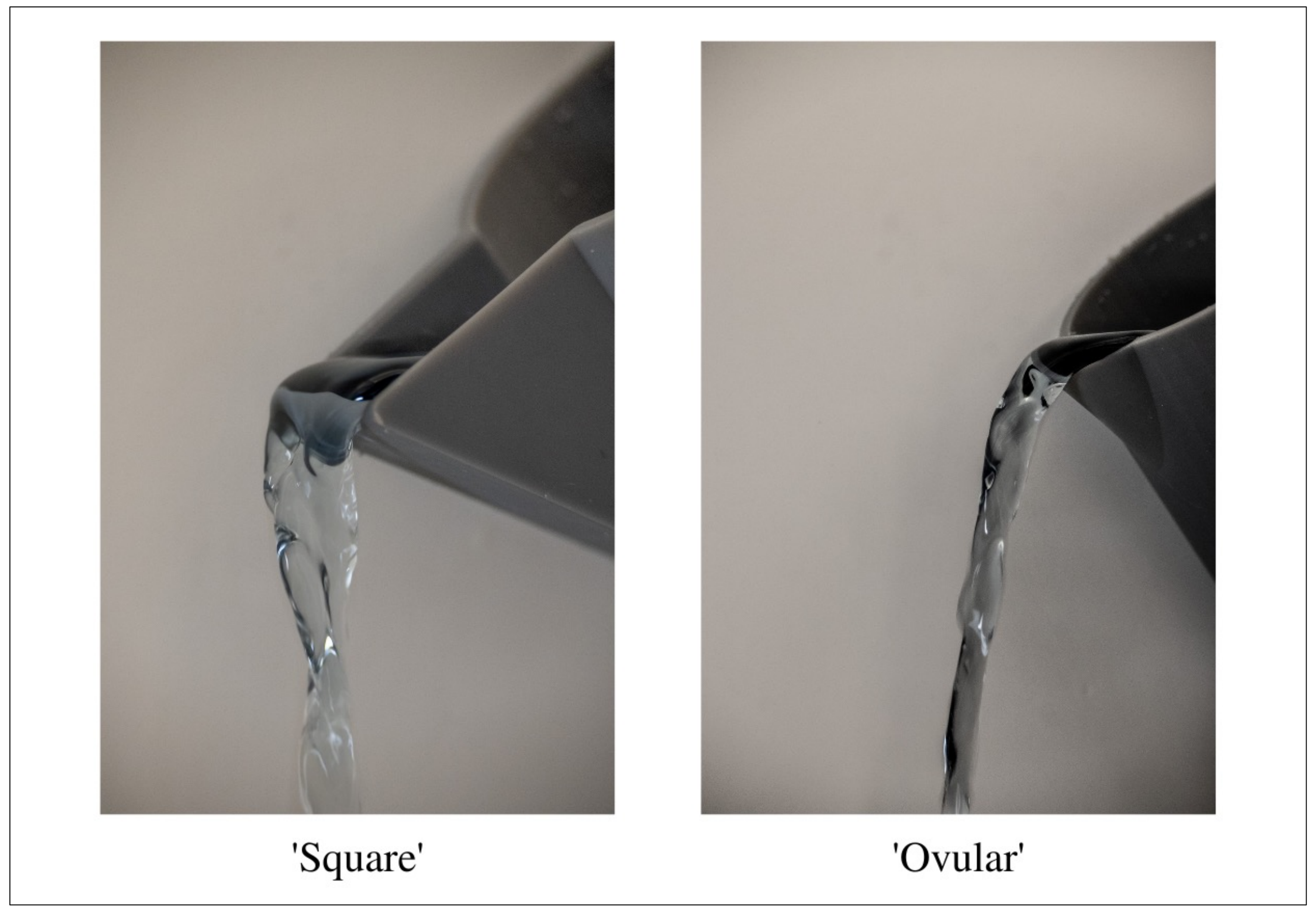


Figure 3. Other types of spout designs with unique behavior

Technical Approach

Experimental setup

To create and sustain the flow for investigation, an experimental setup shown in fig. 4 was devised.

- Pump with tubing system was used to drive the system and create the flow where the flow and patterned behavior is created from the tip of the spout model
- A flow valve was used to restrict the flow to vary flow rates and flow meter used to measure.
- A 0.064 HP pump with conjoined tubing system was used to drive the spout flow through the 3D printed spout model.
- A frame was assembled using materials from 80-20 Inc. to hold the spout model as well as vary the angle at which the fluid is poured using variable pivot breaks.

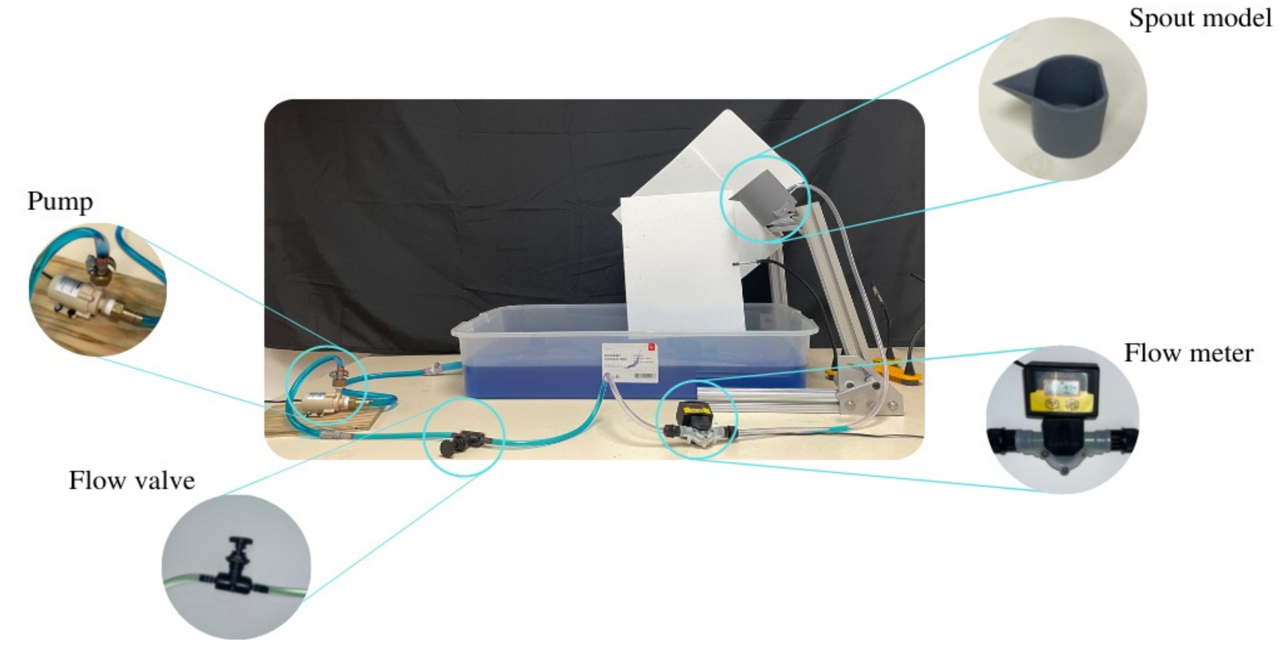


Figure 4. Experimental setup of spout model, pump and tubing, flow valve and flow meter.

Parameters of interest and Nondimensionalization

There are 7 variables of interest and varying all of them more than 5 times will lead to over 10 million experiments. Nondimensionalization simplifies and parameterize the experiment significantly reducing the number of experiments and provides scaling laws allowing experiments to be performed on small, cheap scale models which can then be extended to full-size applications.

$$f(\rho,\mu,V,L,g,\sigma,\ldots)\rightarrow F_2\left(\frac{\rho VL}{\mu},\frac{V}{\sqrt{gL}},\frac{\rho V^2L}{\sigma},\ldots\right)$$

ρ: density V: velocity L: characteristic length
g: gravity μ: viscosity σ: surface tension

Equation 1. Repackaging of variables by use of nondimensionalization

Data acquisition and analysis:

- In image capture for data collection, a Sony Mirrorless Digital Camera with macro lens in parallel perspective to the flow feature was used.
- MATLAB™ Image Processing toolbox was used in conjunction with a scale set in the same plane as the flow for calibration and feature length measurement shown in fig. 5

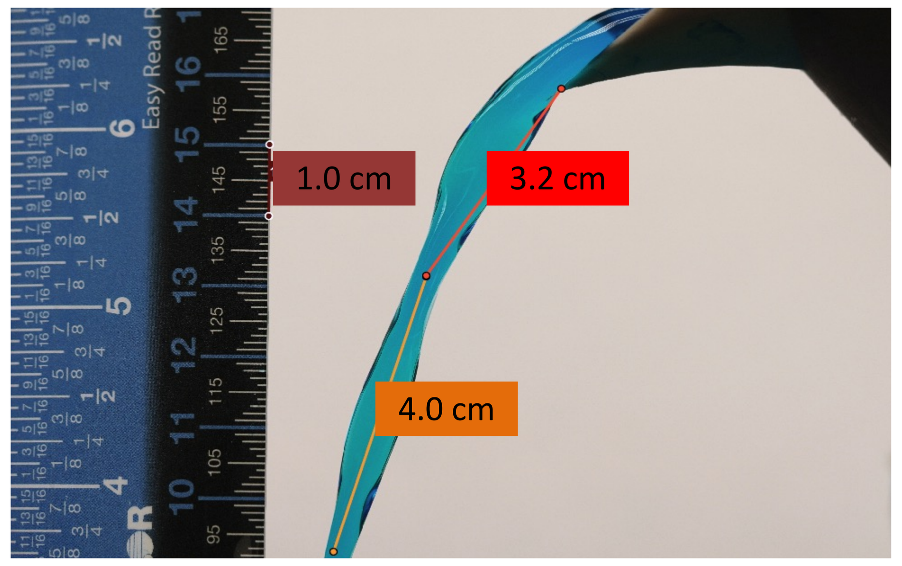
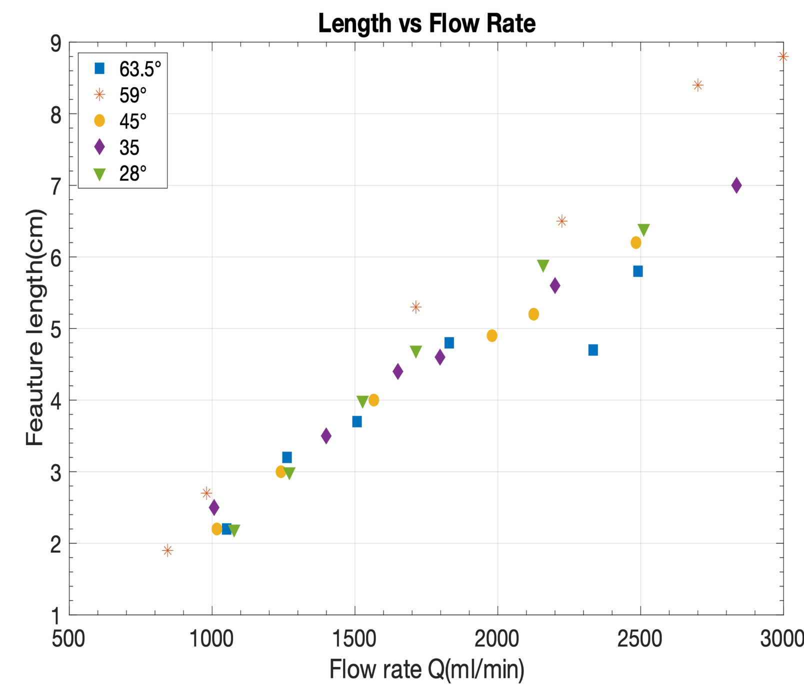
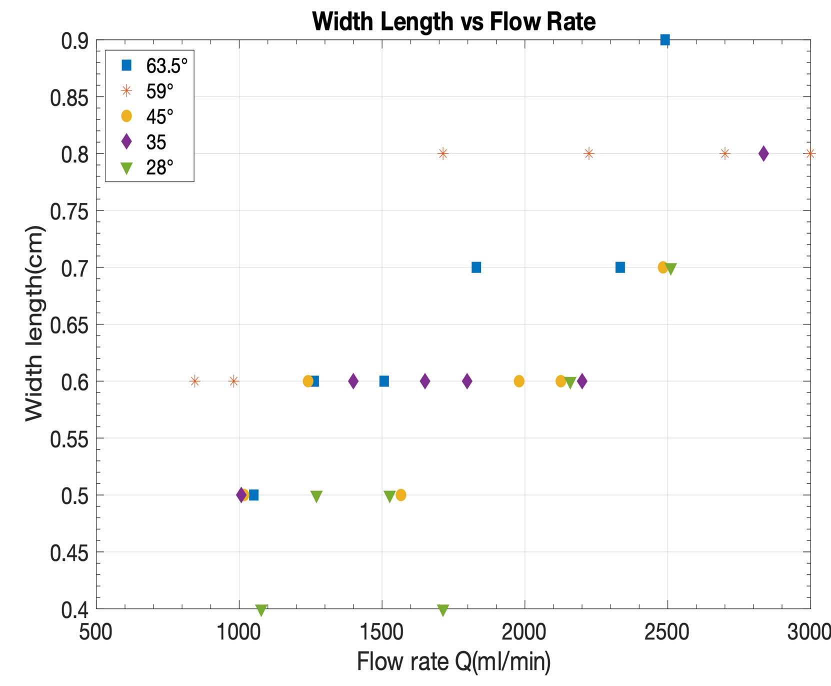


Figure 5. Data collection of feature dimensions using MATLAB™ Image processing toolbox

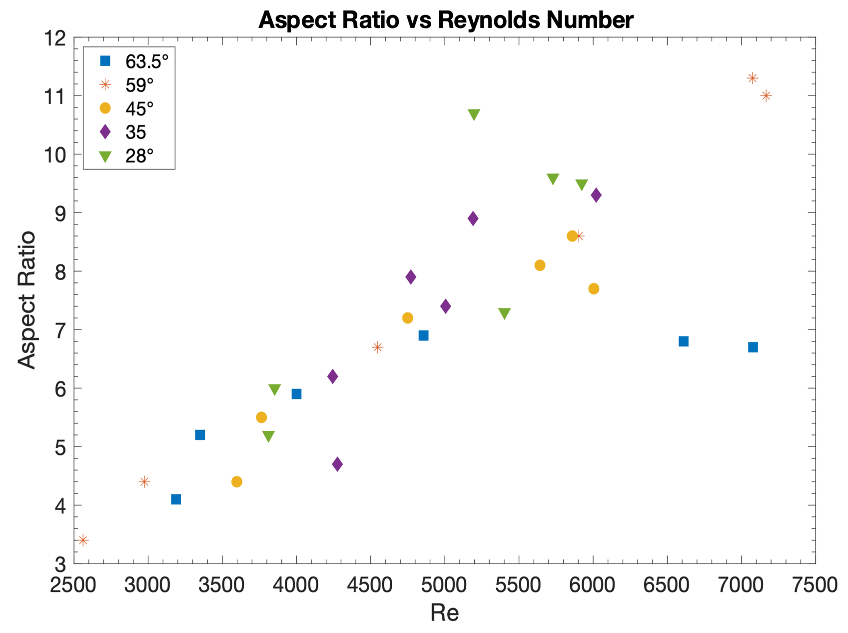
Results



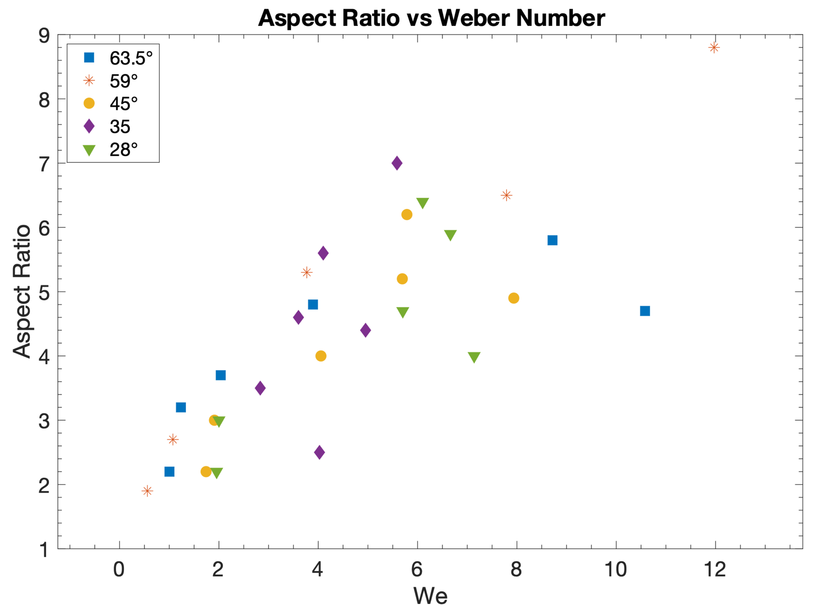
Graph 1: Feature Length Vs Flow rate



Graph 2. Feature Width vs Flow Rate



Graph 3: Aspect Ratio Vs Reynolds number



Graph 4: Aspect Ratio Vs Weber Number

Discussion

The 'chain-link' features' length and width generally increase as the flow rate increases at different pouring angles, as shown in graph.1 and graph.2. The feature-length is independent of the pouring angle; there is a similar trend for all different pouring angles shown in graph 1.

Dimensionless number packages the parameters together. Buckingham's pi theory states that a multitude of flow parameters can be reduced to dimensionless parameters such as Reynolds number and Weber number to explain the behavior of the flow. Reynolds number and Weber number were plotted against aspect ratio to find the general behavior. Graph. 3 shows an increase in the aspect ratio as the Reynolds number increases for all the measured angles. Graph. 4 has points scattered, showing no universal behavior between the Weber number and the aspect ratio.

Future Works

- Investigate different spout geometry (circular, square).
- Utilize different fluids (for viscosity and surface tension changes).

References

Frank M. White. Fluid mechanics. McGraw-Hill series in mechanical engineering. McGraw-Hill, New York, NY, 6th ed edition, 2009.

Acknowledgements

We are thankful for the support and guidance received from Ph.D Clayton Byers on this project.