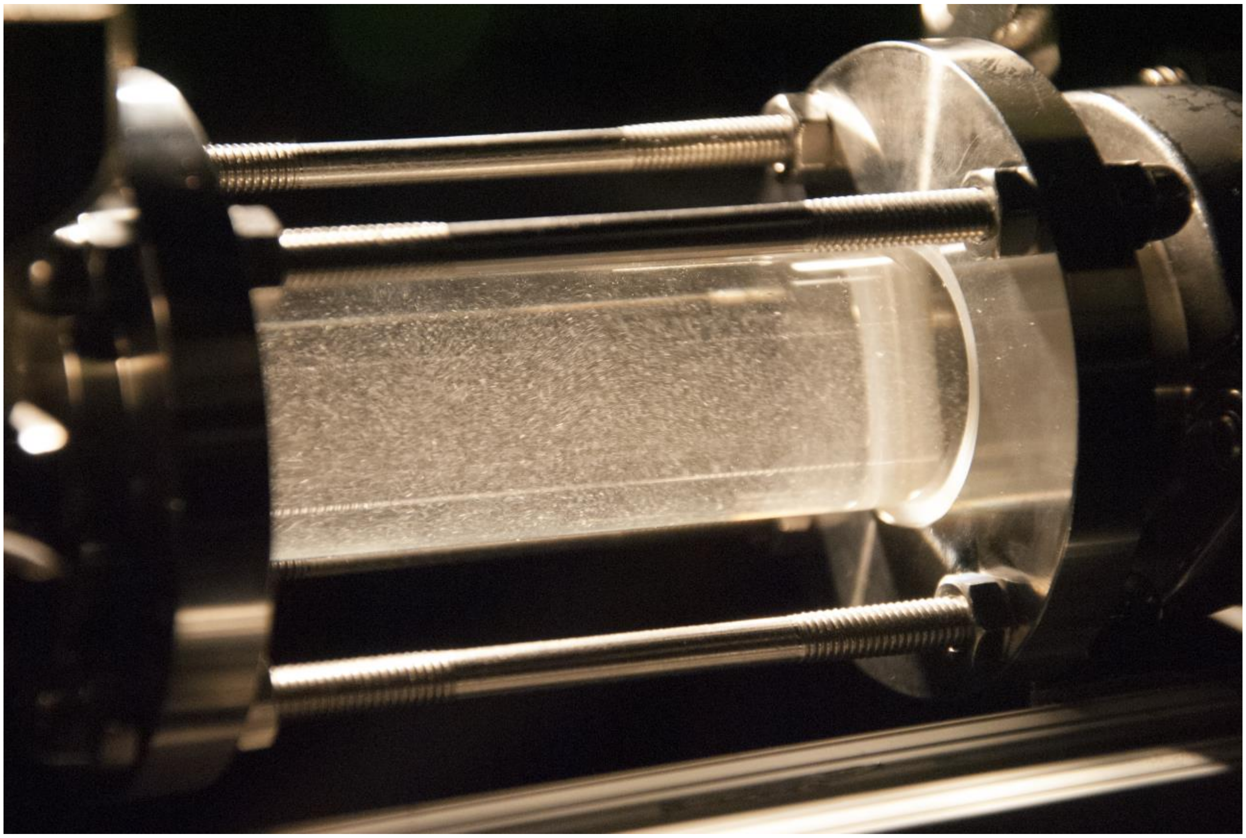
# Team First Video, Spring Semester 2018




Julian Claudio

With help from Michael Sandoval, Dillon Kidd, Alastair Crowe, Ben Roberts, and Ty Gunnlaugsson.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The purpose of this image is to show the flow characteristics inside of a straight, circular section of glass tube. The first video aimed to visualize mixed flow of water inside the straight section, this was done at 1 gallon per minute. The second video showed a turbulent flow illuminated by a laser. This was meant to have a more dramatic effect of visualization. I manned the camera on the setup while my teammates started the flow and controlled the valves on the setup. Ben told me the flowrate from the meter while Dillon adjusted the flow. Michael turned on the pump and the lights. Alastair helped me store the footage on the high speed camera while it was connected to the computer.

To fully explain the setup of the flow, I will need to explain the setup and the cameras. Then, I will explain the tested flowrates. Finally, the reason and methodology of using microbubbles to visualize flow. Below is a SolidWorks 3D model to show the components of the stand.

# I. Test Stand

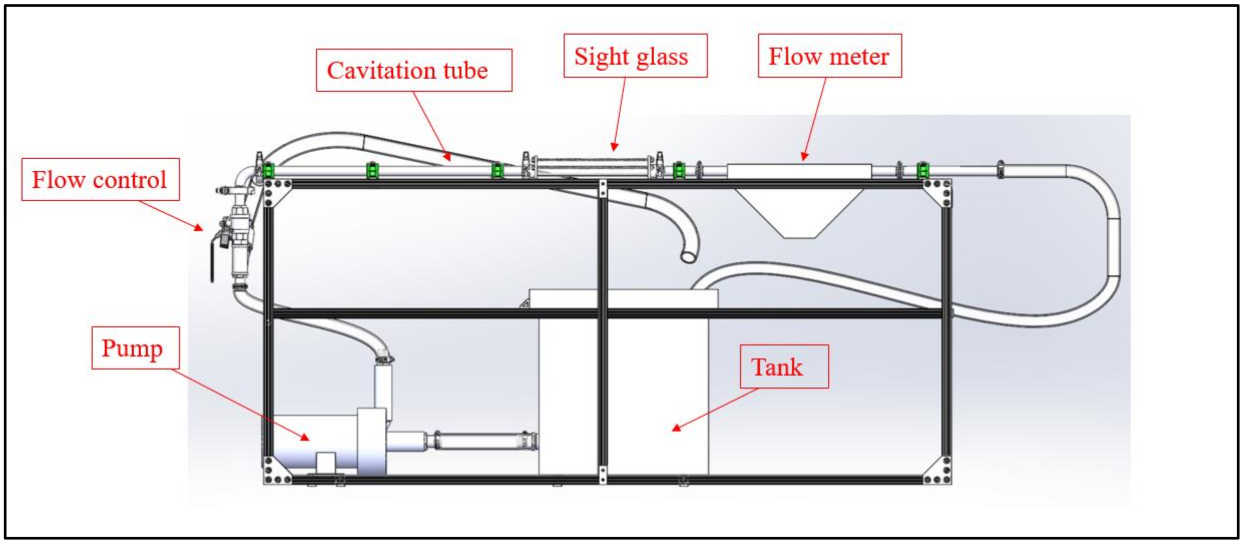


**Figure 1.** SolidWorks model of the flow stand setup.

Below is the actual setup, it is important to note that the actual setup is slightly different than the SolidWorks model. The flow meter is at the start of the flow because this will guarantee that we get an accurate flow rate. If the flow meter sits after the cavitation tube, then it will not read the flow accurately since the cavitation tube causes the formation of bubbles. The bubbles affect the accuracy of the measurement from the flow meter. The size of our visualization section is 6 inches, which is the section that was filmed for the video. The stand itself has overall dimensions of 6’ x 2’ x 3’.

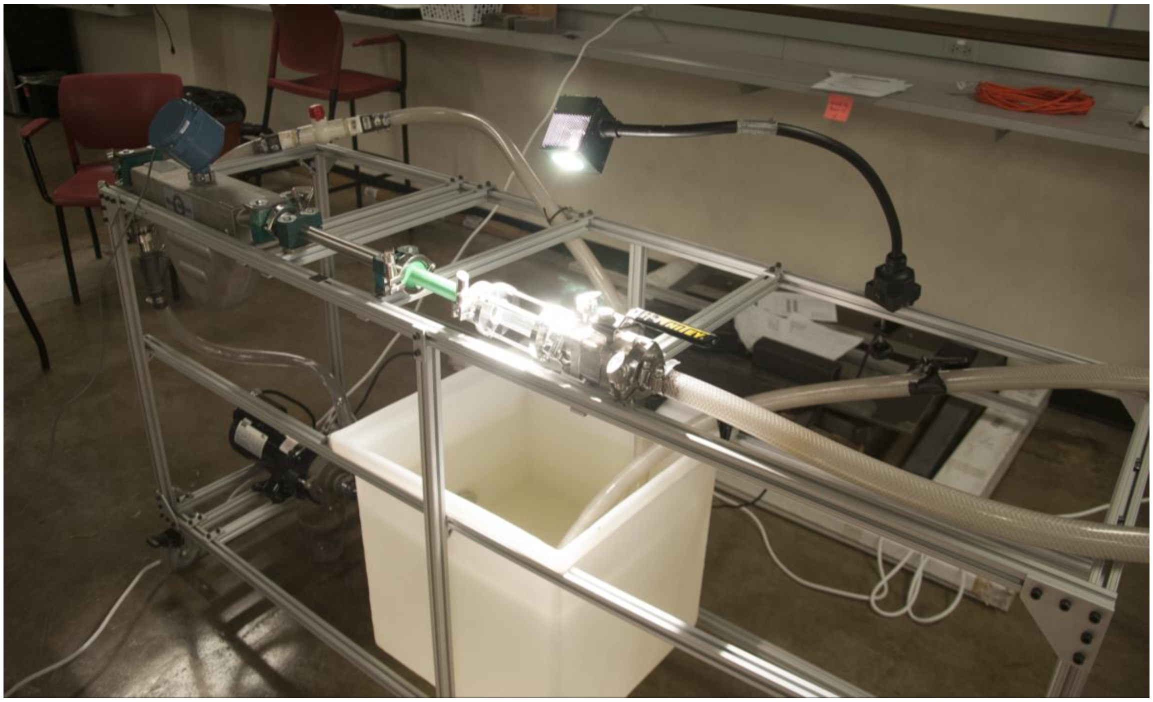

**Figure 2.** The actual flow stand setup.

This setup uses a flow stand that my senior design team constructed to visualize flow for Micro Motion Incorporated. Water leaves the tank, gets pumped through to the valve section where the flow speed is controlled. After the valves, the water flows through the flow meter which records the speed of the flow. The water then moves into a cavitation tube where it is dropped below its vapor pressure to produce tiny bubbles. These bubbles trace the flow very well since they are so small, but more on that later.

## II. Camera

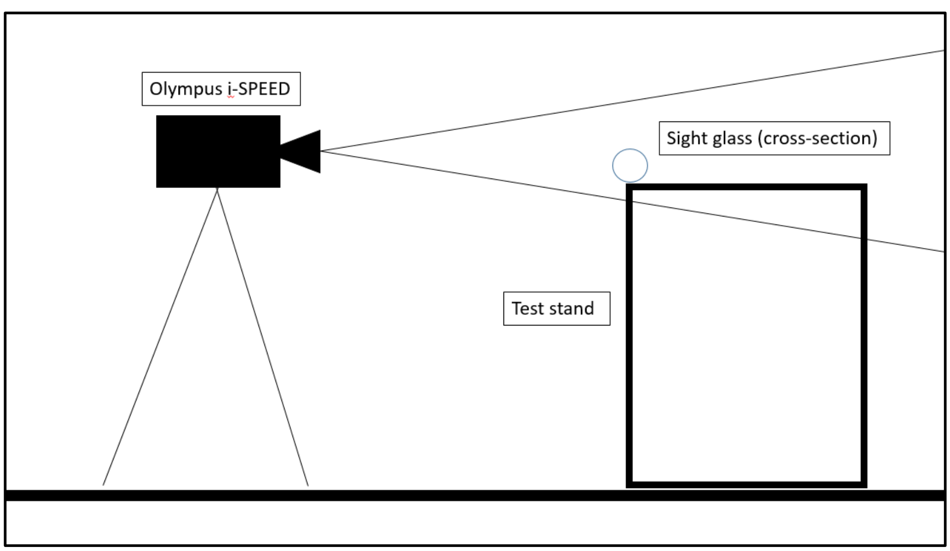


**Figure 3.** Schematic of the high speed camera setup

The first video was shot at 1000 fps on an Olympus i-SPEED camera, a high speed camera that is available in the Idea Forge on CU's campus. The camera was setup on a tripod away from the stand, then set so that it could see the sight glass. We shined a halogen light bulb onto the sight glass to give the shot a lot of light. High speed cameras have very high shutter speeds, so they require a lot of light since the camera's sensor has less time to capture light at high shutter speeds. The Olympus was shot

The second video was shot at 120 fps so that the camera could pick up the light from the laser pointer. At a high frame rate, the high speed camera does not capture enough light to see the laser. So for this I used an iPhone 6s which has some limited high speed video capability.

The team has access to a 25mm and 50mm F/1.4 C-Mount Micro 4/3 lenses. The focal length and viewing angle are the most relevant characteristics to the project. These determine the field of view and pixel size at the minimum focal length, this is important when observing microbubbles that can be smaller than 100 microns. As seen in **Figure 4**, the field of view can be calculated using some simple trigonometry and the lens' focal length and viewing angle. The 25mm lens has a 10.27 inch minimum field of view, the 50mm lens has 8.55 inch minimum field of view.

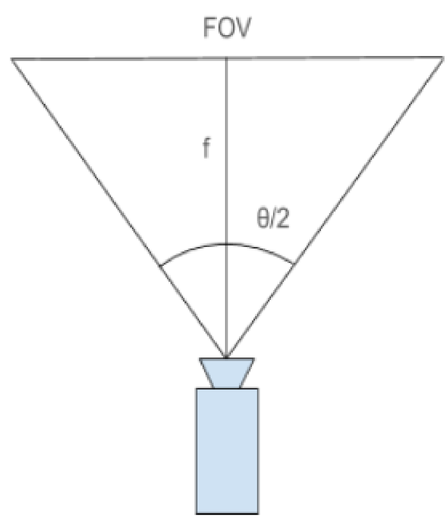


**Figure 4.** Field of view for a camera using its focal length (f) and viewing angle (θ).

## III. Flowrates

The flowrates that I chose were based off of the Reynold's number for water. Reynold's number can be used to determine if a flow is laminar, transitional, or turbulent. Laminar flows are uniform and at Reynold's numbers lower than 2400. Turbulent flows are at Reynold's numbers above 4000 [2]. Anything in between can be considered transitional. Reynold's number can be calculated using:

$$Re = \frac{v * D}{\nu}$$

Where v is the one dimensional velocity of the flow, D is the diameter of the pipe, and ν (nu) is the kinematic viscosity of water. The pump outputs the water at 1 gallon per minute, a volumetric flowrate. So, I converted the flow to a linear velocity by dividing by the cross-sectional area of the pipe:

$$v = \frac{Q}{A}$$

Where A is cross-sectional area and Q is the volumetric flowrate:

$$A = \pi * (D/2)^2$$

Therefore:

$$v = \frac{Q}{\pi * (D/2)^2}$$

Plotting this relationship shows where the flow is laminar. I plotted Reynold's number on a logarithmic scale to make it easier to visualize with this graph:

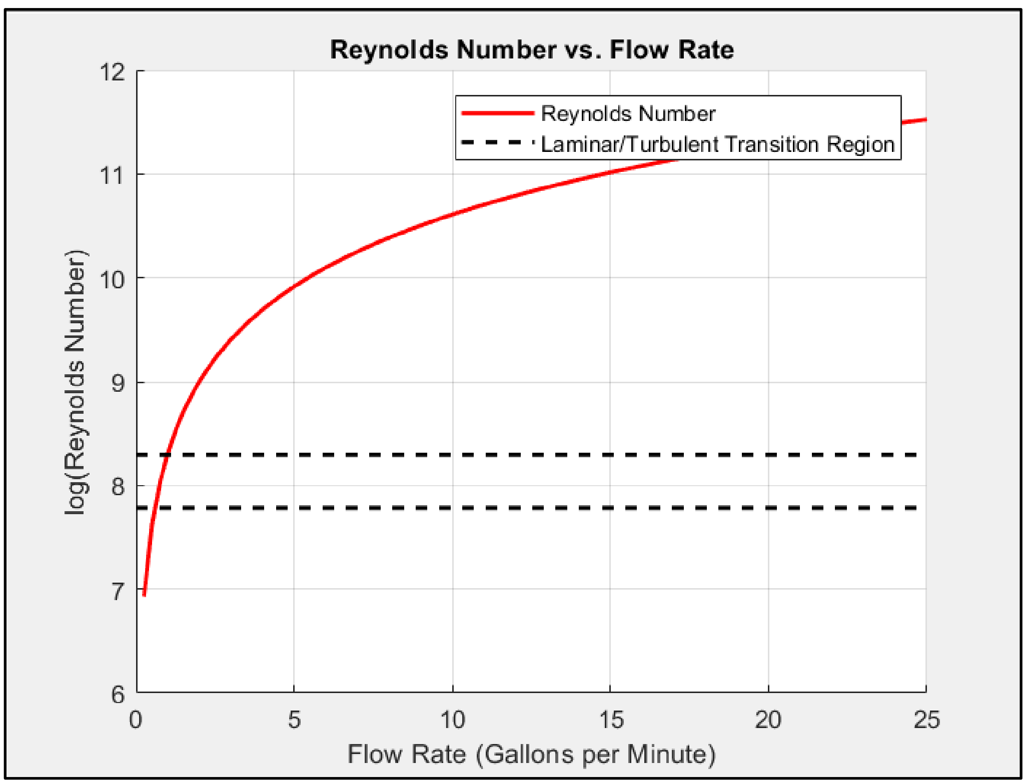


**Figure 5.** Graph of Reynold's number versus the volumetric flowrate on a logarithmic scale.

My first video was shot at 1 gallon per minute, this gives a Reynold's number of 4050, which is just outside the transitional region of the flow. This is the closest that I could comfortably get to laminar flow with water because I didn't want to put too much pressure on the pump. The pump outputs a single flowrate that is controlled with valves, so throttling it that low puts a lot of stress on the pump. Surprisingly, there aren't very many turbulent effects that can be seen inside the flow. The flow in the first video is very straight and follows a normal laminar flow well. This is why I chose this video to demonstrate laminar flow. If you observe carefully, you can see that the bubbles flowing near the edges of the sight glass are moving slower than the bubbles in the center of the flow. This is because the water at the edges is getting slowed down by the glass walls. This is called the laminar profile of flow.

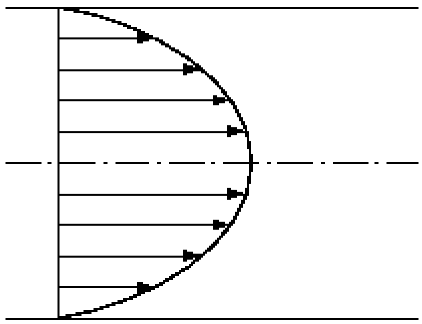

**Figure 6.** The laminar "bullet" profile. [1]

The next video was shot at 15 gallons per minute which yields a Reynold's number of 60758, which is well into the turbulent regime. In the video you can see in the edges of the flow there are many turbulent vortices. This is because a turbulent flow is characterized by chaotic patterns that are unpredictable. So, while the water in the video looks like it is flowing fairly straight, it does not follow the typical laminar profile.

## IV. Method of Visualization

Microbubbles were chosen to visualize this flow because they are small enough to negate the effects of buoyancy, meaning they won't rise to the top of the sight glass.

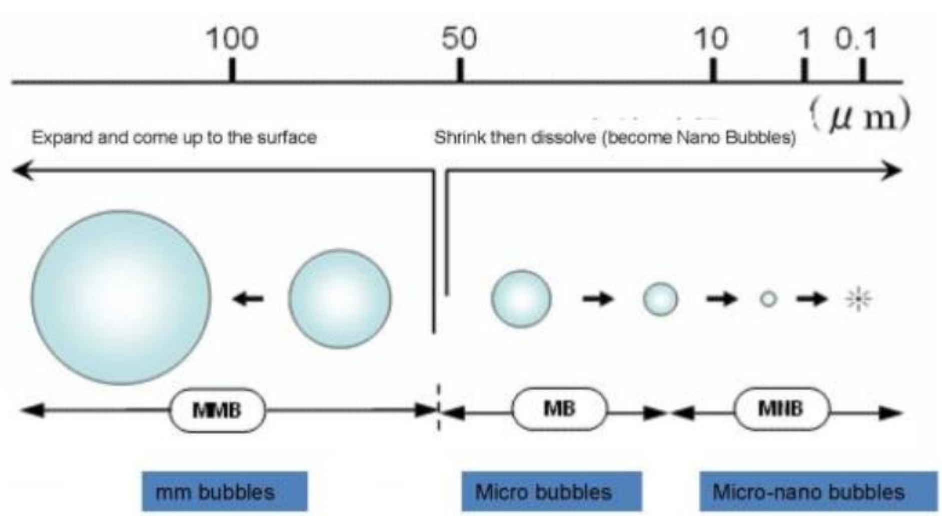


**Figure 7.** The effects of bubble size on buoyancy.

Venturi cavitation tubes work by flowing liquids through a constricted section which causes the velocity to increase that's calculated by setting the mass flow rates equal to each other:

$$V_1 A_1 = V_2 A_2$$

where point one is a reference point with the same mass flow and point two is the parameters in the constricted section of the tube. This increased velocity causes a pressure drop which is described by Bernoulli's equation. The pressure drop will cause cavitation that will cause air bubbles to implode into microbubbles, which can be calculated through rearrange Bernoulli's equation into the following form:

$$P_{cav} = P_{ref} + \frac{\rho}{2} * (V_{ref}^2 - V_{cav}^2)$$

By setting the reference pressure equal to zero, the pressure drop that occurs in the Venturi cavitation tube was calculated for various flow rates that the test stand will operate at, as shown below:

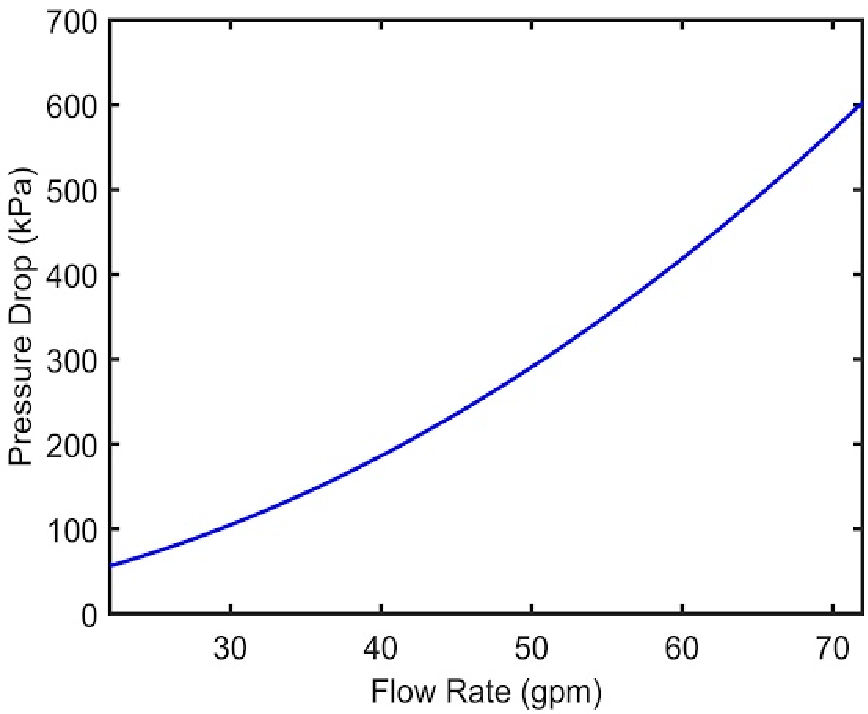


**Figure 8.** Pressure drop required to cause cavitation in the tube.

For 1 gallon per minute, the required pressure drop is 88 kPa. This required the design of a cavitation tube that would cause this amount of pressure drop. By changing the cross-sectional area of the tube, we were able to achieve this pressure drop. The radius of the tube was decreased from .87” to .375” which caused cavitation in the flow. By using images of the sight glass, we were able to determine that the bubbles sizes were around 100 microns which is small enough to avoid the effects of buoyancy. This is seen in the video, the bubbles follow the flow well which confirms that they aren't affected heavily by buoyancy.

# V. Conclusion

The moral of the story is that this flow stand works well to show a simple laminar or turbulent flow of water through a straight section of pipe. There is a lot of explanation and work that needs to go into accurately tracing a flow. I hope this report illuminates the immense amount of time, effort, and attention to detail that flow visualization requires. Adding some artistic flare always makes it great and fun, but getting it scientifically accurate is a daunting challenge. Apologies for such a long report, but the information was necessary to give a full idea of why each component matters in this test stand. This is, after all, my senior design project and Cyron keeps giving me bad grades for my photos and reports, so I hope this is sufficient.

# VI. References

[1]: Scalar Transport. Dr. S D Harris, University of Leeds School of Earth and Environment. https://homepages.see.leeds.ac.uk/~amt6xw/Distance%20Learning/CFD5050TURB/node7.html

[2]: Transition and Turbulence. *The Engine and the Atmosphere: An Introduction to Engineering* by Z. Warhaft, Cambridge University Press, 1997. https://www.princeton.edu/~asmits/Bicycle_web/transition.html

[3]: Michaud, L D. "Venturi Cavitation Tube." Mineral Processing & Metallurgy, 17 Mar. 2017, www.911metallurgist.com/blog/venturi-cavitation-tube.