Final Project: Vortex Ring Dynamics

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Contents

1. Introduction

1.1. Background

Our history has been evolved with the Vortex rings and their dynamics for long time. In this lab, we conducted the related experiment so we can observe vortex rings and analyze their complex airflow dynamics through observation.

1.2. Motivation

Vortex rings are found in many important systems. Many problems in nature and engineering involve multiphase flows, where a different state, such as a solid, liquid, or vapor state, exists in the form of a cloud of particles of various size in an ambient fluid of gas and liquid undergoing time dependent and often turbulent motion. The fluid flows back on itself, making a spinning ring around an invisible core and a doughnut-shaped vortex is formed. One of the noteworthy examples of this are smoke rings, produced by volcanoes and artillery and the bubble rings generated by marine creatures like whales and dolphins. Modeling of particle-laden turbulent flows with low volume loadings typically involves simulations of the carrier fluid using direct numerical simulation, large-eddy simulation, or Reynolds-Averaged Navier Stokes models.

In the tangible situation, the mechanical heart valves in the body produce turbulent to flow the blood through and the facial mask material traps droplets and particles with the combined effects of diffusion, inertial impaction, interception, and electrostatic attraction. Filter efficiency is the ratio of the particle concentrations upstream and downstream of the mask and this is a function of the particle- and fiber-size based Reynolds numbers, fiber-based Péclet number, particle-to-fiber size ratio and Stokes number. The nonlinear variation of filtration mechanisms on these parameters generates a complex dependence of the filter efficiency on flow velocity, particle size and filter.

Finally, the our own mouth can perform as a vortex cannon. When we talk, the air from our body moves as the vortex cannon shoots the air. In the water, the vortex can be even seen visually as the figure 0.

Figure 0. Air out of the Mouth in the Water (0)

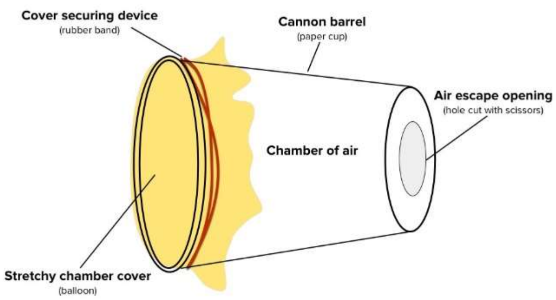

Figure 1. Vortex cannon (1)

2. Experiment

2.1. Material

First, we built Vortex Cannon with two PVC pipes. The outer one was Outer 24-inches long, 4-inch diameter and the inter one was 48 inches long, 3-inch diameter. In front of the out pipe, we put the Screws to stop the inner pipe before the outer pipe. Two pipes are connected with the bungie cables and the zipties on each size. We made the plastic apertures with different size of diameter, 0.75, 1.125, 1.5, and 2 inches, and put them on in front of the outer pipe. we covered the front of inner pipe with the cardboard, so the displacement of fog is maximized in figure 2. Generally, the duct tape was used to hold any object.

Fog machine we used was AGPTEK 500W Portable Led Smoke Machine with Lights and we could control it wirelessly. Construction leveling laser was used, too, so that we can visually the dynamics of air conveniently. We set the multiple Cameras to contains the air dynamics with various angles.

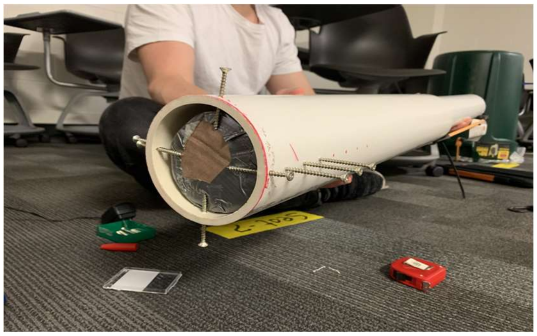

Figure 2. Vortex Cannon without Aperture

2.2. Procedure

We marked the wooden planks with electric tape at every 12 inches. Then we aligned them with the cannon and measured with a tape measure. Displacement of piston was then set: The initial piston displacements was form 0.5 inches to 12 inches. We filled the chamber with gas and allowed it moved come to as close as possible to the equilibrium. The cannon was then fired at the set displacement by releasing the piston. And the action pushed the gas in the chamber through the aperture. We repeated on the new displacement increased by 0.5 inches. Once we were confident of the displacement that would yield the bifurcation, we performed in the dark atmosphere and used the laser to capture cross section and air flow dynamics, like figure 4, probing slightly above and below the critical displacement.

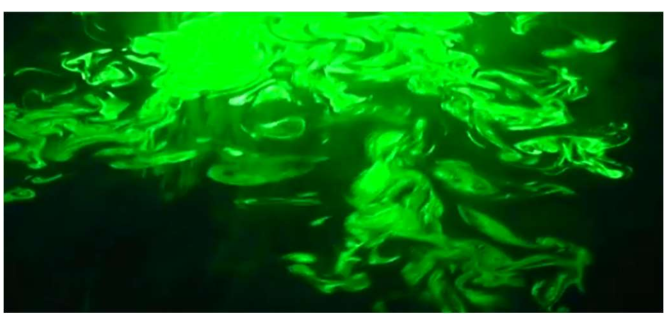

Figure 3. Air Flow Dynamics with Laser

3. Data

displacement	D =1 1/8	tenseband	D=2 (tense)	D = 2 (new band)	D = 2 (tense) (	D = 1 1/8 (tense)	D = 3/4 in (ter	D1 *1/2	D = 3/4	D = 2
0.5	ring	ring	x	ring	x	x	ring	ring	ring	x
1	ring	ring	x	ring	x	ring	no ring	ring	no ring	x
1.5	ring	ring	x	ring	x	ring	x	ring	x	x
2	ring	ring	ring	ring	ring	ring	x	ring	x	ring
2.5	no ring	no ring (ghost)	x	x	x	no ring	no ring	ring	no ring	x
3	no ring	no ring	x	ring	x	no ring, splitting patte	split ring	ring	split ring	x
3.5	no ring	x	x	x	x	x	ring	ring	ring	x
4	no ring	no ring	ring	ring	ring	x	no ring	ring (messy)	no ring	ring
5	x	x	x	x	x	x	no ring	split two	no ring	x
5.5	x	x	x	x	x	x	x	split two	x	x
6	no ring	no ring	ring	ring	ring	x	no ring	no ring	no ring	ring
6.5	x	x	x	ring	x	x	no ring	no ring	no ring	x
7	x	x	x	ring	ring	x	x	no ring	x	ring
7.25	x	x	x	x	ring	x	x	x	x	ring
7.5	x	x	DAMAGED	ring	x	x	x	no ring	x	ring
8	x	x	x	no ring	x	x	x	x	x	no ring
8.25	x	x	x	no ring	x	x	x	x	x	x
8.5	x	x	x	no ring	x	x	x	x	x	x
9	x	x	x	no ring	x	x	x	no ring	x	x
10	x	x	x	no ring	x	x	x	x	x	x
12	x	x	x	no ring	x	x	x	x	x	x
l = 1/2 in	l = 1/2 in	l = 1/2 in	l=1/2	l=1 in	l=1 in	l =1 in	l=1inch	l = 1inch	l=3in	l=3in

Table 1. the data

The last row of the table 1 was referring to the stopping point. We explored the least upper bounds of vortex ring formation. The vortex rings didn't form only after we increased the volume of them. The increasement of width of the aperture diameter increased the amount of the displacement until no rings were formed. At last, the change of stopping points did not affect the displacement at all.

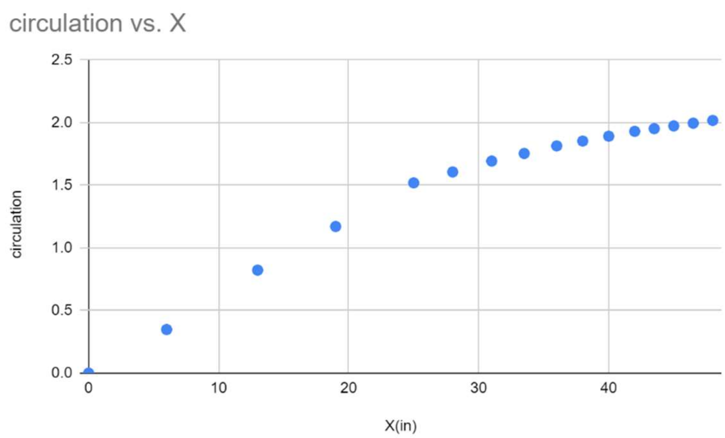

Figure 4. Circulation vs X

The figure 4. Was one of the circulation vs x graphs. The diameter of the aperture was 2 inches.

4. Analysis

In the figure 5, the Circulation is the line integral of a vector field around a closed curve, Circulation fluid/circulation pipe on y axis. L/D is in our case displacement, Δx, divided by diameter of aperture.

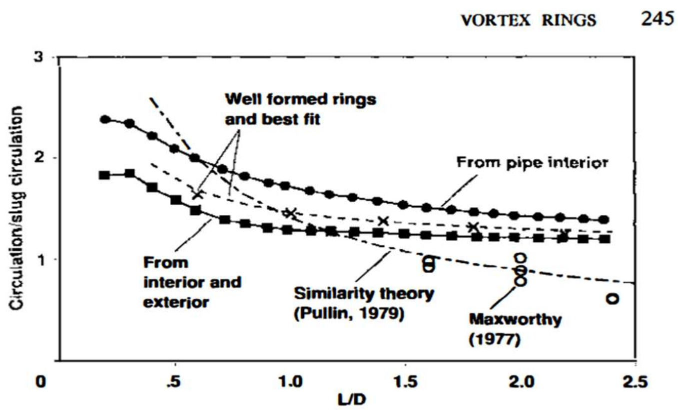

Figure 3 Circulation of vortex rings formed at a pipe referred to the circulation predicted by the slug-flow model, Equation (2.5). Unless indicated, the data are from Didden (1979). The multiple data points of Maxworthy (1977) at the three *L/D* values are for different Reynolds numbers, increasing downward. Well-formed rings seem to have a larger circulation (*crosses*) than the total flux at the pipe (*solid squares*) due to slight inadequacy in measuring the flux at the pipe.

Figure 5. Vortex Ring Circulation (2).

With the two lines of fit, we checked the data was able to fit in the curve.

First, we used the chain line above of Pullin, 1979:

$$\frac{\Gamma_{\text{out expected}}}{\Gamma_{\text{slug expected}}} = 1.41(\frac{\mathrm{L}}{\mathrm{D}})^{-\frac{2}{3}}$$

This fit line is better for higher Reynolds numbers. Then I used the dashed line above of Didden, 1979.

$$\frac{\Gamma_{\text{out expected}}}{\Gamma_{\text{slug expected}}} = 1.41 + 0.32(\frac{\mathrm{L}}{\mathrm{D}})^{-1}, \frac{L}{D} > 0.6$$

The vorticity, curl is the second term of Taylor expanded velocity (first order, rotational term, “rigid body”)

$$\mathrm{u}(x) = u(x_0)(x - x_0) + \frac{1}{2}w(x_0) \times (x - x_0) + O(|x - x_0|^2)$$

can also be derived from Navier-Stokes. With the approximation of vorticity (ω) given a velocity field u(x,t).

$$\frac{\Gamma_{\mathrm{slug}}}{\mathrm{dt}} = \int_0^{t_{piston\ stop}} w u_x d\sigma \sim \int_0^{t_{piston\ stop}} \frac{\partial \mathrm{u}}{\mathrm{u}\sigma} u_x d\sigma \sim \frac{1}{2} U_x{}^2(t) \quad (3)$$

With the 2 points with Diameter aperture size of 2 inches and the frame video analysis, we could get the box integral with displacement as 1/fps.

$$\frac{\mathrm{L}}{\mathrm{D}} = 3.75 \quad \frac{\Gamma_{\mathrm{out}}}{\Gamma_{\mathrm{slug}}} \sim 0.533$$

$$\frac{\mathrm{L}}{\mathrm{D}} = 4.00 \quad \frac{\Gamma_{\mathrm{out}}}{\Gamma_{\mathrm{slug}}} \sim 1.146$$

For the Pullin curve at L/D = 3.75:

$$\frac{\Gamma_{\text{out expected}}}{\Gamma_{\text{slug expected}}} = 1.41(3.75)^{-\frac{2}{3}} = 0.5841$$

The Didden curve fits with L/D = 4.00 points are closer than the Pullin's since there was no ring:

$$\frac{\Gamma_{\text{out expected}}}{\Gamma_{\text{slug expected}}} = 1.14 + 0.32(4.00)^{-1} = 1.22$$

Didden used fluids unlike us while Pullin used similar theory that is better fit for higher Reynolds number.

The values are fit to the curve. The figure 4 suggests that the bifurcation points of the circulation is 2.

5. Summary

Our team wanted to conduct the Vortex Ring related experiments analyze the complex airflow dynamics through observation. Our method was to build the handmade vortex cannon. With the cannon, we air-shoot it with the air fog in under the light and laser and analyze the aerodynamics. We discovered that the displacement of the fog could be calculated but not precisely because the variable in the air was too complicated.

6. Conclusion

The lab results show that how the air flow can be affected by the air vortex cannon. Since one of the social problem, we encounter is COVID- 19, we can apply the results in it. If we assume our mouth is the vortex cannon, and as we speak, the air is comping out of the mouth. Without the acknowledgement, the possible germ can spread to the atmosphere. Hence, based on the results of the procedure, the team recommends a facial mask can prohibit the COVID-19 to spread, without a doubt.

References

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There are several ways to determine weather the dots are patterned or random. First, the frequency and density method. By counting the number of the points in the study are and divide total by unit area. If the number is below 0.5, it is the pattern. Another way to do it was descriptive spatial statistic. By getting the mean of every x and y values and comparing them with the center. Finally, complete spatial randomness, CSR, is to get a random or Poisson distribution of points in the unit square. Weather the number is big, the system is random.