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Flow-Induced Vibration Documentation

Work Accomplished:

I primarily worked on two different tasks throughout the semester. The first was to design and create low m* or density cylinders or bodies that could be optimized to create flow-induced vibrations. The second was to design an apparatus in which the cylinders would be suspended by springs (or strings), experience winds from one direction, and have its motion constrained.

In the development of low density bodies, Vansh and I brainstormed many different options including aerogel, styrofoam, and the various 3D models in Figure 1. I did many different cylinder density calculations and found that styrofoam was still an order of magnitude off the desired density of less than 5 times the density of air. Aerogel seemed to be a bit of an oddity to obtain, so we went ahead with more of the 3D models. I developed more than 10 CAD designs for different cylinders and bodies. Most of them were quite similar though and consisted of a thin shell of PLA with holes for the springs to attach to. Significant differences included shell thickness, the addition of end caps to allow for the cylinder to be constrained vertically, donut shaped holes for smoother spring hook connections, differing aspect ratios (length to width ratios), and the most time consuming (and cool in my opinion), Fusion Shape Optimization.

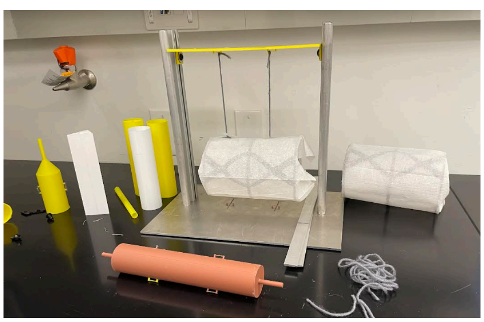
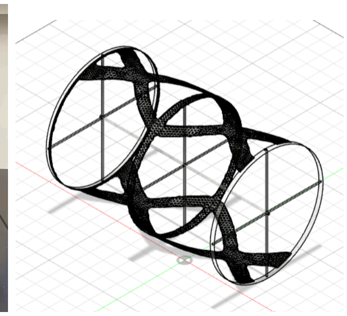

Figure 1 | 2. Various models of cylinders with the apparatus | 3D CAD model of Shape Optimized cylinder.

For the shell thickness, I had to print a few different models to try and get the thinnest possible shell without the PLA losing structural integrity. For the end caps, the cylinders had to have sloped tops so that the end caps could be more easily adhered to the cylinder. The donut shaped holes only worked for solid or thick shelled cylinders. The greater aspect ratios seemed to move less side to side due to less vortices coming off the side of the cylinders, but a higher aspect ratio also greatly increased m*. Lastly, the Fusion Shape Optimization allowed me to create a cylinder with less than 3 times the density of air. Shown in Figure 1 hanging and in Figure 2, this cylinder had a low aspect ratio and was structurally unsound under larger forces, but showed what was needed to get traditional materials to such a low density. The huge volume of air had to balance out the density of the PLA which is approximately 1000 times that of air. This was my first time learning and using Fusion's Shape Optimization tool, so it could definitely be improved on. However, this model did achieve the goal of a very low m*. Our other models had m*'s 1 to 2 orders of magnitude greater.

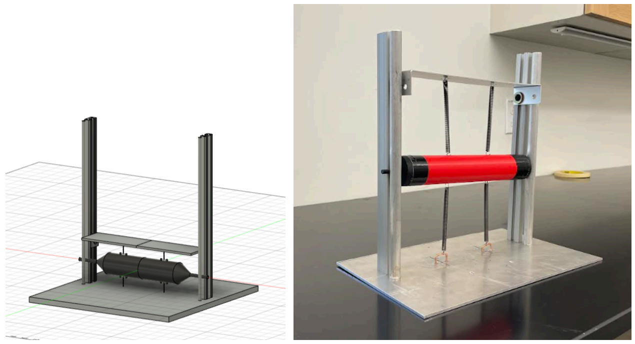

Figure 3 | 4. 3D CAD model and final all metal version of apparatus.

For the second task, I worked a lot with Vansh and J. to design and make the apparatus to hold the cylinder. After we brainstormed and researched a few different options, I created a CAD model of our design (seen in Figure 3) which included a base plate, a top plate, bars to allow for height changes in the top plate, rods to constrain the cylinder motion, and spring attachments. I initially 3D printed the top plate and the spring attachments. For the rest of the design, Vansh and I worked with J. to manufacture it. I eventually added metal handles to the base plate, and Vansh built a metal version of the top plate to create a model fully out of metal which can be seen in Figure 4.

Future Steps:

I thought a decent amount about possible future tasks and designs for this project. There seems to be two main steps before the project can get interesting data. First, the cylinders are not displaying the flow-induced vibrations while constrained. Second, the energy needs to be converted to electrical energy.

For the first step, the side-shedded vortices seem to cause side to side vibrations instead of the vertical ones we want. Using walls to prevent air from flowing off the sides seems to me to be the best way to fix this. If this sideways motion can be prevented this way, (unless I am forgetting another complexity) using low m* cylinders can become feasible again (previously prevented by poor aspect ratios) which would hopefully significantly help in getting the desired behavior given that the current cylinders are 1-2 orders of magnitude more dense than the original target.

There is also an argumentally more pressing problem - friction. However, there are options like lubricants, a redesign with ball bearings, or other friction decreasing designs that could be explored. One such design I am intrigued by is our current design without constraining rods. Theoretically, this would cause the springs to have to hold the cylinder, which would increase the force they are exerting, but would the vertical component of that force increase significantly? If it doesn't, then nothing has to be changed, and if it does, then we could just get lower k-valued springs. I think working out these calculations and seeing if this could work would be a great use of time because it would allow us to circumvent time-costly redesigns or messy lubricants. The question about the oscillations being linear enough would also become important, but I think that when the wind is fast enough to create the vortices we desire, then the springs should be extended enough that the movement will be approximately vertical. This would have to be tested though.

Another possible friction reducing method would be vertically constraining the cylinder using a string that holds the cylinder from a fixed point in front of the cylinder. This would constrain the cylinder to a circular path from the fixed point which could be approximated as a vertical line with a large enough radius and small angle changes. This might affect the airflow, but with a small string, this effect should be minimal (hopefully). This might be the easiest way to prevent the friction problem, and I think it is quite elegant.

For the energy conversion, I think that attaching the coil and having the cylinder move about threaded magnets to induce a current should work well enough to prove the concept and take data, but I am also intrigued by this research group's approach that uses a piezoelectric conversion method instead.

Their research apparatus is significantly different in scale and design though, but with a different conversion method, would it be that we wouldn’t need as nice oscillations to generate energy? I am unsure because I am not too familiar with how piezoelectrics work.

Lastly, I am also intrigued about if any CFD analysis or other simulations could somehow help with our understanding of our system. If I could model the system in CAD and simulate the airflow, perhaps we could glean insights into different models and features without having to build and test each iteration in the wind tunnel. I am planning on learning more about such methods this summer in my free time and would be interested in creating such simulations if I am able to.