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HC 407

Modeling Airflow Using a Simple Wind Tunnel

Abstract

The purpose of this project is to demonstrate the principles of drag and aerodynamics in a digestible manner to K-12 students. This objective was completed by creating a model wind tunnel that is testable for small models of vehicles and other objects. The apparatus was designed for maximum visibility of air flow and disruptions for a crowd of people. The device was constructed using a fan that pushes dry ice smoke through a clear, five inch diameter, acrylic tube. The fan was made to be removable, allowing for swapping out of cars in the center of the tube. Though small in size and relatively cheap with materials, the demonstration illustrates drag and aerodynamics well. The apparatus exhibits behavior similar to much more grandeur wind tunnels.

Background

In vehicle design, the largest resistive force (in addition to rolling friction, if an automobile) is aerodynamic drag. Drag is the force of air moving antiparallel to an object's direction of motion. One common example of drag can be observed when sticking a hand out of the window while driving down the highway. By placing a hand perpendicular to the ground, the air pushes back noticeably against the hand. However, if the hand is placed parallel to the ground, the air exerts much less force. This simple test is often the first time many kids can encounter aerodynamics.

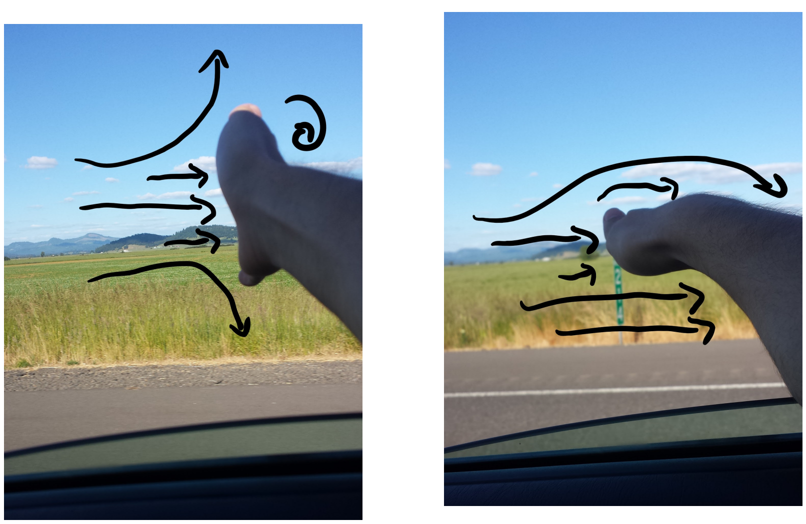

Figure 1: Air pushing on an open palm (left) compared to a horizontal palm (right)

To achieve the highest level of fuel efficiency, reducing drag is a top priority for engineers and scientists. Aerodynamic drag is primarily based on the outer shell shape of the body in motion. As such, different designs have different drag coefficients (measure of amount of drag for each velocity). A series of different shapes are presented with the same initial airflow shown below:

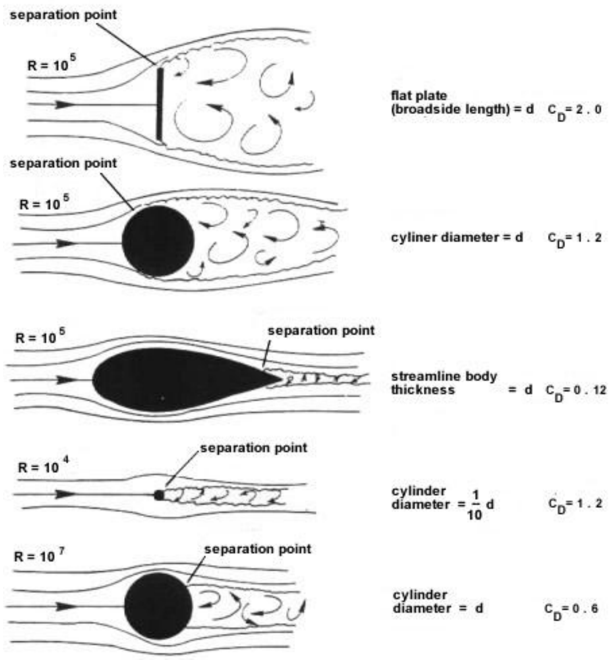

Figure 2: Several bodies with different dimensions and their corresponding drag coefficients[1]

Figure 2 shows a flat plate, three sized cylinders, and a streamlined body subjected to the same left to right airflow. Drag is demonstrated visually as the turbulence (nonuniform flow) directly to the right of each object. Numerically, drag is represented by its coefficient on the right of the figure, C_D. As it turns out, though flat bodies are usually easier to manufacture, more gradually curved bodies create less drag. In fact, the streamlined body above resembles the most aerodynamic body possible: the raindrop. Recently, cars have been moving closer and closer toward this raindrop shape:

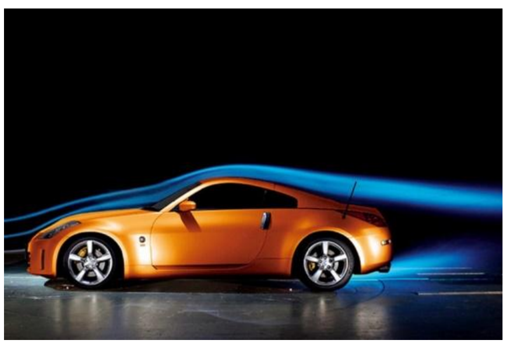

Figure 3: A modern sports car resembling a raindrop from front to back[2]

To test each design under more controllable/observable circumstances than on the road, wind tunnels are constructed. A wind tunnel can subject a body to a variety of wind speeds, along with other conditions, such as rain. Smoke and clever lighting are often used to view the streamlines of air visually (as in Figure 3 above). By using wind tunnels, scientists and engineers are able to determine which shapes produce the least amount of drag.

Wind tunnels are often very complex and expensive pieces of machinery. Unfortunately, other than the "hand outside the window" test mentioned above, a wind tunnel may be the only way for many to easily visualize and understand aerodynamics. The main objective for this project was to build a tunnel with the same functionality as more expensive designs, at a price point that could be manageable for teachers, families, and hobbyists. The design was intended to be simple, to ease the understanding of each component.

Materials:

- 1 4.5" inner diameter 5" outer diameter acrylic tube
- 1 Oyster dryer fan
- 1 green laser pointer
- 1 glass syringe (for creating laser sheet)
- Large package of straws (for flow straightener)
- Styrofoam cups
- ¼ inch flexible tubing
- Dry ice
- Toy cars/ airplanes
- 1 large sheet of plywood
- Wooden baluster
- Hot water

Most of these materials were collected using what was freely available in OSU's Graf 210, as well as Travis Walker's office. As such, there may have been better alternatives available, but in limiting expenses, the project's final cost was under $25. Also, this setup requires the purchase of dry ice for each demonstration. However, dry ice is common at most outreach events, so this problem should be minimal.

Assembly

To create the smoke, a Styrofoam cup was modified so ¼ inch tubing could be fit into the top hole. One end of the flexible PVC tubing was inserted into the smaller hole. For demonstration, the Styrofoam container was filled halfway with hot water, with dry ice added to achieve the desired amount of smoke. The tubing was sealed onto the styrofoam cup with glue.

The dryer was mounted at one end of the plywood. The fan was set into place, held steady by two mounted lengths of baluster. The tube was placed with one end firmly pressed against the fan intake. Two baluster squares were screwed down into the plywood, holding the tube in place. Inside the opposite end of the tube, 1.5 inch drinking straws were laid on top of one another and taped together until the tube was filled. The unattached end of the ¼ inch plastic tubing was placed into a straw about 3 inches down from the top of the straws.

Once a car or object was selected, the fan is removed to allow access to one side of the large tube. The car is placed anywhere in the tube, facing the end with the straws. The laser pointer can be shined through a syringe top in order to better view the smoke stream.

Figure 3: The constructed tunnel. The fan is on the right with the smoke coming in from the left.

Results

The wind tunnel was tested on a small model train car (Thomas the Tank Engine). The setup was used indoors and has not yet been observed outdoors (although external wind shouldn't impact the experiment much, as the majority of it is enclosed by the tube). However, relying on the indoor trials, the apparatus worked reasonably well.. The dry ice produced a steady amount of smoke in a thin stream, hitting the front side of the train, then travelling over its top.   Behind the train, there was visible turbulence caused by the body's shape. Physically, turbulence implies extensive drag caused by a less streamlined body, like the train (see the turbulence in Figure 2).

Figure 4: Testing of the model train. Notice the steady stream (left) breaking up over the top

The device worked well for intervals of about three minutes. However, at the end of the period, the amount of smoke entering the tube began to dwindle down. In most situations, dry ice was still present in the cup; however, no smoke was produced. At the end of the three minutes, the water could be dumped out of the cup and refilled with hot water to produce more smoke. Another slight issue in the design is the visibility of smoke, which will likely be worse if tested outdoors. The white smoke was the most apparent when there contrast was present on the back wall. For future modifications to the design, the addition of a black background could allow for better visualizing the smoke stream.

Acknowledgements and Bibliography

We would like to thank Travis Walker and the rest of the *Exploring the Magic of Physics via Hands on Service Learning* class for insight and inspiration. We would also like to thank Keith Levien for allowing us to modify and use his fan.

[1] Diagram taken from pilotfriend.com
[2] Picture taken from Ecomodder.com