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Article

Wind Resistance and Automobile Shapes

Shiva Neelakantan and Jacklyn Naughton
RISE Online STEM Research Institute

SUMMARY

Increasing a vehicle's aerodynamic efficiency allows it to travel the same distance using less power, and makes the vehicle more fuel-efficient. The purpose of this experiment was to identify which vehicle body features are the most efficient at decreasing the magnitude of wind resistance. We found that curved and torpedo-shaped bodies yielded the least wind resistance. In today's society, efficiency is what drives innovation; by implementing curved features into vehicles today, cars can become more efficient. Higher fuel efficiency makes vehicles not only more economical, but also safer for the environment. We hope our findings will help the automotive industry maximize efficiency.

INTRODUCTION

1.2 billion cars are driven each day, generating nearly 75% of the world's pollution (7). Many of these cars are inefficient and prone to wind resistance, causing them to release more emissions than necessary. The purpose of this research was to analyze various vehicle shapes and attributes to identify which of them yield the maximum aerodynamic design.

In our experiment, we measured wind resistance by keeping objects stationary and applying wind to the front of the object. Wind resistance, or drag, is the amount of frictional force on any moving object in still air. When a car is moving, trillions of air molecules are situated in front of the car. As the car approaches them, they begin to compress. This raises the air pressure in front of the car. The molecules moving along the sides of the car are at a lower pressure compared to the molecules at the front of the car. After the particles' interactions with the front of the car, they move over the hood, roof, trunk and over the rear vacuum. This rear vacuum applies an additional force in the direction opposite the car's motion. Together, these two forces create drag.

Figure 1: Wind tunnel. Completed wind tunnel with all three parts connected to one another.

A vehicle's aerodynamic efficiency is a major component of its overall efficiency. In this experiment, we attempted to analyze specific features of aerodynamic vehicles in order to identify which ones yield the least amount of wind resistance. We tested four shapes, corresponding to the different types of cars: cuboidal, sedan, hatchback, and torpedo. We hypothesized that the curved sedan shape would be the most aerodynamic, because it has the lowest estimated drag coefficient compared to the other designs. By determining which features of a vehicle make it the most aerodynamic, manufacturers can implement them into vehicles. Thereby increasing their fuel efficiency, reducing pollution and costs, and making the world a better place.

RESULTS

Each model was tested in a wind tunnel (**Figure 1**), and the measurements were recorded using a Newton spring scale. The control used in the experiment was the cuboidal shape (**Figure 2**). This shape is similar to that of a school bus. This shape has no curves or geometrical features that can redirect the flow of air in an efficient manner. This shape derails the flow of air and makes it more difficult for the air to go around the top of the car and into the space vacuum. For heavier vehicles like buses, pressure drag is the dominant component due to the shape's inability to effectively redirect the wind around the body's rear (5). The drag coefficient of a cuboidal shape is 0.80, which is substantial and almost double of most other vehicles (3). We predicted that this shape, the control of the experiment, will obviously not be the most aerodynamic, or even aerodynamic at all, for that matter. We found that the average Newtons of wind resistance created on the control during the experiment was 2.269 N.

The next shape used in the experiment was based almost directly off of the models of the Chevrolet Volt and Tesla Model S (**Figure 3**). Aspects of both cars, specifically the curved bodies they share, were applied in designing this second shape. The reason why these two models in particular were chosen was due to a study done in 2014, in which many models that were boasted for their aerodynamic shapes were tested in a wind tunnel one by one (6). In this study, the researchers observed that the Tesla Model S and the Chevrolet Volt had extremely low drag coefficients, with the Model S having .24 and the Volt having .28 (6). Therefore, a blend of both aerodynamic shapes was used in this experiment in an effort to innovate a newer, even more aerodynamic figure. We found that the average Newtons of wind resistance created on the curved shape was 0.921 N.

We next tested a hatchback shape (**Figure 4**). Hatchbacks are thought to be more inefficient than most sedans, because sedans have the ability to further cull the flow of the air over the car once it has passed through the roof, thus creating a more efficient release over the trunk space. However, there

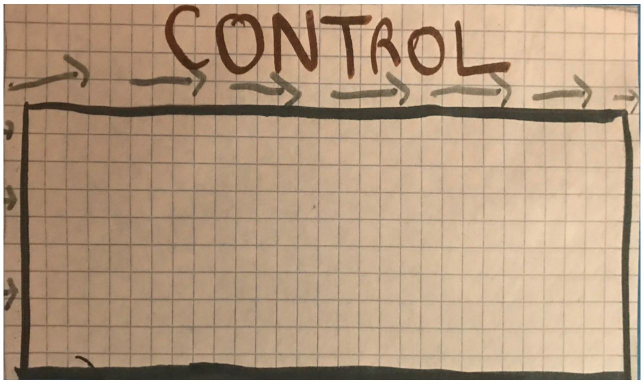

Figure 2: Control. Diagram of the Control.

are hatchbacks such as the Mazda3 or the Ford Focus that have very low drag coefficients, and there is not much published research on the reasons why this is the case. Hence, we tested a hatchbacktype shape in order to see what, if any, subtle aerodynamic features it had (6). We found the average wind resistance on the hatchback shape was 1.389 Newtons.

The last shape used in the experiment was based off of the 1950 Tucker Torpedo, a classic American vehicle (**Figure 5**). This vehicle, as its name suggests, was shaped like a torpedo. The car had a smaller frontal area, potentially directing the air to move around it much more efficiently.The data for all three experimental shapes generated significantly lesser wind resistance than the control. The curved shape and torpedo shape created the least wind resistance, and neither shape was significantly better than the other. The hatchback shape created the most wind resistance of the three experimental shapes tested, but still generated significantly less wind resistance when compared to the control.

DISCUSSION

The purpose of this research was to identify which vehicle shape has the least wind resistance. We hypothesized that the curved shape would be the most aerodynamic as evidenced by the least amount of wind resistance. If the shape experienced a higher force of wind resistance, it was considered to be less aerodynamic. The hypothesis was partially supported as the curved shape had the least amount of wind resistance (0.921 N), followed by the torpedo shape (0.988N) (**Figure 6**); however, there was no significant difference between the two shapes. Therefore, we conclude that the curved and torpedo shapes are the best automobile shapes for decreased wind resistance. There are potential

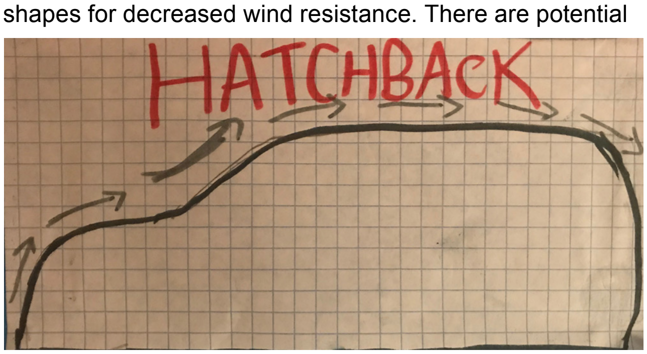

Figure 4: Hatchback. Diagram of the Hatchback Shape.

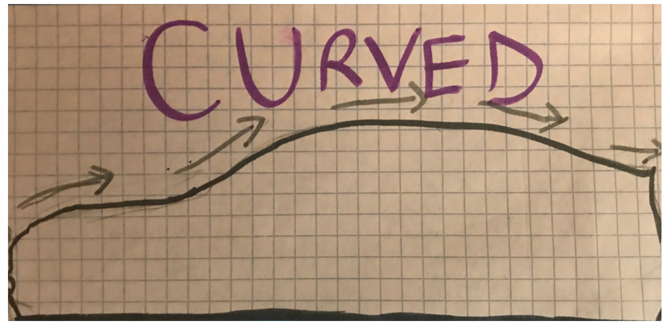

Figure 3: Curved. Diagram of the Curved Shape.

sources of experimental error that might have affected our results. For instance, the shapes did not have completely even surfaces, which may have affected the exact amount of wind resistance observed. The wind tunnel may have also not been entirely smooth, which could have affected the results. As demonstrated by this research, air travelling around jagged shapes creates wind resistance when it has to change its direction. The variety of undesired flat points and unbalanced cuts on the top of the shapes, although minor in size, could affect the measured value of wind resistance.

What one can conceptually draw from this conclusion is that when a vehicle has more curved contouring on its body, it will yield less wind resistance, increasing its aerodynamic efficiency. Both the curved and torpedo shapes had significant amount of curves around the profile, and subsequently had the lowest Newtons of wind resistance in the experiment. By increasing a vehicle's aerodynamic efficiency, it will take the car less power to travel the same distance as a vehicle with a lower aerodynamic efficiency and using less power means saving the fuel the vehicle runs on, meaning that the vehicle will be more fuel-efficient.

By applying curved parts to vehicles' profiles, they can become more efficient, implying higher fuel efficiency, making vehicles better not only economical, but safer for the environment.

METHODS

Constructing model shapes

We gathered the necessary resources for the experiment: graph paper, a pencil, scissors, four blocks of polyfoam (each being 100 mm x 100 mm x 200 mm), a coping saw, a newton spring scale, a sufficient amount of duct tape, a premade
or constructed wind tunnel, and an adequate amount of newspaper. The wind tunnel generated wind that had a

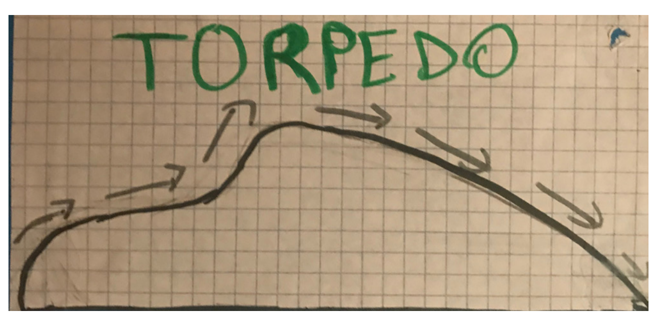

Figure 5: Torpedo. Diagram of the Torpedo Shape.

speed of approximately 1.5 meters per second, and had a cross sectional area of 2.63 m^2 . We drew out each of the four shapes on graph paper, and proceeded to use scissors to cut out the shape from the graph paper to trace it onto one of the 100 mm x 200 mm sides of the polyfoam block. After tracing the cutout
onto the block, we carefully cut along the traced lines using the coping saw until we were left with the body of the model. After that, we taped a sheet of newspaper to the bottom face of the shape, roughly equivalent to that face's area and dimensions, in order to diminish the differences in friction between the models designed in the experiment. The approximate masses of the control, the curved shape, the torpedo shape, and the hatchback shape were 51 g, 47 g, 45 g, and 50 g.

Measuring wind resistance

In the middle compartment of the wind tunnel, we placed the Newton spring scale and duct taped it to the base of the compartment. Next, we attached the bottom of the test model of the first shape to the anchor on the spring scale using duct tape. The shape was attached to the hook of the scale, with the front of the shape facing the spring scale. After connecting all three compartments with the springs at the ends, we began the experiment. We turned on the fan of the wind tunnel, waited approximately five to ten seconds, and then recorded the reading from the Newton spring scale. After doing so, we turned off the fan.

We then recorded the results and calculated the mean, standard deviation, standard error, and 95% Confidence Interval using Google sheets (**Table 1**), an online spreadsheet software. A *z*-test was conducted on the results as well.

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	Shape 1- Control(N)	Shape 2- Hatchback(N)	Shape 3- Curved Shape (N)	Shape 4- Torpedo (N)
Trial 1	2.22	1.42	0.92	0.99
Trial 2	2.23	1.37	0.94	0.98
Trial 3	2.20	1.38	0.93	1.00
Trial 4	2.40	1.40	0.89	1.00
Trial 5	2.32	1.39	0.92	0.99
Trial 6	2.25	1.35	0.93	1.01
Trial 7	2.24	1.38	0.91	0.96
Trial 8	2.21	1.41	0.90	0.98
Trial 9	2.30	1.39	0.88	1.00
Trial 10	2.32	1.40	0.90	0.97
Mean	2.269	1.389	0.921	0.988
SD	0.0638	0.0202	0.0193	0.0155
SE	0.0202	0.0064	0.0061	0.0049
95% CI	0.0370	0.0117	0.0112	0.0090

Table 1. Shows statistics including each of the trials, means, standard deviations, and standard error. The error bars were set at the 95% Confidence Interval, which was calculated using the equation $\bar{x} \pm z(\sigma/\sqrt{n})$, where $\bar{x}$ is the sample mean, z is the z-value, σ is the standard deviation, and n is the number of trials . Each of these values were calculated by google sheets. If the error bars on the graph overlap, then the data is not significant; if the error bars do not overlap, then the data is significant.

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