Making Modern Cars More Streamlined and Aerodynamic

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Practical Applications of Advanced Mathematics.

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Abstract

In my experiment, I wanted to see how aerodynamic modern automobiles are, and what can be done to modify them to be more streamlined and efficient. My goal, therefore, was to discover what car companies are not doing, and what can be done to make modern cars more aerodynamic.

I used a small model of a 2007 Subaru Imprenza for experimentation. I used a 30 inch by 6 inch wooden plank and attached a rubber band to it, weighed the rubber band, and marked points at 0, 81, 162, and 243 grams, to show the grams of drag at 40 mph. Then, I attached four streamers to the car to show the effects of the vortices. Finally, I attached this to the top of my dad's truck and asked him to drive at 40 mph while I observed. Ultimately, the car emitted 108 grams of force in drag, and the streamers indicated the air warped and swirled around the back of the car when it left the sides, creating a vacuum. To modify the cars shape, I removed spoilers, mirrors, the hood camera, and the air valve.

Next, I modified the car by drilling small holes in the hood, windscreen, back window, and front and rear bumpers. I slipped wire through the holes, crafted the wire into a cone in the rear of the car, and covered the entire car with a type of duct tape. When I ran it through the experiment again, it emitted 68.5 grams of drag. Ergo, by elimination of points of pressure, and making the car more streamlined and aerodynamic, I was able to reduce the cars drag by almost forty grams of force.

Background.

In the history of car manufacturing, engineers have struggled with how to make designs more and more aerodynamic and efficient as early as the 1930's, with the introduction of cars such as the Burney car in 1927, and the Tatra T – 77 model in 1933 (Damme, 2009). However, with the introduction of new car technology in the aftermath of WWII, and a general American taste for large, powerful cars, the quest for the perfect aerodynamic design has slackened significantly.

When you think about any object moving through a fluid such as air or water, there are two things that that air has to do for the object to be considered "streamlined"; it must cleave the air evenly and cleanly, and then it must bring it back cleanly and smoothly, preferably with as little air bending at all. The goal is in fact to "prevent any air flow separation."(Designing Tips, 2009) Think of air as a zipper – separate and reunite. A nearly perfect car would need to have a half – circle shape in the front, and an eleven degree cone point in the back, separating and reuniting the air (The first order equation, 2006). It would have to have no indentations, and nothing to absorb the passing airflow, so doors, mirrors, and windshields would be out of the question. Wheels would be possible, but it would be an extreme engineering feat. Such a car would be very hard to mass produce, because the technology to create the curved structure and oddly–shaped frame would have to be state of the art, and therefore, very expensive. Despite this, without the windshields and doors, it would be, to say the least, difficult to sell.

As a car such as this would be impractical, and extremely hard to make, the focus was shifted to how modern cars can be modified by using a few simple laws and rules. To gain speed and efficiency, two forces have to be fought; down force and drag. Down force is the effect of the airflow to push down the car and maintain traction with the ground. Naturally, some of this is needed, but too much has a negative effect on the cars ability to properly function. Racecar designers utilize this to make wings and spoilers for their cars. The other, and more brutal force, is drag. Drag can be broken up into three forms –friction drag, form drag, and induced drag. Friction drag simply states that the smoother an object is, the more easily the air will travel over it. Naturally, this was not a big problem for manufacturers. The less friction you have, the greater speed you can attain. Form drag is determined by the actual shape of the object, meaning that much of the velocity and efficiency of an object are dependent on form drag. Induced drag is formed by vortices, or swirls that trail an object if the air is not properly reunited (Johnston, n.d.).

While designing my car, I followed Bernoulli's Principle: the pressure of a fluid decreases as the fluid flows faster around an object, and pressure increases as a fluid flows slower. (Yeager, 2001) This means that exponentially, the more blunt and boxy a car is, the harder it is for air to flow around it, increasing frontal pressure exponentially, and significantly decreasing the car's efficiency. It would be like trying to cut a piece of cheese with a cube. The areas where the air is gathered in high points of pressure are called pressure points, and they are the main cause of form drag. (McNulty, 2006) I found a useful graph that showed where, on a small sedan, all the pressure points are located. From what I could tell, there are eight main pressure points that harm a car's ability for speed and efficiency. There are four on all the wheels, one big one on the front grill and bumper, two on both windshields, and one where the glass of the windshield meets the hood. (Mcnulty, 2006) This proved useful in the designing of the cover for the front hood and grill. Finally, I wanted to calculate just how much less drag I was creating. I knew that by the end, I would have two measurements of drag, but I wanted to find the drag coefficient. The drag coefficient, or Cd, is a characteristic of a body flowing in viscous fluid, equal to the ratio of twice the force on the body in the direction of flow to the product of the density of the fluid, the square of the flow velocity, and the effective cross-sectional area of the body. This is represented by the equation $Cd = (2Fd)/ pv^2A$, where Fd is the force of drag, (in this case, in grams), p equals the viscosity of the air (in atmospheres), v is the velocity (in mph), and A is the cross sectional reference area. (Benson, 2008) With this information, I was ready to start my experiment.

Research Question

How can I modify a modern sedan to be more aerodynamic and efficient at high speeds, and why are car companies not making these changes already?

Methods

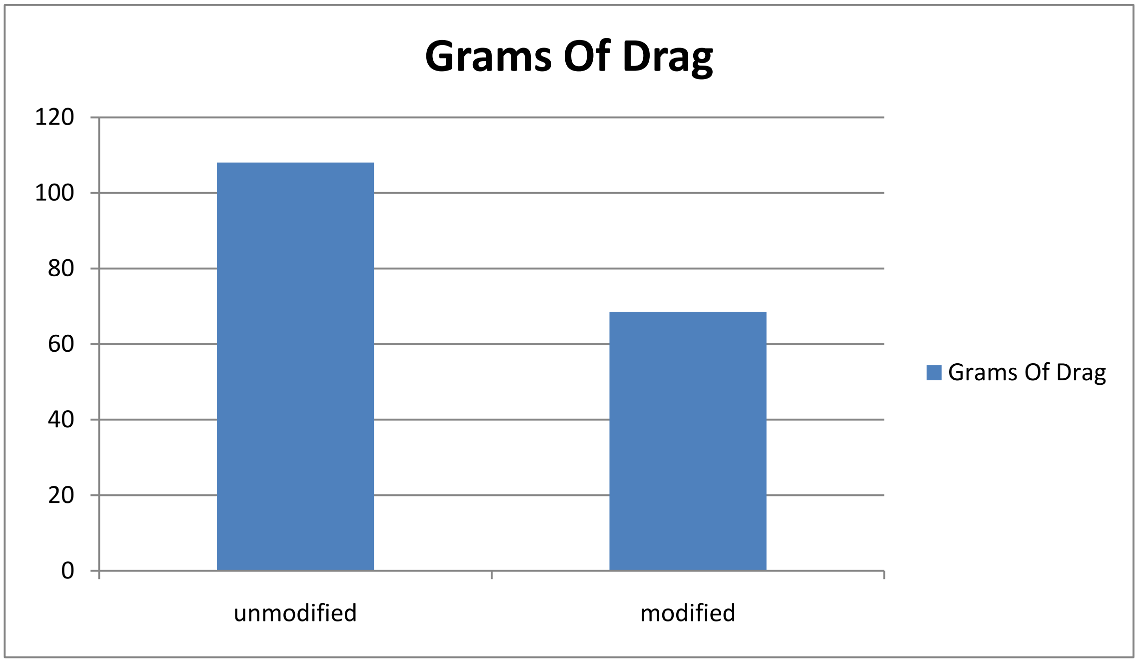
When I started, I knew that first and foremost, I wanted to measure the forces of drag for my equation. If I could lower the force of drag, it would be equivalent to improving a cars fuel efficiency. To measure drag forces, I tried to find the thinnest and flattest surface that I could. Preferably, I would have used a nonexistent, infinitely thin lateral plane, but instead, I used a thin wooden plank with dimensions of 30 inches by 6 inches, half an inch thick. I found a sturdy long rubber band and nailed it to a point near the edge of the plank. It was critical that I use a long rubber hand rather than a short one, because the difference in force would be easier to see. To show the 0 grams of force mark, I simply hung the rubber band down and marked there on the board the farthest part was hanging. I had no definite weights, so I looked up the individual weight of a copper one dollar coin, and found it to be 8.1 grams. I stacked ten of these twice, and taped them together in two cylinders of ten coins each. While I weithed the ribber band, I placed marks at 81 grams of force, 162 grams of force, and 243 grams of force (the distances from 0-81 and 81-162 were exactly the same to the millimeter, so I just made another mark of the same exact distance.) I drilled a small hole in the front grill of the car, and slipped the rubber band through to a hook on the inside. I taped streamers to the hood, two back doors, and underbelly, so that I could effectively see and record the behavior of the vortices. I attached the entire apparatus to the top of my dad’s truck, and had my dad drive at 40 mph on a flat stretch of road. I recorded the grams of drag, from the rubber band to be 108 grams, effectively giving me my first force of drag, or Fd measurement. Also, three of the streamers flared out about two inches behind the car, and then thrashed vigorously afterward. The fourth, bottom one, clung to the bumper of the car, and only flared out at the top of the back compartment. I noted this for later modifications.

Now was the time to modify. I was considering using clay for the proposed modifications, but it was too heavy and unstable, and at high speeds, it would prevent me from getting an acurate drag measurement by weighing the car down. After all, clay is comparatively rough, and so it would contribute in friction drag. Instead, I used wire for a frame, and duct tape for the actual covering, since duct tape is smooth, sturdy, and relatively lightweight.

I went back to my pressure point and wind flow diagram. I had already solved the issue of friction drag, so I wanted to focus on the form drag and induced drag. First, I cut off all unnecessary add–ons that might disrupt the airflow. I removed the spoiler, the wing, the air intake, the hood camera, and the mirrors. To eliminate form drag, I added fairings on the front and back wheels so air would travel over them, rather than through. Then I considered the back bumper. One of the main problems all moving objects experience are wind flow patterns behind the object called vortices. These act like vacuums, and, especially with cars, can significantly harm speed ability and efficiency. To eliminate these, multiple cones to direct the airflow can be added, but on such a small scale with limited information and materials, I decided just to add one large rear cone. According to gassavers.org, the perfect angle would have been an 11 degree angle, but anywhere between 11 and 30 degrees would maximize efficiency. I designed my cone to extend two inches behind the car, and for improved efficiency, made the angle measure approximately 30 degrees (first order, 2006). Any sharper angle would need to have been longer, making the design impractical for use on the road. After implanting the wires, I covered the car with three layers of duct tape.

After this, I decided to address form drag, and modify the hood. According to gassavers.org, to eliminate all turbulence and get a near perfect aerodynamic shape, the front of the car would have to be a 180 degree half–circle shape (first order). Like the long cone, this would be extremely impractical, so I modified the teardrop shape. In the front, I made a sort of elongated sphere, or ellipse which covered the bumper, front grill, windscreen, and some of the front doors. I made the tip of the ellipse come just over a half–inch above the ground so enough air could travel under the car, to stop down force, but not too much to make the wheel drag a major issue. I found some useful software from nasa.gov that I used to model my ellipse. It seemed to flow well, with little trouble form vortices, and little frontal pressure. The only downside was that at 40 mph, it emitted 3.5 lbs of down force. This was expected, however, because the speed we were going was disproportionate to the size of the car, and I wanted to have large measurements so that any change or improvement would be fairly obvious and easily measurable. With these modifications, I was ready to run another test.

Once again, I attached the streamers, the rubber band, and put the apparatus on my Dad's truck. We drove down the same stretch of road, and once again, cruised at 40 mph. The streamers did not travel perfectly down the cone, but nearly. Only the top streamer flared out. The others clung to the cone, and flared out evenly behind the tip. I measured the grams of force to be 68.5 degrees, ultimately giving me an improvement of 39.5 grams. In this way, my experiment was a success.



Results

Since I had performed my experiment, and all the elements had been addressed, I wanted to see just how much I had changed the actual design. Since most of the modifications had just been extensions of the front and rear, the height and width had not changed at all. Thus, friction drag was not a major point of concern. However, with the elongated sphere in the front grill, and directional cone in the back, the new length was 11.5 inches; a 2 and 3/8 inch gain overall. Then, I began the mathematics which was rather more difficult. I was going to use the equation previously described to find the drag coefficient, but first I had to find the reference area, which was a cross section of the front. With some quick measurements, I found these dimensions:

The bottom rectangle was 1.375 by 3.75 inches, giving it an area of 5.15625 square inches. The top was a trapezoid, and more tricky to solve. Using the formula A = a/2(b1+b2) I found that the area of the top section was 2.875 square inches. When added, the total cross sectional area was exactly 8.03125 square inches. Using this, I plugged the figures into the drag equation; Cd = (2Fd)/ pv^2A. For the first car, $(2(108))/1(40^2)8.03125$ this yielded a Cd of 0.0168. When I plugged in the new force of drag, I came up with this: $(2(68.5))/1(40^2)8.03125$, which yielded a Cd of 0.011. This means that if a Subaru imprenza cruised at 17 miles to the gallon, with these modifications, it would cruise at 26 miles to the gallon; a definite improvement.

Conclusions

One of the things that my study encompassed was the moral implications of modifying inefficient cars. In fact, the morality of inefficient cars was one of the key inspirations of my research. Of course, it is economically important to be able to use as little fuel as possible in these times of economic destitution. But more importantly, Americans need to focus on the environmental problems to which they are directly contributing. Each year, an average American car puts out at least nine metric tons of carbon dioxide (US emits, 2006). We also account for at least 50 percent of the world's carbon emissions. Cars are the second biggest energy–consumers, next to homes. If we can eliminate at least some of this negative output, we can have a positive impact on future generations.

Had I more time, I would have tested the car at different speeds to determine its optimal speed. I also would have liked to extend the length of the back cone, because from an aerial view, the back cone was certainly not anywhere near 30 degrees. I also would have liked to extend the front and lower it slightly, making it more rounded at the end. As mentioned above, an elongated teardrop shape would have been preferable. I also would have liked to try new skins, such a saran wrap, aluminum foil, and possibly even a type of thick plastic. This experiment, however, was conducted for the purpose of recording the effects of making a car more streamlined, and seeing if and how I could accomplish that goal.

If cars can be engineered to be very fuel efficient, then why aren't car companies doing this? The simple fact is this; designers design their cars mostly for looks, not for fuel economy. Large boxy cars are also easier to design and mass produce than sleeker, more efficient ones. Angular, straight-framed cars are far easier to put together than curved, low-built cars.

Despite these hindrances, is this not the age of innovation? In my opinion, we should stand up to the automobile companies, and tell them what we want, and reward those who give us well-designed, fuel efficient cars. As a matter of fact, public polls demonstrate that the public really does not even like those kinds of cars. The fact that there are more of them is a product of corporate strategy. According to the Detroit project's website, between 1990 and 2000, the amount of money spent on SUV ad campaigns rose from 172.5 million to 1.51 billion (Detroit project, 2010). Companies such as General Motors trick us into thinking that it is practically un-American not to drive a gas guzzler. As surveys are conducted, and people are asked if they want green houses and cars, the answers come back recurrently, "yes, we do"(DiCaprio, 2007). The time has come to remake the chain between the people, government and corporations. With cooperation, we can alter the course, and create a brighter future.

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