The Effect of Bubbles on a Car's Fuel Efficiency

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Abstract

Since the first automobile in 1885, researchers have been constantly improving the aerodynamics of cars. Aerodynamics plays a huge part in reducing fuel efficiency of cars, as reducing the drag of the car will benefit its efficiency. Approaches like more streamlined models, diffusers, and front splitters, have been used throughout automotive history in an attempt to improve cars' aerodynamics. Recently, golf ball-like bubbles have been placed on a racing-focused supercar to reduce the drag and lift of said car through reducing the separation point on the car, decreasing the size of the vacuum behind the car. This concept could potentially be used to increase the fuel efficiency of the average production car, reducing fuel consumption and emissions. Placement of bubbles along the trunk and roof of an average sedan are tested and compared with a control car. Bubbles along the trunk provided a 2.39% decrease in drag and a 1.6% increase in the fuel economy of the average production sedan, while bubbles along the roof only increased the drag coefficient and decreased the fuel efficiency of the sedan. In conclusion, bubbles provide very slim benefits and require more research and development before they become viable enough to use on production automobiles. The purpose of this research paper is to explore this method of increasing fuel efficiency.

1. Introduction

Automobiles have a long history of rising fuel-efficiency; new improvements and innovations are constantly being implemented for our production cars to use less fuel to go farther distances[7]. Higher fuel efficiencies mean less fuel costs, and more importantly, less pollution from passenger vehicles. Aerodynamic drag, the force of air opposing the vehicle as it moves forwards, is a key factor in determining a car's fuel efficiency, where decreasing drag can lead to the development of more efficient cars.

Aerodynamic drag is caused by drag wake, which is essentially a vacuum which forms behind a car which "sucks" the car backwards. This drag wake occurs because of the separation point; the separation point is where the smooth flow of air around the car detaches itself from the car and goes back into the atmosphere around the car. This separation point causes the drag wake because the air detaches itself from the car, but still flows semi-straight with its initial momentum. Because the air is flowing straight, but the car's rear windshield tapers downward, a vacuum is created between the airflow and the car; creating the drag wake (Figure A).

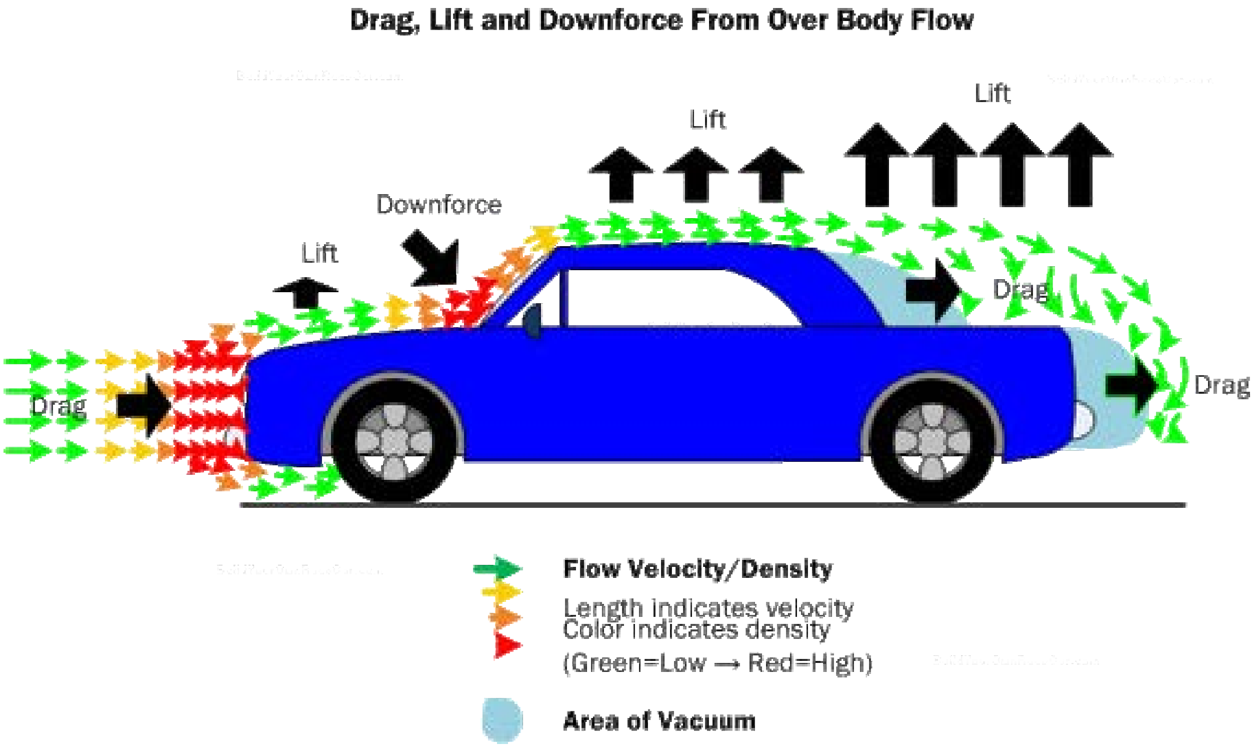

Figure A: Aerodynamics diagram of a sedan[1]

Laminar flow is when air flows in parallel lines, and turbulent flow is when air flows in unpredictable vortexes. A boundary layer is a layer of air on an object's surface that accelerates from a velocity of zero next to the object to the velocity of the air around it as it gets farther away from the object's surface. Boundary layers can either be laminar or turbulent.

A relatively recent Bugatti model, the Bugatti Bolide, used morphable bubbles (Figure B) to "reduce the aerodynamic drag of the scoop by 10 percent and cause a 17 percent decrease in lift", according to Bugatti's simulated figures[3].

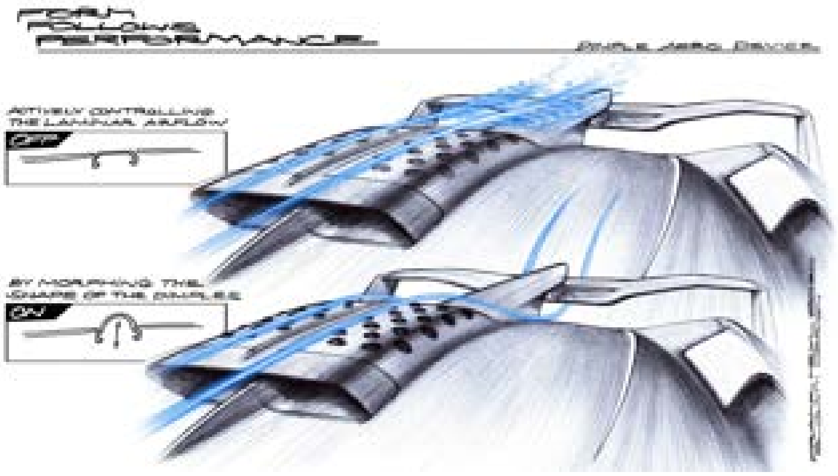

Figure B: Drawing of Bugatti's bubble aerodynamics design

The concept of the dimples comes from golf balls, which have dimpled exteriors because the dimples reduce the ball's overall aerodynamic drag. It does this by creating a turbulent boundary layer around the ball, which pulls the air around it even closer to the ball's surface. This allows the laminar flow around the ball to travel along the ball's surface for even longer, decreasing the separation point between the laminar flow and the ball's surface(Figure C).[2]

Figure C: Image explanation of golf ball dimples

Bugatti used this concept in a similar way, to push the separation point of the Bolide further back for less aerodynamic drag. The turbulent boundary layer created by the bubbles pull the laminar flow in to follow the roof of the car all the way to the spoiler, further increasing the spoiler's efficiency as well.

An old Mythbusters video covered this theory through an experiment, in which they compared the miles per gallon(mpg) of an unmodified Ford Taurus with the mpg of a Ford Taurus with 1082 dimples all over the exterior (Figure D). The result was a significant 3 mpg increase in fuel efficiency(at 65mph). Although this proves the theory, strategic placement of said dimples may increase or decrease fuel efficiency further.

Figure D: Dimpled Ford Taurus used in Mythbusters video

Morphable dimples/bubbles may be key in reducing aerodynamic drag of automobiles, especially on highways and freeways. Through strategic placement of bubbles on automobiles' exterior surfaces, aerodynamic drag can be reduced, improving the automobiles' overall fuel efficiency. The lift of the car can also be reduced, though that would be more useful in the racing world. The purpose of this research paper is to explore this method of increasing fuel efficiency.

2. Model and Model Variations

The base testing vehicle is shown in Figure E. The model was created using the newest version of Fusion 360. The model is exactly 4.65 meters long, with a frontal area of .7724 meters squared and a wheel radius of .325m. This model represents half of an average production sedan, as Simscale, the CFD software used for testing, uses a symmetry boundary condition explained in section *3.1 Boundary Conditions*.

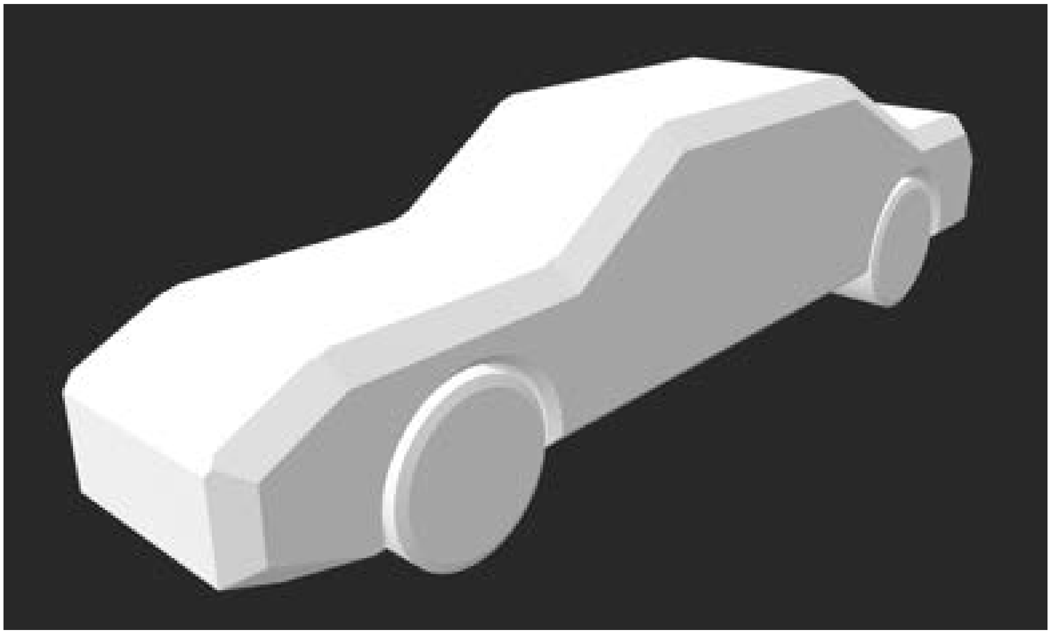

Figure E: Base sedan model

The model in Figure F is the base testing vehicle with bubbles added along the roof of the car. The bubbles are 25 millimeters in diameter and are arranged in 20 rows of 15 bubbles, spanning the entire roof.

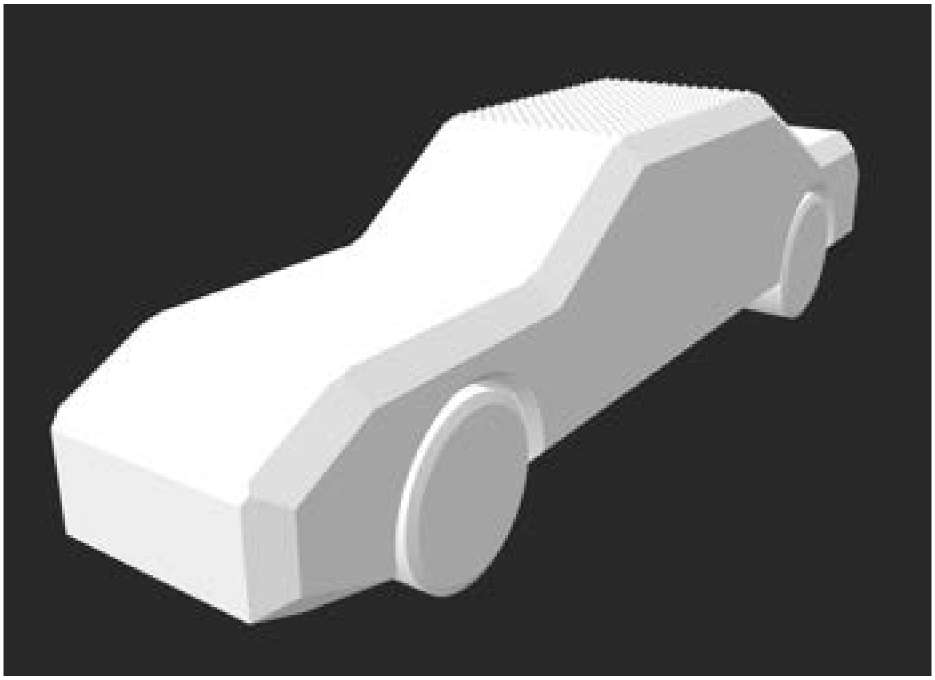

Figure F: Sedan model with bubbled roof

The model in Figure G is the base testing vehicle with bubbles added on the trunk of the car. The bubbles are the same size as the previous version(Figure F) and are arranged in 10 rows of 15 bubbles, spanning the top of the trunk.

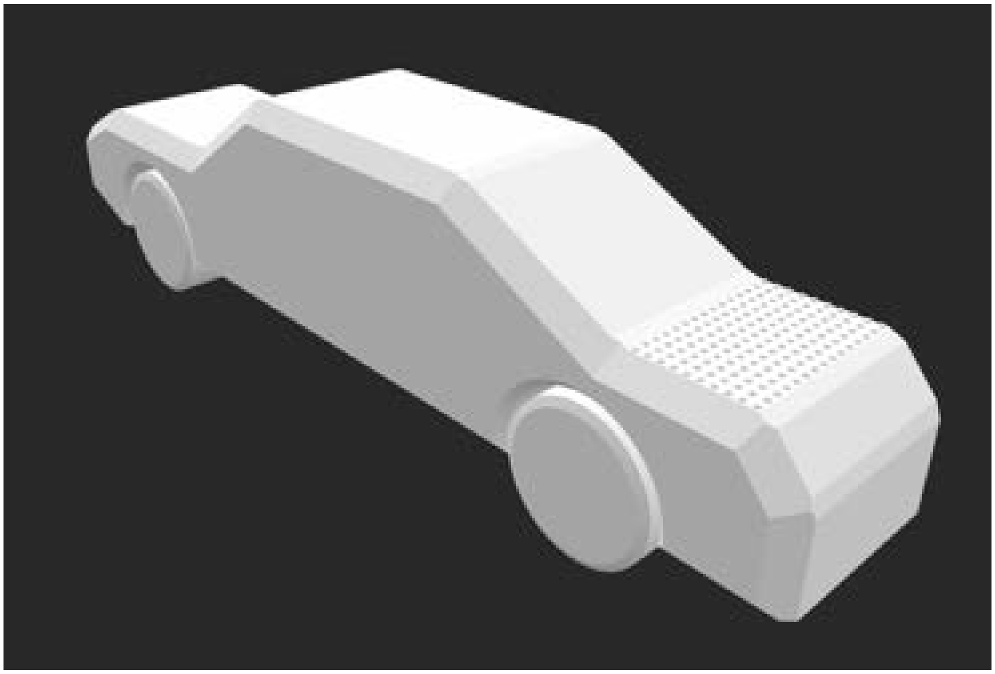

Figure G: Sedan model with bubbled trunk

3. Simulation Method

3.1 Boundary Conditions

Boundary conditions are set to provide an ideal testing environment for the vehicle. Velocity inlet is set to 30 meters per second, or approximately 67 miles per hour, to simulate the average speed limit of a highway in the US. Pressure is constant at 1 standard atmosphere. The ground is set to a moving wall, moving the same speed as the air, 30 meters per second. The top and furthest walls are set to slip walls, which act as frictionless surfaces that air can pass by without a velocity gradient. The wall adjacent to the model is assigned as a symmetry wall, so the program simulates as if the other half of the car was there without having to fully simulate the whole car.

3.2 Simulation Methods

Computational Fluid Dynamics(CFD) uses the Continuity Equation, the Navier-Stokes equation, and Newton’s First Law of Thermodynamics to predict the flow physics given proper operating conditions. CFD software uses an initial guess as a starting point–then, through numerical iteration, the tests converge into a final flow field. The solution converges when the solving continues to iterate but the solution field stays constant. Using the aforementioned boundary conditions, ideal operating conditions are met, and using 3000 iterations the tests converge. In this experiment, Simscale, an online CFD software, is used to run all three experiments.

4. Results/Discussion

The drag coefficient is a number that models the complex dependencies of the flow and shape conditions on drag. Actual drag force is directly proportional to drag coefficient, meaning that drag force will increase as drag increases and vice versa. The lift coefficient is similar, except it determines the lift force on the car. The moment coefficient shown in the charts measures the moment due to only the aerodynamic force, and is as important as the other two[8].

The drag coefficients for the base model, bubbled roof model, and bubbled trunk model, converged at 0.461, 0.517, and 0.450, respectively(Figures H, I, and J). The base drag coefficient is reduced by 2.39% by adding bubbles to the trunk. The lift coefficients for the base, roof, and trunk models were 0.420, 0.310, and 0.223, respectively(Figures H, I, and J). The base lift coefficient is reduced by 47.90% by adding bubbles to the trunk, a significant decrease. For the aforementioned drag and lift coefficients, it is the very last value on the drag and lift coefficient lines on the graphs and not an average because Simscale works by running the simulation over and over until it finally converges on an ideal simulation, which would be the last value.

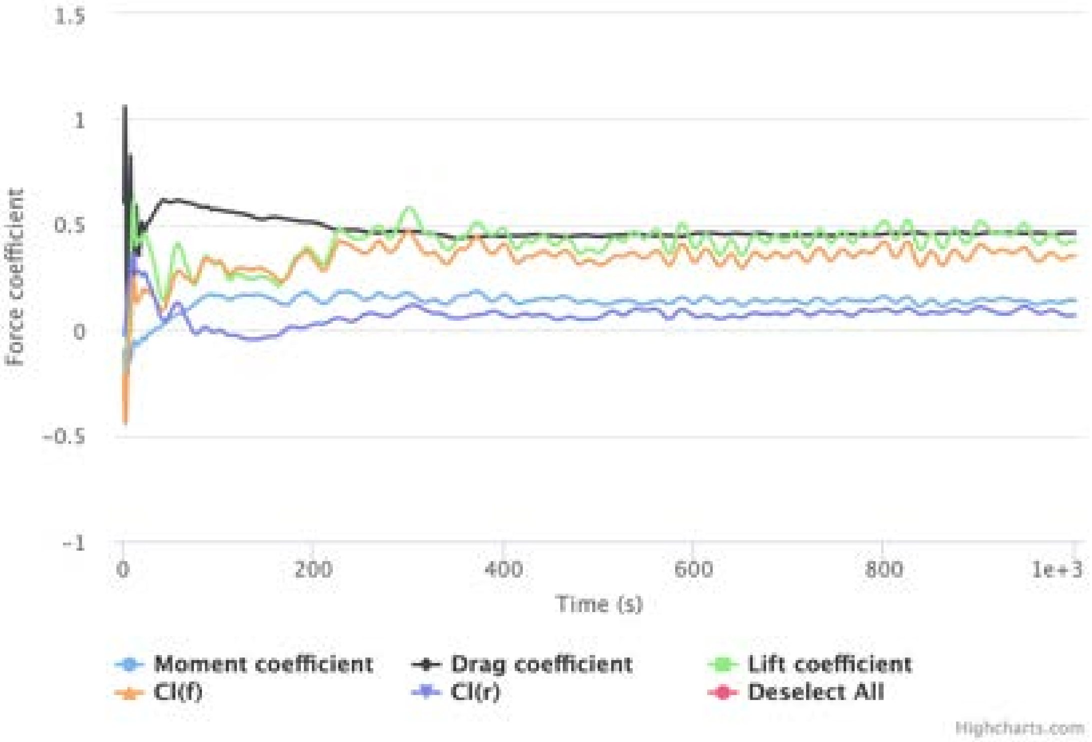

Figure H: Force and moment coefficients chart for the base model

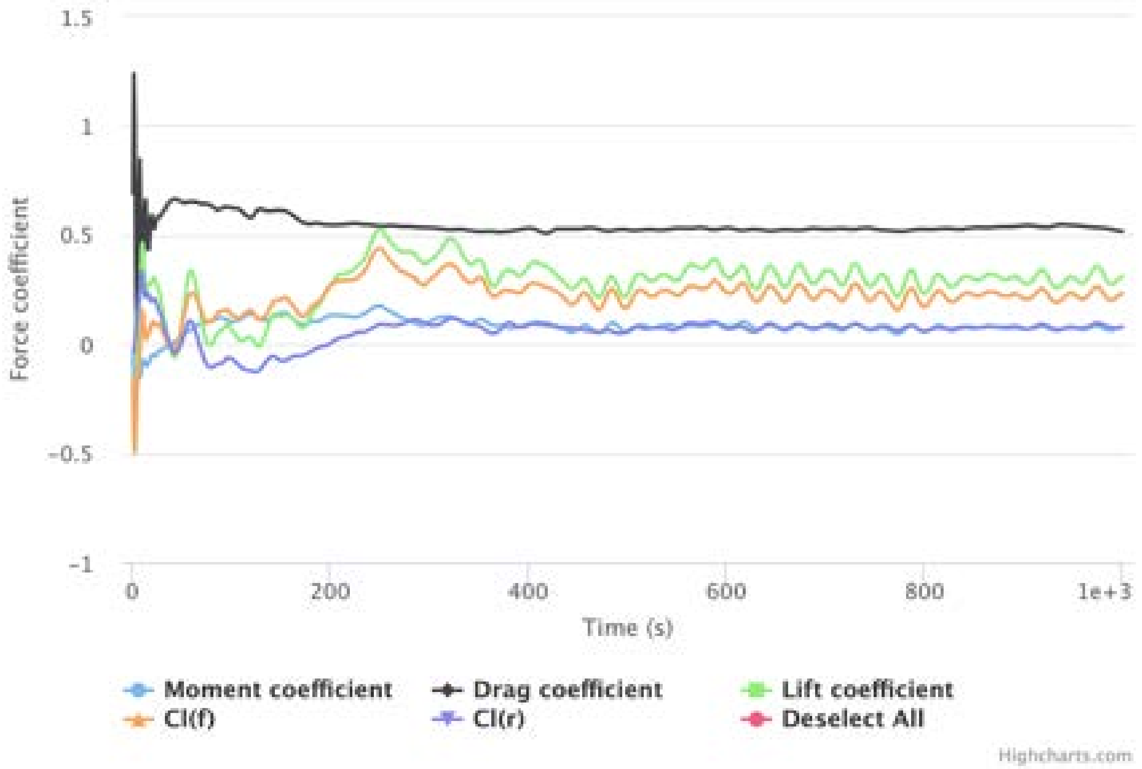

Figure I: Force and moment coefficients chart for the bubbled roof model

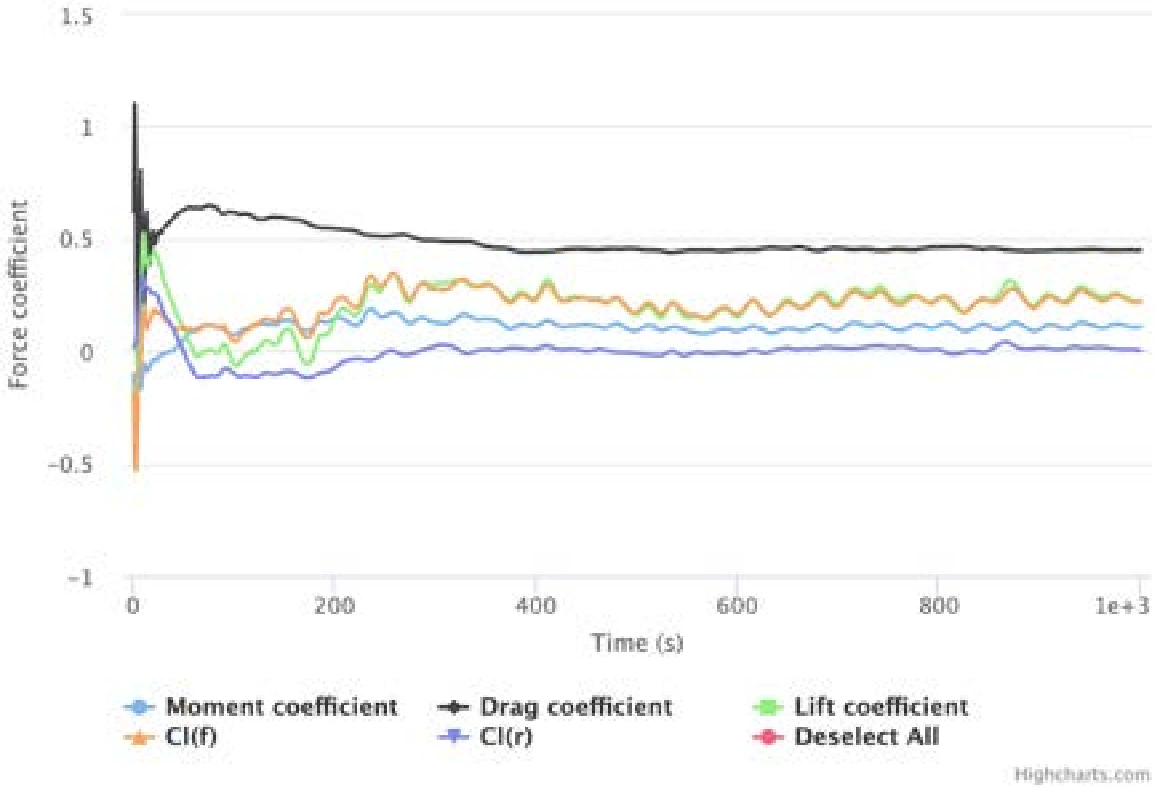

Figure J: Force and moment coefficients chart for the bubbled trunk model

In the surface visualization of the Turbulent Kinetic Energy(TKE) around the cars, the TKE is the least behind the bubbled trunk car, and the most behind the bubbled roof car. The turbulent kinetic energy is essentially a quantitative measure of the intensity of the turbulence. Turbulence in the drag wake will be pulling more air with it–meaning the car will have to drag more air–creating a higher drag coefficient[9]. Since the TKE is lowest behind the bubbled trunk car, the drag coefficient is the lowest, as discussed with the force and moment coefficient charts(Figures H, I, and J). The small patch of TKE behind the bubbled trunk car is most likely very thin because the separation point is further down the car, so there is less overall drag wake and less turbulence behind the car. The TKE charts of the base car and the bubbled roof car are similar, but the base car has significantly less behind it.

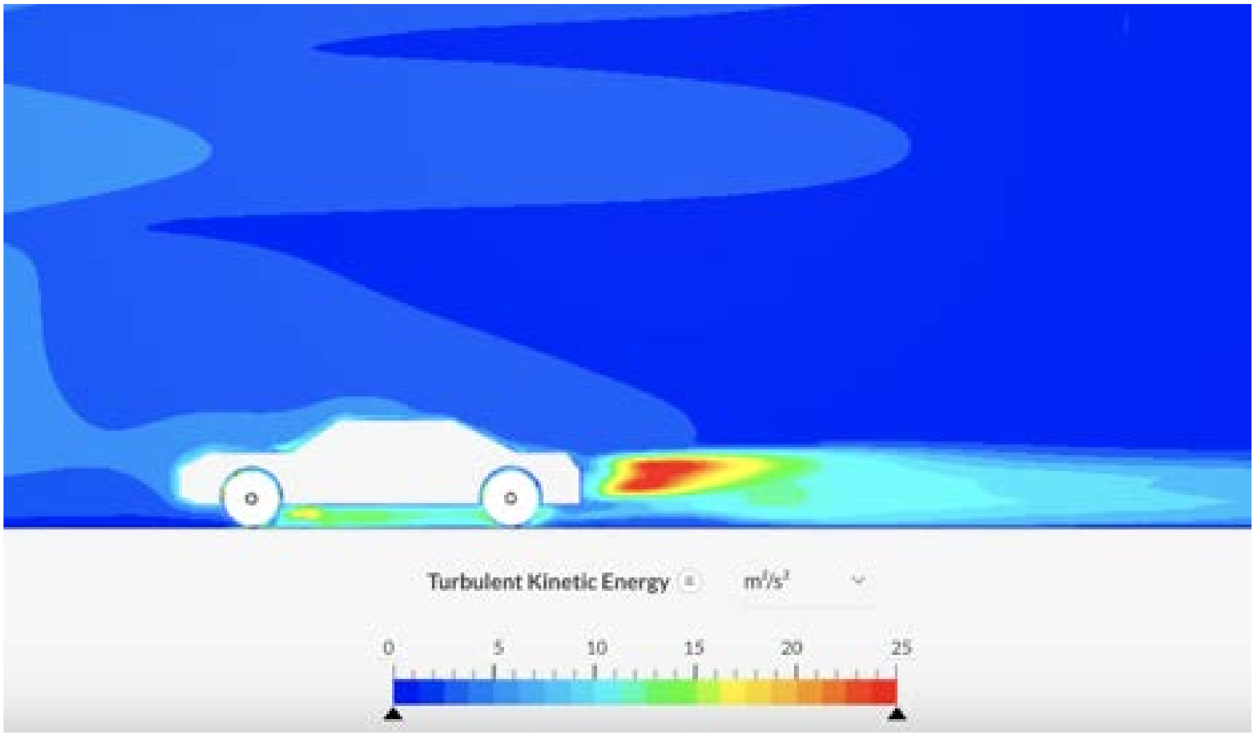

Figure K: Turbulent kinetic energy surface visualization chart for the base model

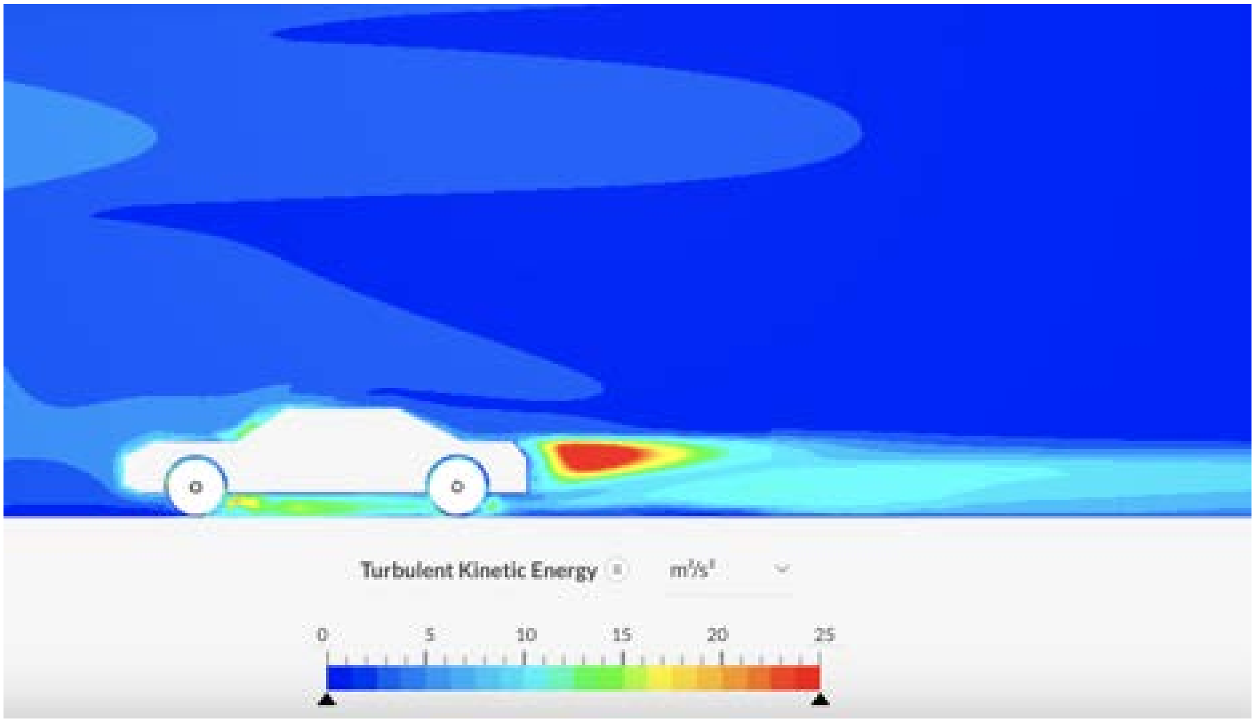

Figure L: Turbulent kinetic energy surface visualization chart for the bubbled roof model

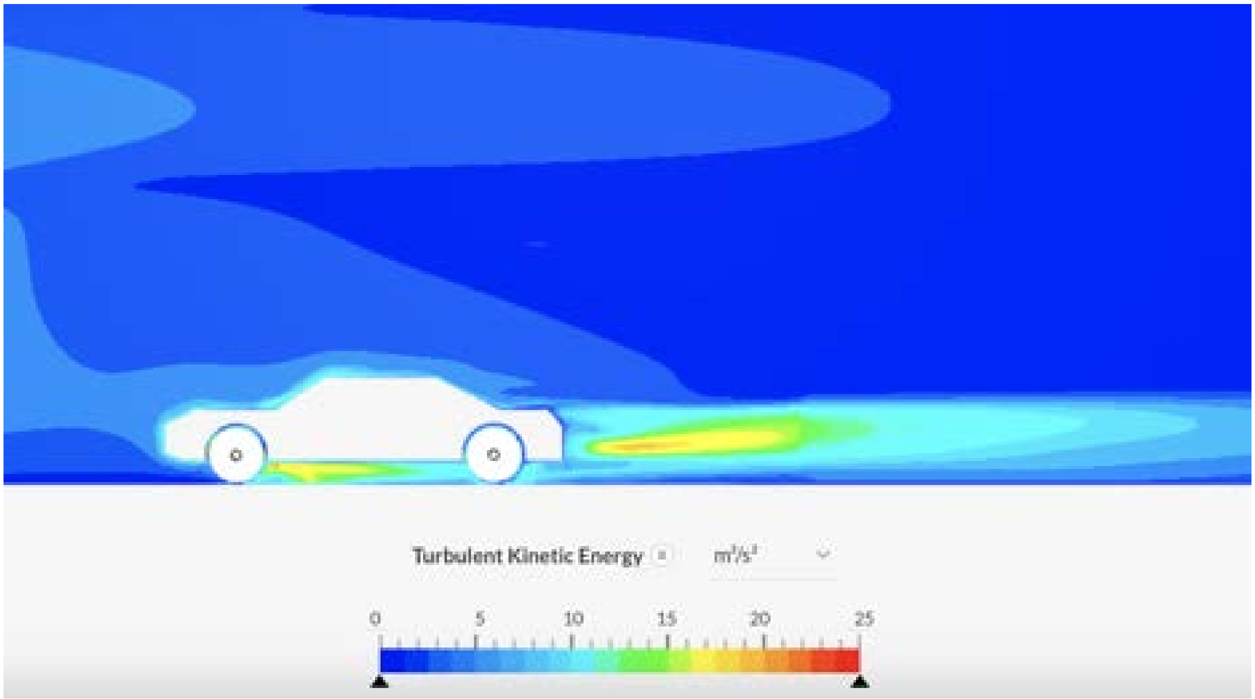

Figure M: Turbulent kinetic energy surface visualization chart for the bubbled trunk model

5. Conclusion

Using an MPG calculator from ecomodder.com(linked in references), the fuel efficiency of the different variations can be calculated. Using average sedan measurements, the fuel efficiency of the cars at 70 miles per hour, the average highway speed in the US, is 34.86, 32.14, and 35.45 miles per gallon, for the base, roof, and trunk models, respectively. There is an increase of 1.6%, or 0.59 miles per gallon in fuel efficiency when comparing the trunk model to the base model, but this is not enough to warrant bubbles on production cars. Rear diffusers, an aerodynamic feature more commonly used than bubbles, reduce the drag coefficient by anywhere from 4%-7%, as compared to the 2.39% from the bubbles. Diffusers themselves are not widely used on cars, and bubbles have even less of an effect than diffusers.

Although bubbles are not great for reducing drag, the lift coefficient was reduced by almost 50%, a significant improvement. In the world of professional racing, bubbles could be used to reduce lift to improve downforce and cornering, as well as help reduce the drag coefficient even by a little.

Although this experiment proved to have conclusive results, so many other variables could be changed, including the size, shape, and placement. Another large factor is the speed of the car; changing speeds may affect the bubbles' effectiveness. With enough testing, bubbles could potentially be used to significantly reduce drag forces for production cars across the world, and help reduce emissions. They could also be reworked to be more aesthetically pleasing, but will require further research and testing.

References

1. "Aerodynamics_DragLiftDownforceOverBodyFlow | Build Your Own Race Car!" *Build Your Own Race Car!*, 28 Sept. 2015, www.buildyourownracecar.com/race-car-aerodynamics-basics-and-design/aerodynamics_dragliftdownforceoverbodyflow.
2. Peherstorfer, Lukas. "Why Do Golf Balls Have Dimples?" *Tomorrow Golf*, Sept. 2022, tomorrowgolf.com/blogs/news/why-do-golf-balls-have-dimples.
3. Edelstein, Stephen. "The Bugatti Bolide's Air Scoop Was Designed Like a Golf Ball." *Motor Authority*, 1 Jan. 2021, www.motorauthority.com/news/1130680_the-bugatti-bolide-s-air-scoop-was-designed-like-a-golf-ball.
4. "VIDEO: Mythbusters Test Golf Ball-like Dimpling Effect on Fuel Economy." *autoblog.com*, www.autoblog.com/2009/10/22/mythbusters-golf-ball-like-dimpling-mpg/#continued. Accessed 20 Oct. 2023.
5. "Ford Taurus in 'MythBusters.'" *IMCDb.org*, www.imcdb.org/v186858.html.
6. "Computational Fluid Dynamics (CFD) - Ultimate Guide | SimScale." *SimScale*, 31 Aug. 2023, www.simscale.com/docs/simwiki/cfd-computational-fluid-dynamics/what-is-cfd-computational-fluid-dynamics/#:~:text=In%20a%20CFD%20software%20analysis,these%20quantities%20are%20calculated%20simultaneously.
7. Niedermeyer, Paul. "An Illustrated History of Automotive Aerodynamics – in Three Parts." *thetruthaboutcars.com*, Feb. 2012, www.thetruthaboutcars.com/2010/02/an-illustrated-history-of-automotive-aerodynamics-in-three-parts.
8. *The Drag Equation*. www.grc.nasa.gov/www/k-12/rocket/drageq.html.

9. Ghalih. “Turbulence Intensity and Drag.” *Physics Forums: Science Discussion, Homework Help, Articles*, 6 July 2016, www.physicsforums.com/threads/turbulence-intensity-and-drag.877291/#:~:text=Turbulent%20fluctuations%20tend%20to%20increase,with%20it%2C%20thus%20higher%20drag.