The Aerodynamics of Small Scale Racing

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In recent years, race car performance has relied more on the ideas of negative lift or downforce and drag than ever before. As early as the 1920s engineers began to consider automobile shape in reducing aerodynamic drag at higher speeds [2]. Engineers, racers and entrepreneurs were attracted by the potential for the substantial advantages aerodynamics offered. The purpose of this research project was to observe and study the aspects of the downforce and aerodynamic drag of small-scale automobile models. Downforce is the downwards thrust created by the aerodynamic characteristics of a car, while the drag of a vehicle is a mechanical force generated by a solid object moving through a fluid. The purpose of downforce is to allow a car to travel faster through a corner by increasing the vertical force on the tires. Formula 1 racing heavily relies on downforce to help keep the car on the ground through the various high-speed turns for each race. NASCAR racing does not really rely as much on downforce.

Until 1726, no major discoveries had been recorded in this field. Sir Isaac Newton was the first to compose a theory of air resistance, making him the father of aerodynamics. As part of his theory, Newton was actually the first one who believed that drag was due to the dimensions of a body, the density of the fluid, and the velocity squared.[1] Later, Daniel Bernoulli, the Dutch-Swiss mathematician described the relations between pressure, density and flow velocity in 1738 in his paper called Hydrodynamica. Today, the Bernoulli principle provides the calculating method of the aerodynamic lift or drag. Francus Herbert Wenham built the first wind tunnel in 1871. It enabled him to calculate aerodynamic forces for the first time due to the basic shape of the tracks.[1] These scientists were all essential to paving a way for the future aerodynamicists and they helped create the high level of racing today.

There will be many different aspects of negative lift tested for two different NASCAR model cars and different accessories that may be attached. The fourth-generation model and the 2013 Dodge Charger were used to compare the different effects for different aerodynamical designs. Additionally, there will also be two separate tests to study the ideas of bump drafting and side force acceleration. Bump drafting is an aerodynamic technique where two vehicles or other moving objects are caused to align in a close group reducing the overall effect of drag due to exploiting the lead object's slipstream.[13] Bump drafting is very common in NASCAR, so it is very important to test to help show there are ways to reduce fuel consumption by reducing the drag or drag coefficient. The drag coefficient is a number that aerodynamicists use to model all of the complex dependencies of shape, inclination, and flow conditions on aircraft drag [6]. The side force test was used to show the varying drag effects when a second car is placed in varying positions on the side relative to the test model.

The Theory

There are several different forces that needed to be explored in order to fully understand what exactly was happening with the tests being run. The first important force that was tested and explored was the aerodynamic drag force. Drag is a mechanical force. It is generated by the interaction and contact of a solid body with a fluid (In our case a gas).[6] The drag force is the force that opposes the car as it passes through the fluid. Figure 1 shows the various forces that act on cars as they move through the air. The drag force is important because if an aerodynamicist or engineer can help reduce the drag as much as possible for racecars, the fuel efficiency will increase, the overall



Figure 1: Aerodynamic Forces Diagram

speed can increase, and many other advantages that can help that particular racing team. The reducing of the drag can also help with standard passenger cars or tractor trailers that common people use on the roads today. For Tractor Trailers specifically, fifty percent of the fuel used is put towards overcoming the aerodynamic drag the truck is experiencing. [12]. The next important force to explore was aerodynamic negative lift or downforce. In current motor racing competitions, including Formula 1, DTM, Indy cars and Touring Car, aerodynamic downforce plays a very important role in the performance of the cars. For these racing competitions the ongoing challenge is to increase the downforce on the car and in turn be able to increase the speed. The downforce acting on the car comes from three different physical aspects of the car, the shape of the car, the use of airfoils, and even the underbody of the car can affect the downforce. Figure 2 shows the two different aspects of lift for airfoils on these cars, the bottom airfoil showing the idea of negative lift.

These two aerodynamic forces were going to be tested on two separate theories of drafting important for NASCAR racing. The first being Bump drafting and the second being side drafting. Bump drafting occurs when two cars are moving in the same slip stream in a straight line at a high speed and is used to increase the overall speed and reduce drag for the rear car in the system. Figure 3 shows the aerodynamic drag acts on the two cars as they begin to bump draft. The idea of bump drafting is used for



Figure 2: Aerodynamic Lift

various purposes throughout a race such as saving fuel or simply overtaking their opponents. Bump drafting became very popular in mainly at the Talladega Superspeedway and Daytona International Speedway racetracks [4], where racing cars can easily reach top speeds and aerodynamic effects become even more important. Due to the open-wheel design of the cars, racing competitions such as IndyCar and Formula 1 do not use the idea of bump drafting for it actually creates a disadvantage for these types of vehicles due to the designs of the body and the different wings that are used.

The second drafting technique that was to be tested was the side drafting test. Side drafting is when the front quarter panel of the rear vehicle lines up with the rear quarter panel of the lead car and creates more drag on the lead car and as the distance between them decreases the drag increases on the lead car, thus helping the rear car pass the lead car. This process can be seen in figure 4. When the rear car approaches to side draft this disrupts the air flowing over their competitors' car and sends it on to the rear spoiler or into the wheel wells, slowing that car. That allows the car doing the side drafting to pull even or ahead. Side



Figure 3: Bump Drafting Being Executed [12]

drafting is quite controversial because at one end side drafting can help create great two person fights for positioning, but also keep the field very stagnant if many drivers are side drafting at the same time.



Figure 4: Side Drafting [10]

In order to study these aerodynamic forces and complete the side and bump drafting tests a wind tunnel was needed to be constructed. Wind Tunnels are large tubes that have moving air through them. The tunnels are used to simulate track conditions without having to worry about unstable wind conditions or having to spend the amount of money it would take for actual track testing. The wind tunnel at Hampden-Sydney uses a XPOWER three horsepower motor that blows about 1700 cubic feet per minute. The basic structure of a wind tunnel has several components including the actual blower, a diffusion section, and a test section. The diffusion section uses hundreds of straws to help diffuse and straighten the air as it flows to the test section. The wind tunnel at Hampden-Sydney can only test car models at about 1/20 to 1/25 the size of the actual cars at speeds reaching close to 45 miles per hour. In order to get the drag readings for this wind tunnel a single load sensor was used to collect the data. Several wind tunnels that test real NASCAR models are much better options for racing teams that want to save money on track testing. These

wind tunnels use up to three different fans using 200 horsepower motors that can create up to 85 miles per hour winds. The wind tunnels use variable frequency drives to control the speeds of the winds and are controlled electronically. These state-of-the-art Wind tunnels such as the A2 wind tunnel use a 6-component load cell balance to calculate all the different forces acting such as downforce, drag, yawing force (rotational force), and pressure differences across the body of the car. [2]

Experimental Process

Due to the time constraint of this research project and several setbacks having to deal with the various design issues that arose once the wind tunnel was being used, only a few tests were able to be completed properly. The problems that presented themselves came solely from the type of blower that was being used. Most modern wind tunnels that test life-sized models of vehicles use a suction-based fan for the wind speeds. The blower that was chosen for Hampden-Sydney's wind tunnel is a much less expensive option, but many tests were not able to be completed in time. Due to the common issue of the wind being blown into the test section from the front of the wind tunnel, the various measurements that were being taken were being affected slightly.

The goal of this summer research would be to test three different NASCAR models and compare



Figure 5: Generation 4, Dodge Charger, Chevrolet Camaro Models

the various drag coefficients, downforce, or even body styles effects to try and figure out which model was best. The three different models, as seen in figure 5, were the Generation 4 model that was used between the years 1992-2007, the 2013 Dodge Charger model, and the late 2010's Chevrolet Camaro model. The Generation 4 model was the only model that was able to be tested thoroughly due to the time constraint on the project, but the goal for future work is to test all three exhaustingly in order to compare the three models accurately. The first test that was completed was the drag force test acting on a singular vehicle in high and low velocity winds. Using a pulley system, thin fishing wire, and a force load sensor as seen in figure 5 the drag force was pulled directly from the reading on the force sensor and was then used to try and calculate the drag coefficient of the particular race car model and compare that value to the large scale model of the racecar.



Figure 6: Small-Scale Wind Tunnel at Hampden-Sydney College

The next test that was completed was a drag force test while simulating bump drafting in the test section of the wind tunnel. A second car was added to the wind tunnel and placed at various positions relative to the lead car. The drag force being measured from the lead car and as the speed increases and the distance between the cars increase, the effective drag force should increase. In figure 6, bump drafting is occurring in the test section for the generation 4 NASCAR model.



Figure 7: Bump Drafting

In order to successfully calculate the coefficient of drag for these particular models, the cross-sectional area must be calculated. The cross-sectional area is the area of a two-dimensional shape that is obtained when a three-dimensional object - such as a model car - is sliced perpendicular to some specified axis at a point. [4] In order to measure the cross-sectional area accurately, an image analysis option inside the PASCO system readily available at Hampden-Sydney was used. A GoPro camera was used to take pictures of the front of each NASCAR

model in order to get the actual measurements. In order to get accurate measurements, there needed to be a scaling factor tool for the program to recognize how big the model actually is.



Figure 8: Pasco Image Software being used for a generation 4 model NASCAR

Once all of the cross-sectional areas were calculated, the drag coefficients were calculated using the equation:

$$Cd = 2Df/\rho(v^2)A$$

Where Cd is the drag coefficient, Df is the drag force measured from a scale, is the density of the fluid that is being used, and A is the cross-sectional area of each NASCAR model calculated with PASCO software.

Results and Analysis

Three different NASCAR models were intended to be used for this research project. However, the only model that was able to be tested was the Generation 4 Chevrolet model. The Generation 4 physical dimensions are listed in Table 1. The raw data and results were obtained using instruments that worked in the Metric system and the drag test information is listed in Table 2 while the bump drafting data is listed in Table 3. It is worth noting that the following data in both Tables 2 and 3 were taken from low speeds in an earlier design for the wind tunnel with a blower that was only blowing up to 10 meters per second. The new blower that was obtained later in the summer and blows up to 25 meters per second, but the data were not able to be taken accurately due to time constraint. Figure 9 compares the bump drafting data for a two-car system versus the normal drag test data with a singular car in the wind tunnel.

Material	Polylactic Acid
Length	.142 m
Width	.055 m
Cross-Sectional Area	.1498

Table 1: Model Vehicle Physical Quantities

Generation

Chevrolet

NASCAR Model

Weight

Table 2: Drag test for Generation 4 NASCAR

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Drag Test	
Wind Speed (m/s)	Drag force (N)
0.622	0.000241
1.807	0.011
2.722	0.037
3.22	0.049
4.123	0.062
4.754	0.079
5.301	0.084

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Table 3: Bump Drafting test for Generation 4 NASCAR

Bump Drafting test	
Wind Speed (m/s)	Drag force (N)
2.414	0.006
2.934	0.024
3.319	0.031
4.189	0.043
5.689	0.053
6.225	0.06





Figure 9: Bump Drafting Test vs Drag Test

Conclusion

This research project proved to exhaust all efforts for measuring drag while using a blower for the wind tunnel. Given the time restraint on the summer research program, accurate data was only able to be taken for one of the three NASCAR models that were intended to be tested due to many systematic and random errors that were discovered while designing and testing the wind tunnel. A few of the errors pertaining to the design of the wind tunnel were the inability to stabilize the small-scale models while it was being tested, the actual NASCAR models were extremely light and behaved irregularly at times, and the fact that this wind tunnel is using a blower to move the air through the test area of the wind tunnel instead of a suction fan like many other designs utilized at other facilities. As one can tell from figures 6 and 7, the cars sat on a wooden ruler to help figure out position changes while being tested. Since there was not an ideal way to mount the cars into the wind tunnel while the tunnel was running, the air pushing the cars needed to overcome the coefficient of friction between the car and the wood ruler. This issue proved to be persistent as it took quite a bit of time to figure out the coefficient of friction for the cars and figure out how to overcome this friction force. In a future project the hope is to be able to use this wind tunnel to be able to complete the testing for all three of the NASCAR models for drag, bump drafting, and side drafting

REFERENCES

- Anon, (2019). Uk Aerodynamics. [online] Available at: http://ukaerodynamics.co.uk/history-ofaerodynamics/ [Accessed 22 Aug. 2019].
- Chad Hicks, A. (2019). A2 Wind Tunnel. [online] A2wt.com. Available at: https://www.a2wt.com/TunnelInfo.html [Accessed 14 Jul. 2019].
- Formula1-dictionary.net. (2019). Downforce. [online] Available at: http://www.formula1dictionary.net/downforce.html [Accessed 12 Aug. 2019].
- Fiolhais MCN, Santos SAD. The physics of bump drafting in car racing. Physics Education 49: 693–696, 2014.
- Grc.nasa.gov. (2019). Drag Measurement. [online] Available at: https://www.grc.nasa.gov/www/k-12/airplane/dragdat.html [Accessed 1 Aug. 2019].
- Grc.nasa.gov. (2019). The Drag Coefficient. [online] Available at: https://www.grc.nasa.gov/www/k-12/airplane/dragco.html [Accessed 1 Aug. 2019].
- Grc.nasa.gov. (2019). The Lift Coefficient. [online] Available at: https://www.grc.nasa.gov/www/k-12/airplane/liftco.html [Accessed 1 Aug. 2019].
- Janna WS, Schmidt D. Fluid Mechanics Laboratory Experiment: Measurement of Drag on Model Vehicles. ASEE Southeast Section Conference.
- Kelly KB, Kyropoulos P, Tanner WF. Automobile Aerodynamics. SAE Technical Paper Series(1960). doi: 10.4271/600195.
- Larrabee EE. Small Scale Research in Automobile Aerodynamics. SAE Technical Paper Series(1966). doi: 10.4271/660384.

- NASCAR Talk. (2019). Side drafting: From a specialist's tool to racing commodity. [online] Available at: https://nascar.nbcsports.com/2016/06/29/sid e-drafting-from-a-specialists-tool-to-racingcommodity/ [Accessed 20 Aug. 2019].
- Newworldencyclopedia.org. (2019). Aerodynamics - New World Encyclopedia. [online] Available at: http://www.newworldencyclopedia.org/entry/ Aerodynamics [Accessed 1 Aug. 2019].
- Rtsfinancial.com. (2019). How Better Aerodynamics Lead to Fuel Savings | RTS Financial. [online] Available at: https://www.rtsfinancial.com/guides/howbetter-aerodynamics-lead-fuel-savings [Accessed 15 Aug. 2019].
- The Building Speed Blog. (2019). Drafting: Regular and Bump : The Building Speed Blog. [online] Available at: https://buildingspeed.org/blog/2017/05/05/dra fting-regular-and-bump/ [Accessed 10 Aug. 2019].