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ROAD RACING AERODYNAMIC SIMULATION + TESTING

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By
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Final Report for 4600:001 Senior/Honor Design, Spring 2021

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Project No. 9

Abstract

There are multiple goals for this project. The first goal of this project is to design, assemble and simulate additional aerodynamic components. Another goal is to create a product that can analyze various angles of attack of Aerodynamic components. The product will be used on, or off the track to determine the lift coefficients of vehicles at varying speeds. I will be using my 1992 Honda Civic for testing and compare my physical results to my simulated tests.

The project did come with a list of design and manufacturing challenges along with additional finical cost which has resulted in some setbacks along the way.

Contents

1. Introduction

The idea for my project was to offer a on track budget solution to road course racers who have an interest in Aerodynamic elements such as Splitters, Air Damns, Diffusers, Wings, and other parts on a road race car. In the road race community these aerodynamic elements are known to make a vehicle's lap time faster by generating downforce which allows for more grip during high-speed corners. These simple modifications have been physically tested in wind tunnels and proven to increase downforce in other CFD programs. Both options are great however they have their limitations. Not all road racers have the money to spend hundreds of dollars on wind tunnel testing. And CFD analyses are not entirely accurate unless given the full 3D underbody dimensions.

The goal in mind for my project was to use vehicle ride height sensors to determine and compare the downforce created by these simple aerodynamic elements. As we test the vehicle at various speeds, the suspension will compress. The vehicle height will decrease as we increase the speeds of the tests, theoretically we can calculate the lift coefficients from these results.

1.1 Road Car Aerodynamics

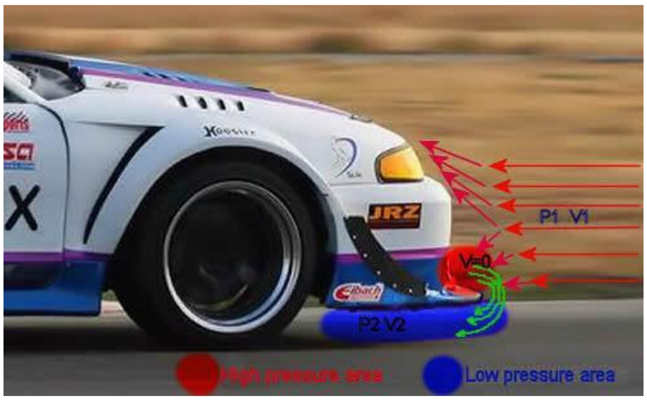
The aerodynamics of race cars have always been intriguing. How air tends to flow can be hard to visualize, but mathematically it seems to make sense. The first ever aerodynamic components started showing up on race cars back in the 1960's. Before then, the idea was that a sports car was light, had a low drag coefficient, with little to no downforce and made a lot of power.

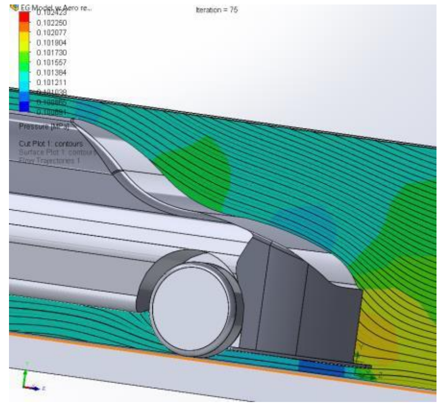
However, moderately increasing drag and adding a drastic amount of downforce to the car has been proven to be beneficial. In fact, with some aero modification we can reduce drag and increase downforce.

In my project I will be focusing on two pieces of aero. A splitter and a diffuser. These two pieces of aerodynamics focus on underbody aerodynamic effects.

1.1.1 What is a Splitter?

The fast-moving air that hits the face of the car will often create a trubulent high pressure region at the bottom edge of the bumper. The air underneath the bumper will move quickly and develop a low-pressure region. This pressure difference creates a downward for on the front most part of the car. A splitter hardly adds any drag. Most importantly it allows a place for the high pressure region to push down on.





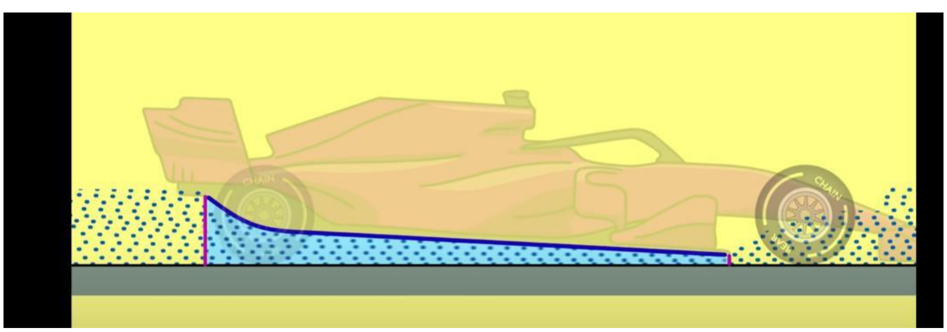
1.1.2 What is a Diffuser?

A diffuser utilizes the Venturi Tube concept using two equations.

$$V_1 A_1 = V_2 A_2$$

$$\frac{p_1}{\rho} + \frac{{V_1}^2}{2} = \frac{p_2}{\rho} + \frac{{V_2}^2}{2}$$

The job of a diffuser is to decelerate the underbody back to ambient air speeds. When Area 1 at the beginning of the diffuser is smaller than Area 2, the air will move faster at the front portion of the diffuser. As velocity starts to decrease, pressure begins to increase at the edge of the diffuser pulling the car into the ground.



1.2 Modeling & Design

There are two ways that I know about to model a car for aerodynamic simulation testing. The first way is by 3D scanning the car with a 3D scanner. This option is generally the most accurate way to measure a car's aerodynamic features. Using a 3D scanner plots points in a 3D CAD program like Solidworks, takes those points out in a 3D space and connects the dots with surfaces. These points and surfaces can be

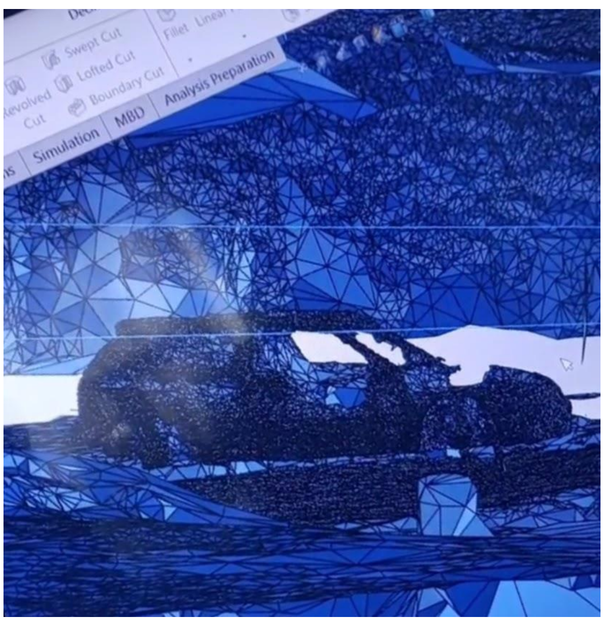
manipulated to form a solid body. The second way is to re-engineer the body of the vehicle and trim out the basic shape of the vehicle.

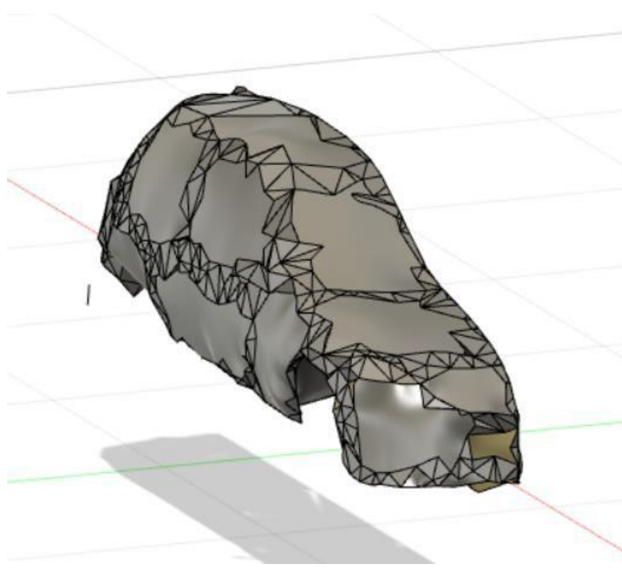
One other way that I thought might work, but unfortunately did not is Photogrammetry.

1.2.1 Photogrammetry

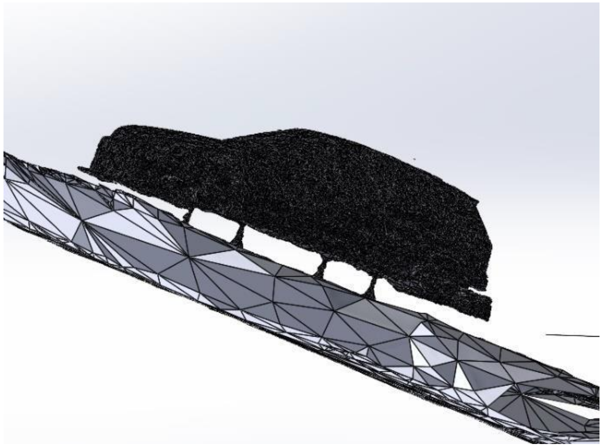
Much like 3D scanning Photogrammetry is primarily used on a smaller scale. I have used this technique before to create models for my 3D printer, but I had never used it on such a large scale. Here is how photogrammetry works. Step one is to take a whole bunch of pictures of the model. Next after taking the pictures, a meshing software creates a depth map to connect particles in your images and create surfaces.

Once we had some nice spring weather, I rolled the car out of the shop and to take the pictures. I ran the pictures through the software and the result was the image below. The scan was missing a good portion of the car. It was a relatively sunny day and the reflection on the doors, windshield and roof produced a glare in multiple images. The mesh room program recognized this glare as a transparency, and I would have to try repair the body.





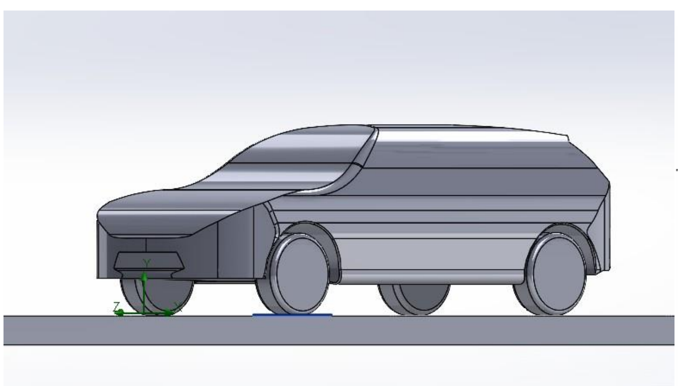
The holes in the surfaces were unfixable but, after researching more about 3D scanning, I found that baby powder was commonly used to prevent reflections and improve texturization.

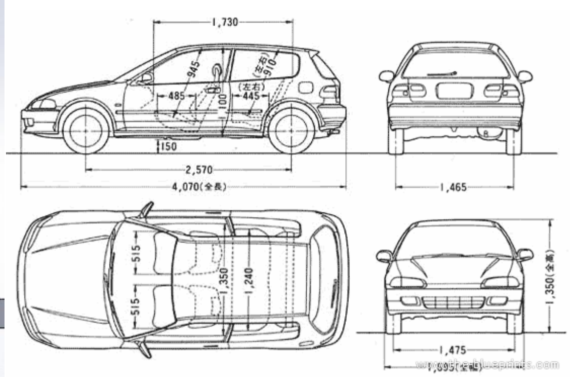


And it actually worked. The baby powder fixed the reflection issue. But, due to the high number of faces that had to be decimated/combined, the scan resulted in poor resolution and I was not able to run the aero simulation using the second scan.

1.2.2 Reverse Engineering

I was running out of time on making a design of the car. The next best option would be to 3D model the vehicle in Solidworks. Using an old wireframe sketch of the car, I was able to create the basic shape of the vehicle. Unfortunately, the underbody is completely flat and I wasn’t able recreated the mirrors. Those two features are key components in determines the drag force of a vehicle. Although, we are more interested in the lifting force then drag force finding the best lift vs drag ratio can be useful to help set up a car.

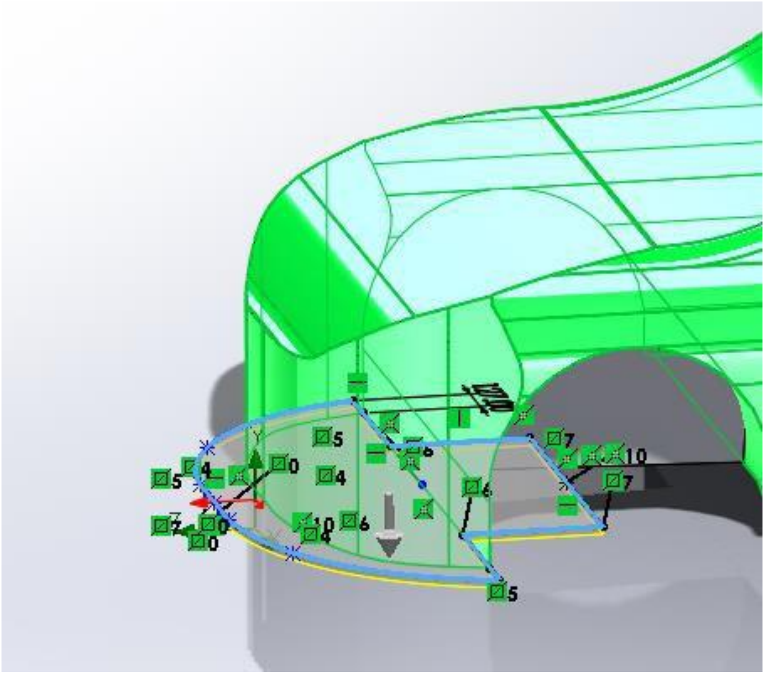


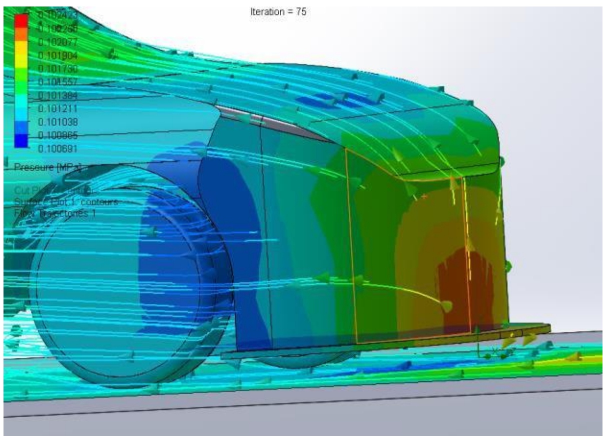


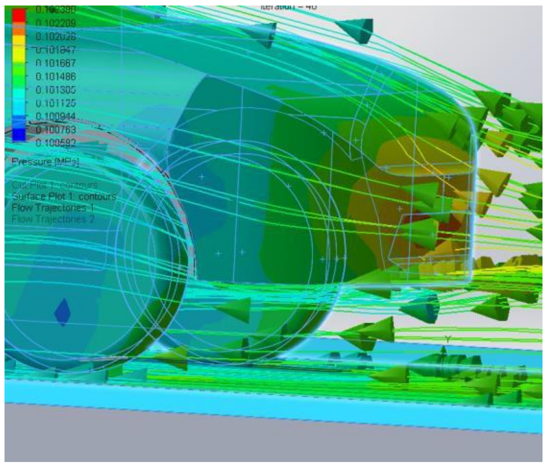
2 Design

2.1 Designing a Air Damn & Splitter

The splitter has been designed to be as close to the ground as the rules allow. Again we do this to reduce the area of the funnel and decrease the pressure. An air dam has been stretched across the bumper to help catch air and create a high-pressure zone.

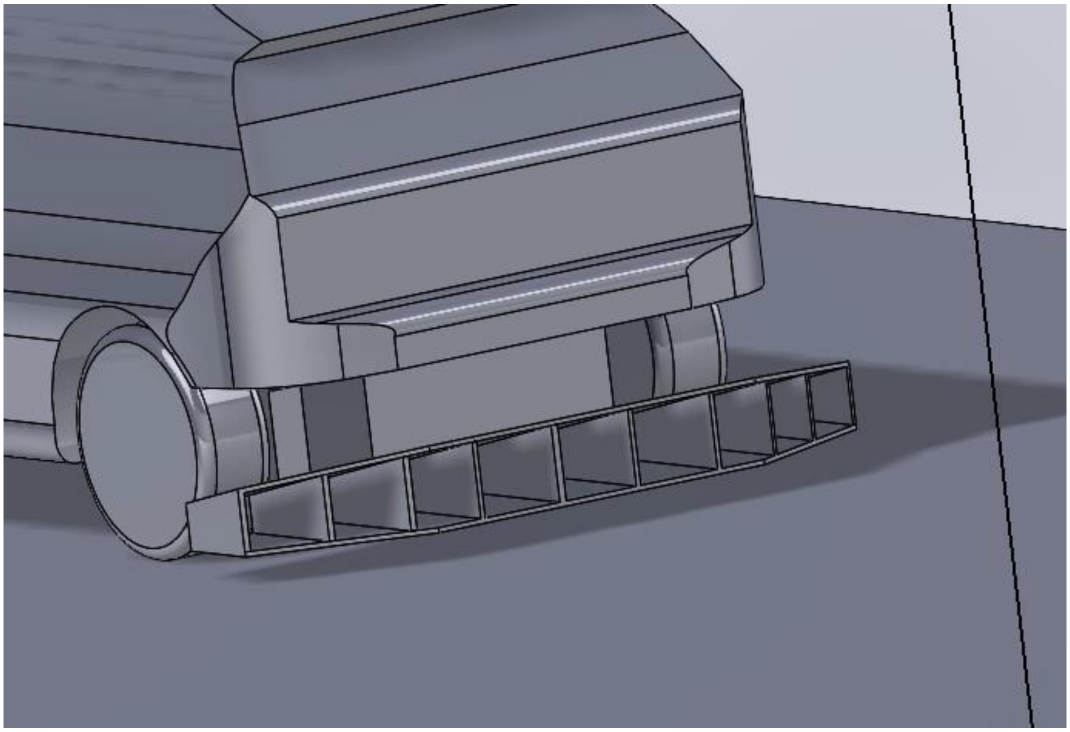






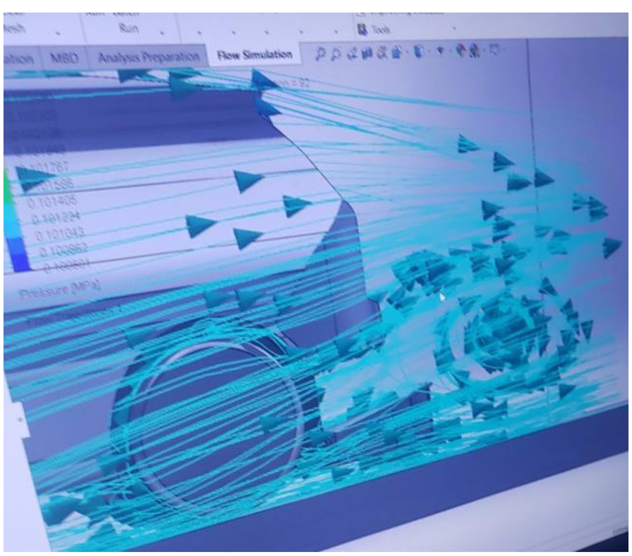
As you can see creating the high-pressure area worked perfectly. Comparing the surface pressure plot to the stock body we can notice a big difference. The high-pressure zone has shifted to the bottom most portion of the bumper and air looks to be staying attached to the bumper.

2.2 Designing a Diffuser



2.3 Overall Lift and Drag Results

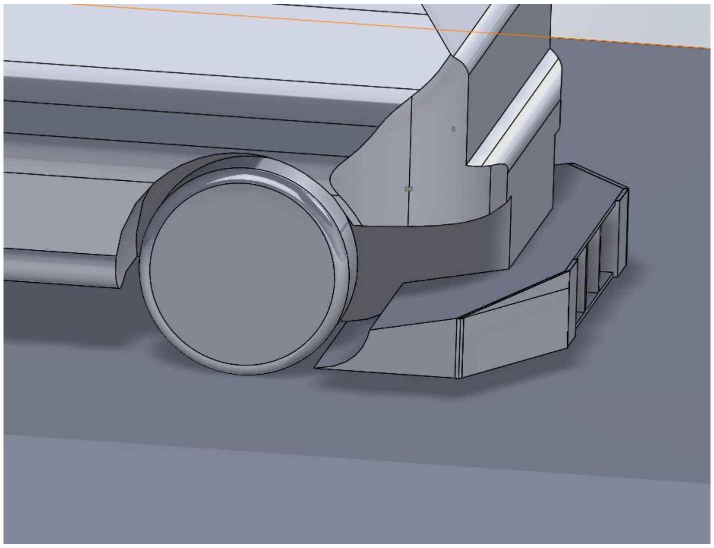
For a base line I wanted to test the stock body against the modified body. I decided to run a test at 70 MPH. The stock body car created 25 N of downforce and 548 N of drag. With the Splitter and Diffuser on the car the normal force increased to 367 N with a drag force of 604 N! Looking deeper into how the air traveled the diffuser, I was perplexed.



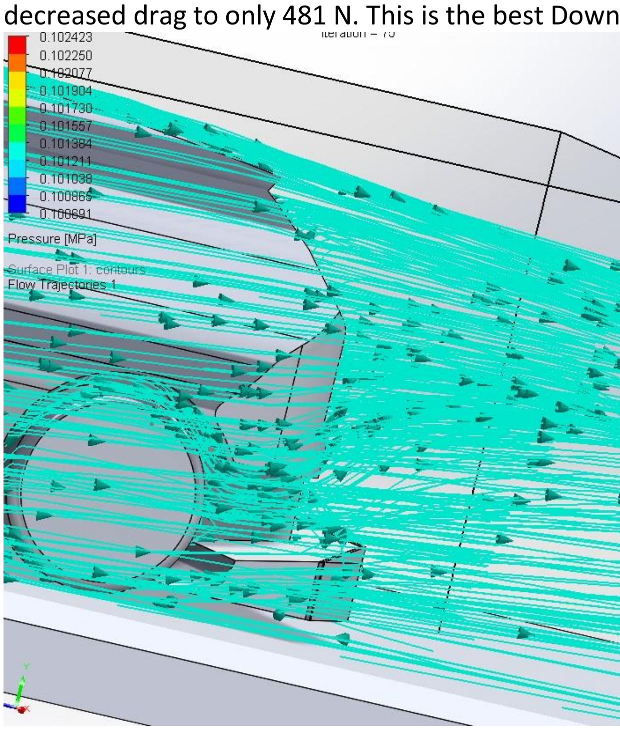
The turbulent air off the tires created an enormous amount of drag as it traveled through the diffuser.

2.3.1 Diffuser Design Change

The nice thing about having a 3D model is that you can quickly make changes to your design. I extended the top portion of the air guard above the diffuser to the edge of the bumper, blocked the funnels that the turbulent air from the wheels were traveling.



Now the wake from the high-pressure turbulent air behind the rear wheels travels up and meets with the low-pressure air above the spoiler. This effectively separates turbulent air from fluid flow. This result in less drag. The newest modification created less downforce only making 316 N, but more importantly decreased drag to only 481 N. This is the best Downforce to drag ratio yet.



2.4 Simulating Design Variations

One thing that I would like to do is simulated the different angles of attack of the splitter and the diffuser. This is not complete yet, but I will certainly be doing this in the future.

2.5 Designing a Physical Test

This system is not yet set up for testing. But it's pretty plug-in play. A 0 to 5V is sent to the datalogger. To calibrate the datalogger simply determine how many volts are being produced at ride height zero the datalogger there and sent the voltage at full compression to read the amount of millimeters traveled.

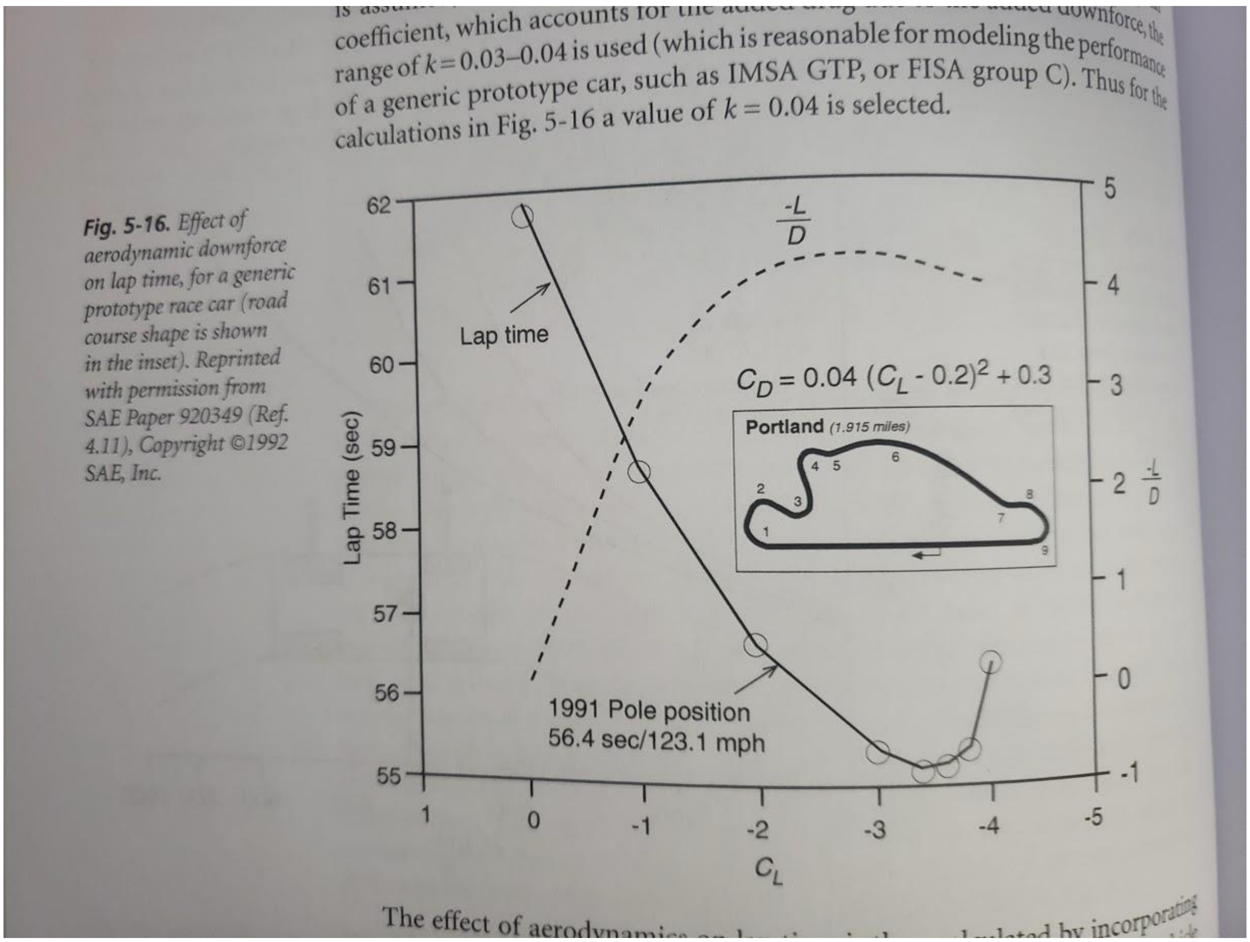
3. Design Verification

3.1 Finding the Proper Angle of Attack

By changing the aerodynamic angle of attack, I will also be changing the effective drag and downforces. The Drag and downforce ratio is a good starting point, but race teams and race engineers have found an equation to optimize drag vs downforce as quickly as possible.

$$C_d = (0.04) * (C_l - C_{l_o})^2 + C_{d_o}$$

The end goal of the project is to set up the car find our Clo and Cdo of the car and go testing on the track. I am interested to see if road racing cars follow the trend as prototype and GT race cars.



coefficient, which accounts for ... downforce, the range of $k=0.03$–0.04 is used (which is reasonable for modeling the performance of a generic prototype car, such as IMSA GTP, or FISA group C). Thus for the calculations in Fig. 5-16 a value of $k = 0.04$ is selected.

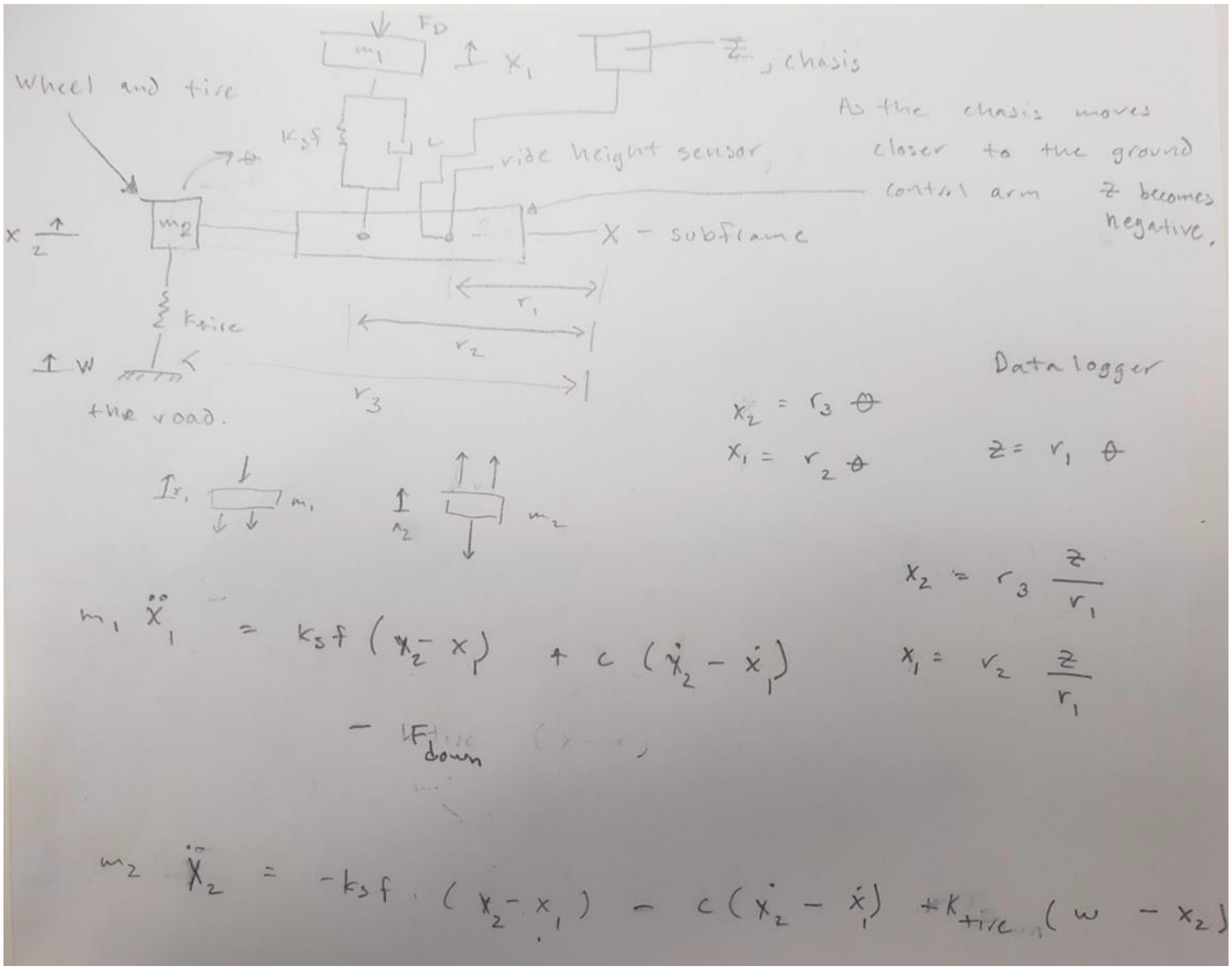
Fig. 5-16. *Effect of aerodynamic downforce on lap time, for a generic prototype race car (road course shape is shown in the inset). Reprinted with permission from SAE Paper 920349 (Ref. 4.11), Copyright ©1992 SAE, Inc.*

The effect of aerodynamic...

3.2 Damping Coefficient & Calculating Downforce

These calculations have not yet been made but below is the FBD of the front lower control arm and the attached suspension.

3.2.1 Calculations



3.3 Requirement & Verification table

I have not thought of the best way to determine drag. I believe if I had a wing I could use a strain gauge based off of the wing mounts to determine how much drag we creating.

Requirement	Verification	Verification status (Y or N)
1. Requirement: Design Functional Splitter and Diffuser	1. Verification: Simulated Design, & Improved Results	Y
2. Requirement: Accurately Calculate Drag/Lift Force	2. Verification: Physical Testing, and Data Analysis	N

4. Costs

The cost of the entire project has been one of my biggest challenges. Building a car from the ground up can be a time-consuming process. This project on top of getting the car running and driving has eaten up a lot of my finances. The costs/labor involved in getting the car running and driving have not been included but going forward when planning a project of this scale I will definitely consider the additional accessory costs.

4.1 Parts

Part	Manufacturer	Cost ($)
Splitter mounts	PCI	$100.00
¾” Plywood sheet (4 x 8)	Home Depot	$69.98
.1” ABS Plastic sheet	Allstar ABS	$40.00
PVC trim panel (4x8)	Home Depot	$82.19
Ride Height Sensors (2x)	Land Rover L319 LR3 LR020157	$111.78
Ride Height Connector Harness	Land Rover YMQ503220	$72.54
Datalogger	DataQ DI-149	$53.48
Splitter Rods (4x)	Allstar Performance	$100.00
Total		**$629.97**

4.2 Labor

The time I have spent on this project has been educational. I did not record the hours I spent working on the project. The manufacturing, painting and installation of the splitter and diffuser took about 40 hours. The reverse engineering of the car model took 40 hours. The design of the aerodynamic elements took 10 hours. Simulation and analysis have taken around 20 hours. Every little thing adds up and considering many of these things are new to me, it has taken me twice as long as I would have liked to complete. This and the due to limited finances have eventually led to my partial completion of my project.

5. Conclusion

This has been a difficult project to do by myself. I have made a lot of progress and I am slowly getting closer to finding meaningful data.

The goal the project was to use vehicle ride height sensors to determine and compare the downforce created by these simple aerodynamic elements. I was able to design the aerodynamic elements in Solidworks and preform CFD analysis on my design.

I made some changes to my designs based on my findings.

Confirming my CFD results using the ride height sensors has not been success yet.

5.1 Accomplishments

Learning how to properly manage my time, resources and my own abilities has been a big part in this project.

In this project, not only have I rebuilt a car from the ground up. I have developed relationships, learned how to design a model of a car in cad, and experimented with CFD analysis techniques.

5.2 Uncertainties

Researching how to properly test CFD results without wind tunnel testing seems to be withheld information. Understandably race teams, have published their data, but will not reveal how they have collected the data and what changes they have made. The most helpful information I have been able to find is on an F1 forum/blog page.

5.3 Future work

I will continue working on what is left in the project. There’s still a lot to do.

References

"Articles." *F1technical.Net*, www.f1technical.net/features/21963.

Katz, Joseph. *Race Car Aerodynamics: Designing for Speed*. Cambridge, MA, USA: R. Bentley, 2006. Print.

Appendix A