Cornell Baja Racing

Fall 2023

Technical Report

Author:
Arnav Tapadia

NetID:
at565

Projects:
Performance Testing, Modeling, Track Design

October 22, 2024

Contents

1 Performance Testing, Modeling, Track Design

1.1 Abstract

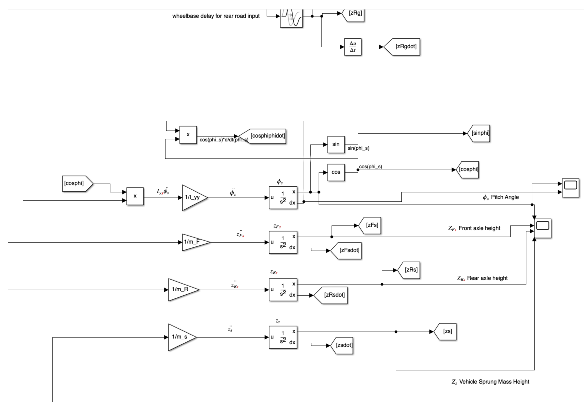

Figure 1: Half-Car Model in Simulink

This project is fairly unexplored. Performance evaluating has been quite qualitative with recent improvements during CVT Tuning and Shock Testing using hall-effect sensors and linpots.

The goal of this project is to setup a strong basis for evaluating car performance, through developing a model for the car, setting up a sensor suite and analysis system. Additionally, this will involve devising tests that can be efficiently completed at the track to determine car performance. The primary emphasis this year revolves around gaining insight into suspension performance as a preliminary undertaking.

1.2 Design Requirements

Explanation

Constraints:

- Testing and sensor setup should be backward/forward compatible, and sensors able to be "hotswapped" on the DAQ
- All sensors and DAQ to be protected from weather

Objectives:

- Create half-car model that can successfully model pitch and heave modes using real world parameters
- Create matlab methods and classes to process sensor data and analyse results
- Setup tests that can evaluate car performance
- Correlate model to track data and use model to influence suspension setups
- Maintain track and redesign for testing

1.3 Initial Research

1.3.1 Last Year's Car

Figure 2: Dewesoft Sirius STG-M

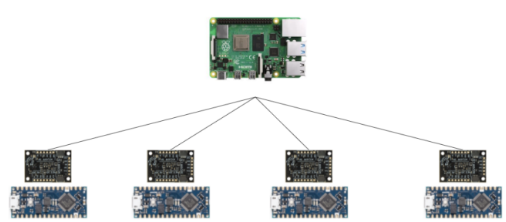

Figure 3: Raspberry Pi Setup Alternate DAQ System

Every year we do some form of data collection, testing with sensors, and data analysis. We do this to determine factors of safety, get some idea on when materials will yield, and to determine the performance of the car. As a team we have a lot of knowledge of how to set up sensors and collect data, however it is all wide spread and almost entirely passed down person by person.

Reading Owen Louis's tech report from Fall 2022, he was trying to set up a new DAQ system using a Raspberry Pi and Arduinos instead of the Dewesoft Sirius DAQ we currently have. Additionally, last year we were using the Labjack T7 for CVT tuning. We also used the Dewesoft DAQ to gather shock data from linpots (and perhaps more). Additionally, in Fall '21/Spring '22, Peter Swaak, attempted to setup a wireless data aquisition system.

Ultimately, it is clear that we have spent a lot of time setting up data acquisition systems, and have had very little use of them. As a result, this year I am hoping to use existing set ups, and go out to track and test the car, as well as use Matlab/Python/Simulink to analyse the data. I believe that setting up a strong foundation for data analysis is promising for improving future car performance as I am unsure if we have delved deeply into this in past years.

Key parts of this will involve 1. creating and correlating a car model 2. creating ways to analyse common sensor data 3. conducting specific tests and using the data to characterize the performance of the car.

1.3.2 Online Research

Dewesoft DAQ website and documentation were very useful in understanding how it works and how to connect it to software. Used online tutorials for Simulink to understand how it worked, and also my classes at Cornell. My internship at Mercedes F1 helped give me a deeper understanding into modeling a race car and analysing its performance.

Books I would recommend reading to improve vehicle dynamics knowledge: 1. Race Car Design by Derek Seward 2. Race Car Vehicle Dynamics by William F. Milliken Jr.

1.4 High Level Description

There are several types of basic car models: Quarter-Car Model, Half-Car Model, Full-Car Model. The difference between these is the number degrees of freedom: quarter car model has 2 DOF, half car model has 4, full car model has 7+. The goal for this semester is to successfully design a half-car model, and over time we can develop the model to correlate better with track data.

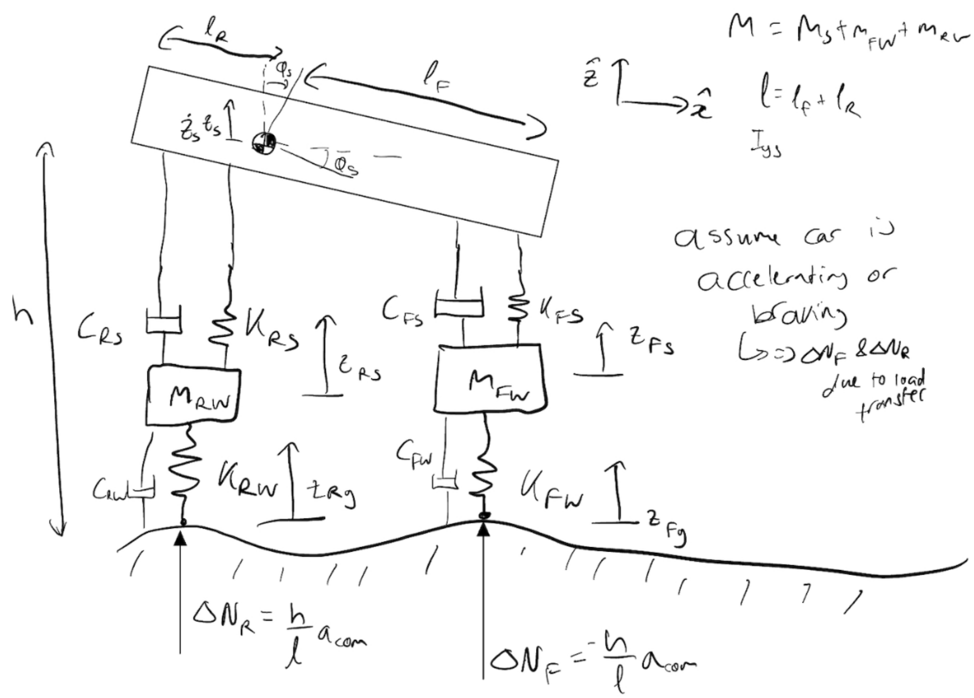

Figure 4: Half-Car Model

1.4.1 Quarter Car Model

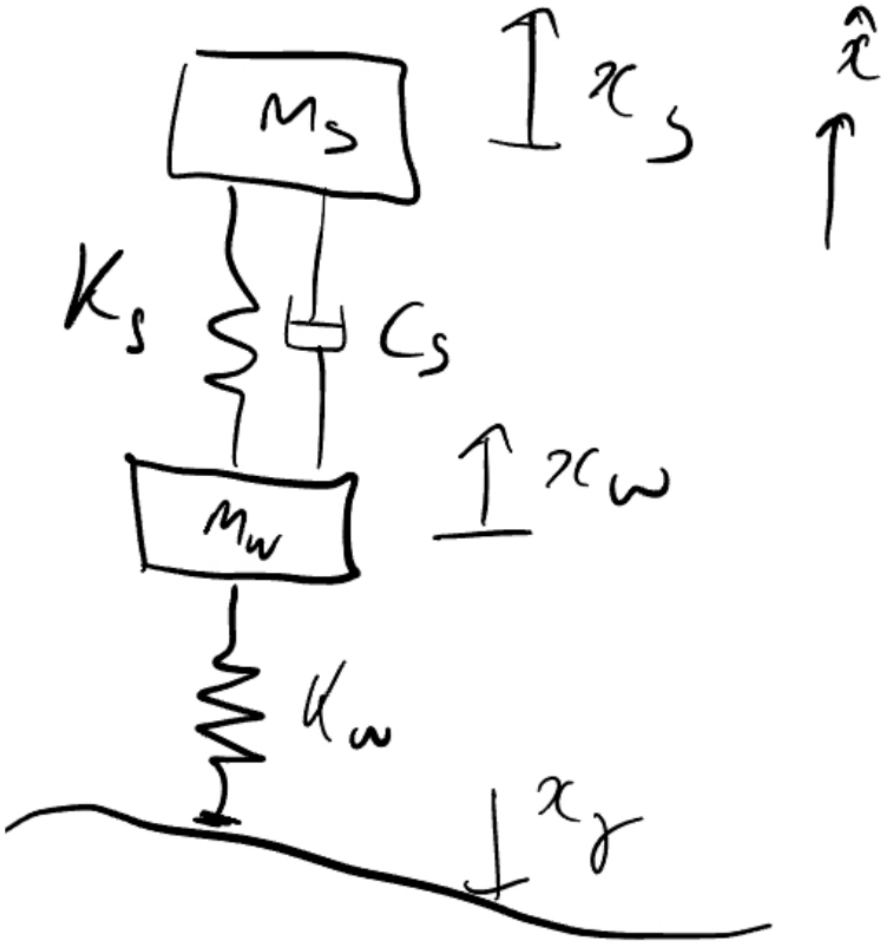

Figure 5: Quarter Car Model Diagram

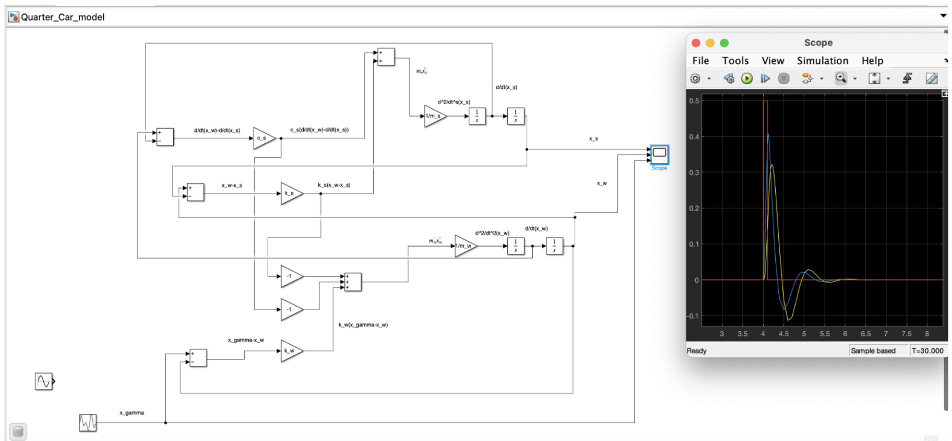

Figure 6: Quarter Car Model Simulink

A quarter car model is shown in Figure 5. The equations of motion are easily determined. The complication is converting this into simulink.

Simulink essentially is like creating a circuit that naturally determines the output from the equations of motion self-consistently. It essentially contains block elements that can act as differential operators, integral operators, amplifiers (scalar coefficients), etc... These allow you to graphically display an equation of motion, and then it is solved by the normal matlab method to solve differential equations (ode45).

It is fairly intuitive to convert a set of equations of motion to a simulink block diagram once the functions of blocks are understood. The challenge is then laying out the blocks in an organized manner with annotations for easy debugging when you inevitably make a mistake.

1.4.2 Half-Car Model

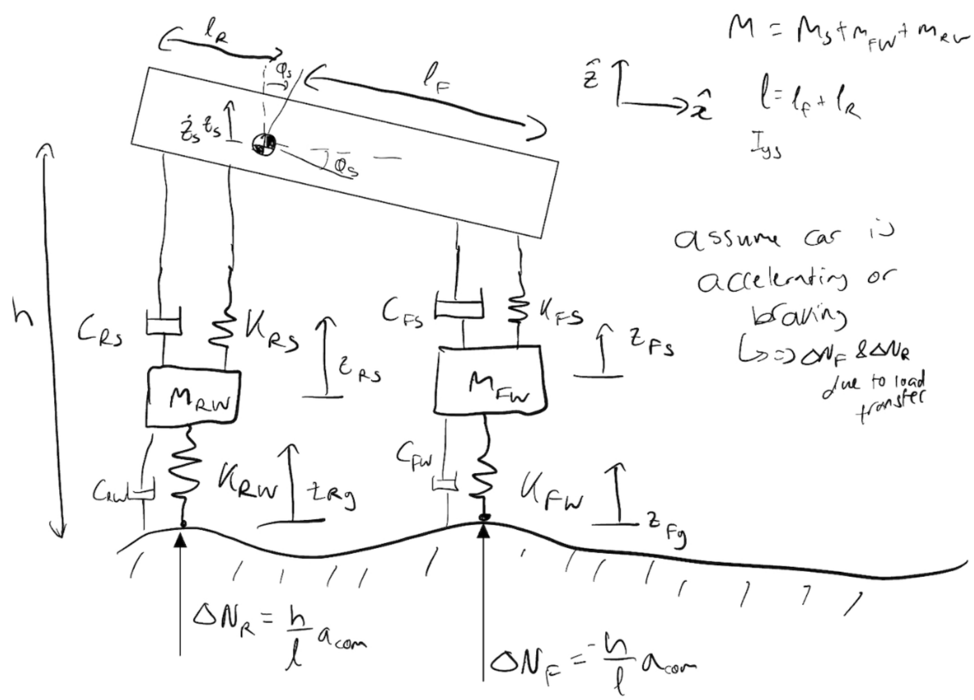

Figure 7: Half Car Model Diagram

Above is the half car model coordinate system and variables I used to determine the equations of motion. It is very important that we always stick to the same conventions and coordinate systems so that when developing models we don't get confused. Next semester I do want to improve the tidyness of the variable names as I think there is still some cleanliness to be desired.

$$
\begin{bmatrix} \ddot{\theta}_s \\ \ddot{z}_{FS} \\ \ddot{z}_{RS} \\ \ddot{z}_s \end{bmatrix} =
\begin{bmatrix}
\frac{\cos\theta_s}{I_{yy}}(l_F^2 K_{FS} + l_R^2 K_{RS}) & \frac{\cos\theta_s}{I_{yy}} l_F K_{FS} & \frac{\cos\theta_s}{I_{yy}}(-l_R K_{RS}) & \frac{\cos\theta_s}{I_{yy}}(-l_F K_{FS} + l_R K_{RS}) \\
\frac{-K_{FS} l_F}{M_{FW}} & \frac{-K_{FS} - K_{FW}}{M_{FW}} & 0 & \frac{K_{FS}}{M_{FW}} \\
\frac{K_{RS} l_R}{M_{RW}} & 0 & \frac{-K_{RS} - K_{RW}}{M_{RW}} & \frac{K_{RS}}{M_{RW}} \\
\frac{K_{FS} l_F - K_{RS} l_R}{M_s} & \frac{K_{FS}}{M_s} & \frac{K_{RS}}{M_s} & \frac{-K_{FS} - K_{RS}}{M_s}
\end{bmatrix}
\begin{bmatrix} \sin\theta_s \\ z_{FS} \\ z_{RS} \\ z_s \end{bmatrix}
$$

$$
+ \begin{bmatrix}
\frac{\cos\theta_s}{I_{yy}}(l_F^2 C_{FS} + l_R^2 C_{RS}) & \frac{\cos\theta_s}{I_{yy}} l_F C_{FS} & \frac{\cos\theta_s}{I_{yy}}(-l_R C_{RS}) & \frac{\cos\theta_s}{I_{yy}}(l_F C_{FS} + l_R C_{RS}) \\
\frac{-C_{FS} l_F}{M_{FW}} & \frac{-C_{FS} - C_{FW}}{M_{FW}} & 0 & \frac{C_{FS}}{M_{FW}} \\
\frac{C_{RS} l_R}{M_{RW}} & 0 & \frac{-C_{RS} - C_{RW}}{M_{RW}} & \frac{C_{RS}}{M_{RW}} \\
\frac{C_{FS} l_F - C_{RS} l_R}{M_s} & \frac{C_{FS}}{M_s} & \frac{C_{RS}}{M_s} & \frac{-C_{FS} - C_{RS}}{M_s}
\end{bmatrix}
\begin{bmatrix} \cos\theta_s \dot{\theta}_s \\ \dot{z}_{FS} \\ \dot{z}_{RS} \\ \dot{z}_s \end{bmatrix}
$$

$$
+ \begin{bmatrix} 0 & 0 \\ \frac{K_{FW}}{M_{FW}} & 0 \\ 0 & \frac{K_{RW}}{M_{RW}} \\ 0 & 0 \end{bmatrix}
\begin{bmatrix} z_{Fg} \\ z_{Rg} \end{bmatrix}
+ \begin{bmatrix} 0 & 0 \\ \frac{C_{FW}}{M_{FW}} & 0 \\ 0 & \frac{C_{RW}}{M_{RW}} \\ 0 & 0 \end{bmatrix}
\begin{bmatrix} \dot{z}_{Fg} \\ \dot{z}_{Rg} \end{bmatrix}
+ \overbrace{\begin{bmatrix} 0 & 0 \\ 1 & 0 \\ 0 & 1 \\ 0 & 0 \end{bmatrix}
\begin{bmatrix} \Delta N_F \\ \Delta N_R \end{bmatrix}}^{\text{To add later to model}}
$$

θ_s: pitch angle of sprung mass

$\Delta N_F = -\frac{h+z_s}{l} a$, $\Delta N_R = \frac{h+z_s}{l} a$

z_s: height of car above eq^n

$z_{F/Rg}$: height of F/R ground

$K_{F/RS}$: F/R shock spring stiffness

$z_{F/RS}$ height of F/R wheel unsprung

M_s: sprung mass

$C_{F/RS}$: F/R shock damping

a_{com}: acc^n of com, h: height com

$M_{F/RW}$: unsprung F/R mass

$K_{F/RW}$: F/R wheel stiffness

$l_{F/R}$: F/R location from COM

I_{yy}: MOI along y axis about com

$C_{F/RW}$: F/R wheel damping

Figure 8: Half Car Model Equations of Motion

Deriving the equations of motion is slightly more tedious, but still possible. I still need to figure out how to add the ground normal forces (and friction forces?) so that the car can leave the ground as it goes over a jump.

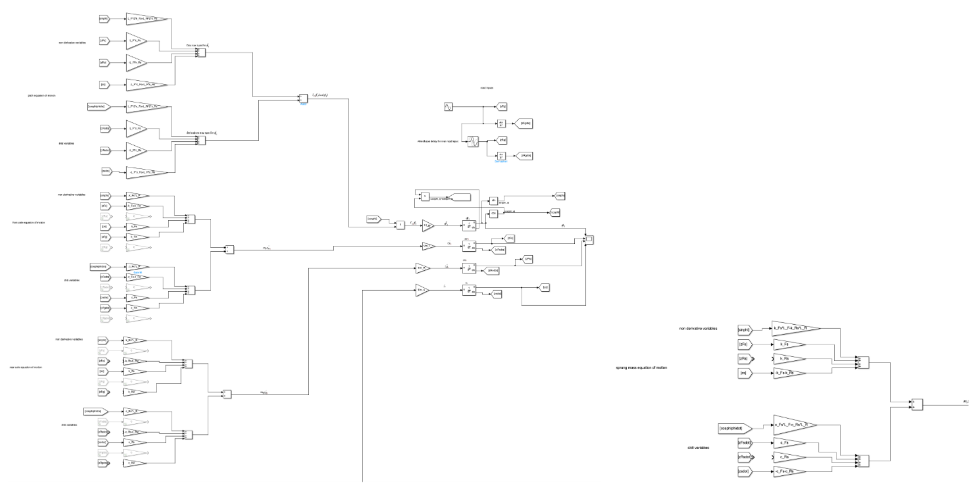

Figure 9: Half Car Model Simulink

Converting this to simulink was by far the most challenging bit of the process, as having a logical and clean layout was extremely important. Currently, the model is not working and I need to fix it a bit; however, I have narrowed the issue to the angle. I think the easiest way to debug and fix these is to determine a way to narrow the different parts into subsystem blocks that can be easily combined to develop the half car model in a more bottom-up design style.

1.5 Data Analysis

I have started creating a folder for common functions that can be used for data analysis. However, I still need to determine whether it is better to start data processing in Matlab or Python. Initially I have written some code in matlab that will interface with the model and allow us to sweep through different values of constants, run the model to find the results, and convert this into a Power Spectral Density (PSD) plot.

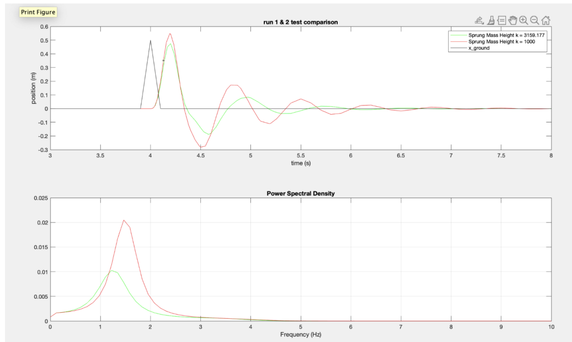

Figure 10: Quarter Car Model k sweep (sweeping through spring constant)

Currently, there a quite a few more data analysis projects that are still in the pipeline and half-developed. The primary ones are as follows:

- Hall-Effect Sensor RPM Data Processing
- LinPot data conversion and Dewesoft X software integration
- Developing a metric to characterize suspension oscillation

1.6 Track Design

A lot of time this semester was spent cleaning up the track and redesigning sections of it to facilitate testing and data collection. We noticed during tyre pressure testing before the first competition that we didn't really have a greate section of track to setup a set maneuvarability course to determine consistent laptimes across different days, cars, and setups.

For the new track design, we wanted to create a track that featured similar obstacles to what we are seeing in recent competitions, as well as obstacles that would provide us with the consistent testing environment described above.

Figure 11: Proposed Track Design

1.6.1 Whups

We needed to create a sections of whups that was at a similar wavelength as to what we see at competition (deciding on the wavelength through videos at competition. This would help us determine how changing shock setup could allow us to go over the whups faster with less oscillation at competition. This would be combined with lin pot sensor data to ensure a more quantitative rather than qualitative result. However, driver feedback would still be important.

Figure 12: New whups section

1.6.2 Current Track Status

Over fall break we managed to clear out what I am calling "the plateau" section of the track using weed whackers. This will be the perfect area to setup log sections and tyre sections. We have currently built a large jump, however it still needs to become sharper. And the whups section is almost done; however, the whups are currently too large and the car is bottoming out on them.

Unfortunately, track changes take a lot of time and are severely impeded by a lack of labor, equipment, time, and seasonal changes. This is a consistent struggle, but I am hopeful that the more time we get to spend at track the more we can design and maintain it.

1.7 Future Improvements

Given the long-term nature of this project, I am excited to continue working on developing the models and data analysis methods over winter break as well as next semester and maybe even during senior year. Hopefully, I will have the half-car model working over winter break and we can get straight to track testing and correlating.

I think the biggest gain next semester will be to head out on track and see everything that we have designed and coded work with the hardware. I have already set up the lin pot connections with the Dewesoft DAQ in anticipation, and hope to go out to the track early in the spring semester (weather permitting) to gather initial data and correlate the (fixed) model. This will also allow a more concrete basis for developing data analysis functions.

2 Personal Reflection

This year I really enjoyed my project. While it is quite unorganized as a new project, it is developing into a new challenge every day, and is testing all my skills as an engineer to work with a constantly evolving project. I am excited to continue working on this project in the long-term, even through my senior year.

This semester I did feel that it was a lot to do alone. I would like to recruit more people to help in terms of sensor setup and track maintenance, as well as data analysis. This will help transfer knowledge of these systems once I leave, as well as make my job more efficient. Additionally, this semester I saw my highest course load, so was unable to make as much headway on the actual hardware and testing side of the project; however, I am hopeful that in the spring I will be able to spend a lot more time at track gathering data to analyse.