



**Mechanical, Automotive, & Materials Engineering**

401 Sunset Avenue

Windsor, Ontario, Canada N9B 3P4

519 253 3000 (2616)

[www.uwindsor.ca/mame](http://www.uwindsor.ca/mame)

## Report 1: Drag Race Simulation

Arjun Posarajah  
104980541  
MECH-4463  
Vehicle Dynamics

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# Contents

Introduction .....	5
1. Theoretical Top Speed .....	5
1.1 Calculating Theoretical Top Speed .....	5
1.2 Theoretical Top Speed Analysis .....	6
2. Torque Data Interpolation .....	6
2.1 Torque Data Analysis .....	6
3. Engine Gear Ratio .....	8
3.1 Geometric Progressions .....	8
3.2 Overgeared or Undergeared? .....	9
4. Maximum Traction Forces Available .....	10
5. Simulations Data Analysis .....	11
5.1 Data .....	11
5.2 Data Comparison .....	13
6. Torque Distribution Analysis .....	14
7. Configuration Simulations .....	15
7.1 Data .....	15
7.2 Analysis .....	17
Conclusion .....	17
References .....	18

# List of Figures

A1 1996 Honda Civic CX Hatchback.....	5
1.1 Resistive force Calculations.....	5
1.2 Maximum power Criterion Calculations.....	6
2.1 RPM vs Torque Linear Interpolation Graph.....	7
3.1 Engine Speed vs Vehicle Speed Graph.....	8
3.2 Simulation data of Engine Speed vs Vehicle Speed.....	9
4.1 Vehicle Speed vs Traction Force Graph.....	10
5.1 Distance vs Time Graph.....	11
5.2 Velocity vs Time Graph.....	12
5.3 Acceleration vs Time Graph.....	12
5.4 Axle Vertical Load vs Time Graph.....	13
6.1 AWD with center of mass height at 0.4809m Graphs .....	14
7.1 RWD with center of mass height at 0.4809m Graphs.....	15
7.2 FWD with center of mass height at 0.48m Graphs.....	16
7.3 RWD with center of mass height at 0.48m Graphs.....	16

# List of Tables

2.1 Data of Torque at RPMs .....	6
3.1: Gear Ratios of corresponding Gears .....	8
4.1 Acceleration of 100km/hr Analysis .....	10
6.1 Speed and Time of Different Torque Configurations .....	14
7.1 Car Configurations with Results .....	17

# Introduction

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**Figure A1:** 1996 Honda Civic CX Hatchback [3] Markus

The car chosen for the drag race simulation analysis is a 1996 6<sup>th</sup> generation Honda Civic CX hatchback. The car is a five-speed manual car with a 4 stroke spark ignition engine and a forward wheel drive configuration. Interest to choose this car stems from whether having a hatchback would be a disadvantage in a drag race and for the fact that the Honda Civic is a very common car allowing for vast amount of data to be used. The overall purpose is to perform a thorough analysis of the longitudinal dynamic capability of the 1996 6<sup>th</sup> generation Honda Civic CX hatchback.

## 1 Theoretical Top Speed

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### 1.1 Calculating Theoretical Top Speed

To calculate for the theoretical top speed of the car, the consideration of both resistive forces had to be analyzed. The drag force and rolling resistance were the two forces to consider when using maximum horsepower criterion. In figure 1.1 shows the calculation process with assumptions made to the Z force being the mass of the vehicle multiplied by gravity.

$$\begin{aligned} F_D &= \frac{1}{2} \rho V^2 c_d A \\ &= \frac{1}{2} (1.23) (V^2) (0.34) (1.94) \\ &= 0.40565 V^2 \\ x_{roll} &= k_{roll} Z \\ k_{roll} &= (6.5 \times 10^{-6}) V^2 + 0.013 \\ Z &= 1008 \text{ kg} \left( \frac{9.81 \text{ m}}{\text{s}^2} \right) \\ x_{roll} &= ((6.5 \times 10^{-6}) V^2 + 0.013) (9888.48) \\ x_{roll} &= 0.064275 V^2 + 128.55 \end{aligned}$$

**Figure 1.1:** Calculation of the drag force and rolling resistance force on the car.

As seen in the drag force equation, the area is based solely on the frontal area which is area is directly in contact with, thus answering one of my interests in analysis of this vehicle. The hatchback design will not give a disadvantage in terms of air resistance; however, it may cause for more weight as it is a different construction compared to the regular build.

With a max horsepower of 106hp converted to Nm/s the maximum horsepower criterion could be solved for with the maximum horsepower equaling to the resistive forces multiplied by the velocity which led to a cubic function as seen in figure 1.2.

$$\begin{aligned}
 106hp &= \frac{79044.191669Nm}{s} \\
 Power &= (F_D + x_{roll})(V) \\
 79044.917 &= (0.4699V^2 + 128.55)V \\
 0 &= 0.469415V^3 + 128.55V - 79044.917 \\
 V &= \frac{53.55m}{s} = \frac{192.78km}{hr}
 \end{aligned}$$

**Figure 1.2:** Calculation for the theoretical max velocity based on the maximum power criterion.

## 1.2 Theoretical Top Speed Analysis

With a resulting 192.78km/hr for the vehicle theoretical speed from the maximum horsepower criterion. This value is reasonable, as an unreasonable amount would be over 200km/hr. With the Honda Civic CX being an entry level purchase with no upgrades this value is a reasonable estimate. While also comparing similar cars like the Volkswagen Golf with a top speed of 192km/hr from [1] Car Specs Database.

From data retrieved on [1] Car Specs Database with the maximum speed of the vehicle being 189.903km/hr which is close with a difference of about 3km/hr. The reason for a 3km/hr difference could be due to assumptions made like the normal forces on the tire as what was input was just the weight force down while there are other factors like downforce, vertical vibrations and more that were not considered in the equations in figure 1.1 and 1.2. Another possible reason is due to power loss from the engine as the maximum horsepower used will not be the same value as the horsepower that is being transferred to the wheels from mechanical losses throughout the transmission process.

# 2 Torque Data Interpolation

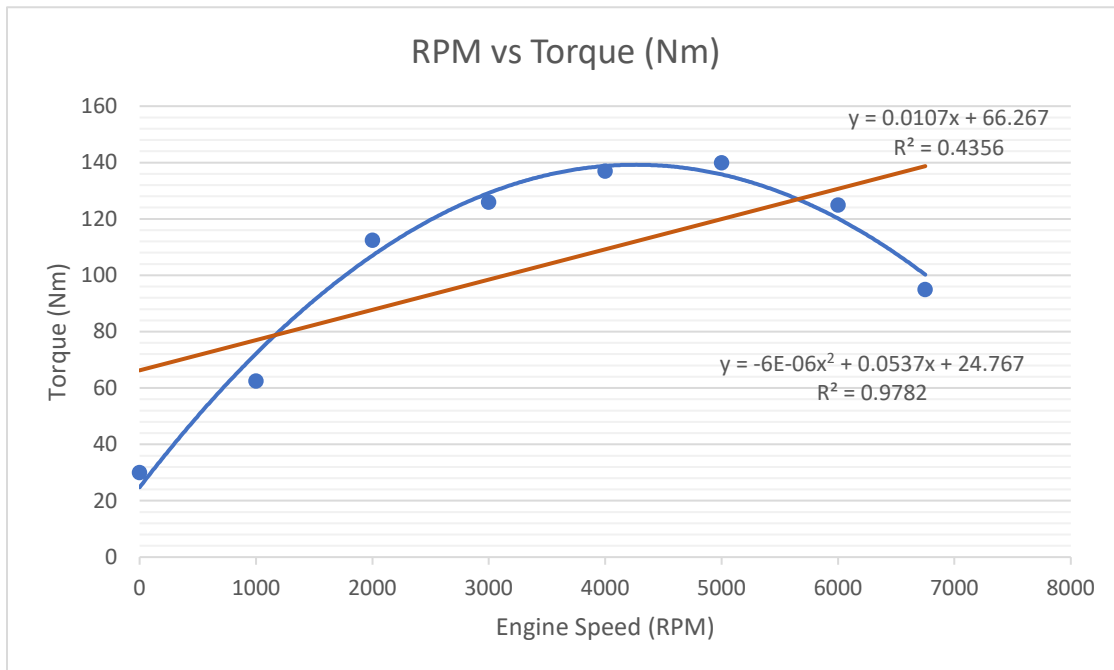
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## 2.1 Torque Data Analysis

As seen in table 2.1, this is the data values of the torque to engine speed that will be used to gather the linear interpolation.

RPM	Torque (Nm)
0	30
1000	62.5
2000	112.5
3000	126
4000	137
5000	140
6000	125
6750	95

**Table 2.1:** Data collected for torque at different RPMs from [2] EcoModder Wordmark.



**Figure 2.1:** RPM vs Torque (Nm) with a linear and a polynomial interpolation at seen by the R value how closely it represents the data set.

As seen in figure 2.1, data on graph does not follow a linear trend but close resembles the trend of a second order polynomial. With the linear interpolation, it is inaccurate from the ranges of 1500RPM to 5500RPM as this linear line does not go anywhere near the correlating points. This has further proof with the R squared value not being close to 1 meaning the fit of the curve is very poor. However, while comparing the data values with the polynomial interpolation its significantly closer to the actual data with a proven R squared value of 0.9782 which very close to 1. This is since the torque curve naturally has similar properties to a polynomial or a sinusoidal curve. Overall, the most amount of power from this engine is when it is around 4000RPM.

The difference between the original data and the linear interpolation occurs between 1500RPM and 550RPM. This is due to the data reaching a max and flattening out then decreasing while the linear interpolation is continuing to increase even when decreasing.

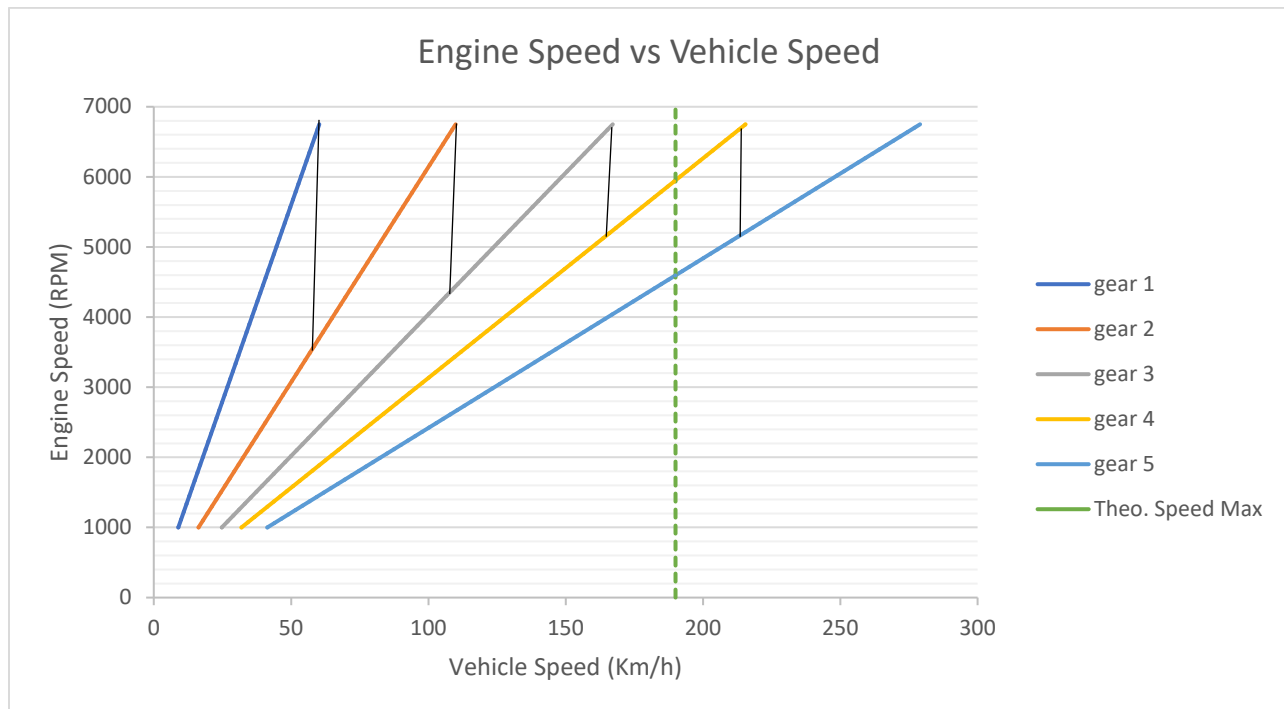
This will affect the calculation through the lack of accuracy of a big portion of the engine speed leading to incorrect values when using such torques. However, after reviewing the polynomial interpolation, it is evident that with better fitting curve for test and simulation purposes to use the polynomials interpolation function as it is a better representation of the data.

### 3 Engine Gear Ratios

Table 3.1 are the values for the 5-gear transmission car with the final drive ratio which was found on [2] EcoModder Wordmark.

Gears	Ratio
1	3.25
2	1.782
3	1.172
4	0.909
5	0.702
final drive	3.722

**Table 3.1:** Gear ratio values for corresponding gears in the manual transmission.



**Figure 3.1:** Engine speed vs Vehicle speed with the theoretical maximum speed as the dotted vertical line showing that even though it mathematically can go close to 300km/hr it does not in real life and other mathematical calculations.



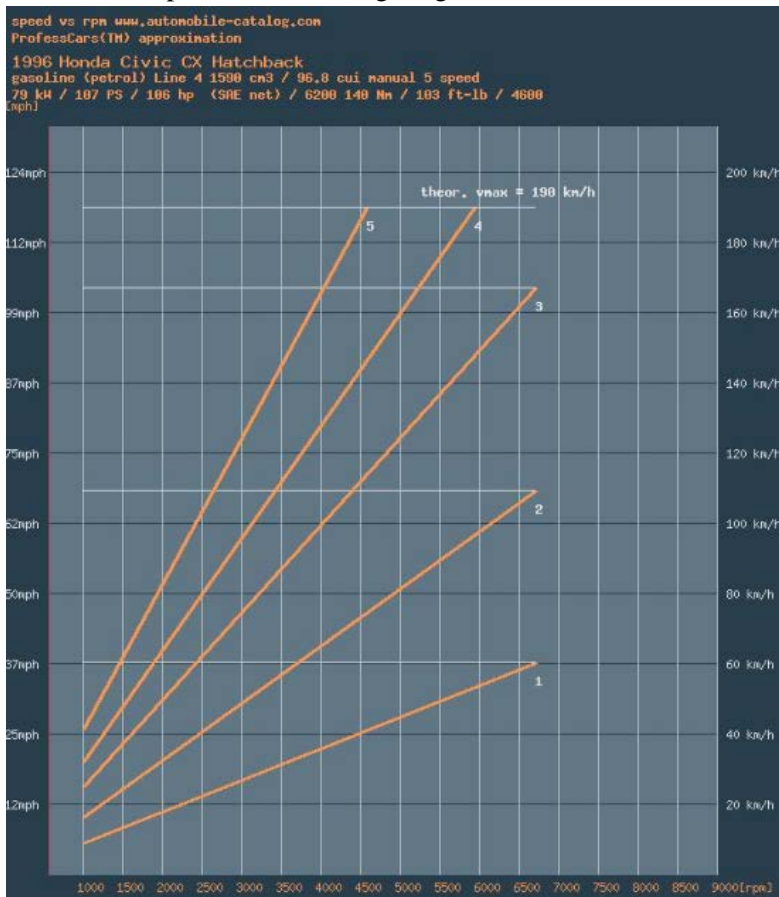
### 3.1 Geometric Progressions

From figure 3.1, first gear is within 8km/h to 60km/hr, second gear is within 16 to 109km/h, third gear is within 24.76 to 167.15km/h, fourth gear is within 31.9 to 215.5km/h and fifth gear is within 41.3 to 279km/h. However, these values are truly attainable as the maximum vehicle speed is 190km/h.

There is a ratio progression is not all geometric from checking the relations of the gear ratios from  $n_2/n_1$  it is 0.55,  $n_3/n_2$  is 0.66, 0.77 at  $n_4/n_3$  and  $n_5/n_4$  is 0.77. The only geometric ratio progression exists between  $n_3$ ,  $n_4$  and  $n_4$ ,  $n_5$ . This is due to both having the same values of 0.77 ratios. This is also proven when viewing figure 3.1 and the same triangle forms when projection of the previous gear is on the next gear between 3, 4, and 5. The reason for not having all geometric ratios is due to the decrease in acceleration performance, so it more important in gear 1 to 3 for acceleration in this vehicle.

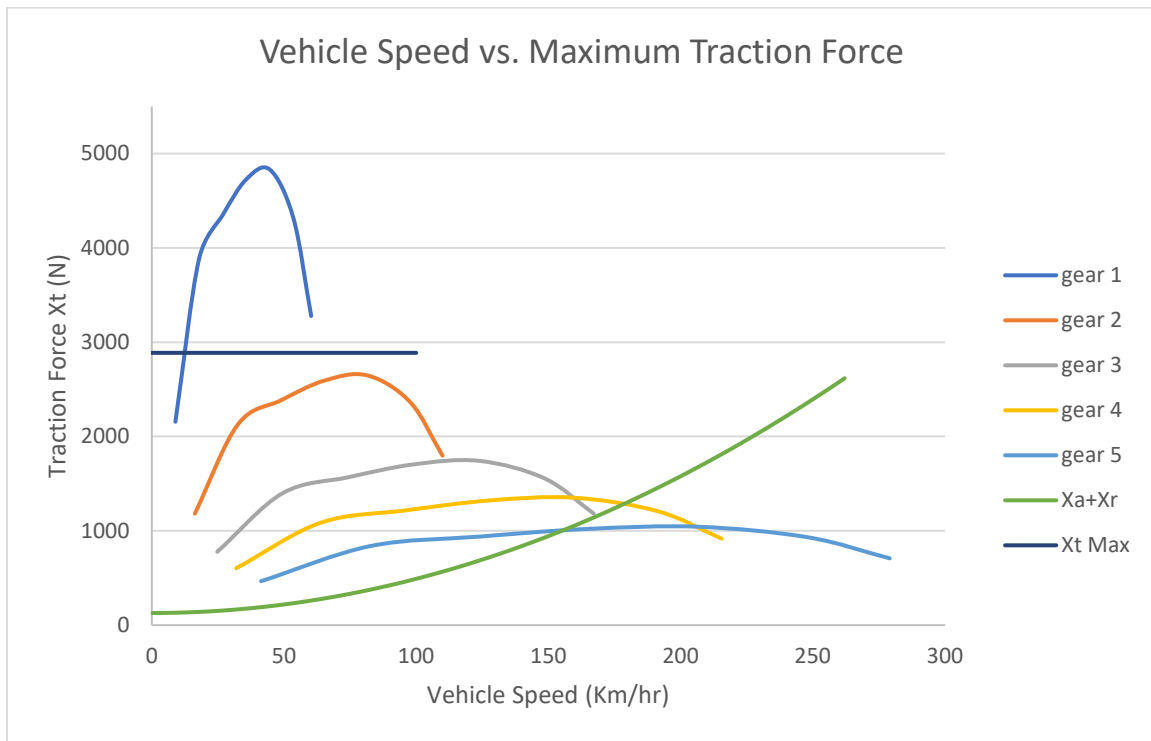
### 3.2 Overgeared or Undergeared?

The vehicle is over geared as it is creating engine speed is above the speed at which it makes maximum power. With the engine speed being at 4000RPM to make the most power however the engine speed goes over to create higher vehicle speeds. This is evident when looking at gear 3 to 4 and gear 4 to 5 as both have a point above 4000RPM, compared to the other gears. The reasoning for over gearing this vehicle is to be more fuel efficient for a passenger vehicle. This allows the vehicle to be able to travel much faster than what the engine has enough power to do. Due to overgearing and not having a geometric ratio progression it allows for the alight decrease in acceleration performance in low gears but a much bigger increase in performance in higher gears.



**Figure 3.2:** Simulation data of Engine speed vs Vehicle speed, as comparison from [1] Car Specs Database.

## 4 Maximum Traction Forces Available



**Figure 4.1:** Vehicle speed vs traction force at each gear with total traction curve and maximum traction force

The maximum speed of the vehicle was 186km/hr in gear 4. As seen in figure 6.1, the  $X_a+X_r$  curve intersects at a further point in the gear 4 curve than on the gear 5 which is based on the max speed engine criteria. The top gear is not where the maximum speed occurs and this is due to the fact that with the total resistive forces, it will not reach that speed, compared to in gear 4 with both curves intersecting allowing for equilibrium from both forces making it the optimal maximum speed without losses. When comparing with theoretical max vehicle at 189.9km/hr and power criterion theoretical max speed at 192km/hr which is close to the results from figure 6.1.

Gears	Force (N)	Acceleration ( $a=F/m$ ) ( $m/s^2$ )
at $X_a+X_r$	515	-----
5	920	0.401785714
4	1250	0.729166667
3	1700	1.175595238
2	1780	1.254960317

**Table 4.1:** To solve for the acceleration available at 100km/hr the forces were converted to acceleration by dividing mass of the vehicle.

The maximum acceleration available at 100km/hr is  $0.4m/s^2$  in gear 5,  $0.7m/s^2$  in gear 4,  $1.2m/s^2$  in gear 3 and lastly  $1.3m/s^2$  in gear 2. Showing that acceleration is significantly higher in the lower gears

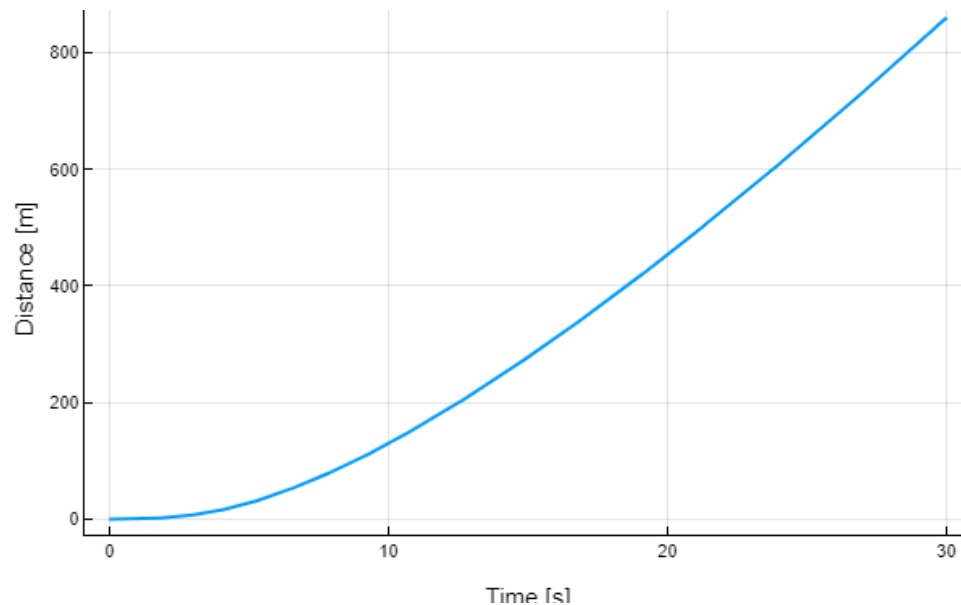
compared to in the higher gears. This was designed to be able to accelerate past the lower speeds to an ideal speed where acceleration is no longer necessary. The gap between gears, allows for the gears that are closer together create a higher torque on the power curve creating more acceleration much does not create high speeds. High speeds are through higher gears which in result will give lower acceleration. The vehicle is sufficient to overtake as the overlapping short shifting occurring in gear 3, 4, and 5 ensure to increase traction force when switching gears. It is beneficial that gear 1 and 2 does not short shift as it can push the acceleration further possible into the shift ensuring traction as well. Within gear 2 alone, the acceleration is very high allowing to a 0 to 100km/hr significantly higher than any other gear as gear 1 will not be reach 100km/hr. Downshifting is necessary if the vehicle needs more power in return for more acceleration which will allow for overtaking. For few scenarios, it would be beneficial by downshifting to gear 4 when comparing the acceleration difference of  $0.33 \text{ m/s}^2$  which will significantly help also considering the beneficial top speed of the vehicle also occurs in gear when the total resistive force intersects with the gear 4 curve.

## 5 Simulations Data Analysis

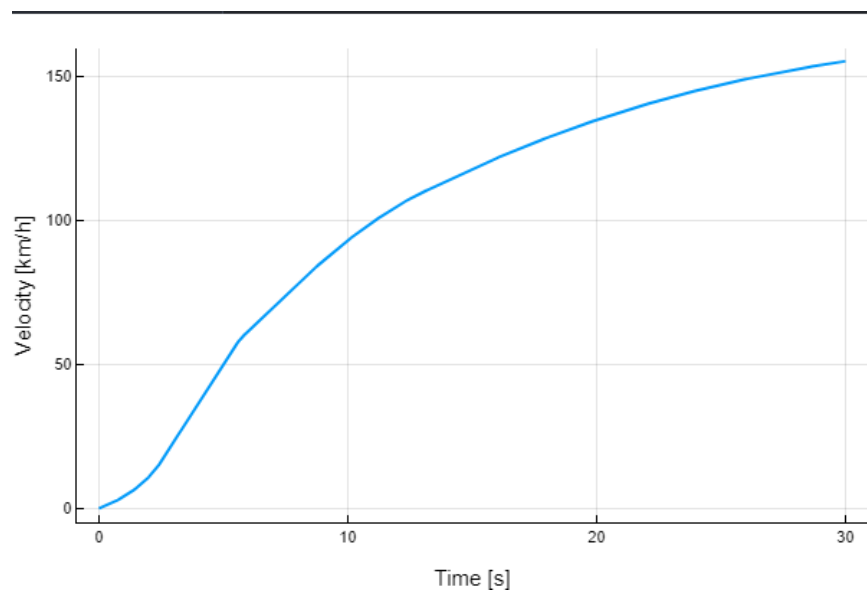
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### 5.1 Data

Through the EOM program created by Dr. Minaker, these graphs were simulated through his model, which allowed for a more in-depth analysis of a drag race of the Honda civic CX hatchback.

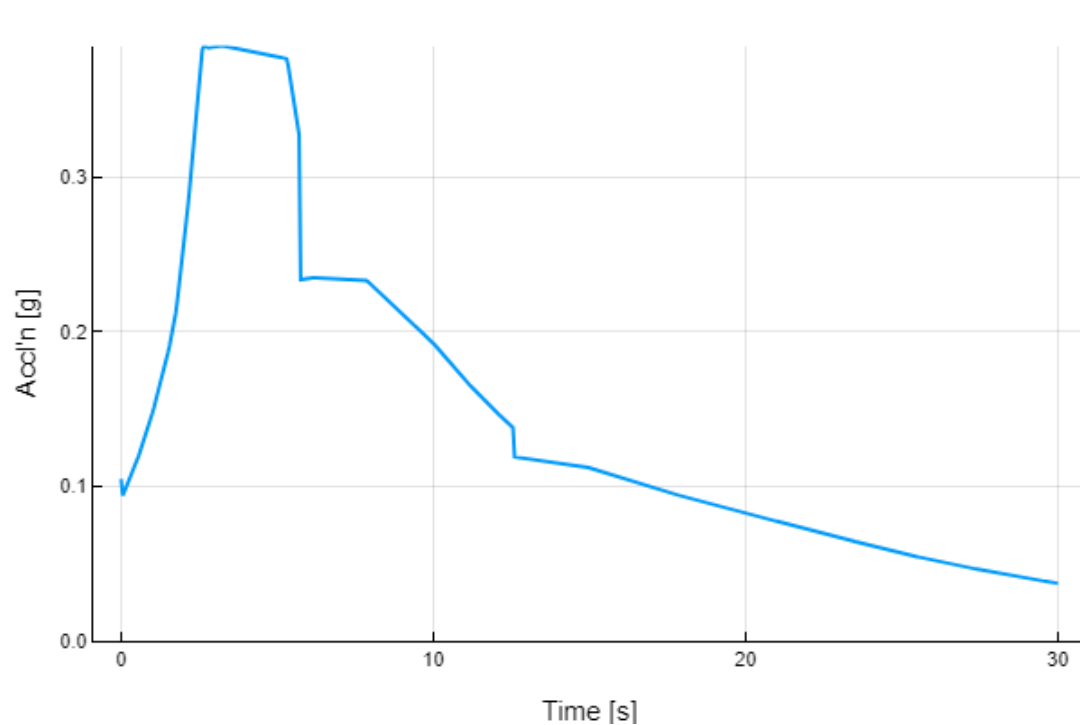
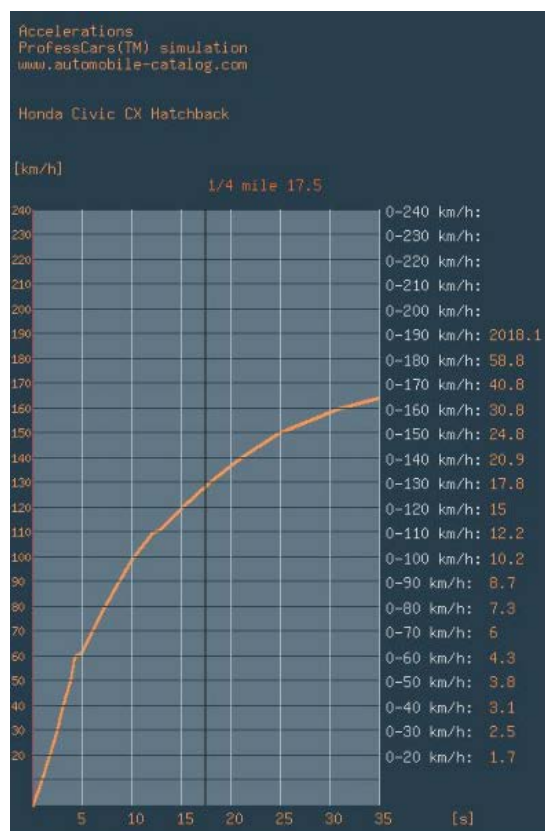


**Figure 5.1:** Dr. Minaker's EOM code plot for the distance vs time graph of the 1996 Honda Civic CX hatchback.

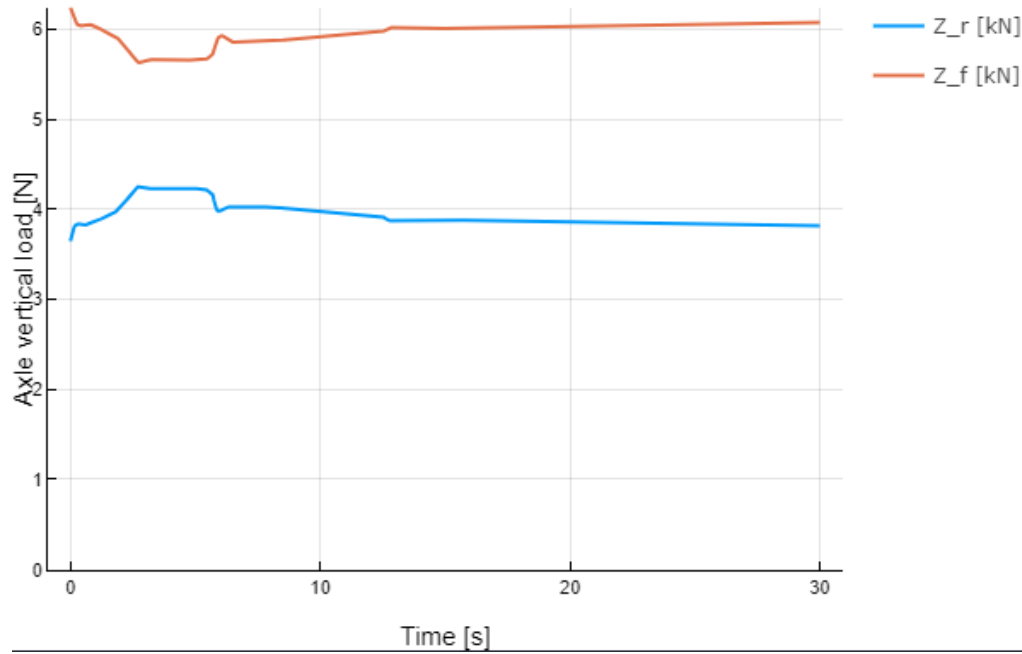


**Figure 5.2:** Dr. Minaker's EOM code plot for the velocity vs time graph of the 1996 Honda Civic CX hatchback. (TOP)

(RIGHT) Through automobile-catalog.com, the simulation run that will be compared with the Julia code simulation.



**Figure 5.3:** Dr. Minaker's EOM code plot for the acceleration vs time graph of the 1996 Honda Civic CX hatchback.



**Figure 5.4:** Dr. Minaker's EOM code plot for the axle vertical load vs time graph of the 1996 Honda Civic CX hatchback.

## 5.2 Data Comparison

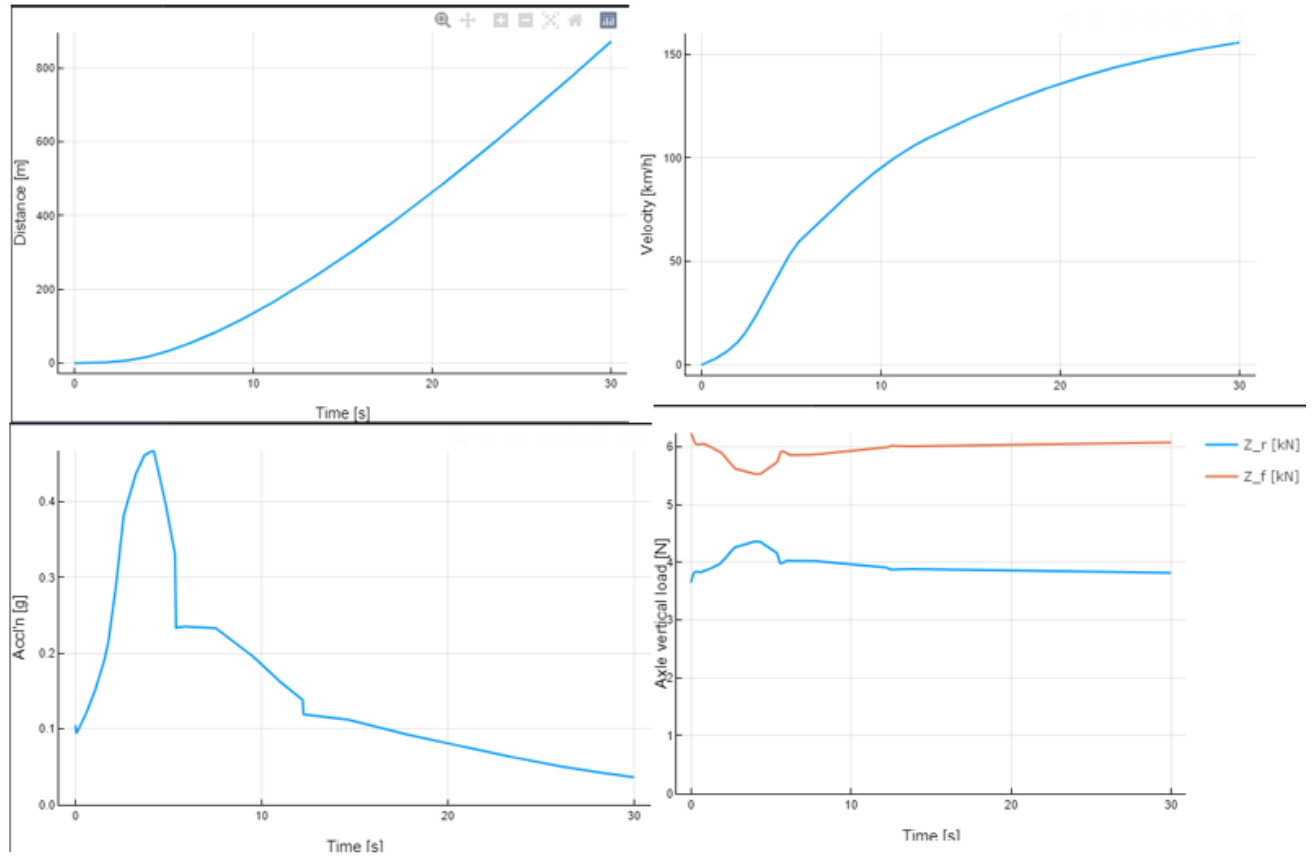
After running the Julia code, the results for the 0 to 60 mph was 10.54 seconds while the other simulations value from [1] Car Specs Database and factory claim was 9.6 seconds which is fairly close. The quarter mile time for the Julia code was 18.61 seconds at 130.61km/hr while the other auto-catalog simulation from [1] Car Specs Database was 17.5 seconds at 129km/hr.

When comparing both simulations data, the auto-catalog data is slightly faster in all points. The performance was under predicted in the EOM software compared to the other simulation. This can be led to many factors like, the other data set that was compared is also a simulation so a guaranteed conclusion can be assessed whether it truly did under perform. Another factor is the accuracy of the  $a$ ,  $b$  and  $hG$  lengths for the vehicle with the information not available online. Those values were calculated estimation to receive a reasonable result. In the Julia program the torque was linearly interpolated which was proven in section 2.1 that the second order polynomial was a better fit for the data points. Inaccuracies are found in the auto-catalog simulations with the assumption of the removal of the speed governor, times did not include the transmission reaction time, and the integration of the ProfessCarstm software for the car dynamics simulation which with no access to the program can not find further possibilities for error.

To overcome the shortcomings with a more sophisticated model is a polynomial interpolation instead of a linear interpolation for a more realistic torque values to be used in other calculations. In my situation I would need better information on the  $a$ ,  $b$  and  $hG$  values for an even more accurate result.

## 6 Torque Distribution Analysis

When modifying the torque distribution, three simulations were assessed. Front wheel drive, Rear wheel drive and All wheel drive are the three torque distributions that were analyzed. The corresponding graphs for front wheel drive and rear wheel drive is figures 5.1 to 5.4 for front wheel and figure 7.1 for rear wheel drive.



**Figure 6.1:** Corresponding simulation graphs for the AWD configurations

Torque Configuration	0 to 60mph Time (s)	Quarter Mile Time (S)	Quarter Mile Speed (Km/hr)
FWD	10.54	18.61	130.61
RWD	11.91	19.59	129.3
AWD	10.21	18.37	130.9

**Table 6.1:** Speed and time of different torque configurations.

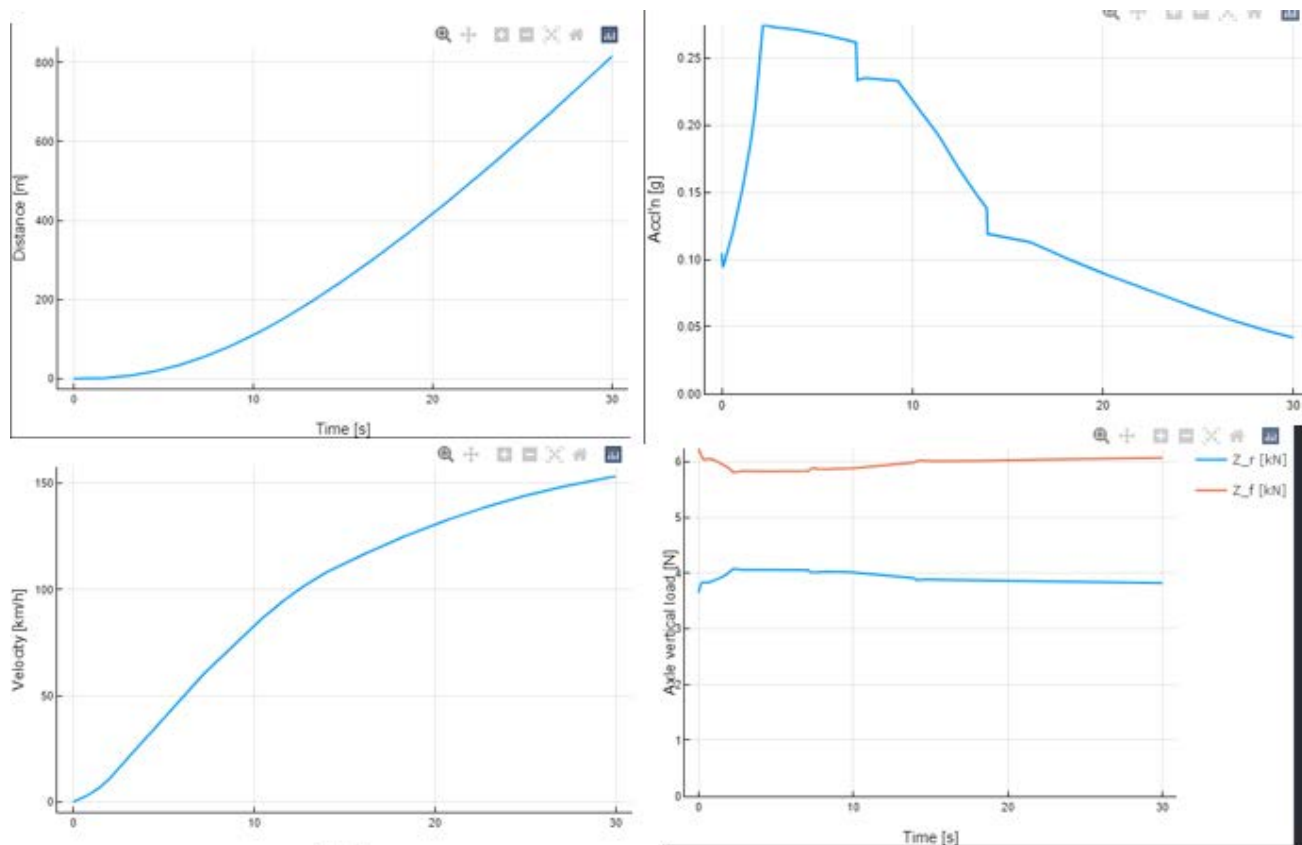
When reviewing table 6.1, it is evident that AWD has the best performance out of all torque configuration with it being slightly better than front wheel drive. This allows for torque to be equally distributed to both front and back axle allowing for more traction, and power in both axles compared to one. This will allow for the vehicle to push more. Although FWD is very close as this car was mainly designed for with the weight distribution to benefit the vehicle. All wheel drive provides the ability to apply power to all points of the vehicle to push even beyond FWD. Therefore, the optimum torque distribution is all wheel drive, although the car is forward wheel drive. Other torque distributions aren't as common for example 0.75 or 0.25 rdf values which is why they were not tested.

The reasoning for all wheel drive had better performance was that since all wheels are spinning with power, it creates significantly more grip creating a more stable feeling vehicle as well. With a big misconception that AWD is bad but many racing platforms have banned this torque configuration.

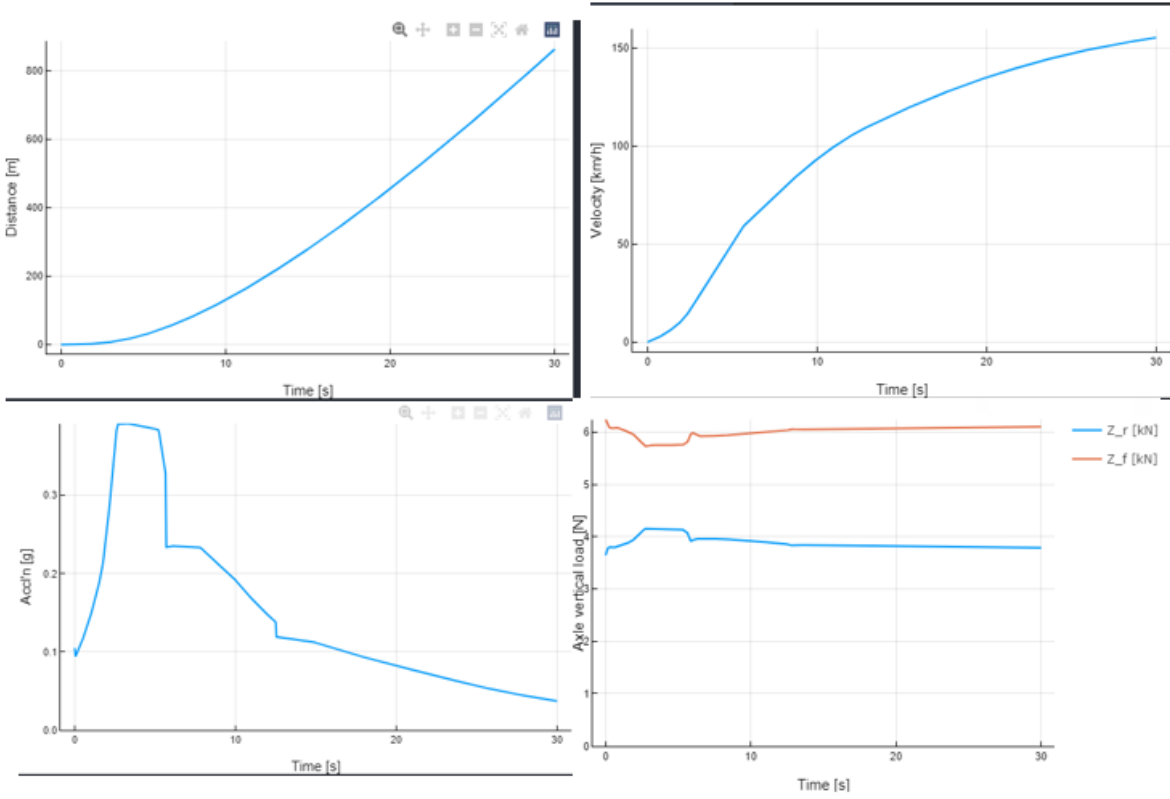
## 7 Configuration Simulations

### 7.1 Data

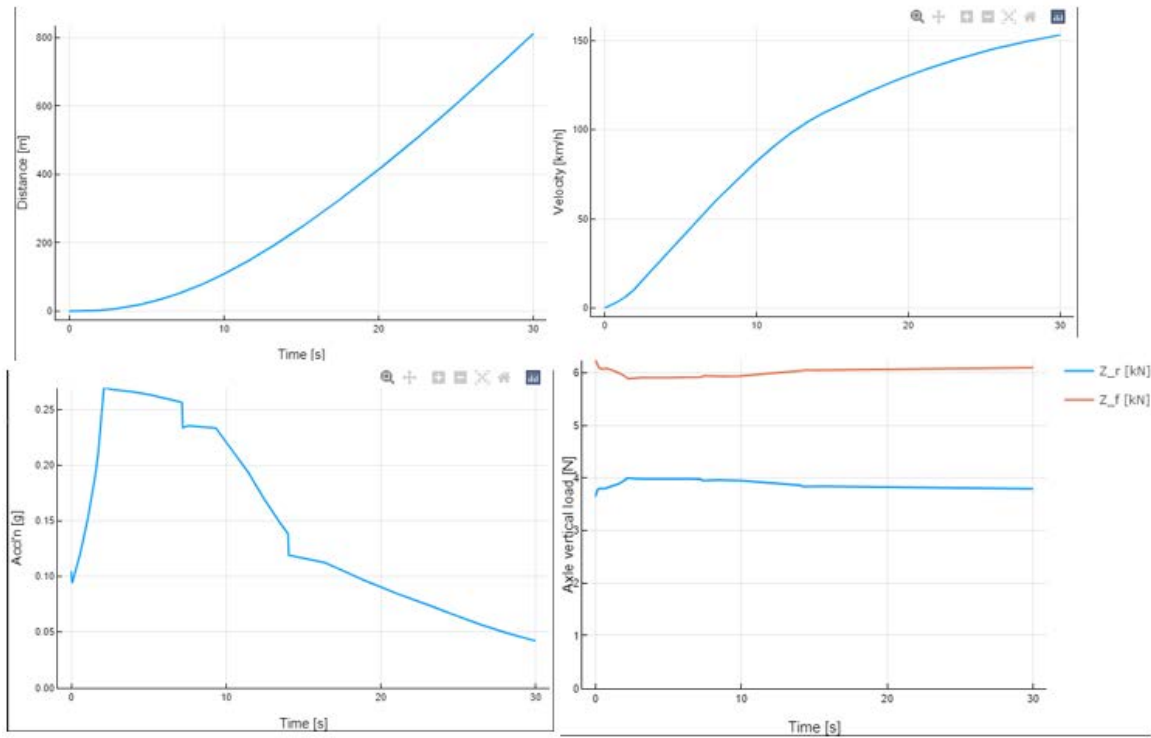
The Julia simulation were run again with the initial switch to rear wheel drive, then front wheel drive with the height of the centre of mass dropped to 0.4m and rear wheel drive with 0.4m height of the centre of the mass.



**Figure 7.1:** These are the graphs corresponding with the rear wheel drive and height of centre of mass at 0.4809m.



**Figure 7.2:** These are the graphs corresponding with the front wheel drive and height of centre of mass at 0.4m.



**Figure 7.3:** These are the graphs corresponding with the rear wheel drive and height of centre of mass at 0.4m.



Configurations	0 to 60mph Time(s)	Quarter Mile Time(s)	Quarter Mile Speed (Km/h)
FWD, HG=0.4809m	10.54	18.61	130.61
RWD, HG=0.4809m	11.91	19.59	129.3
FWD, HG=0.4m	10.5	18.58	130.6
RWD, HG=0.4m	12.02	19.67	129.2

**Table 7.1:** Configurations with time and speed for the 0 to 60mph and quarter mile drag race.

## 7.2 Analysis

When reviewing table 7.1, it is evident that for this vehicle forward wheel drive is the correct selection as regardless of the center of gravity height was changed, the forward wheel drive configuration had always won the race. This may be due to the fact that the vehicle is front heavy with a value being less than the b value. This correlation is the reason for the ability of the front heavy car with the front wheel drive train to have an advantage.

Another evident correlation is that the lower the center of gravity the faster the car goes, this is evident in table 7.1 as with the same drive configuration the lower center of gravity had won the race with 0.03 second advantage with a front wheel drive. This is 0.08 second advantage with a rear wheel vehicle showing even if a rear-wheel-drive vehicle is designed, if the design allows for a lower center of gravity, it will be beneficial for the vehicle.

Overall, the best option evidently is the front wheel drive with the lower center of gravity for this vehicle. It provides the best drive option for the weight distribution and with the lower center of gravity it will increase the stability of the vehicle even with such a big vehicle.

## Conclusion

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Based on the various longitudinal dynamics that were tested for the capability of the 1996 Honda Civic CX Hatchback it does perform well with the configurations which Honda has offered for this vehicle. The front wheel drive helps with the front heavy weight distribution this will also help with traction when trying to accelerate and speed in general. The engine is also Overgeared with the maximum engine speed being above the speed at which it makes maximum power. Gear ratios also benefit with a very minimal need to downshift only between gear 4 and gear 5 as maximum speed occurs at gear 4. Inaccuracies became under question when two different simulations were giving different results with both having errors of their own however giving a relatively close result.

The interest in choosing this car had also been resolved when considering a hatchback being a disadvantage when racing is false as the main backing would be the drag in which it creates but frontal area would be the same and the drag coefficient is the exact same for the sedan model.

## References

- [1] “Catalog the Catalog of Cars, Car Specs Database.” *Automobile*, <https://www.automobile-catalog.com/>.
- [2] “Honda Manual Transmission Specifications & Gear Ratios - Fuel Economy, Hypermiling, EcoModding News and Forum.” *EcoModder Wordmark*, <https://ecomodder.com/forum/showthread.php/honda-manual-transmission-specifications-gear-ratios-26279.html>.
- [3] Markus, Frank. “Tested: 1996 Honda Civic DX Is Clean and Quick.” *Car and Driver*, Car and Driver, 29 Nov. 2021, <https://www.caranddriver.com/reviews/a36521729/1996-honda-civic-dx-by-the-numbers/>.