POWER TRAIN SYSTEMS DESIGN

(MECH 4313)

PROJECT

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Introduction

This project started with making a graphical user interface (GUI) application for designing the gear ratio of the car. This GUI apps will ask the user for the input of the car and engine specifications and used it for calculating the gear ratio. There are 2 methods on determine the gear ratio were used which are Geometric Progression Method (GPM) and Progressive Method (PM). Each of the methods give different behaviour on how gearbox of the vehicle work, such as, shifting time.

Then, the result of gear ratio will be applied on simulation to analyse the time taken for the car to finish the race. The car used will be the same throughout the project with the same engine and body. Furthermore, there will be 2 types of drive system were used which are rear wheel drive (RWD) and front wheel drive (FWD).

Therefore, the project will be focused on making GUI applications to calculate gear ratio and test it on the simulation to take the time taken for it to finish the race.

Graphical User Interfaces

The Graphical User Interface (GUI) of the project will help the user on determining the gear ratio of the vehicle. The GUI are designed using the Visual Studio 2019 with coding language C++. There 2 libraries were added to help on preparing GUI for the gear ratio calculator and some graph which are *Dear ImGUI* and *ImPlot* library.

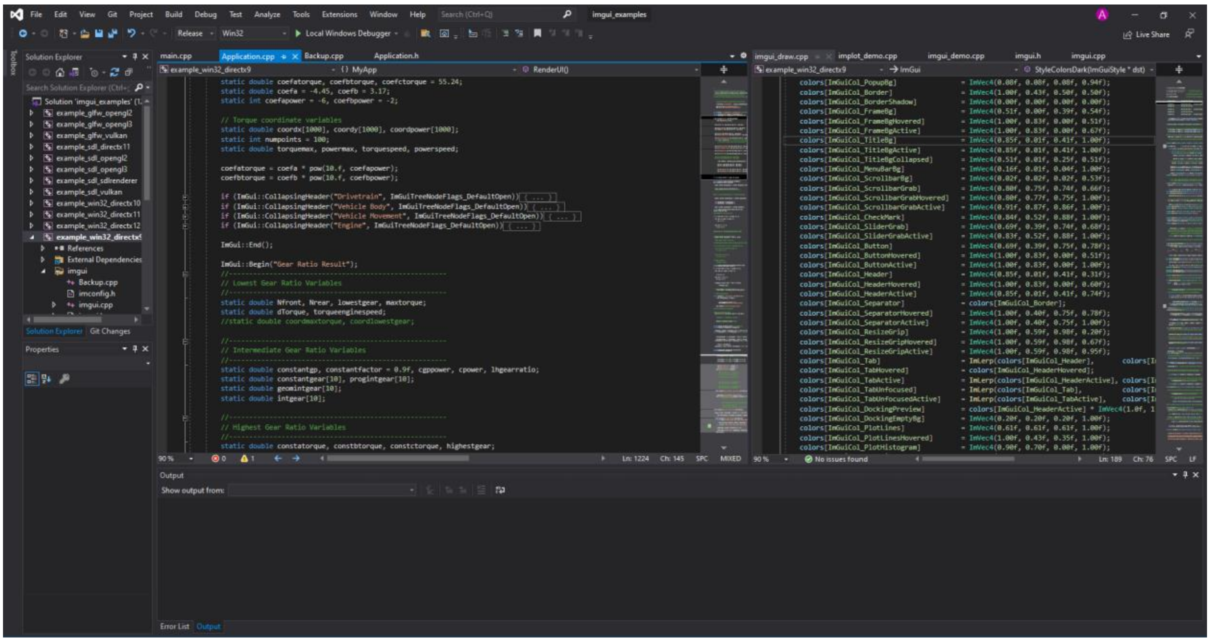


Figure 1: Coding Process of GUI

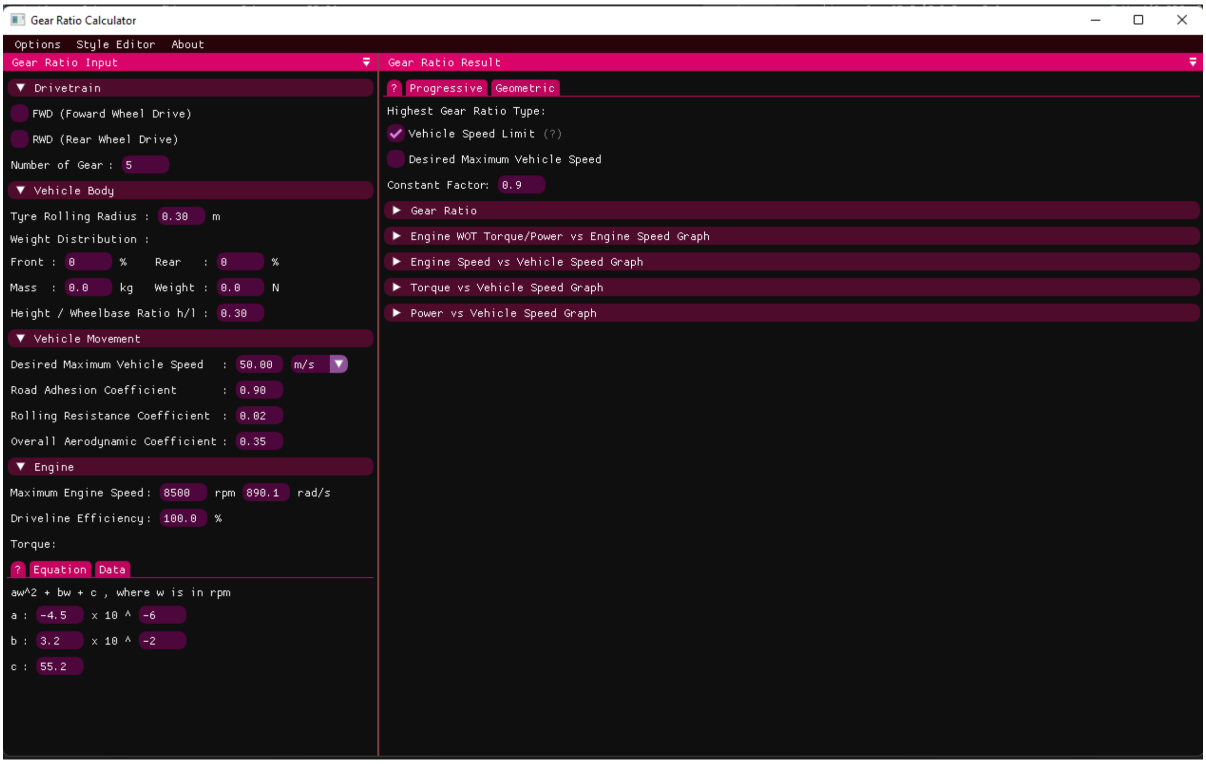


Figure 2: Gear Ratio Calculator GUI

The GUI are divided into 2 category which are Gear Ratio Input and Gear Ratio Result. The Gear Ratio Input category will be focused on user input. Gear Ratio Result category will be focused on the user output.

1. Input

In the Gear Ratio Input category, it will be asking the user for 4 sub-categories of input which are Drivetrain, Vehicle Body, Vehicle Movement and Engine of the vehicle. There are also some inputs that will be asked on Gear Ratio Result category.

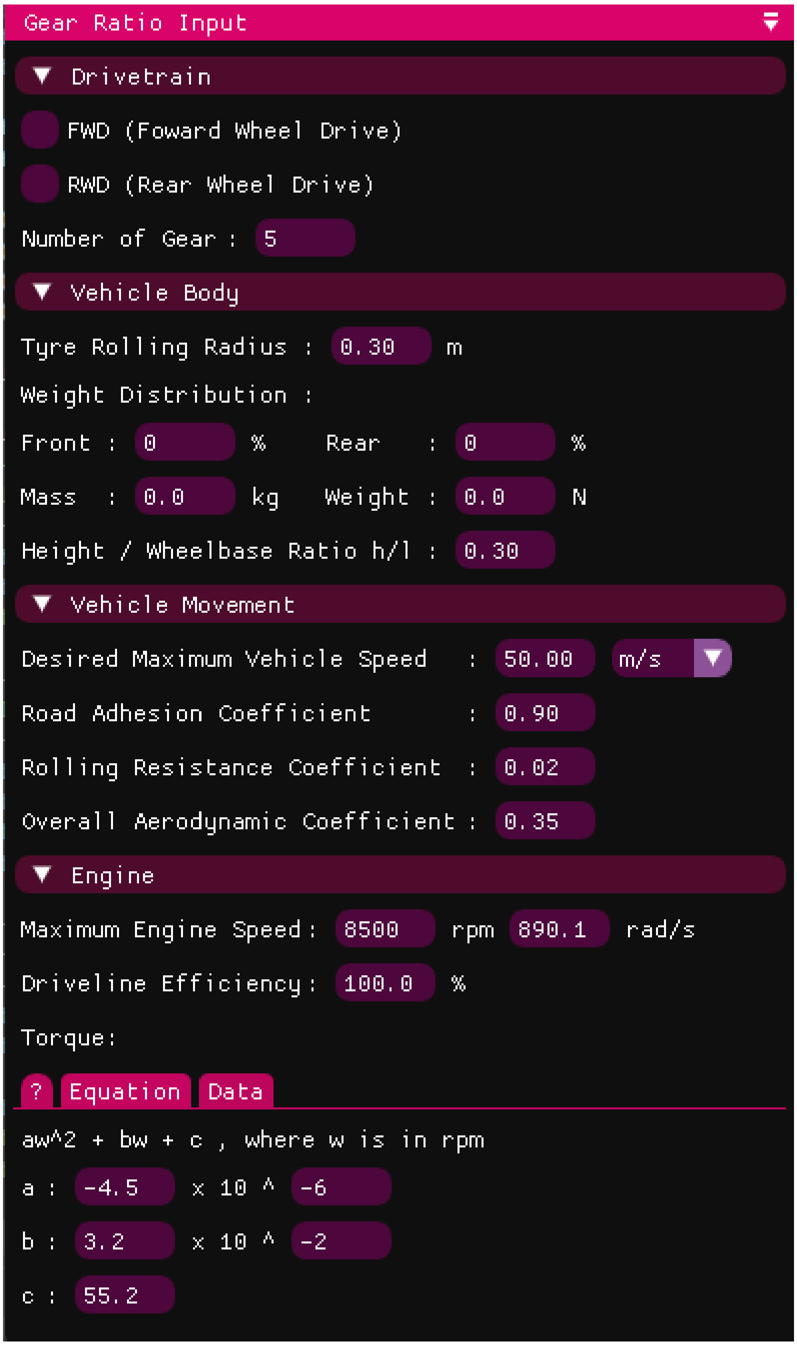


Figure 3: Gear Ratio Input

a. Drivetrain

For Drivetrain sub-category, it will ask for the drivetrain and number of gears of the vehicle used.

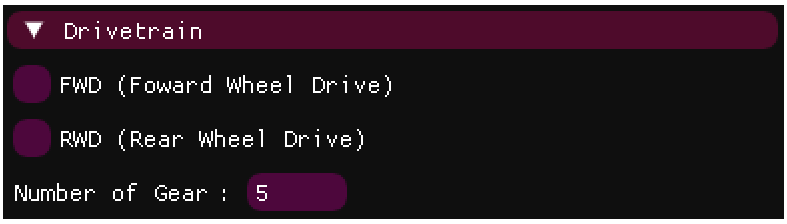


Figure 4: User Input – Drivetrain

b. Vehicle Body

For Vehicle Body sub-category, it will be asking the user for the tyre rolling radius, weight distribution, mass or weight and height/wheelbase ratio of the vehicle.

Figure 5: User Input – Vehicle Body

c. Vehicle Movement

For Vehicle Movement sub-category, the GUI will be asking the user for desired maximum vehicle speed, road adhesion coefficient, rolling resistance coefficient and overall aerodynamic coefficient. The desired maximum vehicle speed units can be changed to km/h or m/s.

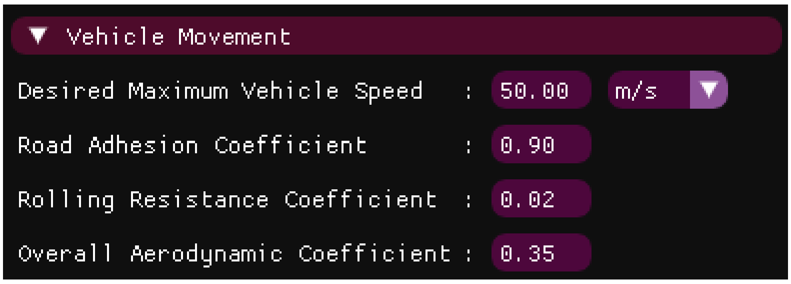


Figure 6: User Input – Vehicle Movement

d. Engine

For Engine sub-category, it will ask the user for maximum engine speed, driveline efficiency and torque of the engine. The maximum engine speed can be input in 2 units which are rpm and rad/s. Under the torque, the user can input the data using equation or data.

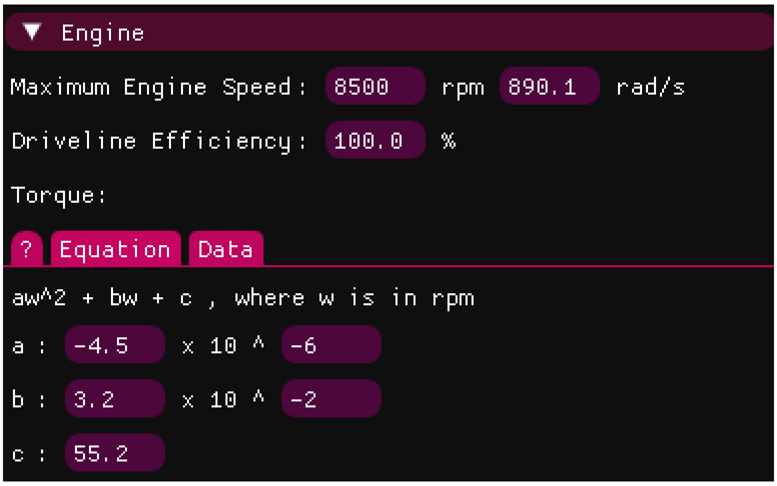


Figure 7: User Input – Engine (Equation)

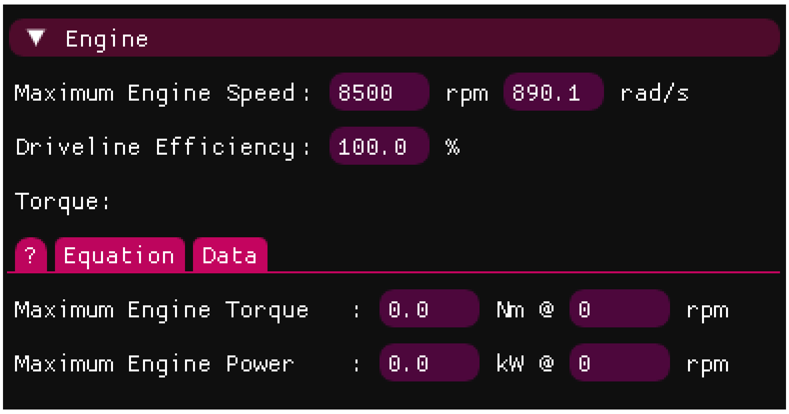


Figure 8: User Input – Engine (Data)

e. Gear Ratio Result Category

For the input on Gear Ratio Result category, it will ask the user for highest gear ratio type and constant factor for progressive method. There are 2 highest gear ratio type which are vehicle speed limit and desired maximum vehicle speed. Vehicle speed limit will give the highest gear ratio based on the maximum vehicle speed that the engine can achieved. Desired maximum vehicle speed will give the highest gear ratio based on the input of the desired maximum vehicle speed on Vehicle Movement sub-category. Furthermore, the constant factor is only available as an input if progressive method is selected.

Figure 9: User Input – Gear Ratio Result

2. Output

In the Gear Ratio Result category, there will be 5 sub-categories of result. One of the sub-categories is gear ratio while others are graph. This calculating of gear ratio will be divided to 2 methods which are progressive method and geometric progression method. User can choose the method by clicking the tab at the top.

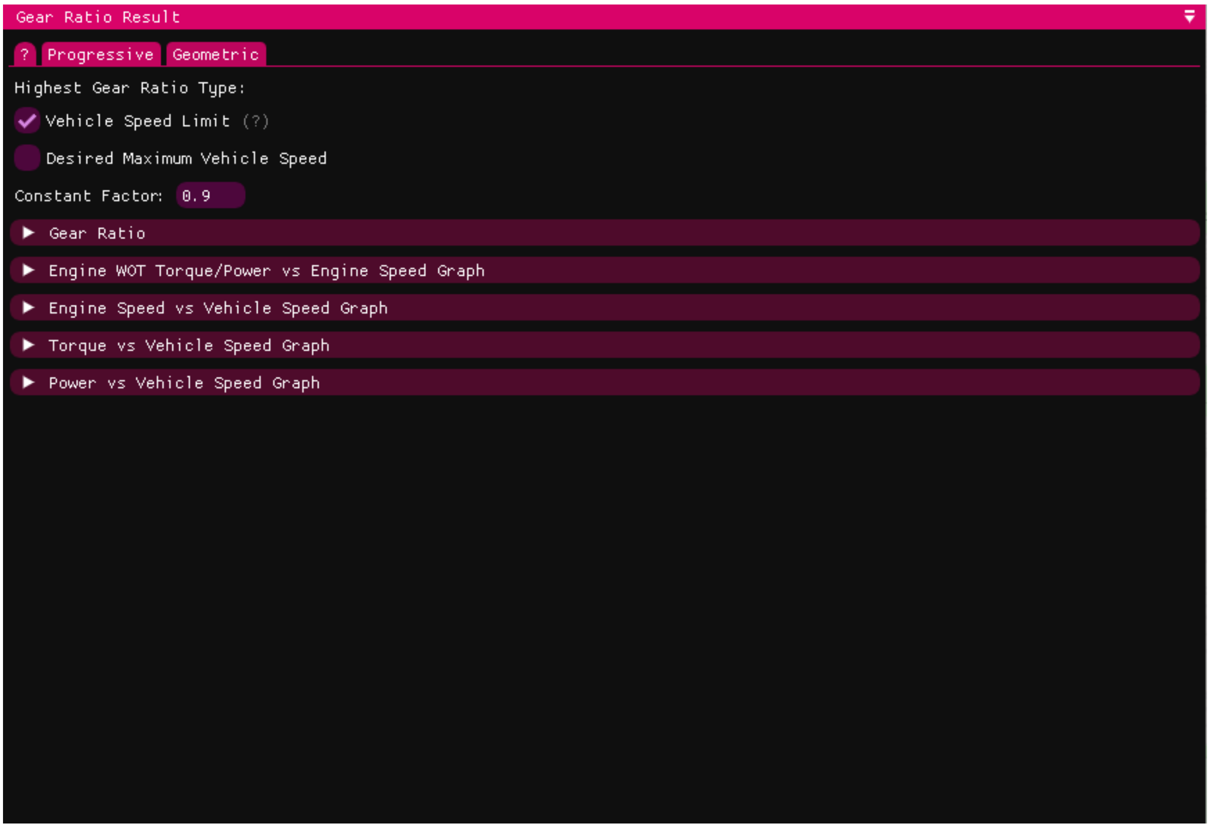


Figure 10: Gear Ratio Result

a. Gear Ratio

This is the gear ratio result that calculated from the user input.

Figure 11: Gear Ratio

To obtain the gear result, GUI program need to calculate the lowest gear ratio and highest gear ratio first. Then, the program can calculate the intermediate gear ratio. There some equations were used on determining it.

To calculate the lowest gear ratio, equation 1, equation 2, equation 3 and equation 4 were used. Equation 1 and equation 3 were used for FWD. Equation 2 and equation 4 were used for RWD. To get the maximum torque of the engine, the program differentiated the equation 5 and equal it with 0. Then, the program can get the value of maximum torque for calculating lowest gear ratio.

$$N_A = \frac{b + hf_R}{l + \mu_P\, h}\, W\cos\theta$$

Equation 1: Normal reaction force of front tire

$$N_B = \frac{a - hf_R}{l - \mu_P\, h}\, W\cos\theta$$

Equation 2: Normal reaction force of rear tire

$$n_L = \frac{\mu_P r_W}{\eta T_e}\, N_A$$

Equation 3: Lowest gear ratio for FWD

$$n_L = \frac{\mu_P r_W}{\eta T_e}\, N_B$$

Equation 4: Lowest gear ratio for RWD

$$T = a\omega^2 + b\omega + c$$

Equation 5: Torque equation

There are 2 methods were used in calculating highest gear ratio. One of the methods are finding maximum velocity from the torque equation (Equation 5) on determining highest gear ratio. Other method is using desired maximum velocity on determining the highest gear ratio.

$$n_H = \frac{r_w \omega_e}{v_{max}}$$

Equation 6: Highest gear ratio

On determining the highest gear ratio by finding maximum velocity, GUI program will start on differentiate the equation 7. Due to velocity are maximum at maximum power, therefore equation 8 equal to 0. Then, the program will get the engine speed when power is maximum. After that, the engine speed will be insert on equation 7 to find the maximum vehicle speed. Then, the program gets to calculate the highest gear ratio using equation 6.

$$P = T\omega = Fv$$

Equation 7: Power equation

$$\frac{dP}{d\omega} = 3a\omega^2 + 2b\omega + c$$

Equation 8: Differentiate power equation

If the user chooses to use the highest gear ratio using desired maximum vehicle velocity, the calculation of it will start by calculating the traction force of the vehicle. Due to the vehicle is at maximum speed, therefore the traction force is equal to resistance force as shown in equation 9. Then, the program will used equation 7 to find engine speed and maximum power. Now, the program can calculate the highest gear ratio using equation 6.

$$F_T = F_R = F_{RR} + F_D + F_W$$

Equation 9: Traction force at maximum vehicle speed

To calculate the intermediate gear ratio, there will be 2 methods. Both methods will used same geometric progression constant as shown in equation 10.

$$C_{gp} = \left[\frac{n_L}{n_H}\right]^{\frac{1}{N-1}}$$

Equation 10: Geometric Progression Constant

If the user chooses geometric progression method, therefore the calculation is as below. The program will used the equation 11 on determine the intermediate gear ratio.

$$n_{i+1} = \frac{n_i}{C_{gp}}$$

Equation 11: Intermediate Gear Ratio – Geometric Progression Constant

If the user chooses progressive method, therefore the calculation is as below. The program will used the equation 12 or equation 13 on determine the constant gear ratio, C_i. The value of constant factor, k usually between 0.8 to 1.0. Then, the program start calculated the intermediate gear ratio using equation 14.

$$C_{gp}{}^{N-1} = C_1{}^{N-1} k^{(1+2+\cdots+N-2)}$$

Equation 12: Constant gear ratio – progressive method

$$C_1 = C_{gp} k^{1-\frac{N}{2}}$$

Equation 13: Simplified constant gear ratio – progressive method

$$n_{i+1} = \frac{n_i}{C_i}$$

Equation 14: Intermediate Gear Ratio – Progressive Constant

b. Engine WOT Torque/Power vs Engine Speed Graph

This graph shows the engine WOT torque or power behaviour as engine speed increasing. Graph engine WOT torque/power vs engine speed are obtained using equation 5 and equation 6.

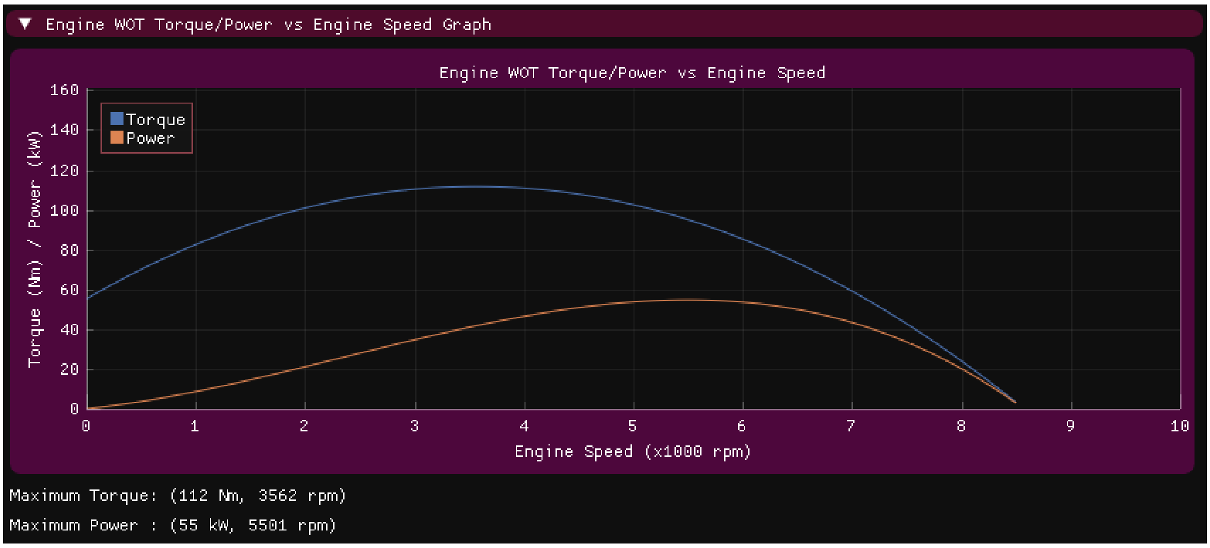


Figure 12: Engine WOT Torque/Power vs Engine Speed Graph

c. Engine Speed vs Vehicle Speed Graph

This graph shows the engine working range of the vehicle according to each gear ratio. Graph engine speed vs vehicle speed are obtained using equation 6. Below the graph, there are also a display of velocity range on each gear ratio.

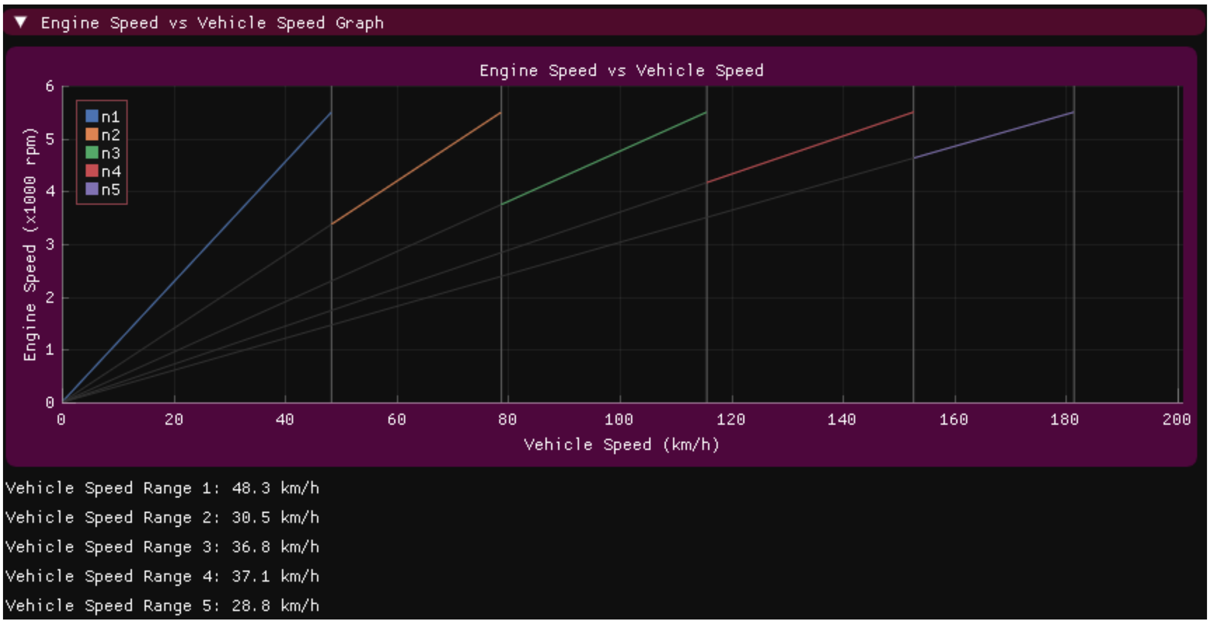


Figure 13 : Engine Speed vs Vehicle Speed Graph

d. Torque vs Vehicle Speed Graph

This graph shows the torque of wheel on each gear ratio. Graph wheel torque vs vehicle speed are obtain using equation 15.

$$T_w = n_i T_e \eta$$

Equation 15: Wheel Torque

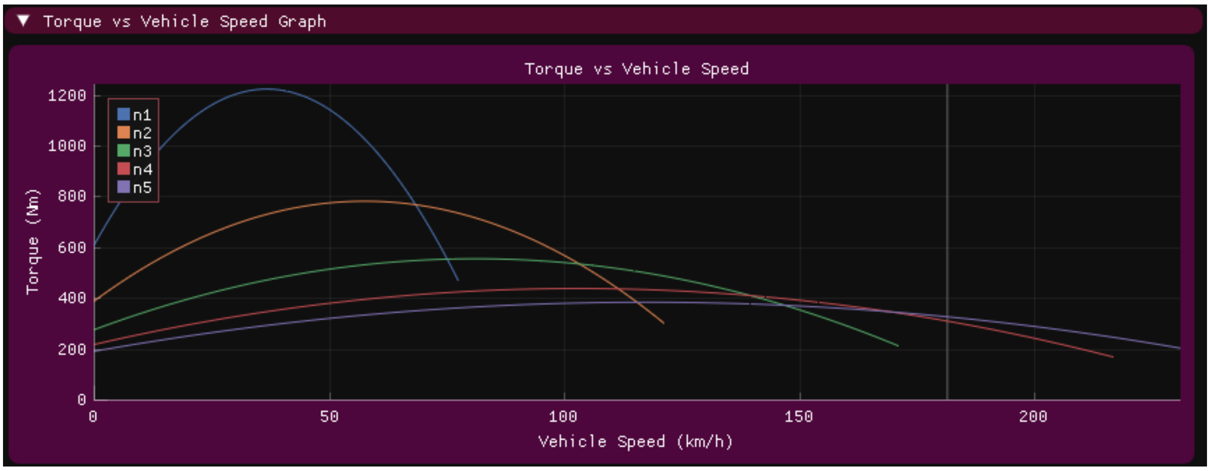


Figure 14: Torque vs Vehicle Speed Graph

e. Power vs Vehicle Speed Graph

This graph shows the power of wheel on each gear ratio need to achieve certain speed of vehicle. Graph wheel power vs vehicle speed are obtained using equation 16.

$$P_w = \eta P_e$$

Equation 16: Wheel power

Figure 15: Power vs Vehicle Speed Graph

Gear Ratio Testing

The gear ratio testing is held using the game Forza Horizon 5 where it has a lot of customization to the car can be made. The testing process were conducted with same vehicle and engine. There are 2 different drivetrain that were being tested which are FWD and RWD. The vehicle used in this experiment are Honda Civic Type R 1997. The engine was used are 2.0L I4 - VVT. There are also some modifications are being made to the engine.

Figure 16: Honda Civic Type R 1997 with 2.0L I4 – VVT Engine

In this testing, will be testing each method of intermediate gear ratio to see the difference of it. There will be 3 tracks being used for the testing. Each track will be held a race and time for the vehicle to finish the race will be taken to see the performance of the vehicle with the gear ratio.

1. Gear Ratio Setup

To start the testing, first we insert the input to the GUI program that being made. The data of the car can obtain from the game and being used in the program.

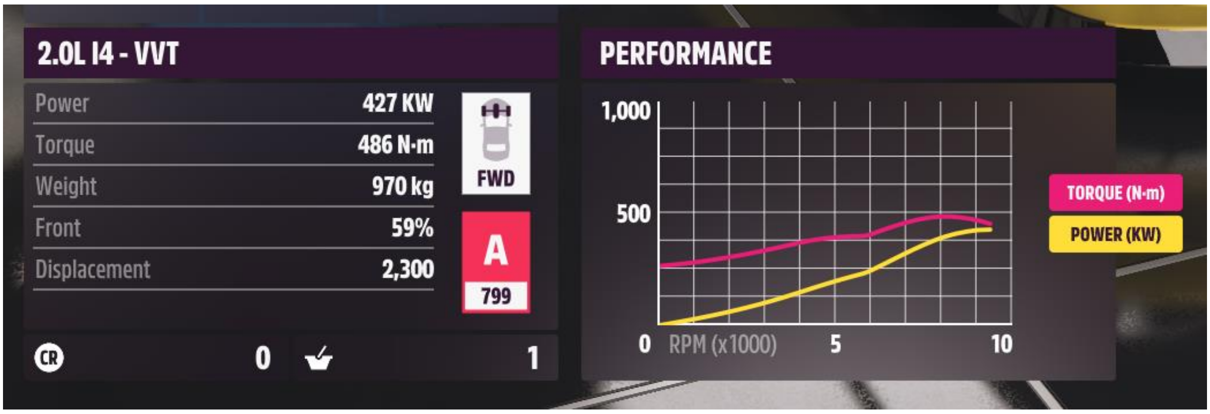


Figure 17: Data of the engine and vehicle in Forza Horizon 5

The data that obtained as shown in Figure 17 were used in the GUI program for the gear ratio value. As we can see the performance of the engine are also being shown. Unfortunate, the data of torque on each engine speed are not obtainable from the graph as it is not very detail. Therefore, we are trying to approach with torque equation that will make a graph of engine WOT torque-speed that are identical with the game as much as possible. So, the value inputs of the car are as below with some assumption being made on the vehicle which are road adhesion coefficient, rolling resistance coefficient, overall aerodynamic coefficient and driveline efficiency. The vehicle maximum speed are also being set to 180 km/h.

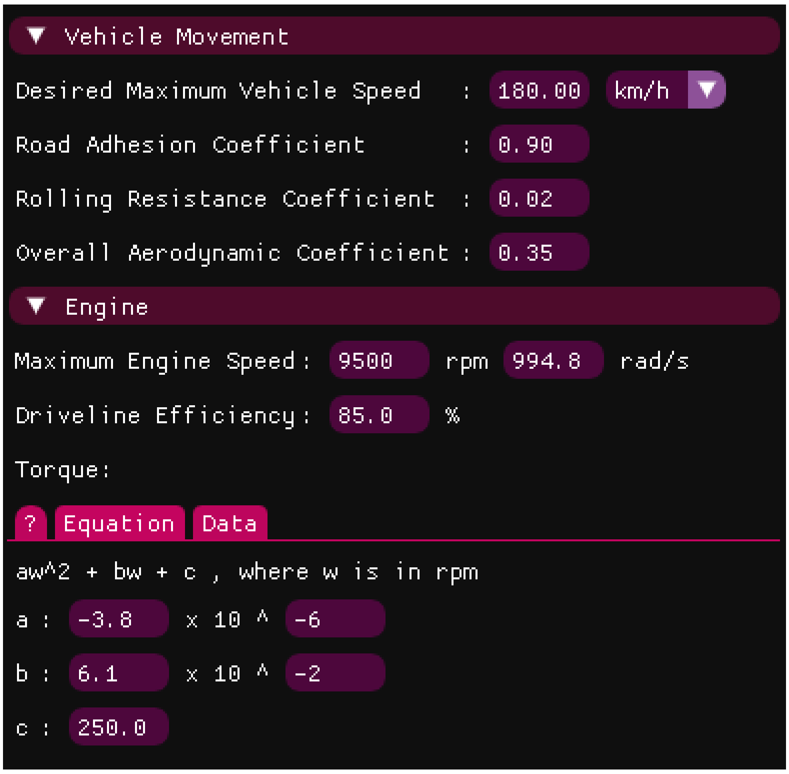


Figure 18: Inputs of the vehicle

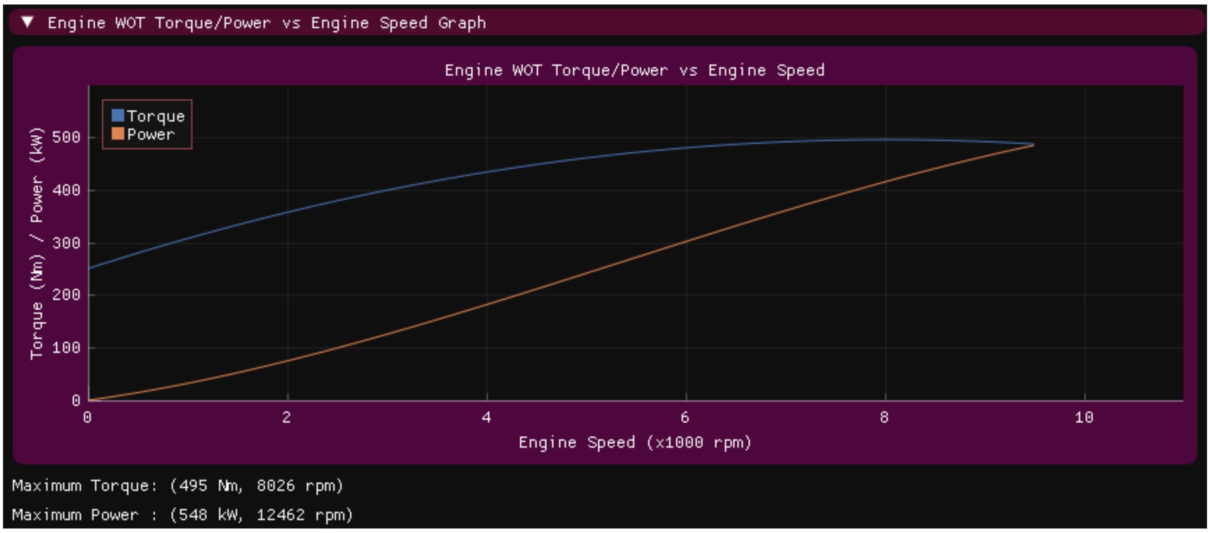


Figure 19: Engine WOT Torque/Power vs Engine Speed based on torque equation

The highest gear ratio type that being used in this testing is desired maximum vehicle speed which is at 180 km/h. The constant factor that being used for progressive method is 0.93.

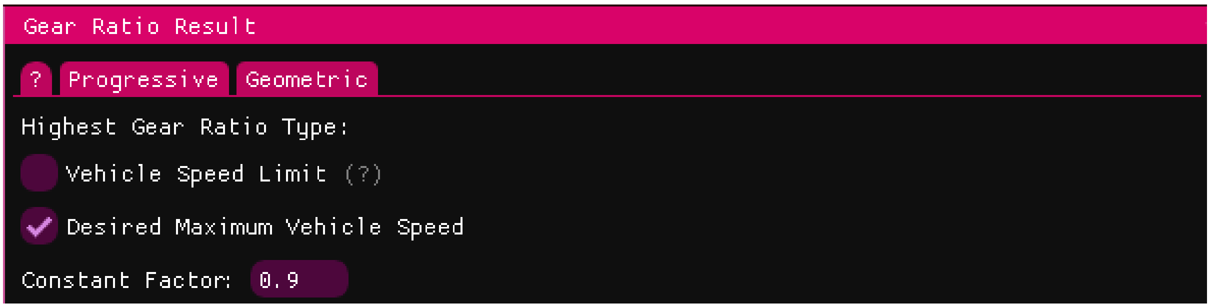


Figure 20: Inputs of vehicle on highest gear ratio

The input value of tyre rolling radius can be obtained from the Forza Horizon 5 which are as below. The front and rear tire are same in size.

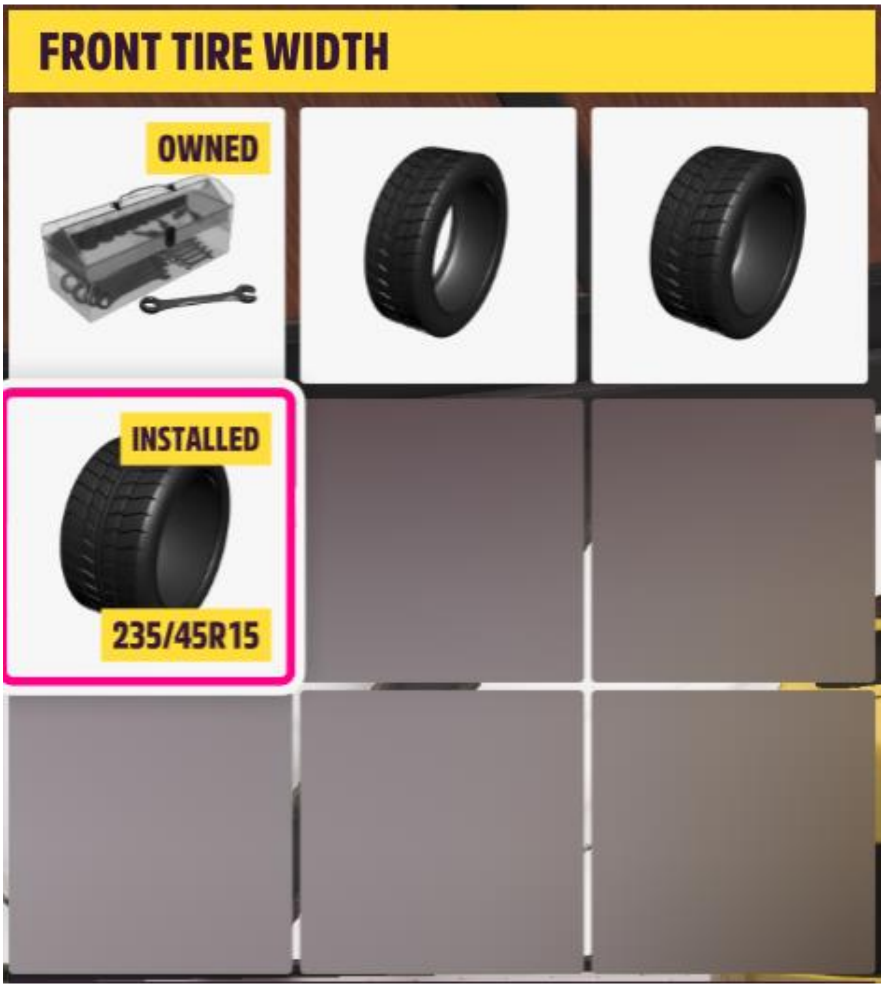


Figure 21: Tyre Size from Forza Horizon 5

The data of obtained gives the tire rolling radius about 295 mm. The height over wheelbase ratio is not obtainable in the games, so it been assumed to be about 0.3. The number of gears that being used for the vehicle is 6 gears. For the input of weight distribution, drivetrain and mass were being set according to the drivetrain of the vehicle.

a. Forward Wheel Drive (FWD)

The input of weight distribution on the front and mass of vehicle are 59 % and 970 kg respectively.

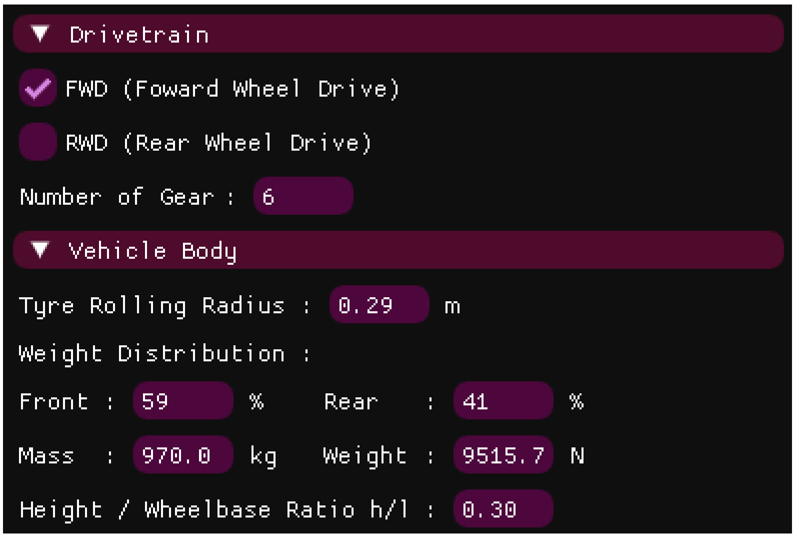


Figure 22: Inputs of vehicles (FWD)

From the input that being set, the gear ratio of the vehicle is obtained for progressive method and geometric progression method.

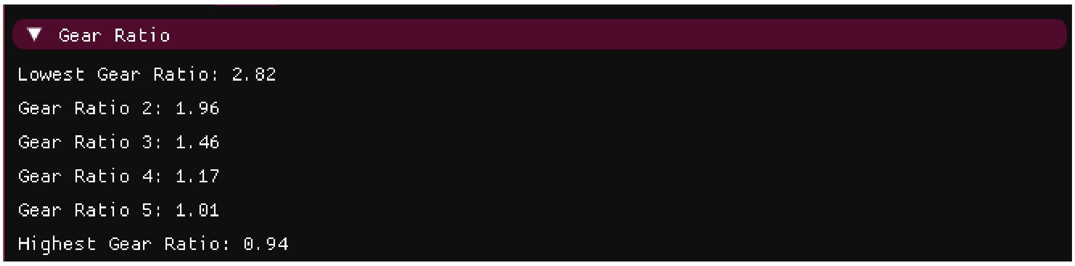


Figure 23: Gear Ratio FWD – Progressive Method

Figure 24: Gear Ratio FWD – Geometric Progression Method

The speed range of the vehicle on both method of gear ratio is obtained from the GUI program which are as follows.

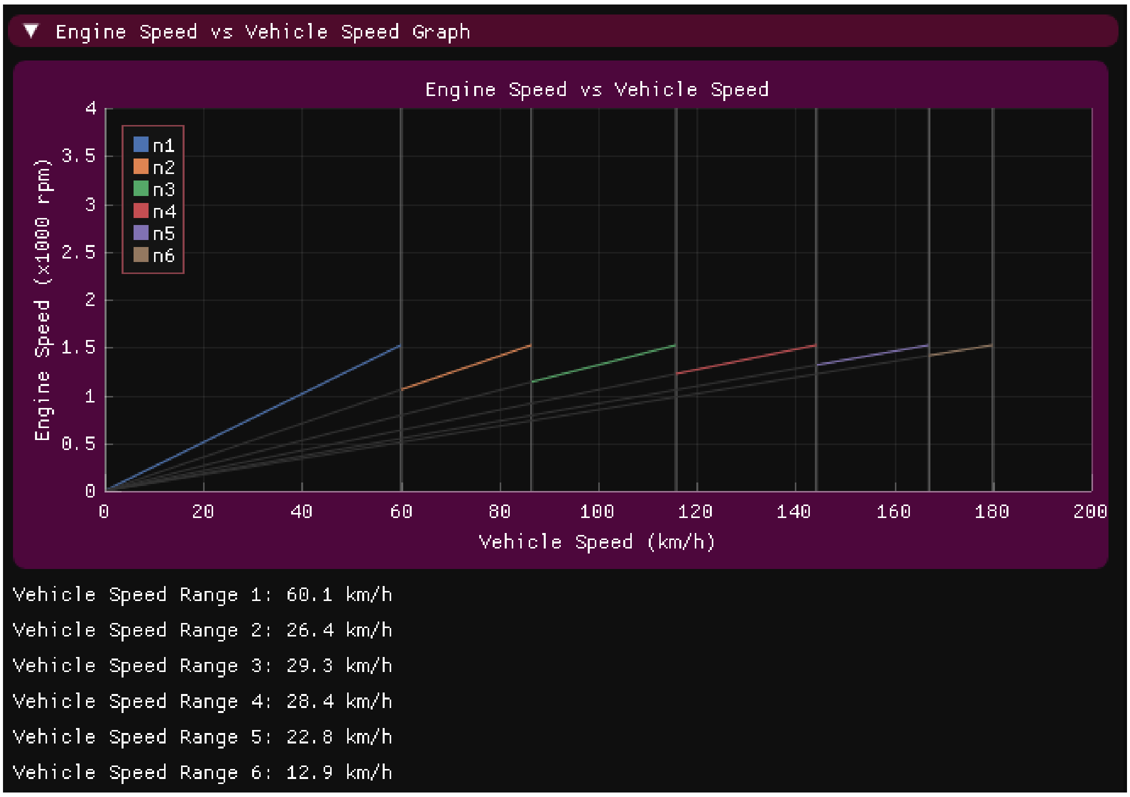


Figure 25: Vehicle Speed Range FWD – Progressive Method

Figure 26: Vehicle Speed Range FWD – Geometric Progression Method

b. Rear Wheel Drive (RWD)

The input of weight distribution on the front and mass of vehicle are 57 % and 960 kg respectively.

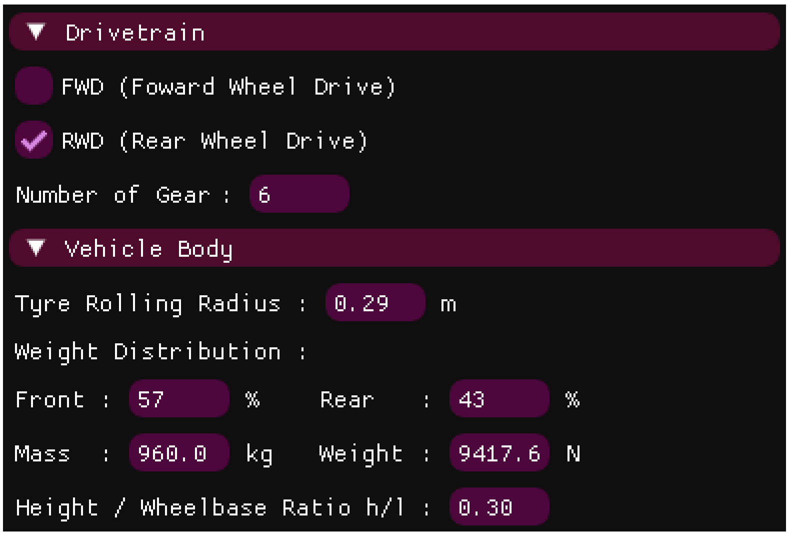


Figure 27: Inputs of vehicles (RWD)

From the input that being set, the gear ratio of the vehicle is obtained for progressive method and geometric progression method. The speed range of the vehicle on both method of gear ratio is also obtained from the GUI program which are as follows.

Figure 28: Gear Ratio RWD – Progressive Method

Figure 29: Gear Ratio RWD – Geometric Progression Method

Figure 30: Vehicle Speed Range RWD – Progressive Method

Figure 31: Vehicle Speed Range RWD – Geometric Progression Method

2. Track Setup and Results of the Race

The gear ratio obtained will be used on the vehicle to be tested on the track. There are 3 tracks that being used which are *Reservorio Sprint*, *Aerodromo Drag Strip* and *Panoramica Sprint*. Each track has different design. *Reservorio Sprint* track are combination of straight and less corner. *Aerodromo Drag Strip* track is a straight-line track that focus on drag race. *Panoramica Sprint* track are more on turn for the vehicle to travel. On these tracks, the vehicle was raced with 2 types of drivetrains with 2 different methods of gear ratio.

a. Track 1 - *Reservorio Sprint*

The track of *Reservorio Sprint* is as below.

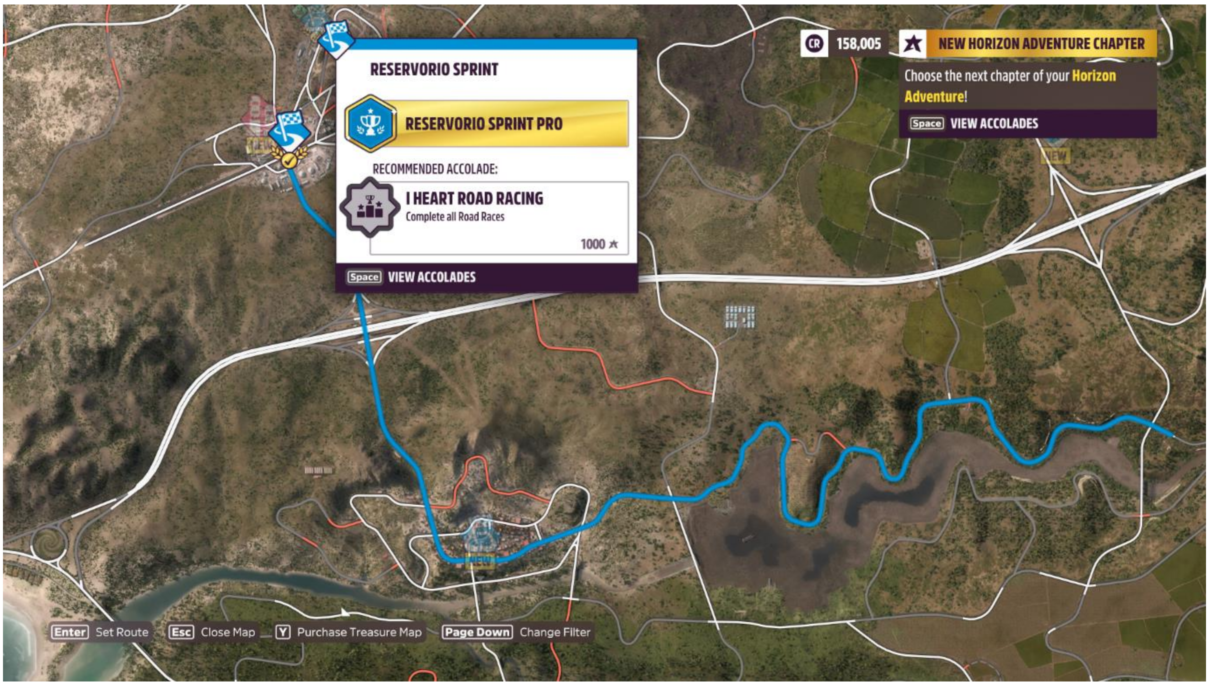
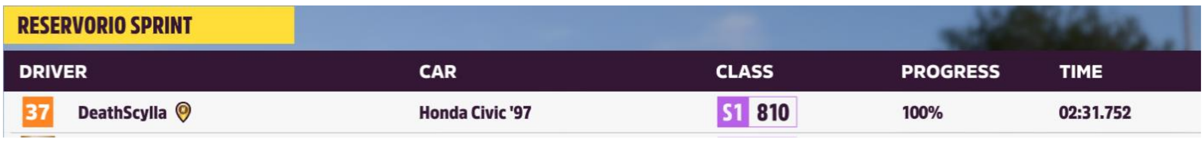


Figure 32: Reservorio Sprint Track

Result of the race as follows are being simplified into the tables for better view on the results.


RESERVORIO SPRINT

DRIVER	CAR	CLASS	PROGRESS	TIME
37 DeathScylla	Honda Civic '97	S1 810	100%	02:31.752

Figure 33: Results of Track 1 FWD – Progressive Method

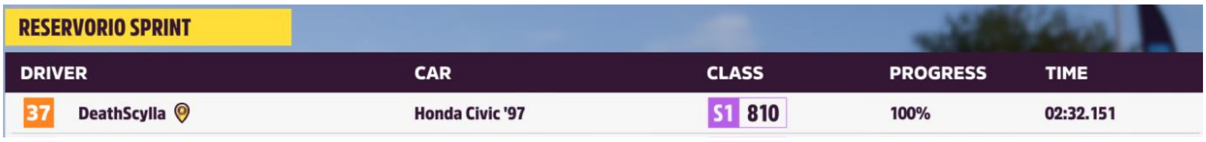


Figure 34: Results of Track 1 FWD – Geometric Progression Method

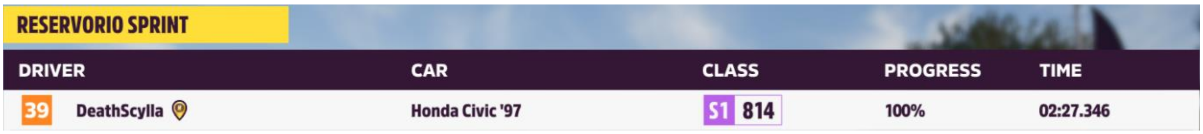


Figure 35: Results of Track 1 RWD – Progressive Method

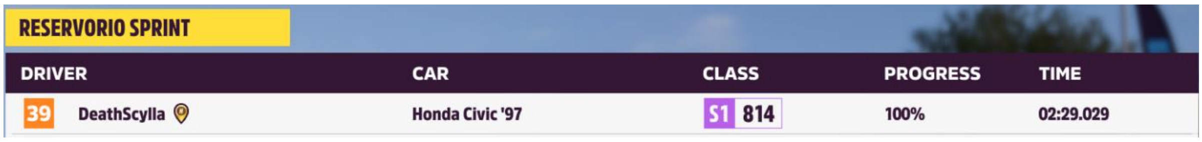


Figure 36: Results of Track 1 RWD – Geometric Progression Method

Drivetrain	Time Taken Finish Race	
	Geometric Progression	Progressive
FWD	152.151 s	151.752 s
RWD	149.029 s	147.346 s

Table 1: Time taken for vehicle finish race – Track 1

From the above result, we can see that the vehicle finishes the race quickly using progressive method gear ratio. The difference of time on FWD are approximately 0.4 s, while on RWD are approximately 1.7 s. The difference is very noticeable as the vehicle race in less turns track.

Moreover, shifting gear for geometric progression are more often on early speed. As for progressive method, shifting gear are less often on the road that start to turn a lot. This is because of the mid speed range that distribute evenly on each gear ratio.

b. Track 2 - *Aerodromo Drag Strip*

The track of *Aerodromo Drag Strip* is as below.

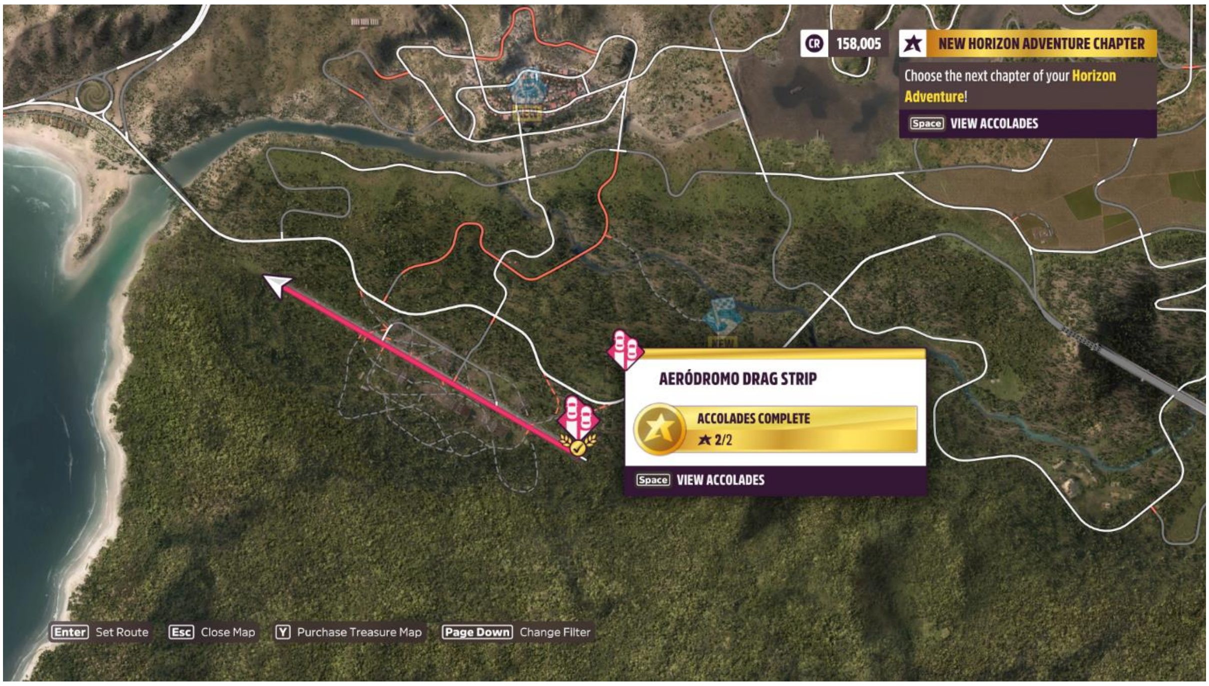
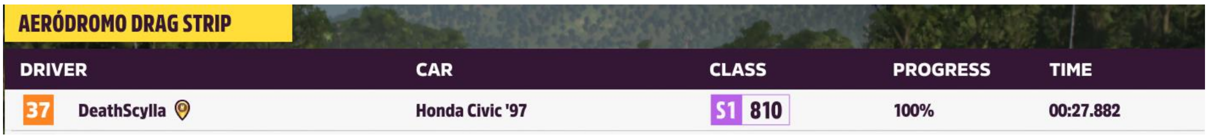


Figure 37: Aerodromo Drag Strip Track

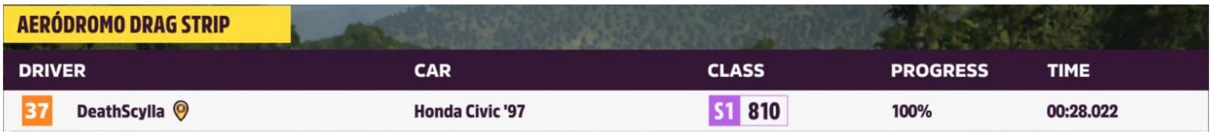
Result of the race as follows are being simplified into the tables for better view on the results.



AERÓDROMO DRAG STRIP

DRIVER	CAR	CLASS	PROGRESS	TIME
37 DeathScylla	Honda Civic '97	S1 810	100%	00:27.882

Figure 38: Results of Track 2 FWD – Progressive Method



AERÓDROMO DRAG STRIP

DRIVER	CAR	CLASS	PROGRESS	TIME
37 DeathScylla	Honda Civic '97	S1 810	100%	00:28.022

Figure 39: Results of Track 2 FWD – Geometric Progression Method

AERÓDROMO DRAG STRIP

DRIVER	CAR	CLASS	PROGRESS	TIME
40 DeathScylla	Honda Civic '97	S1 814	100%	00:26.999

Figure 40: Results of Track 2 RWD – Progressive Method

Figure 41: Results of Track 2 RWD – Geometric Progression Method

Drivetrain	Time Taken Finish Race	
	Geometric Progression	Progressive
FWD	28.002 s	27.882 s
RWD	27.192 s	26.999 s

Table 2: Time taken for vehicle finish race – Track 2

From above result, progressive method gives a quick time for the vehicle to finish the race. The time difference on FWD is approximately 0.2 s, while RWD is approximately 0.1 s. The time taken for the vehicle to finish the race on straight line are not big difference.

Other than that, shifting of gear with geometric progression method are faster on early speed. As it reaches highest gear, the vehicle is still at low speed which make it takes a long time to reach the maximum speed of the car. While for progressive method, shifting of gear are more evenly over time because of the even speed range difference of the gear ratio. As the car shifting to the highest gear, the vehicle already at the high speed which takes less time to reach maximum speed.

c. *Panoramica Sprint*

The track *Panoramica Sprint is as below.*

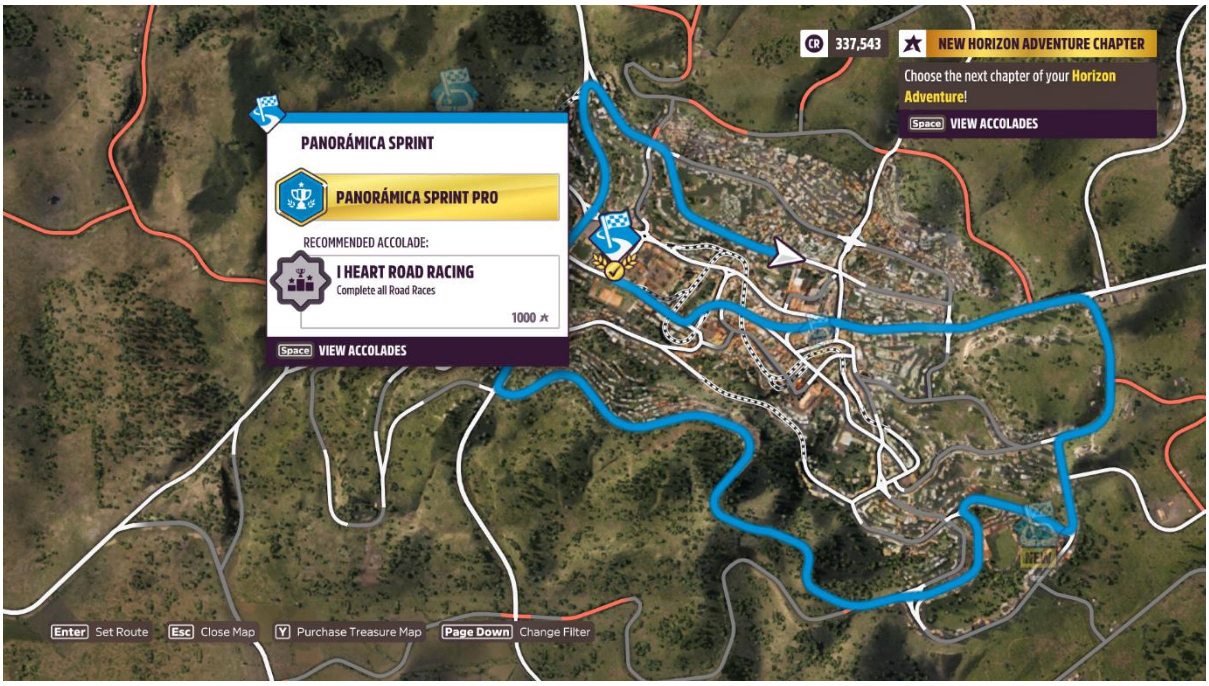


Figure 42: Panoramica Sprint Track

Result of the race as follows are being simplified into the tables for better view on the results.

PANORÁMICA SPRINT					
	DRIVER	CAR	CLASS	PROGRESS	TIME
38	DeathScylla	Honda Civic '97	S1 810	100%	02:44.534

Figure 43: Results of Track 3 FWD – Progressive Method

PANORÁMICA SPRINT					
	DRIVER	CAR	CLASS	PROGRESS	TIME
38	DeathScylla	Honda Civic '97	S1 810	100%	02:44.518

Figure 44: Results of Track 3 FWD – Geometric Progression Method

PANORÁMICA SPRINT					
	DRIVER	CAR	CLASS	PROGRESS	TIME
39	DeathScylla	Honda Civic '97	S1 814	100%	02:44.030

Figure 45: Results of Track 3 RWD – Progressive Method

PANORÁMICA SPRINT					
	DRIVER	CAR	CLASS	PROGRESS	TIME
39	DeathScylla	Honda Civic '97	S1 814	100%	02:45.625

Figure 46: Results of Track 3 RWD – Geometric Progression Method

Drivetrain	Time Taken Finish Race	
	Geometric Progression	Progressive
FWD	164.518 s	164.534 s
RWD	165.625 s	164.030 s

Figure 47: Time taken for vehicle finish race – Track 3

From the results above, we can see that the geometric progression method is quicker on finishing race with FWD drivetrain about 0.02 s differences. However, with RWD drivetrain the progressive method is quicker on finishing race with 1.6 s differences. As we can see the difference on time taken for both methods on FWD are not big differences, while for RWD the differences are very noticeable. Therefore, we can see that the vehicle is better on making turns with progressive method and in RWD drivetrain.

Other than that, when conducting the testing, shifting the gear on geometric progression method are more often because of the short speed range on early gear ratio. For progressive method, shifting of gear on many turns track is less likely to happen because of even distribution of speed range on each gear ratio.

Conclusion

In conclusion, the GUI apps design are working functionally and user-friendly. The result that obtains from the GUI apps are able to give a good result on the testing of the vehicle. Moreover, we can see that progressive method of gear ratio give the vehicle the ability to finish the race quicker than the geometric progression method of gear ratio. The progressive methods also are quicker when racing in the track that many turns. As for drivetrain, the vehicle tends to be faster on RWD on the road that are straight or less turns. However, RWD and FWD give almost the same result on time taken to finish the race on road that have many turns. Furthermore, geometric progression method tends to shift the gear more often on early speed while progressive method have equally time on shifting the gear. Therefore, we can conclude that each intermediate gear ratio method gives different performance towards the vehicle.