Calculating Fuel Efficiency of a Shell Eco-Marathon prototype vehicle using MATLAB & Simulink model

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Abstract - *Shell eco-marathon is an annual competition for mileage efficient vehicles. students from around the world compete for extracting the best mileage possible. Each team has to pass the various Technical as well as Safety inspections to ensure a healthy competition among the teams. This study aims to provide Modeling of various subsystems of the vehicle and to integrate them by mimicking the actual run of the vehicle on track to predict the consumption of fuel using the MATLAB Simulink program. To provide the real-world conditions the model runs on a closed-loop system with all the kinematic variables, also the inclination of shell technological centre Bangalore track at every point, and different driver modes were included as a part of the program. Comparison of the results was done using the competition data from Shell Eco-marathon India 2019.*

Key Words: **(MATLAB, Simulink model, Shell Eco-Marathon, Fuel Efficiency)**

1.INTRODUCTION

Shell Eco-marathon is an energy-efficient competition held worldwide where participants from different region compete with their automotive vehicles to achieve the highest possible fuel efficiency, these vehicles are categorized into two types: Prototype & Urban concept vehicle, with three different energy categories namely Gasoline, Electric and hydrogen powered vehicles. In this study, INFIEON SUPERMILEAGE an official student team of SRM Institute of Science and Technology's gasoline prototype vehicle is taken into consideration. The vehicle shown in Fig 1 is on the track participating in Shell eco Marathon, under the gasoline prototype category. The organizer provides with a rule book and all vehicles has to comply them with the technical and safety inspections.

The aim of this study is to integrate the track conditions, the various vehicle subsystems as well as the driving strategy using MATLAB and Simulink software and hence calculate the fuel efficiency of the vehicle. A better driving strategy can be extracted by analyzing the results given that the driver is considered perfect, also by analyzing the change in variables can suggest changes to be made in the actual vehicle. Weight of the vehicle, rolling resistance due to tyre as well as

bearings, Aerodynamic forces are some of the factors which plays a significant role in extracting better fuel economy from the engine. The importance of these design parameters if unknown can result in a sub-optimal vehicle and hence this model will look onto all such parameters simultaneously and thus better design alternatives can be generated.

2.DEVELOPING VEHICLE MODEL

Before starting the vehicle modelling all the variable parameters has to be extracted and the various relationship between them is to be known.

Fig -1: Prototype Vehicle (Astria) on track

2.1 FORCES ON VEHICLE

Equation 1 shows that the sum of all forces on the vehicle is equal to the difference between the force produced by the drive train and all the net resistive forces acting on the vehicle.

$$\sum F_{net} = F_{dt} - F_r \tag{1}$$

Equation 2 consists of a function of vehicle speed($v = ds/dt$) and the road slope (θ) which is used to calculate the net resistive force.

$$F_r(v,\theta) = \frac{1}{2}\rho A C_d v^2 + mg\sin\theta + F_{rr} \tag{2}$$

The first part of the equation is the aerodynamic drag force where

'ρ' is the density of the air and it is taken constant according to the average temperature and other environmental condition of the track,

'A' is the frontal area of the vehicle which is taken from the CAD model so created of the vehicle.

'C_d' is the coefficient of drag which is acquired from the CFD analysis of the vehicle model.

The second part of the equation 2 is the gradient force it is produced due to the elevation and de-elevation in the track. Here,

m is the mass of the vehicle,

g is the acceleration due to gravity.

θ is the slope of the track in radian.

Hence to find angle θ the track at the Shell Technological Centre Bangalore is mapped on the basis of elevation with the use of google earth. Fig 2 shows the relationship between the distance and elevation of every point along the track, similar graph is feed in to the Simulink model which gives out the value of θ at every point on the track.

Fig -2: Shell Technological Centre Bangalore

The third part of the equation 2 comprises of both, the force produced by the rolling tyre as well as the resistive force due to the bearing motions. One of the important strategies involved in the driving style in the competition is the strategy of kill and coast of the engine so as to travel a large amount of distance without powering the vehicle and hence this resistive due to rolling resistance of the tyre as well as bearings plays an important role in achieving higher mileage efficiency.

$$F_{rr} = C_{rr}mg\cos\theta + C_{br}v \tag{3}$$

Where,

C_{rr} is the co-efficient of rolling resistance,

C_{br} is the co-efficient of bearing resistance.

Fig 3 shows a subsystem modelled for the net resistive forces acting on the vehicle, velocity input used is calculated in real time so as to get close to the accurate values of resistive force experienced by the vehicle.
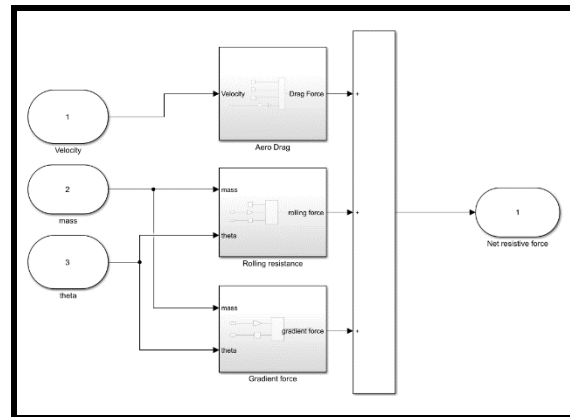

Fig -3: Net Resistive Force Subsystem

2.2 TRANSMISSION FORCE

The SI engine is the power house of the vehicle which is used to overcome the resistive forces that the vehicle experiences and to further propel the vehicle, equation 4 calculates the force produced by the transmission system onto the wheels.

$$F_{dt} = \frac{60(P\mu_t r)}{2\pi N}\eta \tag{4}$$

Where,

P is the power transmitted at the engine shaft.

μ_t is the transmission ratio or gear ratio used.

r is the radius of the wheel.

N is the rpm at the output shaft.

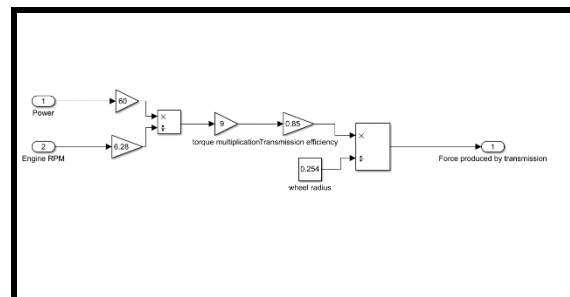η is the transmission efficiency.

Fig -4: Transmission Subsystem

Fig 4 shows the model for the transmission subsystem the power and rpm values are extracted from the power vs rpm graph from the engine specifications.

2.3 DRIVER CONTROL UNIT

The driver plays a major and important role in attaining optimum fuel efficiency. The kill and coast strategy is the most effective strategy given that the velocity range selected so as to complete the run is optimal, although the constraint being an average velocity to be attained should be greater than 25kmph. To stimulate this a MATLAB function is been created so as to take velocity and the output being the transmission force to be zero above the upper limit and again to the transmission force if the velocity drops below the lower limit. Fig 5 shows the driver control subsystem with the MATLAB Function.
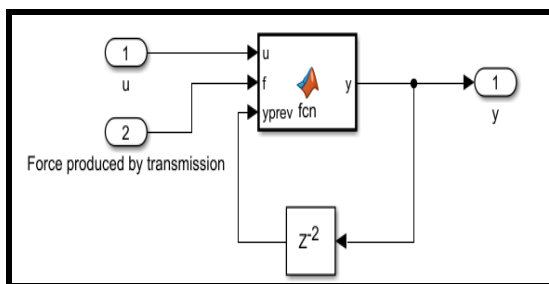
Fig -5: Driver Control Subsystem

2.4 CALCULATING FUEL EFFICIENCY

Apart from the Dynamics of the vehicle, engine is a unit where variety of different variables can be worked upon hence tuning of the engine is done so as to make sure that right amount of fuel is injected to power the vehicle and at the same time not letting in too much to waste any for the modelling purpose and to calculate the amount of fuel consumed the set parameters of the electronic fuel injection is taken into account, the amount of fuel injected per cycle by the fuel injector is monitored and thus used in the model to estimate the fuel consumed with a greater level of accuracy. The fig 6 shows the fuel consumption sub system where a MATLAB function recognizes the engine state.
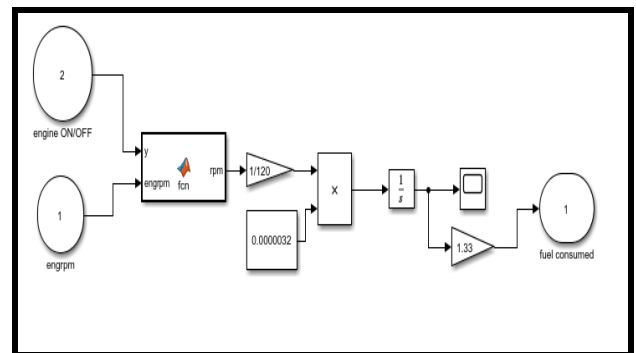
Fig -6: Fuel Consumption Subsystem

With the help of the net force acting on the vehicle the various kinematic values are been calculated like acceleration velocity and distance covered by the vehicle by integration block provided by Simulink and thus using the distance covered and the fuel consumed to calculate the fuel efficiency of the vehicle.
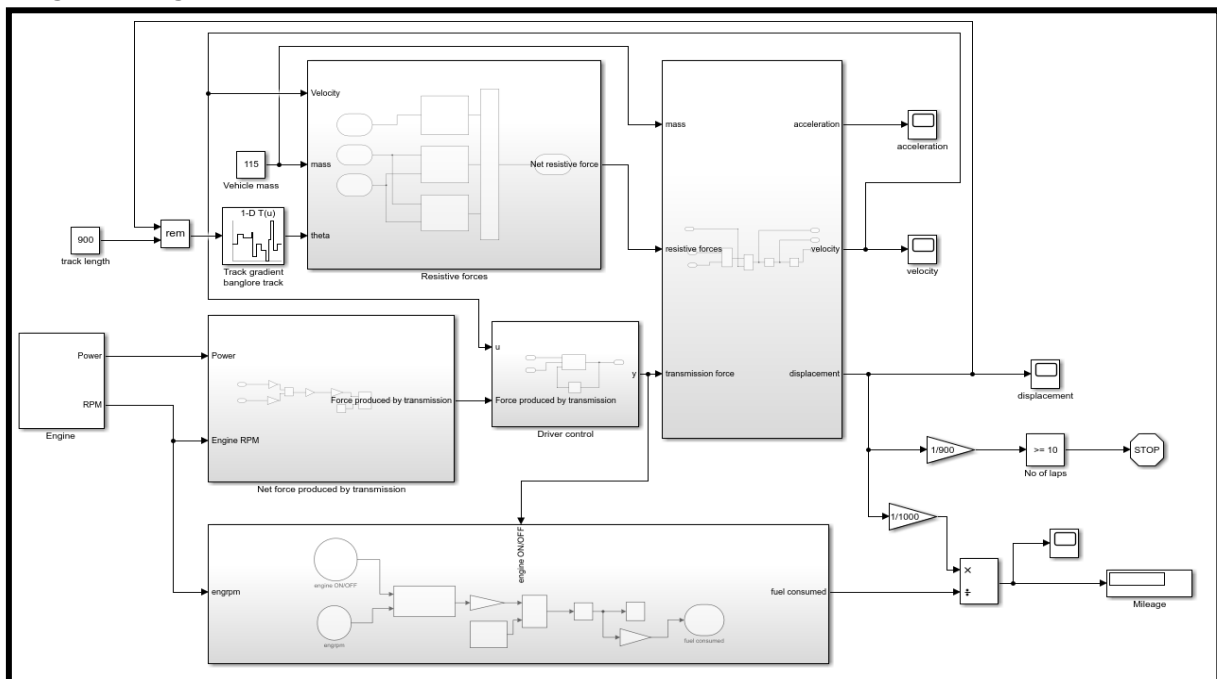
Fig -7: Complete Model of Vehicle, drive train & driver modes

2.4 MODEL OVERVIEW

Fig 7 shows the complete Simulink model of the vehicle running on the Shell technological centre Bangalore track, the various subsystems working on a feedback loop of the distance covered on the track as specified by the organizers 10 laps of this 900m track is to be completed and so the conditions given in the model too where after completing them the simulation stops by itself with a mileage and its variation graph with time also graphs of velocity acceleration and displacement variations are generated so as to analyze better driving strategies and the various fine tuning required in different parts of the vehicle.

3. RESULTS AND DISCUSSION

The vehicle Simulink model is been created and simulated with all the variables extracted from the various testing and simulations on and off the vehicle. Fig 8 shows the simulated mileage obtained from the model. The results were also compared with that from the mileage run in Shell eco Marathon India 2019 held at the same Shell

technological Centre Banglore track, the mileage achieved by the vehicle then was 148.2 Kmpl, Fig 10 shows the event results of INFIEON SUPERMILEAGE.

Fig -8: Mileage obtained from the model

The simulation shows a 12.3 kmpl difference from what the vehicle has achieved in the competition in other terms the vehicle used 4 ml more fuel on the track compared to the simulated results, this can be due to many reasons including the loss of fuel at the start line before the run, drivers efficiency and also due to the dynamic losses at turns as the model is caliberated for straight line motions of the vehicle. Fig 9 shows the velocity of the vehicle with respect to time elapsed, it can be seen that kill and coast strategy is been implimented between the velocity range of 4 m/s to 13 m/s. By analysing the Fig 11 we can see that the coasting of the
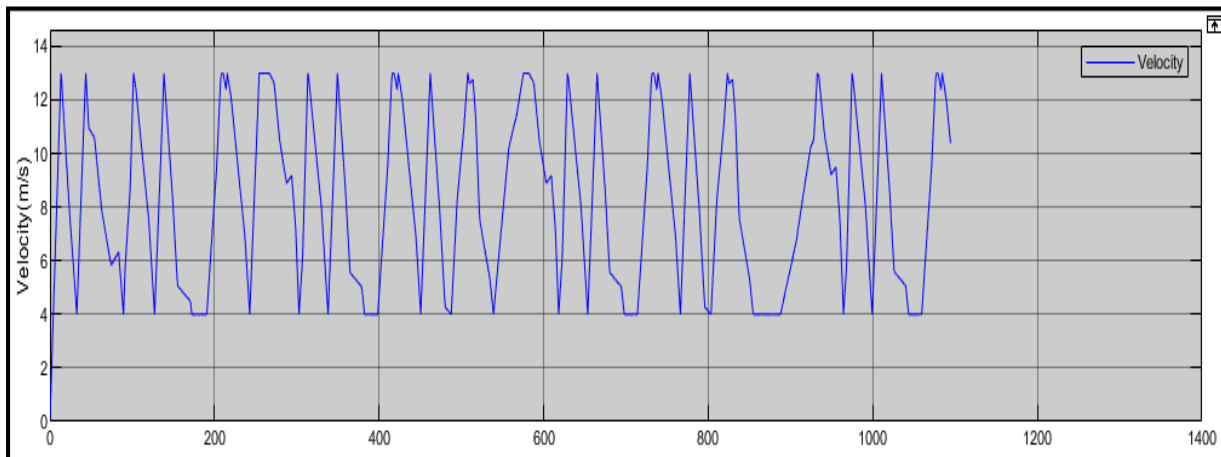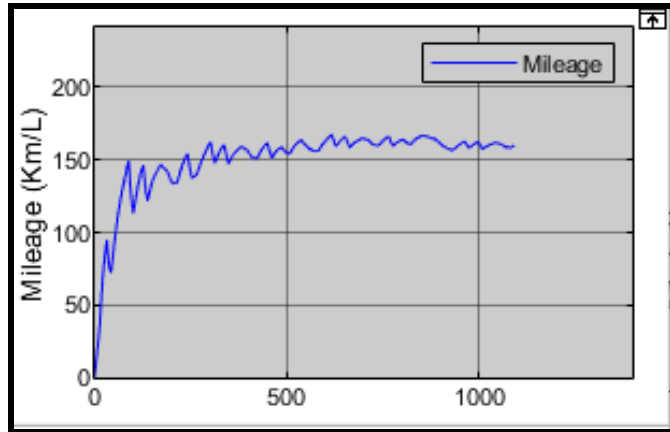
Fig -9: Velocity variation with time

Fig -10: Shell Eco Marathon India 2019 Results

vehicle helps in increasing the mileage to a very significant level, the positive slope curves are the one where the engine is turned off here the vehicle is in coasting mode and the negative slope curve is when the engine is powering the wheel.

Fig -11: Real time mileage plot

4. CONCLUSIONS

Even though there are plenty of variables unknown that effects the milage of the vehicle the simulated results do represents the mileage achieved in the real conditions on track. Now the focus will be more on better tuning of all the subsystems so that it can be easily monitored and analyzed to make the subsystems more efficient in the coming seasons of the competition.

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