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Matlab Based Model Design Optimization of Vehicle Drivetrain of Advanced Vehicle Simulation

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ABSTRACT

This research investigates the dynamic characteristics in a specific vehicle drive train using Matlab. Engine power, Variable gear, Vehicle speed, and general chassis characteristics simulations are conducted on Matlab based software. These simulations are then applied to De Montfort University Formula one racing car. The SIMSCAPE performs simulation calculations for the vehicle and uses the result to study how other designs can be analyzed and modified. Input cycles are generated in step and ramp based on rough estimates of real analog parameters associated with vehicle operational characteristics. The SIMSCAPE software model-based tool is a series of the plot of velocity, energy, angle, and power profile that provide a substantial estimate for the design decision matrix.Results obtained show that system characteristics can be analyzed for various inputs parameters and considerations to achieve optimal balance in design synthesis and manufacturing costs.

Keywords: *MATLAB/SIMSCAPE; Vehicle Drivetrain; Formula hybrid; Modelling;*

I. INTRODUCTION

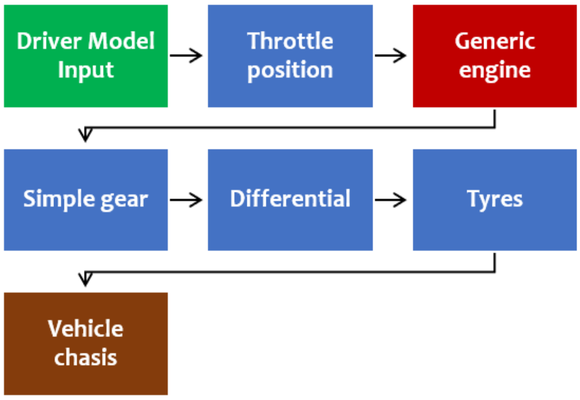
A lot has been studied on variousmachine systems components such as belt drives, clutch and gear systems but lack requisite experience in design, modeling, and systems analysis.Nowadays, designing a system without modeling a prototype and carrying out a test of different parameters on the system under consideration is becoming obsolete of going about design implementation [1]. Different software-based modeling analyses and testing tools are already available for carrying out this effectively. The vehicle drive train design modeling involves more complex parts than other parts, easily simulated using some specific software [2]. The cost and complexity of design implementation without modeling can be mitigated by utilizing MATLAB/SIMSCAPE software-based modeling tool, which predicts the drive train's performance and its sub-systems under various input parameters.Simulations are instrumental in the automotive sector as this greatly eradicates the cost of remanufacturing in the advent of wrong design performance or system architecture. This can primarily be applied to the academic side of things considering individual projects in general and racing car designs. [3,4] This gives students room for improved designs never seen in the market. Reaching to the heightened interest and continuous craving for a more improved and more comfortable way of modeling the vehicle drive train performance characteristics, the society of Automotive Engineers have introduced a competition amongst students in both college and university levels to design, build and showcase high performance racing cars with much emphasis laid on the vehicle drive train model improvement implemented [5,6]. This researchstudies the application of advanced simulator computational software MATLAB/SIMSCAPE to vehicle drive train design and performance optimization for formula one racing vehicles built for competitions. MATLAB developed this software as a modeling tool with enormous robotics, mechatronics, automobile, and renewable energy. Not much has been done utilizing it due to less knowledge about it. The previous study in the literature shows that the utility of the SIMSCAPE program in the adverse application.[7,8] utilized the program in the development of a multiroom thermodynamic model. The software was used to build a virtual room environment and was analyzed based on thermodynamic dependants in his work. I also used the software for object-orientedmodeling and simulation of closed-loop cardiovascular systems. Here, electrical and power models were combined to form a system model that can dictate a cardiovascular system of a human body system via sensing of heartbeat signals. Many researchers [7-9]applied the Simulink design library tools to model the energy behavior in a residential building equipped with resin. Finally, [21] utilized the SIMSCAPE program to analyze a primary vehicle used for studying passenger vehicles of hybrid fuel cells.In this research, the SIMSCAPE modeling tool in a highly competitive and consistent setting appears unique. Here, the SIMSCAPE modeling tool is employed to develop the vehicle drive train model. The vehicle train's individual components' performance characteristics as a pure forward manufacturing approach will be time-consuming and may incur wastage in materials.

II. TIMESCAPE STRUCTURE

SIMSCAPE is a program created in the MATLAB/SIMULINK software environment. It generates system configurations' output performance characteristics via an iterative calculation scheme during a given simulation [10]. In the design model,the throttle's operator inputs are defined by a constant based on desired engine power, Vehicle speed, and other desired parameters. Essentially, the computation proceeds forward from the Engine through the torque converter, Simple differential to the wheels as shown in the simple block diagram below in fig.1

III. METHODOLOGY

The SIMSCAPE user manipulates a series of dashboard parameters on the program GUI to input the necessary vehicle parameter simulation cycle requirements to monitor their effect on the vehicle's performance characteristics [11-12]. In this modeling, there are three central dashboards on the GUI whose parameters are manipulated. They include the Input screen, Simulation screen, and Output Characteristics screen as shown in the fig.2 below



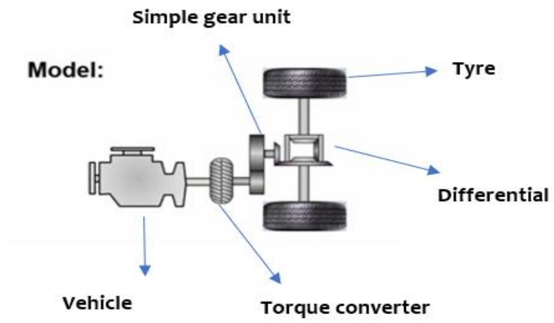


Fig. 1a Block diagram and Model synthesis of Vehicle train and parts

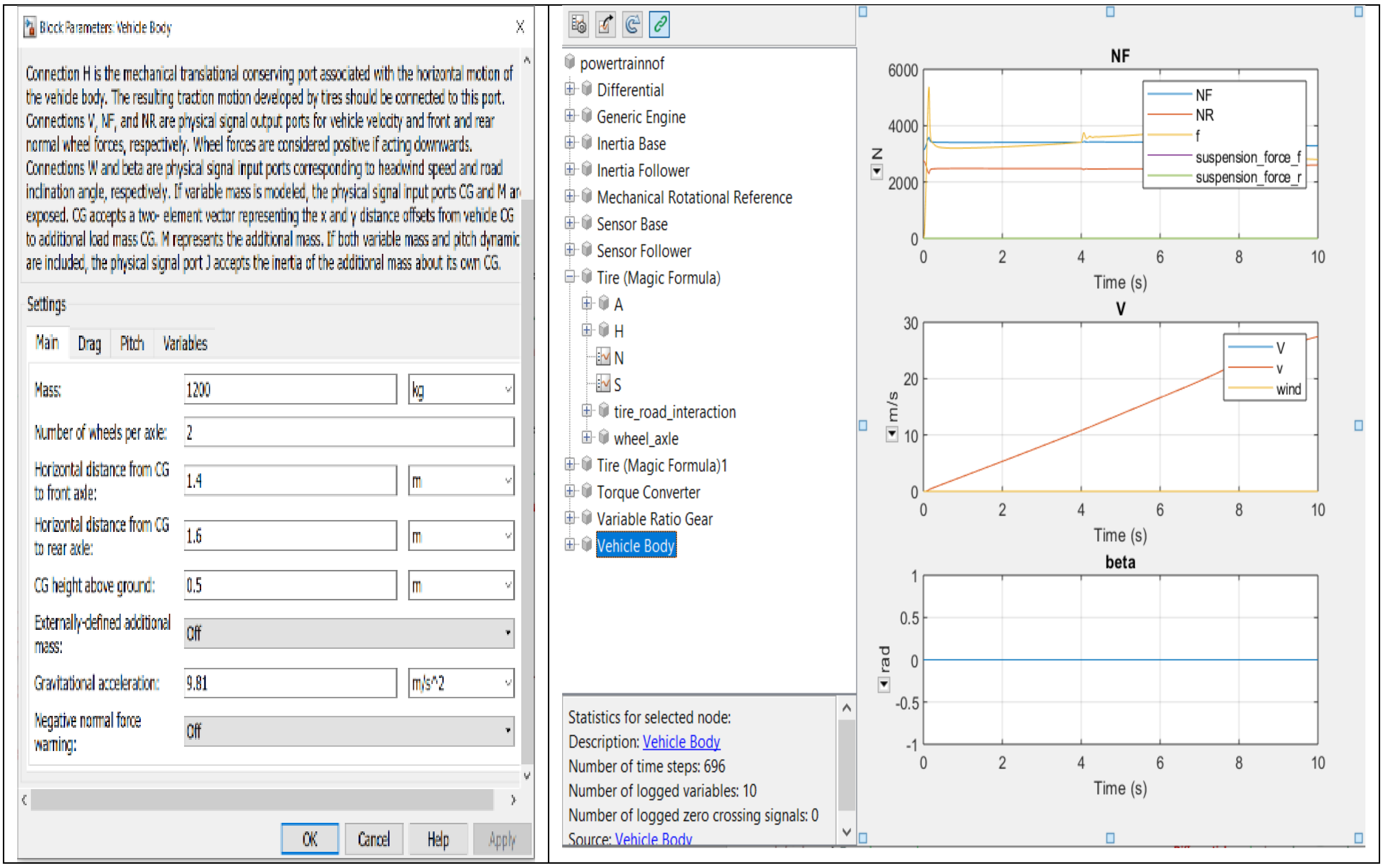


Fig.2Characteristics screen GUI of Vehicle train model (a)Input Screen (b)Simulation screen

In the input screen(fig.2a), a vehicle of the users' interest is built by adjusting the drop-down menus' necessary options. Each list consists of the pre-programmed parameters of the component doubled-clicked on. If a component cannot be found on the library of components, a custom component model can be created. This feature makes the SIMSCAPE versatile and flexible for innovative vehicle train design. In the simulation screen(fig.2b), the user inputs the drive cycle parameters under which the vehicle's throttle position is being investigated [13,14]. Then the vehicle performance characteristics can be viewed on the output screen (fig. 2b)

A. Vehicle-train model

Fig. 3 shows the SIMSCAPE control system model configuration for the vehicle drive train design. The diagram represents how SIMSCAPE applies the drive cycle and set vehicle parameters for each component to analyze the output characteristics for the vehicle's desired parameters. Here, the system model's characteristics differential equation is generated and solved through discrete-time step solution methods. One significantadvantage of using the SIMSCAPE program is that it enables the user to modify a complex set of variables in a vehicle drive train under design consideration. Here, each major component that makes up the drive train can be changed independently to test and simulate different configurations. This research simulation was based on a De Montfort University racing car that participated in the 2019 Formula one racing competition (fig. 3). The objective was to construct a comparison between different sets of configurations investigated. Some non-critical components' values were held constant in a default state to analyze the summary of the variables that were considered in detail during the simulation. Below is a summary of the variables considered. The following variables were adjusted to determine the position of the throttle at different times. They will be modeled in the form of signals in the waveform. Power is an adjusted waveform to depict the signal passed the power tothe Engine can transfer. The throttle is an adjusted waveform to depict the opening of the throttle switch. Generic Engine is a modification of this component's profile selection to determine the component characteristics and performance [15,16].

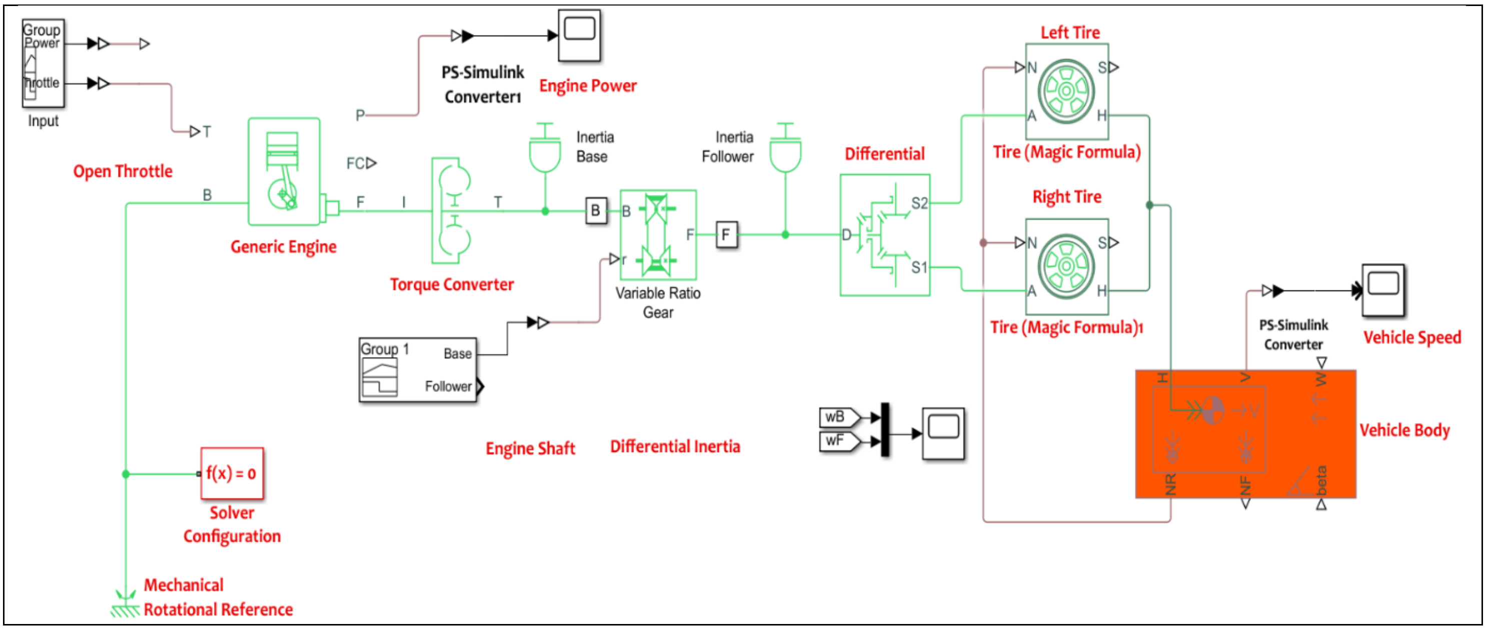


Fig 3.shows a graphical characteristic for different configurations obtained in this simulation.

The parameters modified here are Engine torque, Dynamics, speed limit and threshold, fuel consumption, and speed control.Variable Ratio Transmission is the component that represents a variable ratio gearbox. The input defines the ratio of the input to the output angular shaft velocities. Here, the output shaft direction, compliance, transmission losses, and viscous losses are modified.The differentialrepresents the component, arranged as a planetary bevel gear train equipped with an additional gear transmission between the driveshaft and the carrier[17,18]. In this part, meshing losses, viscous losses, inertia is addressed here.Vehicle Body and Mass are vehicle mass is assumed to be unchanged in the configuration modeled. It was held at 1200kg and thus helped isolate the effect of other variables during the simulation process. Also, drag and pitch are modified.The geometry dynamics rolling resistance and advanced parameters of this component are modified to aid performance stabilization.

IV. RESULT

The figures above show the simulation of a driving behavior where the driver increases power gradually, remains constant for a short interval, and decreasing at the same rate of increasing the engine power.In fig 4a, it will be noticed that the throttling process increases steadily from 0-4secs. This is translated to a rise in the power delivered by the Engine from 0-100kw. At time t=4secs, the throttling signal was constant at 1, and it is maintained from time t=4secs to t=6secs as observed in the plot(fig.4a). The effect of this signal input results in a rise in the power delivered from 100-110kw. At t=6secs, the abrupt decrease in throttling as observed in the input signal in fig. 1a results in a corresponding decrease in power delivered by the Engine from 110kw to 0 as observed in fig.4b

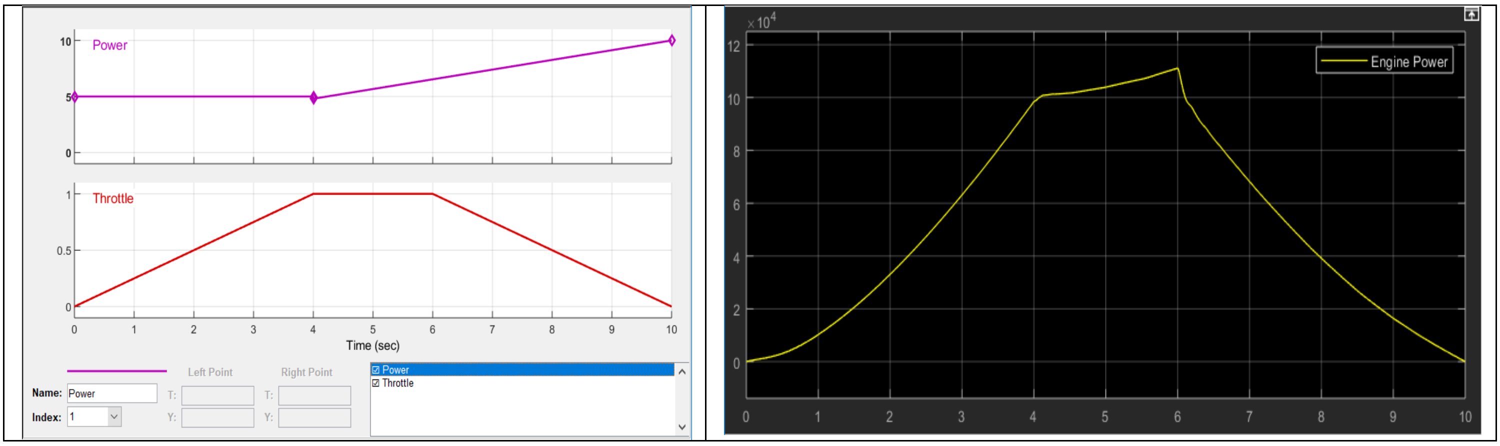


Fig. 4model design optimization of vehicle drivetrain (a)Input to Engine (b)Engine output

Fig. 3c depicts the case of the variable gear. In this model, it is pre-set that the follower axis will rotate in the same direction as the base axis. From fig. 5a, when the Base had a constant signal input of 0.6, a revolution of 140rpm and 255rpm was observed for the Base and follower, respectively. The follower had a higher revolution signifying an amplification delivered to the driveshaft in this case, as observed in fig 5b.

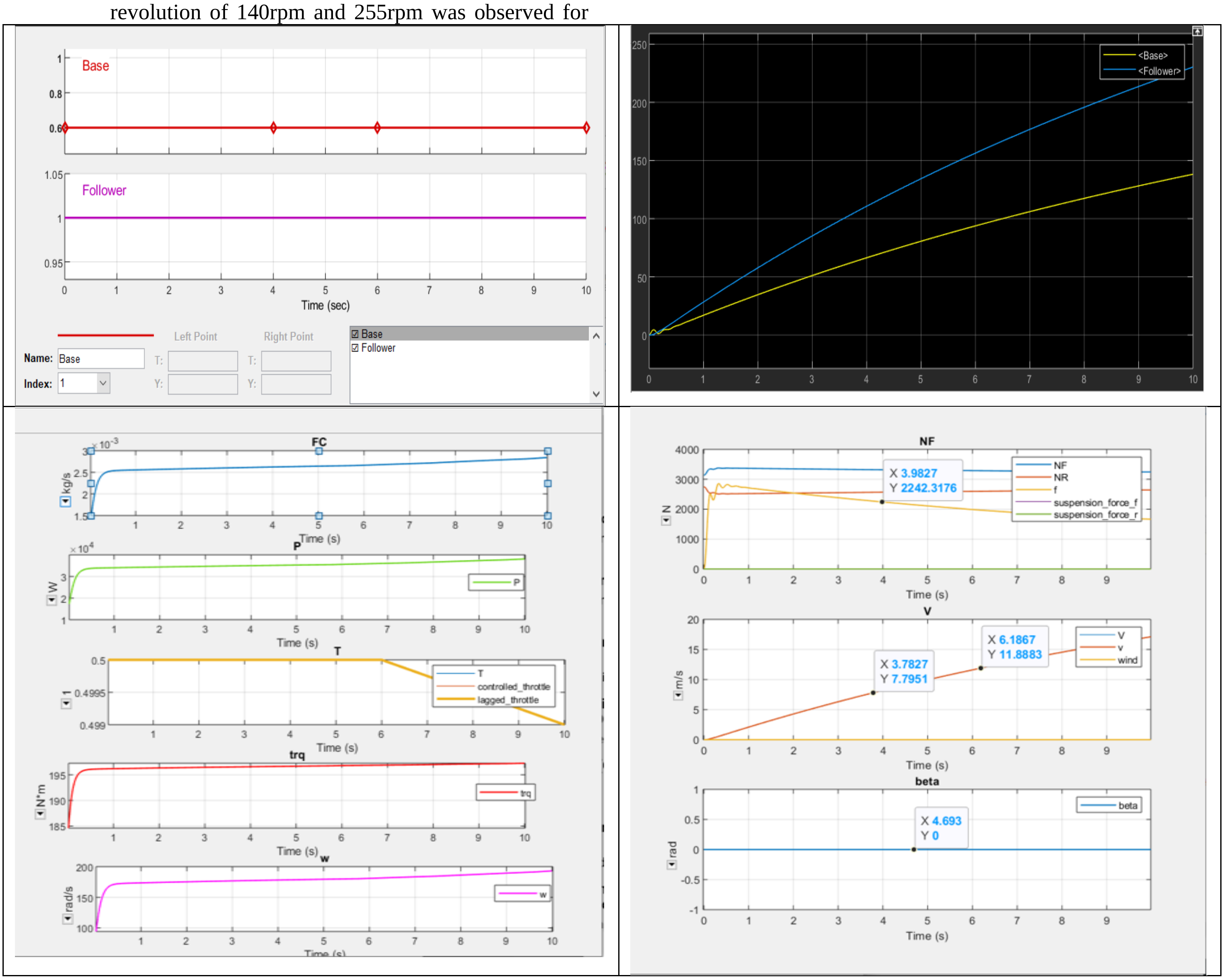


Fig. 5 vehicle drivetrainoptimization (a) Input to variable gear (b) Variable gear output (c) General operational engine characteristics (d) General characteristics of the vehicle chassis

In this model, the throttle is responsible for the intermittent flow of fuel and air needed in the Engine. The engine power can be increased or decreased by the regulation of the aperture of the throttle. The more the throttle's opening, the more the fuel gas allowed into the Engine, and the more power delivered by the Engine. From the fig.6a, it can be observed that when the signal for throttling was constant at one from 0-4secs, the Engine delivered up to 110kw of power. This shows that; constant throttling may not result in constant power being delivered but may increase as the Engine is running effortlessly. It will also be observed from fig.6a when the time was between 4 and 6secs of throttling; there was an abrupt increase in the engine power up to 140kw at that same point in fig. 6b. The spikes at the edge of the transition regions as seen in the peak waveform of fig. 6b indicates a readjustment to the Engine in response to an increase and sudden decrease in the throttling process.

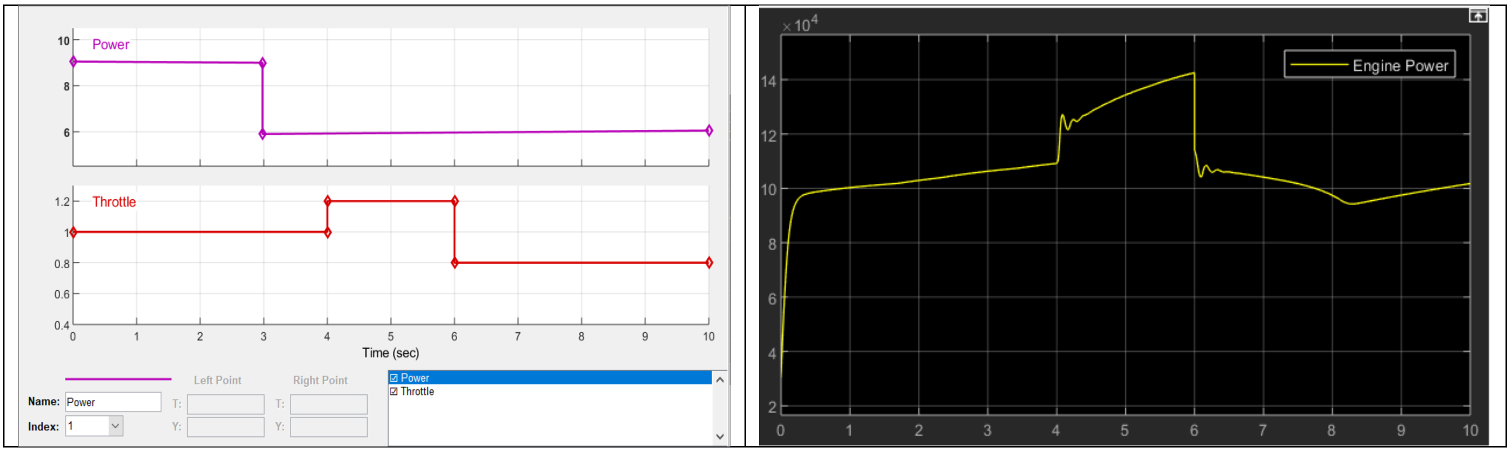
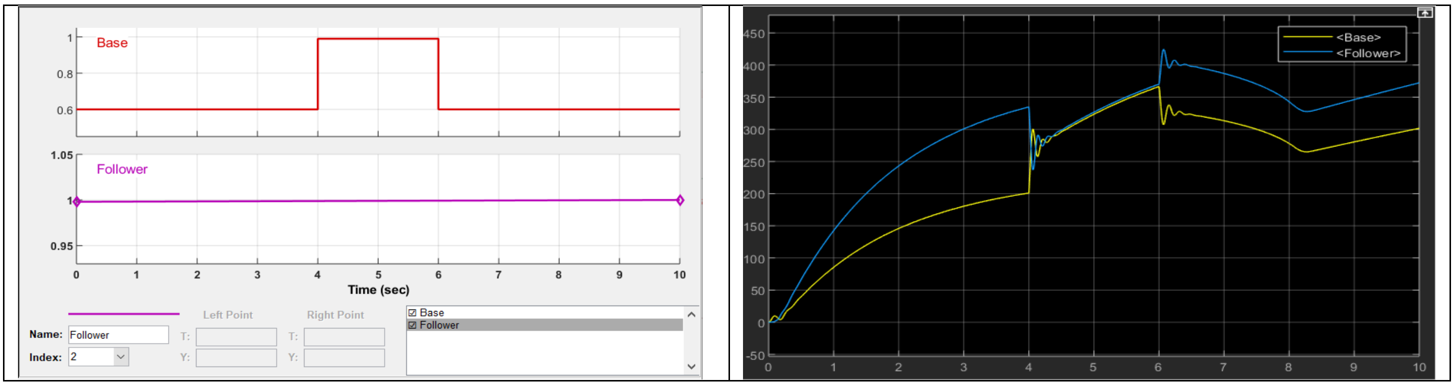


Fig. 6Throttlingvehicle drivetrain optimization of the (a) Input to Engine (b) Engine output

Fig. 7a depicts the case of the variable gear with a pulse signal. Compared to the first case(fig.4b), the signal is constant from time t=0 to t=4secs, resulting in a gradual increase from 0 - 200rpm and 0 – 345 for the Base and follower, respectively. Then there is an abrupt rise in the signal, which is constant from time t=4secs to t=6secs. This is translated to an abrupt decrease from 300 – 200rpm and 345 – 245rpm in the Base and follower, respectively. Subsequently, both the Base and follower overlapped and increased from 255 – 355rpm, as shown in fig 7d when the input signal between time t=4secs to t=6secs presents the same signal input in fig 7a. Mostly, this shows that at this point, both the Base and follower are moving at the same pace before the signal presents a constant decrease again at time t=8 to t= 10secs. Fig. 6a and fig. 7c shows the Engine's general operating characteristics where; **FC** is fuel consumption, **P** **is**the power delivered, **T** is throttling, **trq** is Torque delivered, and **w** is rotational velocities. Fig 6b.And fig. 7c-d shows the general characteristics of the vehicle chassis for every input signal presented to the system. Where **NF** is Front axle reasonable force, **NR** is Rear axle reasonable force, **v** is velocity, **beta** is Road incline angle, **f** is Longitudinal force, and **H** is Horizontal distance from CG.



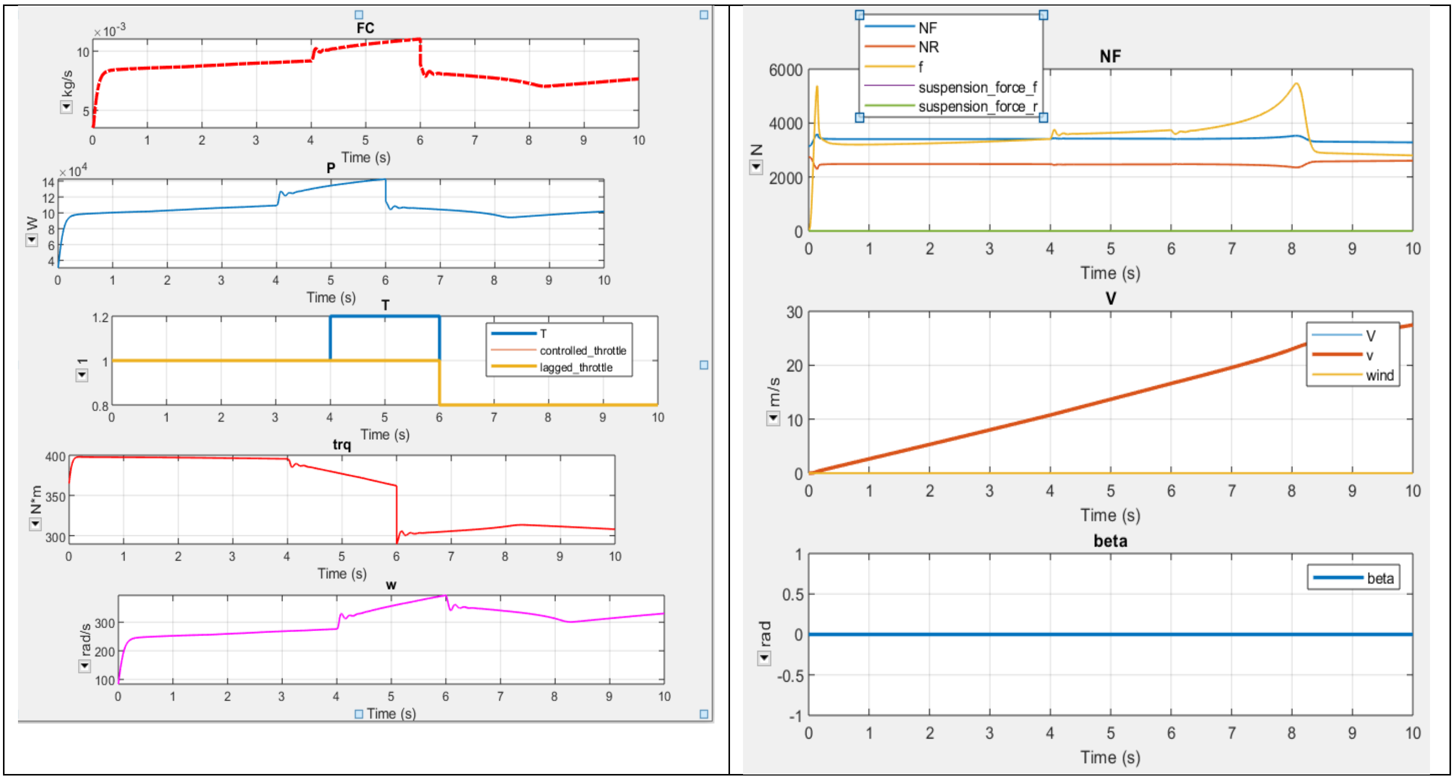


Fig. 7.General operation of the(a) Input to variable gear (b) Variable gear output (c) engine characteristics (d) vehicle chassis

The primary outputs from the SIMSCAPE simulation, as seen above, are plots depicting the vehicle system performance characteristics for different configurations under observation to make conscious and confident decisions in final design implementation. These profiles provide a reasonable estimate of how the formula racing vehicle will perform on the given course [19,20]. A closer look at the two configurations implemented shows a noticeable discrepancy between the engine power, fuel consumption, velocity, Base, and follower profile of the vehicle for the different signals applied, as shown in plots 3a-3f 4a-4f, respectively. This is attributed mainly to the variation of the signal throttle position applied to the different configurations system. Comparing both cases analyzed (3a-3f and 4a-4f), it can be inferred that the higher the magnitude of the opening of the throttle, the higher the power given out by the Engine, the higher the fuel consumption, the higher the Torque delivered, and other parameters considered in the modeling. These results obtained and analyzed can substantially aid in designing desired systems with expected performance characteristics to suit demand. These can also be applied in the education system to enlighten students on the drive train system on a computer-aided scale without dealing with the actual vehicle,which will be quite expensive and needs lots of energy to be expended.

V. CONCLUSION

SIMSCAPE modeling is a versatile modeling tool useful for both the Vehicle Drivetrain design and other applications. This application undoubtedly demonstrates the utility and effectiveness of the SIMSCAPE program. When applied to vehicle Drivetrain design. Simulation results indicate that performancecharacteristics for every component that make up the drive system. This increase can be tweaked to conform to the desired design specification needed for an application. Generic Engine and variable-ratio gearing enough for the research project, although custom transmission gearing would be needed in a more professional competitive environment like the broader global market. Future testing and simulation in the drive system are recommended to model a fully electrical enhanced system (Electrical Vehicle Drive train). Computer simulations for highly optimized vehicle drive from design can be employed in different academic learning areas and the industrial sector, as described in this study.

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