Project Report on

# Develop a Lap-Time Simulation and Energy Consumption Estimation Software for Electric Vehicles

Submitted in partial fulfilment of the requirements of the degree of

**Bachelor of Engineering (B.E.)** in **Mechanical Engineering**

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# Project Report Approval for B. E.

This project report entitled "**Develop a Lap-Time Simulation and Energy Consumption Estimation Software for Electric Vehicles**" by *Soham Raju Khairnar (18105041), Abhishek Amit Kolekar (18105002), Parth Prasad Paranjpe (18105018), Sarvesh Rajendra Pawar (18105022)* is approved for the degree of **Bachelor of Engineering (B.E.)** in **Mechanical Engineering** from University of Mumbai.

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# Declaration

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# Abstract

The mileage of a battery electric car is a significant difficulty in its design. Batteries can account for a substantial portion of the vehicle's weight, so they must be constructed for the least amount of storage space possible. This project implements a Lap Time Simulator (LTS) for Electric Vehicles (EV) with energy consumption estimation feature, and to analyze how the vehicle model's complexity influences simulation and estimation outcomes.

A Formula Student prototype vehicle is parameterized in a Steady State LTS and a Quasi-Static LTS. The LTS designed by us is a Quasi-Static Bicycle Model. It is set to compete against and validated using a commercial Point Mass Model. The results show that the more complex and output rich Bicycle Model has the same approximate lap times with similar code runtime. It also provides energy consumption estimation that the commercial software does not.

The goal of our project is to produce a lap time simulation tool that provides an adaptable, user-friendly, and virtual test environment for making better development decisions in an electric vehicle.

## Keywords

Lap Time Simulation, Quasi-Static, Bicycle Model, Power Consumption Estimation, Optimization.

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# List of Abbreviations

LTS – Lap Time Simulation

EV – Electric Vehicles

CV – Combustion Vehicles

BEV – Battery Electric Vehicles

HEV – Hybrid Electric Vehicles

PHEV – Plug-in Hybrid Electric Vehicle

RWD – Rear Wheel Drive

FWD – Front Wheel Drive

AWD – All Wheel Drive

AC – Alternating Current

DC – Direct Current

BMS – Battery Management System

RPM – Revolutions Per Minute

# List of Notations

$\Phi$ – Roll

$\theta$ – Pitch

$\Psi$ – Yaw

v – Velocity Vector

$\beta$ – Side-slip angle

$\alpha$ – Slip angle

$\tau_y$ – Shear stress distribution

$F_y$ – Lateral force

$\sigma_z$ – Normal stresses

M – Mass of Vehicle

g – Acceleration due to gravity (9.81 $m/s^2$)

$\rho$ – Density ($kg/m^3$)

A – Frontal area of vehicle ($m^2$)

$f_{cl}$ – Lift Coefficient Sensitivity factor

$C_l$ – Coefficient of lift

$f_{cd}$ – Drag Coefficient Sensitivity factor

$C_d$ – Coefficient of Drag

$F_z^{total}$ – Total Force in the Z direction

$F_x^{roll}$ – Rolling Resistance in the X direction

$C_r$ – Coefficient of Rolling Resistance

$F_{drive}$ – Drive Factor

$F_{aero}$ – Aero Factor

$N_{dw}$ – Number of Driven Wheels

$d_m^f$ – Weight Distribution of Vehicle

$d_a^f$ – Aero distribution of Vehicle

$F_{tyre}$ – Normal load acting on tire

μ – Coefficient of Friction

$F_z$ – Normal load

$F_x^{\max acc}$ – Maximum Longitudinal Acceleration

η – Efficiency

ω – Speed of the system in RPM

τ – Torque (N/m)

$R_{tyre}$ – Radius of tyre (m)

$a_x$ – Longitudinal acceleration (m/s$^2$)

$a_y$ – Lateral acceleration (m/s$^2$)

dt – Time step (sec)

$R_{curvature}$ – Radius of curvature of corner (m)

$A_{mast}$ – Area of Master Cylinder

$A_{pist}$ – Area of Piston

$\mu_{pad}$ Friction coefficient of brake pad

$H_{pad}$ – Pad Height

$D_{disc}$ – Disc Diameter

$R_{pedal}$ – Pedal ratio

P – Power Consumed

# Chapter 1

# Introduction

## 1.1 Introduction to Electric Vehicles

### 1.1.1 Types of EVs

### 1.1.2 Trends in EVs

## 1.2 Introduction to Lap Time Simulation

## 1.3 Need of Lap Time Simulation

### 1.3.1 Projections of EV Sales

### 1.3.2 Use of Lap Time Simulation

# Chapter 1: Introduction

## 1.1 Introduction to Electric Vehicles

An electric vehicle (EV) is a vehicle that is propelled by one or more electric motors. It can be powered by a collector system that uses electricity from outside the vehicle, or it can be fueled by a battery that runs on its own (sometimes charged by solar panels, or by converting fuel to electricity using fuel cells or a generator). Due to technology advancements and a greater focus on renewable energy and the possible reduction of transportation's influence on climate change, air pollution, and other environmental challenges in the twenty-first century, EVs have seen a renaissance. Lithium-ion batteries are used in the majority of electric vehicles. Most other practical batteries have a lower energy density, a shorter life duration, and a lower power density than lithium-ion batteries. Safety, durability, thermal breakdown, environmental impact, and cost are all complicating factors. To work safely and efficiently, Lithium-ion batteries should be operated within safe temperature and voltage limits.

### 1.1.1 Types of EVs

There are four types of electric vehicles available:

- **Battery Electric Vehicle (BEV)** – Fully powered by electricity. These are more efficient compared to hybrid and plug-in hybrids.
- **Hybrid Electric Vehicle (HEV)** – The vehicle uses both the internal combustion (usually petrol) engine and the battery-powered motor powertrain. The petrol engine is used both to drive and charge when the battery is empty. These vehicles are not as efficient as fully electric or plug-in hybrid vehicles.
- **Plug-in Hybrid Electric Vehicle (PHEV)** – It uses both an internal combustion engine and a battery charged from an external socket. This means the vehicle's battery can be charged with electricity rather than the engine. PHEVs are more efficient than HEVs but less efficient than BEVs. The PHEVs are also known as series hybrids. They have both engine and a motor. You can choose among the fuels, conventional fuel (such as petrol) or alternative fuel (such as bio-diesel). It can also be powered by a rechargeable battery pack. The battery can be charged externally.

- **Fuel Cell Electric Vehicle (FCEV)** – Electric energy is produced from chemical energy. FCEVs are also known as Zero-Emission Vehicles. They employ ‘fuel cell technology’ to generate the electricity required to run the vehicle. The chemical energy of the fuel is converted directly into electric energy. For example, a hydrogen FCEV.

### 1.1.2 Trends in EVs

As per Global EV Outlook 2021 by IEA [1], after a decade of strong expansion, the worldwide electric car stock reached ten million units in 2020, a 43 percent increase over 2019 and a 1% stock share. In 2020, two-thirds of new electric car registrations and two-thirds of the stock were battery electric vehicles (BEVs). China had the largest fleet, with 4.5 million electric vehicles, but Europe had the largest annual rise, reaching 3.2 million in 2020.

The economic consequences of the Covid-19 pandemic had a profound impact on the global market for all types of automobiles. New car registrations fell by roughly a third in the first half of 2020 compared to the previous year. Stronger activity in the second half somewhat countered this, resulting in a 16 percent year-over-year reduction.

In particular, on a total cost of ownership basis, electric cars are increasingly becoming more competitive in several countries. Several governments granted or extended fiscal incentives to help electric car buyers weather the market downturn.

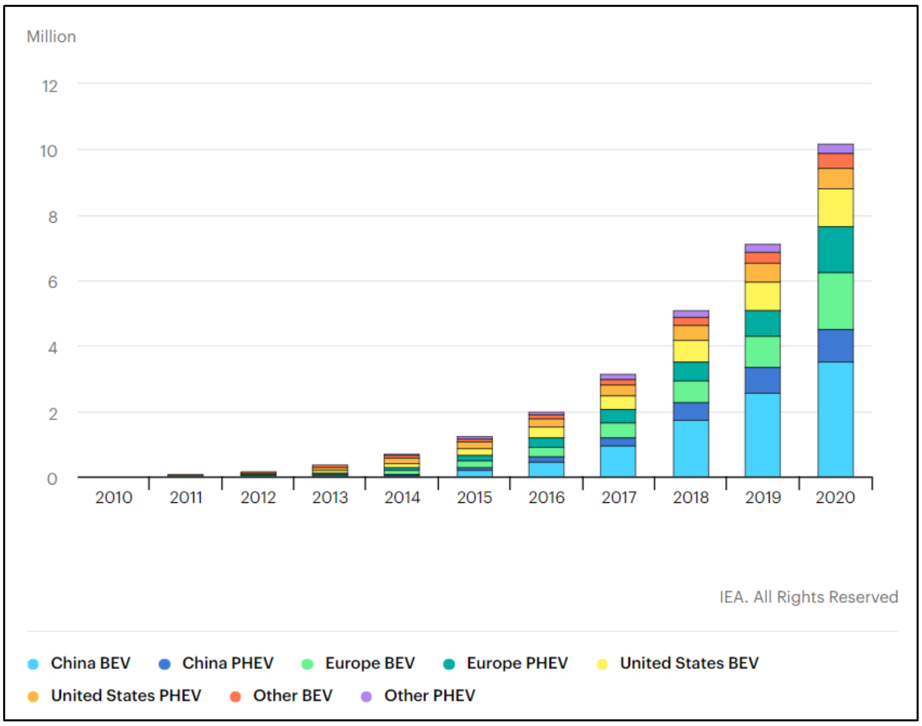


*Figure 1-1: Trend in the sale of EVs in different countries from 2010-2020*

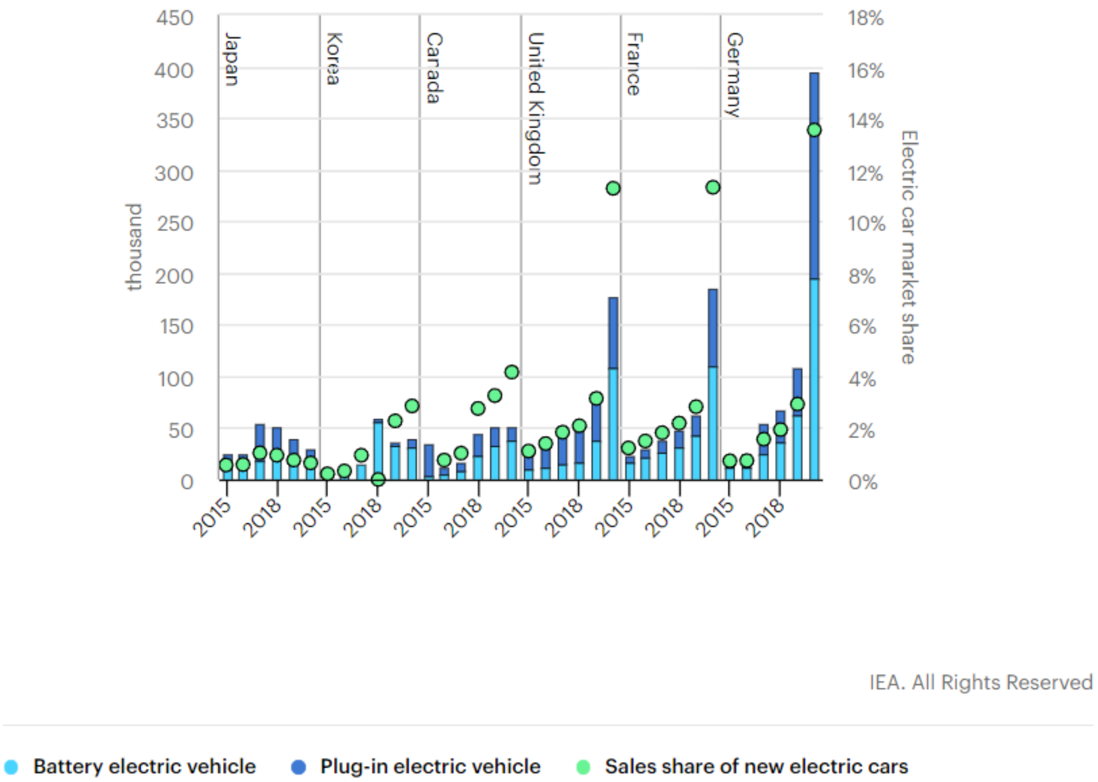


*Figure 1-2: Trend in Percentage of Market Share Captured by EVs in Different Countries*

## 1.2 Introduction to Lap Time Simulation

A Lap Time Simulator (LTS) is a car simulation tool used primarily in motorsport. The purpose of such a tool is to determine the greatest feasible lap time for a given vehicle on a given track and to comprehend how changes in certain of the car's parameters affect that lap time. An LTS, according to Siegler [2], is a vehicle handling model that connects a variety of maneuvers all done at the vehicle's limit. The car is simulated to be at maximum lateral acceleration in curves and maximum longitudinal acceleration in straights, resulting in the fastest lap time achievable.

According to Siegler [2], Mercedes-Benz made the first attempt at an LTS in 1954. Individual hand-made calculations for specific sectors of the track were used in this first simulation, and the resulting sector times were added to generate the expected lap time. Until the 1980s, equations of motion were developed by hand and increasingly solved by digital computers. In the meantime, the first g-g diagram by William Milliken [3] was published in 1971, paving the path for the creation of quasi-steady-state simulations, and Milliken used the "bicycle" model to improve quasi-steady-state simulations.

## 1.3 Need of Lap Time Simulation

### 1.3.1 Projections of EV Sales

Automakers are preparing to phase out cars powered solely by Internal Combustion Engines (ICEs) as governments look to tackle fuel emissions. The growth in Electric Vehicles (EVs) and Hybrid Electric Vehicles (HEVs) is climbing and by 2025, EVs and HEVs will account for an estimated 30% of all vehicle sales. Comparatively, in 2016 just under 1 million vehicles or 1% of global auto sales came from Plug-in Electric Vehicles (PEVs) [1].

By 2025, J.P. Morgan [4] estimates this will rise close to 8.4 million vehicles or a 7.7% market share. While this jump is significant, it doesn’t compare to the kind of growth expected in HEVs - cars that combine a fuel engine with electric elements. This sector is forecast to swell from just 3% of global market share to more than 25 million vehicles or 23% of global sales over the same period.1 This leaves pure-ICE vehicles with around 70% of the market share in 2025, with this falling to around 40% by 2030, predominantly in emerging markets.

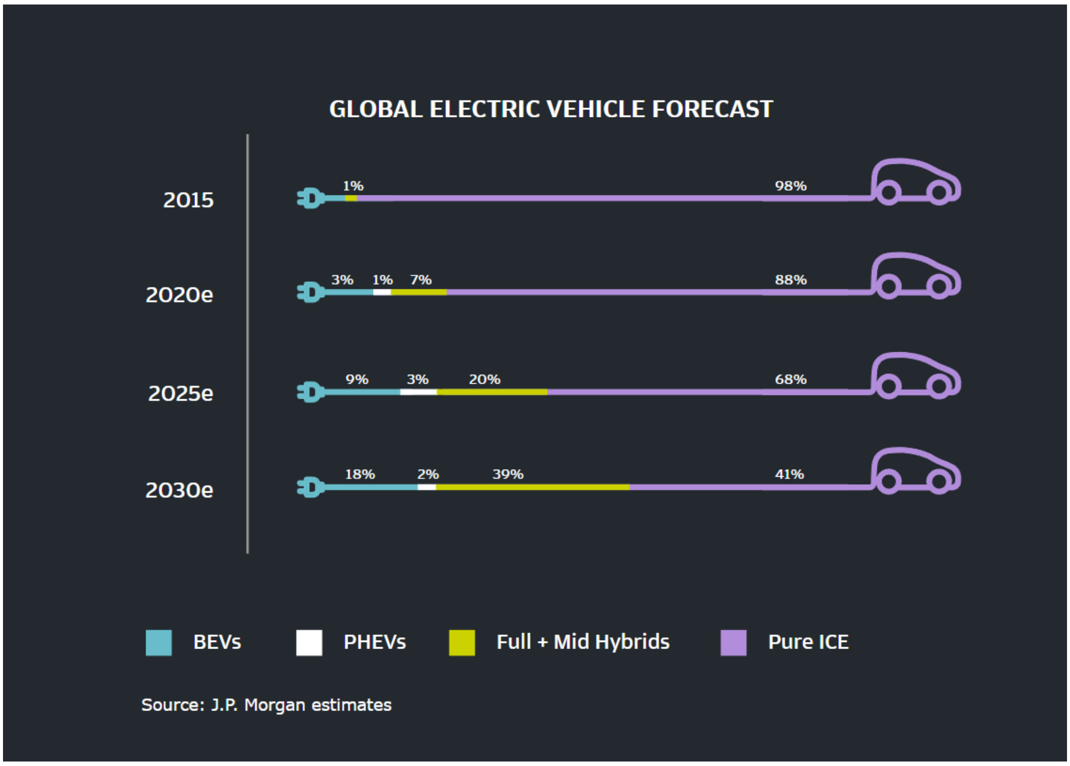


*Figure 1-3: Forecast of Sale of Different Types of Electric Vehicles in Comparison to Internal Combustion Engine (ICE) Vehicle from 2015-2030*

As EVs are gaining more and more popularity, the design and development of EVs needs to be accelerated, thus there is a requirement of a simulation software that provides insights regarding high level key performance indicators.

### 1.3.2 Use of Lap Time Simulation

The use of a Lap Time Simulation (LTS) package is advantageous and complements the many technologies (Computer Aided Design, Finite Element Analysis, Computational Fluid Dynamics) available to teams and designers. Lap Time Simulations are generally used in the motorsport sector to maximize the performance characteristics of the vehicle. However, they are also useful for commercial vehicles in driving the project decisions before the design of the vehicle begins (e.g., number of motors to be used, optimal sizing of the battery pack, impact of vehicle subsystem and aerodynamic parameters on overall performance and efficiency of the vehicle). It can also perform sensitivity analysis, which can be used to understand the amount of impact vehicle parameters have on performance and range.

The LTS modules give a designer a huge advantage over his rivals. This is accomplished by simulating the car negotiating the circuit (which they may have never visited) in each of its potential setup combinations in order to optimize the vehicle's performance before they get at the circuit or even build the vehicle. LTS packages let a costly car to be modelled at its maximum adhesion even without risk of damage to the car or hazard to the driver that track testing entails. Furthermore, it is useful during the original design process, when certain characteristics, such as the location of the center of gravity, cannot be adjusted. The vehicle can then be manufactured with fundamental design variables that are near to optimal. To mimic a full lap, the vehicle's path is usually divided into segments (every 1m, for example) and an evaluation of the vehicle is performed at each segment point, using the external forces acting on the vehicle. The circuit is idealized as a succession of straights and fixed radius turns in a basic model.

# Chapter 2

# Literature Review

**2.1 Fundamentals of Vehicle Dynamics – Thomas Gillespie**

**2.2 Lap Time Simulation for Racing Car Design – Blake Siegler**

**2.3  Lap Time Simulation: Comparison – Siegler et al.**

**2.4 Road Vehicle Dynamics - Georg Rill and Abel Castro**

**2.5 Energy Consumption Estimation in Lap Time Simulation – José Loureiro**

**2.6 Lap Time Simulation Tool for the development of an Electric Formula Student Car - Doyle et al.**

**2.7 Comparison of Different Commercially Available LTS**

# Chapter 2: Literature Review

## 2.1 Fundamentals of Vehicle Dynamics – Thomas Gillespie

"Fundamentals of Vehicle Dynamics" [5] gave us all the pertinent parameters related to the vehicle itself when it moving. As the name suggests, fundamentals change how the vehicle performs in a given situation when the parameters are predetermined. Symbols for different properties of vehicle were understood and noted. We took the ones which were taken into consideration in our version of lap time simulation. This book, which was published by SAE, in Pennsylvania, USA, had all the information we needed. The whole data was found in different chapters of the book which prompted us to read the whole book thoroughly to gain as much knowledge as possible about the basics of electric vehicles.

## 2.2 Lap Time Simulation for Racing Car Design – Blake Siegler

"Lap Time Simulation for Racing Car Design" [2] is a research paper from University of Leeds was inscribed with very useful knowledge. The aim of the paper was to develop a lap time simulation (LTS) for a racing vehicle. This paper gave us the real first push to commence our project. The paper has given us in depth knowledge about how different it is to work in the development of racing cars. Different subsystem models were considered which had all the formulas as well as theory which was absolutely crucial towards the study in this particular topic. These included:

- Aerodynamic model
- Acceleration model
- Brake model
- Powertrain model

## 2.3 Lap Time Simulation: Comparison of Steady State, Quasi-Static and Transient Racing Car Cornering Strategies – Siegler et al.

"Lap Time Simulation: Comparison of Steady State, Quasi-Static and Transient Racing Car Cornering Strategies" [6] describes a comparison between different cornering modelling strategies, including steady state, quasi-static and transient strategies. These three strategies were used to calculate how the race car performed when we used these systems. Some basic parameters like mass, aerodynamic and frictional coefficient and center of gravity were considered along with some advanced parameters like air mass density and rolling resistance coefficient. From the results it can inferred that the difference in overall time wouldn't vary drastically between the different solution techniques. However, the transient solution, which is complicated, accounts vehicle factors that are not accounted for in the other solution techniques. And a steady state simulation would not be able to provide ay high-level information regarding the vehicle. Thus, a quasi-static solution was to be sought.

## 2.4 Road Vehicle Dynamics - Georg Rill and Abel Castro

"Road Vehicle Dynamics" [7] published by Georg rill and Abel Castro imparted us with all the knowledge we needed to further our project. They designed a model of vehicle in MATLAB and they further performed analysis on the vehicle parameters which was similar to what we have done in our project of lap time simulation of for electric vehicles.

## 2.5 Energy Consumption Estimation in Lap Time Simulation – José Loureiro

"Energy Consumption Estimation in Lap Time Simulation" [8] published for master's degree focuses mainly on how the different factors like acceleration and braking impacted the consumption of the battery used in the respective vehicle. Also, some other factors were taken into consideration like battery losses, charging and conversion losses. Similar to previous papers this one also had considered all the vehicle dynamic parameters but unlike any other report it had also accounted the effect of these parameters on the consumption of energy in the battery like mass, acceleration and forces in different direction.

## 2.6 Lap Time Simulation Tool for the development of an Electric Formula Student Car - Doyle et al.

This work details the development of a lap time simulation tool for use by Queen's University Belfast in the Formula Student UK competition [9]. A vehicle model was created using Simulink, and a series of events simulated to generate the performance envelope of the car in the form of maximum combined lateral/longitudinal accelerations against velocity. A four-wheeled vehicle including load transfer was modelled, capturing shifts in traction between each tire, which can influence performance in vehicles where the total tractive power is split between individual wheel motors. Results from this analysis indicate several areas to efficiently focus future resources allocation as well as attempting to quantity trade-offs.

## 2.7 Comparison of Different Commercially Available LTS

We also experimented with a lot of lap time simulation packages are openly available to students. The following is a list of software available with their pros and cons:

*Table 2-1: Pros and Cons of Commercially Available LTS Packages*

| **LTS Package** | **Pros** | **Cons** |
|---|---|---|
| Optimum Lap | Easy to use, low computational power required | High level of inaccuracy, mainly for Combustion Vehicles (CV), does not calculate energy consumption |
| IPG Carmaker | High accuracy, calculates energy consumption | Computationally very intensive, premium, complicated to use, no sensitivity analysis. |
| ChassisSim | Accurate | Computationally very intensive, complicated to use |
| Bosch Lapsim | Accurate | Computationally very intensive, complicated to use |

We found that they are either very computationally intensive requiring high grade workstations for accurate results. The ones with simple simulations do not provide enough information as is required. Furthermore, it was also found that most of the LTS packages available require a drive cycle i.e., velocity time data of vehicle in order to have a track data, which may not be available.

Additionally, most LTS have a strong focus on combustion vehicle. These can be modified to fit electric vehicles, however modifying without appropriate validation will introduce errors and incorrectness in the simulation. Most LTS only calculate the lap times, and provide no data on the energy consumed. This prevents from estimating the theoretical range of the vehicle which drives design decisions.

# Chapter 3

# Methodology

## 3.1 Overview

## 3.2 Selection of Vehicle Model

### 3.2.1 Vehicle Dynamics Model Complexity

### 3.2.2 Vehicle Modelling Strategies

## 3.3 Selection of Cornering Mechanism

# Chapter 3: Methodology

## 3.1 Overview

The following methodology was used for the development for our Lap Time Simulation (LTS): Starting with the selection of type and complexity of the LTS we are designing and then determining what all input parameters will be required. Equations of elements relating to vehicle conditions i.e., function that defines acceleration of vehicle will be determined and coded. Similarly, elements relating to track conditions i.e., braking and cornering functions will be coded. These will be integrated to form final code. This will output raw post processing data containing lap times, velocity, acceleration and power consumption, which will be coded to visualize into graphs. A graphical user interface may be developed if required and feasible considering time constraints. We will then input demo track and vehicle inputs and test the code, which will be then validated using simulation done on Optimum Lap software. Finally, all the findings and conclusions will be published in the final report.

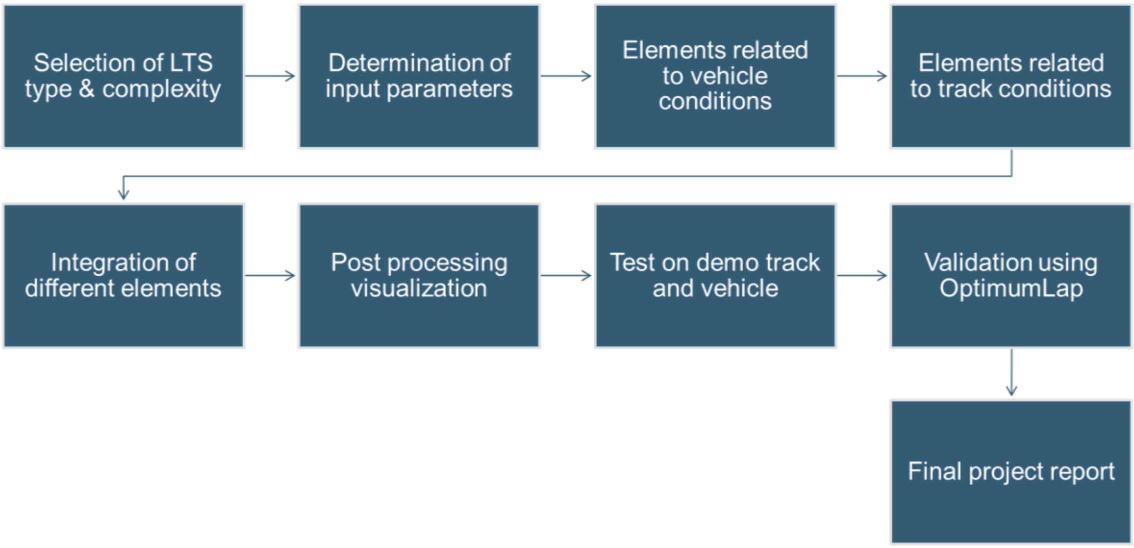


*Figure 3-1: Project Methodology*

## 3.2 Selection of Vehicle Model

### 3.2.1 Vehicle Dynamics Model Complexity

Siegler et al. [2] classifies on the basis of vehicle dynamics model and its complexity:

- **Point Mass Model** – It is the simplest model, where the entire car is "condensed" into a point mass. Due to this simplification, pitch, roll, and yaw dynamics are neglected. This approach can give decently accurate results provided inputs are correct. Very few inputs are required to run this model.
- **Bicycle Model** – It includes two axles for the inclusion of pitch dynamics. Roll and yaw moments are neglected for simplicity. This model is more accurate in drag (straight line) simulations, but due to lack of roll and yaw dynamics, is equally (in)accurate when it comes to entire track simulation.
- **Two Track Model** – All 4 wheels are modelled so that the entire vehicle dynamics of the car can be simulated. It gives the most accurate results, but inputs to be entered are more.

### 3.2.2 Vehicle Modelling Strategies

To simulate a full lap, the vehicle's path is typically divided into segments (for example, every 1m) and an analysis of the vehicle at each segment point is performed using the external forces acting on the vehicle. This is typically done as a simple quasi-static model, with the circuit idealized as a series of straights and constant radius turns. Milliken et al. [3] describe a commonly used method for determining the fastest lap time. It entails using the corners as simulation limiting factors. The maximum speed at which the vehicle can negotiate all of the corners (which is independent of the straight speeds) is determined; this gives the speed at which the vehicle enters and exits all of the straights. Then vehicle's performance on the straights can then be determined.

The three different vehicle modelling strategies used to find the performance of the vehicle, as per Siegler et al. [2], are as follows:

- **Steady State Strategy** – The first model is a simple steady state model that accounts for the vehicle's longitudinal and lateral acceleration separately (i.e., the car brakes and then turns in). Only the vehicle's lateral acceleration performance is considered when cornering. The simulation reaches its steady state solution when the system is in equilibrium and time dependent variables are zero. Calculation, such as eliminating all time dependent variables, can reveal this.

- **Quasi-Static Strategy** – This technique is identical to the one before, except the corner is divided into a sequence of constant radius turns with decreasing path radius (simulating an increase of steer angle towards the apex). The corner has about 50 segments, which keeps the time step in the approach minimal and the simulation accurate. The vehicle's acceleration is established by letting the simulation to settle down to its steady state values at each path segment (represented by a certain path radius). The lateral tire force required to sustain this lateral acceleration can be calculated using a friction circle technique, and the residual tire force can be calculated using a combined Pacejka Magic Formula Tire model [10]. The vehicle's longitudinal acceleration is then calculated using the remaining tire force. This guarantees that the tires' total combined lateral and longitudinal force is comparable to what a genuine tire can produce.
- **Transient Strategy** – This technique aims to find a transitory solution. This is detected when a vehicle is subjected to non-steady linear or rotational accelerations. In reality, the vehicle is never still during cornering since it is continuously accelerating in a mixture of linear lateral, longitudinal, or normal directions, as well as rotating pitch, roll, or yaw directions. The transient modelling technique looks into the vehicle's dynamic yaw response and how it affects the overall findings. The transient simulation accounts for the vehicle's response time when changing its attitude and direction of movement.

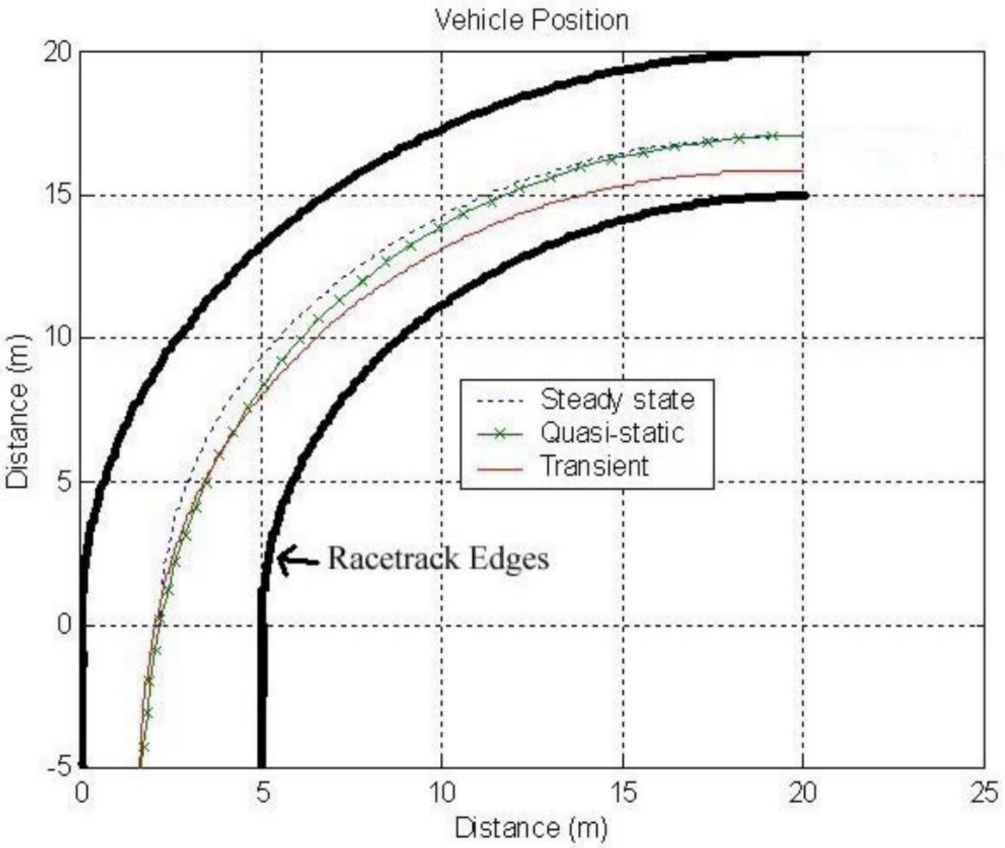


*Figure 3-2: Comparison of Different Vehicle Dynamics Models*

Considering the need of multiple iterations during the design process, a computationally less intensive program would be needed. However, at the same time, the accuracy of the model should be high enough. Thus, considering both these conditions, a Quasi-Static Bicycle Model is selected for the LTS.

## 3.3 Selection of Cornering Mechanism

The track is divided into straights and corners. During the straights, the vehicle is deemed to be limited by the power that can be generated by the powertrain, and supported by the frictional forces generated by the tires due to the longitudinal coefficient of friction. However, during the corners, the lateral coefficient of friction comes into play. If the lateral frictional force exceeds the maximum velocity that can be sustained for given radius of curvature (which is calculated by the centrifugal force relation), then the car will slip off the track.

To simulate this condition, there are two possible methods, as described in Toyoshima Takayuki, et al. [11]:

- **Circular Arc Method** – The circular arc method is a method of specifying the entire driving locus by approximating the driving locus on straight sections as a straight line and the driving locus on corner sections as an arc.
- **Whole Transition Curve Method** – In the whole transition curve method, the driving locus on the straight sections is approximated by a straight line, as in the circular arc method, but the driving locus on the corner sections is not specified using arcs, but rather using particular curves.

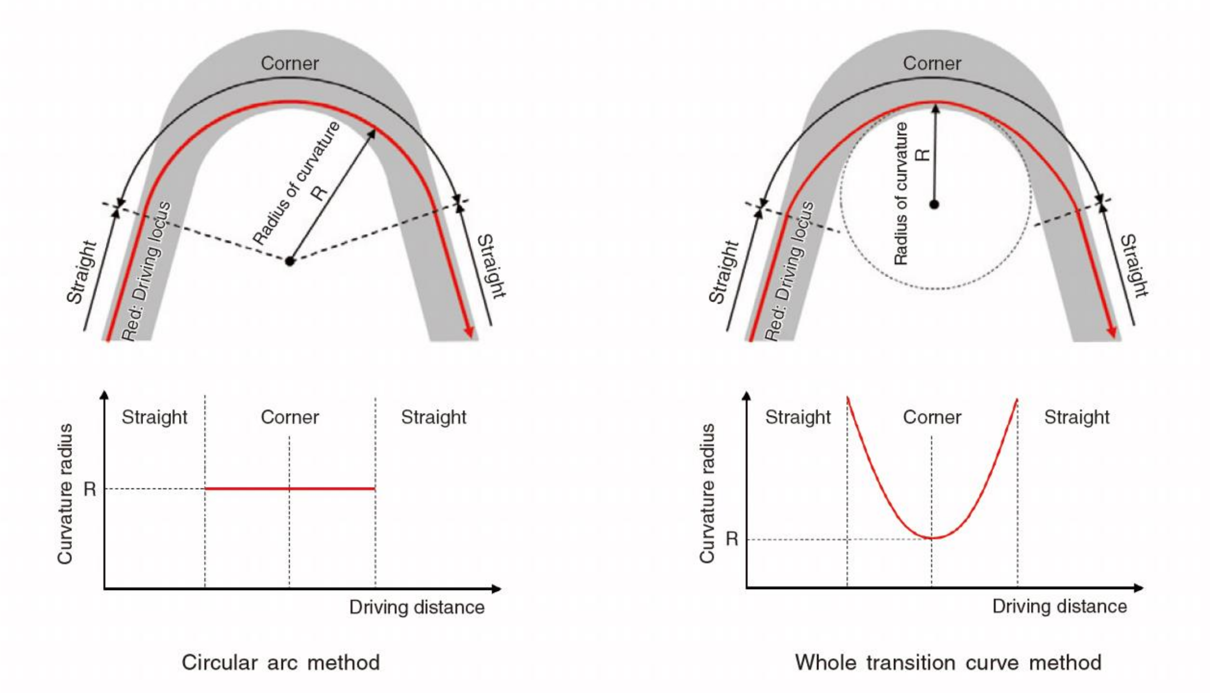


*Figure 3-3: Mechanisms of Navigating a Corner*

The whole transition curve method adds a lot of accuracy to the final result, at the cost of some computational power. Thus, that is the mechanism of choice.

# Chapter 4

# Details of Work

## 4.1 Working of LTS Software

## 4.2 Axes Convention

## 4.3 Force Calculations

### 4.3.1 Inertial and Grade Forces

### 4.3.2 Aerodynamic Forces

### 4.3.3 Rolling Resistance

### 4.3.4 Drive Force

## 4.4 Tire Modelling

# Chapter 4

# Details of Work

## 4.5 Powertrain Equations

### 4.5.1 Motor Model

### 4.5.2 Drivetrain Model

## 4.6 Final Equations of Motion

## 4.7 Brake Modelling

## 4.8 Power Consumption

## 4.9 Inputs Considered

# Chapter 4: Details of Work

## 4.1 Working of LTS Software

The working of the LTS used can be summarized as in the following flowchart:

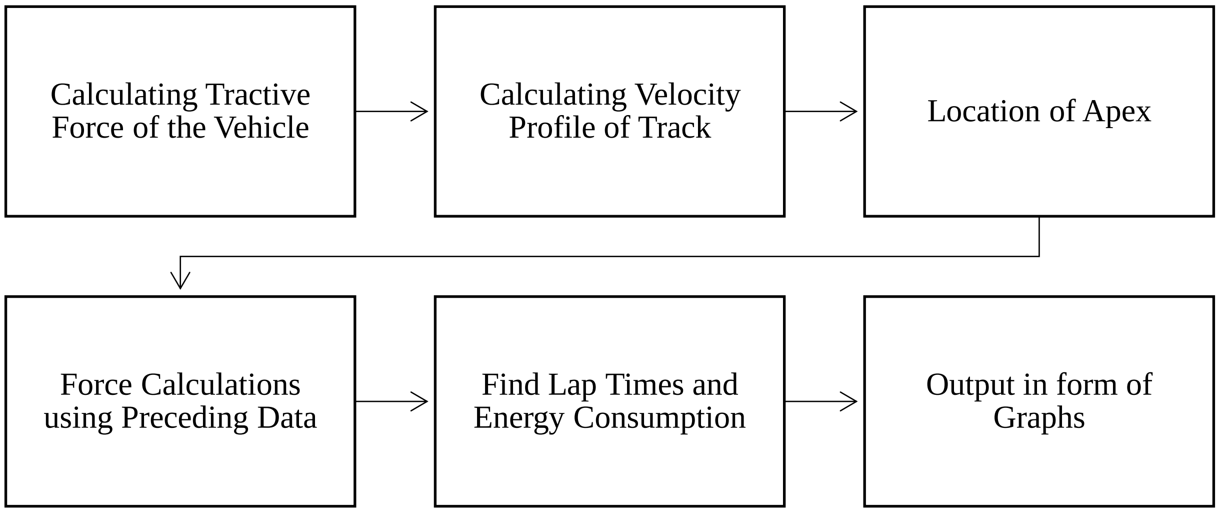


*Figure 4-1: Flowchart of LTS*

1. **Calculating Tractive Force of the Vehicle** – The vehicle will move depending on the amount of tractive force it generated. The tractive force is a function of the powertrain characteristics, aerodynamic device properties as well as high level inputs like mass of vehicle, wheelbase, radius of tires, friction coefficients of tires etc. A diagrammatic representation of the traction limitations is called as the Tractive Force Diagram (see Chapter 5 – Results).
2. **Velocity Profile of Track** – The vehicle is limited by its performance characteristics in a straight line. However, in cornering conditions, the vehicle is limited by the amount of lateral traction it can generate, as well as the characteristics of the road such as banking, inclination, radius of curvature of corner etc. For the consideration of such inputs, the track is discretized into segments, consisting of straights and corners, and the maximum possible velocity of each segment is calculated depending on its radius of curvature and banking.
3. **Location of Apex** – The apexes, which can be described as the point of minimum radius and slowest speed achieved in a corner. Locating the apex of the corner is

important as apex can be considered as the point where the driver stops coasting and starts accelerating.

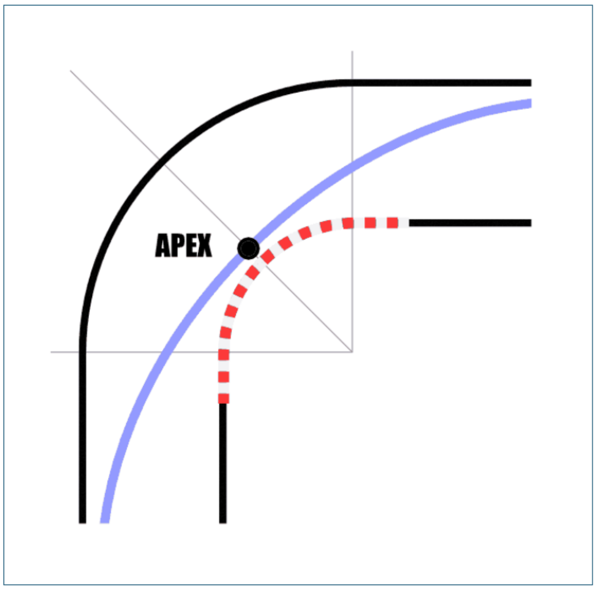


*Figure 4-2: Diagrammatic Representation of Apex with the Blue Line Representing Optimum Path of Vehicle.*

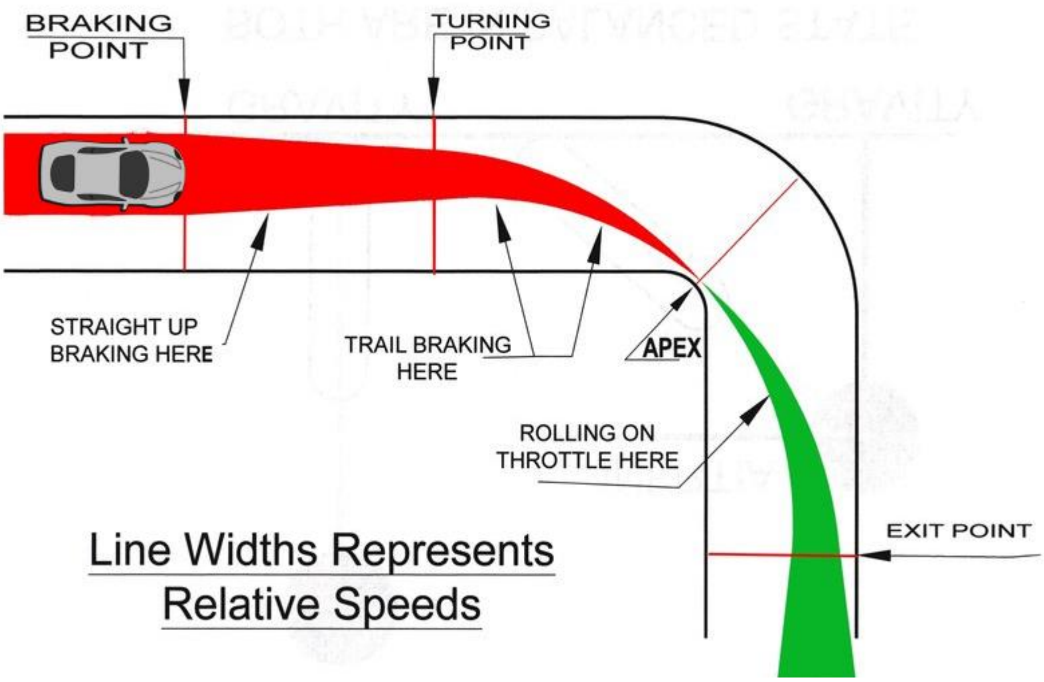


*Figure 4-3: Vehicle Behavior while Navigating a Corner*

4. **Force Calculations using Preceding Data** – The first two steps calculate the vehicle parameters and track parameters separately. In the real world, however, the force act

on the track and vehicle at the same time in different directions. Thus, the data from previous stages is imported in the code and the actual forces acting on the vehicle are calculated.

5. **Finding Lap Times and Energy Consumption** – After force calculations, the lap times are calculated using Newton Euler relations. The energy estimation is done using the force times displacement relation.
6. **Output in form of Graphs** – It is difficult to observe trends in data without the aid of visual representations like graphs. Thus, these are chosen as the preferred mode of data representation for showcasing results. The result data is also exported in a .CSV (Excel file extension) file for storage purposes.

## 4.2 Axes Convention

The Axis System used in the LTS software following the Society of Automotive Engineers Standard - J670_200801 [12]. It is the official standard in the automotive industry; hence it was selected to be used.

The equations are expressed in a coordinate axis system with the origin CG being the vehicle's center of gravity as show in Figure 4.4. When driving on a flat road, the x-axis defines the longitudinal direction pointing towards the front of the automobile, while the z-axis defines the vertical direction perpendicular to the ground heading in the direction of gravitational acceleration. When viewed from above, the y-axis determines the lateral direction and points to the right in order to form a right-hand triad, as shown in Figure 4.4.

The roll ($\Phi$), pitch ($\theta$), and yaw ($\Psi$) movements are rotations about the x, y, and z-axes, respectively. Roll and pitch are not taken into account while merely examining planar dynamics. The vehicle is in circular motion when describing a corner, and the velocity vector ($v$) is tangent to the trajectory. The side- slip angle ($\beta$) is the angle formed by v and the vehicle's x-axis. Figure 4.5 taken from [8] depicts this angle as well as an example of trajectory.

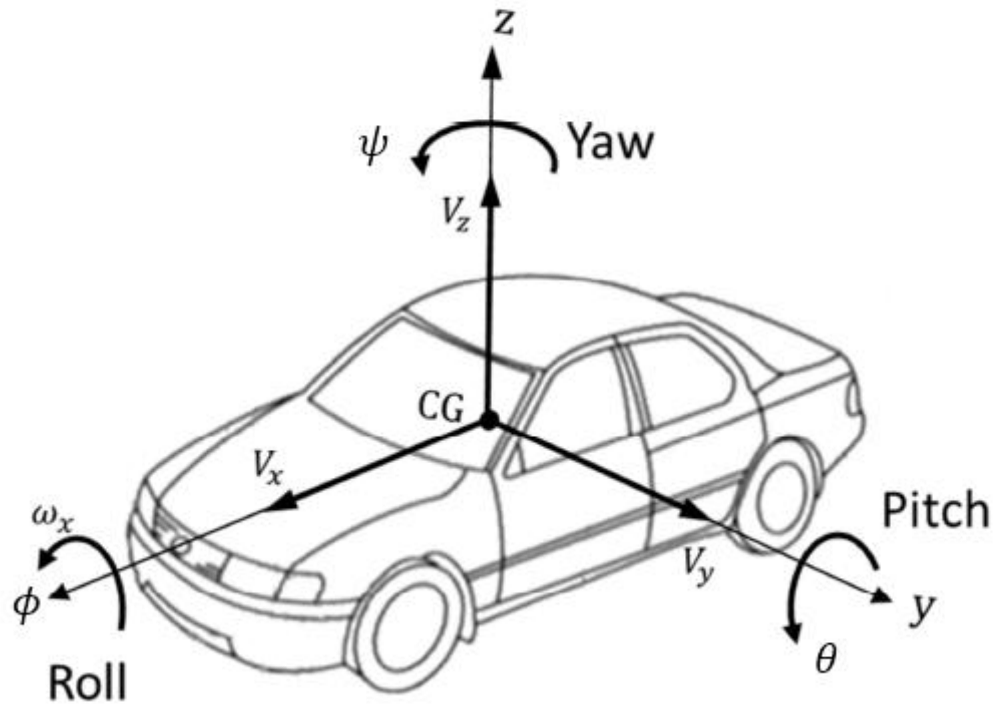


*Figure 4-4: Axis System of the Vehicle as per SAE J670_200801 Standard*

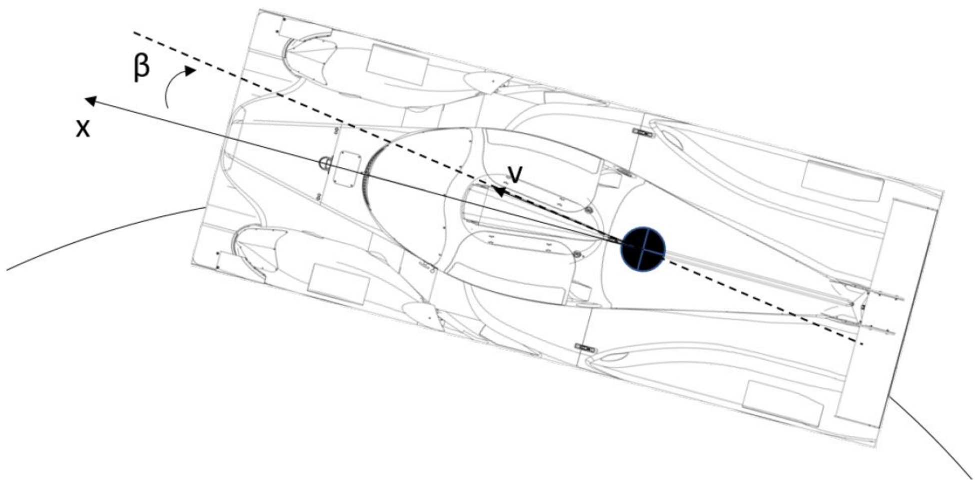


*Figure 4-5: Side-slip Angle when Vehicle is Describing a Corner*

A tire can have its own coordinate axis system, just like a vehicle. In literature, various sign conventions are used, the most common of which are the SAE and ISO. A SAE tire coordinate axis system is shown in Figure 4-6.

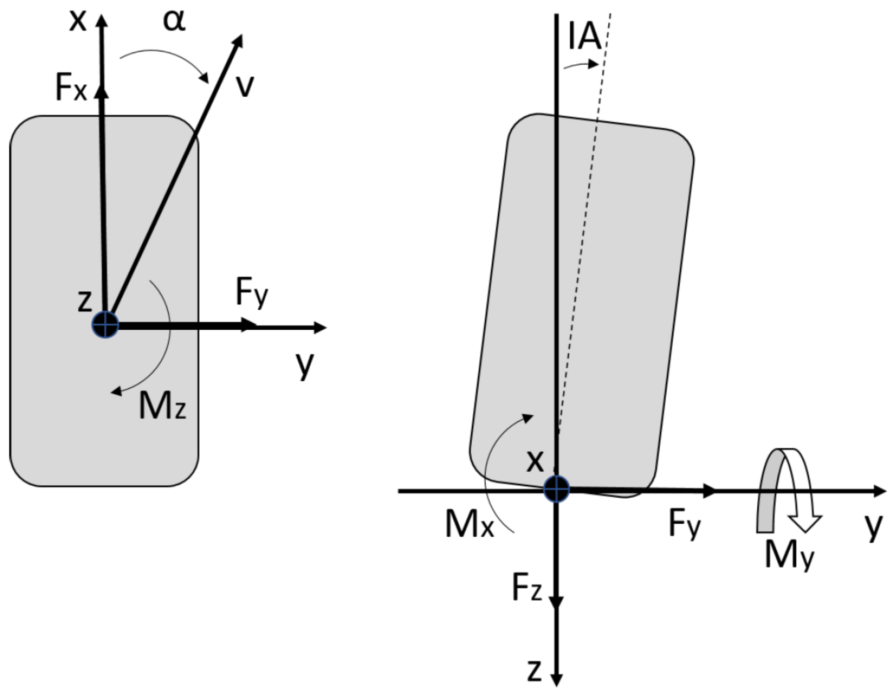


*Figure 4-6: SAE Tire Axis System. Top view (left) and Rear View (right).*

From a top view, the slip angle (α) is the angle between the velocity vector and the x-axis. From a front view, the inclination angle (IA) is the angle between the tire plane and the z-axis.

The slip angle is the angle formed by the tire's heading and the actual direction of motion. This is the result of a lateral force being applied to the tire, causing it to deform. The tire deformation causes a torsion around the vertical axis of the tire, changing the geometry of the contact patch. The shear stress distribution ($\tau_y$) changes as a result of this shift, resulting in the point where $F_y$ is deemed to be applied. Figure 4-7 is an illustration of this explanation. Because imparting a lateral force to the tire generates a deformation, which causes a reaction at the contact patch, creating lateral force, $F_y$ and work as a pair action-reaction.

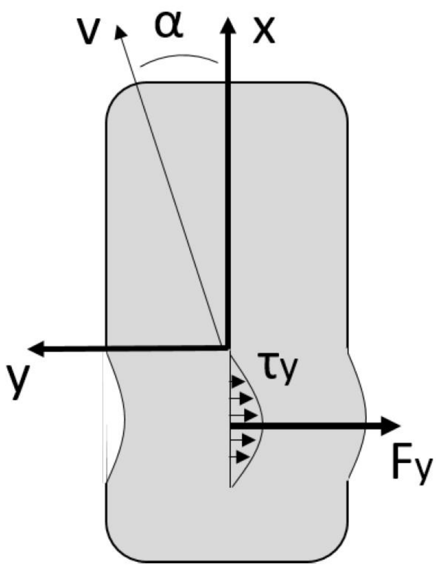


*Figure 4-7: In Bottom View, Slip Angle Tire Deformation and Pressure Distribution.*

## 4.3 Force Calculations

### 4.3.1 Inertial and Grade Forces

To overcome the inertias of movement, more forces must be applied to the body. This is both linear and angular in that it creates acceleration to describe a trajectory while also turning the wheel. Newton's 2nd law of motion applies in the situation of linear inertia.

In the case of incline roads, potential energy is required to overcome the hill climb. The road inclination angle (θ) is used to measure this. The weight of the car causes a resisting force.

The equations for linear inertial forces in x, y, and z directions respectively, as from [3], are as follows:

$$F_x^{mass} = M * g * sin(\theta_{track\ inclination}) \quad \ldots (1)$$

$$F_y^{mass} = -M * g * sin(\psi_{track\ banking}) \quad \ldots (2)$$

$$F_z^{mass} = -M * g * cos(\theta_{track\ inclination}) * \cos(\psi_{track\ banking}) \quad \ldots (3)$$

An approximation of load transfer can be made by modelling the dynamics of the vehicle's sprung mass. This is carried out by adding roll and pitch DOF to the model. Ellis [13] demonstrates this by splitting the car into three bodies: the front unsprung mass, the rear unsprung mass and the sprung mass. The sprung mass is pin jointed and free to rotate about the vehicle roll and pitch axis. Its motion is opposed by torsional springs and dampers on both axes, which relate to the vehicle's actual suspension components. Suitable values of roll, pitch and yaw inertia are then assigned to the sprung mass body, with the body masses again assumed to be concentrated at the center of gravity position of each body. A vertical DOF may also be given to the sprung mass body to model its ride behavior but, this is not normally an important factor when modelling racing cars running on smooth surfaces. Crolla [14] shows that by making each wheel into a separate body with an extra DOF each for spin, camber and/or steer (once more with suitable inertia values), the modelling of powertrain/brake and suspension kinematics effects is possible. Using this approach, other effects may also be modelled such as steering system, axle and chassis compliance.

### 4.3.2 Aerodynamic Forces

The vehicle is acted upon by aerodynamics forces, namely downforce and drag [15]. Downforce (also known as negative lift) is generated by the vehicle’s contoured shape, as well as the aerodynamic components like front and rear wings and undertray. Downforce allows the car to go quicker by increasing the vertical force on the tires, resulting in increased grip. The downforce is directly proportional to the density of medium the object is going through (ρ), the frontal area (A), the lift coefficient sensitivity factor (fcl), and coefficient of lift (Cl) and the velocity of the vehicle (v). Downforce is generated in the negative Z direction, and is represented by the formula:

$$F_z^{aero} = \frac{1}{2}\rho * A * (f_{cl} * Cl) * v^2$$

The drag force generated in the negative X direction, by the skin friction of the vehicle's body and the side effect of downforce generating aerodynamic components, such as the wings and undertray, is known as aerodynamic drag. This force opposes movement and represents air resistance throughout the body. The downforce is directly proportional to the density of medium the object is going through (ρ), the frontal area (A), the drag coefficient sensitivity factor (fcd), and coefficient of lift (Cd) and the velocity of the vehicle (v). Its expression is:

$$F_x^{aero} = \frac{1}{2}\rho * A * (f_{cd} * Cd) * v^2 \qquad \dots (4)$$

The total force in the Z direction is the sum of downforce, inertial and grade forces, and is given by the equation:

$$F_z^{total} = F_z^{mass} + F_z^{aero} \qquad \dots (5)$$

This total normal force is used to calculate the drive forces and rolling resistance.

### 4.3.3 Rolling Resistance

When a tire rolls down a road, the contact point is a part of the tire tread that deforms when it comes into touch with the ground. When the tread is no longer in touch with the ground, the energy spent deforming the tire is not entirely returned in relaxation, causing the contact pressure distribution in the tire to alter [3][10]. As a result, the heading (front) half of the tread will experience larger normal stresses ($\sigma_z$) than the tailing (back) region in forward motion, moving the normal force applied to the tire in a horizontal direction, as shown in Figure 4-8 [8].

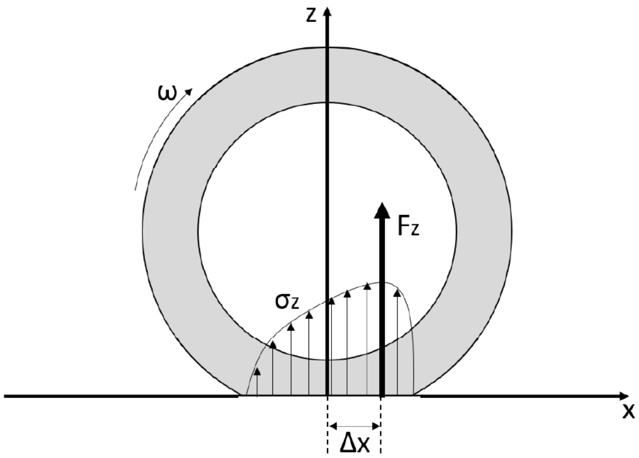


*Figure 4-8: Distribution of Normal Stresses on a Tire's Tread and the Resulting Shift in Application of Normal Force*

Rolling resistance comes from the moment about the y-axis that the new application of the normal force Fz creates in the opposing direction of the wheel's angular movement.

Rolling Resistance = $F_x^{roll} = Cr\ |F_z^{total}|$ … (6)

### 4.3.4 Drive Force

The drive force ($F_z^{drive}$) will differ considering the type of vehicle drivetrain (RWD, FWD, AWD) as well as front and rear aerodynamic devices. 2 factors, called drive factor ($F_{drive}$) and aero factor ($F_{aero}$) are allocated for the calculation of the drive force. The number of driven wheels is also an important feature that determines the drive force ($N_{dw}$).

The drive factor is determined by the weight distribution of the vehicle ($d_m^f$). The aero factor is determined by the aero characteristics in the front and rear of the vehicle ($d_a^f$).

The following table describes the number of driven wheels, aero and drive factors:

*Table 4-1: Determination of Drive and Aero Factors*

| Factor | RWD | FWD | AWD |
|---|---|---|---|
| $N_{dw}$ | 2 | 2 | 4 |
| $F_{drive}$ | $1 - d_m^f$ | $d_m^f$ | 1 |
| $F_{aero}$ | $1 - d_a^f$ | $d_a^f$ | 1 |

## 4.4 Tire Modelling

The tire model considered is a simplistic model, where the normal load sensitivity is assumed to be linear. The effects of phenomena such as rise in tire temperature, camber pressure, and slip angles is not considered as it does not make a big difference in the working of a road vehicle. The general tire force is given by the following equation [10]:

$$F_{tyre} = \mu(Fz)Fz\ = (\mu_0 + \frac{\delta\mu}{\delta Fz}(N_0 - \mathrm{Fz}))\mathrm{Fz} \quad \dots (7)$$

$\frac{\delta\mu}{\delta Fz}$ represents that the friction coefficient (μ) varies linearly with normal force ($F_Z$), where $\mu_0$ and $N_0$ are the initial friction coefficient and initial normal load respectively.

In the case of maximum longitudinal acceleration, only the driver tires are considered for force transmission, and can be represented by the equation:

$$F_x^{\max acc} = N_{dw}\left[\mu_x^0 + \frac{\delta\mu x}{\delta F}\left(N_x^0 - F_z^{driver\ tires}\right)\right] * \ F_z^{drive} \qquad \ldots (8)$$

Here, the values of friction coefficient, normal load are taken for the longitudinal direction and are represented by the letter 'x' in the subscript. However, it is considered that all tires assist in braking, thus the force causing maximum longitudinal deceleration is placed on all tires, and is represented by:

$$F_x^{\max dec} = [\mu_x^0 + \frac{\delta\mu x}{\delta F}\,(N_x^0 + \frac{F_Z^{total}}{4})] * F_Z^{total} \qquad \ldots (9)$$

Similarly, in case of lateral acceleration, the force is considered on all tires, and the result equation to describe it is:

$$F_y^{max} = [\mu_y^0 + \frac{\delta\mu y}{\delta F}\,(N_y^0 - \frac{F_Z^{total}}{4})] * F_Z^{total} \qquad \ldots (10)$$

Here, the values of friction coefficient, normal load are taken for the lateral direction and are represented by the letter 'y' in the subscript.

The actual combined force acting on the tire can be calculated by using the Friction Ellipse [3]. The Friction Ellipse, also known as the GG diagram, is a plot on a chart representing a tire's maximum grip in both the lateral and longitudinal directions. The GG stands for G-forces in the lateral and longitudinal direction. The sign convention can be considered as follows: turning right is positive lateral grip, and turning left is negative lateral grip. Accelerating is positive longitudinal grip, and braking is negative longitudinal grip. Finally, lateral acceleration is on the x-axis and longitudinal acceleration is on the y-axis.

The friction ellipse relation is given by the formula:

$$\left(\frac{F_x}{F_x^{max}}\right)^2 + \left(\frac{F_y}{F_y^{max}}\right)^2 = 1 \qquad \ldots (11)$$

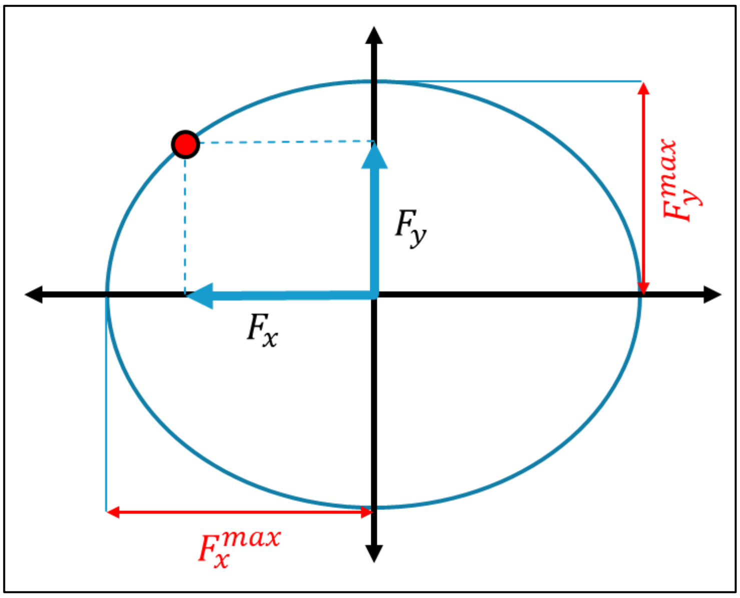


*Figure 4-9: Diagrammatic Representation of a Friction Ellipse*

## 4.5 Powertrain Equations

### 4.5.1 Motor Model

An idealised electric motor is considered for the sake of multi-level usability and simplicity. It is assumed that the motor is first torque limited i.e., it can constantly deliver its datasheet peak torque, and once it reaches the peak power, the motor becomes power limited i.e., the torque reduces as RPM increase. The algorithm can be represented as follows:

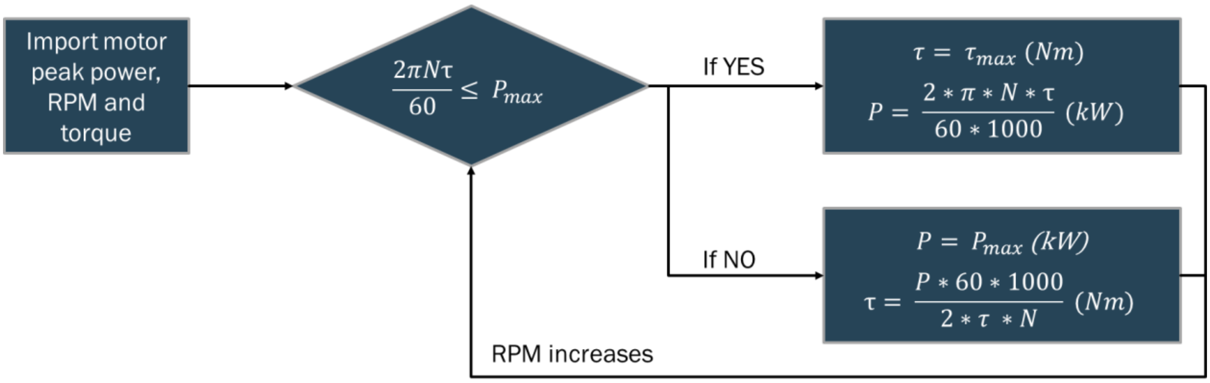


*Figure 4-10: Algorithm of Motor Model*

### 4.5.2 Drivetrain Model

As electric motors can deliver torque efficiently across a large range of RPM, there is essentially no use of a multispeed gear box. However, in some instances, a designer may choose a high-speed motor, in which case a speed reduction is required to achieve desired torque and acceleration. For such scenarios, a single speed reduction transmission system is considered. The system consists of a motor, which converts the electrical energy stored in the battery to mechanical energy. The transmission system reduces the speed by a selected reduction ratio, and there is equal distribution of torque to both the wheels. For the sake of simplicity, torque vectoring or differential system is not considered in the drivetrain model.

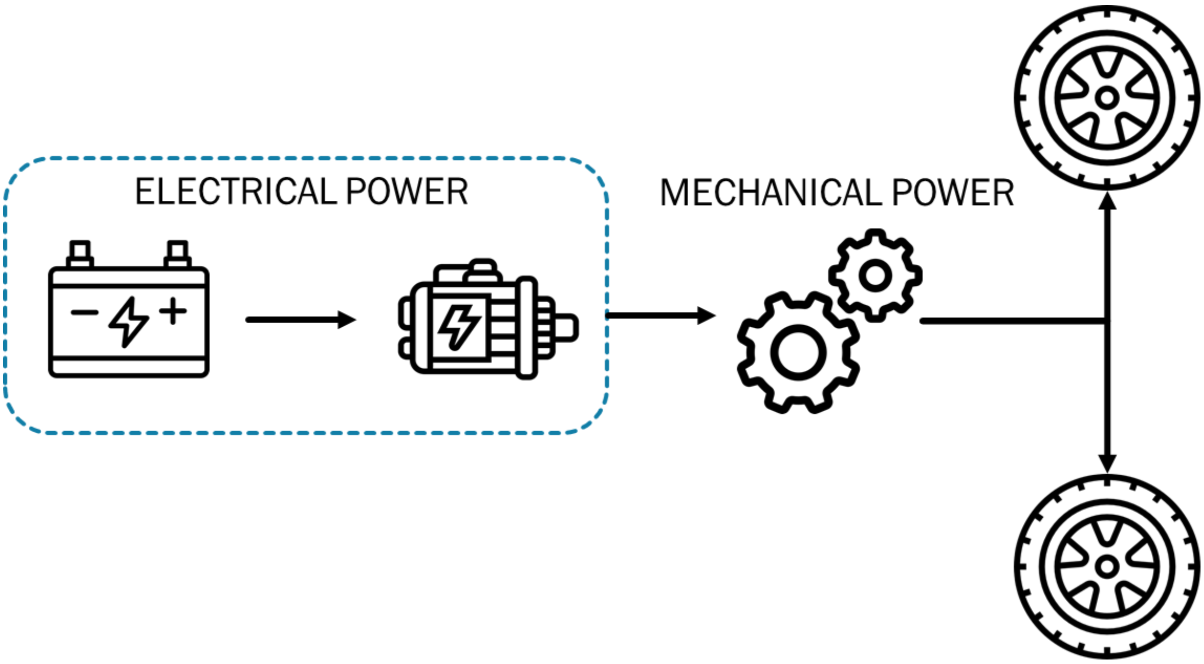


*Figure 4-11: Diagrammatic Overview of Powertrain Model*

The overall efficiency of the powertrain is calculated by:

$$n = n_{motor} * n_{drivetrain} \qquad \dots (12)$$

The reduction ratio (gr) reduces speed and increase torque as per the following equations:

$$\omega_{wheel} = \omega_{motor}/gr \qquad \dots (13)$$

$$\tau_{wheel} = \tau_{motor} * gr * n \qquad \dots (14)$$

The vehicle velocity and maximum tractive effort (pertaining to the powertrain limitations) are calculated using the respective relations:

$$v = \frac{2\pi}{60} * \omega_{wheel} * R_{tyre} \qquad \dots (15)$$

$$F_x^{wheel} = \frac{\tau_{wheel}}{R_{tyre}} \quad \ldots (16)$$

## 4.6 Final Equations of Motion

The resultant force is the tractive force minus all resisting forces:

$$F_x^{resultant} = F_x^{wheel} - (F_x^{mass} + F_x^{aero} + F_x^{roll}) \quad \ldots (17)$$

However, the tires cannot always sustain the maximum force exerted by the powertrain, and the wheels would spin due to a lack of traction. For considering this condition, the minimum value between the tire longitudinal force and resultant powertrain force is taken:

$$F_x^{effective} = \min\,(F_x^{resultant}, F_x^{max}) \quad \ldots (18)$$

Using Newton's second law, and further using the Newton-Euler kinematic equations, the acceleration, velocity and displacement of the vehicle can be calculated:

$$a_x = \frac{F_x^{effective}}{M} \quad \ldots (19)$$

$$v = v_0 + a_x * dt \quad \ldots (20)$$

$$x = x_0 + (v_0 * dt) + (\frac{1}{2} * a_x * dt^2) \quad \ldots (21)$$

Furthermore, using the centrifugal force relation, the lateral acceleration can be calculated:

$$a_y^{circ} = \frac{v^2}{R_{curvature}} \quad \ldots (22)$$

## 4.7 Brake Modelling

The brake model consists of hydraulic disc brakes mounted on all 4 wheels. A hydraulic brake system transmits force into the system by using brake fluid. The hydraulic braking system's operation is entirely based on Pascal's law, which states that the intensity of pressure inside a system closed by a liquid is always the same in all directions. The fluid is responsible for transferring pressure from the control mechanism to the braking mechanism. The mechanical forces transmitted by the driver on the brake pedal are converted to hydraulic pressure by a device known as a master cylinder in this type of braking system, and this hydraulic pressure is then sent to the final drum or disc. It rubs against the brake pads, causing the vehicle to decelerate.

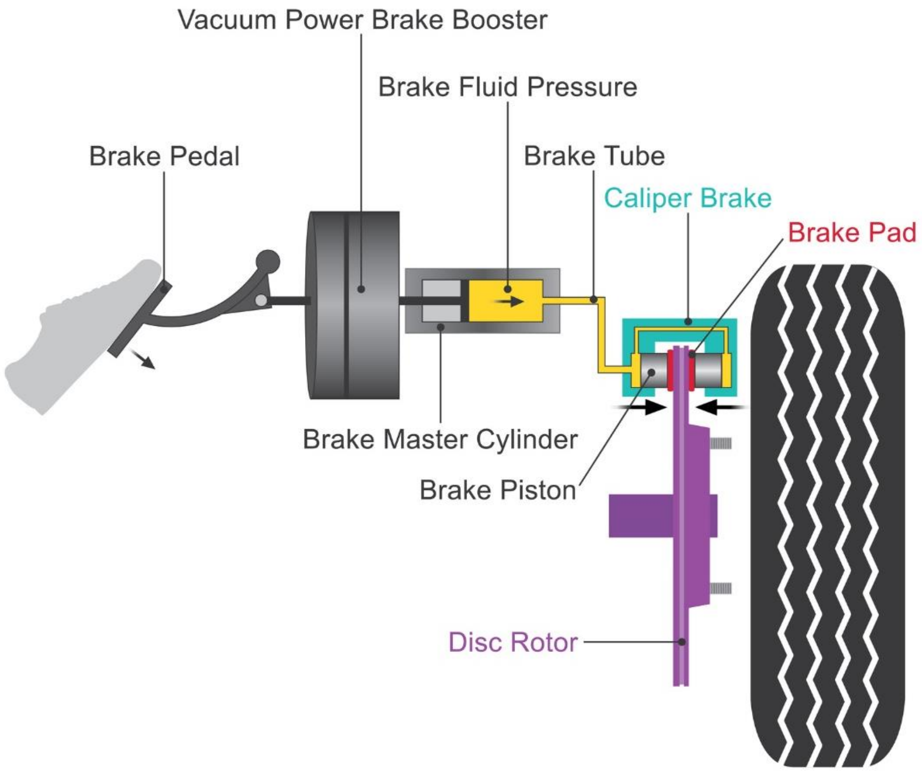


*Figure 4-12: Brake System Representation*

The area of the master cylinder and piston are calculated by the following equations:

$$A_{mast} = \frac{\pi D_{mast}^2}{4} \quad \ldots (23)$$

$$A_{pist} = \frac{N_{pist}\pi D_{pist}^2}{4} \quad \ldots (24)$$

The Brake Pedal Force as well as the Brake Pressure is calculated using the formula below [5]:

$$F_{pedal} = \overbrace{\left(2\frac{A_{mast}}{R_{pedal}}\right) * \underbrace{\left(\frac{1}{4}\frac{R_{tyre}}{\frac{D_{disc}}{2}-\frac{H_{pad}}{2}}\frac{1}{\mu_{pad}}\frac{1}{A_{pist}}\right) * F_{tyre}^{long}}_{\textbf{Brake Pressure}}}^{\textbf{Brake Pedal Force}} \quad \dots (25)$$

Though the braking force does not have a significant impact on the lap time simulation, it is included to calculated the brake pedal position, which can help in understanding how much energy can be regenerated if regenerative braking is implemented in the vehicle.

## 4.8 Power Consumption

In electric vehicles, there are a lot of losses in the electrical powertrain and supporting systems. Losses in the electrical system include I2R losses in the motor, motor controller, and battery, AC/DC conversion loss in the motor controller, DC/DC transmission losses, active power consumption by components like the battery management system (BMS), cooling system, and motor controller. [16] provides an example of power losses in the electric vehicle in form of a Sankey diagram:

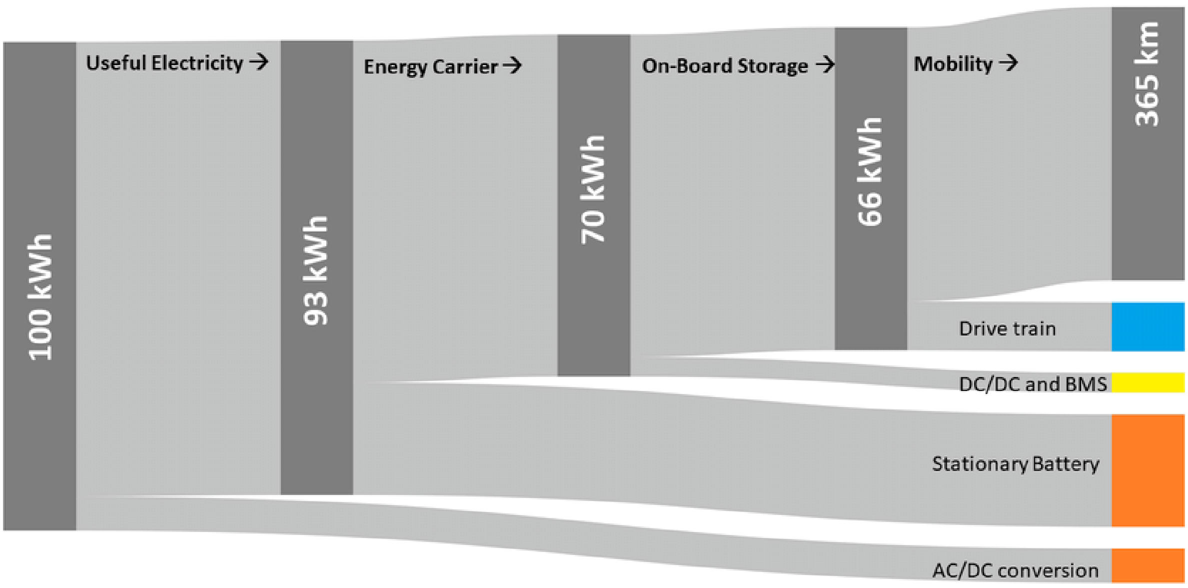


*Figure 4-13: Power Losses in an Electric Vehicle*

To find the power consumption, the overall efficiency of the powertrain is assumed. This includes all the electrical system losses. Then the force exerted by the motor at each point is multiplied by the displacement occurring in that segment, to find the power loss in the segment.

$$Power\ consumed, P = \eta_{powertrain} * F_x^{wheel} * x \qquad \dots (26)$$

The power consumed at each step is cumulatively added to obtain the total power consumption across the entire lap.

## 4.9 Inputs Considered

*Table 4-2: Inputs of LTS*

| **Parameter** | **Unit** |
|---|---|
| Total Mass | kg |
| Front Mass Distribution | % |
| Wheelbase | mm |
| Lift Coefficient | - |
| Drag Coefficient | - |
| Front Aero Distribution | % |
| Frontal Area | m2 |
| Air Density | kg/m3 |
| Disc Outer Diameter | mm |
| Pad Height | mm |
| Pad Friction Coefficient | - |
| Caliper Number of Pistons | - |
| Caliper Piston Diameter | mm |
| Master Cylinder Piston Diameter | mm |
| Pedal Ratio | - |
| Grip Factor Multiplier | - |
| Tyre Radius | mm |
| Rolling Resistance | - |
| Longitudinal Friction Coefficient | - |
| Longitudinal Friction Sensitivity | 1/N |
| Lateral Friction Coefficient | - |
| Lateral Friction Sensitivity | 1/N |
| Power Factor Multiplier | - |
| Thermal Efficiency | - |
| Final Gear Efficiency | % |
| Final Gear Reduction Ratio | - |
| Motor Peak Torque | Nm |
| Motor Peak Power | kW |
| Motor Peak RPM | RPM |

# Chapter 5

# Results and Conclusion

**5.1 Traction Model**

**5.2 GGV Plot**

**5.3 Track Map and Curvature Graph**

**5.4 Lap Time Results**

**5.5 Power Consumption**

**5.6 Validation**

**5.7 Conclusion**

**5.8 Future Scope of Project**

# Chapter 5: Results

## 5.1 Traction Model

The speed-torque-power characteristic of the motor are plotted, to understand the limitations of the motor.

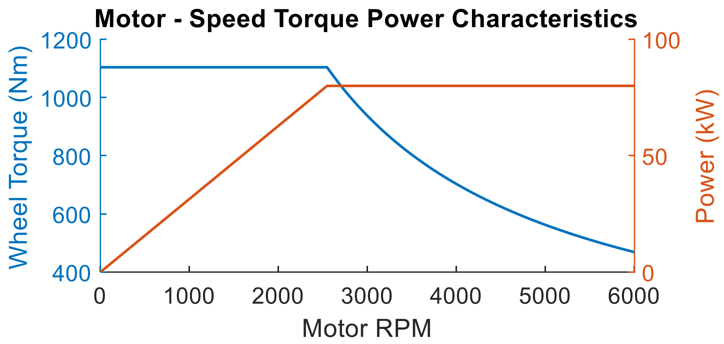


*Figure 5-1: Motor Speed Torque Power Characteristics*

The following Traction Model describes the forces acting on the vehicle, and the effective longitudinal force that the vehicle can generate.

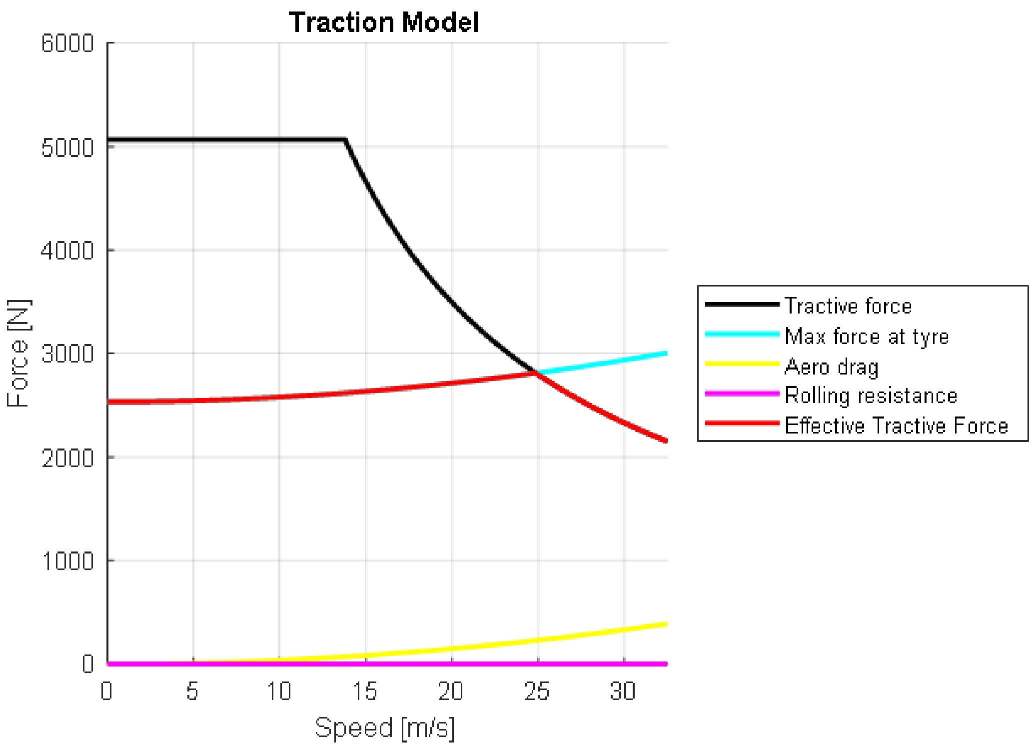


*Figure 5-2: Force Acting on the Vehicle and Traction Model*

It can be observed that even though the tractive force generated by the vehicle (denoted by black line) is very high, the tire is not capable of transmitting the force, hence the effective tractive force (denoted by red line) is lower. As the vehicle velocity increases, the downforce increase, resulting in increase in the amount of force that can be transmitted by the tire (denoted by blue line). However, at high velocity, the vehicle becomes power limited, and hence effective tractive force falls down.

## 5.2 GGV Plot

A GG diagram [3] is a graphical way to represent the performance envelope of a car, the equations of which are explained in Chapter 4. If the GG diagram is extrapolated by calculating the lateral and longitudinal accelerations for each increase in velocity, the GGV [17] diagram is obtained. The GG stands for lateral and longitudinal forces that the vehicle can withstand, and the V stands for velocity of the vehicle. The GGV diagram is used to set the maximum performance capabilities of the vehicle over a wide range of speeds.

As shown in the figure below, if the GGV diagram is looked at from the top, it is clear that the vehicle is much more limited in acceleration than in deceleration. This is because of the fact that acceleration requires overcoming the drag and rolling resistances, whereas deceleration is helped by those.

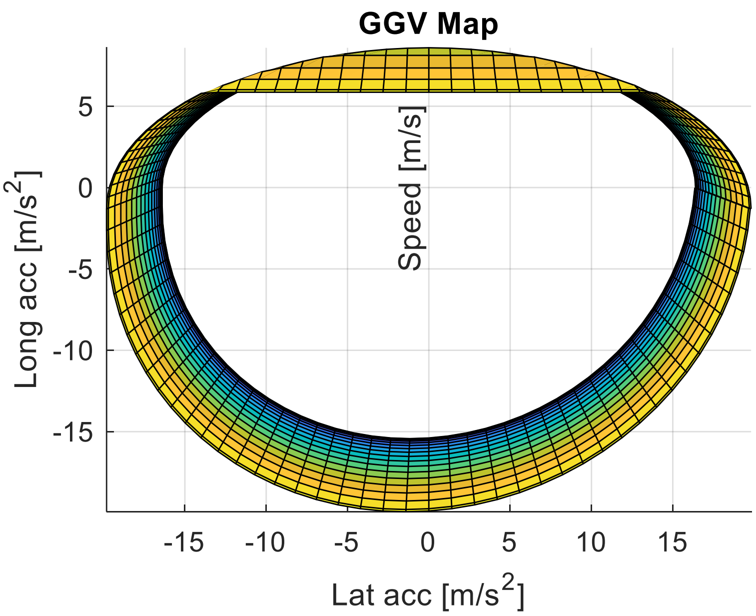


*Figure 5-3: GGV Map as seen from Top View*

If the GGV diagram is looked at from the front, as seen below, the relation between lateral acceleration with speed is seen. The lateral acceleration increases as speed increases due to increase in normal load as a result of increased downforce at high velocity, causing an increase in the capability of tires to transmit the load.

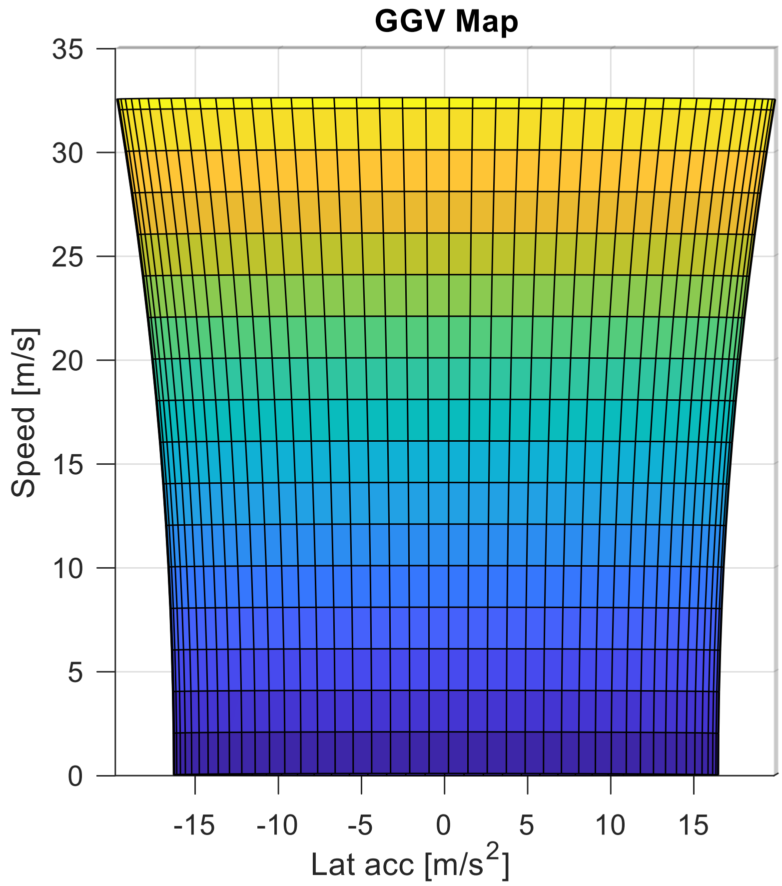


*Figure 5-4: GGV Map showing the Relation of Lateral Acceleration and Velocity*

Looking at the GGV diagram from the side, as seen in the Figure 5-5, shows the relation of longitudinal acceleration with speed. As speed increases, the drag increases, therefore the vehicle is resisted more causing a decrease in longitudinal acceleration. However, the drag, in turn, assists deceleration, that is why the diagram tilts towards the negative direction.

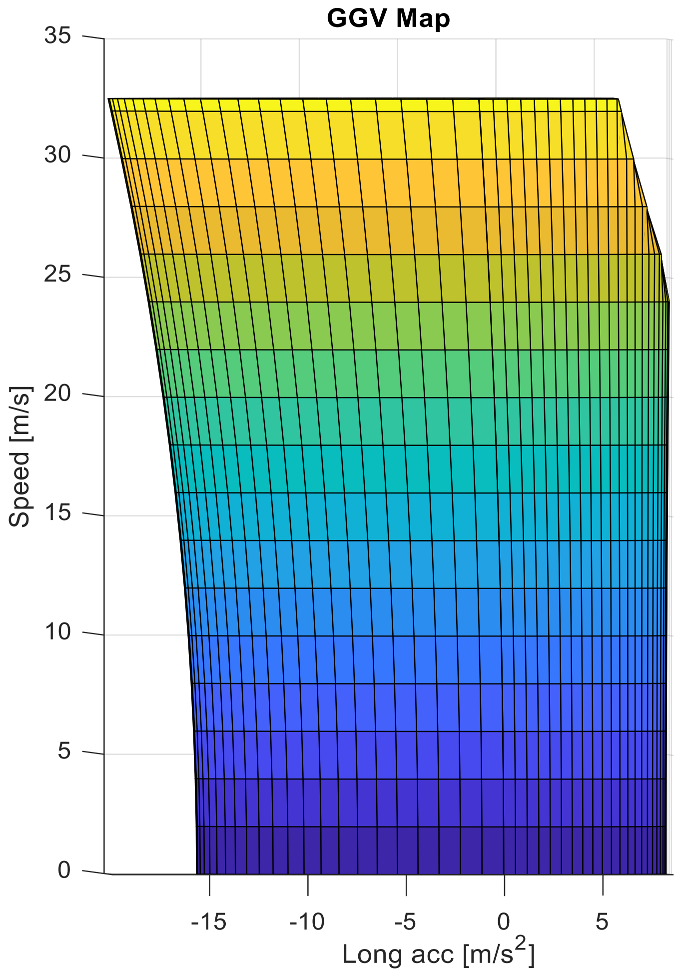


*Figure 5-5: GGV Map showing the Relation of Longitudinal Acceleration and Velocity*

## 5.3 Track Map and Curvature Graph

The track data is available on the internet, in the form of Excel files containing the linear distance and corresponding radius of curvatures. Some data also provide data related to the banking, inclination and elevation of the track. For our purpose, we used the data for the Circuit de Spa-Francorchamps, motor-racing circuit located in Stavelot, Belgium. This data is taken, and the track map is created as shown in Figure 5-6.

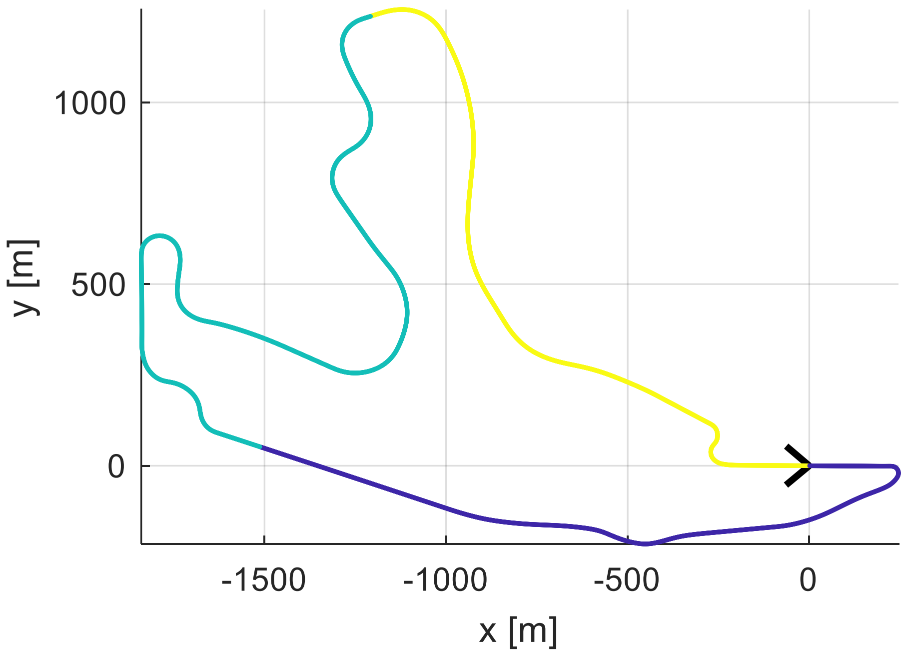


*Figure 5-6: Track Map divided into Sectors*

The track is discretized using the algorithm from [18], and the radius of curvature, inclination, and elevation of each discrete segment is calculated. The apexes are then located at points of maximum radius of curvature between 2 straights. The outputs of these can be seen in Figures 5-7, 5-8, and 5-9.

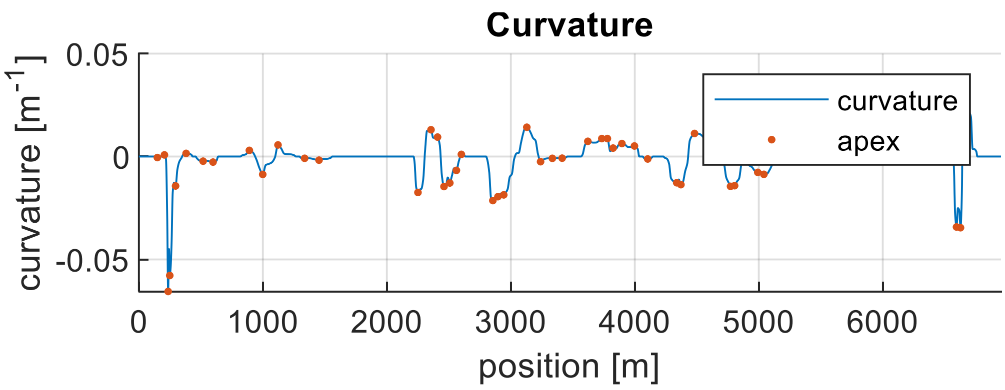


*Figure 5-7: Curvature of the Track Corners as a Function of Distance*

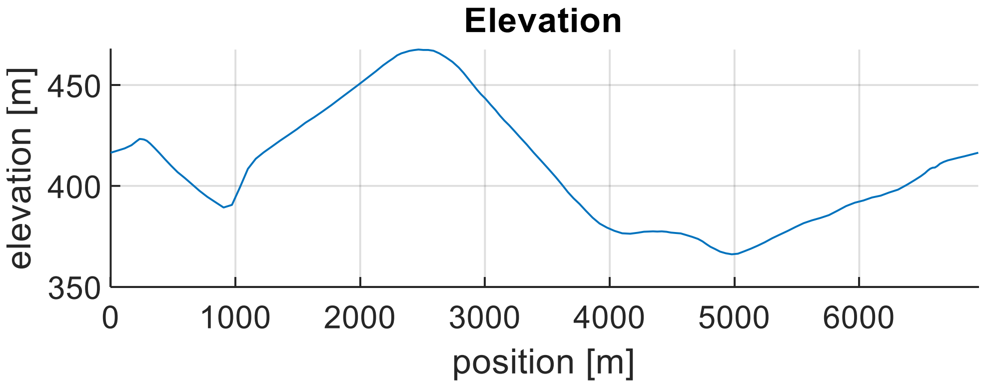


*Figure 5-8: Elevation of the Track Corners as a function of Distance*

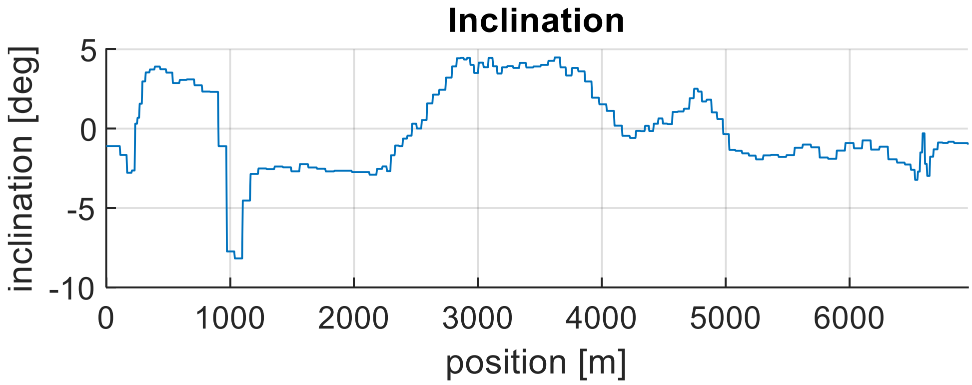


*Figure 5-9: Inclination of the Track Corners as a function of Distance*

## 5.4 Lap Time Results

Figure 5.10 following is a screenshot of the output of LTS, where the lap time (in seconds), power consumption (in kWh), and sector times (in seconds).

```
Simulation completed.
Laptime:  217.109 [s]
Power Consumption:  2.990 [kWh]
Sector 1: 66.058 [s]
Sector 2: 85.588 [s]
Sector 3: 65.371 [s]
Plots created and saved.
```

*Figure 5-10: LTS Output*

Figures 5-11, 5-12 and 5-13 show the relations of speed, longitudinal and lateral accelerations, acceleration and brake positions as a function of distance travelled.

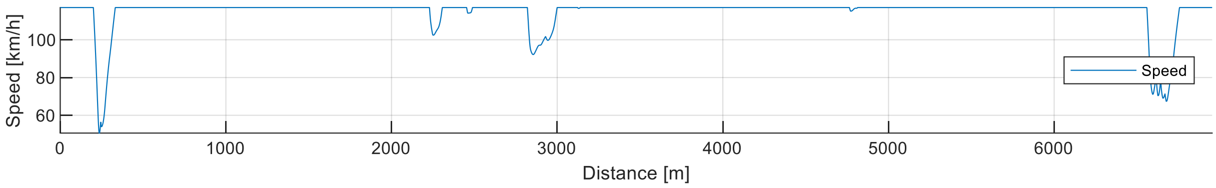


*Figure 5-11: Vehicle Speed as a Function of Distance*

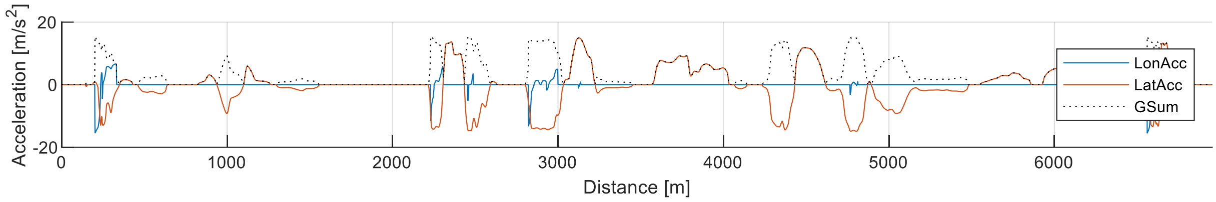


*Figure 5-12: Lateral, Longitudinal and Combined Acceleration as a function of Distance*

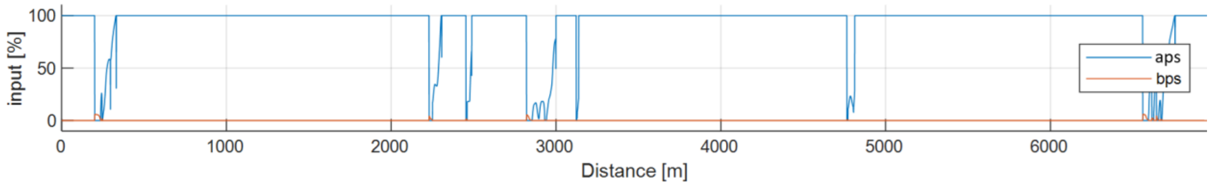


*Figure 5-13: Acceleration Position Input and Brake Position Input (in % of pedal travel) as a function of Distance*

## 5.5 Power Consumption

As the vehicle is power limited for a lot of time, the accelerator pedal needs to be fully pressed to achieve maximum speed. Thus, the power consumption is pegged to the maximum value for a lot of segments. However, when navigating through the turns, with the accelerator pressed halfway, it is observed that the power consumed is lower. Figure 5-14 shows the relation between the power consumed (in kWh) in each segment as a function of the distance travelled.

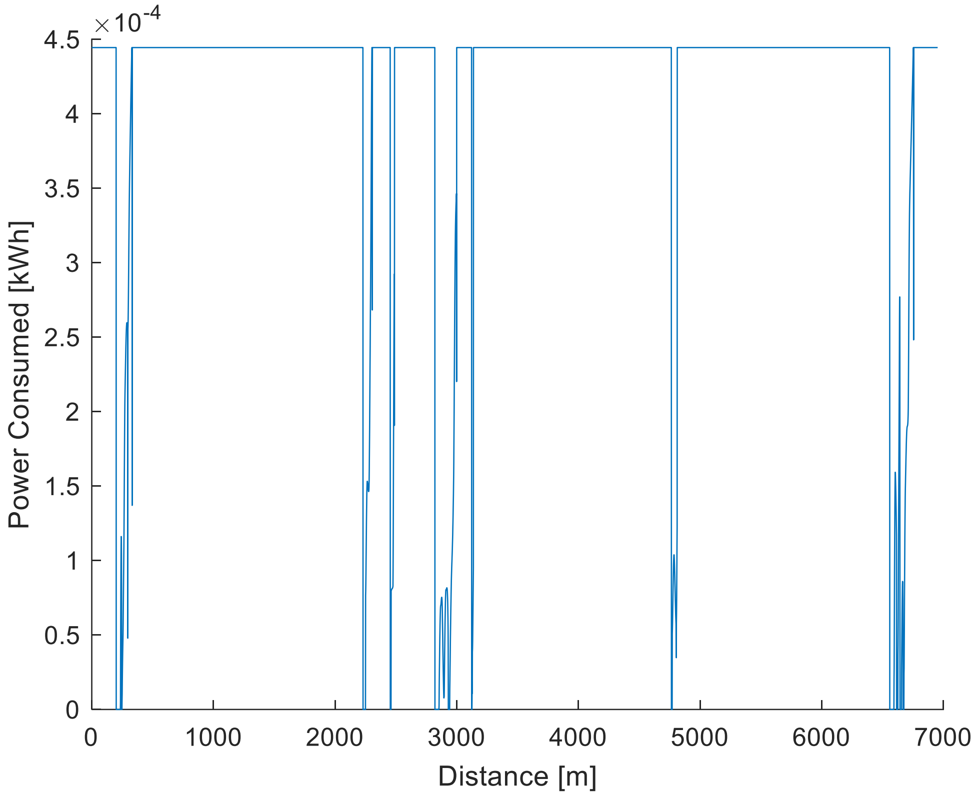


*Figure 5-14: Power Consumption in Each Discrete Distance Segment*

## 5.6 Validation

To ensure that the output data is accurate, our LTS was tested with a commercially available LTS package called as Optimum Lap. Figure 5-15 shows a comparison of lap times in both outputs.

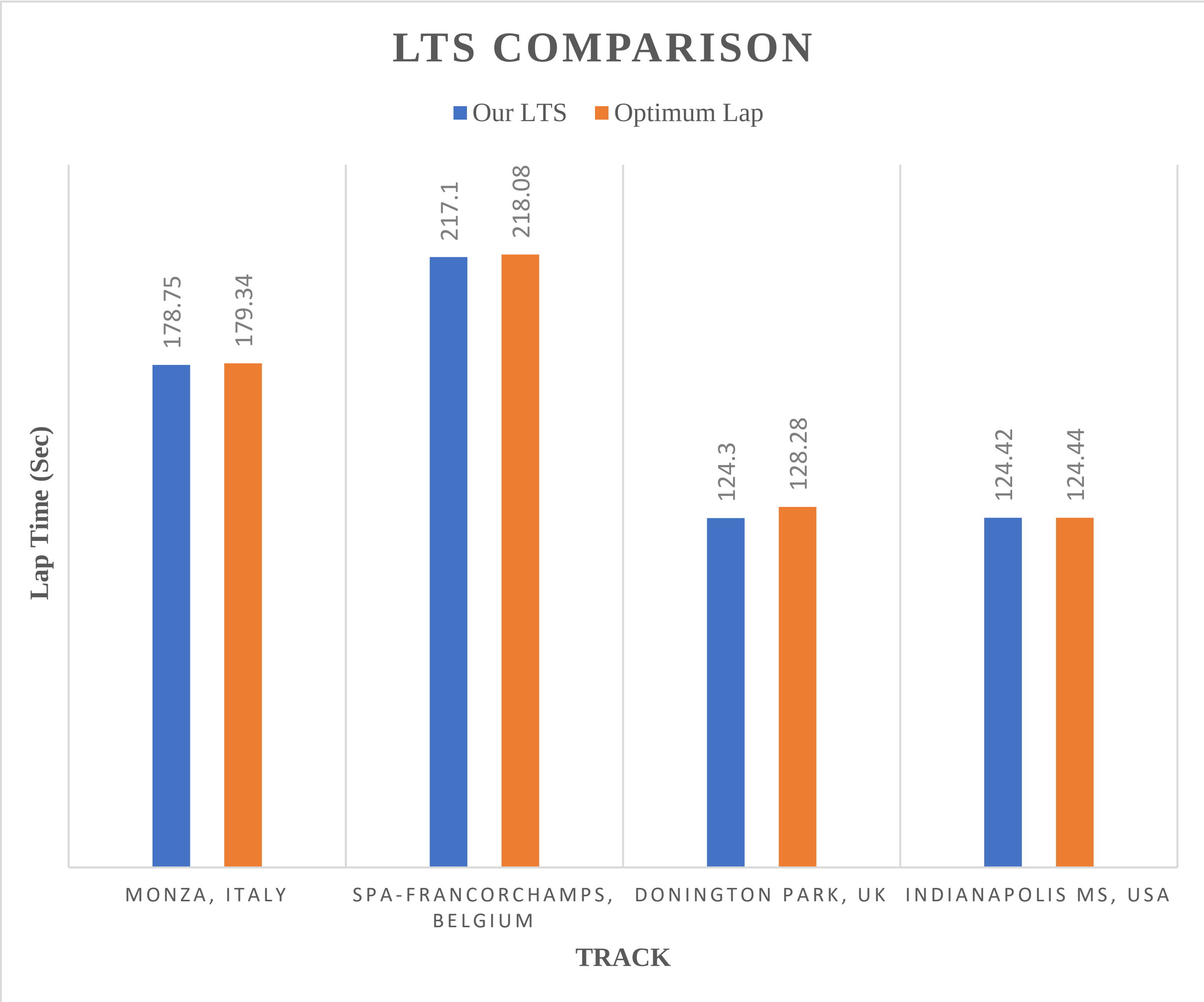


*Figure 5-15: Comparison of Lap Times against Commercially Available Optimum Lap Software*

It can be observed that there are very slight differences, with the maximum difference being approximately 3% in case of Donington Park. This proves that the output we achieve is correct and reliable.

## 5.7 Conclusion

As a simpler and easier alternative to predicting vehicle performance on a race track, a quasi-static, bicycle model lap time simulator was developed. It was then tested against various other approaches in this development to see which one simplified simulation the most.

The simulator was composed of a powertrain model containing the motor torque curve and a single gear ratio, an aerodynamic model made from constant drag and downforce coefficients (with some sensitivity factors), a chassis model that includes the vehicle weight and static weight distribution, and a tire model with the wheel radius and the longitudinal and lateral friction coefficients of the Pacejka 2002 [10] as function of vertical load.

Two approaches to track modelling were tested. It was observed that distinguishing between straights and corner segments is better than modelling all segments as corners, even though it yields similar results because of simplicity of procuring track data.

The variation of the motor's peak power as well as the reduction ratio has a significant impact on the resulting performance. This led to the conclusion that the source of longitudinal acceleration that has the greatest impact on the vehicle's top speed is the powertrain propulsion force.

The energy consumption is successfully modeled. The output matches the hand calculation, but proper testing with an actual electric vehicle, which is not possible at present, would provide adequate data for the validation of energy consumption.

## 5.8 Future Scope of the Project

Simulation tool implementation must always be accompanied by testing for validation purposes. To validate a Lap Time Simulator, the trajectory of a track where the vehicle will be tested must be modelled and the driver must be trained and certified to operate at maximum accelerations. It is also necessary to understand the evolution of the energy storage system's efficiency over several laps and possibly implement this variation in the Lap Time Simulator.

Furthermore, the model can be incorporated in a Graphical User Interface for easier and faster usability.

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# Conferences and Publications

Paper entitled "**Review: Development of Lap Time Simulation Software to Drive EV**" is presented at the "**MAS 16th International European Conference on Mathematics, Engineering, Natural & Medical Sciences**" by *Soham Raju Khairnar, Abhishek Amit Kolekar, Parth Prasad Paranjpe, and Sarvesh Rajendra Pawar* under the guidance of *Mr. Amol Shahaji Shinde*.

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