Tire Modelling using Pacejka Tire Model (Lateral Model)

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1. Motivation:

The development of a vehicle depends on the accurate representation of the system on a software. Apart from the mathematical representation of the powertrain and the chassis, the most important component of a vehicle, that governs the performance, is the tire. In order to replicate the behaviour of the tire using mathematical equations, it is important to carry out physical testing and then use regression methods to create a representative Tire Model.

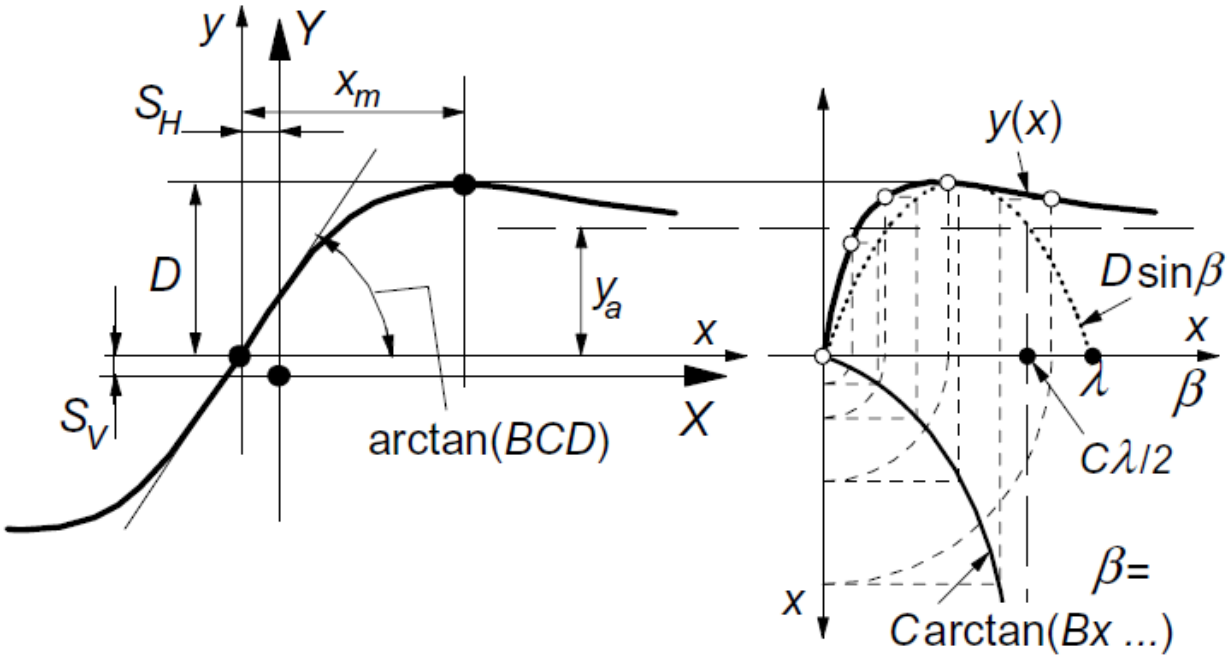
Through this project, I intend to showcase my learning of Pacejka Tire Model and how I used it to create a MATLAB Application. The output of this project is utilised in creating a Lap Simulator using MATLAB & Simulink.

2. Pacejka Tire Model (My Understanding):

In 2017, working as a suspension member for Formula Student, I was choosen to carry out Tire Modelling. Having no idea about the topic, I started my research on the internet and if I were to explain the process, it would be as follows:

Tire modelling is the processes of finding the best possible curve that fits the data of the forces generated by the tyres to be used for simulations. In order to test the tire and accumulate the data of the forces, Outdoor (On track) and Indoor (On machine) methods are used. Outdoor method involves use of a trailer pulled by a car. The trailer has a system which holds the tire to be tested and keeps it attached to the ground. The data received is then utilised to obtain the tire model. An advantage is, that with this method the exact relation between the road and tyre can be recorded. On the other hand, indoor methods are based on machine testing. These machines have a belt that is a replication of the road. The belt rotates over drum that is driven by the motor. This method provides better control over the conditions of the tyre and the surrounding except for the fact that the belt is not same as the road surface.

The first model that I came across was the Pacejka Tire Model by Hans B. Pacejka. This is a widely used equation to represent the behaviour of a tire mathematically. Since the discovery of the model there have been modifications to this model but the basic equation still stands the same. The general form of the formula that holds for given values of vertical load and camber angle reads:



$$y = D\sin[C\arctan\{Bx - E(Bx - \arctan Bx)\}]$$

with

$Y(X) = y(x) + S_V$

$x = X + S_H$

where

Y: output variable *Fx*, *Fy* or possibly *Mz*

X: input variable tanα or κ

and

B stiffness factor

C shape factor

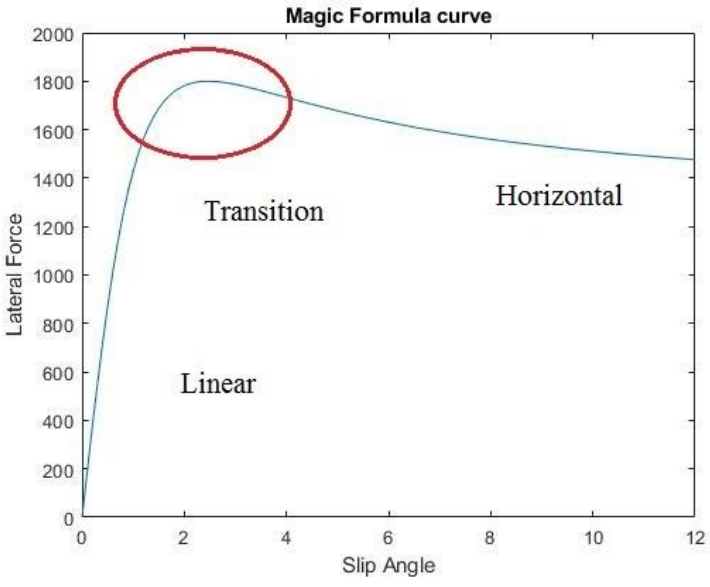
D peak value

E curvature factor

S_H horizontal shift

S_V vertical shift

The above defined variables are iterated to obtain a better fit. In order to find the values of these variables, regression methods have to be used. Before using the regression techniques, it is important to understand the effects of these variables on the curve. The *Magic Formula y(x)* typically produces a curve that passes through the origin *x* = *y* = 0, reaches a maximum and subsequently tends to a horizontal asymptote. For given values of the coefficients *B*, *C*, *D* and *E* the curve shows an anti-symmetric shape with respect to the origin. To allow the curve to have an offset with respect to the origin, two shifts *SH* and *SV* have been introduced.



As explained earlier, my task is to model the Hoosier FSAE tyres so as to aid the designing of the vehicle. Being a college project, it is not possible for a student team to raise the funds required to carry out tire testing independently. Fortunately, FSAE Tire Testing Consortium along with Dr. Kazprak Milliken have been providing the tire test data for Formula Student teams for a (fairly moderate) life-time membership fee. Using the data provided by the TTC, I was able to create a tire model.

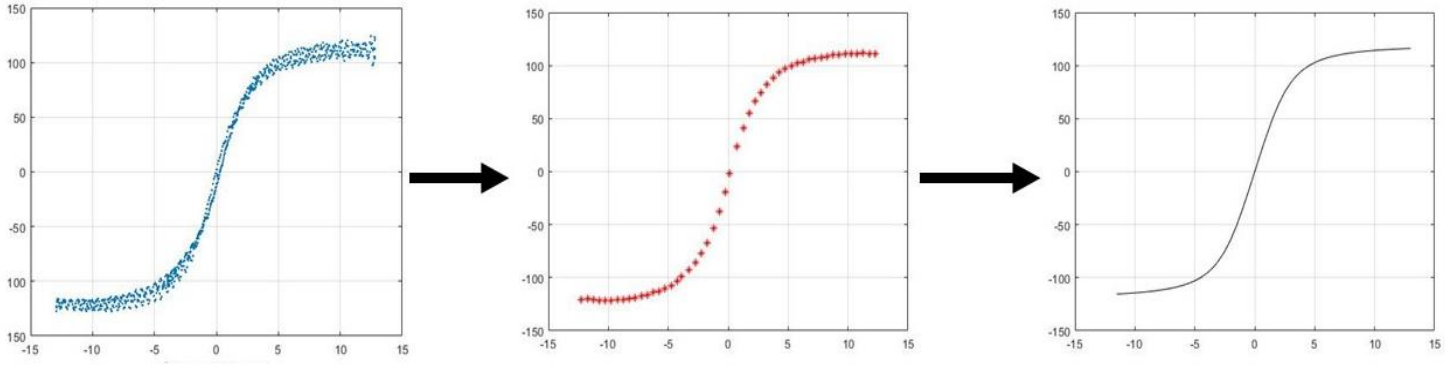
3. The Application:

The algorithm that I used in creating the model is as follows:

i. Separating the data based on the test parameters (i.e. Load, Pressure & Inclination Angle)

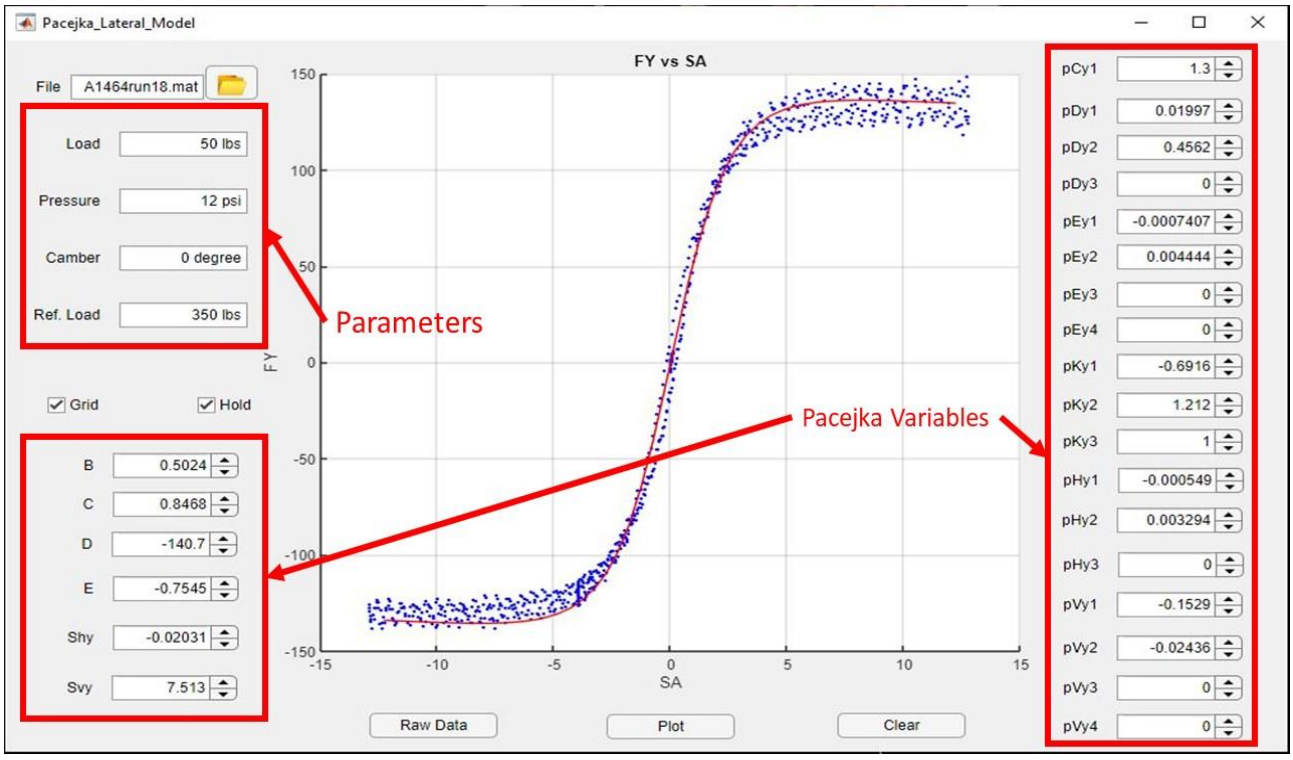
ii. Forming the clusters to visualise the rough path of the curve

iii. Initialise the variables and using Machine Learning to minimise the error.



Step 1 Step 2 Step 3

In the figure below, the start screen of the application is shown. The application provides the freedom to the user to adjust the parameters of the Pacejka Tire Model to change the profile of the curve.



4. Skills Gained:

- Data Analyses
- Regression
- Machine Learning
- Problem Solving

5. Work ahead:

Using this application, it will be easier to create a Look-up Table that can be used to simulate the tire. Using this table, I intend to create a complete Lap-Time Simulator which can accurately depict the behaviour of a vehicle around a circuit. Using the simulator it will be easier to make the setup changes and improve the performance of the vehicle.