DOCTORAL PROGRAM IN ENGINEERING SCIENCES AT ITESO

VEHICLE DYNAMICS AND CONTROL SIMULATION PLAYGROUND: THE USER MANUAL

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Abstract

This user manual provides documentation for a Simulink and MATLAB model designed to support students and researchers in the fields of vehicle dynamics, control systems, and electric motor applications. The model is publicly available to facilitate learning, experimentation, and validation of custom models or control strategies. By sharing this resource, we aim to contribute to the advancement of clean and intelligent mobility, particularly in the development of electric and autonomous vehicles.

I. INTRODUCTION

This project is a MATLAB/Simulink model that simulates the longitudinal and lateral dynamics of a vehicle, incorporating electric motors as the main actuators. The goal is to provide a flexible and modular environment for studying and developing controllers for electric and autonomous vehicles.

It might feels frightening to face for the very first time to vehicle dynamics or control theory applied to it. A lot of math, many physical models that maybe don't fully understand at the first explanation. But don´t worry, you are not alone. You will discover that once the fear is gone, this is an amazing and fascinating topic to dive in.

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Now, getting to the topic, let me warn that this is not a complete model that contemplates all known science about the vehicle. At the moment of writing this, it is only an introductory model, but the intention is to grow it and introduce more dynamics making it more precise. However, maybe the best strategy is to build different versions of the model, because you don't always need the whole complexity; sometimes you only need a fraction or a simplified model. We will see the best approach along the time.

This model, at this time, is intended to comprehend the dynamics involved in vehicle displacement. That is, the physical forces and phenomenons acting on the vehicle when we drive it from one place to another. Don't forget that this is a 1 ton, or more, of iron rolling over rubber on asphalt, and many things occur in that process that we are not aware of.

Lets start with few definitions and concepts: **Vehicle Dynamics**: refers to the study of how vehicles move in response to driver inputs, road conditions, and external forces. It involves multiple subsystems, including longitudinal, lateral, and tire dynamics. In Fig. 1 shows to the left, the longitudinal dynamics and to the right the lateral dynamics which are described below.

Longitudinal Dynamics: Deals with vehicle motion along the forward/reverse direction. Involves acceleration, braking, and traction forces. Key factors: engine power, braking force, rolling resistance, and aerodynamic drag.

Lateral Dynamics: Governs the vehicle's motion side to side (yaw, sway). Determines steering response, cornering, and stability. Key factors: steering angle, tire slip angle, and centrifugal force.

Tire Dynamics: Describes how tires generate grip and forces on the road. Includes tire slip, friction, and deformation under load. Governed by models like the Pacejka "Magic Formula". These dynamics together define a vehicle's handling, stability, and safety in various driving conditions.

Now, as in the case of autonomous driving, we want the vehicle to follow a certain reference path. In this regard, a method that was popularized in the DARPA Grand Challenge (2004, 2005) and Urban Challenge (2007) was so called **waypoints** which are predefined reference points used in navigation to guide a vehicle along a specific path. In the context of autonomous vehicles, waypoints represent positions in 2D or 3D space that the vehicle follows to reach its destination. We have global waypoints: Large-scale path planning waypoints, often obtained from a GPS map.Define the general route from the start to the final destination. Local Waypoints: Short-range points used for fine control and path smoothing. Generated dynamically based on sensor data and road conditions. Each waypoint typically includes: Position (x, y, z), Defines location in world coordinates. Orientation (yaw, pitch, roll), Defines heading direction. Velocity or Time Stamp, Used for trajectory planning.

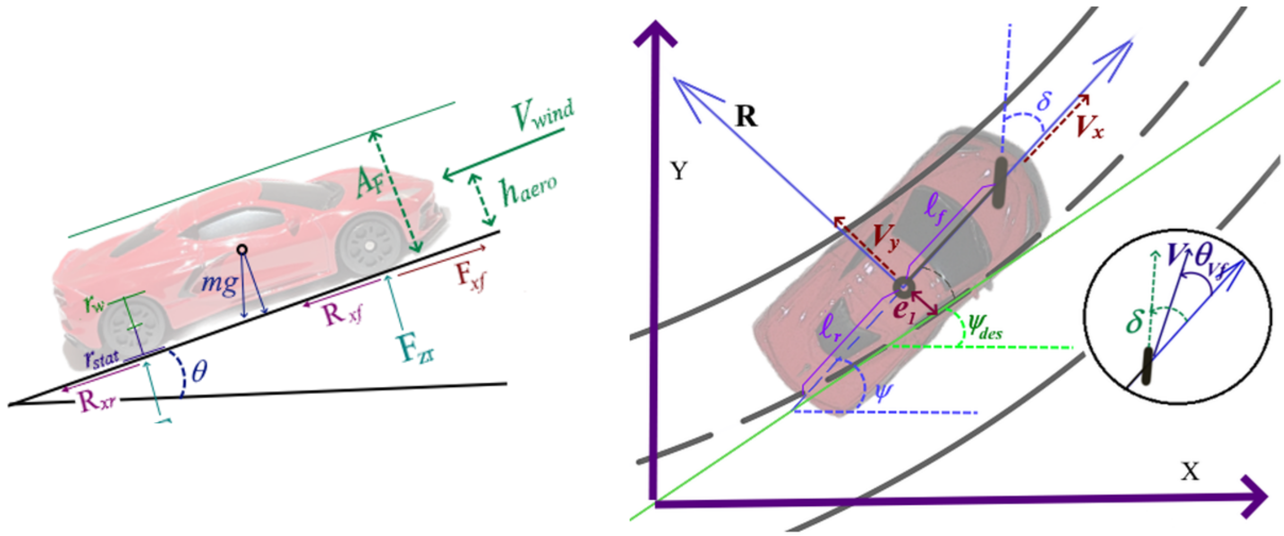

Figure 1: Typical scheme of the longitudinal and lateral dynamics

II. QUICK START

The intention of this section is to guide you to perform the first simulation of the vehicle and show you the first insights you can get at first hand.

Download the repo in Github from [1]. Fig. 2 shows the root directory of the repository. For now, we will be interested only in the highlighted directory named **./VehicleModel**. Go inside.

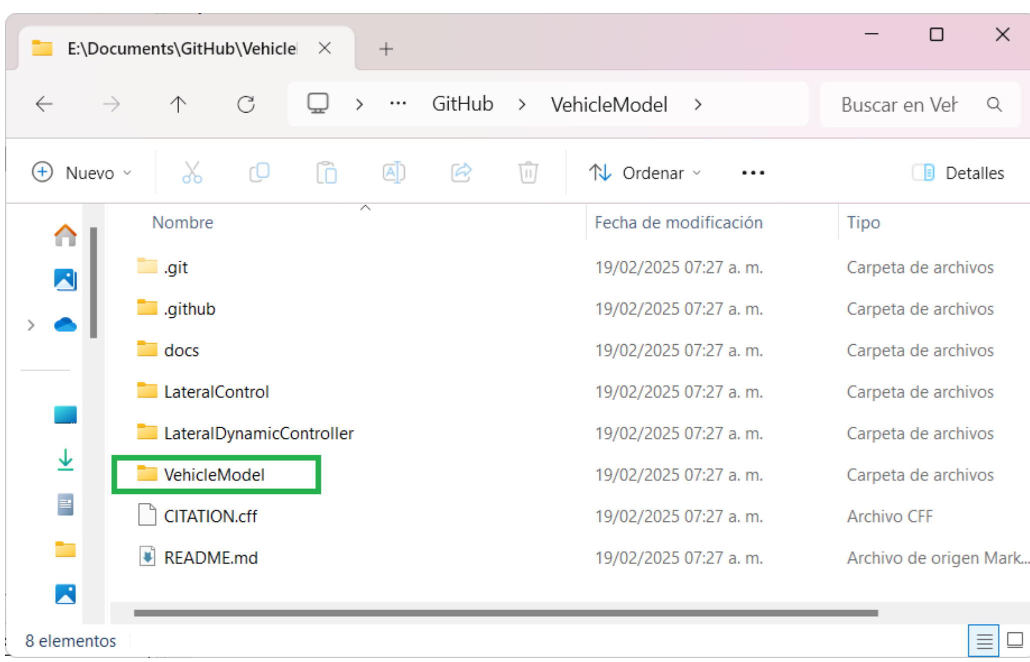

Figure 2: Root folder in the repository.

In Fig. **??** you can see the files within. the marked files are the ones we are interested for the moment. Let me explain you them. the most important files is **LongLatDriveline.slx** since this is the main simulink model where our virtual vehicle is running. The file **VehicleData.sldd** is a Simulink data file that contains all parameters we can tune, according the characteristics we want for our vehicle. Finally, the file **waypoints.mat** constains the route that our vehicle will follow; this route can be modified, but we will see how to do that, further in the document.

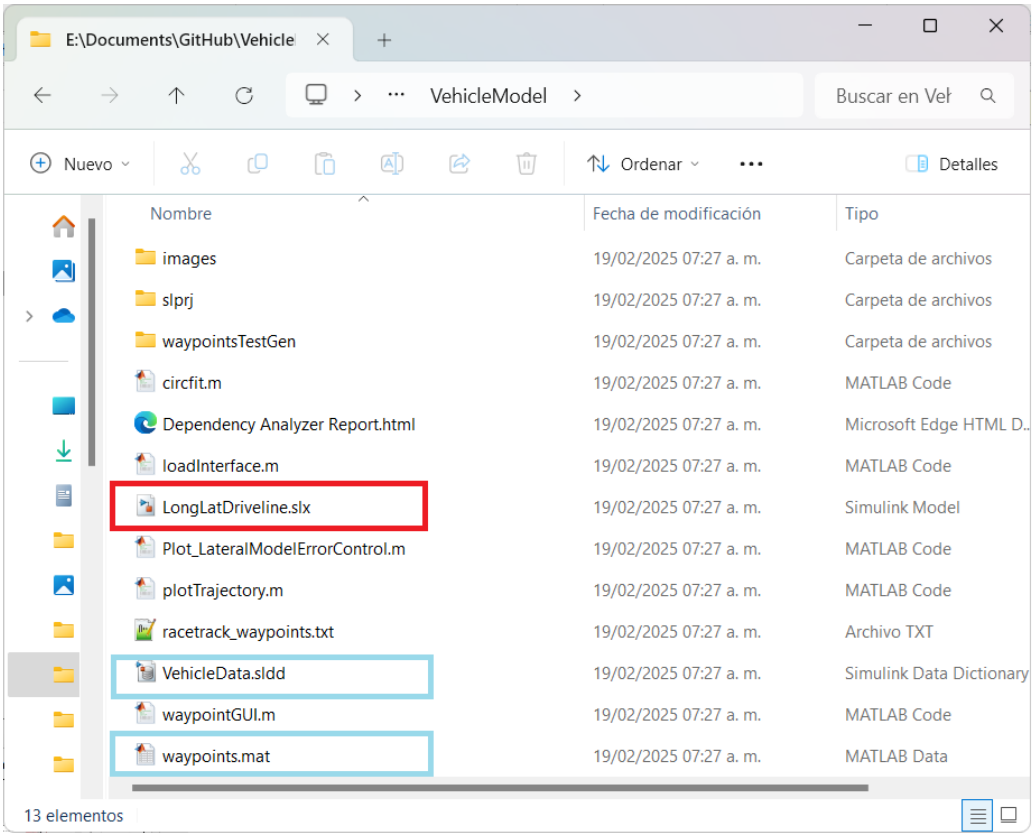

Figure 3: Main working files for simulation.

Open Matlab and select **VehicleModel** as working directory as in Fig. 4 and double click the file **LongLatDriveline.slx**

When the Simulink model is open, it will appear a window called *Initial conditions* as shown in Fig. 5. This window will contain, by default, the initial position and initial orientation detected in the way-point file **waypoints.mat** located in the root directory. If you want to use this initial state of the vehicle, just click in ”Accept”. However, you can change it. It is recommended not to change them too far from the detected position because this might cause the lateral controller get lost and never find the route. If you don’t want to change any previous initial conditions setting, just close the window.

The open model will have the appearance as shown in Fig. 6

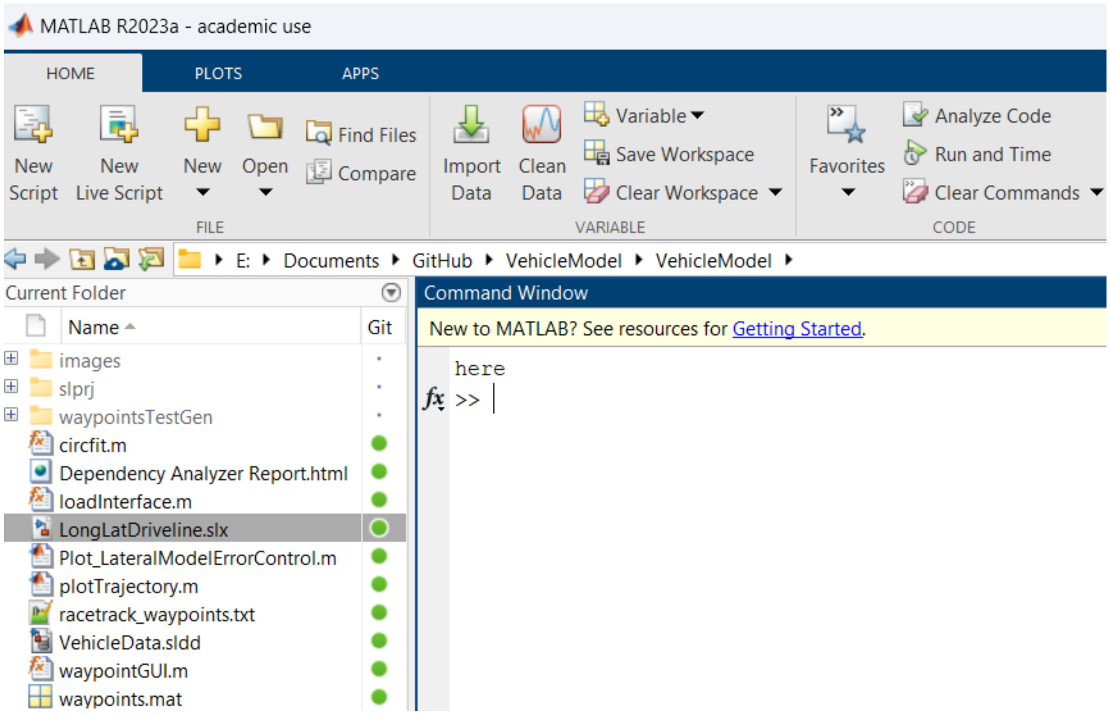

Figure 4: Working folder in matlab.

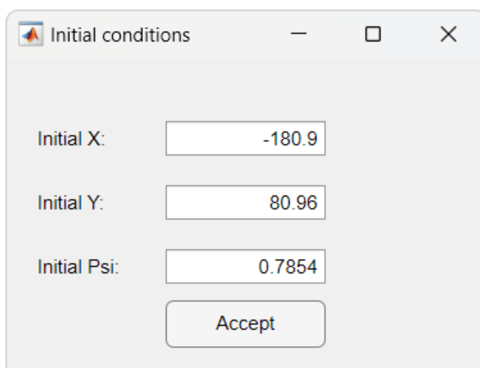

Figure 5

The Model is divided in two sections. The upper part corresponds to the longitudinal dynamics and the lower part are the lateral dynamics.

Now, let's verify that we have all the settings needed for our first run. For this first run, we won't use any electric motor as actuator or power element. So, let's verify that we have the simplest configuration.

First, in the Simulink window, locate the "*Model Settings*". A common place where to locate is shown in Fig. 7

Now, be sure that the settings are as follows in Fig. 8. The important configurations are in the

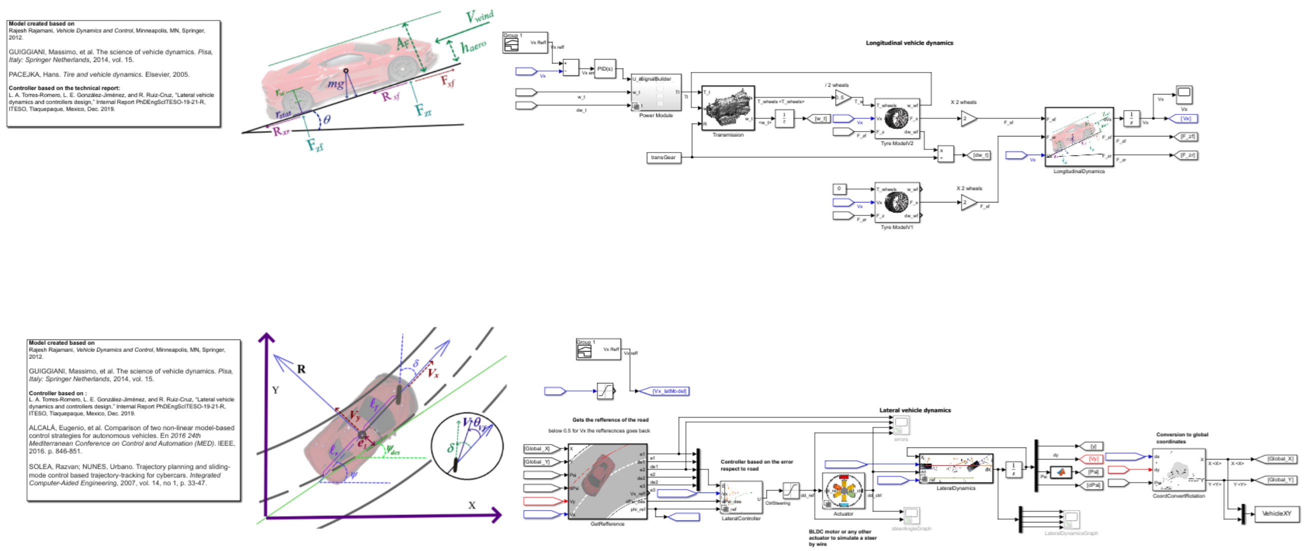

Figure 6: Simulink main model.

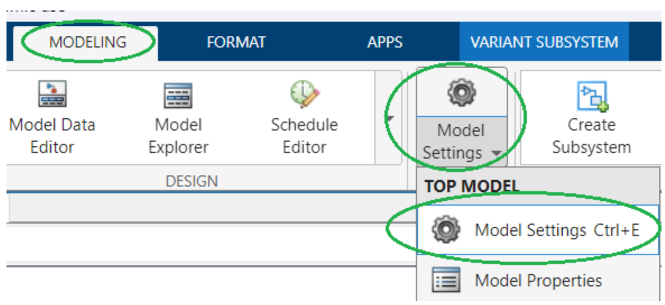

Figure 7: Model settings location.

solver section. *Type* = "Fixed-step", *Solver* = "Auto", and *Fixed-step size* = 0.002

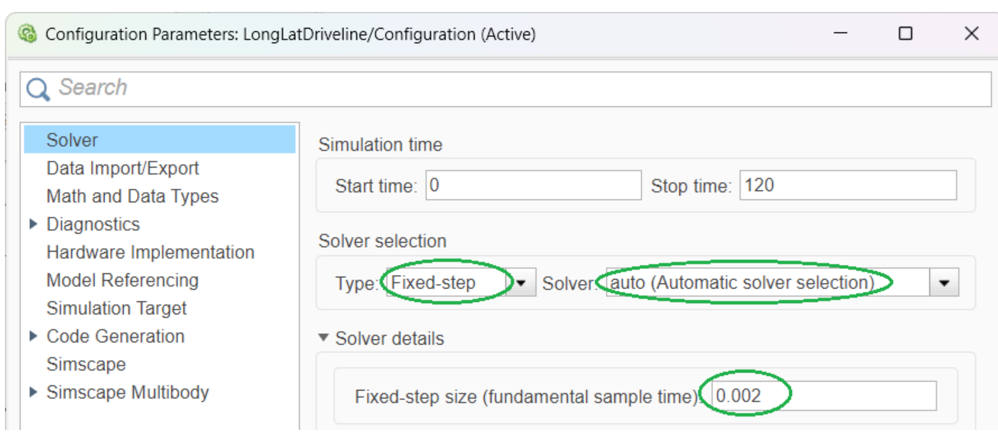

Figure 8: Model settings.

now, let's verify the variant blocks configurations. For longitudinal dynamics be sure that the power module block is *Direct signal (Signal builder)* and for the lateral dynamics, the lateral controller block, the controller *Ackermann error feedback* control is selected, for the actuator block, *No actuator* shall be selected, and for the LateralDynamics block, *simplified model* shall be selected. Figs. 9 and 10 show these blocks.

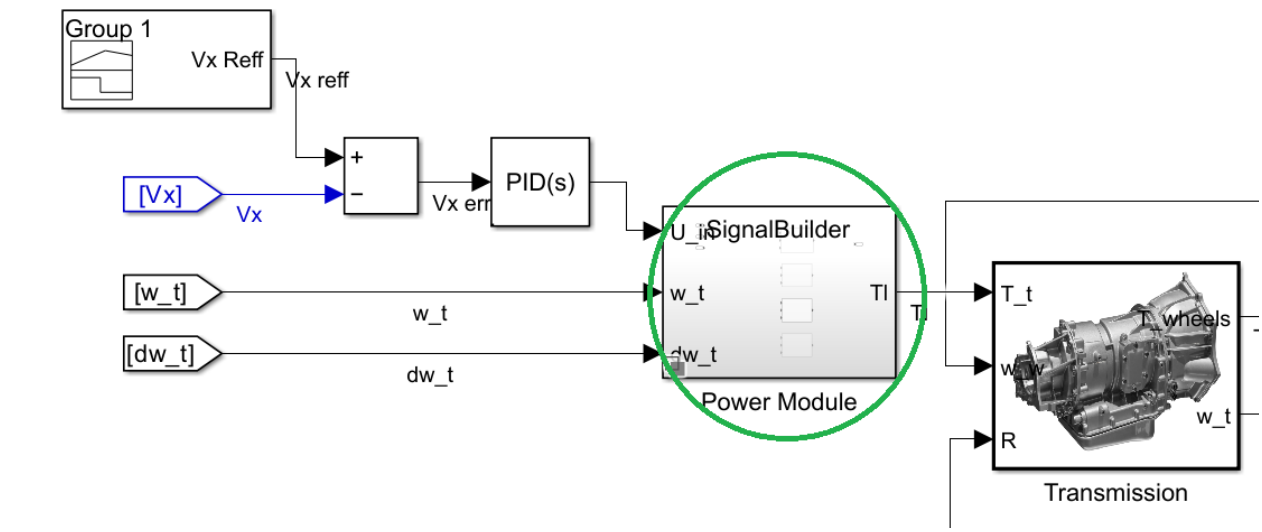

Figure 9: Power block.

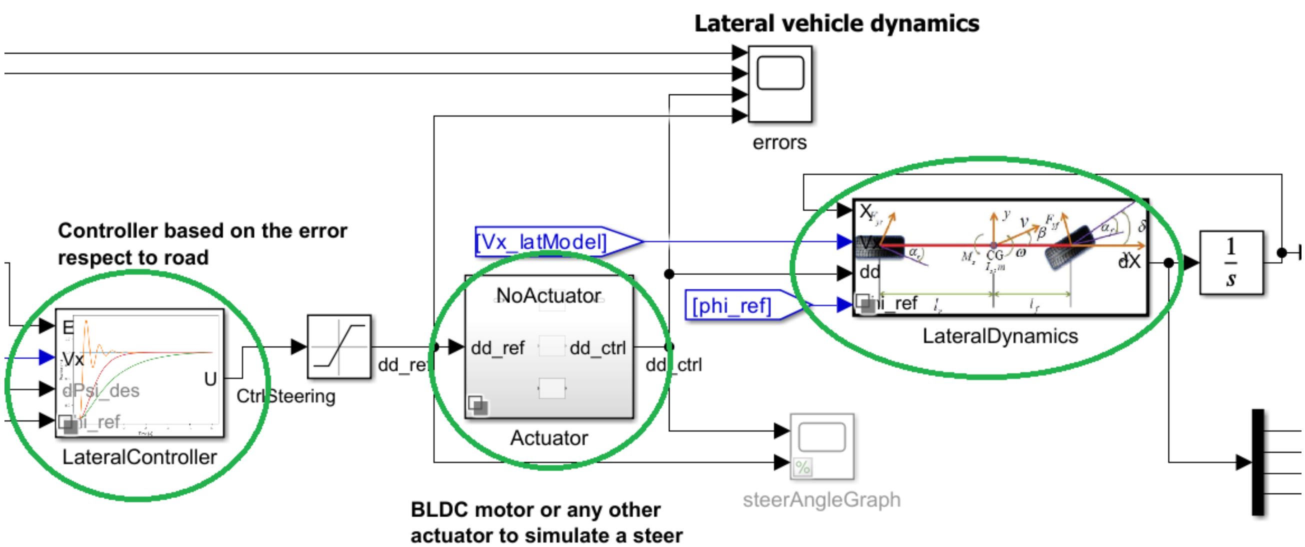

Figure 10: Lateral blocks selection.

In this point, we have everything ready. Just click run and wait until the simulation finalizes. When the simulation ends, if the vehicle completed the task, a pop up message with the message ”You have arrived” appears, and a window with the trajectory appears too as in Fig. 11. Figs. 12 and 13 show and example of the data you can get from the simulation. for example, how the vehicle is accelerating, or the errors respect the road, in this case, Fig. 13 shows e1 and e2 that correspond to the lateral error and orientation error. From here, your next steps could be running several times this simulation, putting several scopes throughout the model to see the behavior of the dynamics. You can explore further the model, change dynamic blocks, actuators, controllers, etc. In later chapter you can see how to do so. It is required a brief explanation modifying these elements because you will need to modify some configurations of the simulation in order to get good results, otherwise you might get errors or incorrect results; however, in this quick start you have the basic to start up.

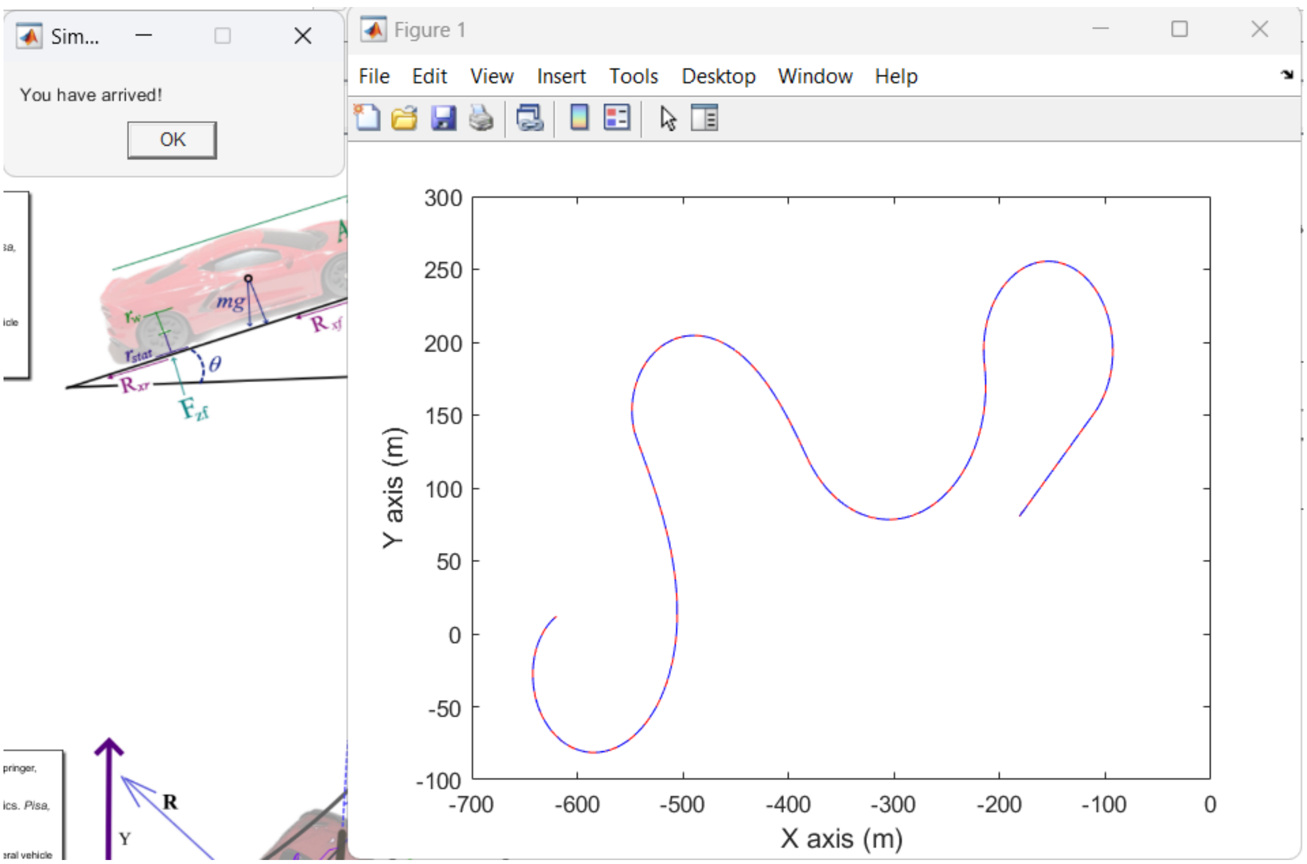

Figure 11: Trajectory and message of completed task at the end of the simulation.

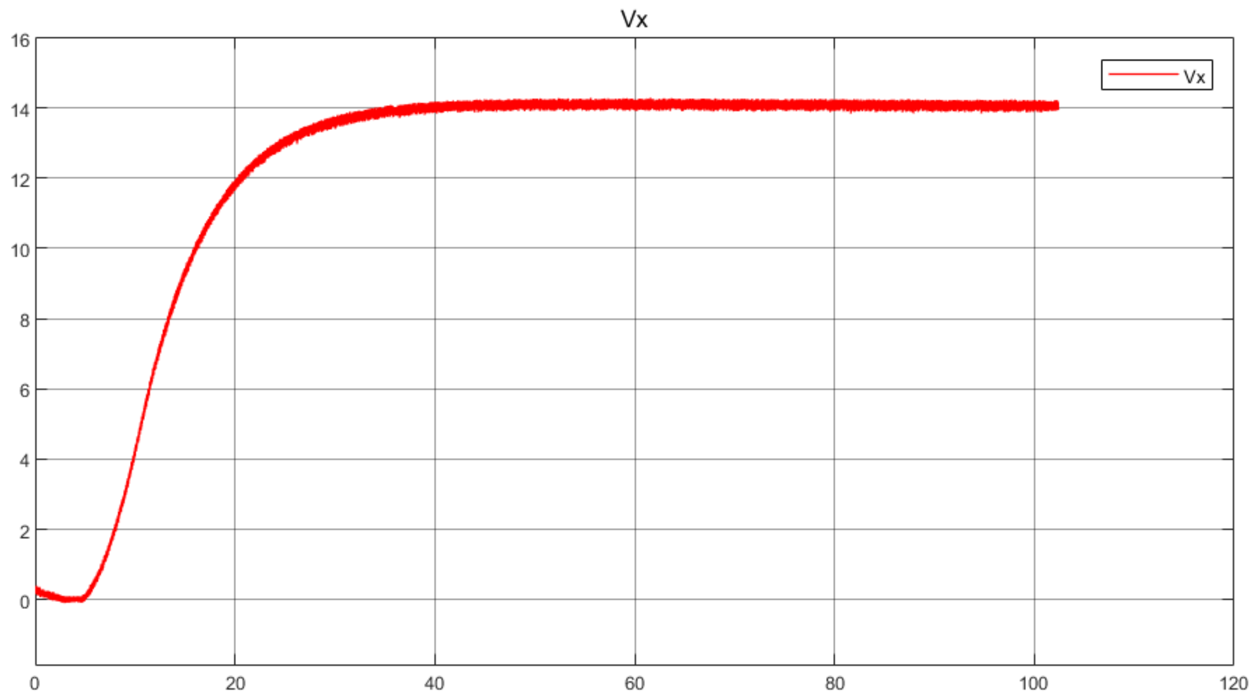

Figure 12: Longitudinal velocity profile.

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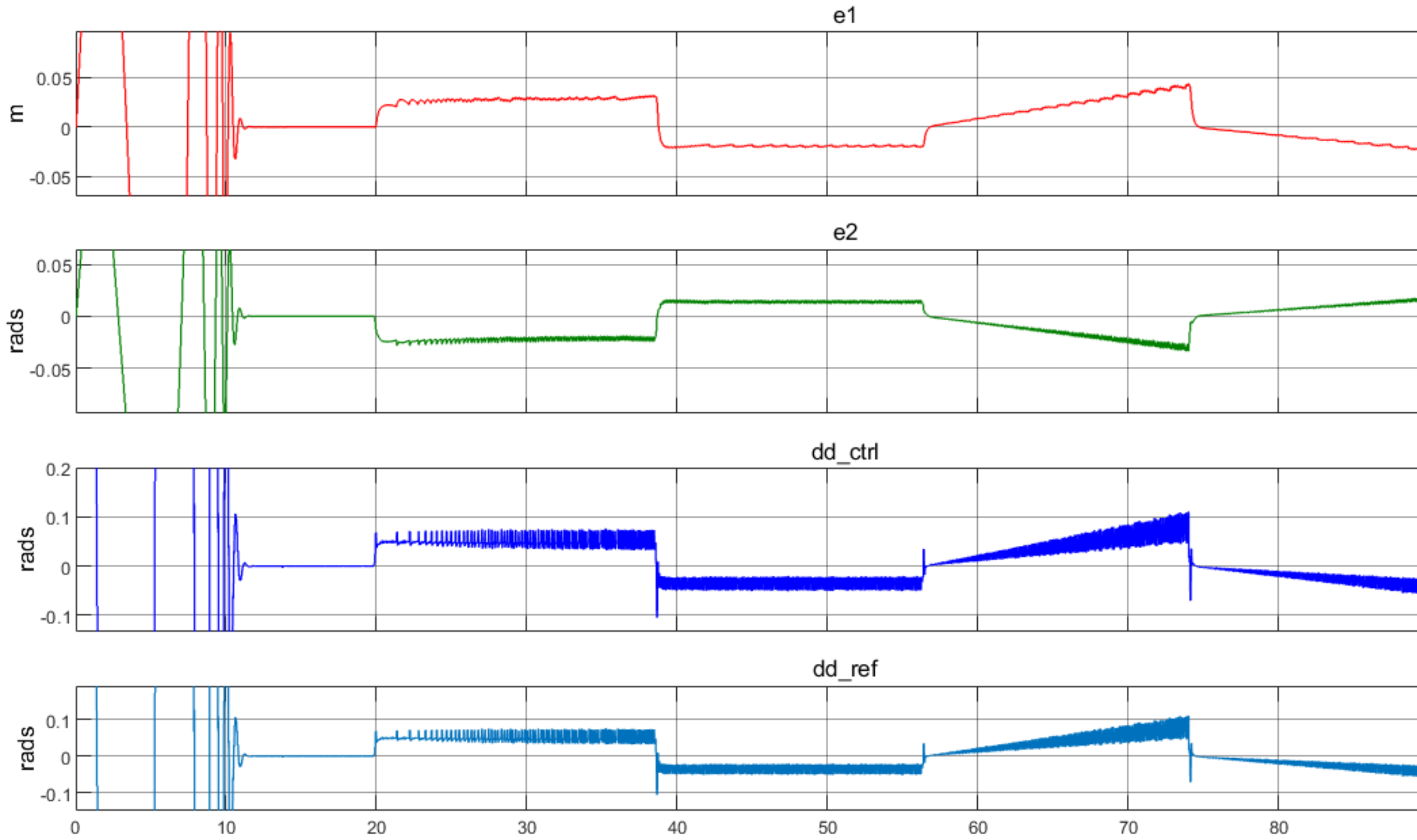

Figure 13: Lateral errors ans response of the actuator.

III. TABLES

TABLE I: ENVIRONMENT DATA

	Matlab Name	Sym	Unit	Val
1	g	g	m/s^2	9.81
2	V_wind	V_{wind}	m/s	0
3	theta	θ	rad	0

TABLE II: VEHICLE DATA

Matlab Name	Sym	Unit	Tesla ms val	src	Mustang val	M-E src	Lucid val	src
lr	l_r	m	1.58					
lf	l_f	m	1.1					
transGear	R		0.1027	[2]				
Iz	I_z	Nm	2873					
m	m	Kg	2238.932	[3][4]				
Nf	N_f		2					
Nr	N_r		2					

TABLE III: COMMERCIAL VEHICLE DATA FOR COMPARISON

Feature	Sym	Unit	Tesla ms val	src	Mustang val	M-E src	Lucid val	src
Transmission efficiency	η	-	0.97	[2][5]				
Acceleration 0–60 mph	-	s	3.2	[4]				
Acceleration 0–100 km/h	-	s	-					
Torque	-	Lb-ft	687	[4]				
EM motor type	-	-	3 IM Cu					
Electric Motor Output	-	Hp/kw	691/515	[4]				
Battery Range	-	Miles/km	275/442	[4]				
EM max speed	-	rpm	16000	[5]				
EM speed at max power	-	rpm	5k-8.6k	[5]				
EM speed at max torque	-	rpm	5.1k	[5]				
EM max power front	-	kW	193	[5]				
EM max power rear	-	kW	375	[5]				
EM max torque	-	NM	967	[5]				

TABLE IV: AERODYNAMIC DATA

Matlab Name	Sym	Unit	Tesla ms val	src	Mustang val	M-E src	Lucid val	src
xx	ρ	kg/m^3	1.225	[2]				
xx	A_F	m^2	2.341157	[6]				
xx	$C_d A_F$	m^2	0.57599	[6]				
xx	C_d	-	0.24	[6]				
xx	h_{aero}	m	-					

TABLE V: TIRE DYNAMICS

Feature	Sym	Unit	Tesla ms val	src	Mustang val	M-E src	Lucid val	src
Model			Pirelli Sottozero 3	-				
tire stiffness	C_σ							
Effective radius	r_{eff}							
Static radius (with load)	r_{stat}	-						
Radius of wheel (no load)	r_w	m	0.352					
Tire Size	-	-	P245/45WR19	[7]				
Rolling Resistance Coefficient	C_r	kg/t	$7.8 \leq RRC \leq 9.0$	[5]				

TABLE VI: TYRE FORCE PROFILE

Generic model Name	Sym	Unit	Val
Name Model			Generic
C_ar	$C_{\alpha r}$		80000
C_af	$C_{\alpha f}$		80000
D	D		3
C	C		1.5
B	B		20
E	E		0
sh	Sh		0
sv	Sv		0

TABLE VII: BLDC ELECTRICAL MOTOR FOR STEERING

Name	Sym	BLDC Electrical Motor Unit	Val
Name Model			Generic
R	R	Ω	0.35
L	L	H	0.001
M	M	H	0
J	J	Kgm^2	0.00018
P	P		4
b	b	$N\,ms\,rad^{-1}$	0.0034
lambda	λ	$V/rad/s$	0.0433