VIETNAM NATIONAL UNIVERSITY, HO CHI MINH CITY

HO CHI MINH CITY UNIVERSITY OF TECHNOLOGY

OFFICE FOR INTERNATIONAL STUDY PROGRAMS

FACULTY OF TRANSPORTATION

Capstone Project

Analysis, 3D modeling and dynamic simulation of the vehicle steering system in the VIOS car.

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Faculty of Transportation Engineering

Department of Automotive Engineering

PROJECT MISSION

1. **Student's name**: Trịnh Tiến Long - Student ID: 1852047
2. **Major**: Automotive Engineering - Class: CC19OTO1
3. **Thesis title**: Analysis, 3D modeling and dynamic simulation of the vehicle steering system in the VIOS car.

Content:

_Build EPS model on Solidworks then import to Simscape to determine the torque acting on steering wheel with certain steering angle on EPS system

_ Build 3D model of the steering system

_Simulation of dynamic behavior in Matlab/Simulink with Simscape

_Validation the model for the control of an equivalent electric powered steering system

4. Product:

❖ Full report.

❖ Poster.

❖ Simulink simulation.

5. **Assigned day**: 23^{th} December, 2022
6. **Finished day**: 22^{th} May, 2023

The content and requirements of the thesis is already approved by the Head of Department of Automotive Engineering.

HCMC, day…..... month…… year 2023 HCMC, day… . month…… year 202

Head of Department **Instructor**

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I would like to express my gratitude to the most important people in my academic journey.

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I wish my parents, family, lecturers in the Faculty of Transportation Engineering, as well as lecturers in the Department of Automotive Engineering, and all my friends good health and happiness.

ABSTRACT

This study presents a simulation of an Electric Power Steering (EPS) system using MATLAB Simulink and Simscape, based on the parameters of a Toyota VIOS passenger car with front-wheel drive.

The EPS model was built using SolidWorks and was designed to simulate the steering behavior of the VIOS under different driving conditions. The simulation results show that the EPS system provides the desired steering response for different driving conditions.

The study includes two parts: In the first part, the EPS system's responsiveness was evaluated by applying more torque on the steering wheel without help from motor. The simulation results showed that the steering system responded quickly to changes in steering input, providing accurate and responsive steering control.

In the second part, the study evaluated the torque changes needed to maintain a predefined driving situation. The simulation results showed that the EPS system provided the necessary torque changes to keep the VIOS on the desired path, demonstrating the system's effectiveness in maintaining vehicle stability.

The study also analyzed the effects of different parameters, such as the steering gear ratio and the controller gains, on the EPS system's performance. The simulation results showed that adjusting these parameters had a significant impact on the EPS system's performance, and that proper tuning of these parameters is essential for achieving optimal performance.

Overall, the simulation results demonstrate the effectiveness of the EPS system in providing responsive and accurate steering control for a Toyota VIOS passenger car with front-wheel drive. The study provides insights into the design and performance evaluation of EPS systems for this specific vehicle model, which could be useful for future research and development in this area.

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1) General information and objective:

a) About Electric Power Steering System

During the past ten years, EPS has been introduced in gradually increasing numbers. Although electric power steering system offer significant advantages over their hydraulic counterparts, electric motor technology and controls had not reached the point where they could be used in this application until just recently. Electrically assisted power steering is replacing the traditional hydraulic system where the pressure is provided via a pump driven by the vehicles engine. The hydraulic system is constantly running and by using the EPS the fuel consumption can be reduced. In electric and hybrid vehicles, the engine does not run continuously so electric power steering is the only possible solution.

Advantages:

- EPS is more energy-efficient than hydraulic power steering systems, resulting in improved fuel economy.
- EPS is quieter than hydraulic systems because it doesn't require a hydraulic pump.
- EPS offers better control and quicker response times, as the level of power assist can be adjusted based on the vehicle's speed and other factors.
- EPS can be integrated with other electronic safety features like lane departure warning and stability control.

Disadvantages:

- EPS systems can be more expensive to repair or replace than hydraulic systems.
- Some drivers may find that EPS lacks the same level of feedback and "feel" as hydraulic systems, leading to a less engaging driving experience.
- EPS systems can be heavier than hydraulic systems because they require an electric motor to provide the power assist.
- In the event of a power failure, EPS may become difficult or impossible to operate,

whereas hydraulic systems would still function with greater effort required from the driver.

b) About Matlab/Simscape

Simscape is a physical modeling language and simulation tool in MATLAB that enables engineers to design and simulate multidomain physical systems. This tool allows engineers to create models that represent the behavior of physical systems, including electrical, mechanical, hydraulic, and thermal systems, among others. With Simscape, engineers can model systems at a higher level of abstraction, which simplifies the creation and analysis of complex systems.

Simscape provides pre-built components and libraries that engineers can use to design and build models. These components and libraries can be customized to meet specific modeling requirements and can be combined to create complex systems. For example, an engineer can use a pre-built hydraulic pump component and combine it with a pre-built valve component to create a hydraulic system. This flexibility allows engineers to design and simulate diverse physical systems.

Simscape offers a visual representation of simulation results, which is an essential feature for understanding system behavior. Engineers can visualize simulation results in the form of graphs, plots, and animations. This capability allows engineers to analyze and interpret system behavior more effectively.

Simscape also offers several other features that make it a powerful tool for physical modeling and simulation. For instance, it allows engineers to perform parameter sweeps and sensitivity analyses, which can be used to optimize system performance. Additionally, Simscape can be integrated with other MATLAB tools, such as Simulink, to create more complex models that include control systems and other components.

Overall, Simscape is a powerful tool that enables engineers to model and simulatecomplex physical systems more efficiently and accurately. It provides an intuitive platform for designing and analyzing multidomain physical systems, making it a valuable tool for engineers in various fields, including mechanical, electrical, and aerospace engineering. With its vast library of pre-built components and simulation capabilities, Simscape can help engineers design and optimize complex systems, reduce development costs, and improve overall system performance.

Tool	**Concept**	**Application**	**Advantages**
Matlab	Software	Calculation and simulation	Widely-used platform, versatile, powerful numerical computation abilities, supports graphical user interface (GUI) for easy visualization and interaction with data, offers a large library of built-in functions and toolboxes for various applications, supports various file formats for importing/exporting data, can be integrated with other programming languages.
Simscape	Physical modeling language	Modeling physical systems	Allows for modeling and simulation of complex physical systems with ease, supports multi-domain modeling (e.g. electrical,

			mechanical, hydraulic), provides a library of pre-built components for easy modeling, offers a unified platform for modeling and simulation, can be integrated with Matlab for further analysis and visualization.
Simulink	Block diagram modeling	Dynamic system modeling and simulation	Provides a graphical user interface for modeling, simulating, and analyzing dynamic systems, supports a wide range of modeling and simulation tasks (e.g. continuous-time, discrete-time, hybrid systems, etc.), offers a large library of pre-built blocks for various applications, supports automatic code generation for embedded systems, provides real-time simulation capabilities, supports co-simulation with other software and hardware systems, offers various analysis and visualization tools for system analysis and optimization.

Table 1: Introducing software

c) Objective

The objective of this content is to demonstrate the process of building an Electric Power Steering (EPS) model using Solidworks and Simscape, creating a 3D model of the steering system, simulating the EPS system's dynamic behavior in Matlab/Simulink with Simscape, and validating the model for the control of an equivalent electric-powered steering system. The primary goal is to determine the torque acting on the steering wheel with a certain steering angle on the EPS system and to provide insights into the design and evaluation of EPS systems for future research and development in this area.

2) Scope of implementation:

The scope of this thesis is to analyze the dynamic behavior of the Electric Power Steering (EPS) system in the VIOS model, by creating a simulation model in MATLAB/Simulink. Aerodynamic simulations will not be included, the analysis will be limited to lower speeds.

3) Working condition:

Constant steering angle, constant speed: In this scenario, the VIOS vehicle will be driven at a constant speed on a predetermined road, while the steering angle is kept constant. The purpose of this scenario is to evaluate the performance of the electric power steering system in maintaining the steering angle at a constant value, given the driving conditions and the characteristics of the road.

Following a predefined road: In this scenario, the VIOS vehicle will be driven on a predefined road with a set of steering commands to follow the road. The steering commands will be generated based on the road curvature and the desired speed. The purpose of this scenario is to evaluate the performance of the electric power steering system in tracking the desired steering commands and following the road accurately, given the driving conditions and the characteristics of the road.

4) Technical requirement:

Correct technical specifications are ensured to guarantee that the system operates within specified parameters with low margin of error.

5) Limitation

The limitation of this study is that the parameters based on the VIOS vehicle were measured at an automotive workshop at the HCM University of Technology, so they may not be entirely accurate.

6) Conditions and Requirements for Building Simulation Models, Conditions for Applying Matlab Simulink/Simscape Software

Conditions for building models and applications Matlab Simulink - Simscape	Technical requirements
Establishing a compatible linkage between the Solidworks graphics environment and Matlab Simulink.	Building a mechanism model that closely matches reality on Solidworks and linking it to Matlab.
In terms of kinematics, the steering system is analyzed as a series of steps, linked together by rotating or sliding joints.	Identifying the component steps and types of linkage between them.
The mating steps in the entire mechanism are interconnected through established linkages.	Establishing the correct type of linkage for each step, setting up a common coordinate system, and coordinates on each step as a basis for locating the position of each step in space.
Using functional blocks in the Simulink library linked to the model to establish a	Determining the theoretical basis for testing the working process and providing

program for testing the working parameters of the mechanism.	input parameters corresponding to the working process.
Converted from the Solidworks model to an equivalent Simscape model for ease of communication between the two software programs.	Checked whether the mating steps were converted correctly as per practical requirements.

Table 2: Conditions and technical requirements

II/Parameter of Electric Power Steering Model

1. Complete 3D model

Figure 1: Complete 3D model of Electric Power Steering

2. Parameter and design for each part

a. Parameter table

Name	Value
Rack	0.37m
Pinion:Rack ratio	1:3
Track Width	1.4m
Tie Rod	0.265m
Steering Linkage	0.1m

Table 3 : Parameters table for 3D model

b. 3D model of each part

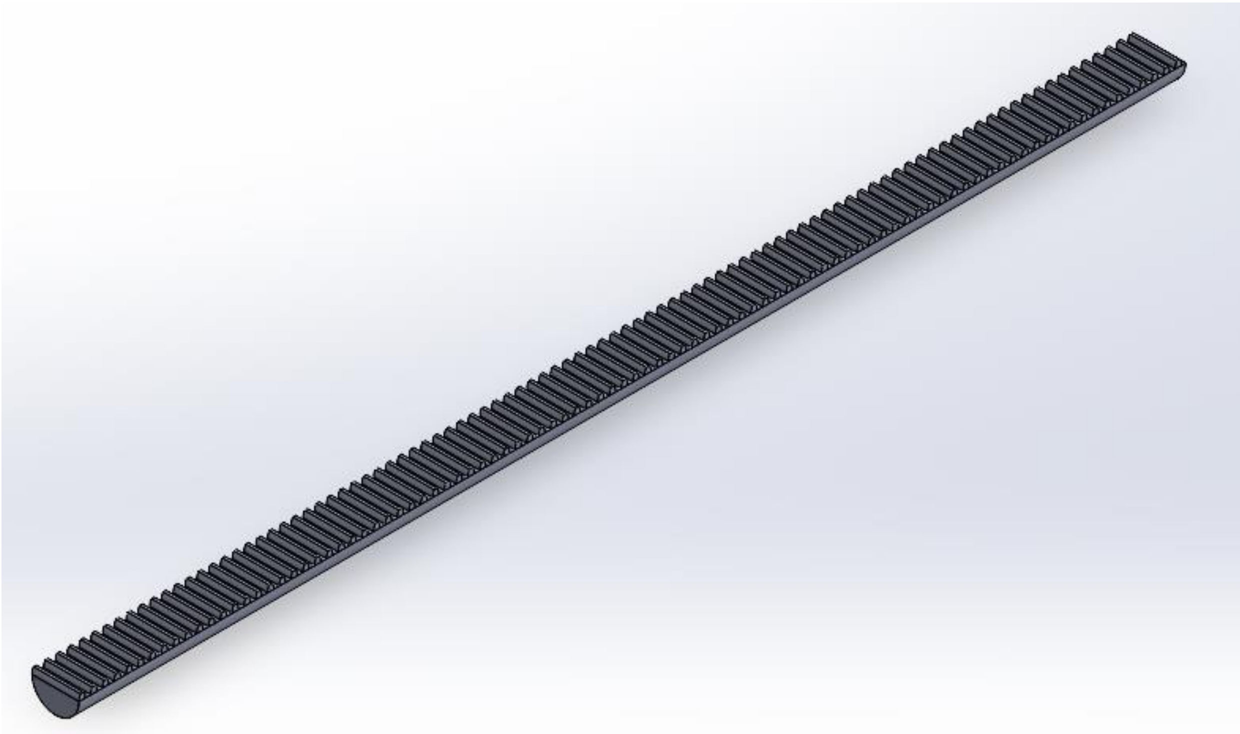


Figure 2: Rack

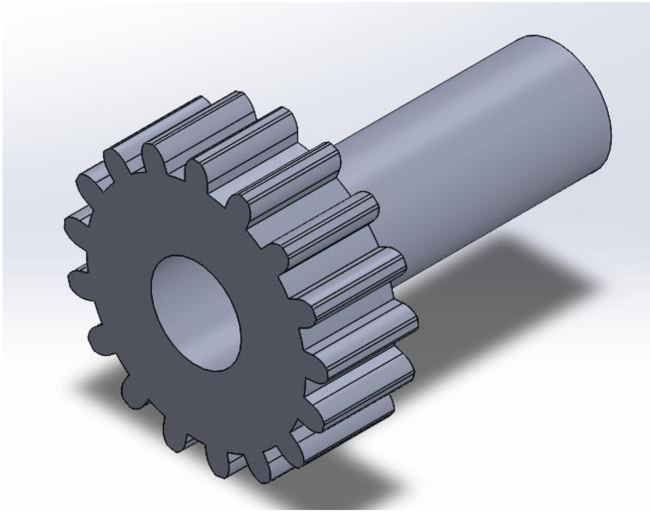


Figure 3: Pinion

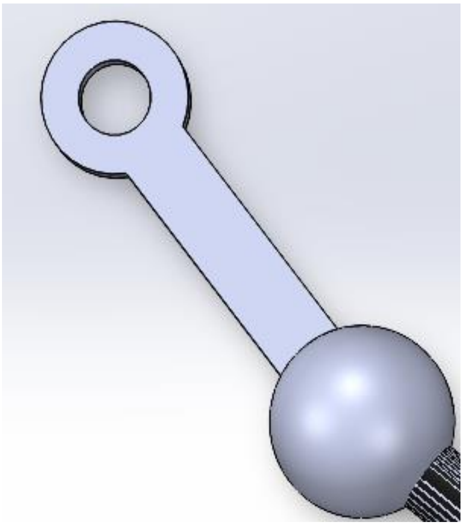


Figure 4: Tie rod

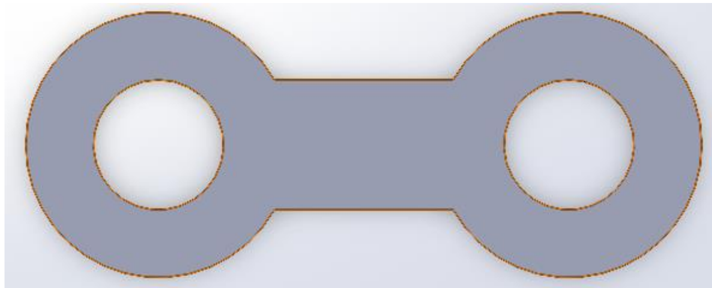


Figure 5: Steering Linkage

Parameter	**Unit**	**Value**
Wheelbase	mm	2550
Distance between two vertical pillars	mm	1470
Radius of steering wheel	mm	180
Steering gear ratio		19.5
Wheel radius	mm	354
Number of teeth on the pinion		9
Number of teeth on the rack		27

Table 4 : Parameter of model

Other parameters will be listed in table above.

3. How to export from Solidworks to Simulink on MATLAB

Step 1: Enable Simscape Multibody Link Plugin in SolidWorks

The Simscape™ Multibody™ Link plugin allows SolidWorks® CAD assembly models can be exported to Simscape Multibody. To download and install the plugin, watch on: [Install the Simscape Multibody Link Plugin].

Enable the Plugin

To enable the plugin:

1. At the MATLAB® command prompt, enter smlink_linksw.
2. Start SolidWorks.
3. On the SolidWorks menu bar, click **Tools** > **Add-Ins**.

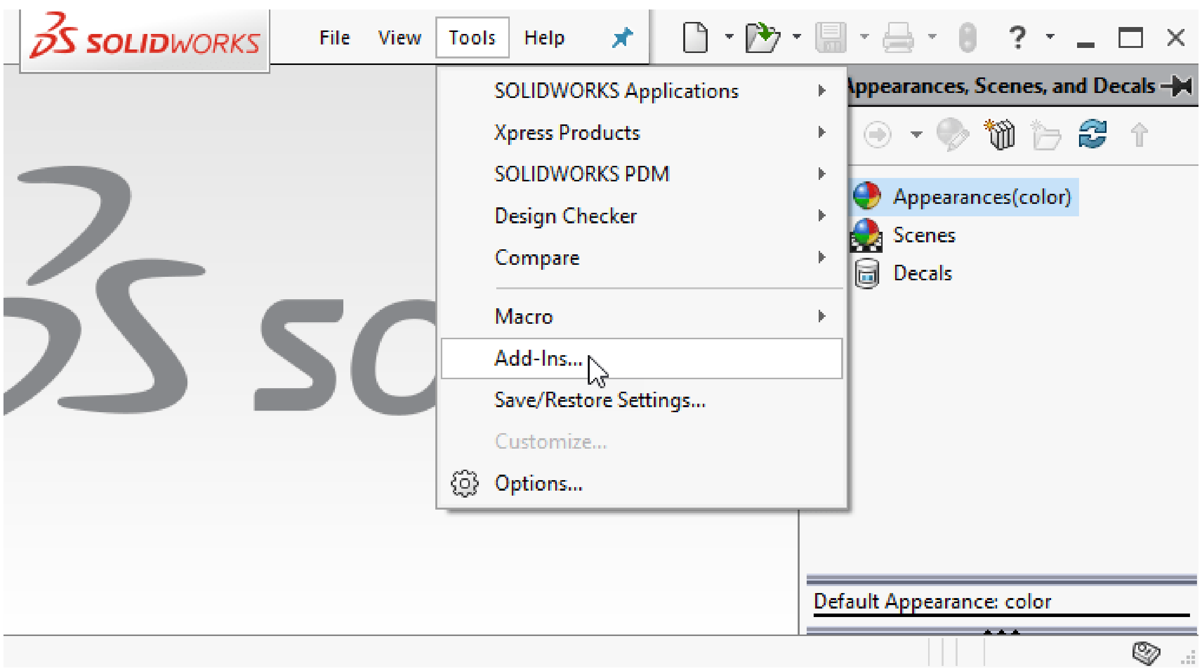


Figure 6 : Add-Ins

4. In the Add-Ins dialog box, select the **Simscape Multibody Link** check box.

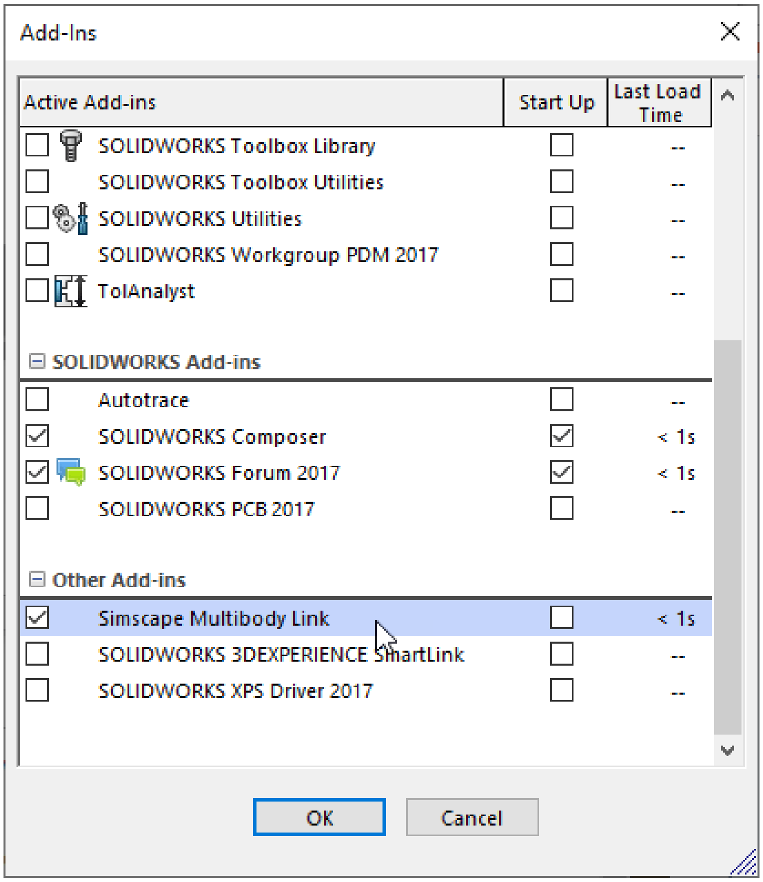


Figure 7: Turn Add-ins on

After enabling the plugin, **Simscape Multibody Link** option is available when SolidWorks assembly is opened. To export an assembly model, on the menu bar, click **Tools** > **Simscape Multibody Link** > **Export** > **Simscape Multibody**.

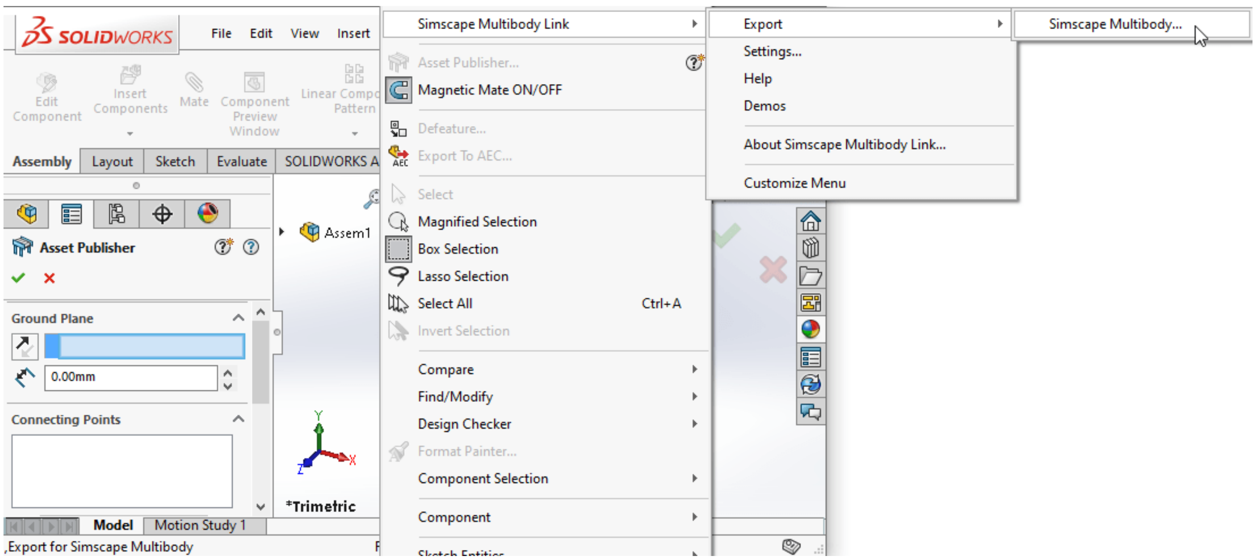


Figure 8: Export to .xml file

Step 2: Use smimport to get .xml file that exported from Solidworks to Simulink

1. To export an assembly drawing to Matlab Simulink, we need to open the drawing file type Assembly go to Add-Ins and click Export Simscape Multibody, choose where to save the file and file name (usually the file name is recommended by name drawing Assembly), the file will be created in the .xml which is format of Simscape Multibody Link.

2. To open the file, first after starting Matlab need to select the folder containing file: click Browse for folder and select the folder containing the file, then click Select Folder

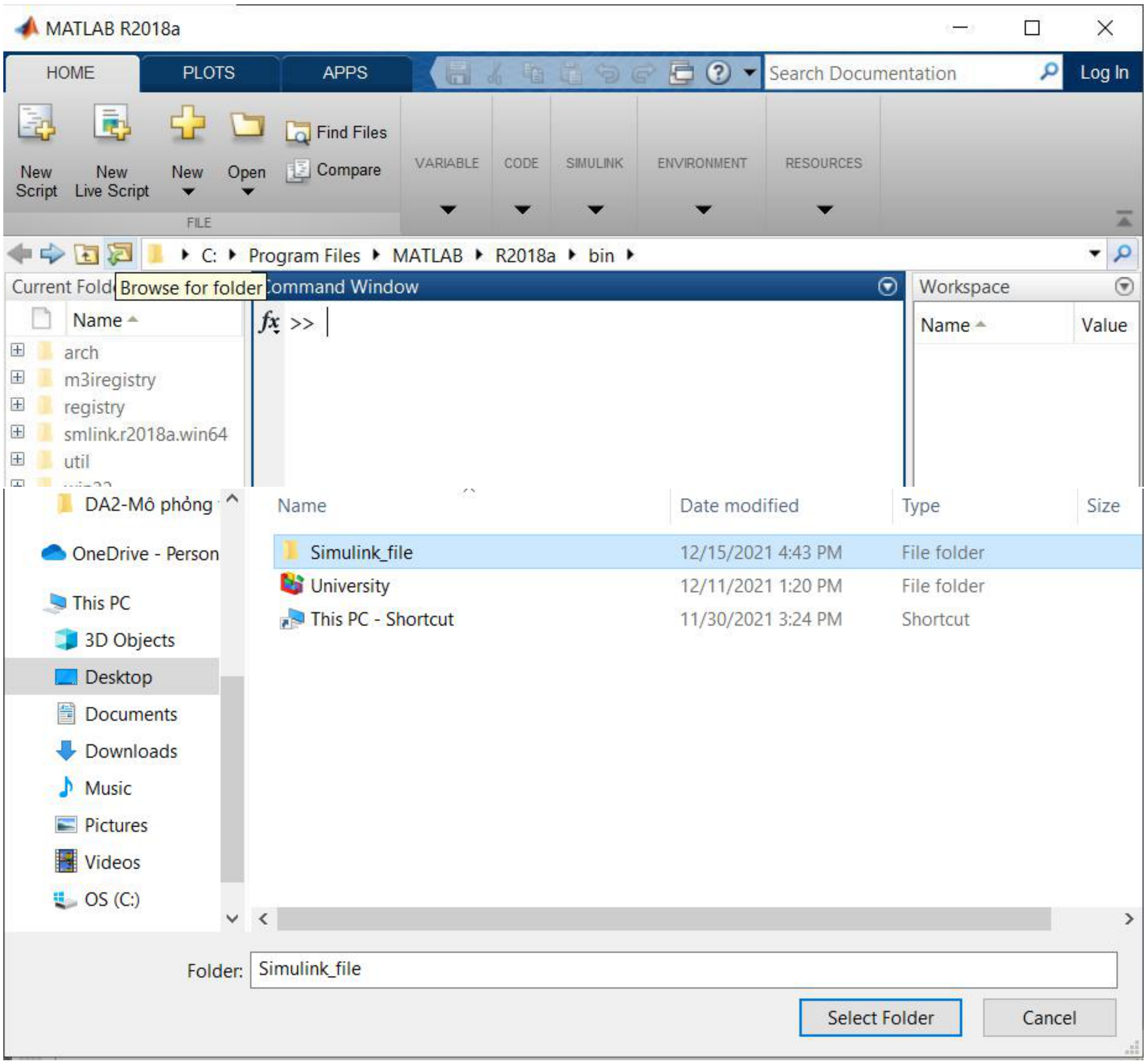


Figure 9 : Opening Folder

3. In the Command Window in Matlab, enter the command smimport('filename.xml') and wait for the importing model to finish running

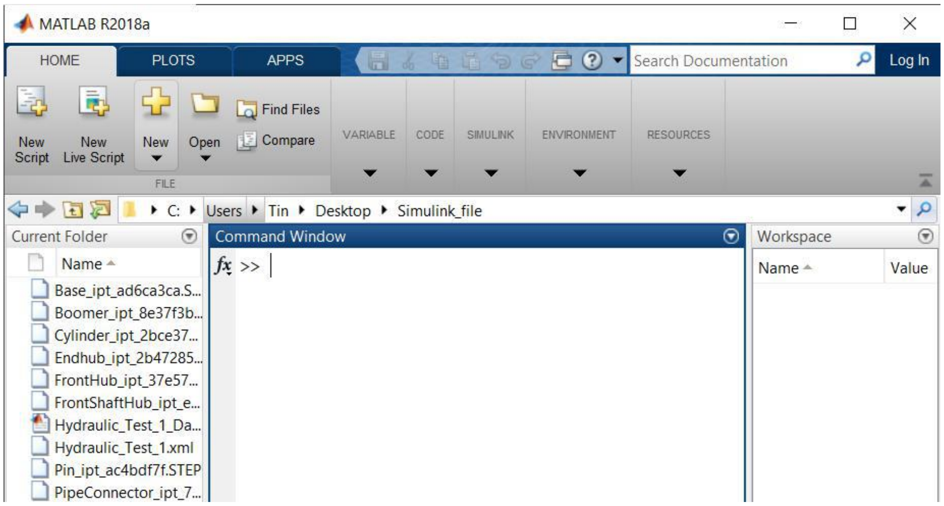


Figure 10: Command Window

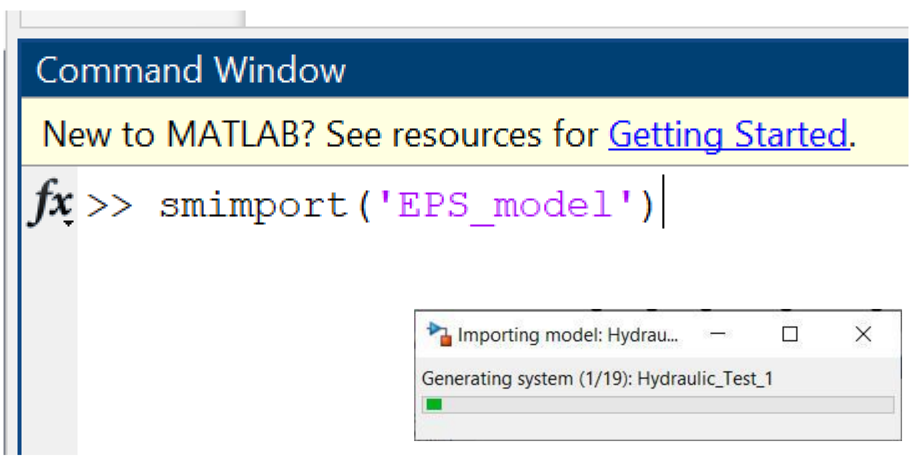


Figure 11 : Use smimport command to import

4. Then we get the Simulink window with the 3D drawing in the Inventor converted to Matlab Simulink as functional blocks

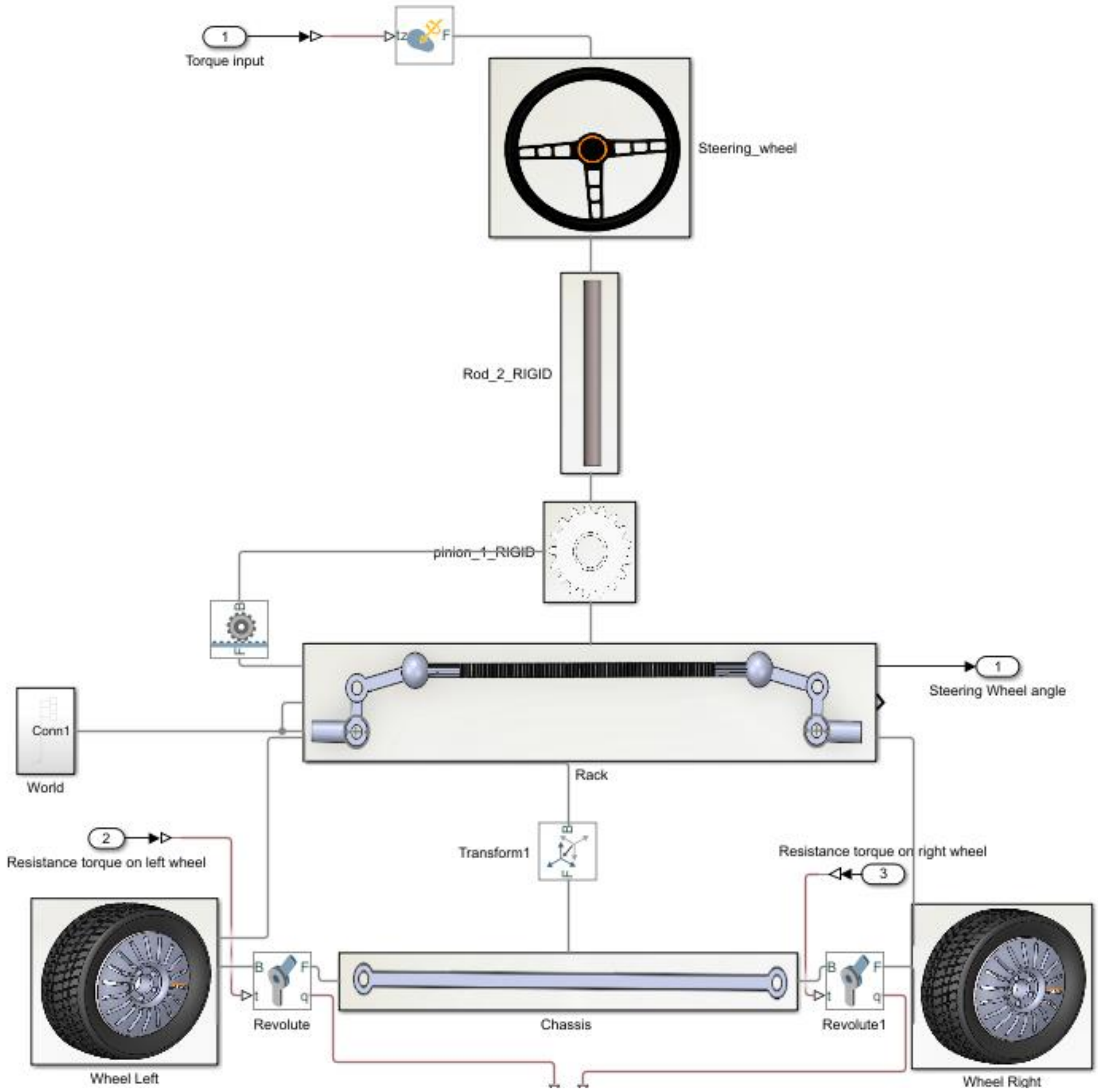


Figure 12: Steering Dynamic

5. In the Simulink window, you can select Run and check if the mechanism runs as designed in the Mechanics Explorers dialog box

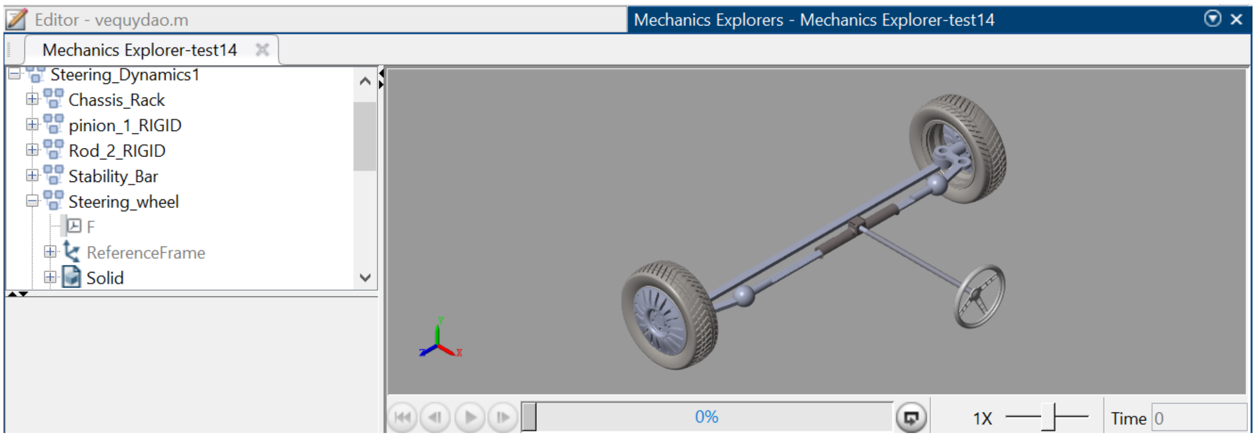


Figure 13: Mechanics Explorers

Name and Symbol	Function and Configuration
Subsystem	Contains a set of blocks within a model or system. A Subsystem block may represent a virtual subsystem or a nonvirtual subsystem. For example, in Figure 5.1, there are Subsystem blocks for Fluids, Simulink, Multibody, etc.
Inport	Brings a signal from outside a system into the system. The port number of an Inport block is assigned as follows: it is automatically numbered sequentially in the highest-level system or subsystem. If a new Inport block is added, its label is the next available number. If an Inport block is deleted, the port numbers of other blocks are automatically reassigned to ensure that the Inport blocks are numbered sequentially and that no numbers are skipped. If an Inport block is copied into a system, its port number is not reassigned unless its current number conflicts with an existing input port in the system. If the Inport block's port number is not sequential, renumber the block. Otherwise, an error message will be received when simulating or updating the block diagram.
Outport	Sends a signal from a system to an external destination. They can connect signals transmitted from a subsystem to other parts of the model. They can also provide the top-level outputs of a hierarchical model. The port number of an Outport block is assigned as follows:

Name and Symbol	Function and Configuration
	Outport blocks in the base-level system or subsystem are numbered sequentially, starting with 1. If a new Outport block is added, it is assigned the next available number. If an Outport block is deleted, the port numbers of other blocks are automatically reassigned to ensure that the Outport blocks are numbered sequentially and that no numbers are skipped.
Connection Port	This block is used in a subsystem when physical ports need to be connected.
Mechanism Configuration	Sets mechanical parameters and applies simulation for the entire machine, target machine that the block is connected to. In the Properties section below, we can specify a uniform gravity force for the entire mechanism and set linear delta t. Port C is the frame node that we connect to the target machine with a connection path at any frame node of the machine.
World Frame	Provides a space with a stationary, orthogonal coordinate frame, defined by the right-hand rule, in any mechanical model. The World Frame is the basis of all frame networks in a mechanical model. A model can have multiple World Frame blocks, but they all represent the same frame. Port W is a frame port defined with the World Frame.

Name and Symbol	Function and Configuration
	Any frame port directly connected to W is also defined with the World Frame.
Rigid Transform	Determines a fixed 3D rigid transformation between two frames. The two components independently specify the translational and rotational parts of the transformation. Translation and rotation motions can be combined freely. Ports B and F correspond to the Base and Following Frames, respectively.
Revolute Joint	Connects two frames with a hinge joint that has only one degree of freedom. Port B corresponds to the Base and F corresponds to the Following Frames. In the expandable nodes under Properties, we can specify state targets, actuation methods, sensing, and internal mechanics.
Reference Frame	Defines a frame to which other frames in the network can be referenced or blocks can be attached. (Optional) Port R is a frame port defined with the reference frame. Any frame port directly connected to R is also defined with the reference frame.
Cylindrical Joint	Connects two frames with a cylindrical joint that has one translational and one rotational degree of freedom. Port B corresponds to the Base and F corresponds to the Following Frames. In the expandable

Name and Symbol	Function and Configuration
	nodes under Properties, we can specify state targets, actuation methods, sensing, and internal mechanics (equilibrium position, spring stiffness, damping coefficient) of these joints (one translation along Z and one rotation around Z). After applying these settings, the block will display corresponding physical signal ports.
Planar Joint	Represents a planar joint between two frames. This joint has two translational and one rotational degree of freedom. Port B corresponds to the Base and F corresponds to the Following Frames. In the expandable nodes under Properties, we can specify state targets, actuation methods, sensing, and internal mechanics (equilibrium position, spring stiffness, damping coefficient) of these joints (two translations along X and Y and one rotation around Z). After applying these settings, the block will display corresponding physical signal ports.
Prismatic Joint	Connects two frames with a prismatic joint that has only one translational degree of freedom. Port B corresponds to the Base and F corresponds to the Following Frames. In the expandable nodes under Properties, we can specify state targets, actuation methods, sensing, and internal mechanics (equilibrium position, spring stiffness, damping coefficient) of this joint (one

Name and Symbol	Function and Configuration
	translation along Z). After applying these settings, the block will display corresponding physical signal ports.
Gain	The Gain block multiplies the input signal by a constant value (gain). The input can be a scalar, vector, or matrix signal. The value of the Gain can be specified in the Gain parameter. The Multiplication parameter allows us to specify element-wise or matrix multiplication. For matrix multiplication, this parameter also allows us to specify the order of the multiplication.
Signal Editor	The Signal Editor block displays, creates, and edits signal parameters that can be exchanged between blocks. This block can be used to convert signal parameters inside and outside the model.
Converter	The Converter block converts Simulink signals to physical signals.
PS Constant	The PS Constant block generates a physical signal with a constant value. The value and unit of the signal can be specified as a constant.
Solver Configuration	The Solver Configuration block specifies the solver parameters required for a Simscape block diagram to start simulation. Each Simscape block diagram has a unique structure and connectivity that requires an accurate Solver Configuration block to be connected

Name and Symbol	Function and Configuration
	to it. The solver configuration parameters include the type of solver to be used, the maximum step size, the relative and absolute tolerances, the maximum number of iterations, and other solver-specific options. The Solver Configuration block allows the user to specify these parameters and configure the solver accordingly. Choosing the appropriate solver configuration is important for obtaining accurate and efficient simulation results. The default solver configuration in Simscape is suitable for most models, but for complex models or those with stiff differential equations, a different solver configuration may be necessary for accurate and efficient simulation.
PS-Simulink Converter	The PS-Simulink Converter block converts physical signals to Simulink signals.
Scope	The Scope block displays the signals generated during simulation. It can be used to visualize the behavior of different signals and debug the model.
Mux	The Mux block combines separate signals into a single vector signal. This block can be used to combine multiple signals into a single signal for further processing or analysis.

Table 5: Block with functions

III/ Theoretical basics:

1. Kinematics of the steering trapezium:

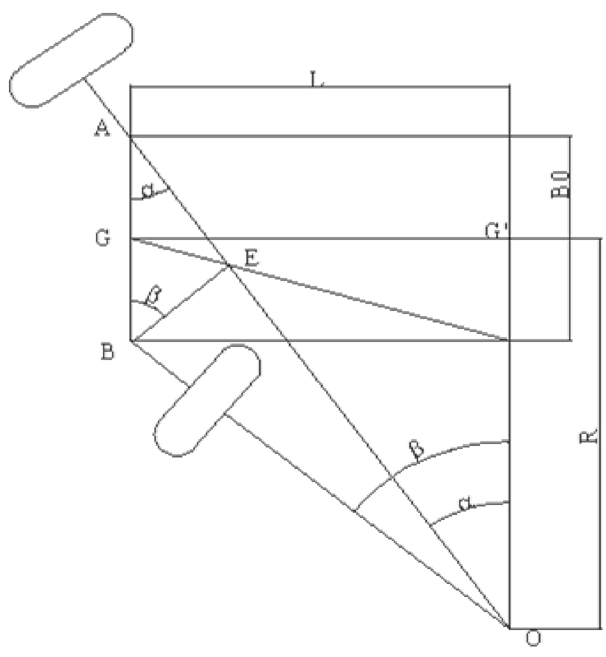
Theoretical basis for calculating the kinematics of the steering trapezium

According to the theory of wheel rotation, the ideal turning condition for the wheels to avoid lateral slipping is:

$$\text{Cotg}\beta_i - \text{cotg}\alpha_i = \frac{B_0}{L}$$

where:

- β_i: the turning angle of the inner steering wheel (degrees);
- **δi**: the turning angle of the outer steering wheel (degrees);
- **L**: the wheelbase of the vehicle (mm);
- B_0: the track width of the vehicle (mm).



From Figure above, we have: angle (GAE) = α (the turning angle of the outer steering wheel).

We have: $\cot \alpha_i = \dfrac{\frac{B_0}{2} + R}{L}$ substituting into above equation, we get:

$$\frac{\frac{B_0}{2} + R}{L} - \cot \beta_i = \frac{B_0}{L}$$

$$\Rightarrow \cot \beta_i = \frac{R - \frac{B_0}{2}}{L}$$

Therefore, the turning angle of the inner steering wheel β is equal to angle (GAE). From this, by substituting the pairs (αi, βi) from above formula into the diagram, we can obtain the intersection points Ei lying on the line GC. This ensures that the kinematics of the steering trapezium allows the vehicle to turn without lateral slipping.

However, in reality, the steering trapezium does not satisfy the above condition, which means that the actual values of the pairs (αi, βi) do not satisfy equation , causing the steering wheels to still experience lateral slipping. The degree of lateral slipping is minimized when the intersection points Ei are as close as possible to the line GC.

* **Checking steering angle from Ackerman equation with simulation results**

Input: β_i (degree)	α_i from model (degree)	α_i (Ackerman) (degree)
5	4,75	4,76
10	9,07	9,09
15	13,03	13,07
20	16,69	16,74
25	20,1	20,18
30	23,31	23,42
35	26,38	26,51

Table 6 : Calculation and simulation results

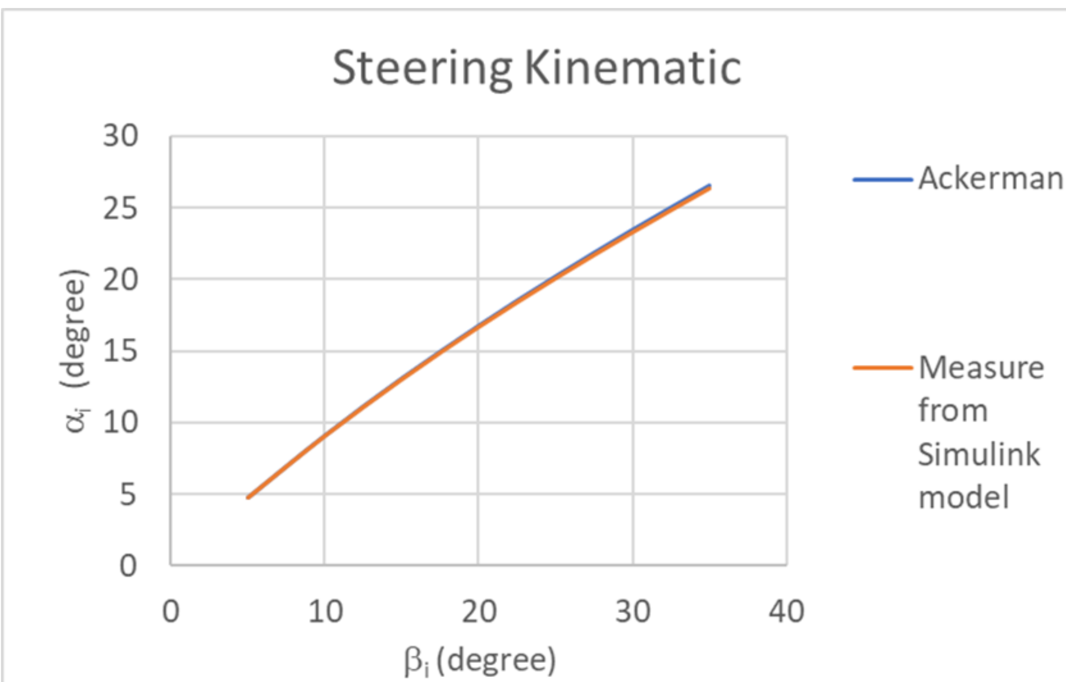


Figure 14 :Ackerman vs Simulink model

We utilized the input β_i to run the simulation model and obtain the value of α_i. The simulation model was designed to replicate the steering kinematics of a vehicle.

In addition to the simulation model, we also applied the Ackerman equation to calculate the value of 'ai' from β_i. The Ackerman equation is a well-known formula used to determine the steering angle of a vehicle's front wheels based on the wheelbase and turning radius.

By comparing the results obtained from the simulation model and the Ackerman equation, we were able to assess the accuracy of the simulation model. We observed that the value of α_i obtained from the simulation model was very close to the value of α_i calculated from the Ackerman equation.

This finding indicates that the simulation model was able to accurately replicate the steering kinematics of the vehicle. It confirms that the simulation model has correct steering kinematics and can be relied upon for future studies and applications in the field of vehicle dynamics and control.

2. Dynamic Equilibrium Equations of EPS System

The dynamic equilibrium equations of a system are a set of mathematical equations that describe the motion and behavior of the system over time. These equations are used to determine how the system will respond to external forces and inputs, and they are essential for understanding the stability and performance of the system.

The function of the dynamic equilibrium equations is to establish a relationship between the forces acting on the system and the resulting motion and behavior of the system. These equations consider the mass, velocity, acceleration, and other physical properties of the system, as well as the external forces and inputs that are acting on it.

By using the dynamic equilibrium equations, engineers and scientists can simulate the behavior of a system under different conditions and inputs and can optimize the system's performance and stability. These equations are also essential for designing and testing new systems, and for troubleshooting problems in existing systems. Overall, the dynamic equilibrium equations are a fundamental tool for understanding and controlling the behavior of complex systems in a wide range of applications.

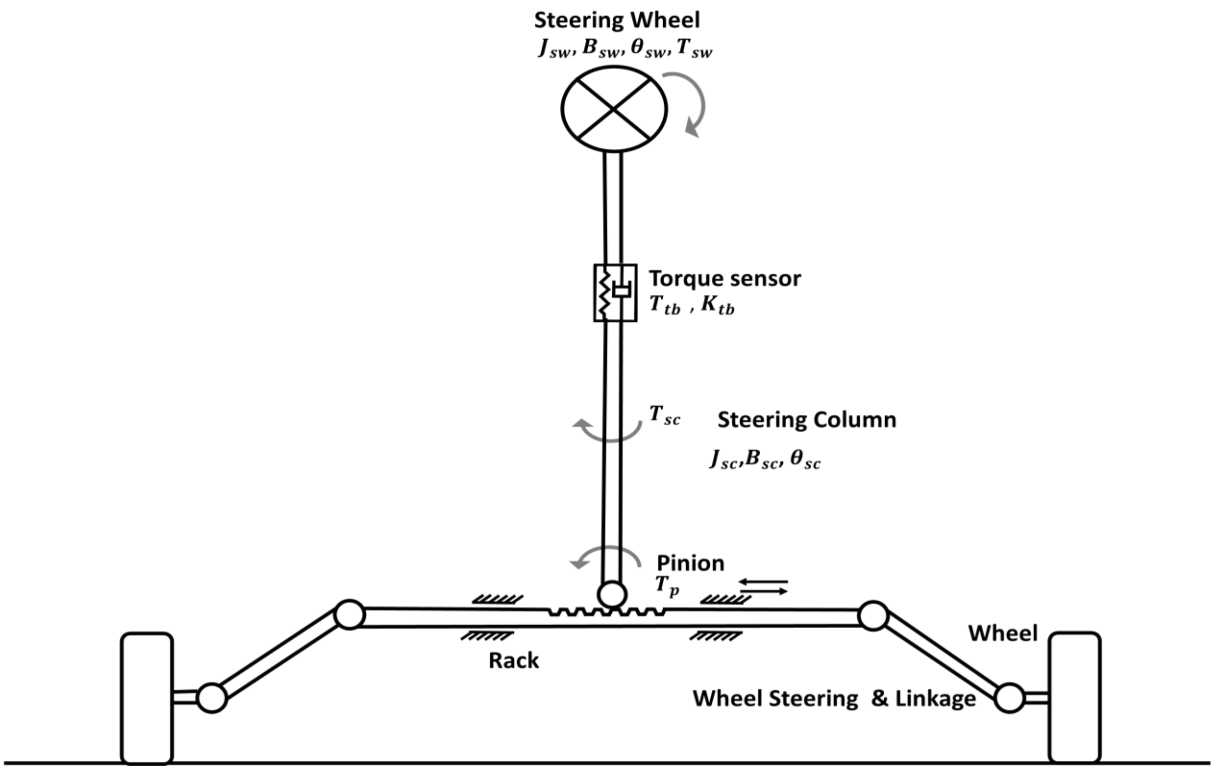


Figure 15: Steering Dynamics

To be specific, we focus on dynamic equation that can be used to explain simulation results:

$$T_{steering\_wheel} = \sum T_{resistance} + J_{sw}\ddot{\theta}_{steering\_wheel}$$

With this equation, we can just take input with $\ddot{\theta}_{steering\ wheel} \sim 0$, so torque from steering wheel with equal to sum of all resistance torque.

In the past, we need to use dynamic equations to determine the behavior of dynamic system. Now with help from MATLAB, we can use simulation model to calculate those equations quickly and accurately.

IV. MATLAB/SIMULINK SIMULATION

1. General information about block is used

1.1) Complete model

A complete model has been developed for testing in various scenarios including Steering Dynamics that is built by 3D model in Solidworks and Total resistance torque

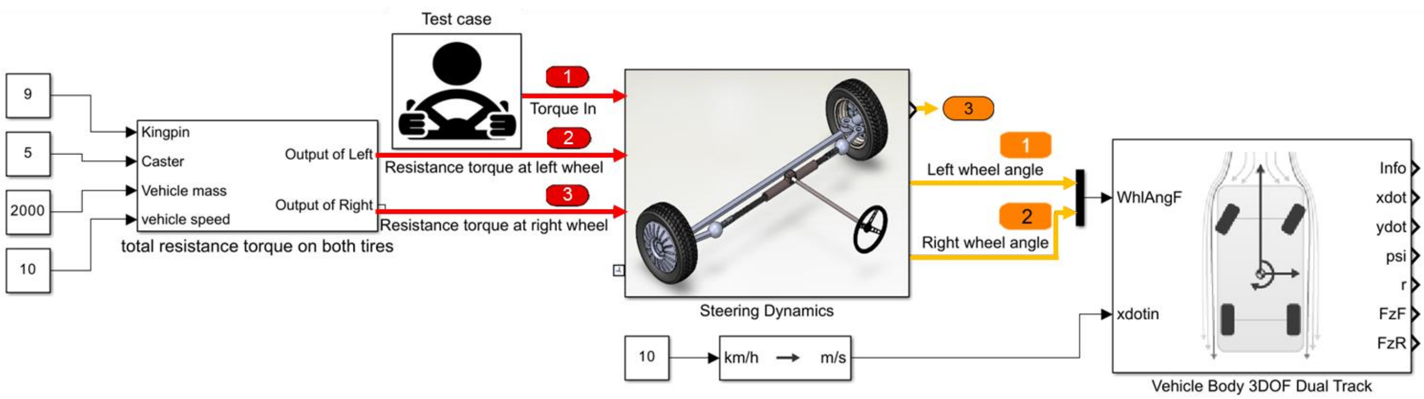


Figure 17 : Complete model in Simulink

To be specific, the input and output are used in this project will be shown below:

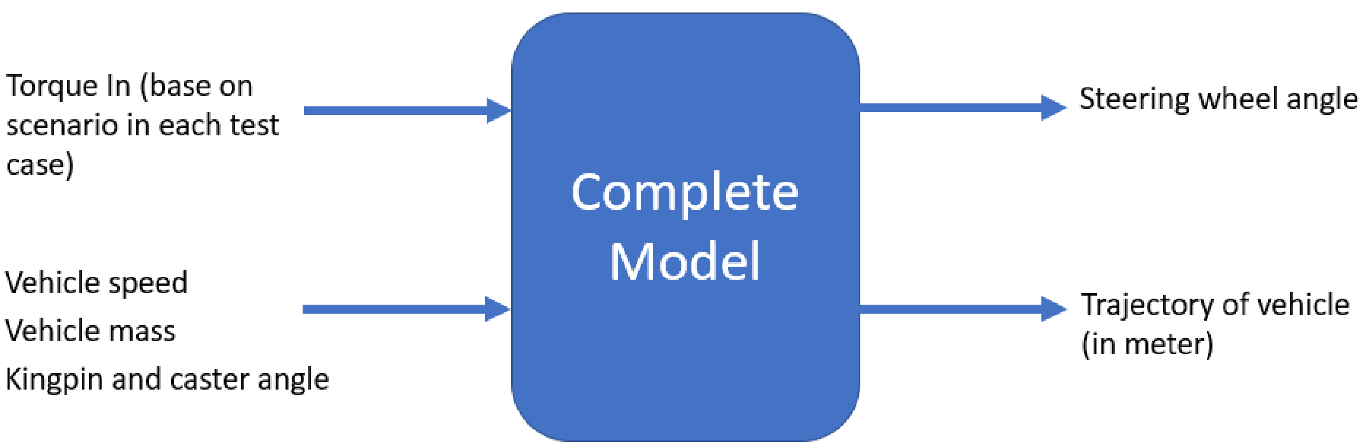


Figure 16: Operation Flow of Complete model

1.2) Steering dynamics block

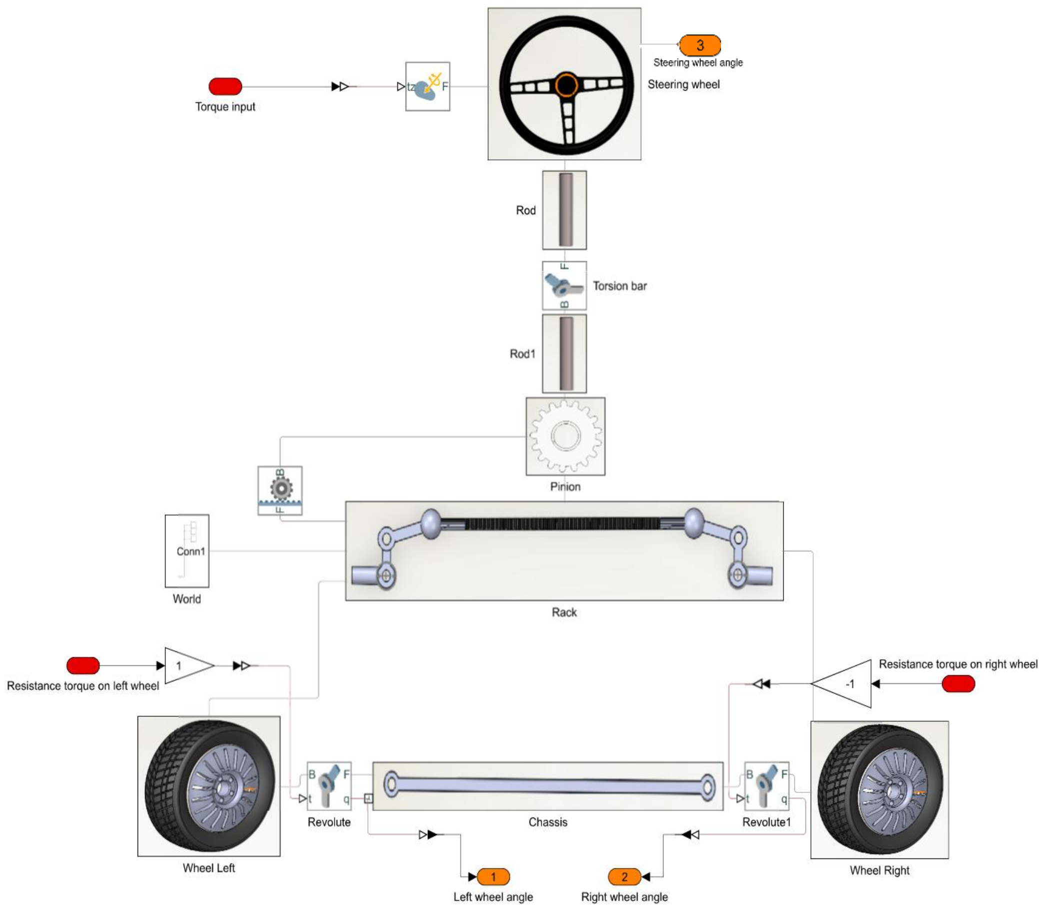


Figure 18 : Complete model

After building 3D models on SolidWorks, using Matlab/ Multibody to build dynamic models and simulate the models to evaluate the technical characteristics of the Electric steering system.

To be specific, the input and output are used in this block will be shown below:

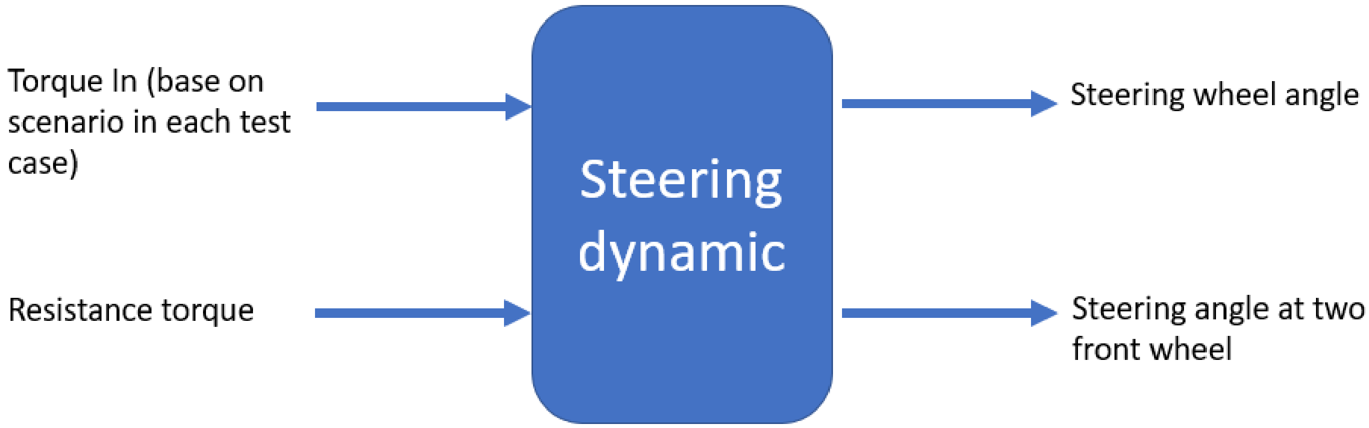


Figure 19: Operation Flow of Steering Dynamic

1.3) Total resistance torque block

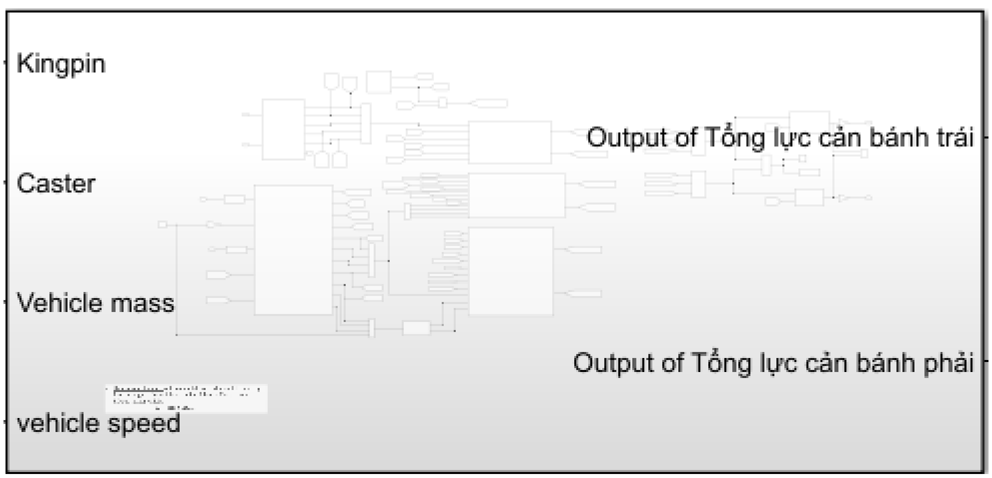


Figure 20: Total resistance torque

This block receives inputs such as Kingpin, Caster, Vehicle Mass, and Speed, and outputs the resistance torques at the left and right wheels.

1.4) Vehicle 3DOF Dual track block

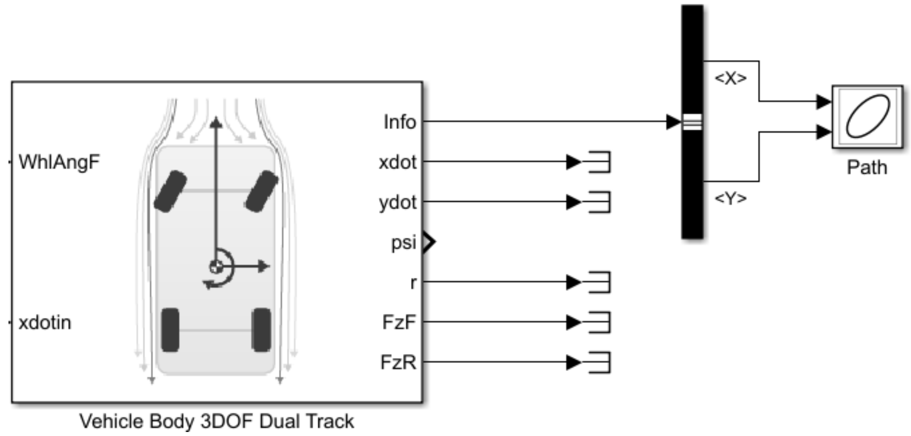


Figure 21: 3DOF Dual Track block

This block takes in the steering angle at the front wheel (WhlAngF) and the vehicle speed in the x-direction (xdotin), and outputs the **trajectory** of the vehicle as a combination of its X and Y coordinates.

2. Dynamic steering system

2.1) Block corresponding to the part in Mechanics Explorer

Determining the corresponding block or module for a part in Mechanics Explorer is crucial for understanding and analyzing the properties and performance of the system's components. By identifying the corresponding block or module, parameters and settings of that block can be observed and adjusted them to achieve the design goals or analyze the system's performance.

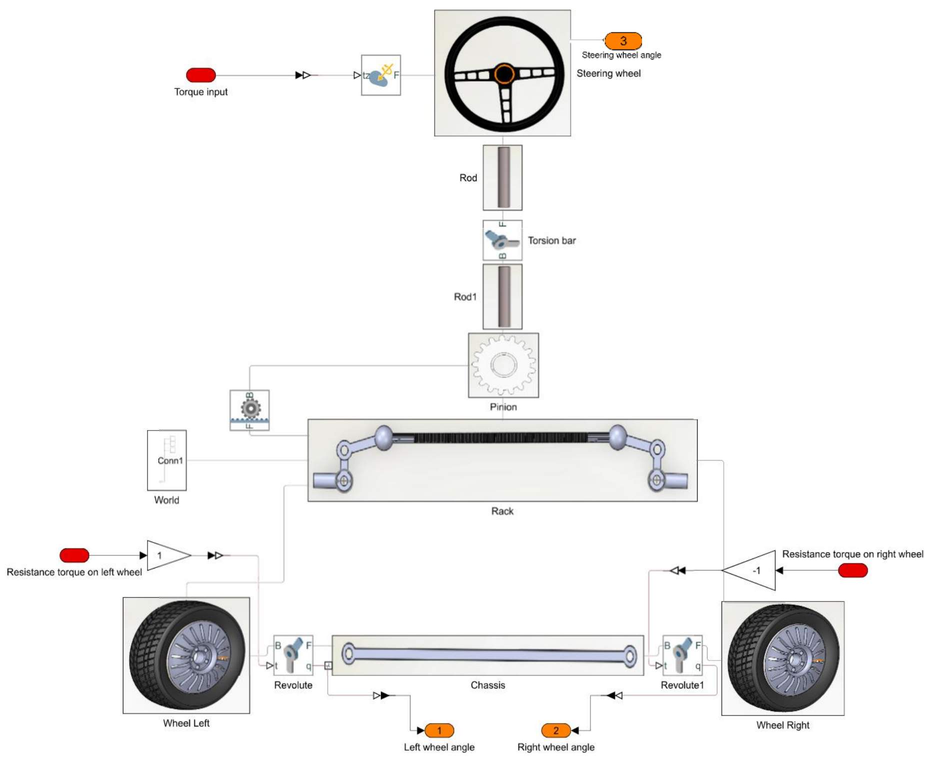


Figure 22 : Steering Dynamic

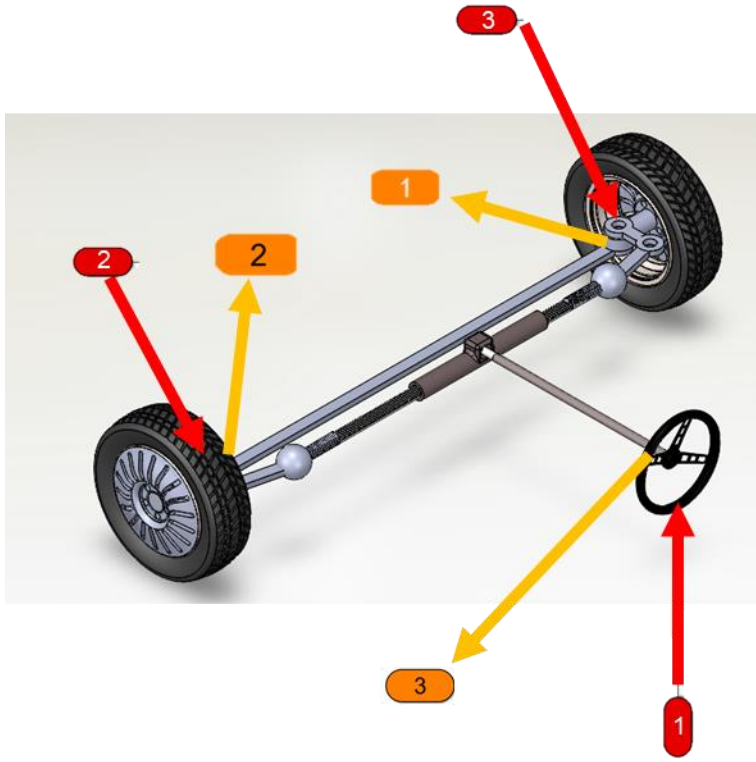


Figure 23: Input and Output

2.2) Simulation scenarios

a. Relationship between torque input and steering wheel angle

To understand the relationship between torque input and steering wheel angle, two test case has been developed. Both test case use parameters in below table:

Parameters	Value
Vehicle mass (full load)	1520kg
Caster	5 degree
Camber	9 degree

Table 7 : Parameters for simulation

In first scenario, vehicle will run with v=1km/h, we get the result:

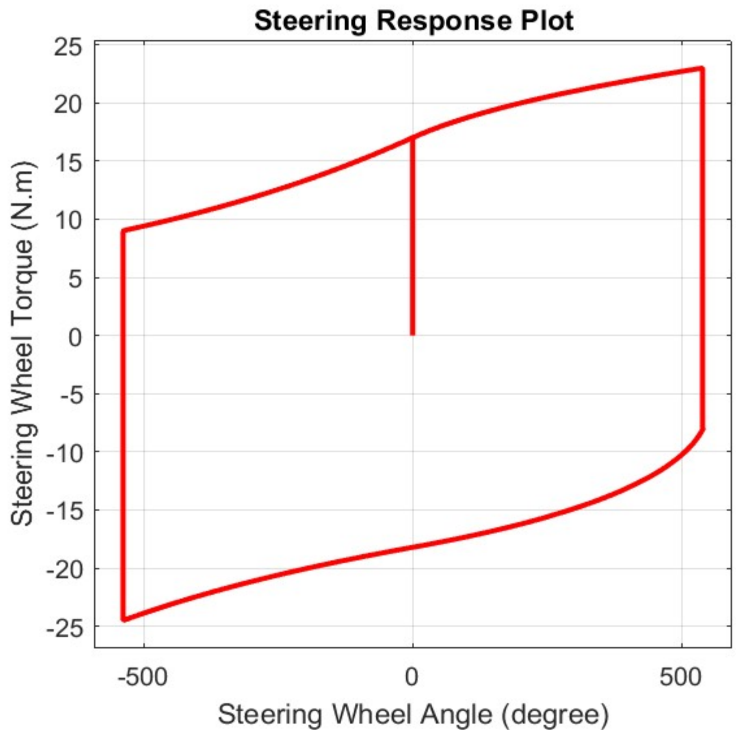


Figure 24: Model Simulation at 1km/h

Comparison with real vehicle experiments is recommended to validate the relationship between steering torque and vehicle speed observed in this study.

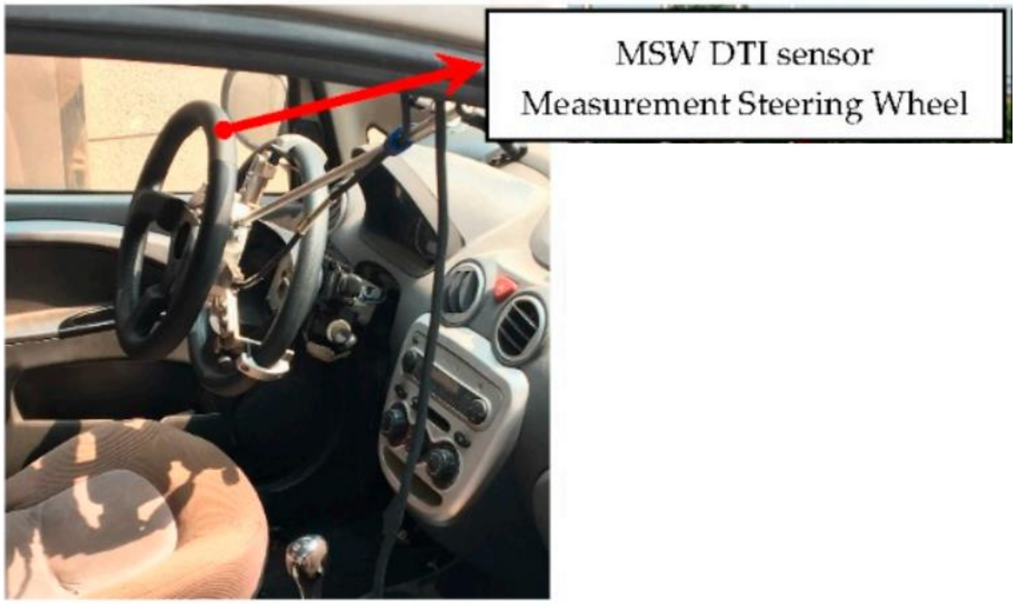


Figure 26: Real Vehicle Testing

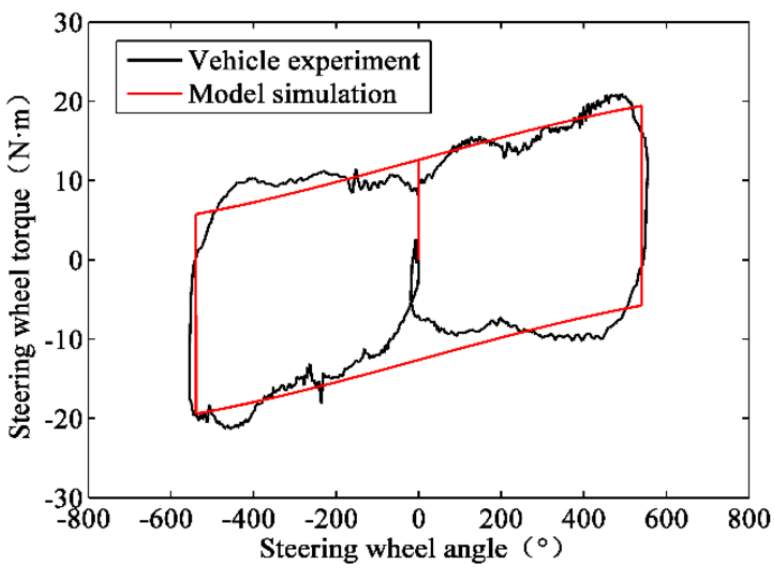


Figure 25:Real Vehicle Testing at 1km/h

In second scenerio, vehicle will run with v=5km/h, we get the result:

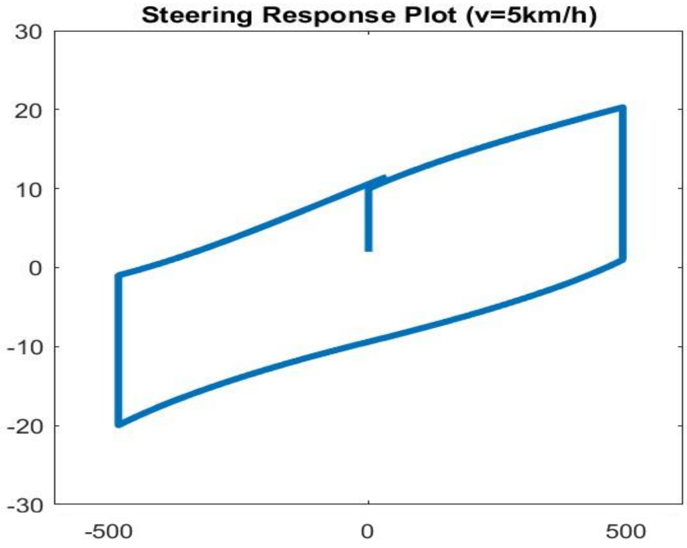


Figure 28: Model Simulation

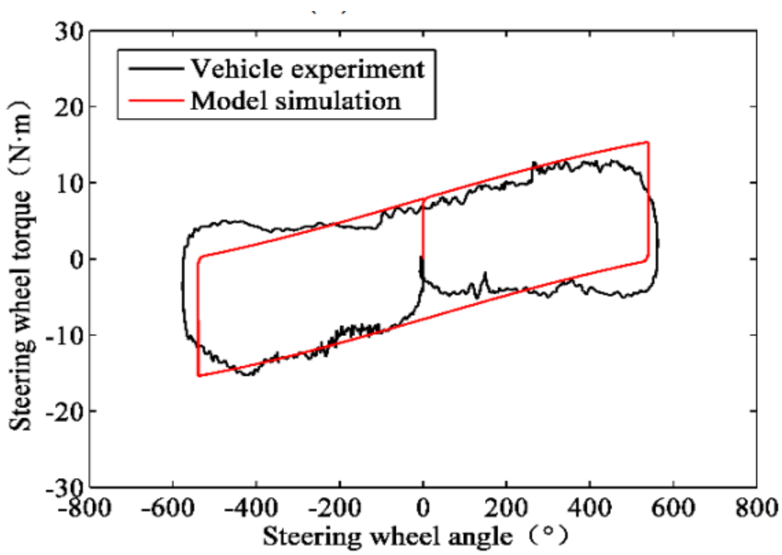


Figure 27: Real Vehicle Testing at 5km/h

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Similarly, diagram above shows the relationship between torque and steering wheel angle at 5km/h

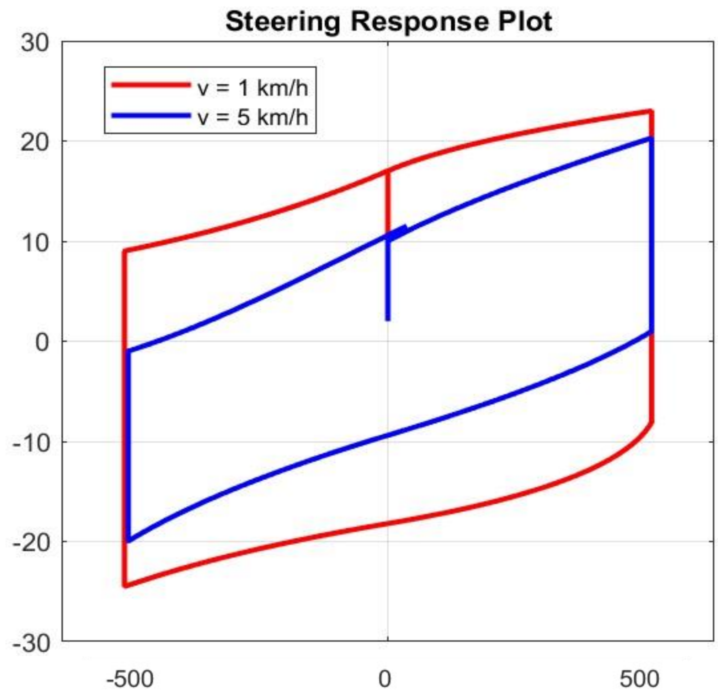

Figure 29: Result Comparision

By conducting both simulation and real vehicle testing, we were able to observe that the simulation results closely matched the real-world results. This close agreement between the simulation and real-world testing provides a strong validation of the simulation model, and underscores the value of using simulation to investigate complex engineering problems. The ability to accurately simulate real-world behavior can help to reduce the need for costly and time-consuming physical testing, and can provide valuable insights into the performance and behavior of complex systems. Overall, the close agreement between the simulation and real-world results highlights the effectiveness and reliability of simulation as a tool for engineering design and analysis.

b. Steering effort corresponds to the changes of vehicle weight and speed

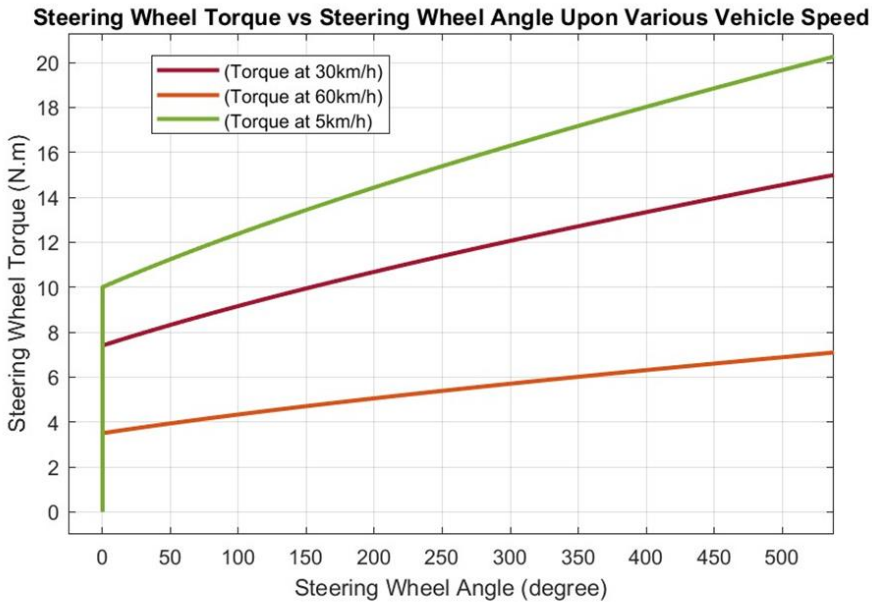

Figure 30 : Steering Effort with various speed

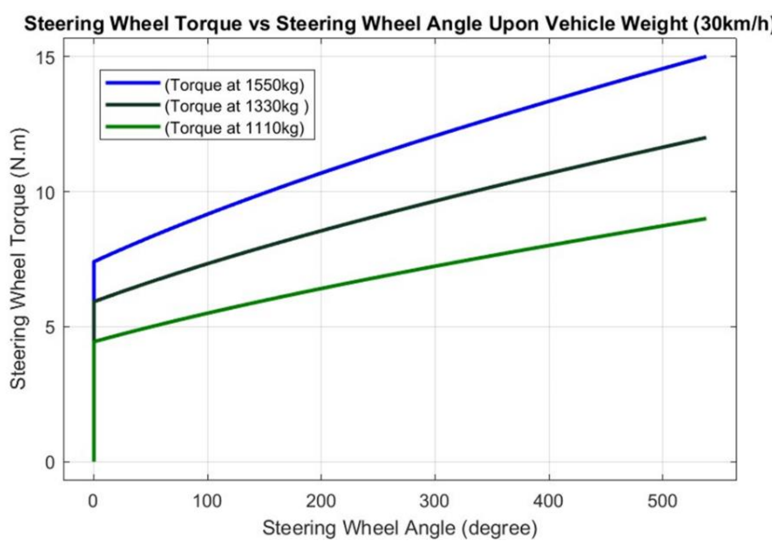

Figure 31: Steering Effort with various weight

We aimed to investigate the relationship between steering force and vehicle speed/weight using increasing torque input (angular acceleration = 0) to turn the steering wheel and determine the necessary force/torque to steer. We conducted two separate experiments to explore this relationship under different conditions.

In the figure 30, we observed the force required to steer at different vehicle weights and speeds. Specifically, we tested the steering force required to steer a vehicle weighing 1550kg at speeds of 5km/h, 30km/h, and 60km/h. To ensure accuracy, we repeated each test three times and computed the average force required for each weight and speed combination. We found that the force required to steer decreased as the speed of the vehicle increased. This suggests that the steering system becomes more effective at higher speeds, likely due to the increased stability of the vehicle and the greater centrifugal forces acting on the vehicle.

In figure 31, we explored the relationship between steering torque and vehicle weight at a constant speed of 30km/h. We varied the weight of the vehicle from 1110kg (unloaded) to 1550kg (fully loaded) and observed the torque required to steer the vehicle at each weight. Similar to the first case, we repeated each test three times and computed the average torque required for each weight. We found that the torque needed to steer the vehicle decreased as the weight of the vehicle decreased. This suggests that steering systems can be optimized to require less torque at lower vehicle weights, which could be beneficial for improving vehicle handling and fuel efficiency.

V. CONCLUSION AND FUTURE WORK

It is important to note that all the simulation models discussed above have successfully achieved our objectives. By simulating the behavior of the steering system in a virtual environment, these models have been able to optimize the design and performance of steering components and systems for different vehicle speeds and driving conditions. This has led to improved safety and handling at higher speeds.

However, it is important to consider that with the increasing of weight and decreasing of speed, the required torque to steer is increasing. This means that the steering system must be designed to handle different weight loads and speeds to ensure optimal performance. By taking into account the relationship between steering torque and vehicle speed, designers can develop steering systems that provide the appropriate level of control and responsiveness for different driving conditions.

In conclusion, the relationship between steering torque and vehicle speed is a crucial aspect of steering system design and performance. By using simulation models to optimize steering system design, researchers and designers can tailor steering systems to provide the appropriate level of control and responsiveness for different vehicle speeds and driving conditions. The findings of these studies provide valuable insights for the design and optimization of steering systems in vehicles, emphasizing the importance of considering the effects of vehicle speed on steering performance.

Appendix

Tire Size	Camber	Caster	King Pin Angle
175/65R14	-0°08' +/- 0°45' (-0.13° +/- 0.75°)	4°41' +/- 0°45' (4.68° +/- 0.75°)	11°14' (11.23°)
185/60R15	-0°08' +/- 0°45' (-0.13° +/- 0.75°)	4°41' +/- 0°45' (4.68° +/- 0.75°)	11°13' (11.21°)

Table 8 : Tires and kingpin axle parameters

No.	Parameter Name	Unit	Value
1	Overall dimensions (length x width x height)	mm	4300 x 1700 x 1460
2	Wheelbase	mm	2550
3	Track width (front/rear)	mm	1470/1460
4	Curb weight	kg	1055-1110
5	Gross vehicle weight	kg	1520
6	Tires and wheels		185/60R15 Alloy wheels
7	Steering wheel angle	degree	-540 -> 540

Table 9 : Overall parameters of VIOS car

VII. REFERENCE

1. Cossalter, Vittore. Motorcycle Dynamics. Lulu, 2010.
2. Genta. The Automotive Chassis. Springer International Publishing, 2020.
3. Hiremath, R. R., and Isha, T. B. “Modelling and Simulation of Electric Power Steering System Using Permanent Magnet Synchronous Motor.” IOP Conference Series: Materials Science and Engineering, vol. 561, no. 1, 2019, p. 012124, doi:10.1088/1757-899X/561/1/012124.
4. Jazar, Reza N. Vehicle Dynamics: Theory and Applications. Springer, 2008.
5. Nasir, M. Z., et al. “Hardware-in-the-Loop Simulation for Automatic Rack and Pinion Steering System.” Applied Mechanics and Materials, vols. 229-231, 2012, pp. 2135-2139, doi:10.4028/www.scientific.net/AMM.229-231.2135.
6. Nemes, Radu-Octavian, et al. “Integration of Real-Time Electric Power Steering System MATLAB/Simulink Model into National Instruments Veristand Environment.” 2018 IEEE 18th International Power Electronics and Motion Control Conference (PEMC), 2018, doi:10.1109/epepemc.2018.8521888.
7. Pacejka, Hans B. Tyres and Vehicle Dynamics. Butterworth-Heinemann, 2002.
8. Qun, Zhang, and Juhua, Hu. “Modeling and Simulation of the Electric Power Steering System.” 2009 Pacific-Asia Conference on Circuits, Communications and Systems, 2009, doi:10.1109/PACCS.2009.67.
9. Ingale, Amol. “Modeling Mass-Spring-Damper System Using Simscape.” Journal of Engineering Research and Application, no. Preprint, no date, doi:10.9790/9622-0801033033.
10. Sh., A., H., E., and A., E.-H. “Side-Stick Control of Power Rack and Pinion Steering System.” The International Conference on Applied Mechanics and Mechanical Engineering, vol. 12, no. 12, 2006, pp. 383-396, doi:10.21608/amme.2006.41261.
11. Setiawan, A. and Baharom, M. R. "Development of Force Feedback in Steering

Systems: A Review." Journal of Mechanical Engineering and Sciences, vol. 9, no. 1, 2015, pp. 1573-1586, doi:10.15282/jmes.9.1.2015.12.0147.

12. Tuan, N. A., and Thang, N. V. "Determining the Vertical Force When Steering." Journal of Science and Technology, vol. 55, no. 3, 2017, pp. 7-14, doi:10.15625/2525-2518/55/3/9129.
13. Nguyen, V. H., et al. "Study on Low-Speed Steering Resistance Torque of Vehicles Considering Friction between Tire and Pavement." Journal of Mechanical Engineering Research and Developments, vol. 41, no. 4, 2018, pp. 51-60.
14. "Front Steering Gear Link." Toyota Vios / Soluna Vios, Japan Parts EU, 2010, http://www.japan-parts.eu/toyota/gr/2010/vios-soluna-vios/ncp42l-eepskr/2_149310_015/powertrain-chassis/4505_front-steering-gear-link/1.
15. Huu, Nguyen Ngoc and Quang, Tran Ngoc. "Real-Time Simulation of Electronic Power Steering System on TOYOTA VIOS." Proceedings of the 2nd Annual International Conference on Material, Machines and Methods for Sustainable Development (MMMS2020), edited by Bui Trong Long et al., Springer, 2021, pp. 273-281, doi:10.1007/978-3-030-69610-8_28.
16. Pang, Jong-Hyuk and Jang, Seong-Ho. "Steering Wheel Torque Control of Electric Power Steering by PD-Control." International Journal of Automotive Technology, vol. 12, no. 3, 2011, pp. 391-397, doi:10.1007/s12239-011-0050-5.
17. Inallu, Prasanthi and Raju, G. Jaya Krishna. "Design of Steering Wheel Force Feedback System with Active Disturbance Rejection Control." 2018 International Conference on Circuit, Power and Computing Technologies (ICCPCT), 2018, pp. 1-5, doi:10.1109/ICCPCT.2018.8473152.
18. Sharma, R., Ganai, P., Pare, V., Kanchwala, H., Srihari, S.J. (2023). Validation of a Steering System Mathematical Model via Test Rig Measurements. In: Gupta, V.K., Amarnath, C., Tandon, P., Ansari, M.Z. (eds) Recent Advances in Machines and Mechanisms. Lecture Notes in Mechanical Engineering. Springer, Singapore.

https://doi.org/10.1007/978-981-19-3716-3_13

19. Kang, Seung-Woo and Oh, Jung-Hwan. "Active Return-to-Center Control Based on Torque and Angle Sensors for Electric Power Steering Systems." International Journal of Automotive Technology, vol. 22, no. 6, 2021, pp. 1867-1874, doi:10.1007/s12239-021-0177-7.
20. Đặng, Quý. Tính Toán Thiết Kế Ôtô. NXB Hồ Chí Minh, 2001.