A Study of Semi-Active Steering System Performance On An All-Wheel Drive Flat Chassis Vehicle

By

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Dissertation submitted in partial fulfillment of
the requirement for the
Bachelor of Engineering (Hons)
(Mechanical Engineering)

JANUARY 2014

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CERTIFICATION OF APPROVAL

A STUDY OF SEMI-ACTIVE STEERING SYSTEM PERFORMANCE ON AN ALL-WHEEL DRIVE FLAT CHASSIS VEHICLE

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Project Dissertation submitted to the

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In partial fulfillment of the requirement for the

BACHELOR OF ENGINEERING (Hons)

(MECHANICAL ENGINEERING)

Approved by :

....

(Mui'nuddin Bin Maharun)

Main Supervisor

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JAN 2014

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or personal.

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ABDUL MUHAIMIN BIN MD SHAHID

ABSTRACT

There are many type of steering system exist nowadays. However, the main focus of this paper is to study on the Semi-active steering (SAS). This project deals with the effect of using SAS in combination with the flat chassis. One of main concern for using a conventional steering method is the lack of backup steering system. The recently developed steer-by-wire (SBW) system does have a backup system. However, the difference between SAS and SBW is in the usage of a flexible shaft in the SAS system, while SBW uses a rigid shaft. This, combine with flat chassis with all in-wheel motor configuration provide a new and simpler package of car. This paper will collect the data and analyse the effect of SAS on flat chassis vehicle. The result will then be compared with the conventional system currently used.

ACKNOWLEDGEMENT

First and foremost, my deepest gratitude to Allah SWT for His blessing and Guidance in various aspects for me to accomplish my final year project entitled "A Study of Semi-Active Steering System Performance on an All-Wheel Drive Flat Chassis Vehicle". Not to forget, special thanks to my parent and family members for their continuous support and encouragement towards me all this while completing this project.

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ABBREVIATIONS AND NOMENCLATURES

SAS: Semi-active steering

EV: Electric vehicle

ICE: Internal combustion engine

FYP: Final Year Project

SLC: single lane change

CG: centre of gravity

SS: step steer

CHAPTER 1: INTRODUCTION

1.1 Problem statement

1. During the event of failure, some steering system may cause catastrophic incident, with the conventional steering system only relying on the mechanical linkage between steering and the tyre for control.
2. For packaging purpose, the installation on the flat Electric Vehicle (EV) chassis is more favourable, as the parts are easily packaged and assembled.
3. A steering system with conventional Hydraulic Power-Assisted Steering (HPAS) is consuming is not fuel efficient as they will consume fuel to be operated.

1.2 Objectives :

1. To model a vehicle with the semi-active steering (SAS) system using the ADAMS/Car software and a finite element analysis (FEA) software.

2. To simulate and analyse the performance of the vehicle with SAS as compared to the conventional rack and pinion steering system

1.3 Scope of Study

The main purpose of the project is to develop a vehicle dynamic model for a vehicle with an SAS system by using ADAMS/Car software. The scope of study for this project title include mainly the study of steering system of a vehicle. This also include the rack and pinion steering, power steering, and the Steer-By-Wire (SBW) system It is also important to study on the steering effect of a vehicle. The scope of study also involve the understanding of flat chassis.

CHAPTER 2: LITERATURE REVIEW

2.1 Steering system

2.1.1 Rack and pinion

The conventional steering system that are most commonly used are the rack and pinion steering. The steering system is fully dependent on mechanical linkage between the steering and the wheel by utilising the rack and pinion gear mounting. The light and compact design of the steering gear make it suitable for a FWD vehicle. Since there are few friction points in the rack and pinion steering, the driver has a greater feeling of the road through the steering wheel. However, fewer friction points reduce the steering system's ability to isolate road noise and vibration [5].

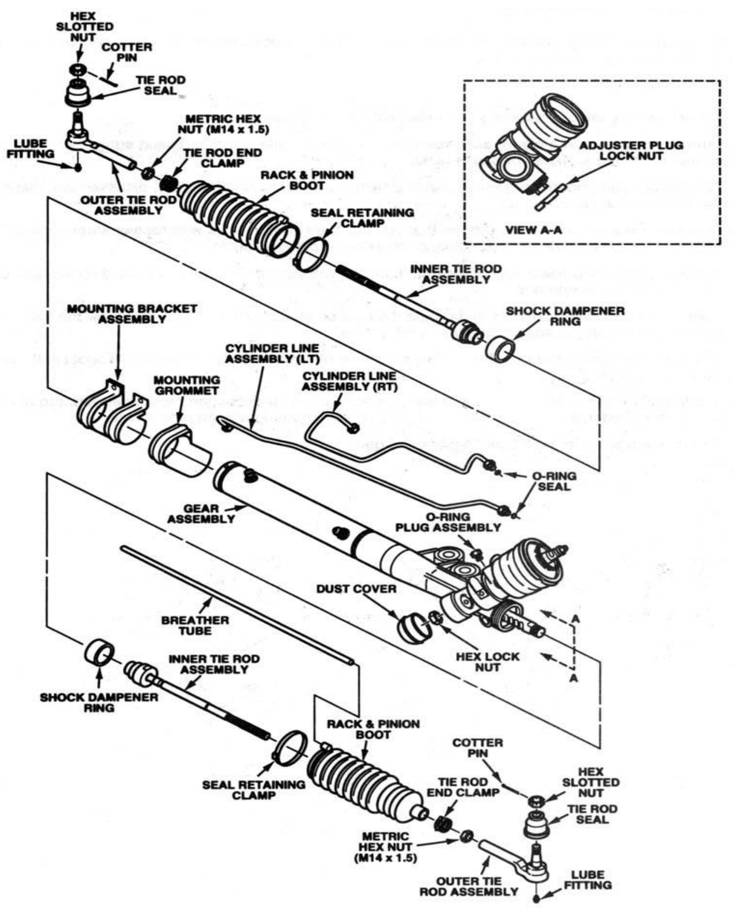


Figure 1: Exploded view of a typical rack-and-pinion system [15]

As the manual rack and pinion system become heavier to steer, especially on a heavy duty vehicle, power steering was invented [1]. The system still use the same pinion and rack mechanical linkage. However, power assisted steering has additional components that functions to reduce the driver's steering force [5]. There are two types of power steering that are used. One is Hydraulic Assisted Power Steering (HAPS), and another one is Electric Power Steering (EPS) [2].

HAPS systems includes the following:

- Power cylinder – a hydraulic cylinder inside the rackor gear housing
- Power piston – a double-acting, hydraulic piston in the power cylinder that acts upon the rack
- Control valve mechanism – located in the steering gear; senses and controls power assist
- Hydraulic lines – steel tubing from the control valve to the power cylinder that carries the power steering fluid
- Most power rack-and-pinion units have a small tube that runs along the housing and connects to each bellows boot. This tube allows the air pressure in thebellows boots to equalize from one side to the other during turns.

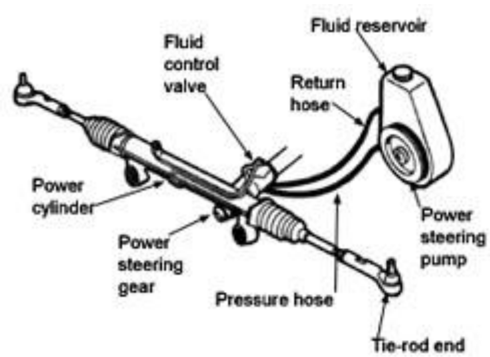


Figure 2: Components of a HAPS [16]

2.1.2 Steer-by-wire

Another steering system that was quite recently developed was Steer-by-Wire (SBW) system [7]. In this system, the linkage between the steering wheel and the wheels are controlled by a computer processing unit. The location of the turning steering wheels are recorded using a sensor, and the data are sent to the computer and interpreted into the turning of the wheels. The advantages of SBW is that the steering control are flexible and customisable. It is even possible to use your game console joystick to control the vehicle. SBW are also able to isolate the road tire noise and vibration. The SBW also has a failsafe system. In case of malfunction, there is still the traditional rack and pinion linkage to switch into [11].

2.1.3 Semi-active Steering (SAS) system

Semi-active Steering (SAS) system also use a similar concept as SBW. However, for the backup system, instead of using a rigid shaft, SAS uses a flexible shaft as a connection between steering and the steering gear.

The most important safety feature of the SAS is that it has a permanent mechanical connection, namely the low stiffness resilient shaft (LSRS), between the steering wheel and the steered wheels. The LSRS is an integral part of the SAS steering system, and is always available to provide a basic steering function in case of system failure. The components are attached as permanent connections and not through clutches or meshing gears that may introduce more failure modes. Thus the system operates as a mechanical steering system in the event of active system failure. Since SBW system reliability is most strongly characterized by electronic system reliability, this represents a considerable advance in addressing the safety issues of such critically important vehicle control systems.

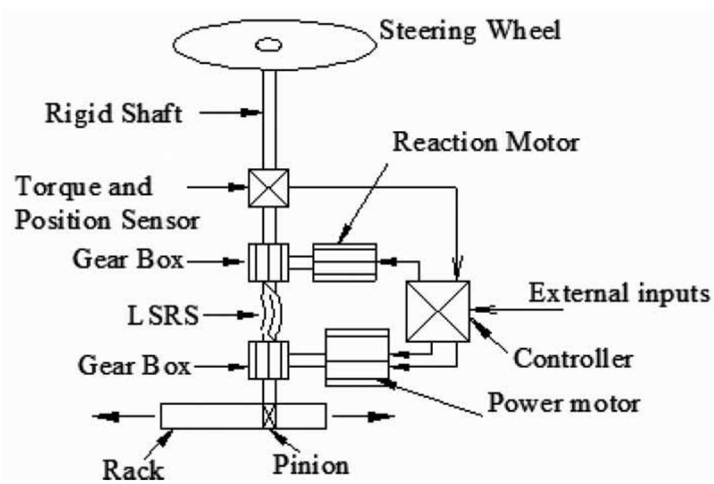


Figure 3: Schematic configuration of semi-active steering system

Thus, this SAS configuration provide the advantage of a more flexible packaging, smoother steering feedback, besides being a safety system [7][8].

2.1.4 Steering Effect

When experimenting on the steering system, we must take into consideration the effect of steering system. There are some examples of steering system effects. The first is the steering ratio, which is defined as the ratio of steering wheel rotation angle to steer angle at the road wheels. Normally, these range from 15 or 20 to 1 on passenger cars, and 20-36 to 1 on trucks.

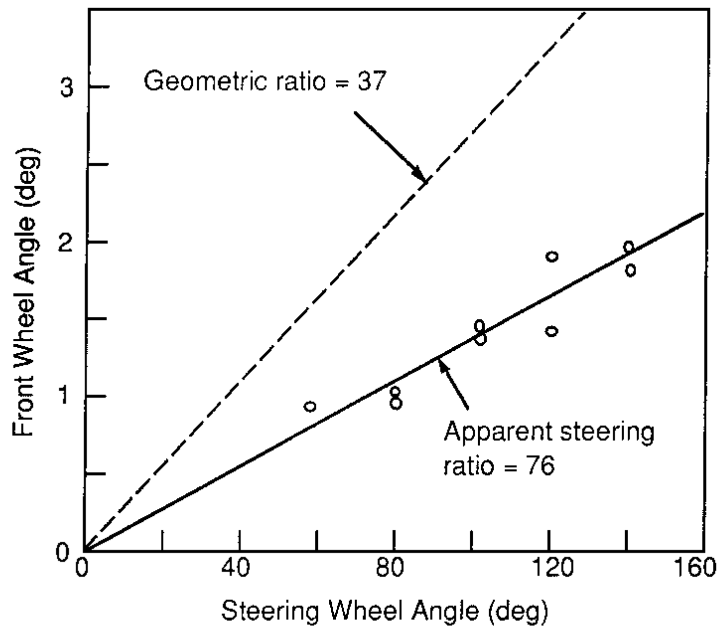


Figure 4: measurement of steering ratio on a truck [14]

Because of the compliance and steer torque gradients with increasing steer angle, the actual steering ratio may be twice as much as the designed ratio. While the compliance property is unchanged on a vehicle, the torque gradient will vary. Hence the actual steering ratio may vary (always above the design value) and influencing the low-speed manoeuvrability. Another steering system effects is the understeer. The steady-state cornering performance of a vehicle is frequently characterised by the understeer gradient measured at the steering wheel. Because compliance in the steering system allows the road wheels to deviate from the steering wheel input, the results obtained are influenced by the steering system properties.[12].

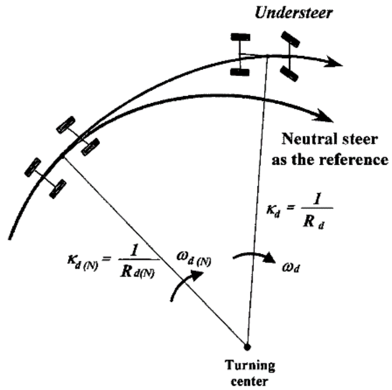


Figure 5: understeer of a truck [14]

The vehicle has a very high understeer gradient at the steering wheel equal to approximately 150 degrees/g (the initial slope of the steering wheel gradient on the plot). Corrected for the ratio of the steering system (36 to 1) it is equivalent to an apparent gradient of 4 degrees/g at the road wheel. However, independent measurement of the road wheel angle indicated an initial slope that is nearly horizontal- equivalent to neutral steer at the road wheel. The differences arises from deflections in the steering linkage as the reactions on the road wheel act against the steering compliance [14].

The magnitude of the steering system contribution is dependent on the front wheel load and caster angle. From a simple analysis for the understeer influences in which the lateral forces and the aligning torques are dominant (neglecting vertical force effects), it can be shown that the understeer gradient is:

$$K_{strg} = \frac{W_f(rv + p)}{K_{ss}}$$

Where:

K_{strg}	= Understeer increment (deg/g) due to the steering system
W_f	= Front wheel load
r	= wheel radius
p	= pneumatic trail associated with aligning torque
v	= caster angle
K_{ss}	= Steering stiffness between road wheel and steering wheel

As seen here, caster angle and aligning torque effects add to the understeer in the presence of a compliant steering system. For typical values of the above parameters, the equation above would account for understeer increments on the order of 4-6 deg/g.

Another steering system effect is the braking stability. The steering system design plays an important role in the directional response [13]. The design especially has a direct effect on stability and resistance to brake imbalance effects. Vehicle pitch and front suspension windup may overcome the few degrees of caste angle designed into the system at normal trim conditions. Moreover, the tire aligning torques which effectively act like 4-8 degrees of caster angle under free-rolling conditions can also reverse in direction during braking. This tire effect is illustrated in figure 5, where the plot is obtained by dividing the aligning torque by the lateral force to determine the pneumatic trail at each data point. The result shows that the normal stabilizing effects of positive caster and tire aligning torque may be substantially reduced or eliminated during high-level braking.

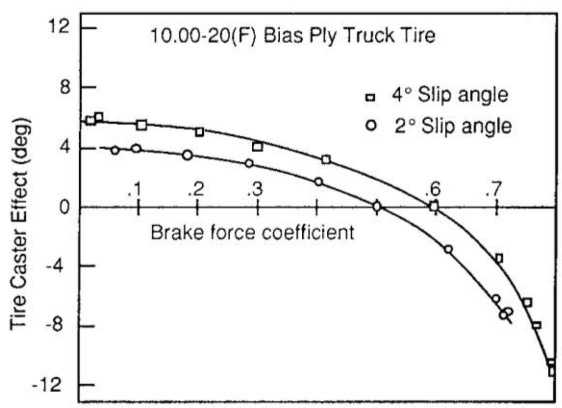


Figure 6: Change of tire aligning torques with braking coefficient [14]

Brake force imbalance will also act on the compliant steering system, attempting to steer the vehicle. Using split coefficient surface as an example, the higher the brake force on the high-coefficient surface will attempt to rotate the vehicle onto that surface by virtue of the moment produced on the vehicle. With a positive lateral offset, the dominant front wheel brake force on the high-coefficient surface will also attempt to steer the vehicle onto that surface. The brake force steering effect may be as much as 2-3 times greater than the direct moment on the vehicle in causing the vehicle to veer onto the high-coefficient surface. Negative offsets have been used on certain cars to counteract this mechanism on split coefficient braking, and when diagonal-split brake failure modes are employed [14].

2.2 Chassis

Chassis type also comes in many variation. One of them is the ladder frame. The ladder frame is the simplest and oldest of all designs. It consists merely of two symmetrical rails, or beams, and crossmembers connecting them [6]. The design provide good beam resistance because of its continuous rails from front to rear, but low resistance to torsion or warping if simple, perpendicular crossmembers are used. Also, the vehicle's overall height will be higher due to the floor pan sitting above the frame instead of inside it.

The space frame are also available. Space frame is a truss-like, lightweight rigid structure constructed from interlocking struts in a geometric pattern. In a vehicle spaceframe chassis, the suspension, engine, and body panels are attached to a skeletal frame of tubes, and the body panels have little or no structural function. A drawback of the spaceframe chassis is that it encloses much of the working volume of the car and can make access for both the driver and to the engine difficult [6].

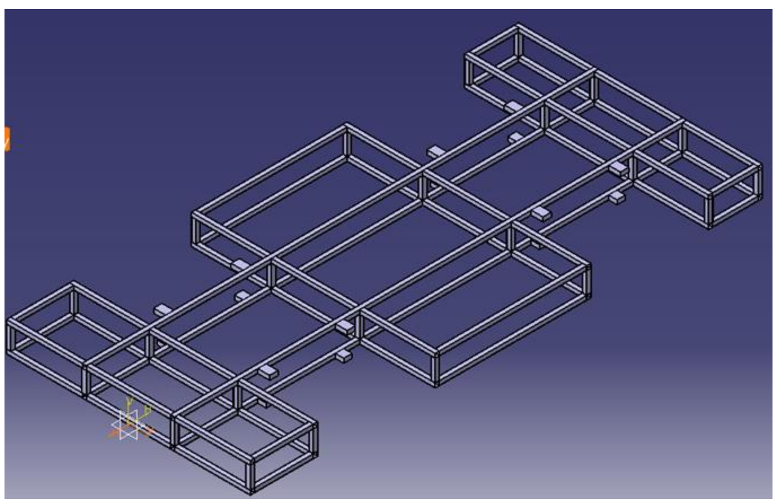
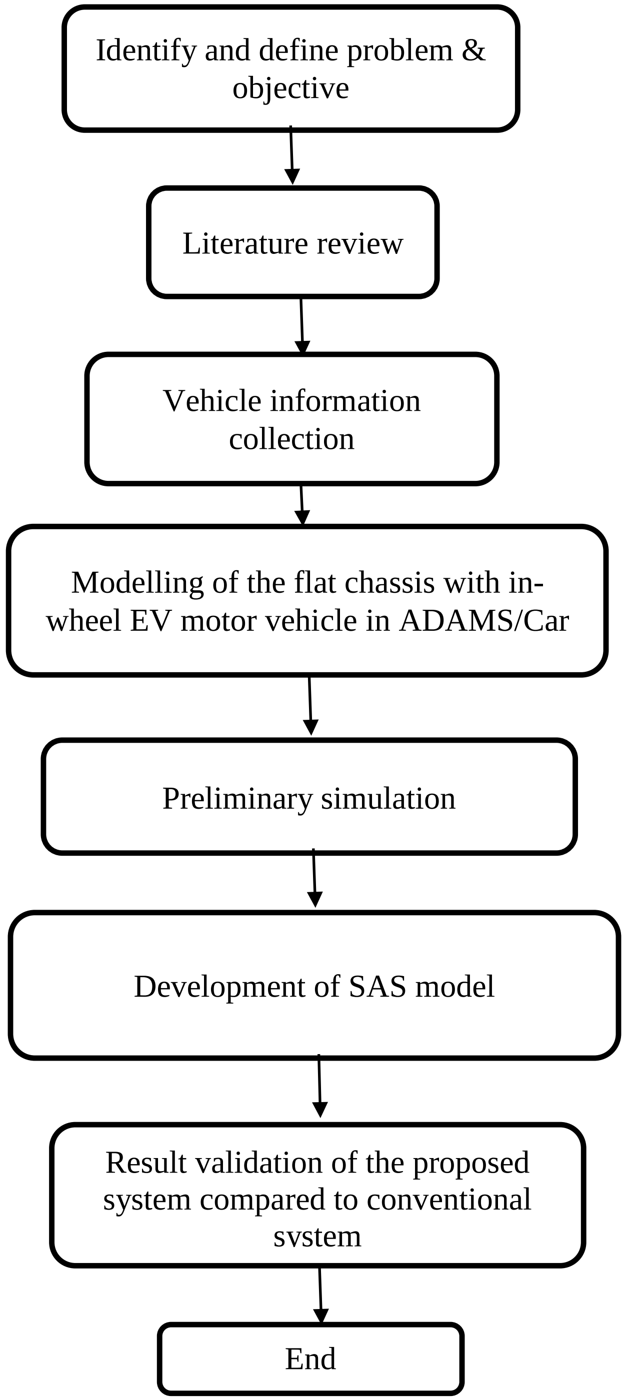


Figure 7: Flat chassis

There are also flat chassis. A substantially flat and relatively thin vehicle chassis enables compact storage of multiple vehicle chassis. This improves packaging and shipping efficiency, reduces plant floor usage for storage during or before testing, assembly or shipping processes, and may reduce overall manufacturing, assembly, shipping, and/or vehicle costs. Flatness of the chassis also increases available passenger space in any attached vehicle body and facilitates compatibility between the chassis and bodies of varying configurations.

CHAPTER 3: METHODOLOGY

3.1 Research Methodology



3.1.1 Explanation of Methodology

3.1.1.1 Identify and define problem & objective:

Define problems statement and the objective of conducting this project. The main purpose is to identify effects of vehicle dynamics when using SAS.

3.1.1.2 Literature review:

Gather articles, paper works and previous study related to the SAS, flat chassis, and all-wheel drive with in wheel EV motor

3.1.1.3 Vehicle information collection:

Collecting information about the vehicle that is to be simulated, such as its size, weight, and hard points

3.1.1.4 Modelling of the flat chassis with in-wheel EV motor vehicle in ADAMS/Car:

This is the base modelling of the vehicle without any modification done to the steering system. Modelling is done in MSC Adams software

3.1.1.5 Preliminary simulation:

Preliminary simulation is done to make sure that the vehicle is correctly modelled.

3.1.1.6 Development of SAS model:

A modification of the steering system is done to make the SAS system. This is done using MSC Nastran and MSC Adams

3.1.1.7 Result validation of the proposed system compared to conventional system:

Simulation was done on the modified vehicle and the result was compared to the unmodified vehicle. Result was analyzed, discussed and a conclusion is reached

3.2 Project Activities

Several activities related to the project were done in order to complete this project. The activities are as mention below:

3.2.1 Extract chassis measurement from CATIA file

3.2.2 ADAMS/Car software:

- Generate subassemblies using templates
- Define appropriate coordinate for wheel centre, suspension parts, and centre of gravity of the vehicle models based on chassis measurement specification
- Apply torque on each wheel by using ADAMS/View interface.
- Verify and simulate vehicle models using “single lane change” (SLC) simulation command
- Verify simulation result data of conventional steering and SAS system

3.2.3 Finite element analysis (FEA) software:

- Flexible shaft is constructed inside the MSC Nastran software.
- The flexible shaft is imported into the Adam/car by converting it into a modal neutral file (mnf)

3.3 Gantt chart

Table 1**:** Gantt chart of FYP 1 and FYP 2

Activity (FYP1)	**Week of May 2013 Semester**													
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**
Preliminary research work			/	/	/		SEM BREAK							
Submission of extended proposal						/								
Proposal defence								/	/					
Modelling of the vehicle with conventional steering										/	/	/	/	/
Submission of Interim Draft Report													/	
Submission of Interim Report														/
Activity (FYP2)	**Week of Sept 2013 Semester**													
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**
Modelling of the vehicle with conventional steering	/	/	/	/										
Preliminary simulation				/	/									
Pre-SEDEX						/								
Development of SAS						/	/	/	/	/	/	/	/	
Result validation with conventional steering system													/	/
Desertation and Viva														/

CHAPTER 4: RESULTs AND DISCUSSION

4.1 Vehicle Modelling in ADAMS/Car

Before making the model of the vehicle in the ADAMS/Car, it is essential to identify the components into several subsystems. The subsystem that will be used inside the vehicle is the chassis, suspensions, tires, breaks, powertrain engine, and steering. These, subsystem is then further divided into minor role, which is either front or rear part.

4.1.1 Brakes

The braking components used in this vehicle is the disk brakes on all the four wheel. The template for the brakes are already available in the ADAMS/Car database under the name "_brake_system_4Wdisk.tpl".

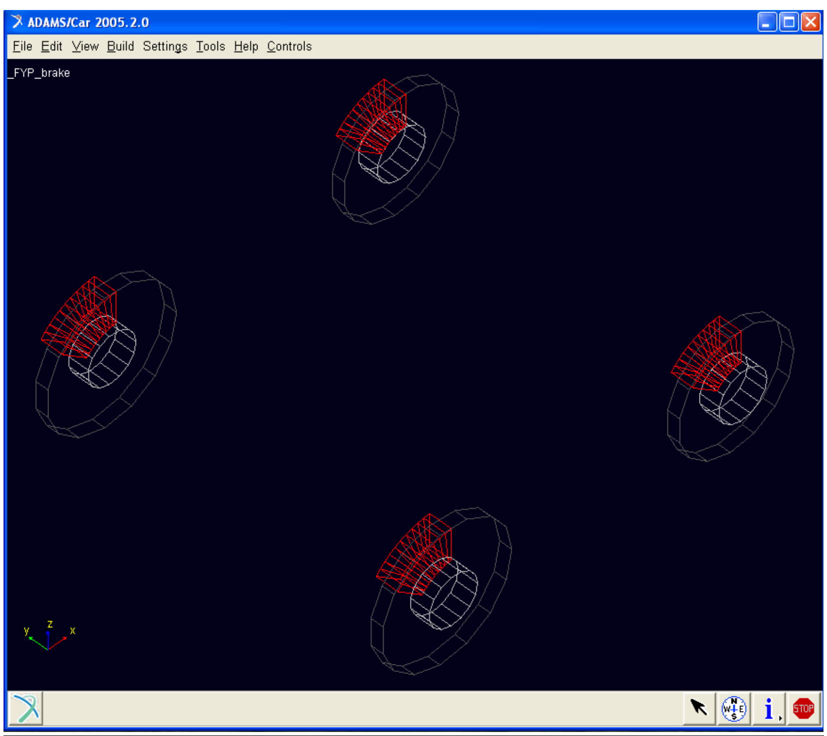


Figure 8 : The render of the brakes used in the vehicle modelling

4.1.2 Suspensions

The type of suspension used in this vehicle modelling is the double wishbone suspension, which can be found under the name "_double_wishbone.tpl". It is used at both the front and back. However, the drive shaft has been removed. The function of a drive shaft is to transmit torque and rotation from engine to the wheels. However, since we are modelling an EV with in-wheel motor, a drive shaft is unnecessary due to the torque coming directly from the motor inside the wheel hub.

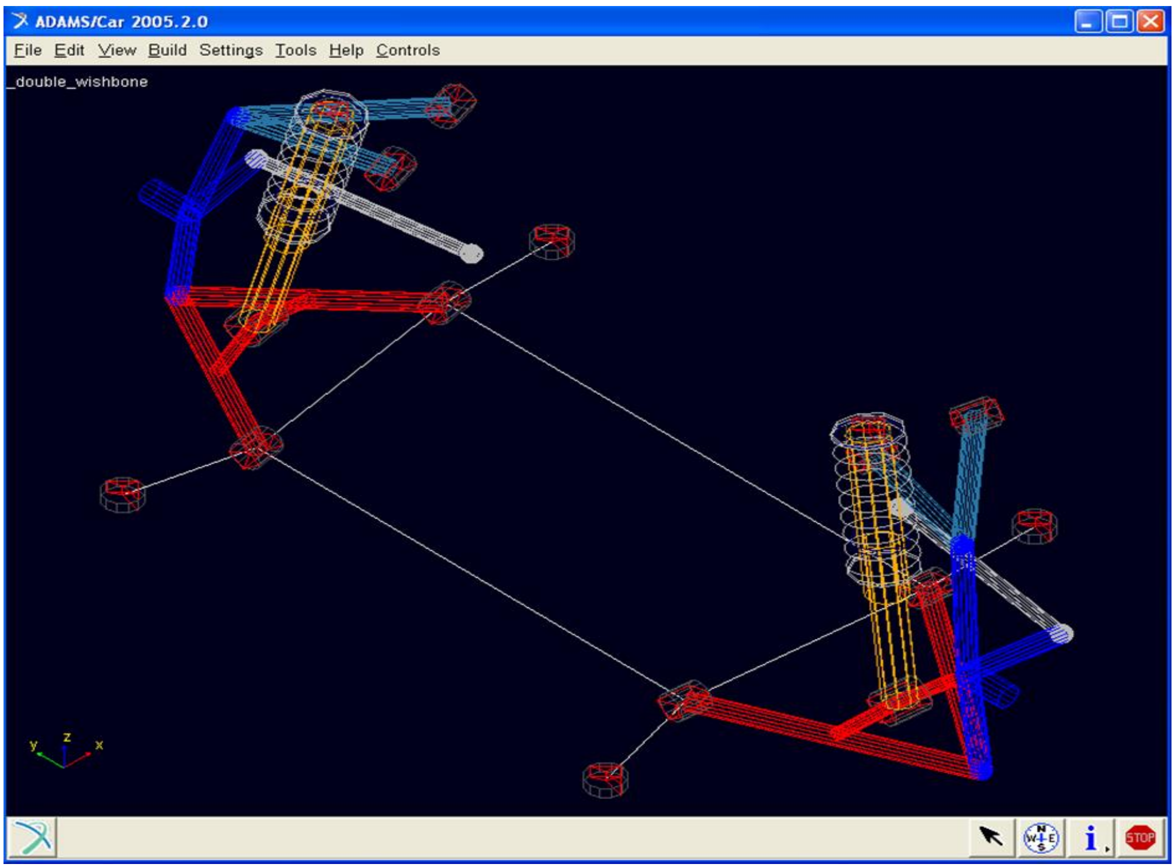


Figure 9: Double wishbone suspension used by front and rear suspension subsystem

Figure 9 shows that the type suspension used at both front and rear wheels. The drive shafts of both suspensions were deleted because; in this project the vehicle will be propelled by four in-wheel motor instead of an ICE.

4.1.3 Chassis

For vehicle body subsystem, template of "_rigid_chassis" in the ADAMS/Car is used to simulate the flat chassis that being used for the vehicle.

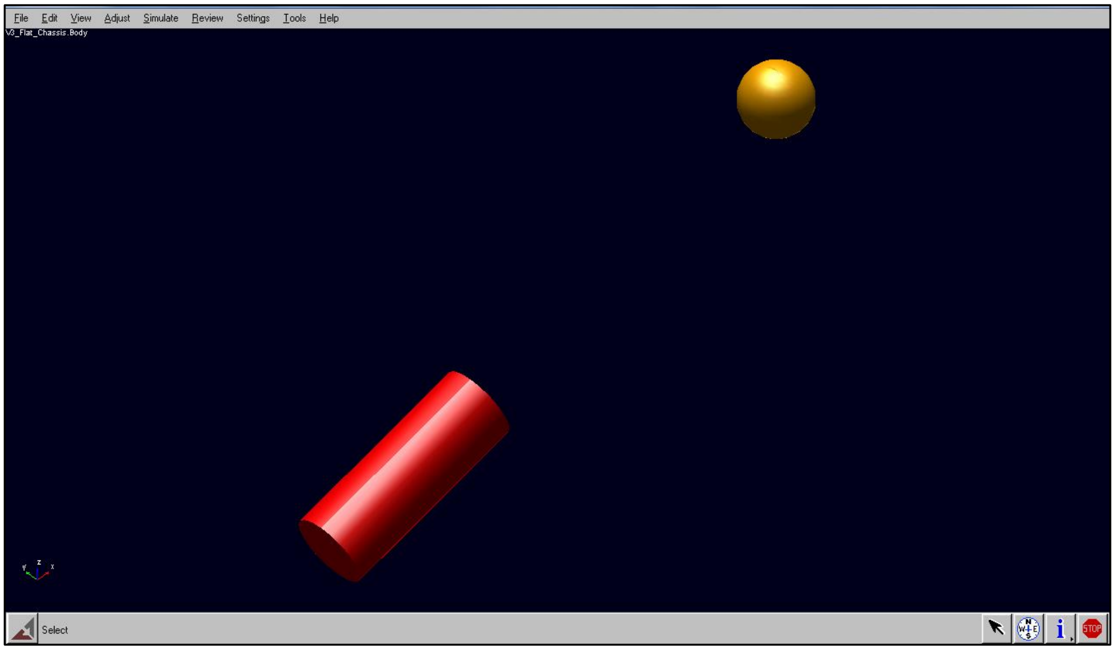


Figure 10: chassis representation in Adams/car

Figure 10 shows the representation of the flat chassis in the ADAMS/Car. The yellow sphere indicate the centre of gravity and is the overall chassis body properties. The red cylinder indicates the steering column housing

4.1.4 Tires

For the type of tire, a normal one is used. The template is "_handling_tire.tpl".

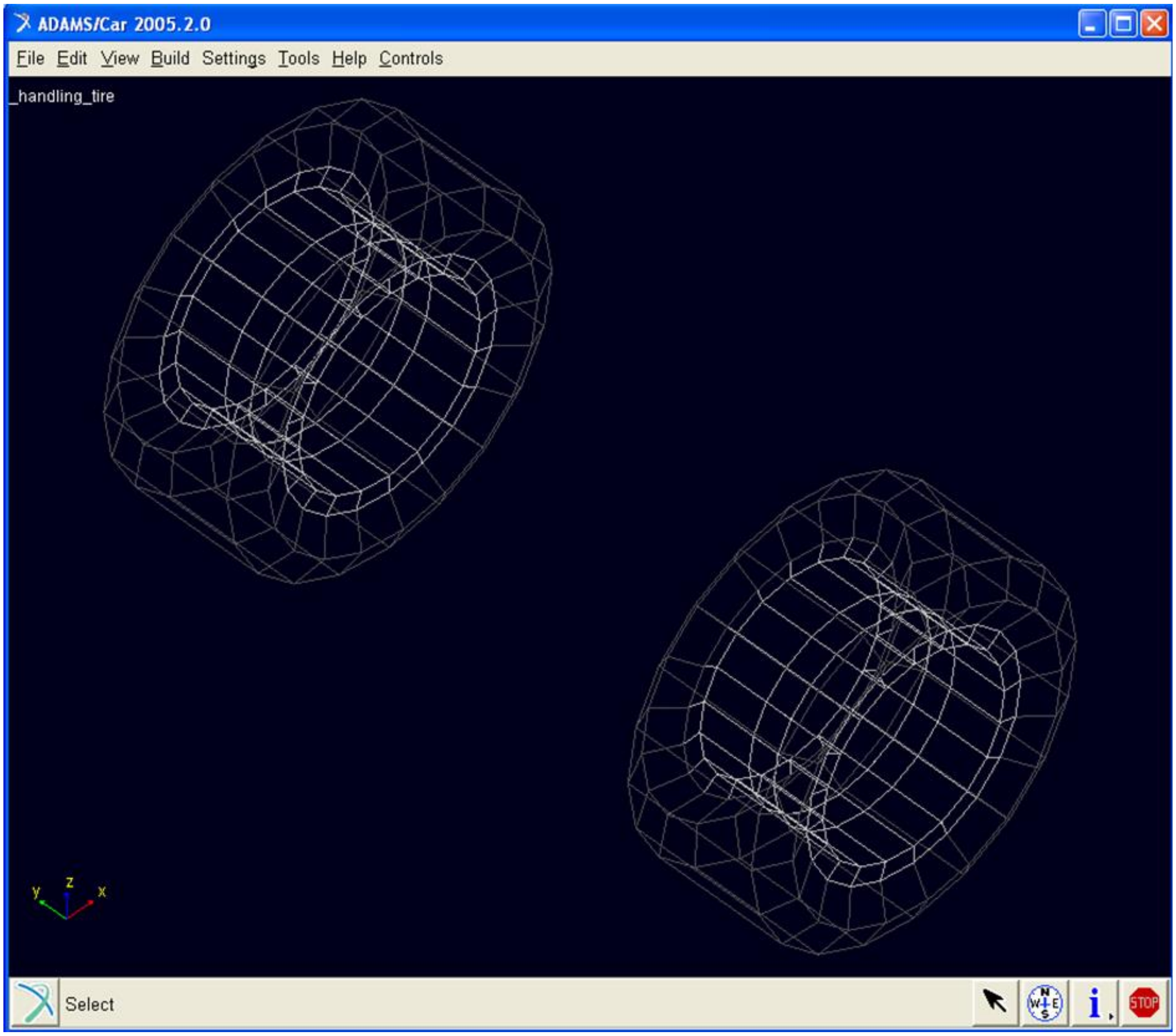


Figure 11: Wheel system used in the project

Figure 11 shows a pair of tire rendering in ADAMS/Car. Two of these are created, of which one with a minor role of the front and another with the minor role of the rear. For this vehicle which will be powered by in-wheel motor, torque will be applied at the centre of each wheel using ADAMS/View.

4.1.5 Steering

Steering subsystem used for this project is rack and pinion type. The template used is "_rack_pinion_steering".

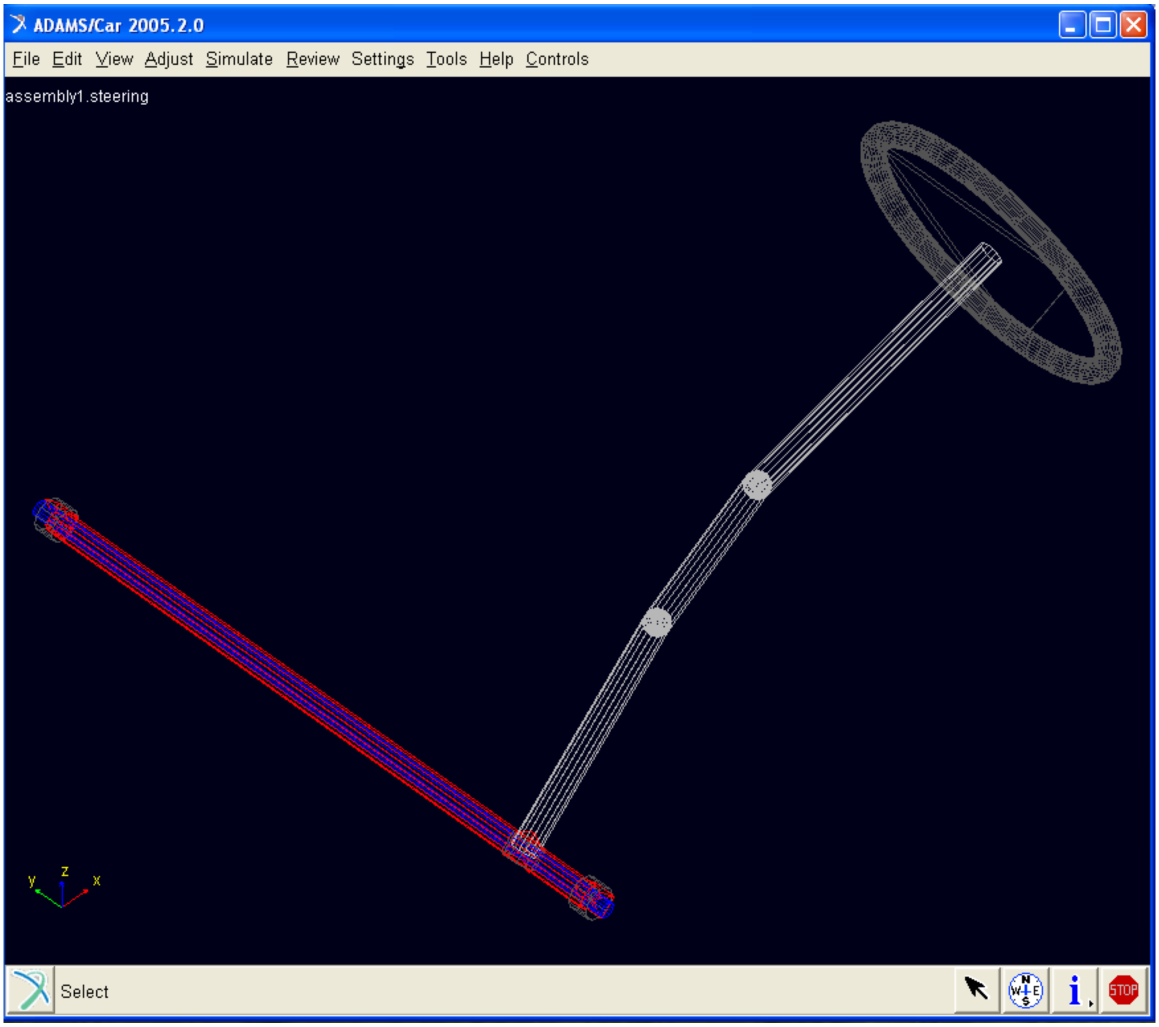
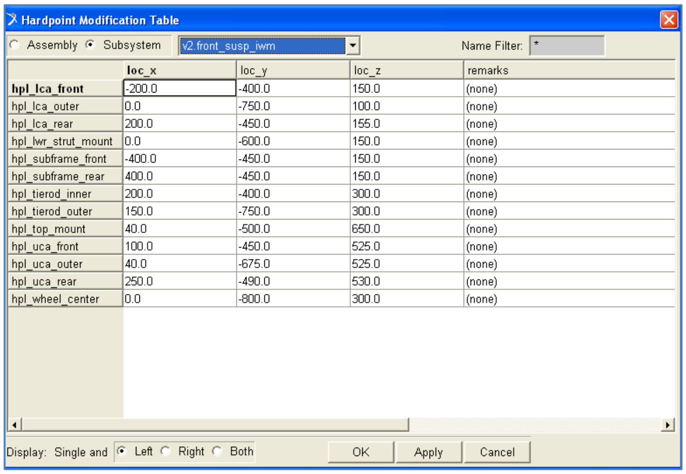


Figure 12: rack and pinion steering.

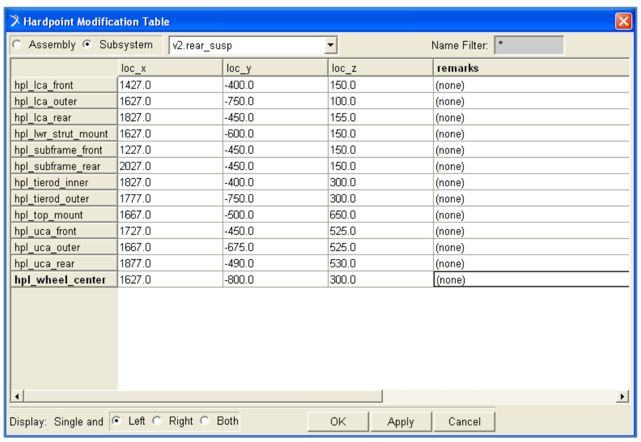
Figure 12 shows that the disk type of brake subsystem used in the project.

Before all the templates of the subsystem save as subsystem file (.sub), the coordinate of the front and rear suspensions need were defined and modified according to the right coordinate generated in CATIA to get an accurate result of ADAMS/Car modeling.



	loc_x	loc_y	loc_z	remarks
hpl_lca_front	-200.0	-400.0	150.0	(none)
hpl_lca_outer	0.0	-750.0	100.0	(none)
hpl_lca_rear	200.0	-450.0	155.0	(none)
hpl_lwr_strut_mount	0.0	-600.0	150.0	(none)
hpl_subframe_front	-400.0	-450.0	150.0	(none)
hpl_subframe_rear	400.0	-450.0	150.0	(none)
hpl_tierod_inner	200.0	-400.0	300.0	(none)
hpl_tierod_outer	150.0	-750.0	300.0	(none)
hpl_top_mount	40.0	-500.0	650.0	(none)
hpl_uca_front	100.0	-450.0	525.0	(none)
hpl_uca_outer	40.0	-675.0	525.0	(none)
hpl_uca_rear	250.0	-490.0	530.0	(none)
hpl_wheel_center	0.0	-800.0	300.0	(none)

Figure 13: Hard point coordinate of front suspension



	loc_x	loc_y	loc_z	remarks
hpl_lca_front	1427.0	-400.0	150.0	(none)
hpl_lca_outer	1627.0	-750.0	100.0	(none)
hpl_lca_rear	1827.0	-450.0	155.0	(none)
hpl_lwr_strut_mount	1627.0	-600.0	150.0	(none)
hpl_subframe_front	1227.0	-450.0	150.0	(none)
hpl_subframe_rear	2027.0	-450.0	150.0	(none)
hpl_tierod_inner	1827.0	-400.0	300.0	(none)
hpl_tierod_outer	1777.0	-750.0	300.0	(none)
hpl_top_mount	1667.0	-500.0	650.0	(none)
hpl_uca_front	1727.0	-450.0	525.0	(none)
hpl_uca_outer	1667.0	-675.0	525.0	(none)
hpl_uca_rear	1877.0	-490.0	530.0	(none)
hpl_wheel_center	1627.0	-800.0	300.0	(none)

Figure 14: Hard point coordinate of rear suspension

4.1.6 Full Vehicle Assembly

Lastly, each subsystems needed were attached together to model the full assembly design.

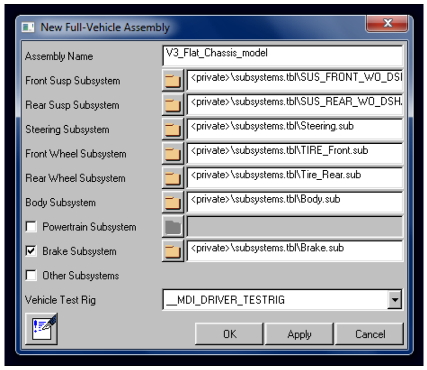


Figure 15: full vehicle assembly command in ADAMS/Car

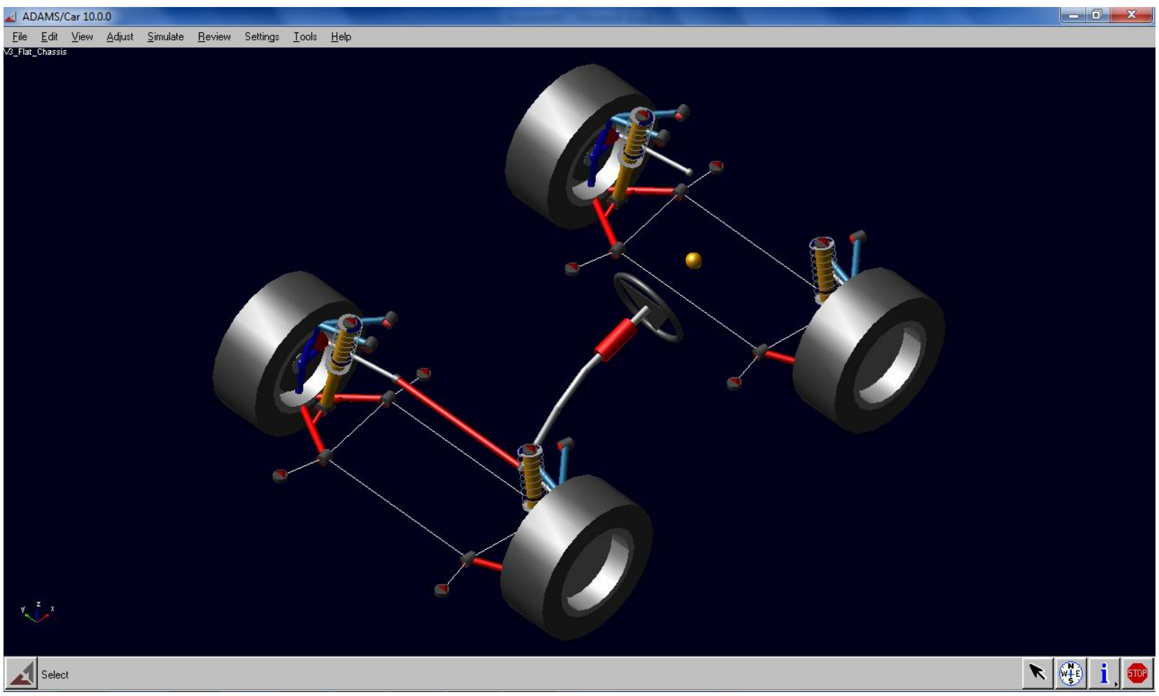


Figure 16: vehicle dynamic model for an electric vehicle with 4 in-wheel motors in ADAMS/Car

Figure 16 above shows the full assembly design vehicle model of the electric vehicle that used 4 in-wheel motors and conventional rack and pinion steering. Next step is to design the LSRS and integrate in into the vehicle assembly.

4.2 Simulation and Verification of Base Vehicle Model

Prior to modification of base vehicle model to become SAS system, some validation is required in order to validate the ADAMS/Car model with stock rack and pinion steering model. For comparison purposes, single lane change (SLC) simulation was selected. Single Lane Change simulation is basically to simulate vehicle that change lane at certain speed as shown in figure 19 below.

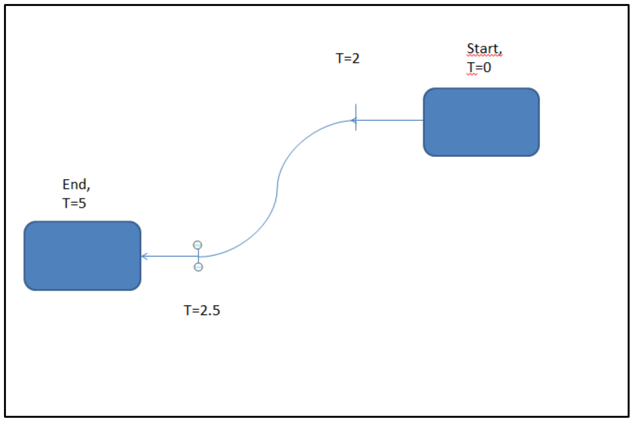


Figure 17: Overview of single lane change

This simulation also held to verify if the structures of the model are strong enough to handle all forces exist during the simulation. If the structures of the vehicle failed, modification of subsystems hard point coordinates must be done.

4.3 Modification of Base Model to Become SAS

To modify the base model to become SAS, the intermediate shaft of the steering shaft must be modified to become flexible. In order to create a flexible material, an FEA software must be used. In this case, MSC Nastran was used. The flexible body was saved as a modal neutral file (.mnf) to be able to be used in Adams/car

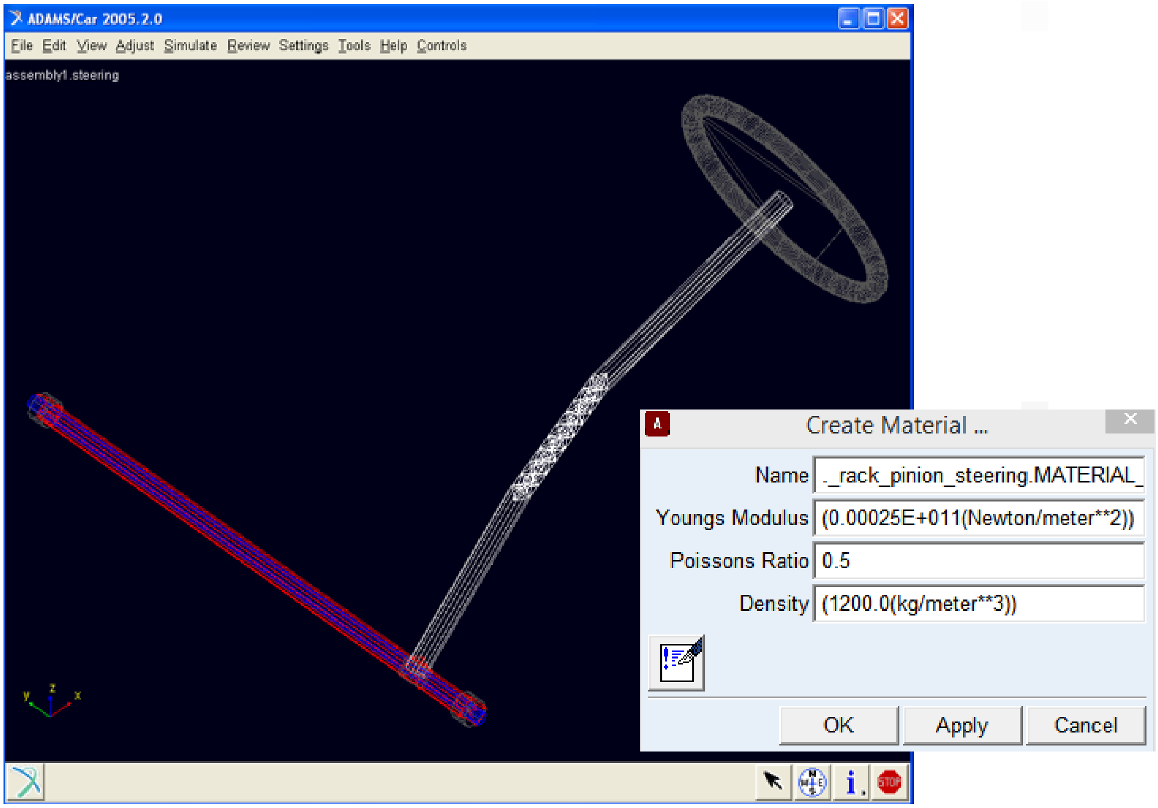


Figure 18 : Flexible intermediate shaft and its properties

The steering subsystem of the previously done assembly was then replaced with the SAS model.

4.4 Result validation

To assess the performance of the SAS system, three type of simulation was done, which is single lane change (SLC), and the step steer (SS). The result and discussion of the simulations are as shown below:

4.4.1 Single lane change simulation

As stated before, SLC is to simulate vehicle that changing lane at certain given speed. The vehicle input condition for the SLC simulation is given as shown below:

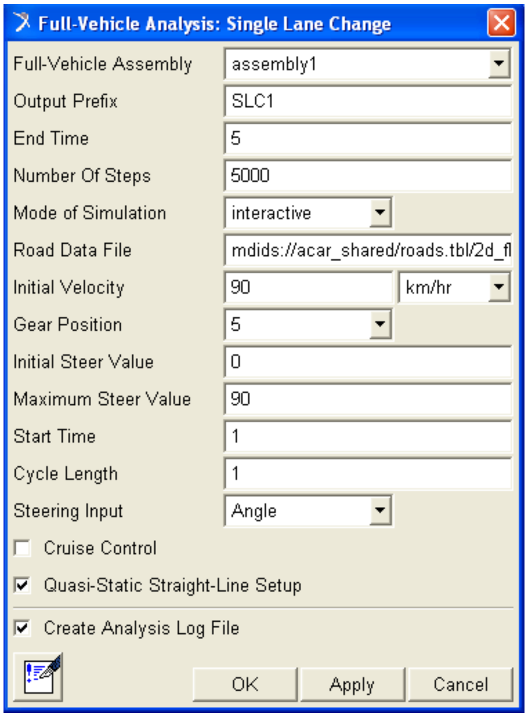


Figure 19: SLC simulation condition.

Time taken for the SLC simulation is 5 second, and the SLC manoeuver will start at T= 1sec where the steering wheel angle started to turn from 0 to 90 degree for 1sec and turn back from 90 to 0 degree for another 1sec. The vehicle speed was set constant at 90 km/h.

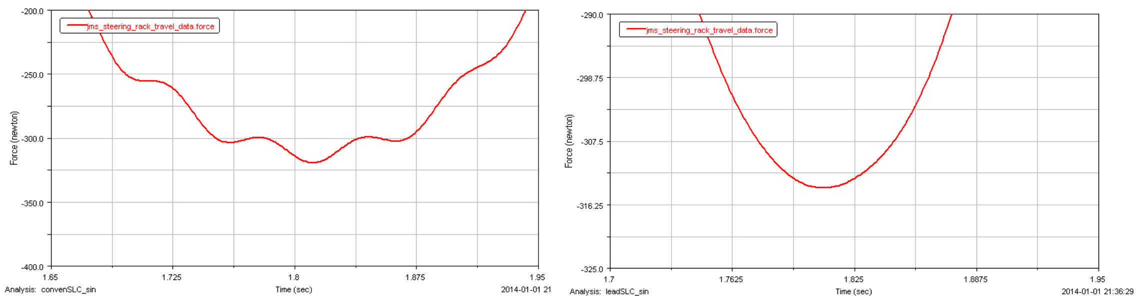


Figure 20: steering rack travel force comparison (conventional vs SAS)

Based on steering rack travel force graph above, the SAS model reduce a lot of the vibration force. A lot of it was absorbed by the flexible shaft.

4.4.2 Steep steer simulation

SS simulation is j-turn simulation of a vehicle at a certain speed. The input condition of the simulation is as shown below:

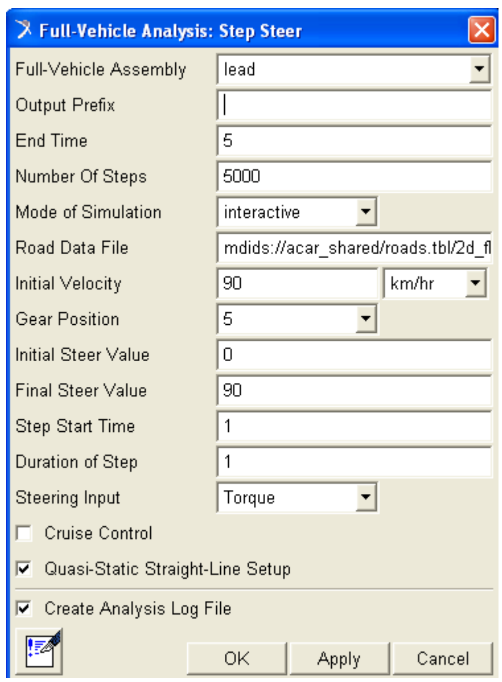


Figure 21: SS simulation condition.

The vehicle speed was set constant at 90 km/h. Time taken for the SS simulation is 5 seconds, and the SS manoeuver will start at T= 1sec where the steering wheel angle started to turn from 0 to 90 degree for 1 seconds and stay at 90 degree until the end of the simulation (5 seconds).

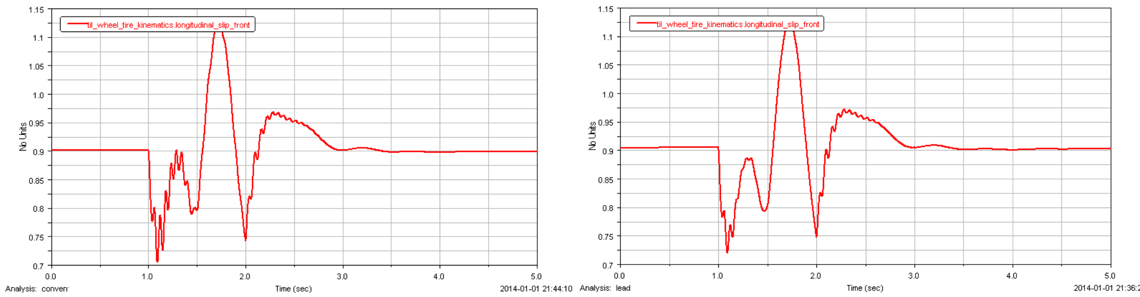


Figure 22 Front tire slip value

The figure shows that the SAS doesn’t reduce the slip value. However, the erratic value of slip is eliminated, making the graph smoother. This is quite similar to the previous figure.

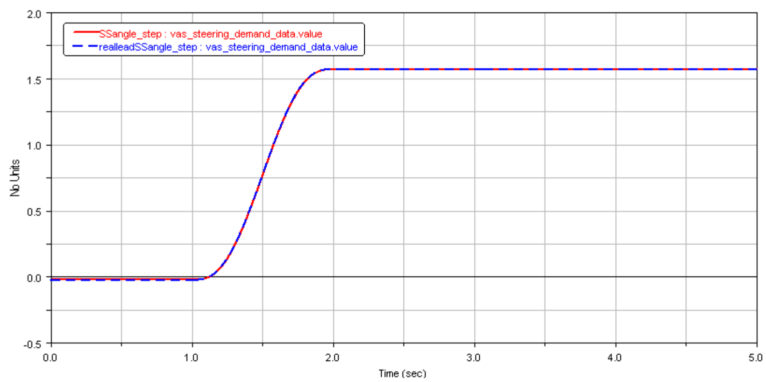


Figure 233 steering demand graph of SAS (red) and conventional (blue)

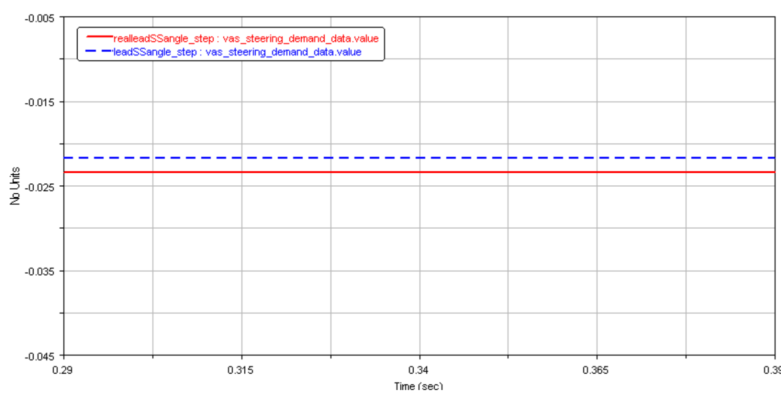


Figure 24 Steering demand graph zoomed in

This figure prove that the steering ratio are increased when SAS is used. Because of the flexibility of the steering shaft which introduce different steering ratio depending on the speed, an average driver may need to familiarize the system first

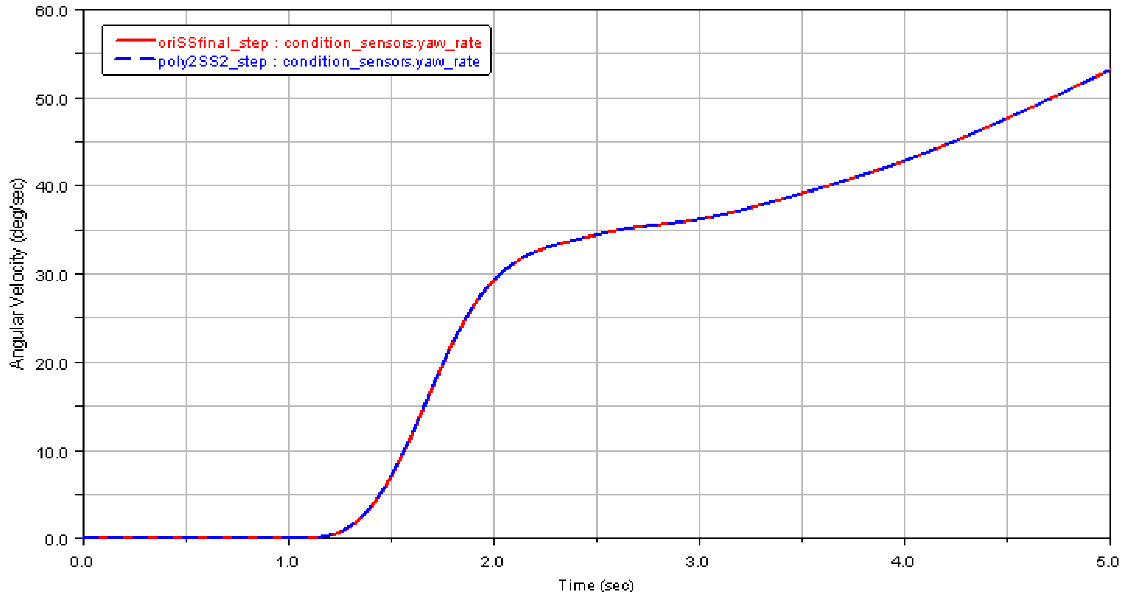


Figure 25 Yaw rate SAS vs Conventional

The figure above show the yaw rate of the vehicle with SAS against the conventional rack and pinion. Eventhough the change are minimal, it can still be consider as different because the maximum value of the yaw rate for SAS vehicle is lower, at 53.0125 deg/sec against the 53.0984 deg/sec of the conventional steering. The average also is lower for SAS at 26.191 deg/sec against the 26.226 deg/sec of the conventional steering.

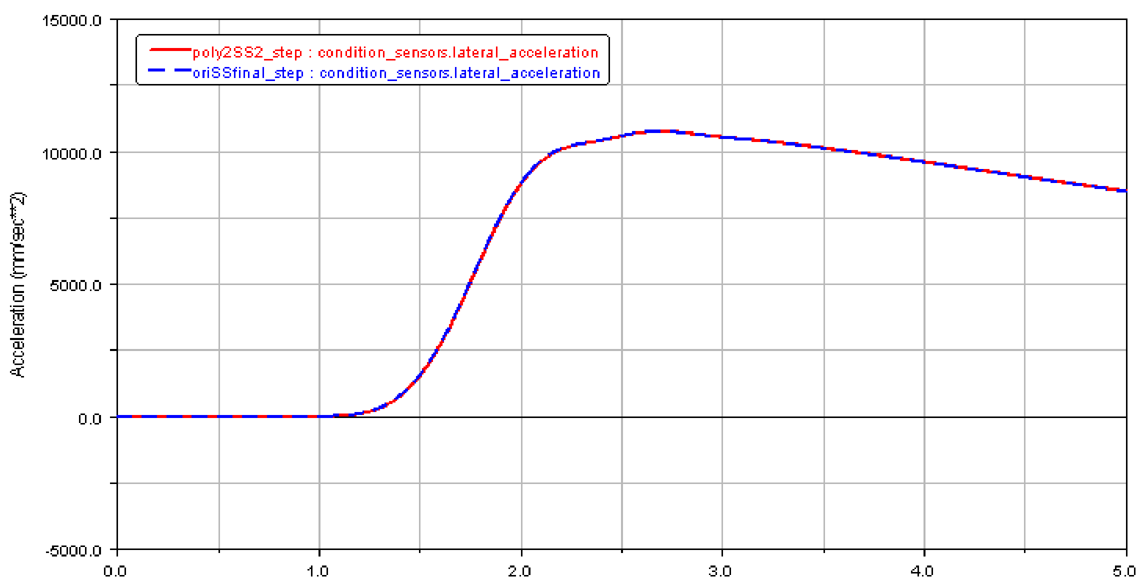


Figure 26 Lateral accelaration SAS vs Conventional

The figure above show the lateral accelaration of the vehicle with SAS against the conventional rack and pinion. Eventhough the change are minimal, it can still be consider as different because the maximum value of the yaw rate for SAS vehicle is higher, at 10743.2081 mm/sec^2 against the 10743.3953 deg/sec^2 of the conventional steering. The average is also higher for SAS at 6438.5705 mm/sec^2 against the 6438.2138 mm/sec^2 of the conventional steering.

This results show that the lateral acceleration increased, but the yaw rate is reduced when SAS is used.

CHAPTER 5: CONCLUSION AND RECOMMENDATION

5.1 CONCLUSION

The initial step in study SAS for an all-wheel drive electric vehicle was to develop base model in ADAMS/Car which include several subsystem such as front and rear double wish bone suspensions, chassis, steering, brake, and wheels. In-wheel motor is then added at each wheel to become dynamic model in ADAMS/Car. Up to this point, the first objective which is to develop a vehicle dynamic model for an EV with 4 In-wheel motor and flat chassis in ADAMS/Car is achieved.

Prior to simulate and characterize the performance of the vehicle, the modelling of the SAS system is done using an FEA software, which is MSC Nastran. After finishing the modelling of the SAS, it was imported back into ADAMS/car by using MNF format. At this stage, half of the second objective which is to develop SAS system for the vehicle is done

Next, simulation and characterization of the performance of the SAS and compare it to conventional steering model that was made. The simulations involved are single lane change and step steer. According to the result, the force on the steering rack are smoother, front tire slip angle are smoother, and the steering demand are more in using the SAS system. At this stage, the second objective which is to simulate and analyse the performance of the SAS are completed.

In conclusion, SAS approach has the potential to improve response and stability when the driver has familiarize with the control.

5.2 RECOMMENDATION

The result of the study concluded that the modeling and simulation of the SAS is a success. The simulation performed shows that SAS system performance on an all-wheel drive flat chassis with in-wheel EV motor is good in some aspect

To improve the study for future work, the modelling of SAS control system in MATLAB can be done. This simulation is done in assumption that the motor controlling the rack is always in failure. Therefore, to get accurate prediction, it is better to include control system of SAS using MATLAB or similar software.

Simulation alone will not give a very accurate result towards the realistic vehicle that will be built. Thus, to ensure that SAS is really improving the handling of the vehicle, experimental base on real electric vehicle is needed so that the technology can be proved in real life.

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