Simulation and Analysis of Hatchback Car Driving Comfort and Handling Performance

Mohamad Yamin*, Cokorda Prapti Mahandari, Mega Maulida Mumtaz

Abstract— Hatchback cars are one type of car that is widely used in Indonesia. Indonesia has various road conditions. What is essential for a vehicle is its driving comfort and handling performance. These aspects are not only to fulfill individual interests but also to increase safety while driving. The driving comfort can be tested through the chassis twisted road test, and the handling performance is tested through the double lane change test. Both tests are carried out by simulation with the CarSim software that applies mathematical modelling. The driving comfort is tested with a speed variation of 8 km/h to 16 km/h. Handling performance was tested with variations in loading of 1 passenger, four passengers, and four passengers + luggage. The parameters used to measure driving comfort are vertical acceleration, pitch, and roll angle. The parameters for handling performance are lateral acceleration, yaw and roll angle, and shear force. The results show that the best driving comfort is obtained at 8 km/h. The handling performance value will improve if the vehicle load decreases.

Index Terms—driving comfort, handling performance, hatchback car, simulation

I. INTRODUCTION

CARS are one of the vehicle types to provide transportation for people and goods [1]. Car ownership has been growing from year to year in Indonesia. One type of car that people in Indonesia commonly use is the hatchback type [2]. This type of car has a high level of practicality and is classified as compact. A hatchback car is a sedan-based car with a shorter rear, and the trunk door is designed to open upwards. The cargo and passenger compartments are combined for simultaneous use. Rear door access can be used through the third or fifth door, hinged upwards. The foldable rear seat feature allows flexibility in using cargo and passenger compartments simultaneously [1].

Indonesia has many different types of road surfaces. Comfort driving performance involves vehicle pitch and rolling induced by road roughness in forced vibration [3]. Driving comfort issues for drivers are not only related to individual satisfaction but also due to the deteriorating driving environment and performance, driving safety, and long-term health conditions of the driver [4]. On the other hand, handling performance is the vehicle performance that allows the vehicle to be safely controlled by the driver to maintain the desired trajectory easily at high longitudinal and lateral accelerations [5].

The performance of driving convenience and handling of the vehicle will be analysed with CarSim software simulation. CarSim uses mathematical modelling to investigate a car in real life. CarSim offers the most accurate, detailed, and efficient method of driving vehicle simulation [6]. The Chassis twisted road test procedure is used to determine the comfort of driving, which is done by simulating varying vehicle speeds, namely 8 km/h, 10 km/h, 12 km/h, 14 km/h, and 16 km/h. The handling performance is done by double lane change, adapted to the vehicle weight into three load scenarios: one passenger (driver only), four passengers, and four passengers + full luggage weight. The vehicle industry continues to innovate by improving vehicle performance and features or trying out the latest technologies, such as autonomous vehicles. However, vehicle comfort and handling are the primary considerations [7],[8]. The results of this study are expected to be considered as a reference for further improvement of other innovations in hatchback cars.

II. LITERATURE REVIEW

CarSim is software used to simulate the dynamics of passenger vehicles. CarSim uses a three-dimensional multibody dynamics model to accurately describe the vehicle in response to controls from the driver and or automation: steering, throttle, braking, and gear changes. Environmental conditions include three-dimensional land/road surfaces, aerodynamics, and wind. CarSim as software is extensively validated and correlated with real-world results measured and observed by many researchers worldwide. The fundamental technologies of CarSim are called VehicleSim (VS), VS Visualizer (video and plotting), and VS Commands (scripting language) [9].

The driving comfort simulation is based on a road surface profile with a continuous bumpy pattern. This simulation is known as the Chassis twisted road test. The road surface profile in this test is the rough road excitation, resulting in an uneven road profile [10]. The Chassis twisted road test chosen to test ride comfort performance is a ride quality that refers to the effects of vertical vibrations caused by road irregularities such as road bumps and potholes. The road profile used for the chassis twisted road test with CarSim simulation is shown in Figure 1.

Fig. 1. The road profile used for the Chassis twisted road test

Double lane change manoeuvres are used for vehicle handling tests. ISO 3888-2 defines the double lane change manoeuvre to test the obstacle avoidance performance of vehicles. In this test, the driver must accelerate, release the accelerator pedal, turn the steering wheel following the
lane into the left lane, and turn the steering wheel following the road back into the right lane when the vehicle reaches the target speed [6]. If the car and driver can manoeuvre without hitting traffic cones, the car passes the test. Figure 2 shows the double lane change trajectory following ISO Standard 3888-2 [11].

![Fig. 2. Double lane change scheme](image)

III. METHOD

A. Vehicle Parameters

The car used in this simulation is a 2017 B-Class Hatchback available in the CarSim database. This type of car was chosen because it is widely used in Indonesia. The parameters of this car are shown in Table 1.

<table>
<thead>
<tr>
<th>Vehicle Parameters</th>
<th>Nominal Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sprung mass</td>
<td>1110 kg</td>
</tr>
<tr>
<td>Roll Inertia</td>
<td>440.6 kgm²</td>
</tr>
<tr>
<td>Pitch Inertia</td>
<td>1343.1 kgm²</td>
</tr>
<tr>
<td>Yaw Inertia</td>
<td>1343.1 kgm²</td>
</tr>
<tr>
<td>Distance of CG to Front Axle</td>
<td>1.04 m</td>
</tr>
<tr>
<td>Distance of CG to Rear Axle</td>
<td>1.56 m</td>
</tr>
<tr>
<td>Front Steering Damping Coefficient</td>
<td>4.5 Ns/m</td>
</tr>
<tr>
<td>Wheelbase Length</td>
<td>2.6 m</td>
</tr>
<tr>
<td>Width</td>
<td>1.695 m</td>
</tr>
<tr>
<td>Height</td>
<td>1.535 m</td>
</tr>
</tbody>
</table>

![Fig. 3. B-class Hatchback 2017 CarSim](image)

B. Chassis Twisted Road Test

The Chassis twisted road test determines the driving comfort of the 2017 B-Class Hatchback car with varying speeds. This simulation uses speed variations between 8-16 km/h because, in general, bumps make the vehicle speed in that speed range [12]. The five-speed variations are 8 km/h, 10 km/h, 12 km/h, 14 km/h, and 16 km/h.

The object of this test is the 2017 B-Class Hatchback vehicle type, and in the procedure section, the chassis twist road test is selected by changing the speed. The outputs set in this simulation are vertical acceleration, pitch angle, and roll angle. The driving comfort criteria are shown in Table 2 based on the RMS value of vertical acceleration.

<table>
<thead>
<tr>
<th>Load scenario type</th>
<th>Vehicle Load, kg</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1110</td>
</tr>
<tr>
<td>2</td>
<td>1110</td>
</tr>
<tr>
<td>3</td>
<td>1110</td>
</tr>
</tbody>
</table>

![Fig. 4. Vertical acceleration](image)

Vertical acceleration is the acceleration in the vertical direction affected by the acceleration of gravity. The results show that vertical acceleration is proportional to the increase in speed. The slightest vertical acceleration is

<table>
<thead>
<tr>
<th>RMS Value (m/s²)</th>
<th>Subjective Indication</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 0.315</td>
<td>Not uncomfortable</td>
</tr>
<tr>
<td>0.315 – 0.63</td>
<td>A little uncomfortable</td>
</tr>
<tr>
<td>0.5 – 1.0</td>
<td>Fairly uncomfortable</td>
</tr>
<tr>
<td>0.8 – 1.6</td>
<td>Uncomfortable</td>
</tr>
<tr>
<td>1.25 – 2.5</td>
<td>Very uncomfortable</td>
</tr>
<tr>
<td>&gt; 2.0</td>
<td>Extremely uncomfortable</td>
</tr>
</tbody>
</table>

C. Double Lane Change Test

The simulated double lane change test was used to determine the handling performance of the 2017 B-Class Hatchback. This test uses a variety of vehicle loading because the total vehicle load significantly affects the vehicle's handling performance. The loading is divided into three types/scenarios: the first is a car with one passenger (only the driver). Second, is a car containing a total of four passengers. The third is a car containing four passengers and entire luggage, as shown in Table 3.

<table>
<thead>
<tr>
<th>Load scenario type</th>
<th>Vehicle Load, kg</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1110</td>
</tr>
<tr>
<td>2</td>
<td>1110</td>
</tr>
<tr>
<td>3</td>
<td>1110</td>
</tr>
</tbody>
</table>

The average body weight of Asians is 57.7 kg [13]. The trunk mass of an Indonesian hatchback car is 440 kg [14]. The input of this test is the 2017 B-Class Hatchback vehicle type by changing the loading mass. In the procedure part, a double lane change with a speed of 100 km/h was chosen because the speed limit of cars on the highway set by the national government is 100 km/h [15]. The outputs set in this simulation are lateral acceleration, yaw angle, roll angle, and front tire vertical force.

III. RESULT AND DISCUSSION

A. Results of Chassis twisted road test

The twisted road chassis test for five-speed variations was successfully simulated with CarSim. The simulation results are in the form of data in Microsoft Excel and then processed into a graph. The simulation result graph is shown in Figures 4-6.
indicated by 8 km/h speed, and the largest at 16 km/h.

For the same road profile or bump (as in this test), the vertical acceleration is measured when the rear wheel axle enters and hits the bump [16]. So, what is more comfortable based on the results of this simulation of driving is driving at a speed of 8 km/h.

The higher the pitch angle and roll angle, the more uncomfortable it is for passengers to drive [6],[17],[18]. So, the simulation results show that the more comfortable value is at the smallest pitch and roll angle at the speed of 8 km/h.

### B. Analysis of Double Lane Change Test Results

The double lane change test for three variations of loading scenarios was successfully simulated with CarSim. The results of this simulation are in the form of data in Microsoft Excel, which is then processed and becomes a graph. The graphs of the simulation results are shown in Figures 7-9.

![Pitch Angle](image)

**Fig. 5. Pitch angle**

The pitch angle is the angle of rotational motion on the Y-axis. The results show that the pitch angle increased proportionately to the increase in speed until the speed of 14 km/h, then decreased slightly. The smallest pitch angle is shown by the speed of 8 km/h, and the largest at the speed of 14 km/h.

![Roll Angle](image)

**Fig. 6. Roll Angle**

Roll angle is the angle of rotational motion on the Z-axis. The results show that the roll angle increased proportionately to the increase in speed until the speed of 14 km/h, then decreased slightly. The smallest roll angle is shown by the speed of 8 km/h, and the largest at the speed of 14 km/h.

From these results, the RMS (Root Mean Square) value is calculated to facilitate analysis. The RMS value for each output is shown in Table 4.

### TABLE IV. RMS VALUE CHASSIS TWISTED ROAD TEST

<table>
<thead>
<tr>
<th>Parameters</th>
<th>8 km/h</th>
<th>10 km/h</th>
<th>12 km/h</th>
<th>14 km/h</th>
<th>16 km/h</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vertical acceleration (m/s^2)</td>
<td>0.68</td>
<td>1.27</td>
<td>1.34</td>
<td>1.55</td>
<td>2.11</td>
</tr>
<tr>
<td>Pitch angle (deg)</td>
<td>1.97</td>
<td>2.16</td>
<td>2.30</td>
<td>2.45</td>
<td>2.40</td>
</tr>
<tr>
<td>Roll angle (deg)</td>
<td>7.89</td>
<td>8.33</td>
<td>8.76</td>
<td>8.87</td>
<td>8.62</td>
</tr>
</tbody>
</table>

The RMS vertical acceleration for a speed of 8 km/h is 0.68 m/s^2, categorised as somewhat uncomfortable. A speed of 10 km/h is 1.27 m/s^2, categorised as awkward; for a speed of 12 km/h, 1.34 m/s^2 is classified as uncomfortable. A speed at 14 km/h is 1.55 m/s^2, categorised as uncomfortable, and a rate at 16 km/h is 2.41 m/s^2, classified as very uncomfortable.

The results show that the lateral acceleration is inversely related to the increase in vehicle load. The greater the vehicle load, the smaller the lateral acceleration value. Load Scenario 1 shows the highest lateral acceleration value, and the smallest is shown by load Scenario 3.

![Lateral Acceleration](image)

**Fig. 7. Lateral Acceleration**

Yaw angle is the angle of rotational motion on the X-axis. The results indicate that the yaw angle is inversely proportional to the increase in vehicle load. The greater the vehicle load, the smaller the yaw angle value. Load Scenario 1 shows the highest yaw angle value and the smallest is shown by load Scenario 3.

![Yaw Angle](image)

**Fig. 8. Yaw Angle**
The results indicate that the roll angle is inversely proportional to the increase in vehicle load. The greater the vehicle load, the smaller the roll angle value. Load Scenario 1 shows the highest roll angle value, and the smallest is shown by load Scenario 3.

The results indicate that the front tire's vertical force is proportional to the increase in vehicle load. The greater the vehicle load, the smaller the front tire's shear force value. Load Scenario 1 shows the smallest front tire vertical force value and the highest is shown by load Scenario 3.

The roll angle and front tire vertical force will increase in value as the vehicle load increases. Low values of roll angle and front tire shear force indicate that the vehicle has good handling performance. Cars with low loads show good vehicle roll stability because roll angle is defined as the vehicle's stability to control side motion so as not to roll over. Then, cars with high vehicle loads will produce high vertical forces. This happens because a high normal force will be generated when the car is heavy [21],[22]. The vehicle that has the smallest roll angle and front tire vertical values is with loading Scenario 1, so this scenario has better handling performance.

V. CONCLUSION

The twisted road chassis test simulation to test the driving comfort of the 2017 B-Class Hatchback and the double lane change test to test the vehicle's handling performance have been successfully conducted using CarSim software. The driving comfort test used five-speed variations ranging between 8–16 km/h, while the vehicle handling performance test used three loading variations. The results indicate that the best driving comfort of the five-speed variations is obtained at the lowest speed of 8 km/h. This result was obtained after analysing the vertical acceleration, pitch, and roll angle. While analysing lateral acceleration, yaw, roll angle, and lateral force, the results show that the vehicle with the lowest load. Scenario 1 is the scenario with the best handling performance. This simulation can be a reference for simulations with other types of cars, speed variations, and additional loadings, as well as for developing comfortable autonomous vehicles with good handling performance.

REFERENCES

Yamin et al.: Simulation and analysis of hatchback car driving comfort and handling performance (pp. 89-93)


Mohamad Yamin is the Center for Automotive Research Head at Gunadarma University, Jakarta, Indonesia. His undergraduate degree is in Aeronautics from Institut Teknologi Bandung, Indonesia (1993), and his doctorate (2003) is in Aerodynamics, ILR, TU-Berlin, Germany. His research interests are Computational Fluid Dynamics, Aerodynamics, Dynamics and Control, EV, and Machine Learning. (email: mohay@staff.gunadarma.ac.id).

Cokorda Prapti Mahandari is the Vice Director of the Technology and Engineering Directorate of the Magister Program at Gunadarma University. She graduated from Sepuluh Nopember Institute of Technology, majoring in Mechanical Engineering in 1993. Her M. Eng in Energy Technology was from AIT (1997), and her doctorate was from UI (2010). Her research interests are energy conversion and energy conservation. (email: coki@staff.gunadarma.ac.id).

Mega Maulida Mumtaz is a Researcher at the Center of Automotive Research, Gunadarma University. She received her B.S. in Mechanical Engineering from Gunadarma University, Indonesia, in 2020. Her master’s degree in mechanical Engineering was obtained from Gunadarma University in 2022. Her research interests are vehicle dynamics and control systems (email: mega.ugcar@gmail.com).