SUSPENSION OPTIMIZATION AND VEHICLE DYNAMICS ANALYSIS – EVALUATION OF STEP STEER AND SINGLE LANE CHANGE MANEUVERS USING ADAMS CAR

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Exam date: 29/07/2024

ACADEMIC YEAR: 2023/2024

Summary

Introduction

This report examines the optimization of various suspension parameters in a vehicle, focusing on **toe angle**, **camber angle**, and **caster angle**, which are crucial in determining the vehicle's handling characteristics and dynamic response:

- The **toe angle**, which refers to the wheels' inclination relative to the vehicle's centerline, directly affects directional stability and tire wear. Precise adjustment of the toe angle can improve steering accuracy and reduce rolling resistance.
- The **camber angle**, the tilt of the wheels relative to the vertical, is vital for maximizing tire contact with the road, thereby influencing grip, traction, and overall handling.
- The **caster angle**, defining the tilt of the steering axis relative to the vertical, is essential for straight-line stability and steering responsiveness, enhancing the driver's sense of control and safety.

This report aims to illustrate how minor adjustments to these parameters can significantly affect the vehicle's dynamics through detailed simulations using ***Adams Car*** software; it is an advanced tool for dynamic simulation, allowing engineers to create virtual vehicle models and perform comprehensive analyses without costly physical prototypes.

Specifically, the simulations include “**Step Steer Analysis**” and “**Single Lane Change Analysis**”:

- The **Step Steer Analysis** involves applying a sudden input to the steering wheel and observing the vehicle's response, focusing on parameters such as steering-wheel angle, lateral acceleration, yaw rate, vehicle speed, and tire output. This test is crucial for evaluating the vehicle's stability and control in emergency situations or sudden maneuvers.
- The **Single Lane Change Analysis** simulates a rapid lane change maneuver at a constant speed. This test assesses the vehicle's ability to perform safe lane changes, critical for highway and multi-lane road driving. It examines the same parameters as the **Step Steer Analysis**, providing insights into the vehicle's handling of lateral forces during quick direction changes and identifying potential issues with maneuverability and stability.

Additionally, simulations with an **Anti-Roll Bar** are conducted to observe its impact on the dynamic behaviour of the vehicle. The **Anti-Roll Bar** reduces body roll during cornering, enhancing vehicle stability and handling.

1. Front and Rear Suspensions optimization: Generalities and Design of Experiment Analysis

First of all, it is important to set a procedure for characterizing **Front** and **Rear Suspension Parameters** to optimize vehicle handling performance using the **Opposite Wheel Travel Analysis**; it involves moving the left and the right wheels through equal, but opposite, vertical amounts of travel to simulate body roll. This is achieved by having the wheels undergo specified bounce and rebound travel, 180° out of phase with each other. Parameters for vertical wheel travel and the fixed steer value must be defined when submitting the analysis. The key quantities measured during this analysis are:

- **Toe angle**;
- **Camber angle**;
- **Roll angle**.

The main objectives to reach through this analysis are:

- To **minimize** the **maximum value** of the **toe angle** to improve the toe angle range and variation;
- To ensure that the optimized model for the toe angle also provides favorable results for **camber angle** variation.

For setting the suspensions' parameters for the **Opposite Wheel Travel Analysis**, an optimization through the **Design of Experiments (DOE) Analysis** is performed, in order to find the correct values of the following hardpoints, which make the previous objectives reachable:

- HP locations X, Y, Z (**hpl/hpr tierod outer**) ;
- HP location Z (**hpl/hpr lca outer**).

DOE is a systematic method for determining the relationship between factors affecting a process and the output of that process; it involves designing controlled tests to understand the effects of multiple variables and to identify the optimal conditions.

After performing **81 simulations** for the Front Suspensions, following the settings of the ***figure 1***, one gets the result presented in the ***figure 2***:

Factors Table (All)

	abbreviation	name	type	settings	nominal value	distType	distParams	delta type	units	tolerance	ease
1	lca_z	TR_Front_Su...	Continuous	-10, 10	130	Uniform		Relative		0.0	Moderate
2	tierod_x	TR_Front_Su...	Continuous	-30, 30	417	Uniform		Relative		0.0	Moderate
3	tierod_y	TR_Front_Su...	Continuous	-10, 10	-750	Uniform		Relative		0.0	Moderate
4	tierod_z	TR_Front_Su...	Continuous	-10, 10	330	Uniform		Relative		0.0	Moderate

Figure 1: Factors table and settings for the DOE Analysis for the Front Suspensions

Minimum and maximum for regression "OBJECTIVE_1"

	Minimum	Maximum
Response	2.7575	10.031
lca_z	140	120
tierod_x	447	387
tierod_y	-740	-760
tierod_z	320	340

Figure 2: DOE results for the Front Suspensions for minimizing the maximum value of the toe angle

Then, after performing **81 simulations** for the Rear Suspensions, following the settings of the ***figure 3***, one gets the result presented in the ***figure 4***:

Factors Table (All)

	abbreviation	name	type	settings	nominal value	distType	distParams	delta type	units	tolerance	ease
1	lca_z	TR_Rear_Su...	Continuous	-10, 10	190	Uniform		Relative		0.0	Moderate
2	tierod_x	TR_Rear_Su...	Continuous	-30, 30	2977	Uniform		Relative		0.0	Moderate
3	tierod_y	TR_Rear_Su...	Continuous	-10, 10	-750	Uniform		Relative		0.0	Moderate
4	tierod_z	TR_Rear_Su...	Continuous	-10, 10	350	Uniform		Relative		0.0	Moderate

Figure 3: Factors table and settings for the DOE Analysis for the Rear Suspensions

Minimum and maximum for regression "OBJECTIVE_1"

	Minimum	Maximum
Response	3.0507	10.307
lca_z	200	180
tierod_x	3007	2947
tierod_y	-740	-740
tierod_z	340	360

Figure 4: DOE results for the Rear Suspensions for minimizing the maximum value of the toe angle

From the previous figures, it is clear that, by using the values provided by the software for modifying the hardpoints, one can perform, for both the Front and Rear Suspensions, two Opposite Wheel Travel Analyses to compare the **Baseline Layout** and the **Optimized Layout**, in order to display the improvements in terms of vehicle's handling characteristics and dynamic response.

For summarizing:

- Front Suspensions Hardpoints:

  "**hpl_lca_outer**" (**Lower Control Arm Outer**):
  - **loc_z** changed from **130** mm to **140** mm.

  "**hpl_tierod_outer**" (**Tie Rod Outer**):
  - **loc_x** changed from **417** mm to **447** mm;
  - **loc_y** changed from **-750** mm to **-740** mm;
  - **loc_z** changed from **330** mm to **320** mm.

- Rear Suspensions Hardpoints:

  "**hpl_lca_outer**" (**Lower Control Arm Outer**):
  - **loc_z** changed from **190** mm to **200** mm.

  "**hpl_tierod_outer**" (**Tie Rod Outer**):
  - **loc_x** changed from **2977** mm to **3007** mm;
  - **loc_y** changed from **-750** mm to **-740** mm;
  - **loc_z** changed from **350** mm to **340** mm.