Scilab Case Study Project

On

2-DOF Quarter Car Suspension System
Xcos Simulation and Analysis

Submitted by

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Vehicle System Dynamics

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Abstract

This case study presents the development of a dynamic quarter car suspension model using the Scilab/Xcos environment. The two degrees of freedom system represents sprung and unsprung masses connected via suspension and tire elements modeled with springs and dampers. Differential equations of motion are implemented in Xcos using block diagrams that replicate the system dynamics. Simulations investigate the impact of key suspension parameters—sprung mass, unsprung mass, spring stiffness, damping, and tire stiffness—on vertical acceleration, a critical factor for ride comfort. The model is validated against experimental data from a suspension test rig, demonstrating the accuracy and usefulness of this open-source simulation approach for suspension analysis and rapid design iteration.[1]

Keywords: Quarter car model, suspension dynamics, Scilab, Xcos, mechanical system simulation, parameter analysis, ride comfort, model validation

1 Introduction

Modern vehicle suspension systems play a crucial role in ensuring ride comfort, safety, and vehicle handling by isolating the chassis from road irregularities. The quarter car model is a simplified dynamic representation widely used in vehicle suspension analysis to study vertical motion and vibration isolation. It captures the essential dynamics by considering two degrees of freedom that represent the vehicle body (sprung mass) and the wheel assembly (unsprung mass), connected through spring and damper elements modelling the suspension and the tire.

The use of open-source tools such as Scilab and its graphical programming environment Xcos for modelling and simulating such mechanical systems offers a cost-effective and flexible alternative to commercial software. This case study utilizes the dynamic quarter car suspension model implemented in Xcos to analyse the effect of varying suspension parameters on the vehicle's vertical acceleration response.

2 Problem Statement

The primary aim of this project is to develop a dynamic quarter car suspension model using the Scilab/Xcos environment that accurately simulates the vertical dynamics of a vehicle suspension system with two degrees of freedom. Specifically, the objectives include:

- Formulate and implement the differential equations of motion representing the suspension system in the Xcos environment.
- Simulate the system response for various suspension parameters and road inputs.
- Analyze and understand the effects of varying sprung mass, unsprung mass, suspension spring stiffness, damping, and tire stiffness on the vertical acceleration of the sprung mass.
- Validate the simulation model against experimental results from a physical suspension test rig.

Achieving these goals will demonstrate the capability of Scilab/Xcos as an accessible open-source platform for suspension system analysis and rapid design iteration in vehicle dynamics.

3 Basic Concepts Related to the Topic

3.1 Equations of Motion

Let $z_s(t)$ denote the vertical displacement of the sprung mass and $z_u(t)$ denote the vertical displacement of the unsprung mass. Applying Newton's second law to each mass yields the coupled second-order differential equations:

$$m_s \ddot{z}_s = -k_s(z_s - z_u) - c(\dot{z}_s - \dot{z}_u) \tag{1}$$

$$m_u \ddot{z}_u = k_s(z_s - z_u) + c(\dot{z}_s - \dot{z}_u) - k_t(z_u - y_r) \tag{2}$$

where,

- $\ddot{z}_s$, $\ddot{z}_u$ are the accelerations of sprung and unsprung masses respectively,
- $\dot{z}_s$, $\dot{z}_u$ are their velocities,
- $y_r(t)$ is the road input displacement.

3.2 Ride Comfort Criterion

A key objective of suspension design is to minimize the vertical acceleration of the sprung mass ($\ddot{z}_s$), as it directly correlates with passenger comfort. By tuning suspension parameters, the model studies trade-offs between isolation from road disturbances and handling performance.

3.3 System Parameters and Variables

Table 1: System parameters of the quarter car model

Parameter	Description
m_s	Sprung mass (kg)
m_u	Unsprung mass (kg)
k_s	Suspension spring stiffness (N/m)
c	Damping coefficient (Ns/m)
k_t	Tire stiffness (N/m)
z_s	Sprung mass vertical displacement (m)
z_u	Unsprung mass vertical displacement (m)
y_r	Road disturbance displacement (m)

3.4 Simulation Approach

The differential equations are implemented in Scilab Xcos as a block diagram representation. This approach facilitates rapid simulation and parameter variation studies without deriving closed-form solutions. The system response to various road inputs and parameter variations can thus be visualized and analyzed effectively.

4 Flowchart

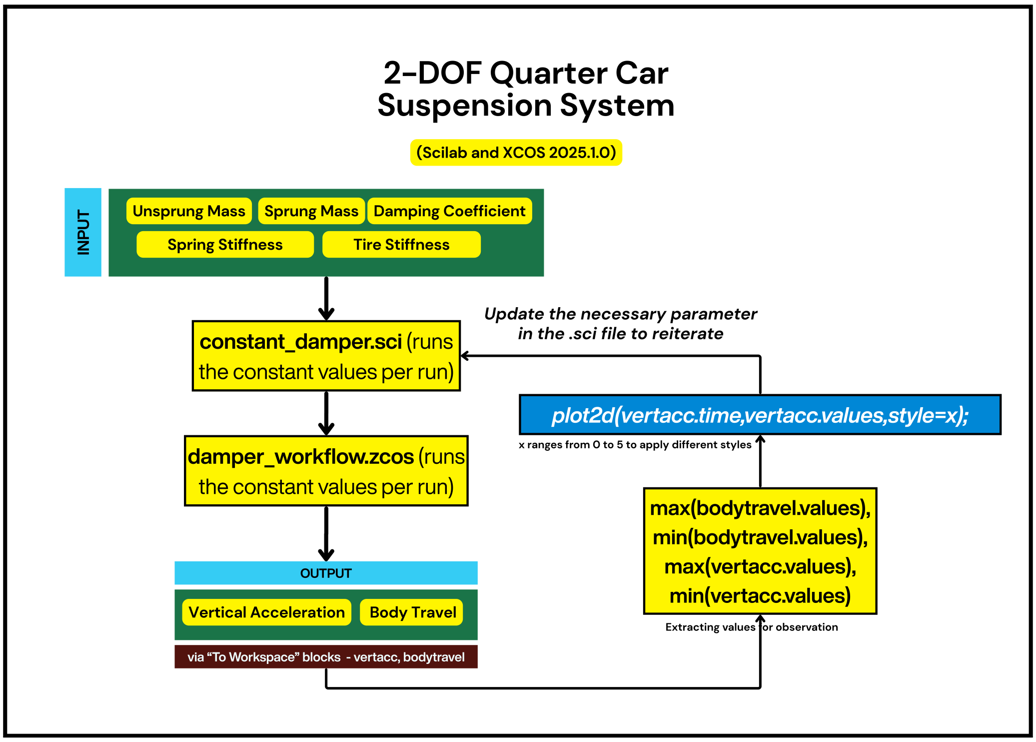

Figure 1: Flowchart and Data Extraction of the Case Study

4.1 Software/Hardware Used

The software that has been primarily used is the normal **Scilab 2025.1.0** scripting console and the Xcos Library. The device on which the program has been ran is a **Windows 11 OS** machine.

5 Procedure of Execution

The execution of the code can be done as follows:

1. Open Scilab on desktop. For the constant value inheritance, open the **constant_damper.sci**
2. Run the file to add the constant values to workspace.
3. Run the **damper_workflow.zcos** to run the entire DOF system.
4. There are two **TOWS blocks** to extract the **bodytravel** and **vertacc** parameters, 100 datapoints each - that is stored in the workspace as a 1x1 struct of 99x2 nature on extract with a values and a time parameter in each.
5. To get the maxima and minima necessary - input ***max(bodytravel.values),min(bodytravel.values)*** and simultaneously for the vertacc too.
6. To plot a curve here, begin with ***plot2d(vertacc.time,vertacc.values,style=1)***;

7. **Do not close the figure generated.**

8. Now again, change a parameter (say damping coefficient) in the constant_damper.sci and do the same steps.

9. **In the graph step, change the style count, and you will observe two graphs on same figure of vertical acceleration vs time, for different values of c (here).**

10. An example for the console inputs are also added in the work files in the **Example Console Run.pdf**.

5.1 Acceptable Input Value Range

Parameter	Minimum	Maximum	Unit
Sprung Mass	100	250	kg
Unsprung Mass	50	100	kg
Suspension String Stiffness	10000	19165	N/m
Damping Coefficient	800	1300	Ns/m
Tire Stiffness	10000	170000	N/m
Road Disturbance	0	0.1	m

Table 2: Acceptable Input Ranges for 2-DOF Analysis

6 Results

As discussed, the parameters are thus changed, within the permissible input ranges and thereby the value is obtained. A **step input** that visualised bumper was given of 0.1m at around 5 seconds for a 10 second simulation, which is to reduce toiling iterations for 120 seconds as in simulation, which was just to replicate the experimental system - and the value came about like the curves. The key minmax observations have been discussed in the later section.

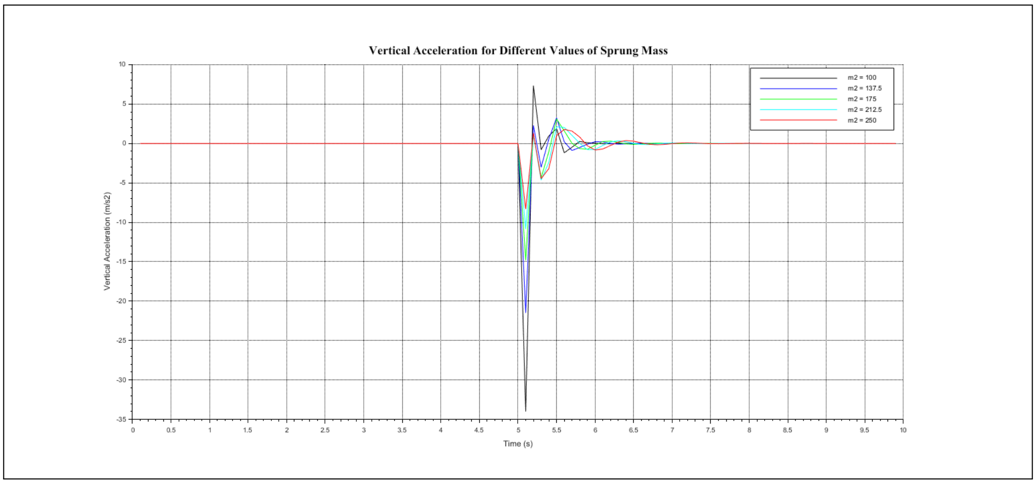

Figure 2: Vertical Acceleration for Different Values of Sprung Mass

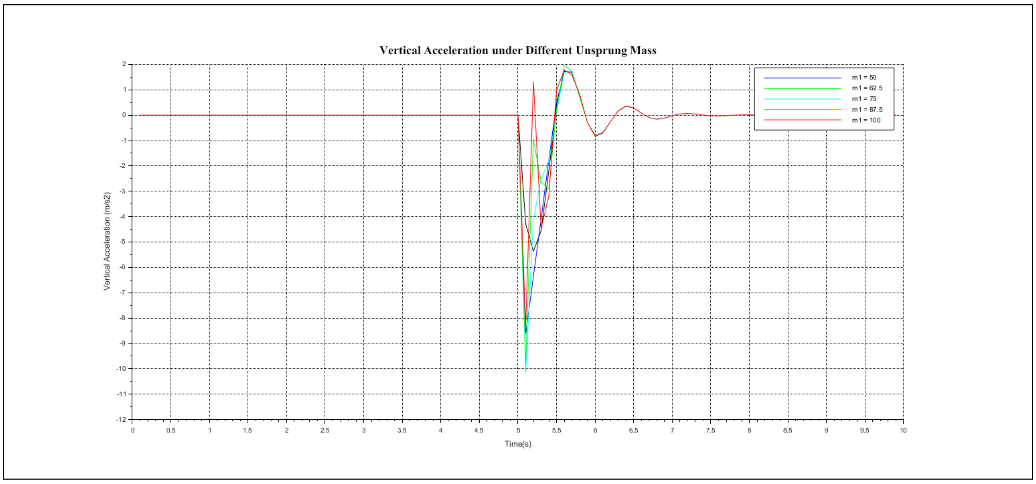

Figure 3: Vertical Acceleration for Different Values of Unsprung Mass

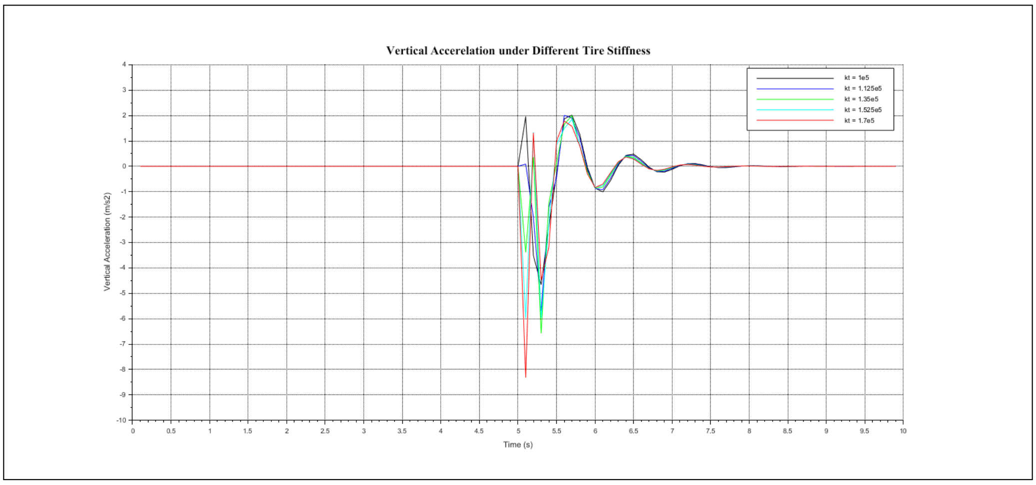

Figure 4: Vertical Acceleration for Different Values of Tire Stiffness

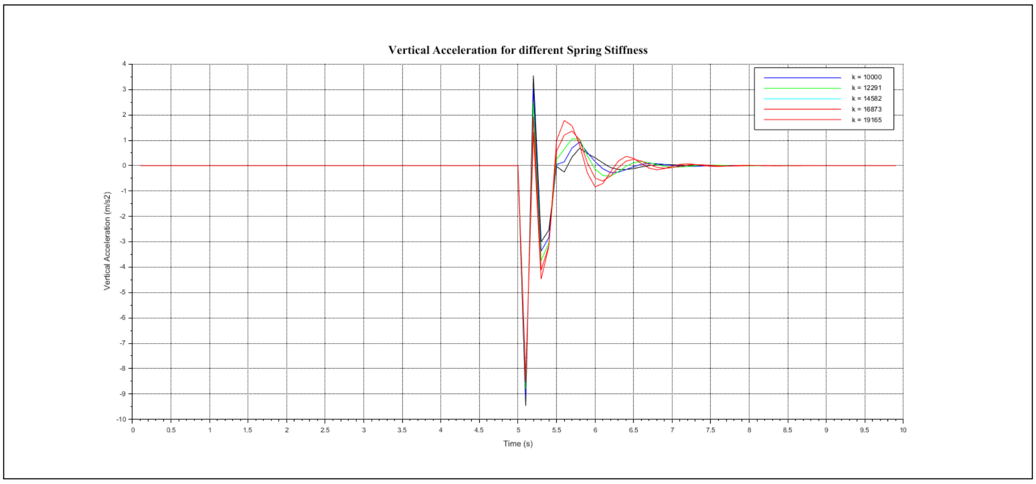

Figure 5: Vertical Acceleration for Different Values of Spring Stiffness

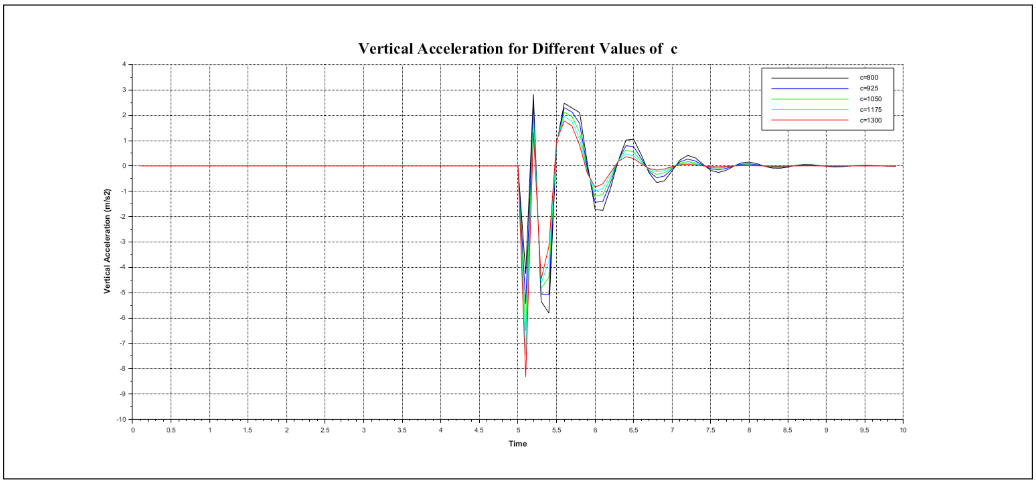

Figure 6: Vertical Acceleration for Different Values of Damping Coefficient

7 Observations

On analysing the curves using the procedure, the values of minimum and maximum of the various parameters have been measured to be as follows.

Sprung Mass (kg)	Vertical Acceleration (m/s^2)		Body Travel (m)	
	Min	Max	Min	Max
100	-34.007300	7.3328168	-0.0228088	0.0285981
137.5	21.49638	3.2597362	-0.0403096	0.043019
175	-14.819838	3.1053762	-0.05245	0.0540577
212.5	-10.858746	2.1071556	-0.0612772	0.0585907
250	-8.3194442	1.7817658	-0.0679579	0.0590034

Table 3: Analysis by varying sprung mass, m_2

Unsprung Mass (kg)	Vertical Acceleration (m/s^2)		Body Travel (m)	
	Min	Max	Min	Max
50	-5.366863	1.728624	-0.0204625	0.0462262
62.5	-8.6097222	1.7568985	-0.0268585	0.0422458
75	-10.166393	1.7296584	-0.0401282	0.0440983
87.5	-9.7770009	1.9744121	-0.0546109	0.0523591
100	-8.3194442	1.7817658	-0.0679579	0.0590034

Table 4: Analysis by varying unsprung mass, m_1

Tire Stiffness (N/m)	Vertical Acceleration (m/s^2)		Body Travel (m)	
	Min	Max	Min	Max
100000	-4.6610291	2.0141733	-0.0936159	0.0498144
118000	-6.033547	1.9811755	-0.0906198	0.0437132
135000	-6.5737557	1.9953016	0.0489244	0.0500798
153000	-5.9831473	1.8494116	-0.0770418	0.0567026
170000	-8.3194442	1.7817658	-0.0679579	0.0590034

Table 5: Analysis by varying tire stiffness, k_t

Spring Stiffness (N/m)	Vertical Acceleration (m/s^2)		Body Travel (m)	
	Min	Max	Min	Max
10000	-9.4679041	1.550286	-0.0826583	0.0400781
12291	-9.1146625	3.0491224	-0.0788352	0.0466103
14583	-8.8069162	2.5056126	-0.075112	0.0518423
16874	-8.542533	1.926349	-0.0714874	0.0559279
19165	-8.3194442	1.7817658	-0.0679579	0.0590034

Table 6: Analysis by varying spring stiffness, k

Damping Coefficient (Ns/m)	Vertical Acceleration (m/s^2)		Body Travel (m)	
	Min	Max	Min	Max
800	-5.8034202	2.8267267	-0.0754838	0.0802762
925	-5.4380785	2.4192597	-0.0733685	0.0739494
1050	-6.5010501	2.119929	-0.0714216	0.0683703
1175	-7.4575661	1.9455439	-0.0696239	0.0634281
1300	-8.3194442	1.7817658	-0.0679579	0.0590034

Table 7: Analysis by damping coefficient, c

The value differences from the reference paper [1] can be due to multiple reasons:

1. The horizontal velocity components may have been an influence which cannot be mathematically influenced.
2. The suspensions are not perpendicular to ground, the struts are incline - that can cause some differences.
3. Inconsistency in certain values.
4. Different in integral schemes maybe, which is not ensured. The best possible scheme for the Xcos has been carefully chosen over default setting on our end.

References

[1] J. Ashtekar and A. Thakur, “Simulink model of suspension system and it’s validation on suspension test rig,” *Int. J. Mech. Eng. Robot. Res*, vol. 3, pp. 2278–0149, 2014.