MAE 3260 Final Project: Active Suspension

Marcus Pang

12/9/2025

Abstract

Active suspension systems utilize sensors and onboard control to regulate the vertical motion of the vehicle body relative to the unsprung wheel assembly. Generally, used in more luxurious vehicles, it improves ride comfort and handling compared to traditional spring-damper suspensions. In this project, I study a quarter-car active suspension, designing a feedback controller using a state-space model. This work includes selecting reasonable modeling assumptions, deriving performance requirements such as ride comfort, suspension travel limits, and developing closed-loop performance under representative road disturbances. The results are a model and controller that improves body acceleration response while maintaining the constraints.

Student/Role

Marcus Pang	Researched how active suspension functions, and what assumptions need to be made for the system to be modelled. Key takeaway was how modeling assumptions trade realism for tractability.	https://github.com/Cornell-MAE-UG/fall-2025-portfolio-marcuspang28

List of MAE 3260 Concepts

- System modelling/idealization: simplifying a real suspension system into a control-oriented model
- Modeling assumptions and scope definition: deciding what dynamics to include/ignore
- Dynamic system representation

Introduction

Active suspension systems involve an actuator that raises or lowers the chassis independently at each wheel. To achieve better ride quality and handling dynamics, the main goal of the active suspension is maintaining the car parallel to the road during corners and while going over various road surfaces [1]. The quarter-car abstraction reduces the vehicle into a 1-D, two-mass spring damper system while capturing behaviors that matter for ride comfort and road handling. Within this scope, the goal of the assumptions is to create a model that is simple enough to design feedback control, but realistic enough that simulation results are meaningful.

Quarter-Car System Description and Variables

The quarter-car active suspension model represents a single corner of the vehicle using two interacting masses: the sprung mass m_s(a quarter of the vehicle body mass) and the unsprung mass m_u(wheel, tire, hub, and associated components). The suspension between these masses is modeled as a spring $k_s$and damper c_s. The tire is modeled primarily as a stiffness $k_t$connecting the wheel to the road input $r(t)$. Active suspension introduces a controllable actuator force $u(t)$applied between $m_s$and m_u.

To keep the modeling consistent, define:

- $x_s(t)$: sprung mass vertical displacement
- $x_u(t)$: unsprung mass vertical displacement
- $r(t)$: road displacement disturbance input
- Suspension deflection: $x_s - x_u$(suspension travel)
- Tire deflection: $x_u - r$(proxy for road holding/tire load variation)

These variables directly connect to the performance goals: minimizing body acceleration, limiting $| x_s - x_u |$, and keeping $| x_u - r |$small.

Modeling Assumptions

1. Quarter-car representation

Assumption: The vehicle can be approximated by modeling only on wheel station, consisting of a sprung mass and an unsprung mass [2]. This is the starting point for suspension modeling; it captures the dominant vertical vibration modes, such as body bounce and wheel hop without needing a full 4-wheel model.

2. One-dimensional vertical motion only

Assumption: All motion is purely vertical; ignore pitch/roll, steering, braking and lateral dynamics. As we are modeling this system to control ride comfort and suspension travel, the other factors are not what we are trying to model. We are trying to model the reaction between the road surface, body and wheel. Specifically, we are trying to create a model where constraints are the components' displacement and acceleration depending on the road conditions.

3. Linear Spring and damper behavior about an operating point

Assumption: The spring and damper behave linearly

- Spring force proportional to suspension deflection
- Damper force proportional to relative velocity

For small to moderate motions linearization produces a control-friendly state-space model.

4. Tire modeled as linear spring without damping [3]

Assumption: Tire dynamics are represented by a linear stiffness element; tire damping is neglected.

5. Rigid, lumped masses

Assumption: Sprung and unsprung masses are treated as rigid bodies with lumped parameters; structural flexibilities such as chassis bending, bushing compliance and wheel flexibility are ignored. This keeps the model at two degrees of freedom while capturing key vertical dynamics most relevant to ride comfort and road holding.

6. Continuous road disturbance input

Assumption: The road profile is an external disturbance input r(t), which can be e.g., bump, step, sinusoid etc. Aligns with typical suspension control studies that evaluate disturbance rejection under road irregularities [4].

7. Tire remains in contact with road

Assumption: The wheel maintains contact with the road surface; contact loss not modeled. This is a common linear-model assumption [5].

8. Active actuator modeled as an ideal for input

Assumption: The actuator produces a commanded control force u(t) directly between sprung and unsprung masses, actuator dynamics neglected initially. This allows us to start with an idealized actuator to focus on feedback design. Limits such as force saturation and bandwidth can be added later.

According to the assumptions listed above, the quarter-car active suspension is modeled as a two-DOF,1-D vertical system consisting of lumped sprung and unsprung masses, where the road is represented as a disturbance input r(t).

References

[1] “Active suspension,” *Wikipedia*. [Online]. Available: https://en.wikipedia.org/wiki/Active_suspension [Accessed: Dec. 9, 2025.]

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[3] P. Sathishkumar, J. Jancirani, D. John, and S. Manikandan, “Mathematical modelling and simulation quarter car vehicle suspension,” *International Journal of Innovative Research in Science, Engineering and Technology (IJIRSET)*, vol. 3, Special Issue 1, Feb. 2014. [Online]. Available: mathematical-modelling-and-simulation-quartercar-vehicle-suspension.pdf [Accessed: Dec. 9, 2025.]

[4] MathWorks, “Robust Control of Active Suspension,” *MATLAB & Simulink Documentation (Robust Control Toolbox)*. [Online] Available: Robust Control of Active Suspension - MATLAB & Simulink [Accessed: Dec. 9, 2025.]

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