FSAE Intern Project: Quarter Car Model

Vehicle Dynamics Intern - Highlander Racing (FSAE), Fall 2024, UC Riverside

Overview:
This project models quarter-car suspension dynamics using a MATLAB Live Script. The model is built with a state-space representation and solved numerically with ode45(). The script simulates the behavior of a spring-mass-damper system between the vehicle body and the wheel, and outputs time-displacement graphs based on velocities integrated into displacements.

Development:
The live script was developed iteratively with the assistance of ChatGPT. This process involved restructuring code sections, creating custom functions, and refining variable naming for clarity.

Code Details:
The script includes:
- Functions to calculate displacement across time intervals
- Initialized variables for vehicle body mass, wheel mass, suspension stiffness, damping coefficients, and tire stiffness
- Outputs for Time-displacement graphs for sprung and unsprung masses

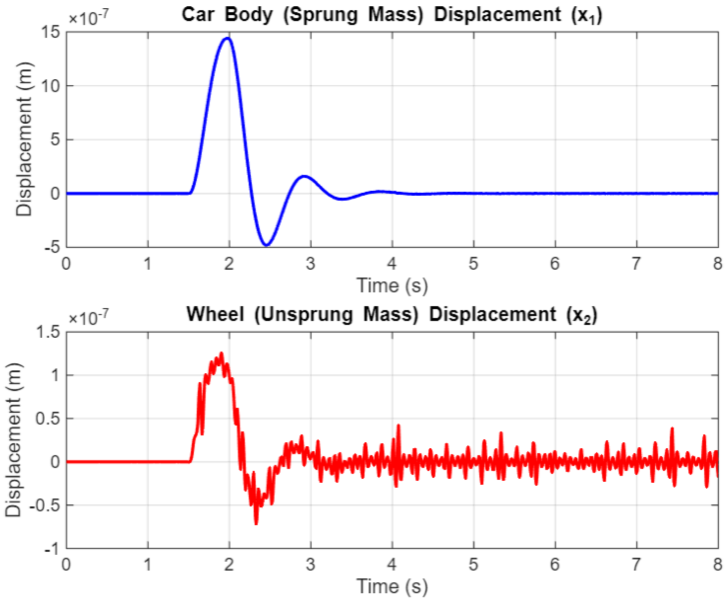
Concepts & Conventions (for this script):
- Displacement (m) for sprung and unsprung mass is positive when going up
- **NOTE:** Plots labeled below with **"x1" and "x2"** correspond to **x1 (body) and x3 (wheel)** from the MATLAB script, respectively
- Spring compression/extension: $x_s(t) = x_1(t) - x_3(t)$
  - $x_s > 0$ = Compression
  - $x_s < 0$ = Extension

Sedan

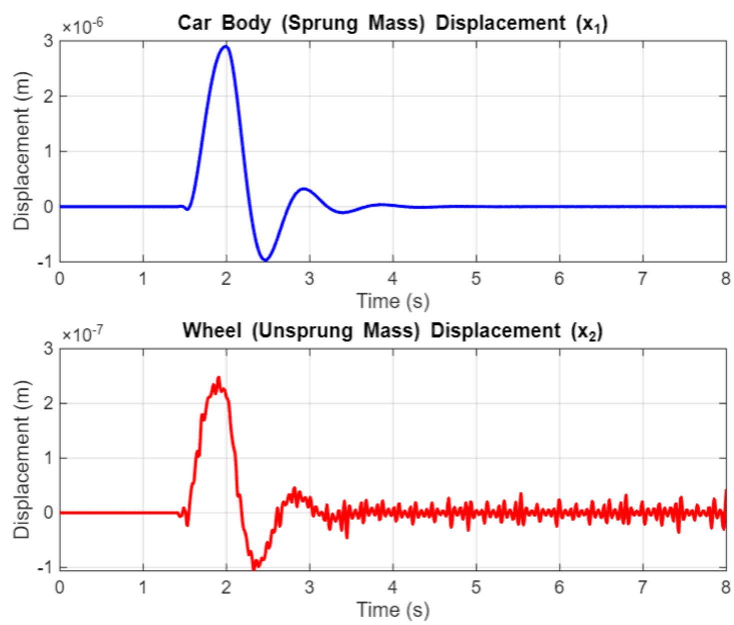
“Baseline vehicle” for the quarter-car model.

Observations:

- When encountering a road bump, the sedan body exhibits ~5 oscillations, each decreasing in amplitude



- Doubling the bump height (0.04 m displacement) proportionally increases displacement amplitude while maintaining the same oscillatory behavior

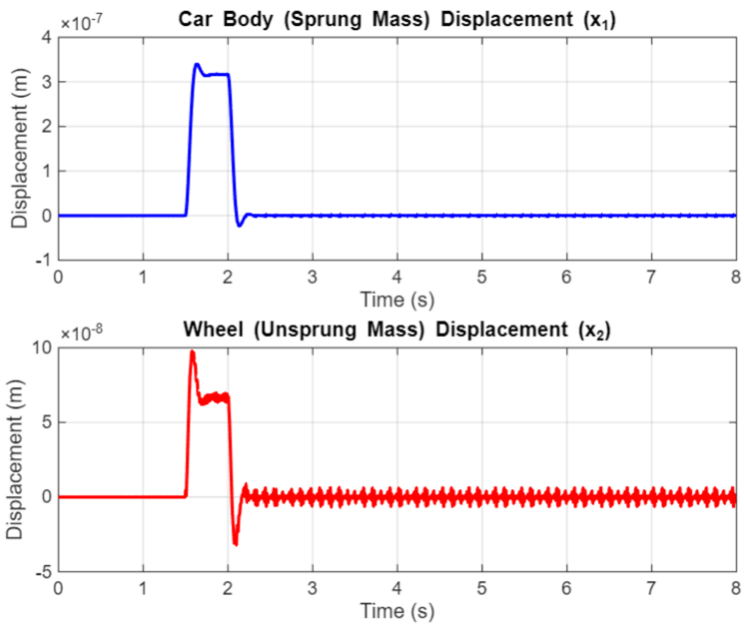


Formula Race Car

Low sprung mass (due to its lightweight construction), high suspension stiffness (to handle aerodynamic downforce and sharp handling requirements), high damping (larger coefficient to handle oscillations effectively at higher speeds), and stiffer tires (for minimal deformation under extreme loads).

Observations:

- The maximum displacement for the sprung mass is roughly 3 x 10^-7 m (significantly less than the sedan's max displacement of 15 x 10^-7 m)
- Vehicle body displacement remains relatively constant due to high suspension stiffness (body encounters a prolonged and somewhat constant spring compression)
- Tire displacement, in contrast, encounters a prolonged spring expansion (prolonged peaks in displacements are consistent with higher spring stiffness and the nature of formula racing, when sharp turns apply stress to a vehicle)

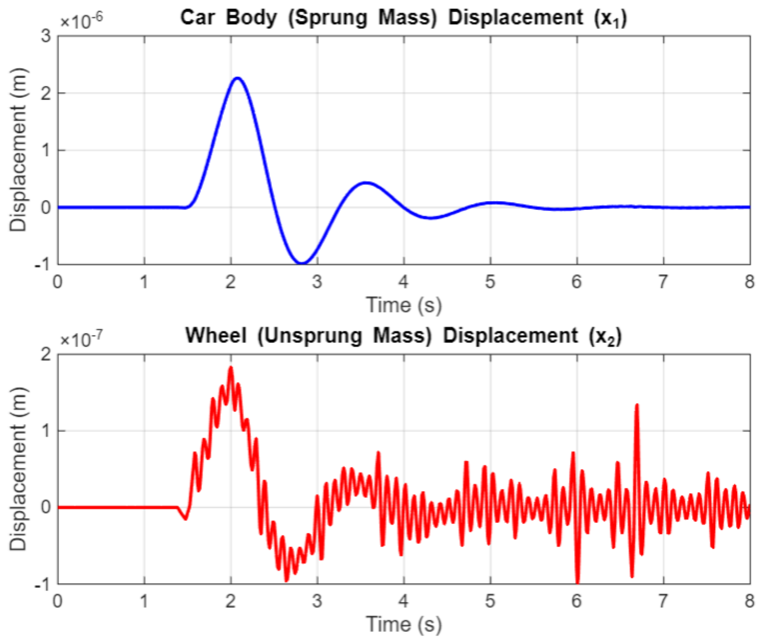


Pickup Truck

Heavier weight, softer suspension (some trucks), and larger tire sizes (trucks often prioritize load-carrying and utility over speed handling, leading to different suspension and tire characteristics from sedans and race cars)

Observations:

- Larger displacement magnitudes for sprung and unsprung mass


Car Body (Sprung Mass) Displacement (x1)
×10-6
Displacement (m)
Time (s)
Wheel (Unsprung Mass) Displacement (x2)
×10-7
Displacement (m)
Time (s)

EXTENSION: Observing Force Impulses & Natural Frequencies

For this phase of the project, the road displacement code is replaced with direct force inputs (N) applied to both masses. Additionally, code is added to calculate and classify natural frequencies

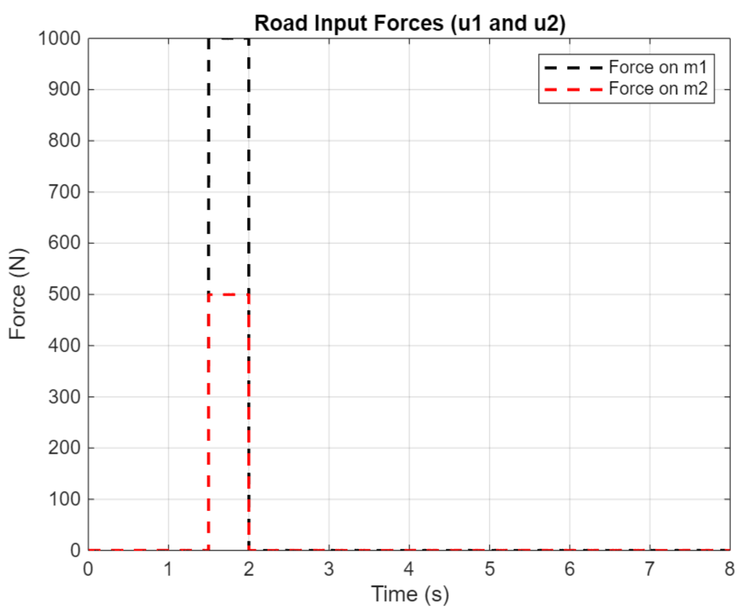
Modifications:

- The original 4x1 State matrix (B) is replaced with a 4x2 matrix to account for forces applied to both masses
- Two interpolating functions (one for each mass, with extrapolation), implemented for the applied forces

Input Forces:

- Sprung mass set to 1000 N and unsprung mass set to 500 N (chosen to produce a clearly observable response, strong enough disturbance to visualize differences)
- Applied between 1.5 - 2.0 seconds (imitating the road displacement from the previous phase of the project)

Road Input Forces (u1 and u2):



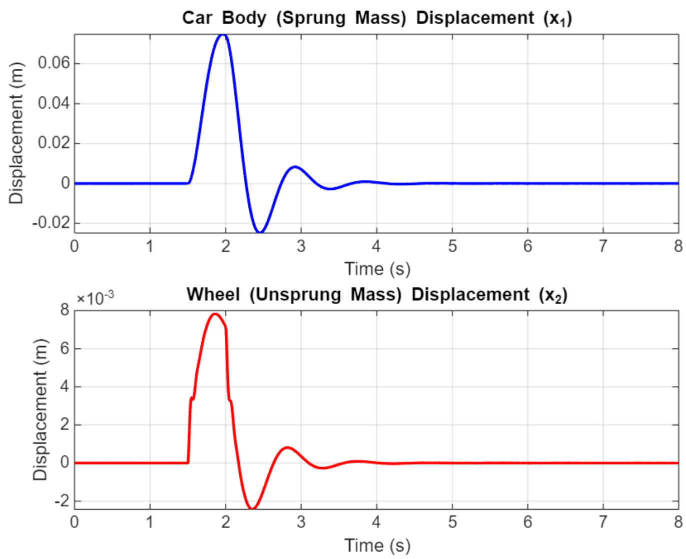
Undamped Natural Frequency

The undamped natural frequency is the rate at which a system would vibrate after a disturbance if no damping were present.

- A higher natural frequency means the vehicle responds more quickly to bumps; a lower natural frequency means a slower, smoother response.

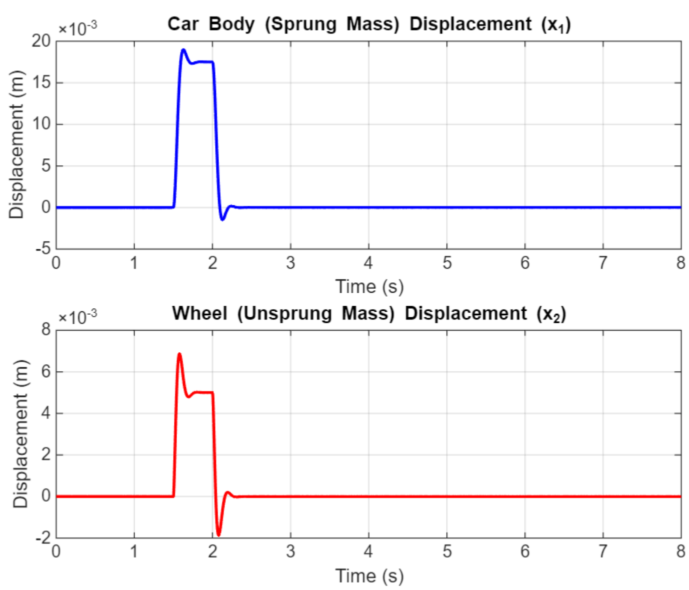
Sedan

- Sprung mass displacement: 0.08 m
- Unsprung mass displacement: 8 x 10^-3 m
- Natural Frequency: 1.1623 Hz
- Damping Ratio: 0.36515 / Damping Classification: Underdamped



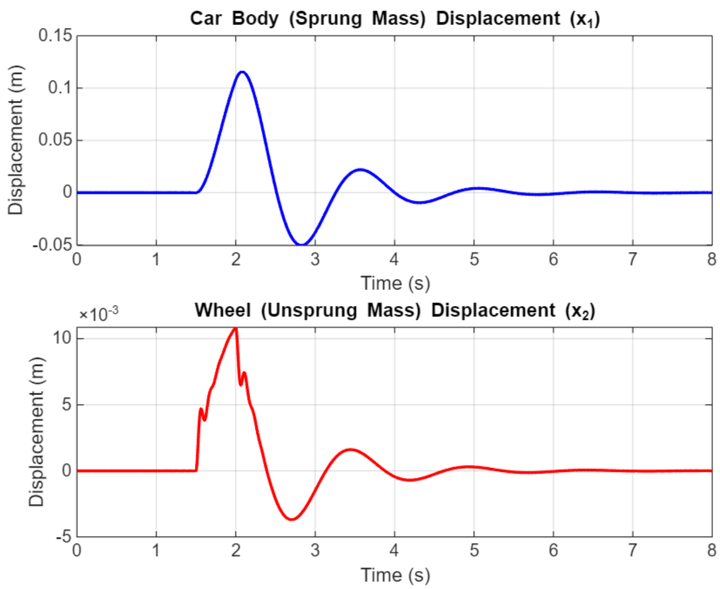
Formula Race Car

- Sprung mass displacement: 0.02 m (1/4th of sedan response)
- Unsprung mass displacement: 7 × 10^-3 m (Rapid stabilization with minimal oscillation is consistent with a stiff suspension design)
- Natural Frequency: 4.11 Hz
- Damping Ratio: 0.807 / Damping Classification: Underdamped



Truck

- Sprung mass displacement: roughly 0.10 m
- Unsprung mass displacement: roughly 0.01 m (Larger responses consistent with heavier mass and lower damping)
- Natural Frequency: 0.71 Hz
- Damping Ratio: 0.280 / Damping Classification: Underdamped



Project Challenges:

- Gaining familiarity and understanding of how state space representation works
- Modeling and interpreting force impulses applied to single vs. multiple masses
- Difficulty generating force impulse plots for both sprung and unsprung masses
- Working outside of my primary academic background introduced additional learning challenges, particularly in mechanical engineering concepts