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System Initial Values:

- **Sprung mass (ms = 300 kg)** → the vehicle body
- **Unsprung mass (mu = 40 kg)** → wheel + axle
- **Suspension spring (ks = 15,000 N/m)**
- **Suspension damper (cs = 1,000 Ns/m)**
- **Tire spring (kt = 200,000 N/m)**
- **Tire damping (ct = 50 Ns/m)**
- **Road input** (a bump applied as a step of 1 cm)

The simulation runs for 5 seconds using an ODE45 solver.

Mathematical Model:

Body (sprung mass):

$$m_s \ddot{z}_s = -k_s(z_s - z_u) - c_s(\dot{z}_s - \dot{z}_u) + u$$

Wheel (unsprung mass):

$$m_u \ddot{z}_u = k_s(z_s - z_u) + c_s(\dot{z}_s - \dot{z}_u) - k_t(z_u - z_r) - c_t(\dot{z}_u - \dot{z}_r) - u$$

u is the Skyhook control force.
For passive suspension, u = 0.

Natural Frequencies (How the car vibrates):

Mode	Frequency	Damping Ratio

Body mode	**1.09 Hz**	**0.212**
Wheel-hop mode	**11.59 Hz**	**0.183**

These values are typical for cars:

- 1–2 Hz → felt by passengers (comfort zone)
- 10–12 Hz → wheel vibration (tire dynamic)

Skyhook Control

Skyhook control acts like a virtual damper connected to the sky:

$$u = -c_{sky}(z\_s)'$$

It only damps the body motion, not the wheel.
This improves comfort without making the suspension too stiff.

Value used in my project is:
c_sky = 2000

Skyhook adds additional damping **only to the body**, improving comfort without increasing stiffness.

Comparison of results:

a) Comfort (Body Acceleration):

Metric	Passive	Skyhook	Improvement
RMS (acc_s)	**0.289**	**0.262**	**9.2% better**
Peak (acc_s)	**2.061**	**1.882**	**improved**

b) Suspension Travel:

Passive	Skyhook
0.0134 m	0.0135 m

c) Settling Time:

Passive	**Skyhook**
1.021 s	1.011 s

Frequency-Domain Comparison:

Passive Suspension

- GM = 7.85
- PM = 60.40°

Skyhook Suspension

- Gain Margin = 8.079 (18.15 dB)
- Phase Margin = 149.41°

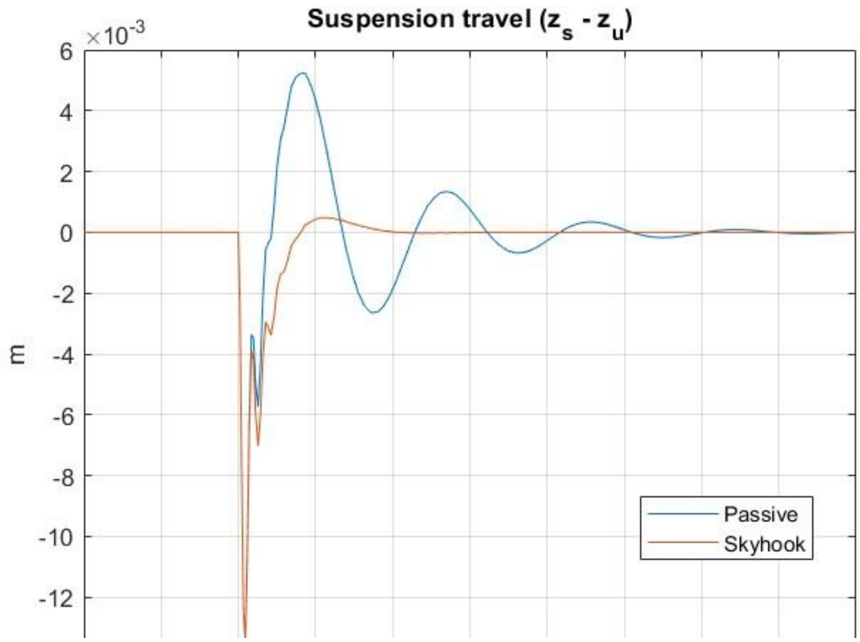
This huge increase in phase margin shows:

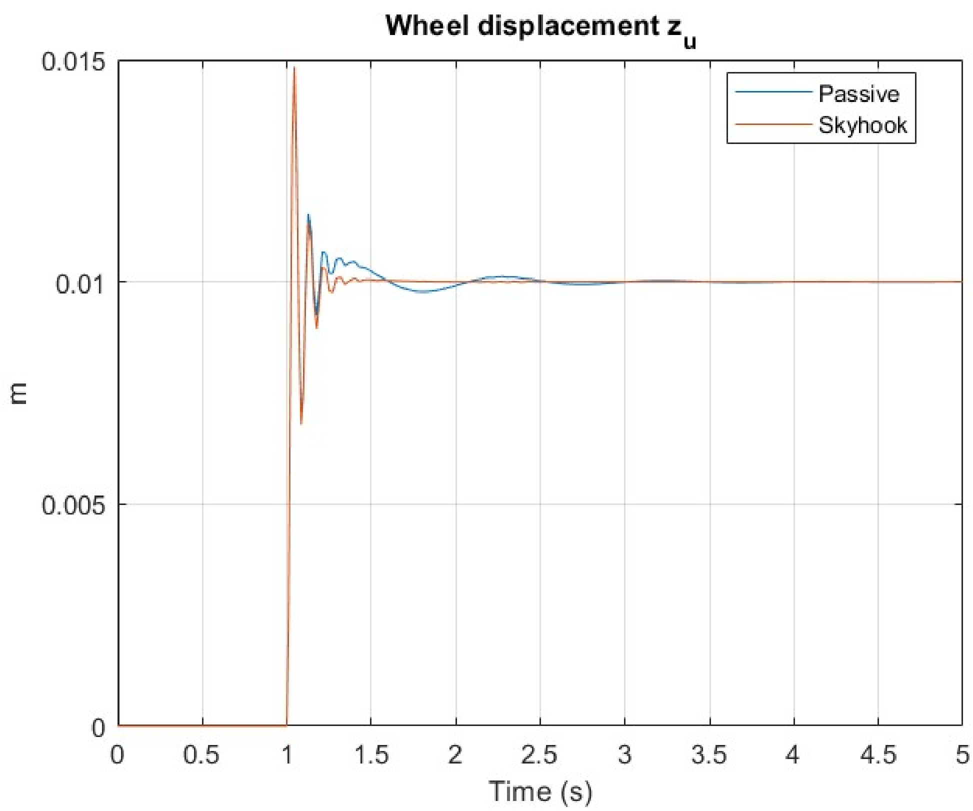
- Much higher stability
- More damping
- Increased robustness

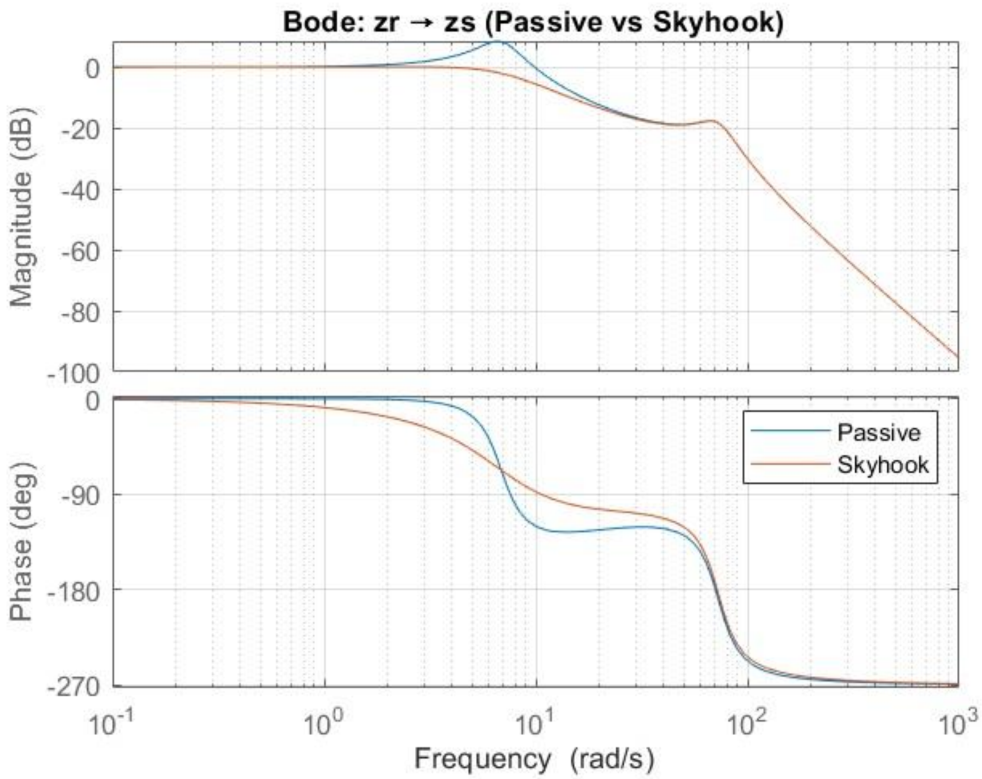
Modal Damping with Skyhook:

Mode	**Damping Ratio**
Body mode	**0.7048** (vs. 0.2124 passive)
Wheel-hop mode	unchanged

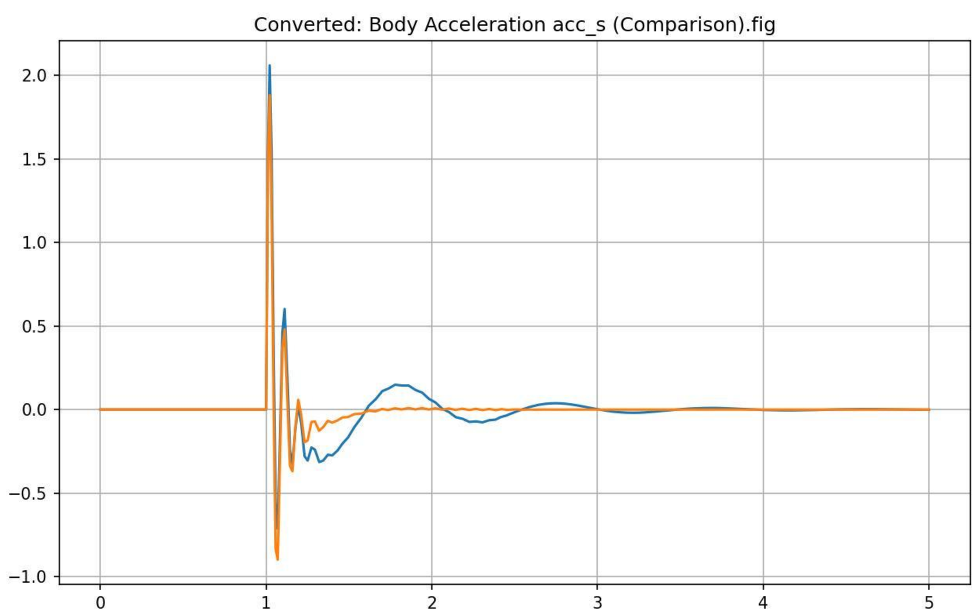
Comparison Graphs:



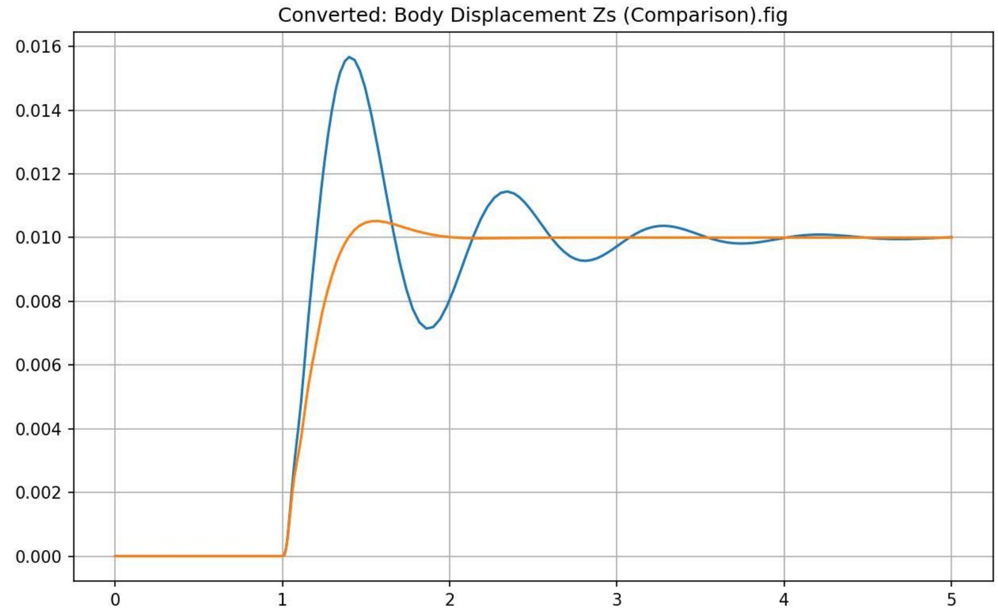




Bode: zr → zs (Passive vs Skyhook)
Magnitude (dB)
Phase (deg)
Passive
Skyhook
Frequency (rad/s)



Converted: Body Acceleration acc_s (Comparison).fig



Conclusion:

With a 1 cm road bump, the quarter-car suspension system behaves realistically.
Skyhook control clearly improves comfort by:

- Reducing RMS acceleration by 9.2%
- Lowering peak acceleration
- Increasing body-mode damping by more than 3×
- Increasing phase margin to 149°, showing excellent robustness
- Maintaining safe suspension travel

This confirms that Skyhook damping is an effective approach for enhancing ride comfort without compromising the vehicle's mechanical limits.