

Vehicle Roll & Active Roll Control

Roll physics, passive vs active control, and an air-spring roll control simulation

Key Terms

Roll	Rotation of the body about its longitudinal axis in a corner.
Roll angle	Tilt between the body and the road.
Roll center	Point in the suspension geometry the body rotates about (front and rear).
Roll axis	Line joining the front and rear roll centers.
Roll gradient	Roll angle per unit lateral acceleration; a core handling-tuning metric.
Moment arm	Distance from CG to roll axis. Larger arm = more roll and rollover tendency (SUVs, lifted trucks).

Model Relationships

Roll moment	$M_{\text{roll}} = m a_y h'$	h' = CG distance above the roll axis (standard).
Natural frequency	$\omega_n = 2\pi f_n$	Model fixes $f_n = 1.5$ Hz.
Damping coefficient	$b_d = 2\zeta\sqrt{k m}$	ζ chosen between 0.25 and 0.30; 0.30 selected.
Adiabatic air spring	$P V^\gamma = \text{constant}, \gamma = 1.4$	Air is compressible, so the spring is non-linear.
Controller current	$i = k_1 \theta + k_2 \dot{\theta} + k_3 \ddot{\theta}$	Feedback on roll angle, velocity and acceleration.

Passive vs Active Roll Control

System	How it works	Pros	Cons
Passive sway bar	Torsion spring linking left and right suspension	Simple, cheap, no power	Fixed stiffness
Active anti-roll bar	Motor or hydraulic actuator varies bar stiffness from lateral accel, speed, steering	Adapts to mode; better ride and handling	Cost, complexity, weight
Active air-spring (this model)	Motor + ball screw shift air-spring pressure side to side	Continuously variable, tunable	Harder to model and control
Full active suspension	Hydraulic actuator per wheel holds ride height and pitch	Steady aero platform (race cars)	Complexity, weight, power

Simulation Parameters & Results

2000 N·m

Input torque at CG simulating cornering

1 rad/s

Peak roll velocity before leveling out

680.38 kg

Sprung mass

6 rad/s²

Initial roll acceleration, decaying to 0

1.0×10^5 N/m²

Initial air-spring pressure P_0

$\zeta = 0.30$

Damping ratio chosen at rest

5

State variables (one per I or C element), 37 bonds

R ↑ / L ↓

Air-spring pressure shift while rolling

Design Takeaways

- Minimize the CG-to-roll-center distance to cut roll and improve handling; roll center can shift with terrain.
- Front/rear roll-stiffness split sets balance: softening the front bar reduces understeer (Newey).
- Hard braking moves the aero center of pressure forward, adding front grip at turn-in; active suspension holds the platform steady.
- EVs roll less thanks to a low, floor-mounted battery, which makes electronic anti-roll less critical.
- Road-car active systems mainly target comfort and body control; passive setups remain the norm.