Guard Rail Impact Module: User Manual & Technical Reference

1. Introduction

The Guard Rail Impact Module is a browser-based, 6-Degree-of-Freedom (6-DOF) physics simulation designed to model vehicle–barrier collisions. It focuses on the transient response of a suspended vehicle striking a fixed roadside barrier, capturing complex behaviors such as:

- Pitch-over
- Spin-out (yaw)
- Structural rail failure

2. Quick Start Guide

2.1 Setting Up the Vehicle

Chassis Dimensions: Enter the Length, Width, and Height of the vehicle frame in Box 1.

Mass Properties: Adjust the weight of the chassis (Box 1) and payload (Box 2). The simulation automatically calculates:

- Center of Gravity (CG)
- Mass Moments of Inertia: I_{xx}, I_{yy}, I_{zz}

Suspension: Tune the Spring Rate k and Damping c for front/rear axles to match the desired ride frequency (typically 1–2 Hz).

2.2 Configuring the Barrier

Rail Position: Set Center Y to determine how far down the road the barrier is located (default: 300 in).

Impact Angle: Use the Angle input to rotate the rail.

- **0°:** Perpendicular (head-on wall)
- Positive angle (e.g., 20°): Angled barrier deflecting the vehicle to the right

Rail Height:

- **Low (< 15")** – Acts as a curb or trip hazard; tires may climb over, causing severe roll.
- **High (> 24")** – Acts as a wall; main contact is with bumper/chassis.

2.3 Running the Simulation

1. Select a Tire Preset (e.g., *Sedan*, *Panel Truck*).

2. Set the Initial Speed (e.g., 300 in/s).
3. Click ▶ Solve.

Visualize: Watch the 3D playback. If the rail breaks, a visible gap appears.

Analyze: Use the charts to review:

- G-forces (X, Y, Z)

3. Theoretical Background

3.1 Equations of Motion (6-DOF)

The simulation solves the **Newton–Euler equations** for a rigid body in 3D.

Translation: $F = ma$(Solved for Surge x, Sway y, Heave z)

Rotation: $T = I\alpha$(Solved for Roll ϕ, Pitch θ, Yaw ψ)

The state vector Scontains 20 variables, including:

- Position
- Velocity
- Suspension deflection at all 4 corners

Integration uses 4th-Order Runge-Kutta (RK4) at 240 Hz ($dt = 0.004s$) for stability during high-frequency impacts.

3.2 Collision Detection

Collision is modeled using continuous interference detection between:

- Vehicle geometry (4 corner points relative to CG)
- Barrier geometry

Normal Force (Kelvin-Voigt model):

$$F_{\text{contact}} = k_{\text{rail}} \cdot \delta + c_{\text{rail}} \cdot \dot{\delta}$$

Where:

- δ= penetration depth
- $\dot{\delta}$= closing velocity

Moments: Applied at the impact point, generating:

- **Yaw Moment** T_z– from lateral offset
- **Pitch Moment** T_x– from vertical offset $(Z_{\text{rail}} - Z_{\text{cg}})$

Low rails trip the vehicle (pitch-down). High rails tip it backward.

3.3 Rail Failure Model (Shear)

The simulation uses a Brittle Fracture model.

- Threshold: If contact force exceeds Rail Break Load, the rail breaks.
- Impulse: At the break frame, the full Break Load is applied as a final impulse.
- Release: After breakage, force drops to zero and the mesh becomes a "phantom."

3.4 Tire Model (Lateral Dynamics)

A **linear viscous scrub model** is used for stability during spin-outs.

Lateral Force:

$$F_{\text{lat}} = -\left(k_{\text{lat}} \cdot x_{\text{slip}} + c_{\text{lat}} \cdot v_{\text{slip}}\right)$$

This acts as a viscous anchor, resisting sideways motion.

4. Preset Library

Tire Presets

Preset Name	k_{lat} (lb/in)	c_{lat} (lb·s/in)	Description
Sports Car	1200	60	High grip, stiff sidewalls; fast response; stops sliding quickly.
Sedan / SUV	800	40	Balanced; moderate sideslip; standard street tires.
Panel Truck	600	35	Tall sidewalls; heavy mass response; "wallowy" feel.
Off-Road	400	25	Soft, balloon-like tires; significant sway and delay.
Drift / Ice	800	5	Stiff carcass, very low damping; long sliding distance.

5. References

Gillespie, T. D. (1992). *Fundamentals of Vehicle Dynamics*. SAE. Reference for sprung mass equations and coordinate systems.

Milliken, W. F., & Milliken, D. L. (1995). *Race Car Vehicle Dynamics*. SAE. Reference for moment generation and simplified tire models.

Blundell, M., & Harty, D. (2004). *The Multibody Systems Approach to Vehicle Dynamics*. Elsevier. Reference for penalty-method contact force modeling.