دانشگاه سمنان

Semnan University
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دانشکده مهندسی مکانیک

دانشکده مهندسی مکانیک

درس طراحی سیستم های شاسی خودرو

Vehicle Chassis Systems Design

Chapter 9 – Roll-over

Class Lecture

❑ Contents:

INTRODUCTION

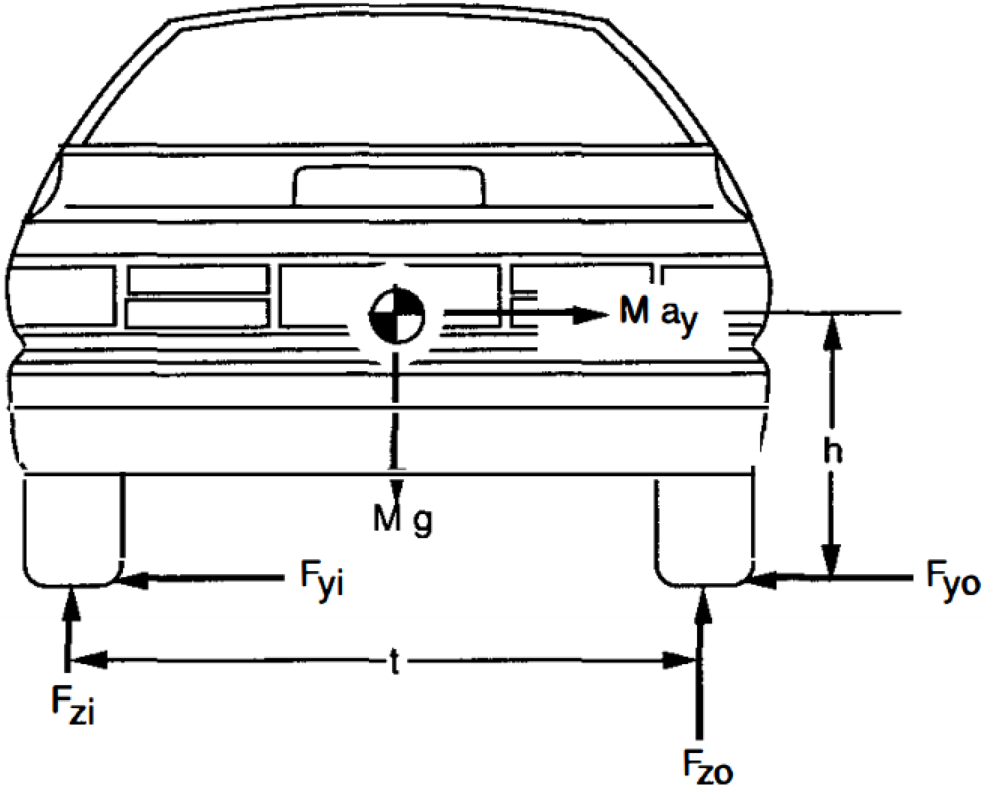
- Rollover may be defined as any maneuver in which the vehicle rotates 90 degrees or more about its longitudinal axis such that the body makes contact with the ground.

- Rollover may be precipitated from one or a combination of factors:
  - Lateral acceleration
  - Road contribution

- The process has been investigated analytically and empirically

Quasi-Static Rollover of a Rigid Vehicle

- Considering the balance of forces on a rigid vehicle in cornering
  - Rigid vehicle: deflections of the suspensions and tires will be neglected



Quasi-Static Rollover of a Rigid Vehicle

- With transverse slope of road: φ

  - Moments about the center of contact for the outside tires

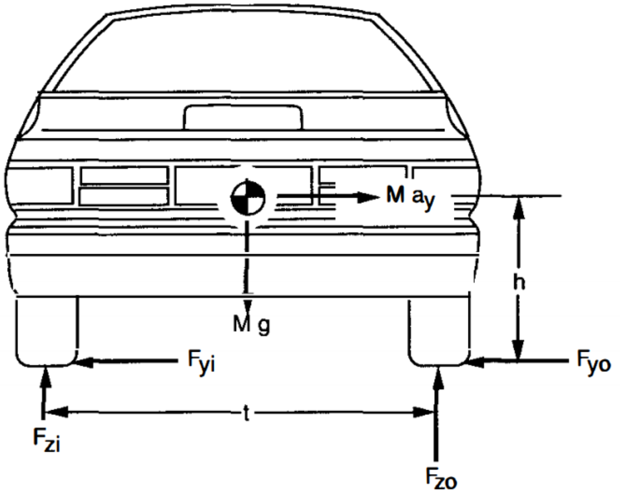
$$M a_y h - M \varphi h + F_{zi} t - M g t/2 = 0$$

  - Solve for a_y:

$$\rightarrow \quad \frac{a_y}{g} = \frac{t/2 + \varphi h - \frac{F_{zi}}{M g} t}{h}$$

  - Proper slope for equal Fzi and Fzo:

$$\rightarrow \quad \varphi = \frac{a_y}{g}$$



Quasi-Static Rollover of a Rigid Vehicle

- The limit cornering condition will occur when the load on the inside wheels reaches zero.

- The lateral acceleration at which rollover begins is the "rollover threshold“

$$\rightarrow \quad \frac{a_y}{g} = \frac{t/2 + \varphi h}{h}$$

  - This estimate is very conservative (predicting a threshold that is greater than the actual) and are more useful for comparing vehicles rather than predicting absolute levels of performance.

QUASI-STATIC ROLLOVER OF A RIGID VEHICLE

- The rollover threshold typical values

Vehicle Type	CG Height	Tread	Rollover Threshold
Sports car	18-20 inches	50-60 inches	1.2-1.7 g
Compact car	20-23	50-60	1.1-1.5
Luxury car	20-24	60-65	1.2-1.6
Pickup truck	30-35	65-70	0.9-1.1
Passenger van	30-40	65-70	0.8-1.1
Medium truck	45-55	65-75	0.6-0.8
Heavy truck	60-85	70-72	0.4-0.6

Quasi-Static Rollover of a Rigid Vehicle

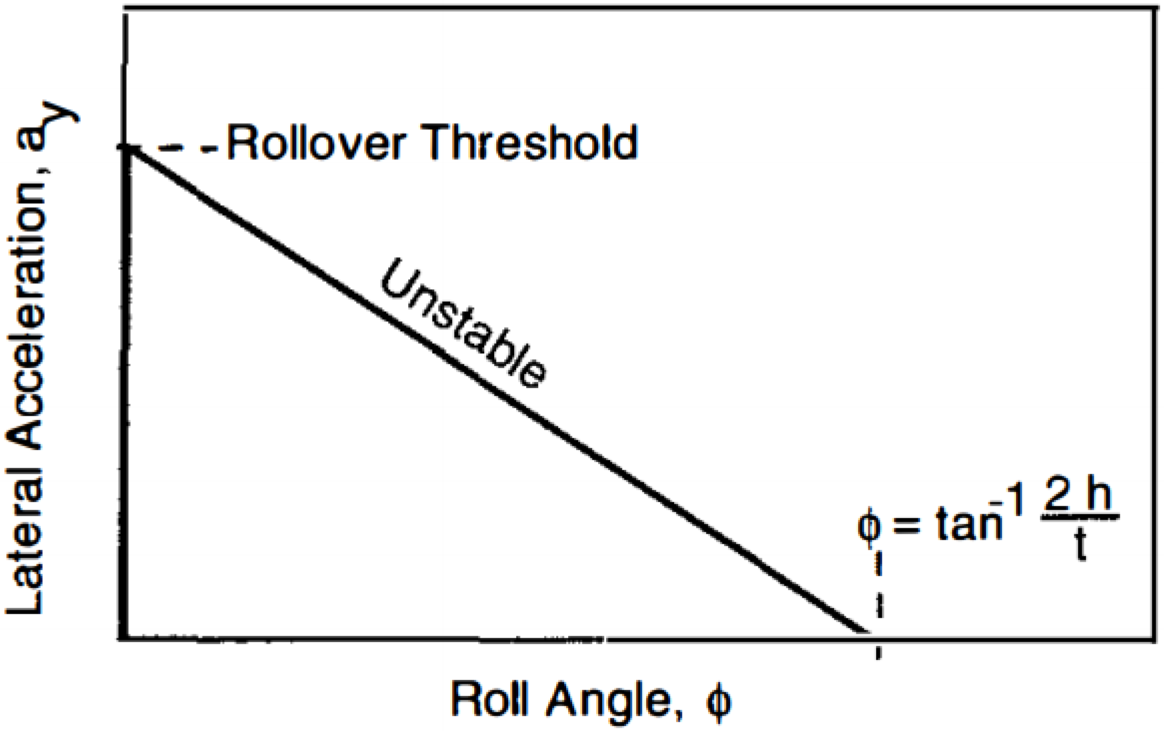
- Typical peak coefficients of friction are on the order of 0.8.

- The rigid-vehicle model suggests that the lateral acceleration necessary to reach the rollover of passenger cars and light trucks exceeds the cornering capabilities arising from the friction limits of the tires.

- That being the case, it is possible for the car to spin out on a flat surface without rolling over.

Quasi-Static Rollover of a Rigid Vehicle

- Equilibrium lateral acceleration in rollover of a rigid vehicle

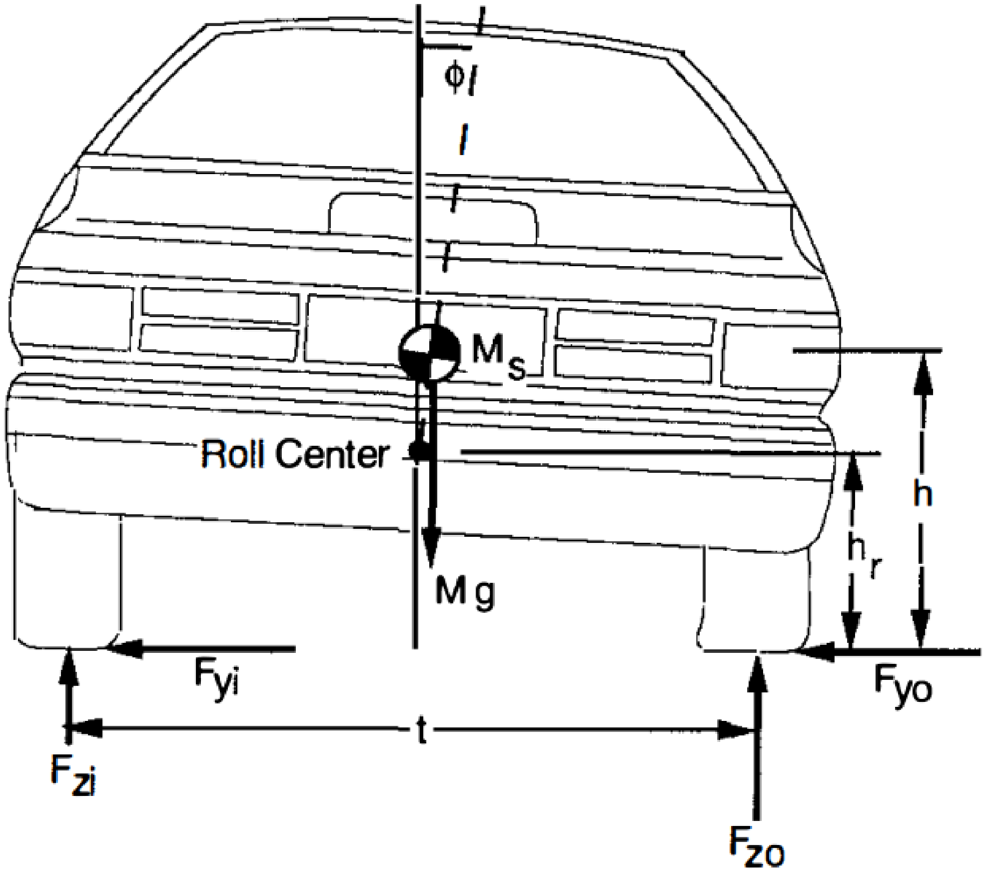


Quasi-Static Rollover of a Suspended Vehicle

- Neglecting the compliances in the tires and suspensions overestimates the rollover threshold of a vehicle.
- In cornering, the lateral load transfer unloads the inside wheels of the vehicle and increases load on the outside wheels.
- Concurrently the body rolls with a lateral shift of the center of gravity toward the outside of the turn.
- The offset of the center of gravity reduces the moment arm on which the gravity force acts to resist the rollover

Quasi-Static Rollover of a Suspended Vehicle

- Roll reactions on a suspended vehicle



Quasi-Static Rollover of a Suspended Vehicle

- A simple analytical solution for the rollover threshold
  - Neglecting mass and roll of the axle

$$\Sigma M_o = 0 = M_S\, a_y\, h - M_S\, g[t/2 - \phi\,(h - h_r)]$$

  - Roll angle of the sprung mass: $\boldsymbol{\varphi = R_\varphi \times a_y}$

$$\rightarrow \quad \frac{a_y}{g} = \frac{t}{2\,h}\,\frac{1}{[1 + R_\phi(1 - h_r/h)]}$$

h = Height of the center of gravity above the ground
h_r = Height of the roll center above the ground at the longitudinal CG location
t = Tread
R_ϕ = Roll rate (radians/g)

  - For a passenger car, rollover threshold is reduced approximately 5 percent.

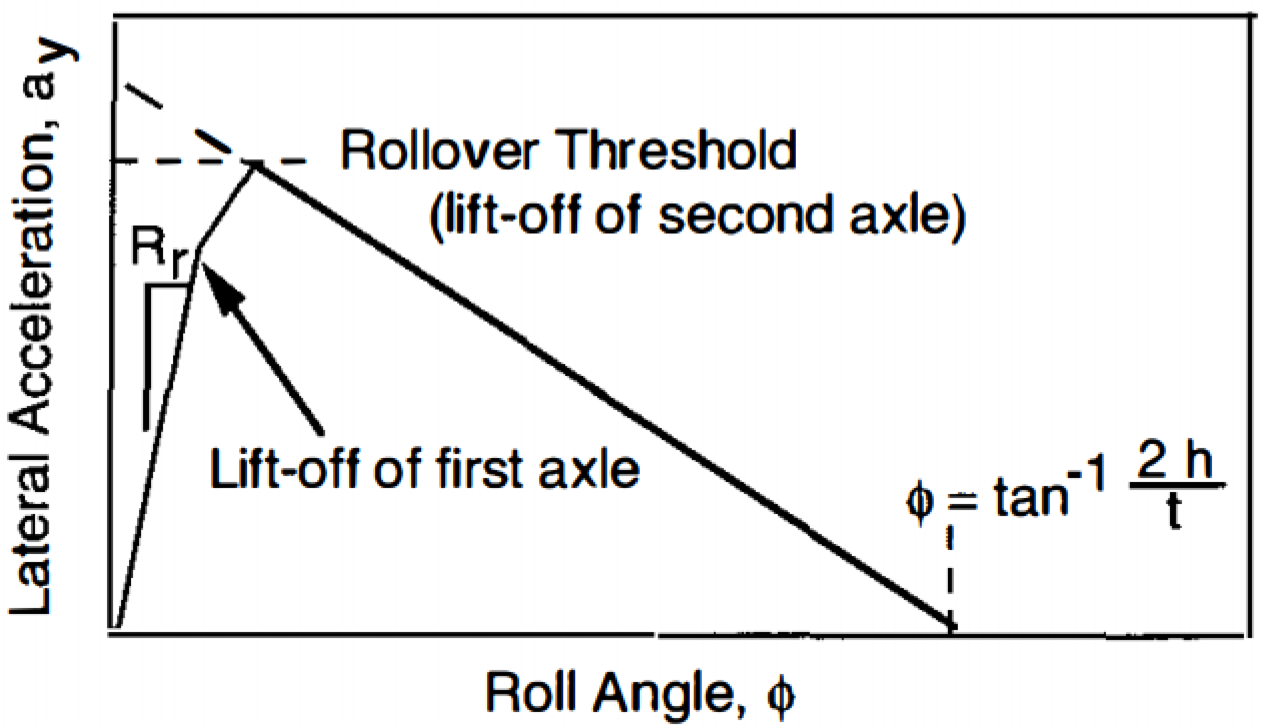
Quasi-Static Rollover of a Suspended Vehicle

- A similar mechanism arises from lateral deflections of the outside tires (another 5 percent reduction to the threshold).

- More precise analysis:
  - Lateral shift of the sprung mass center of gravity caused directly by roll about the suspension roll center
  - Lateral shift of the suspension roll center with respect to the tread, due to roll of a solid axle or camber of independently sprung wheels
  - Lateral movement of the action point of the tire vertical force due to cornering forces and deflections
  - Differences in behavior of the front and rear suspensions and wheels

QUASI-STATIC ROLLOVER OF A SUSPENDED VEHICLE

- Equilibrium lateral acceleration in rollover of a suspended vehicle



Transient Rollover

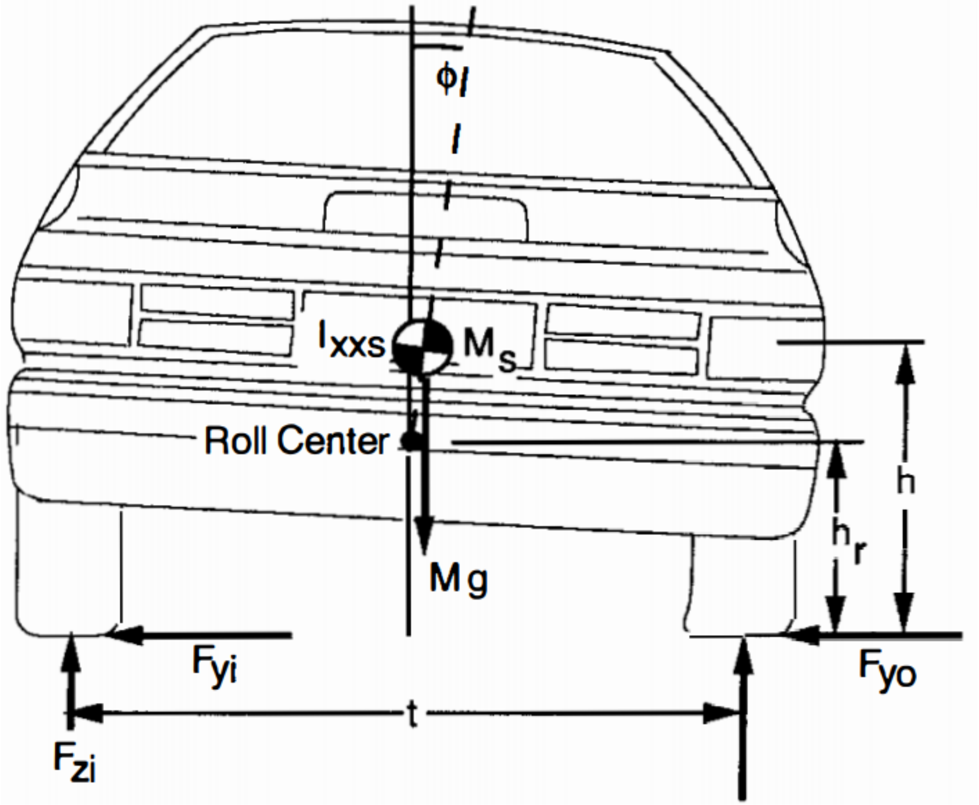
- In order to examine vehicle response to rapidly changing lateral acceleration conditions, a transient model is necessary.

- At the most elementary level, a simple roll model may be used to examine response to analytically simple examples of time-varying lateral accelerations.

- Alternately, more comprehensive models combining motions in the yaw and roll planes have been developed to examine roll response associated with specific maneuvering conditions

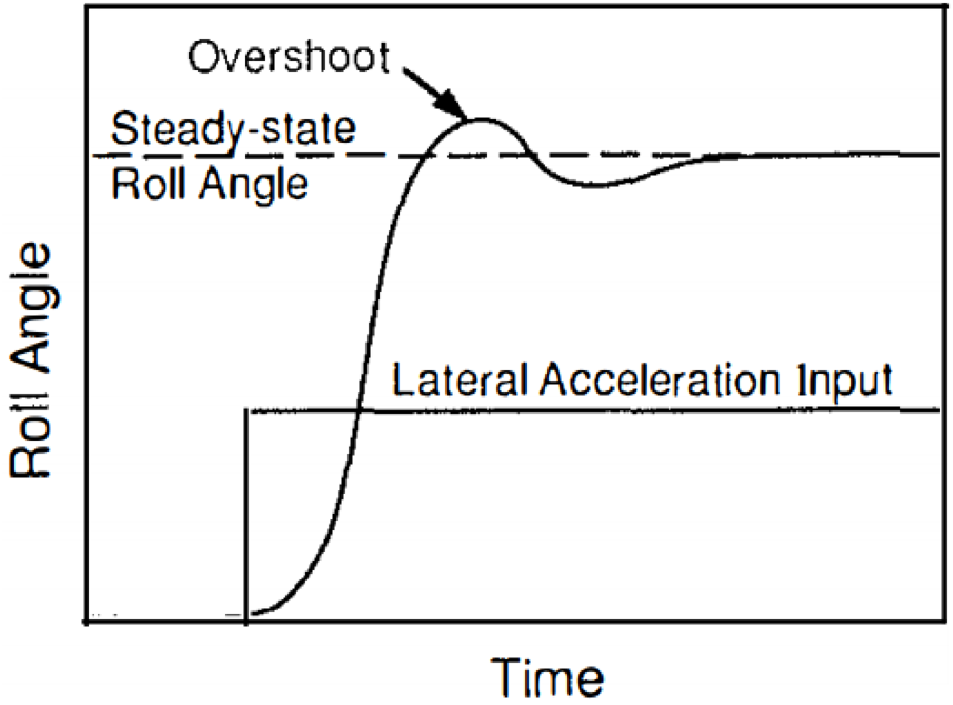
Transient Rollover

- Simple Roll Models
  - A model similar to the suspended vehicle with a roll moment of inertia for the sprung mass



Transient Rollover

- Simple Roll Models
  - This model can be useful for examining vehicle response to suddenly applied lateral accelerations in the nature of a step input.

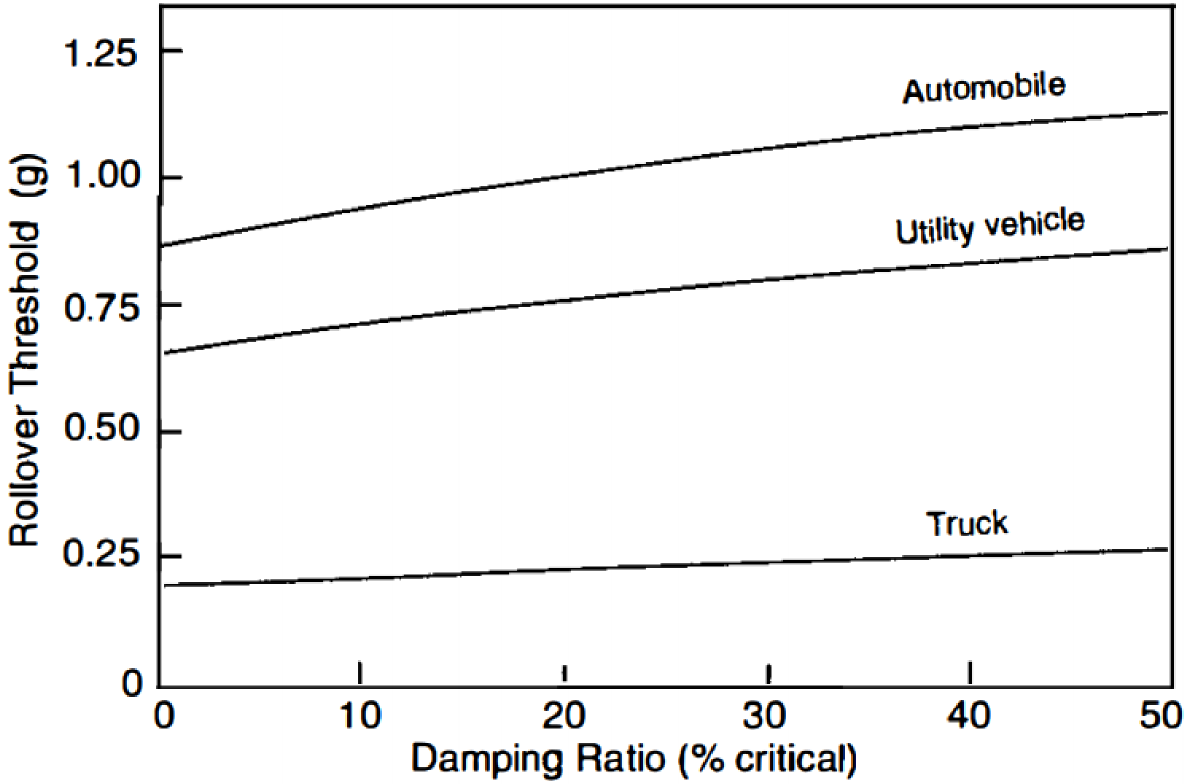


Transient Rollover

- Simple Roll Models
  - With the sudden acceleration input the roll angle responds like a second order system.
  - The fact that the roll angle can overshoot means that wheel lift-off may occur at lower levels of lateral acceleration input in transient maneuvers than for the quasi-static case.
  - So a step steer maneuver that produces a lateral acceleration level just below the quasi-static threshold can result in rollover in the transient case because of the overshoot. Thus the rollover threshold is lower in transient maneuvers.

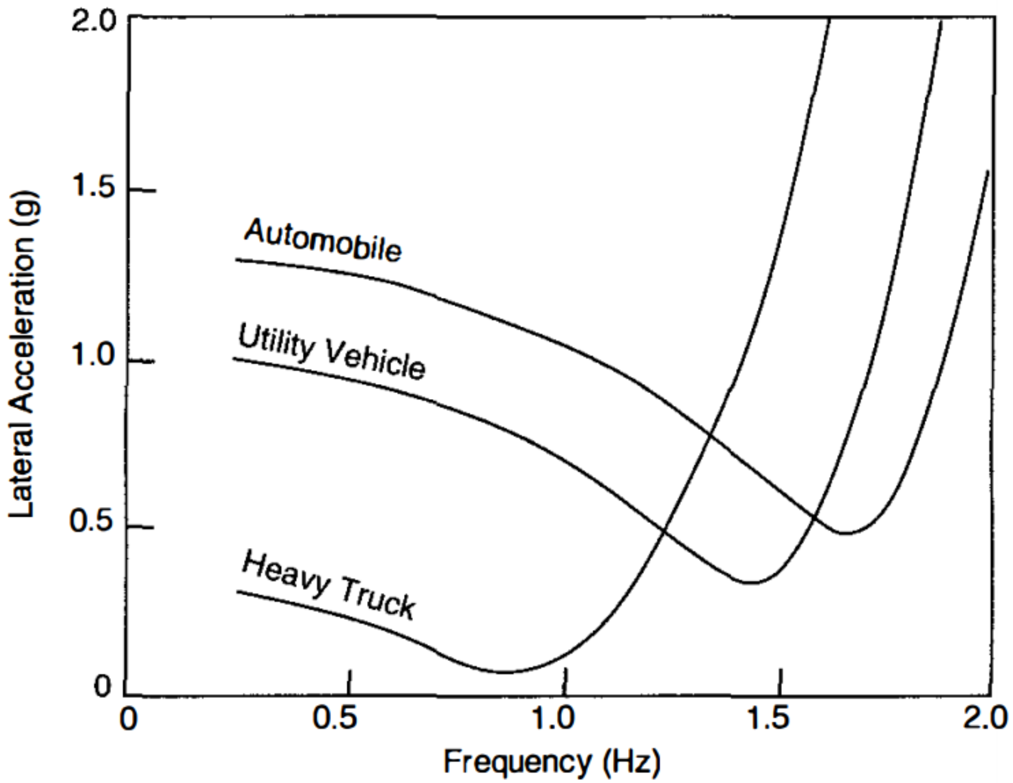
Transient Rollover

- Simple Roll Models
  - Effect of damping ratio on rollover threshold in a step steer



Transient Rollover

- Simple Roll Models
  - Exercising this model with a sinusoidal acceleration input
    - ✓ Effect of roll resonance on the rollover threshold



Transient Rollover

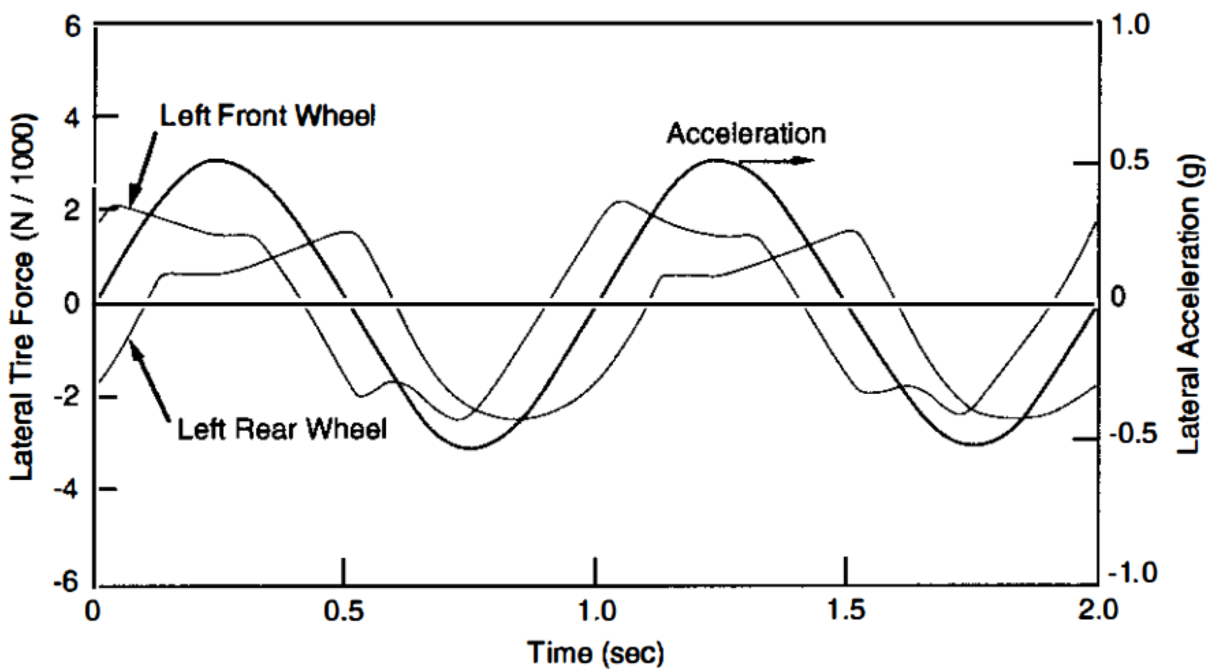
- Simple Roll Models
  - A sinusoidal acceleration is similar to the input that would be experienced in a slalom course.
  - The roll resonant frequency for a heavy truck, which is less than one cycle per second because of its high center of gravity, makes it especially vulnerable to these dynamics.
  - Experience has shown that "lane-change type" maneuvers executed over two seconds (one-half Hz) are well capable of exciting roll dynamics that can precipitate rollover of heavy trucks.

TRANSIENT ROLLOVER

- Yaw-Roll Models
  - To develop the most complete and accurate model of vehicle roll behavior, it is necessary simulate both yaw and roll response.
  - Yaw motions produce the lateral accelerations causing roll motions, and roll motion in tum alters yaw response through the modification of tire cornering forces arising from lateral load transfer and suspension action.
  - Several computer models have been developed by the vehicle dynamics community to investigate this behavior.

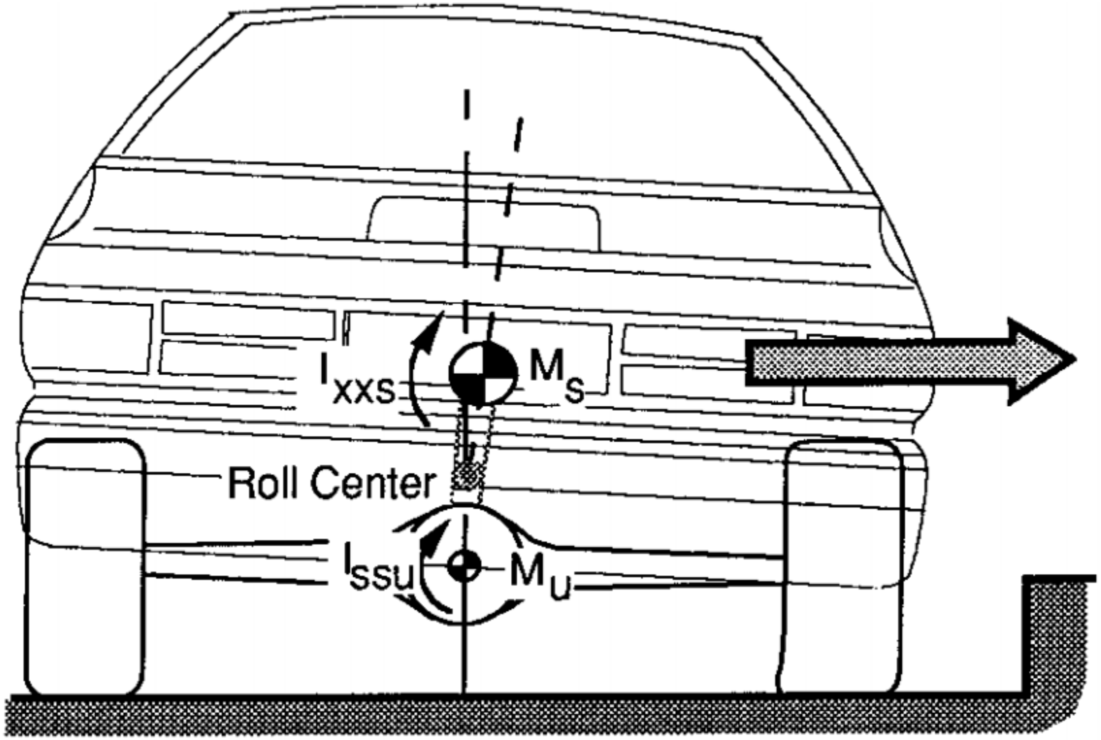
Transient Rollover

- Yaw-Roll Models
  - Using a more comprehensive model to examine sinusoidal steer reveals an additional phenomenon of importance to vehicle roll response:
    - ✓ The phasing of front and rear tire forces



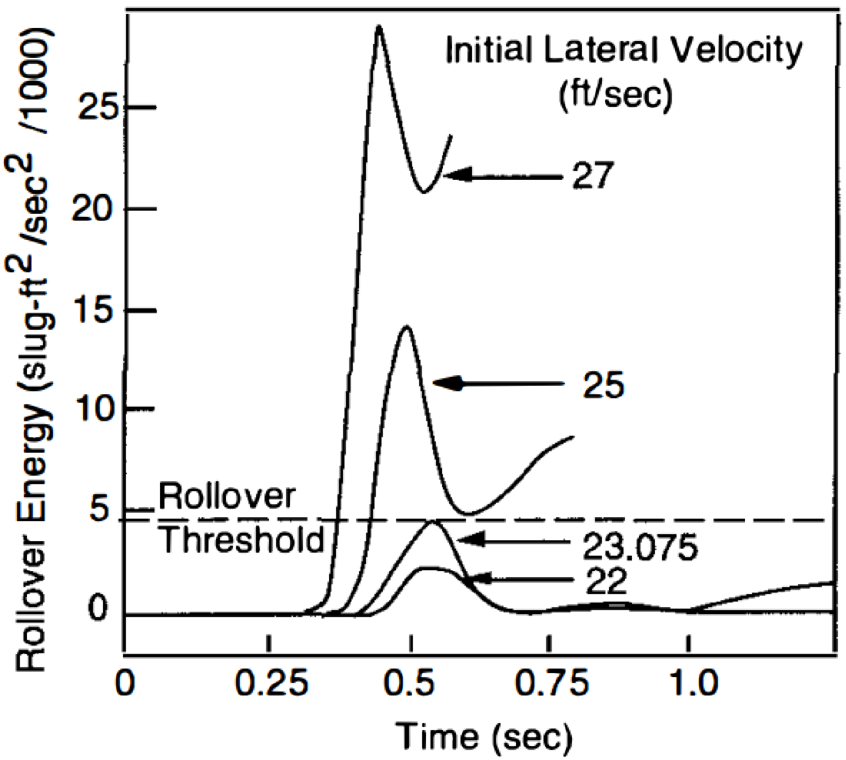
Transient Rollover

- Tripping
  - A final class of rollover accidents is the case where a vehicle skids laterally impacting an object.



Transient Rollover

- Tripping
  - The focus is on whether sufficient energy is developed in the curb impact to raise the CG of the vehicle to the rollover point.

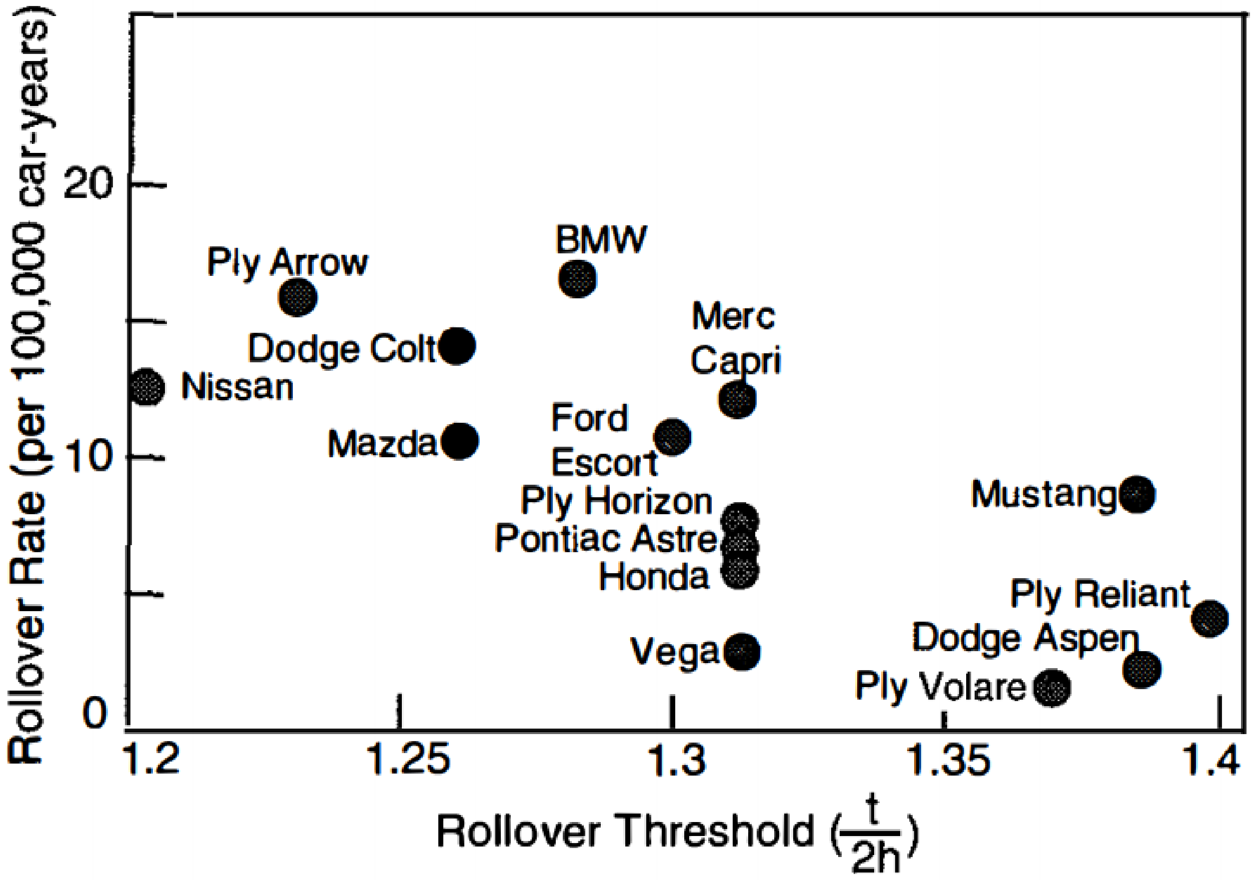


ACCIDENT EXPERIENCE

- The primary motivation for giving attention to the mechanics of rollover in vehicle design is to reduce or prevent rollover accidents.
- It is common practice in these studies to stratify the analyses both in the types of accidents and the types of vehicle.
- Systems Technology Inc. examined the rollover accident experience of small cars as a function of the rollover potential. Also a methodical analysis of rollover accident experience for passenger cars and utility vehicles was conducted by Robertson and Kelley in which some of the potential explanatory factors were examined.

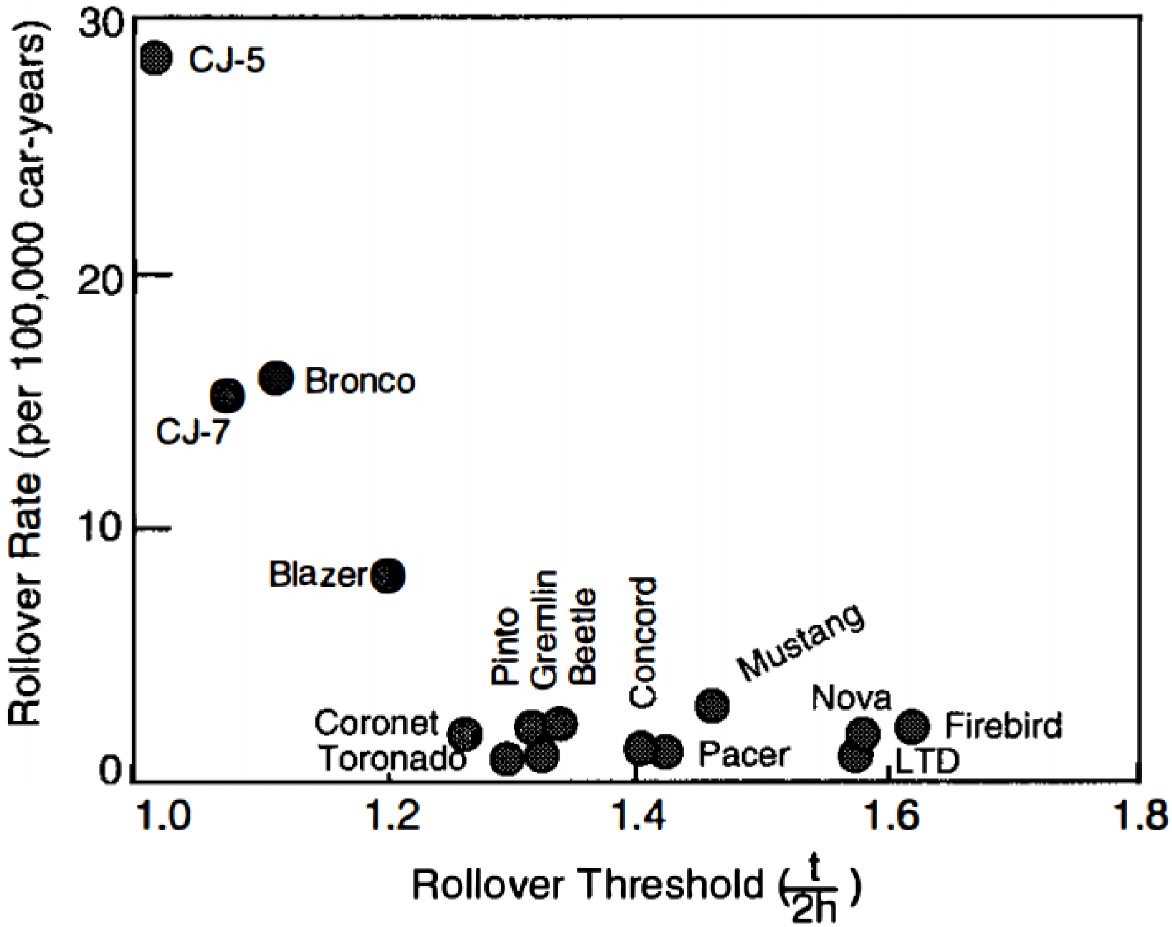
Accident Experience

- Rollover accident rates of small cars



Accident Experience

- Rollover rates of cars and utility vehicles



ACCIDENT EXPERIENCE

- The data show a trend of decreasing rollover involvement as the threshold increases. However, the degree of scatter in the plot suggests that more than just the rollover threshold is needed to explain the accident experience.

- When driver characteristics (suspended licenses, history of traffic violations, or blood alcohol level at the time of the accident, …) were examined, no explanations were found.

- Similarly, the road environment-urban vs. rural, interstate vs. other roads, straight vs. curved, dry vs. wet, etc.-had no correlation.