PDHonline Course G526 (2 PDH)

Motor Vehicle Accident Reconstruction Rollover Analysis

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Discussion Areas

- Introduction to Rollover Analysis
- Basic Models of Rollover
- Advanced Models of Rollover
- Limitations of Rollover Analysis
- Examples

Introduction to Rollover Analysis

- Vehicle rollover is defined as when a vehicle loses contact with the ground on two or more wheels and rotates greater than or equal to 90 degrees about a horizontal axis.
- The goal of a rollover analysis is typically to attempt to determine:
  - The number of rolls the vehicle experienced
  - The cause of the roll
  - Pre-incident vehicle speed
  - A timeline of events
- A rollover event is generally broken up into three phases[1]:
  - A Pre-Trip phase
  - Trip phase
  - Rollover or Roll-out phase

1 Brach and Brach, Vehicle Accident Analysis and Reconstruction Methods, SAE, 2005

Basic Analysis and Models of Rollover

- Pre-Trip Phase Analysis
- Site and Scene Diagram
- Basic Model 1: Drag Factor Model
- Basic Model 2: Quasi-Static Steady State Model
- Basic Model 3: Critical Trip Speed

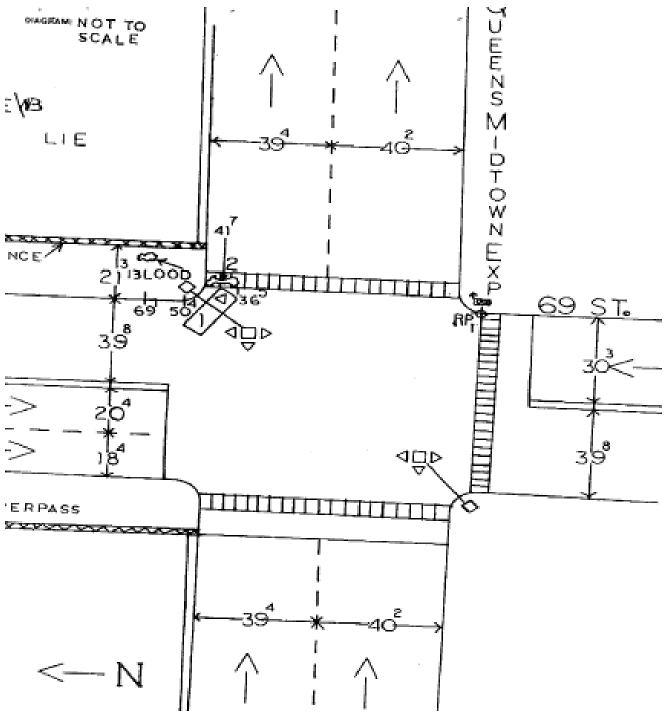
Pre-Trip Phase Analysis

- The Pre-Trip phase analysis includes analyzing the roadway evidence, Electronic Data Recorder (EDR) evidence, police reports, and statements to reconstruct what occurred prior to the rollover.
- The goal of a Pre-Trip analysis is to attempt to determine:
  - Speed of vehicle or Δ Speed of the vehicle prior to the Trip Phase
  - Orientation of the vehicle prior to the Trip Phase
  - Location of the vehicle prior to the Trip Phase
- The Analysis methodologies for the Pre-Trip phase will not be discussed in this training as they are generally covered in the training class:

  G513 Motor Vehicle Accident Reconstruction – Skid to Rest and Skid Mark Analysis

Site and Scene Diagram Analysis

- In the absence of actually being present at the scene to diagram the location of skid marks, tire marks, gouges, contact marks, debris, and etc., a site or scene diagram by the police, or accident reconstruction team is key and vital to performing a rollover analysis.
- An alternative is to perform a site inspection proximate to the time of the accident while roadway evidence may still be present.

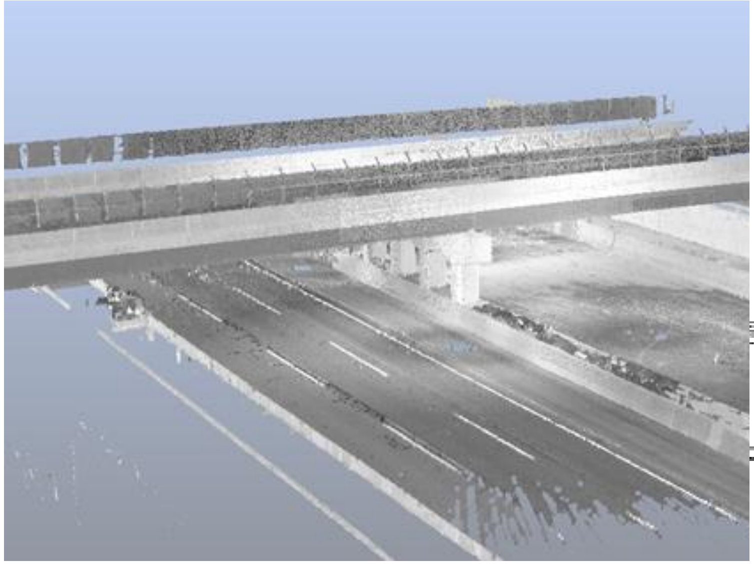


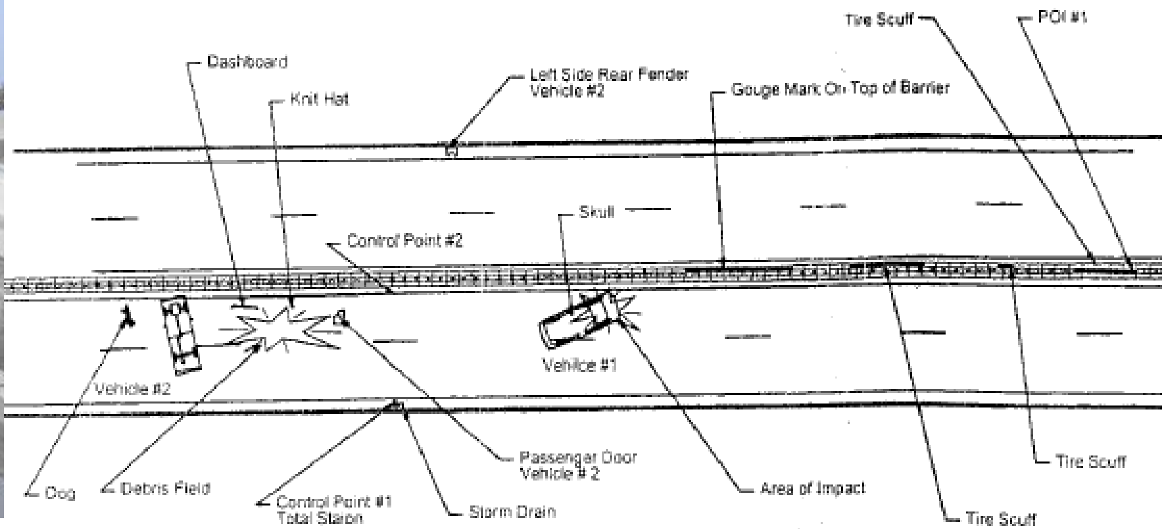
Site and Scene Diagram Analysis

- In the absence of a good diagram, an alternative is to perform a site inspection using details present in police photos as a guide to locate positions relative to stationary objects.

Site and Scene Diagram Analysis (cont.)

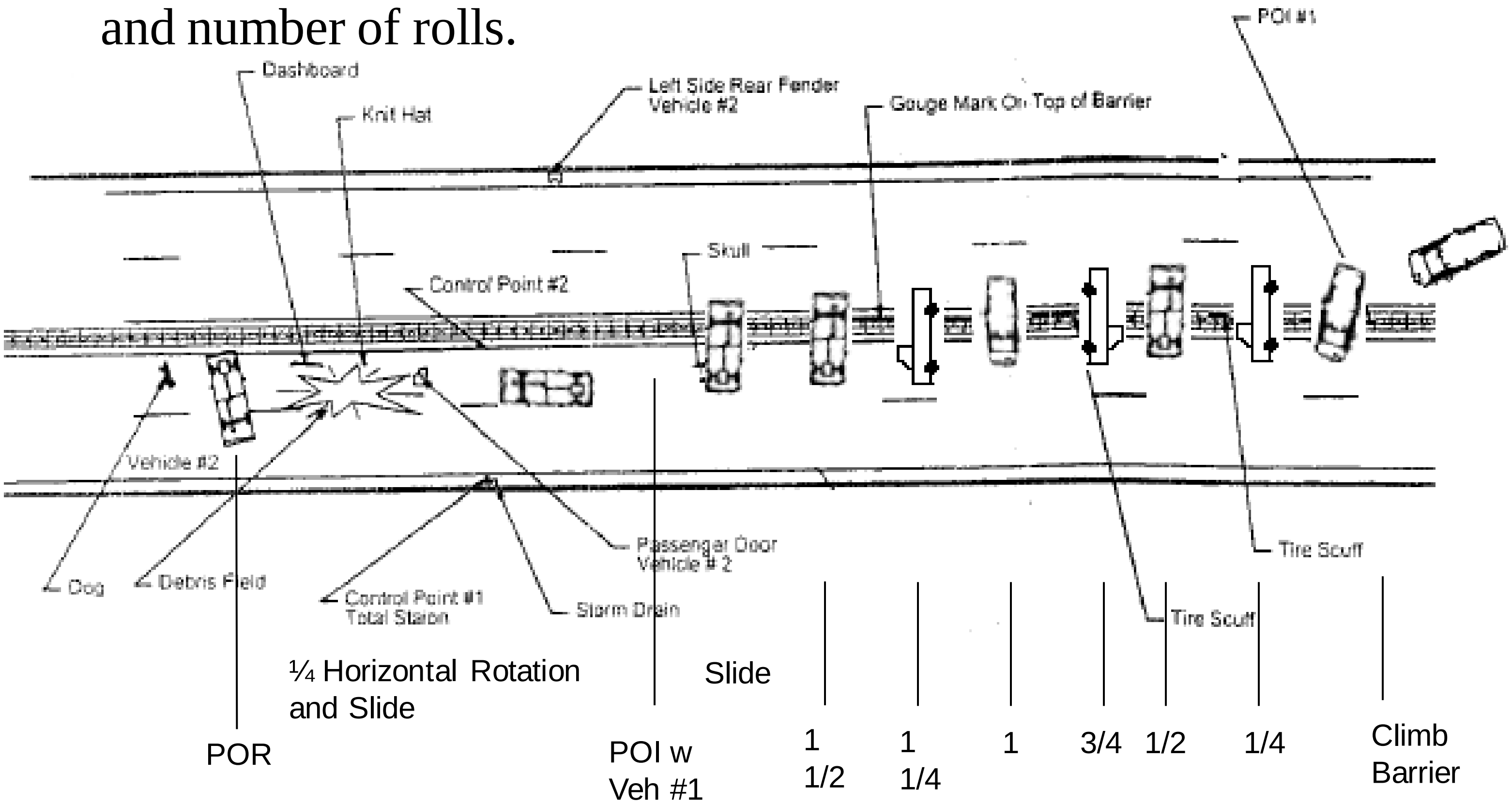
- If one is lucky, you can get or perform a 3D scan of the scene. Or you can get a data table from Total Station map and scan of the scene.





Site and Scene Diagram Analysis (cont.)

- The site and scene diagram along with vehicle inspection and/or data allows the reconstructionist to determine the time line of the rollover and number of rolls.



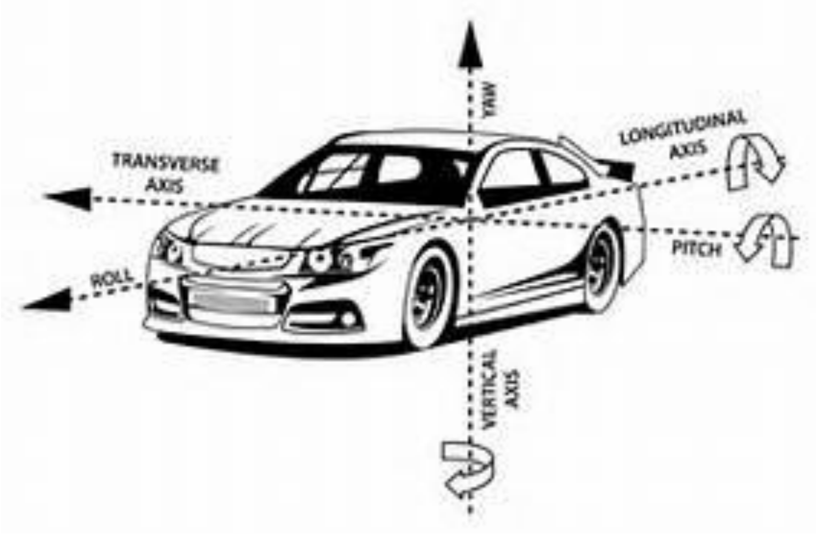
Site and Scene Diagram Analysis (cont.)

- The energy required to achieve the roll rate (number of rolls/time) can be calculated with published moments of inertia (see Expert Autostats).
- Then the equivalent ΔV may be calculated, and used with the Combined Speed formula (see G513 Motor Vehicle Accident Reconstruction – Skid to Rest and Skid Mark Analysis) to determine speeds.

$KE = ½ I \omega^2 = ½ m \Delta V^2$

Where

I = Roll Moment of Inertia



Basic Model 1: Drag Factor

The Skid to Rest formula is classically known as:

$$S = \sqrt{30Df}$$

Where,

S = Speed in miles per hour

30 = A conversion factor

D = Skid distance in feet

f = Drag factor, dimensionless, of the road

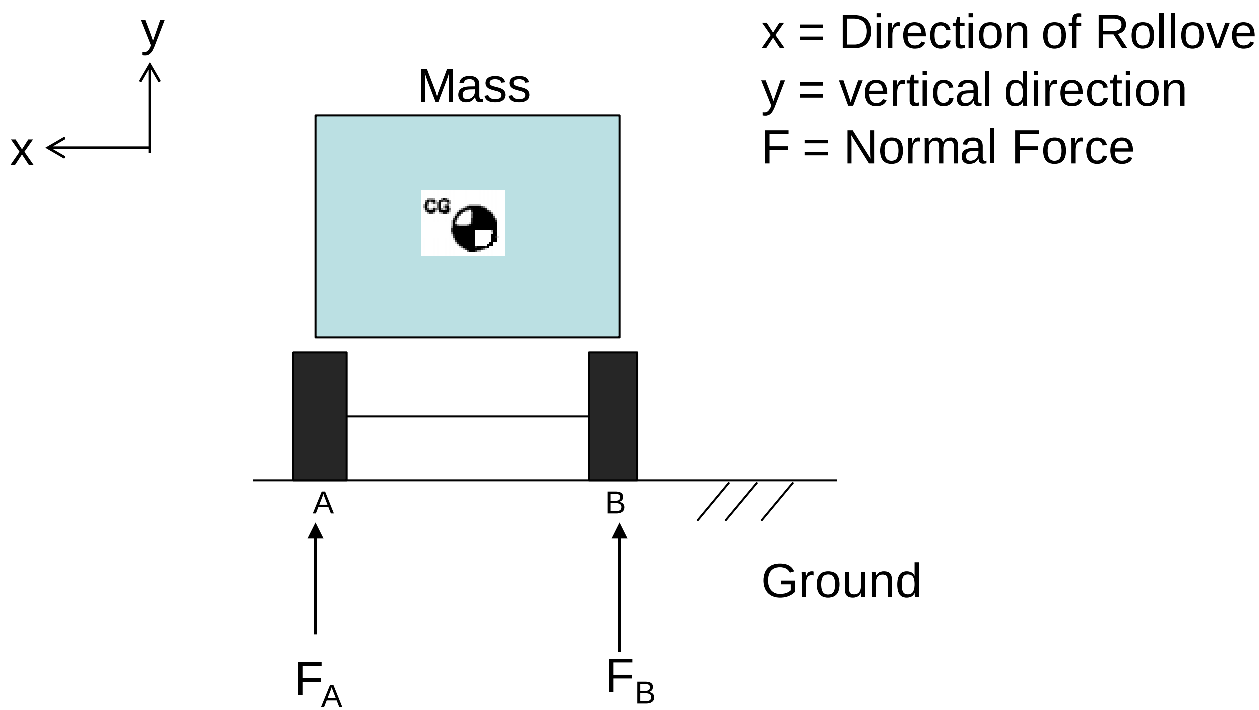
- The Drag Factor model is a simple model that uses a drag factor, f, for the rollover. D would now be the distance of the rollover as measured or documented from the scene of the accident.

Basic Model 1: Drag Factor (cont.)

- In Arndt, Arndt, Stevens, "Drag Factors from Rollover Crash Testing for Crash Reconstructions", AMSE 2011 IMECE2011-65537, the authors studied numerous published rollover tests.
- Range of drag factors for naturally occurring rollovers was 0.39 to 0.50 with upper and lower 15 percent statistically trimmed.
- The average drag factor for naturally occurring rollovers was 0.44 with a standard deviation of 0.063.
- This conclusion tightened the range typically used by accident reconstructionists of 0.4 to 0.65 (average 0.53).

Basic Model 2: Quasi-Static Steady State

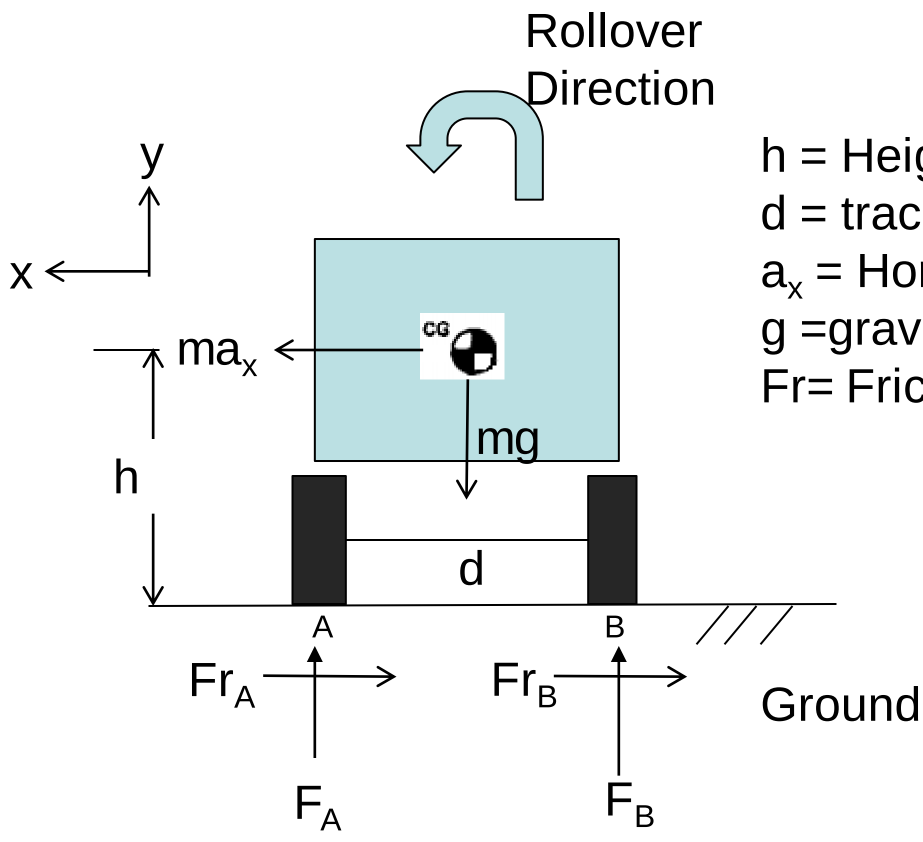
- Let's imagine the car as a single lumped mass.
- For simplification, we are assuming 2D and contact points A and B



View Looking Aft

Basic Model 2: Quasi-Static Steady State

- For a Rollover analysis, we are assuming sideward motion or acceleration of the Vehicle.
- We are assuming that the Vehicle is going to rollover about one of the points, or Pt. A for this example



h = Height from Ground
d = track width of tires
a_x = Horizontal Acceleration
g =gravity
Fr= Friction Force of Tires

Basic Model 2: Quasi Static Steady State (cont.)

- At the point the vehicle begins to rollover about point A, the normal force at point B, $F_B = 0$.
- Therefore calculating the Moment about point A assuming steady state, we get:

$F_B d + m a_x h = mgd/2$

or

$m a_x h = mgd/2$

Or

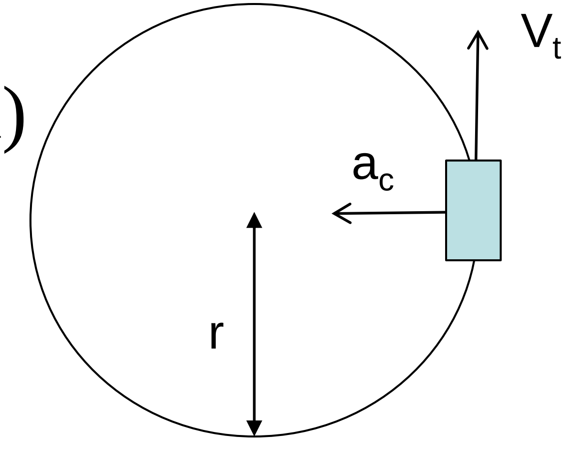
$a_x/g = d/2h = SSF$

also known as the Static Stability Factor (SSF)

Basic Model 2: Quasi Static Steady State (cont.)

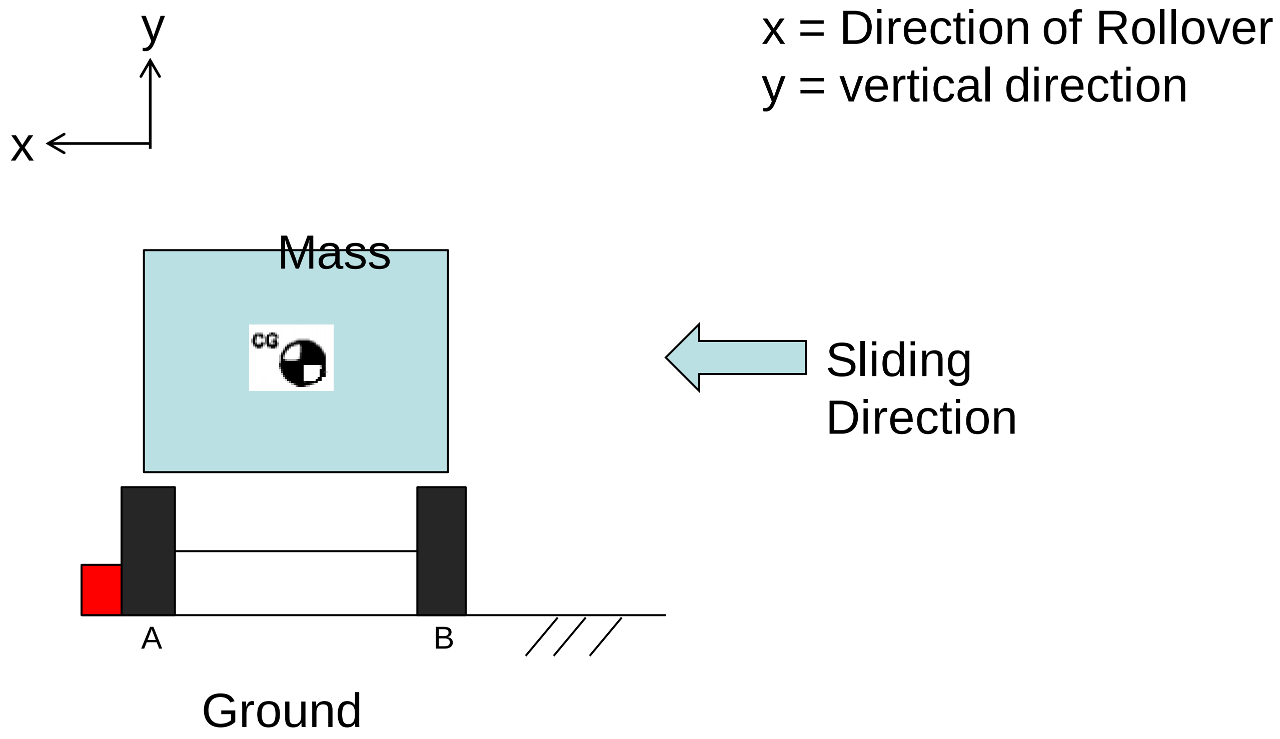
- This means when the ratio of the lateral acceleration, a_x, to gravity, g, is greater than the ratio of the track width, d, to twice the center of gravity height, the vehicle will start to rollover.
- This technique is useful for events involving rollovers as a result of turning at high speeds. The centripetal acceleration would be compared to the critical lateral acceleration, a_x.

$a_c = v_t^2/r$ (centripetal acceleration)



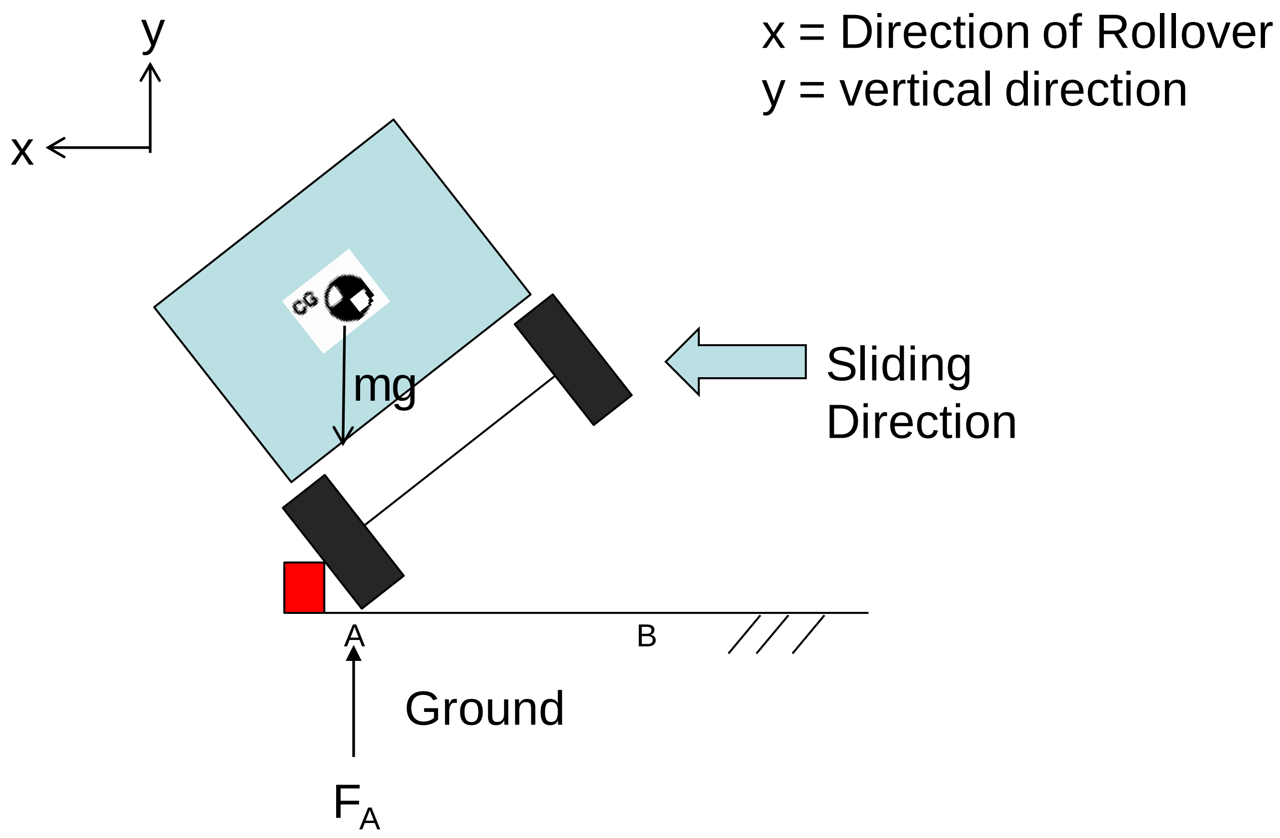
Basic Model 3: Critical Trip Speed

- Let's imagine the car as a single lumped mass.
- Let's also assume the car is sliding or moving sideways, until it hits a curb or trip.
- What speed would be required to cause the vehicle to roll over.



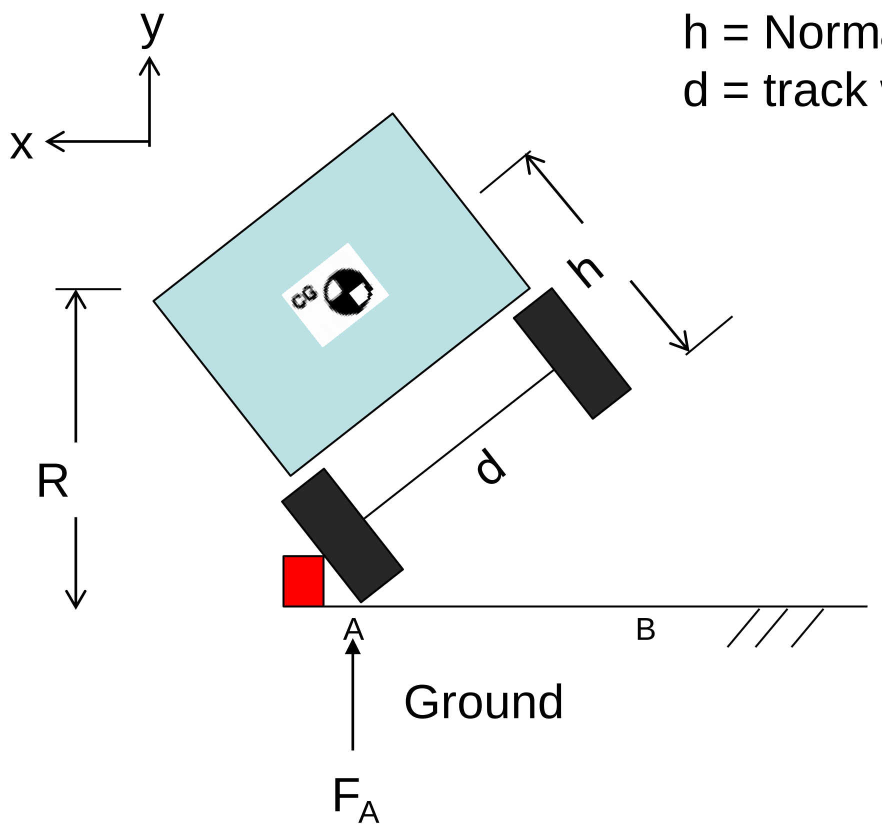
Basic Model 3: Critical Trip Speed (cont.)

- As the vehicle begins to rotate about the trip point A, as long as the center of gravity doesn't travel beyond the reaction force, FA, then the car will not tip over.
- However if CG gets beyond FA, then there will be no restoring moment, and the vehicle will roll over.



Basic Model 3: Critical Trip Speed (cont.)

- From Geometry, the Pythagorean theorem allows us to calculate the tipover CG height, R.



h = Normal height from Ground
d = track width of tires

$$R = \sqrt{h^2 + \left(\frac{d}{2}\right)^2}$$

or

$$R = h\sqrt{1 + SSF^2}$$

Where SSF = d/2h
(See Model 2)

Basic Model 3: Conservation of Energy

Before tipover:

$\frac{1}{2} mV_1^2 + mgh = KE + PE$

After tipover:

$\frac{1}{2} mV_2^2 + mgR = KE + PE$

at critical tipover, $V_2 = 0$

Therefore,

$\frac{1}{2} mV_1^2 + mgh = mgR$

And

$$V_1 = \sqrt{2g(R-h)} = \sqrt{2gh(\sqrt{1+SSF^2}-1)}$$

Basic Model 3: NHTSA

The National Highway Transportation Safety Administration (NHTSA) has analyzed Static Stability Factor (SSF) with respect to risk of rollover. Please see: NHTSA Data Resource Page . Search on Static Stability Factor and review DOT HS# 81244.

A higher SSF means a greater wheel track width vs. the CG height which would lead one to believe that a higher SSF would be less likely to rollover. Vice versa for a lower SSF.

NHTSA caveated their analysis by stating that low SSF vehicles may tend to be used differently than vehicles with high SSF, and therefore the vocation may have [illegible] risks.

Basic Model 3: Minimum Tripped Rollover Speed

So what are some minimum tripped lateral rollover speeds? Using data published by a database provider, Expert Autostats (see: http://www.4n6xprt.com/4n6as.htm), we can calculate some sample minimum tripped lateral rollover speeds:

Make	Model	Year	Track Width (in)	CG Ht (in)	SSF d/2h	Critical Speed (ft/sec)	Critical Speed (mph)
Chev	Equinox	2012	62	26.33	1.18	8.8	6.0
Ford	Focus	2012	60	22.77	1.32	8.9	6.1
Ford	Explorer	2000	59	26.73	1.10	8.4	5.7
Ford	Explorer	1992	58	26.73	1.08	8.3	5.6
Toyota	Highlander	2005	61.5	26.33	1.17	8.7	5.9
Nissan	Sentra	2010	61.5	23.55	1.31	9.0	6.2

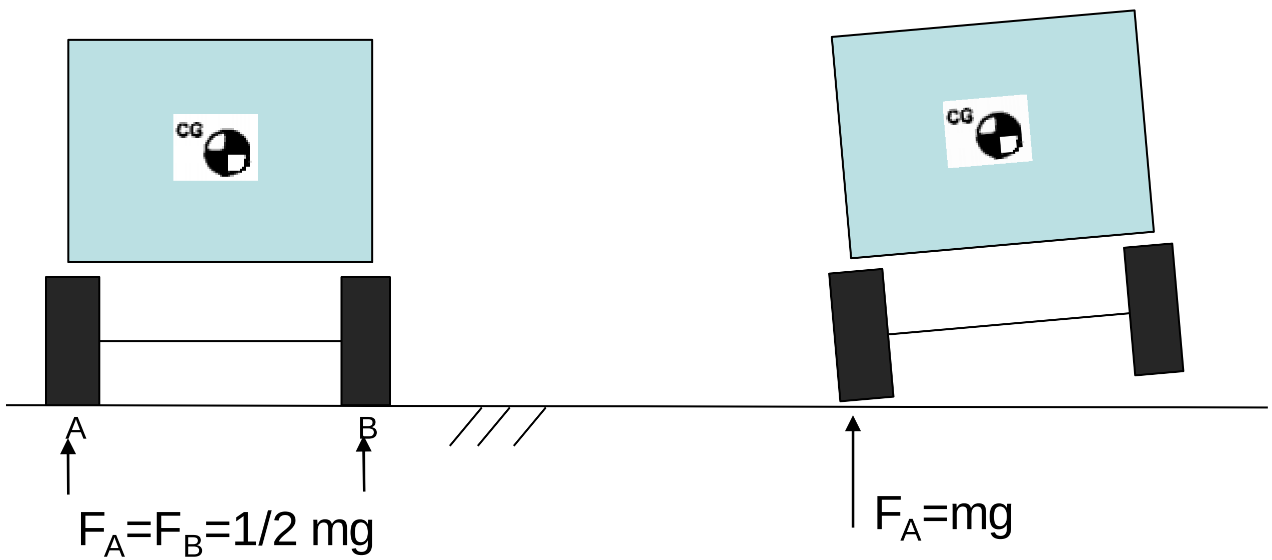
Advanced Models of Rollover

- Advanced Model 1: Tire Deflection
- Advanced Model 2: Suspension Deflection
- Advanced Model 3: Dynamic Testing

Advanced Model 1: Tire Deflection

In rollovers that involve driving around corners or curves, tire deflection may be calculated and used to alter the equation for Center of Gravity heights used in Quasi-Static Steady State model, and Critical Lateral Speed model.

The assumption is that under normal conditions, tires on each side of the vehicle are supporting the vehicle weight. As the vehicle is approaching rollover, the tires about which the vehicle is pivoting will be deflected more due to the additional force the tires have to support.

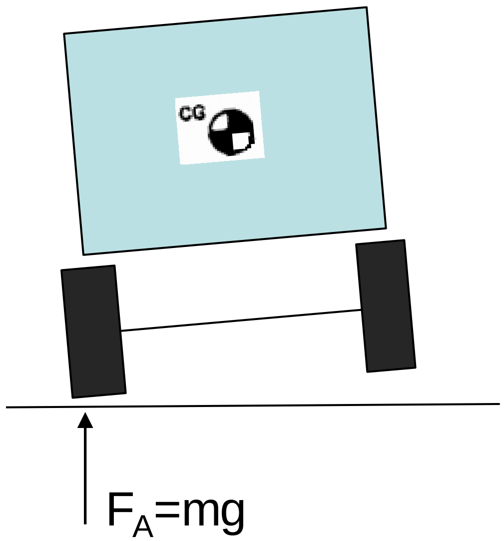


Advanced Model 1: Tire Deflection

The additional load would be essentially the additional half weight of the vehicle.

If we know the spring rate of the tire from exemplar testing, K, then we can calculate the deflection due to the additional load:

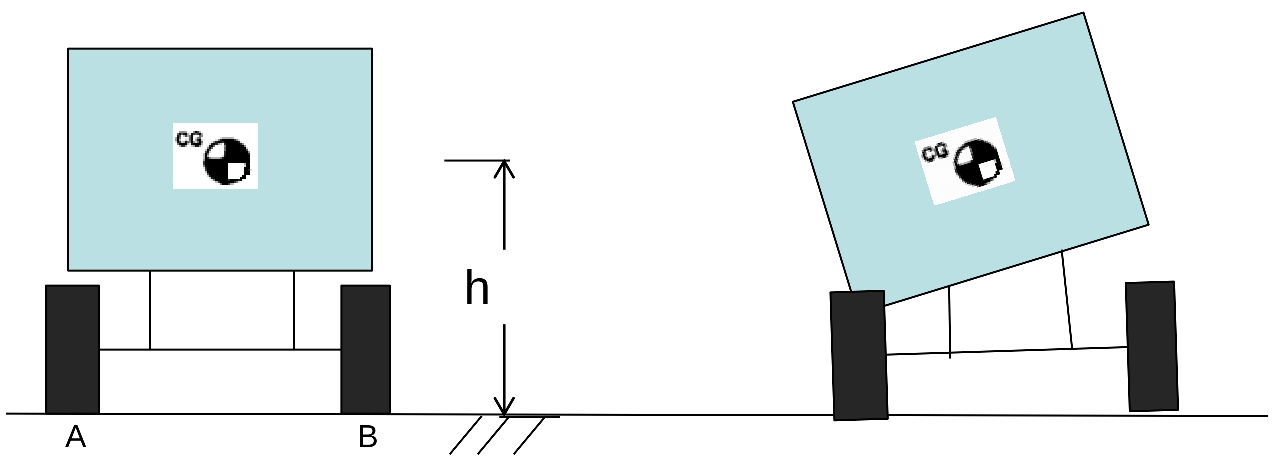
$$\Delta r = \frac{mg}{2K_{tire}}$$



Advanced Model 2: Suspension Deflection

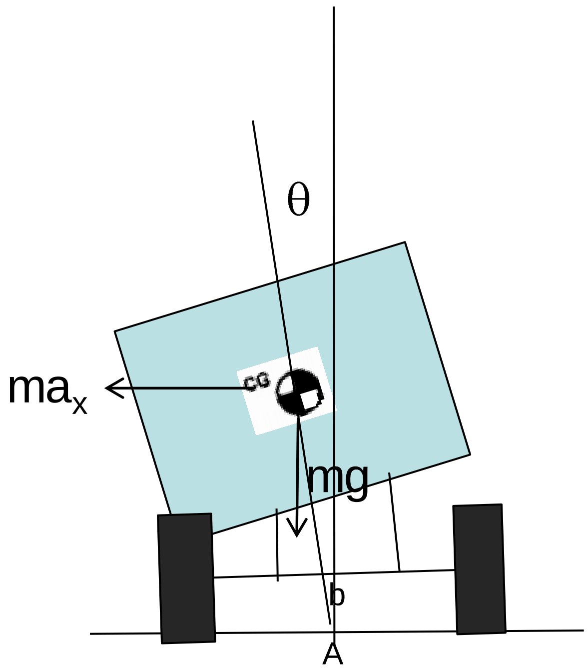
In rollovers that involve driving around corners or curves, an attempt may be made at suspension deflection which can then be used to alter the equation for Center of Gravity heights used in Quasi-Static Steady State model, and Critical Lateral Speed model.

The assumption is that under normal conditions, suspension on each side of the vehicle are supporting the vehicle weight. As the vehicle is approaching rollover, the vehicle may be experiencing suspension sway.



Advanced Model 2: Suspension Deflection

If we know the spring rate of the suspension from exemplar testing, Ks, then we can calculate the deflection due to lateral acceleration:

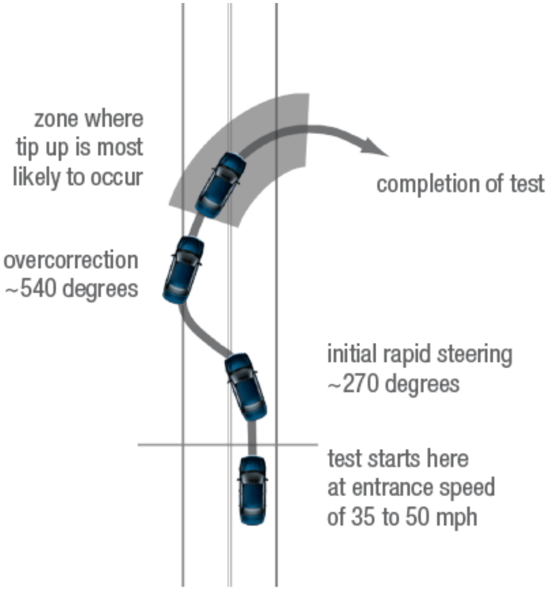


b = Distance between Suspension
θ = Angle of Sway

Sum of Moments about reference pt. A:
$ma_x(h \cos\theta) + mg(h \sin\theta) - F_K b = 0$
Where
$F_K = Ks\Delta h = Ks(h - h\cos\theta)$

Advanced Model 3: Dynamic Testing

- In 2013, the New Car Assessment Program (NCAP) put forth "The Fishhook Maneuver Test Procedure" essentially to attempt to replicate or represent an avoidance maneuver.
- Please review the following NHTSA publication:
- https://govtribe.com/file/government-file/attachment-j-dot-1-fishhook-maneuver-test-procedure-dot-pdf
- The official test procedure should be skimmed and is located here:
- file:///C:/Users/Peter/Downloads/NCAP_Fishhook_Test_March_2013.pdf



Advanced Model 3: Dynamic Testing

Examples of Fishhook testing:

Ford Clio
Tire Failure Testing
E350 Testing

Examples of Foreign Stability testing requirements:

The Moose Test

Limitations of Modeling and Analysis

- Rollovers are a dynamic event, whereas many of the analytical model assumes a quasi-static steady state trip or event.
- Quasi-static steady state assumption may under predict the amount of energy, speed, or acceleration required to roll a real vehicle.
- Tires not only deflect vertically, but also horizontally. Tires aren't straight and in-line as modelled especially during turning or cornering events.
- In side slide and trip, the tripping mechanism may burst tires, bend rims, break wheels off of wheel bearing studs, or cause suspension failures instead of causing a rollover.
- Despite increased model complexity to include the energy of the trip, rolling, gouges, contact, vehicle deformation, projectile motion while airborne, and skids, the simple drag factor model results in reasonably accurate results.

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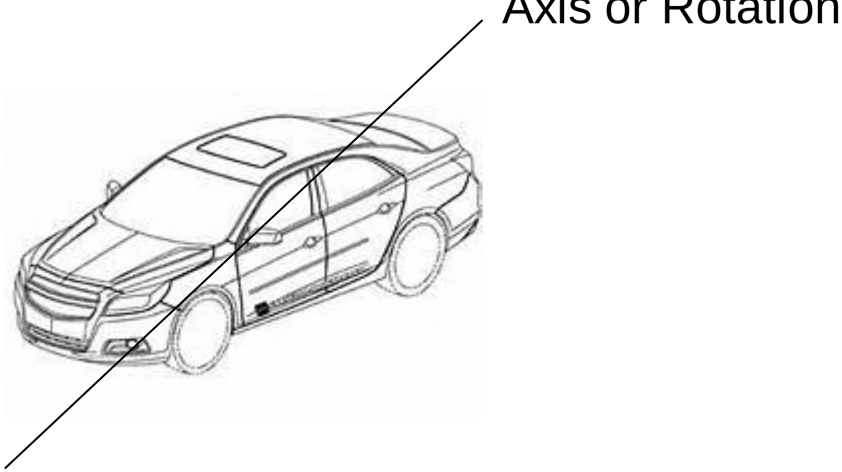
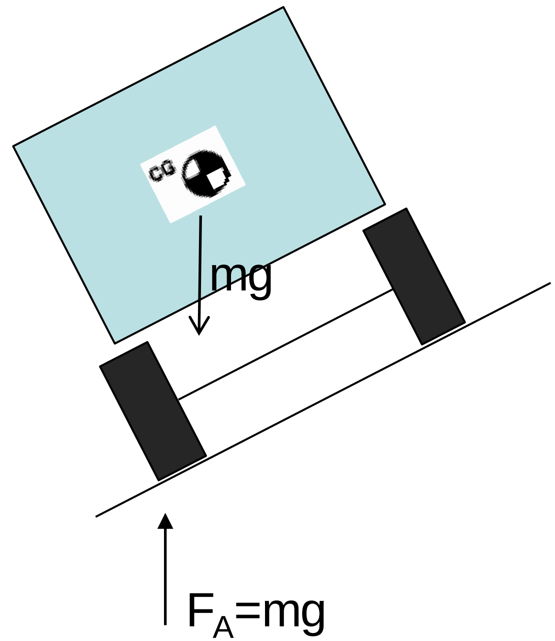
Example 1: Limitation of Analysis

- In the example below, the vehicle experience a rollover at highway speeds due to leaving the road and encountering a ditch
- This is a common rollover condition.

Example 1: Limitations of Analysis

- Quasi-Static Steady State or Critical Speed Trip Models aren't applicable because the vehicle rolled about a diagonal axis.
- The energy of the roll is complicated because there are no known published moments of inertia about the diagonal axis.
- A tip-over analysis could be attempted with regards to the geometry of the ditch.





Example 2: Incomplete Information

- In the example below, only the vehicle was available for inspection.
- The vehicle crash data was retrieved using a CDR kit.
- There was no diagram made of the scene and no photographs taken of the scene.

Example 2: Incomplete Information

- Rollovers are relatively long dynamic events.
- The event doesn't necessarily result in high front to back deceleration (from view of seated driver).
- Despite the high amount of vehicle damage, the airbag did not deploy.
- There was stored pre-crash information.

CDR File Information

User Entered VIN	1GKDT13S4423[redacted]
User	[redacted]
Case Number	[redacted]
EDR Data Imaging Date	07/23/2011
Crash Date	08/13/2007
Filename	[redacted]1GKDT13S4423[redacted]DOWNLOOADED 7.23.2011.CDRX
Saved on	Saturday, July 23 2011 at 14:24:23
Collected with CDR version	Crash Data Retrieval Tool 3.5
Reported with CDR version	Crash Data Retrieval Tool 3.5
EDR Device Type	airbag control module
Event(s) recovered	Non-Deployment

Example 2: Incomplete Information

- Without a scene diagram, the pre-crash information doesn't complete the entire timeline of the rollover.

System Status At Non-Deployment

SIR Warning Lamp Status	OFF
Driver's Belt Switch Circuit Status	BUCKLED
Ignition Cycles At Non-Deployment	7979
Ignition Cycles At Investigation	7982
Maximum SDM Recorded Velocity Change (MPH)	-9.84
Algorithm Enable to Maximum SDM Recorded Velocity Change (msec)	255
Crash Record Locked	No
Event Recording Complete	Yes
Multiple Events Associated With This Record	Yes
One Or More Associated Events Not Recorded	Yes

Seconds Before AE	Vehicle Speed (MPH)	Engine Speed (RPM)	Percent Throttle
-5	95	3520	100
-4	42	2240	0
-3	51	1408	0
-2	44	1280	1
-1	30	1280	11

Seconds Before AE	Brake Switch Circuit State
-8	OFF
-7	OFF
-6	OFF
-5	OFF
-4	OFF
-3	OFF
-2	OFF
-1	OFF