Fundamentals of Rollover Crash Reconstruction

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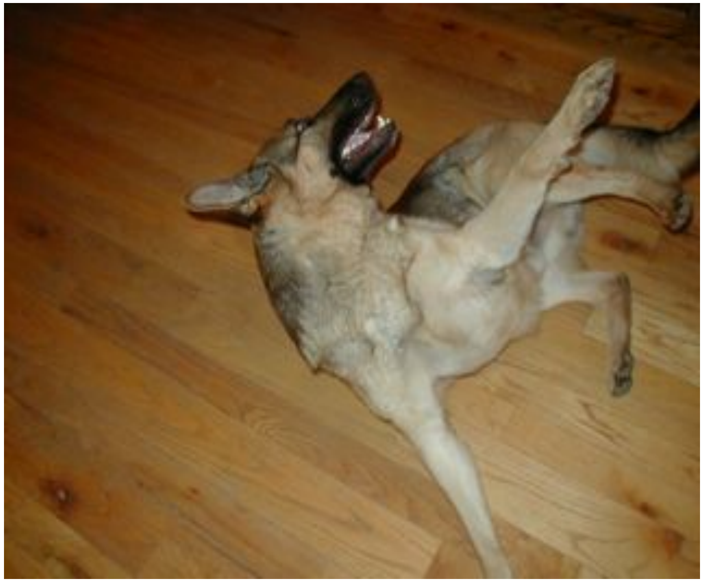
Introduction

- Crash investigators routinely handle a myriad of collisions.
- These collisions can range from single vehicle to double digit vehicle involvement.
- A variety of techniques are utilized in analyzing the collisions.
- These techniques can include conservation of linear momentum, damage energy, airborne, and critical speed, to name a few.



"Ike" rolling over.

Introduction (cont.)

- However, many crashes involve situations where the vehicle overturns, or rolls over.
- When this happens, the analysis may become more complex.
- There are many factors an investigator must consider in a rollover analysis.
- Often, there is more than one occupant in the rolled vehicle, and one or both may be ejected.
- Many times the focus of a rollover analysis becomes determining who was the driver or occupant seating.

Introduction (cont.)

- In potential criminal cases, the identity of the driver becomes important if some occupants are killed and others survive.
- In civil cases, the identity of the driver may be important for determining responsibility, regardless of the occupants' survival.
- It is up to the reconstructionist to determine who was driving when the rollover event occurred.
- However, identifying the driver or determining occupant seating becomes difficult in cases where one or more people are ejected in the rollover.
- In these situations, close attention must be given to both occupant kinematics and vehicle dynamics.

Introduction (cont.)

- In addition to driver identity, the reconstructionist often needs to calculate the speed of the vehicle.
- Also, it is important to know what kind of rollover event this actually was, so the proper analysis may be performed.
- We will break our presentation into five sections:
  - Taxonomy of Rollover Events
  - Vehicle and Scene Evidence
  - Determining Speed
  - Who was Driving?
  - Case Studies

Section 1

Taxonomy of Roll Events

Types of Rollover Events

- Rollover Crashes may be broken into three broad categories:
  - Side to Side Roll
  - Barrel Roll
  - Flip-Over (“Endo”)
- In addition, each may be sub-categorized by the relative violence of the event:
  - Tip-Over – Less than one full revolution
  - Rollover – One or more revolutions

Side to Side Roll

- This overturn is what many investigators think of when the word “rollover” is spoken.
- In essence, the velocity vector of the vehicle is nearly at right angles to its heading. It is sliding sideways.
- It may have obtained this orientation as a result of an impact or inappropriate steering, which causes the vehicle to spin.
- The roll event may be precipitated by a curb strike, furrowing in soft material, or by dynamic instability.

Side to Side Roll

- This SUV is in an orientation to roll over.
- Note the pavement being dug up by the leading wheel rims.
- Both leading tires are unbeaded from the wheels and are flat.
- Surprisingly, this vehicle did not overturn. (IATAI Conference 2004)

Barrel Roll

- A barrel roll overturn may be defined when the velocity vector of the vehicle is more in line with its heading.
- A force acts to rotate the vehicle about its longitudinal axis, which precipitates the overturn.
- A vehicle running off the road onto a steep shoulder may roll onto its side or top, whereupon it will skid to a stop or to an impact.
- An example of the barrel roll is the “movie” collision where a vehicle vaults over another upon collision. It’s not real life, but is entertaining…

Barrel Roll

- Often the overturn of a tractor-trailer is a barrel roll.
- The TT is traveling down the road at highway speed and drops into the ditch.
- The trailer tips onto its side, often taking the tractor with it.
- The unit then slides to a stop or to impact.

Flip-Over ("Endo")

- A flip-over is an overturning event characterized by rotation about an axis lateral to the vehicle.
- A vehicle with a high center of mass in a frontal collision with a frame-high barrier may undergo a flip-over. This would of necessity be a violent collision.
- Vehicles going airborne off of mountainous roads or bridges may also undergo a flip-over upon landing.

Flip-Over ("Endo")

- This pickup went off a steep mountain pass after a CSY.
- Its overturning was a combination of all three basic rollover types.
- Note how the frame is bent.

Rollover or Tip-over?

- By our definitions, a tip-over is not as energetic event as a rollover.
- A tip-over may be characterized by less than one revolution.
- A rollover consists of one or more revolutions.
- The dynamic loads on the occupants *from the tip-over itself* are usually less than the dynamic loads experienced during a rollover.
- However, a tip-over may be fatal to occupants even though the dynamic forces are not as high.

Rollover or Tip-over?

- Both vehicles were involved in fatal crashes.
- The pickup in the upper photo tipped over onto its top in a side to side roll, overturning ½ revolution.
- The car in the bottom photo overturned as the result of a high speed rollover.
- In both cases, the passengers were killed.
- Note the relative damage.

Section 2

Vehicle and Scene Evidence

Scene Evidence

- Scene evidence may include tire marks leading up to the point of overturn.
- Once the overturn has happened, there may be gouges in the pavement or soil indicating where the vehicle may have come into contact with the ground.
- Debris of many kinds, including occupants, may be left in the path of the overturning vehicle.
- All of this evidence should be measured and mapped.

Scene Evidence

- Rim gouge left in pavement.

Scene Evidence

- Side skids leading to a tip-over point.
- Note the fence is not damaged, indicating low velocity.
- The pickup making these marks had spun about 180 degrees by this point.

Scene Evidence

- Side skids leading to a steep slope, where the vehicle overturned and went airborne.

Scene Evidence

- Furrow leading to an overturn point down slope.

Scene Evidence

- Debris can show vehicle path and orientation in conjunction with other evidence, such as soil gouges.

Scene Evidence

- Clearly, these few examples do not show all possibilities.
- Examine the scene carefully, and look for disturbances in the pavement or soil.
- When debris is noted, ask yourself how it got there.
  - Was it jammed into the soil or pavement by impact?
  - Was it thrown off or out of the vehicle?
  - Where did it come from? Glass, plastic, occupant, etc.?
- Ask *"What can this evidence tell me about the orientation and path of the vehicle at this point".*

Exterior Vehicle Evidence

- Evidence from the outside of the overturned vehicle can tell us much about how the crash happened.
- All of the scratches, dings, dents and missing parts will help us to determine the vehicle motion in the rollover event. Some questions:
  - What was the leading side?
  - Where was the first ground contact on the vehicle?
  - Subsequent ground contacts?
  - How many times did it roll?
  - Did it hit anything along the way?

Exterior Vehicle Evidence

- As a passenger vehicle overturns in a side to side roll, one side will be leading.
- As the vehicle begins to tip, the tire bead may become partially or completely unseated and/or the rim may gouge into the surface.
- Evidence of this may be material scraped off of the road surface or grass trapped between the bead of the tire and the wheel

Exterior Vehicle Evidence

Wheel Rim Gouging

Grass Trapped between Tire and Rim

Exterior Vehicle Evidence

Leading Side Tire Dismount

Grass Trapped between Tire and Rim

Exterior Vehicle Evidence

- As the vehicle tips, the following may happen:
  - The center of mass lifts off the ground, and the vehicle may have enough roll velocity to allow the leading side roof edge to clear the ground.
  - Higher vehicles, such as pickups and vans, may contact the ground with the leading roof edge.
  - The first ground contact for passenger cars is then with the trailing roof edge at some angle with respect to the ground.
  - Often times, this first ground impact is the most severe impact in the roll sequence.

Exterior Vehicle Evidence

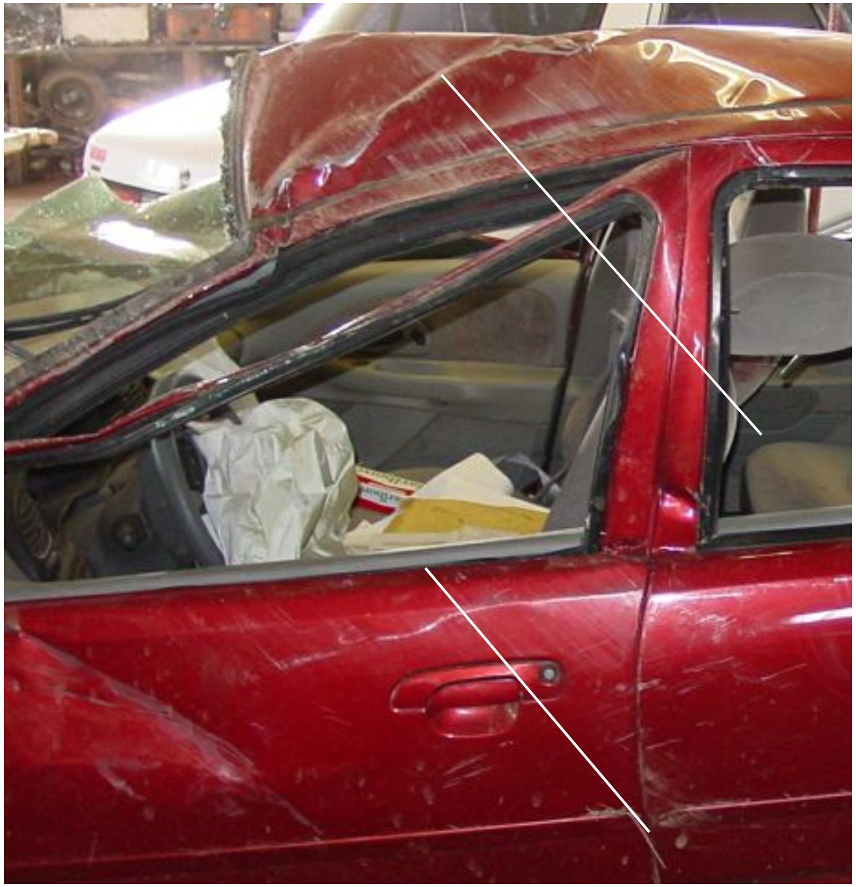
Passenger side trip with major impact on Driver's Side

Exterior Vehicle Evidence

- Number of Rolls
  - It is convenient to determine the number of quarter-rolls the vehicle undergoes.
  - Evidence of ground contact will show as scratching on the contacting surface, as it is sliding with respect to the ground.
  - We may examine the scratching to see if multiple patterns exist.
  - Scratches on top of scratches indicate multiple ground contacts for that surface.
  - Real world crashes are often one roll or less (Orlowski, SAE 890857)

Exterior Vehicle Evidence

Lines show angle of scratches



Exterior Vehicle Evidence

Multiple Direction Scratching

Exterior Vehicle Evidence

Circular Scratches indicate rotation

Exterior Vehicle Evidence

- Document the scratching on the vehicle, both photographically and with a sketch.
- The number of scratches overlapping on a given side may tell us the number of times that side came into contact with the ground.
- We may then figure the number of rolls based upon ground contacts (4 sides per roll) and final position.
- If the vehicle is on its wheels, then there was at least one full roll.
  - A vehicle on its top would have rolled “x” & ½ times.

Interior Vehicle Evidence

- Evidence from inside the vehicle may assist us to determine occupant position in the vehicle at the moment of trip.
- People inside the vehicle tend to move toward the periphery of the vehicle when the vehicle is in the air. (SAE 851757, Orlowski, et al)
- When a hard ground contact is made, then the occupants may tend to move toward that impact force.

Interior Vehicle Evidence

- Note the bulge in this passenger door.
- The vehicle rolled with the driver's side leading.
- The first hard impact was on the passenger side roof edge.
- The impact direction was probably about 10:30 (clock).
- The passenger's body pushed out the door.

Interior Vehicle Evidence

- Blood, hair, and fiber evidence from the interior of the vehicle.
- Document the position inside the passenger compartment and recover the evidence for forensic examination.

Interior Vehicle Evidence

- A shoe print on the brake pedal may be important.

Interior Vehicle Evidence

- If the driver and passengers are of different stature and size, the position of the seat may be important in determining who was driving.
- Seat positions do not usually change in a rollover event.
- The seat adjustments may be measured with a tape measure, either to the seat back or to the front of the seat cushion.
- The seat position may be determined by exemplar people, *IF* all other forensic work has been accomplished.

Interior Vehicle Evidence

Interior Vehicle Evidence

- Note structures or controls inside the passenger compartment that may leave distinctive marks on the occupants.
- Ask yourself when and where in the roll sequence the occupant could have come into contact with the structure or control.
- *Pattern Injuries* are often the result, and marks on the occupant may be matched.

Interior Vehicle Evidence

- Ejection Portals are those openings in the passenger compartment that will allow occupants to move out of the passenger compartment and outside the vehicle.
  - A partial list includes door windows, doors opened during the roll, broken out windshields & back glass, and sunroofs.
- It takes *time* for a person to traverse the ejection portal.
  - Because of the combination of rotation and translation of both the passenger and the vehicle, it is likely the occupant will leave forensic evidence behind around the portal.
  - The edges of the ejection portals should be examined forensically for trace evidence.
  - Clothing, hair, and blood samples should be taken from occupants to match up to the evidence gathered from both inside the passenger compartment and the ejection portals.

Ejection Portal Examples

Several!

Sunroof and Driver's Door

Popped out Windshield

Section 3

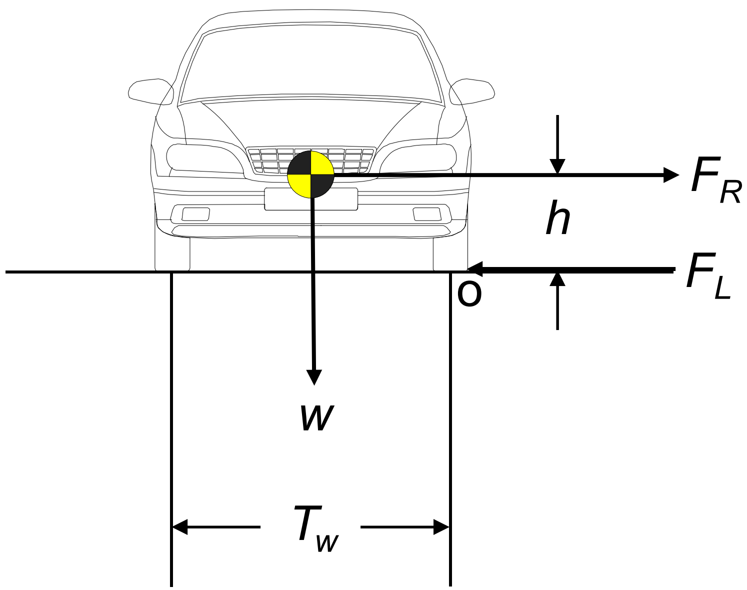
Speed Calculations

Overturning Vehicle Speed

- We will examine two kinds of analysis in this section
  - The first analysis will examine the lateral acceleration required to cause the vehicle to overturn.
    - Within this analysis, we will consider this lateral force acts for enough time to precipitate the overturn.
  - Secondly, we will see how to determine vehicle speed at the moment of the overturn.
    - This speed may then be used in a combined speed equation to determine speeds at other points in the trajectory.

Lateral Acceleration to Overturn

- Consider the Diagram on the right.
- This vehicle has a lateral force being applied at ground level.
- Because the center of mass is higher than the force application plane, there will be a *moment (torque)* placed on this vehicle. This moment is about point "O".
- If the torque produced by this side force is greater than the resisting torque caused by the vehicle weight, then the vehicle will overturn.



Lateral Acceleration to Overturn

- For a level surface, the equation on the right defines the lateral acceleration required to *trip,* or overturn.
- This is sometimes called the "*tip-over stability ratio*", or the "*propensity to roll*".
- In this equation:
  - f = lateral acceleration
  - T_w = Track Width
  - h = CM height

$$f = \frac{T_w}{2h}$$

Lateral Acceleration to Overturn

- In the equation just presented, the vehicle is considered to be a *rigid body.*
  - This means we do not consider any suspension deformations in the propensity to roll for the vehicle.
  - Dealing with suspension deflections is beyond the scope of this presentation.
  - A straightforward inclusion of suspension deflections may be found in SAE 2002-01-0965, “Rollover Stability Index Including Effects of Suspension Design” Aleksander Hac, Delphi Automotive Systems.

Lateral Acceleration to Overturn

- Consider a vehicle going around a turn…
  - A lateral force (acceleration) is required to change the direction of the vehicle.
  - Assume the vehicle is in a maximum performance turn:
    - If the lateral acceleration factor, f, required to cause the vehicle to overturn is *less than* the friction available on the road surface, then the vehicle will tip over rather than begin to slide.
    - On the other hand, if the propensity to roll is higher than the available friction, the vehicle will enter a CSY or slide out rather than overturn.

Examples: Car Left, Truck Right

$$f = \frac{T_w}{2h}$$

$$T_w = 5.5$$

$$h = 1.7$$

$$f = \frac{5.5}{3.4}$$

$$f = 1.61$$

$$f = \frac{T_w}{2h}$$

$$T_w = 7.5$$

$$h = 7.0$$

$$f = \frac{7.5}{14}$$

$$f = 0.53$$

Lateral Acceleration to Overturn

- In the example just presented, let $\mu = 0.80$.
- The car would either slide out or enter a CSY before it was able to overturn as it would require 1.61g from the road to overturn.
- The truck would tip over before it was able to slide because it needed only 0.53g to overturn and the road was able to give 0.80g.

Truck Tip-Over Speed

- Consider this tractor-trailer rounding a level curve with a 250 foot radius.
- At what speed will it overturn?
- The result is the *tip-over speed* for this tractor-trailer.

$$S = 3.86\sqrt{rf}$$

$$r = 250$$

$$f = 0.53$$

$$S = 3.86\sqrt{250(0.53)}$$

$$S = 3.86\sqrt{132.5}$$

$$S = 44.43mph$$

Lateral Acceleration to Overturn

- As we have seen, it usually takes more lateral acceleration to overturn a passenger car than is provided by tire – surface friction.
- This is because cars generally have lower centers of mass in relation to track width than do pickups, SUVs and commercial vehicles.
- SAE 900366, "Testing and Analysis of Vehicle Rollover Behavior", Cooperrider, et al, identifies lateral accelerations based upon soil trip tests as well as curb strikes.
  - The average lateral f for soil furrowing was 1.62g.
  - The average lateral f for a curb strike was 12.4g.
  - In this testing, investigators reported it was not uncommon for the suspension to be knocked out from under the vehicle in a curb strike.
  - In these test cases, the vehicle did not overturn, but slid to a stop upright. Crash vehicles may still overturn.

Speed at Overturn

- Once a passenger car, light truck, van, or SUV begins to roll, it will start decelerating.
- If it hits nothing except unencumbered ground (or pavement) until it stops, we may apply a drag factor to this motion and treat it as a skid.
  - If the vehicle does undergo an impact, we may deal with the impact in the same way as if the vehicle skidded to the impact.
  - The impact speed becomes part of the combined speed equation.

Speed at Overturn

- Drag Factors of Vehicles During the Rollover:
  - SAE 720966, Hight: f = 0.4 – 0.65
  - SAE 890857, Orlowski: f = 0.36 – 0.61
  - SAE 2002-01-0942, Altman: f = 0.48 (average)
  - SAE 890859, Bratten: f = 0.5 (average)
- These references are for differing surfaces that are level and not covered with brush or other impeding objects.
- For soft soil or sand situations, then the drag factor will tend to increase.
- Any brush, large rocks, or other things the vehicle may interact with will clearly increase these values!

Speed at Overturn

- Drag Factors of Vehicles Sliding on the Top or Sides (SAE 830612, Warner):
  - Sliding on Concrete: f = 0.3 – 0.4
  - Rough Asphalt f = 0.4
  - Gravel: f = 0.5 – 0.7
  - Dry Grass: f = 0.5
- These values are for level surfaces…
  - In general, the softer the surface, the higher the drag factor.

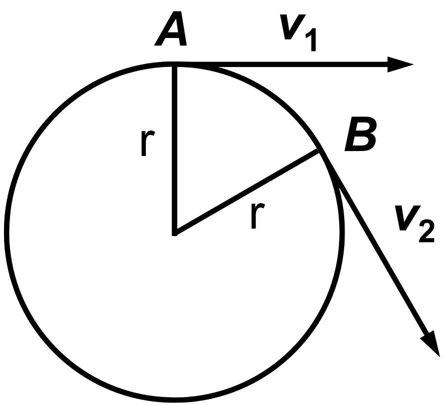
Section 4

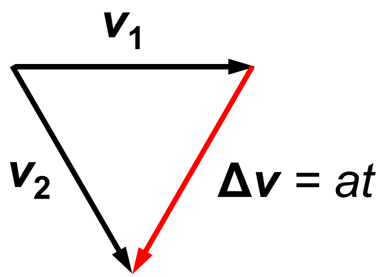
Who was Driving?

Occupant Ejection

- Many times in a rollover situation, the occupants of the vehicle become ejected.
- This is due to the high forces involved which are magnified by the rotational motion.
- All occupants are subjected to these forces.
- However, it is the unrestrained occupants that generally become victims to these forces.
- They do not have the strength to oppose the forces and are thrown from the vehicle.
- If they are partially ejected, many times the vehicle will roll over them and crush them.
- Where do these forces come from?

Rotational Dynamics





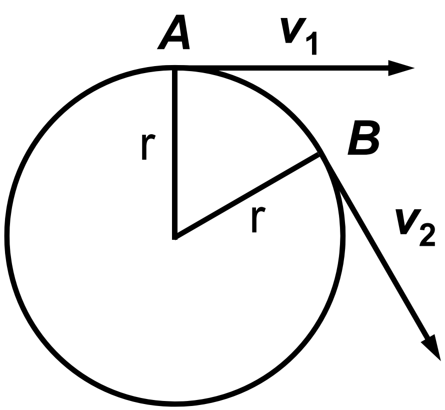
$$\frac{r}{vt} = \frac{v}{at}$$

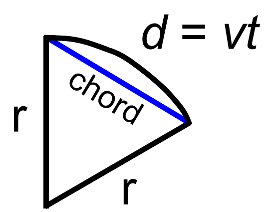
$$rat = vvt$$

$$rat = v^2 t$$

$$ra = v^2$$

$$\boxed{a = \frac{v^2}{r}}$$





Rotational Dynamics (cont.)

- This acceleration is called *centripetal acceleration*.
- It is directed toward the center of the curved path of the object.
- The force associated with this acceleration is called *centripetal force*.
- Centripetal acceleration is also referred to as *lateral acceleration*.

$$a = \frac{v^2}{r}$$

$$F = Ma$$

$$F = \frac{Mv^2}{r}$$

Rotational Dynamics (cont.)

- Consider a vehicle going through a normal turn.
- The path the vehicle takes is a curved one.
- What causes the vehicle to take the curved path?

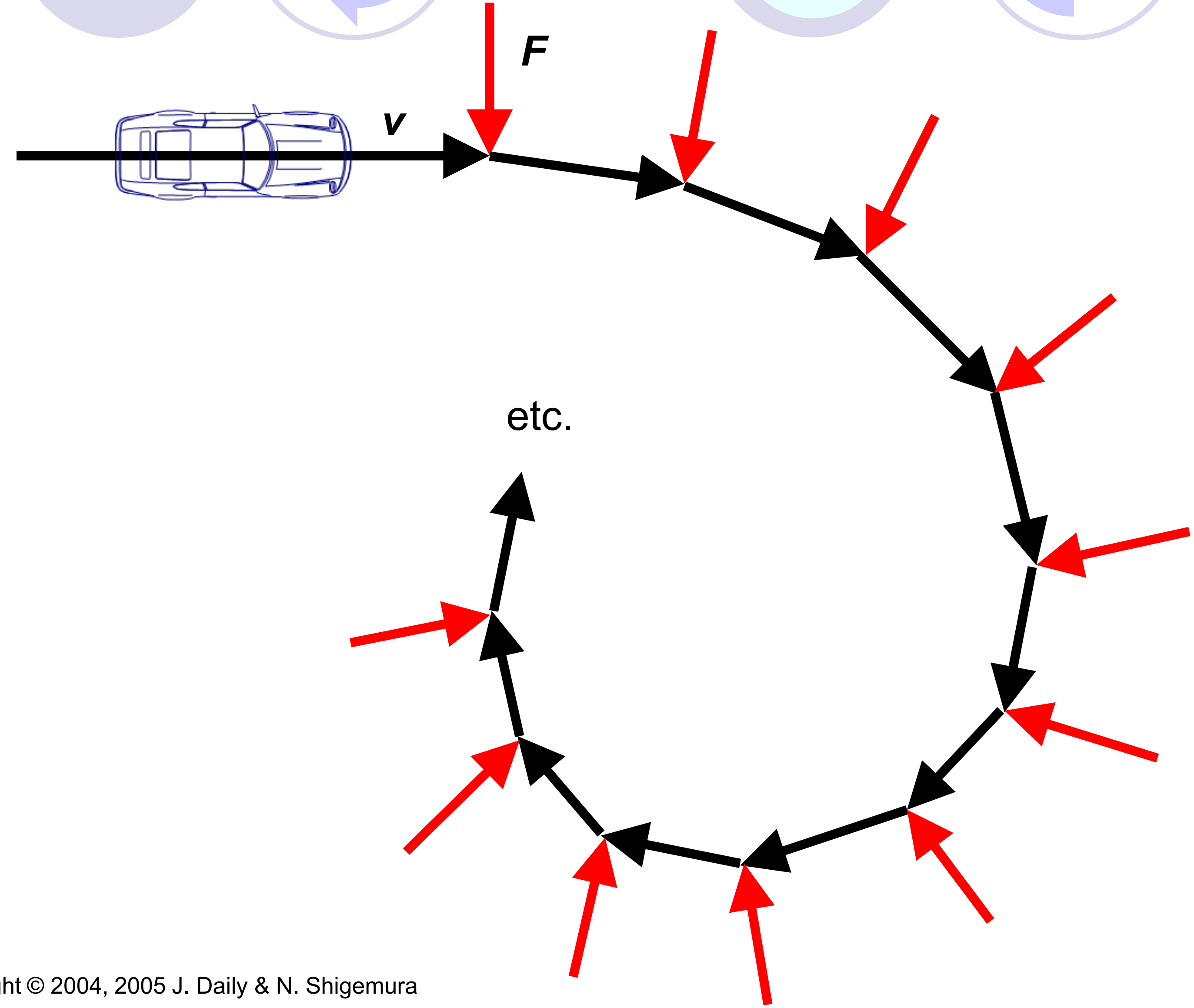
Friction

- Why?
  - Think about Newton's First Law.
- What type of force does friction produce?

$$F = fW$$

- This force operates laterally to the direction of the vehicle's velocity vector.

Rotational Dynamics (cont.)

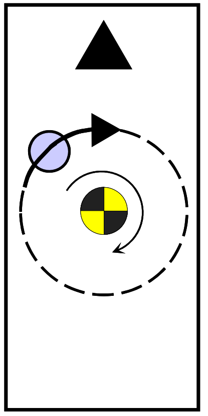


Rotational Dynamics (cont.)

- Let’s move into a smaller arena.
- Let’s consider a vehicle that is spinning (on its tires).
- What kind of forces are acting on the driver?
- Let’s look at an example.

Rotational Dynamics (cont.)

- “A car is whacked in a collision causing it to spin at a rate of 5.17 radians/second (296 degrees/second).
- The driver weighs 200 lbs and his center of mass is 2 feet from the center of mass of the car.
- How much force is “pushing” him into the driver’s door immediately after the impact?



Rotational Dynamics (cont.)

- As seen in Fig. 1, as the vehicle spins, the driver rotates or spins about the center of mass of the vehicle.
- The driver is "orbiting" the center of mass of the vehicle (Fig. 2).
- The driver is orbiting with some angular velocity, ω, and linear (or tangential) velocity, $\boldsymbol{v}_t$, along the circumference.
- We can relate the tangential velocity to the angular velocity with the following equation:

$$V_t = r\omega$$

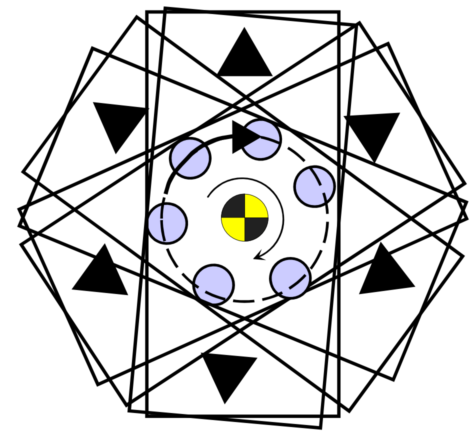


Fig. 1

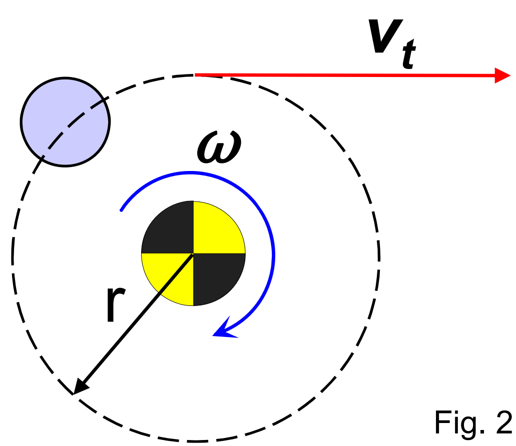


Fig. 2

Rotational Dynamics (cont.)

- Thus, calculate the tangential velocity of the driver:

$$v_t = r\omega$$
$$= 2(5.17)$$
$$= 10.34 \text{ fps}$$

- So the driver, sitting 2 feet from the center of mass of the vehicle that is spinning at a rate of 5.17 rad/sec, is traveling 10.34 fps tangentially (circumferentially).

Rotational Dynamics (cont.)

- Now calculate lateral acceleration:

$$a = \frac{v^2}{r}$$

$$= \frac{10.34^2}{2}$$

$$= 53.45 \text{ fps}^2$$

- And from the lateral acceleration the lateral acceleration factor:

$$f = \frac{a}{g}$$

$$= \frac{53.45}{32.2}$$

$$= 1.66\, g$$

Rotational Dynamics (cont.)

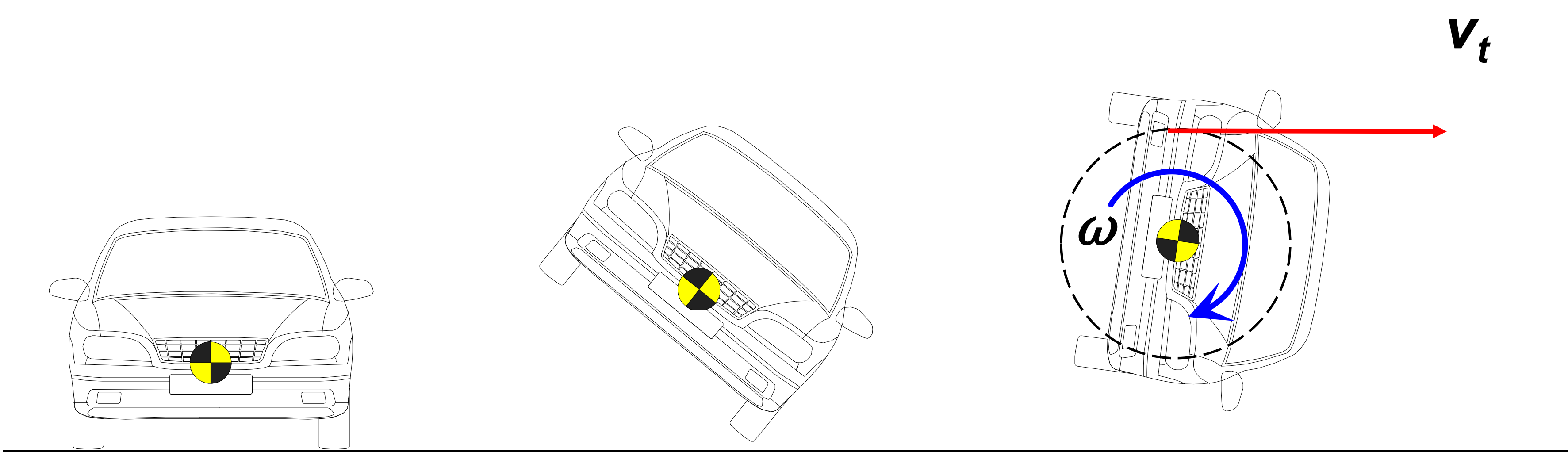
- Finally, calculate the force the driver experiences:

$$
\begin{aligned}
F &= wf \\
&= 200(1.66) \\
&= 332 \text{ lbs.}
\end{aligned}
$$

- This is the centripetal force the car body places on the driver. (This is <u>not</u> centrifugal force! There is no such thing.)
- And, if an avenue of exit exists or presents itself …

Rotational Dynamics (cont.)

- Applying the same logic to a rolling vehicle it is seen the forces can be very large as angular velocities can be quite fast.



Rollovers (cont.)

- As we see in the following slides, rollover events can be violent.
- Vehicles can bound, attaining vertical distances and increase in angular velocities.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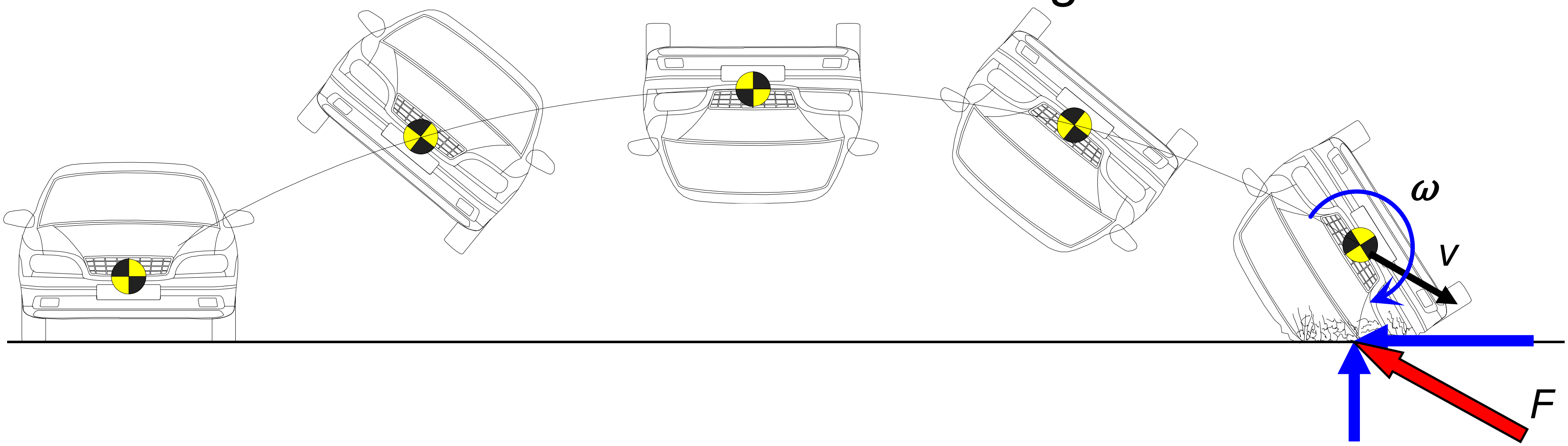
Rollovers (cont.)

- Determining occupant seating in rollover events are more problematic than ground based collision events.
- Occupants are subject to both rotational forces and linear forces as the vehicle strikes the ground.



- Correct kinematic analysis requires proper interpretation of the dynamic forces involved.

The Rollover Event

- We have seen that rollover events may be complex in nature.
- We will examine the rollover event and see how we may relate the kinematics of the event to the question of “Who was Driving”.

Rollover Event, cont'd.

- In many cases, the vehicle will trip with one side leading.
- The center of mass lifts off the ground, and the vehicle may have enough roll velocity to allow the leading side roof edge to clear the ground.
- The first ground contact is then with the trailing roof edge at some angle with respect to the ground.
- Often times, this first ground impact is the most severe impact in the roll sequence.

Rollover Event, cont'd.

- The occupants in the vehicle will tend to move parallel to the applied force.
- The direction of this force will be a combination of the translation and rotation of the vehicle, but will still tend toward the impact zone.
- As the vehicle rolls away from this first ground impact, the occupants may either be ejected or set up for the next ground impact.
- In order to examine the overall roll trajectory, we generally look at the number of quarter rolls the vehicle undergoes.

Rollover Event, cont'd.

- For example, if a vehicle trips on the driver's side and makes first ground contact on the passenger side, it will have rolled between two quarters and three quarters, or a bit more than a half-revolution.
- During the trip event, the vehicle will pick up an angular velocity in the vicinity of one revolution per second, or about 6.28 radians/second.
- When the vehicle impacts the ground, it will lose some translational velocity and may pick up some rotational velocity. (SAE 890857, Orlowski)
- The overall deceleration in the roll is reported by Orlowski in dolly tests on asphalt as 0.36g to 0.61g.

Rollover Event, cont'd.

- Orlowski reports in 890857 that real world crash data indicates most rollover events are one revolution or less.
- Generally, dolly rollover tests result in a higher number of rolls than do real world crashes.
- The vehicle most times has a rotational velocity ($v = R\omega$) lower than its translational velocity.
- This means a couple of things:
  - The surface of the vehicle making ground contact will be sliding with respect to the ground, and
  - The vehicle will NOT be rolling like a rolling pin. Rather, it will be sliding, engaging, and disengaging the ground.

Rollover Event, cont'd.

- If the roof of the vehicle crushes downward into the passenger compartment, it is unlikely the vehicle will continue to roll. (Down reference is to normal vehicle orientation)
- This kind of impact is very inelastic, and is like trying to bounce a lump of clay off a hard surface.
- In order for the vehicle to continue rolling, it will have to undergo another trip, probably by digging into softer earth or other significant tripping mechanism.

Occupant Motion

- As we might expect, the people inside will be doing some moving around, especially if they are not restrained.
- In the first impact with the ground after the trip, the people inside will tend to move toward the force.
- Because of the roll dynamics, there will not be much time for this movement.
- Thus, any contact the people make inside the vehicle on this first impact will be with something close by.
- It would be unlikely for the driver to hit his head on the passenger side window frame during this first ground impact, especially if there were a passenger in the way!

Occupant Motion

- In examining the crash, we will want to look for evidence of this interior impact the occupants may have with the inside of the vehicle.
- We will have to examine the interior of the vehicle for material transfer or specific impact marks. We also look for objects in the occupant space that may produce pattern injuries.
- We must also examine the occupants themselves for evidence of either material transfer or pattern injuries.
- During the rollover event, the occupants tend to move toward the periphery of the vehicle and stay there while the vehicle is in the air. (SAE 851734, Orlowski, et al) If this part of the vehicle impacts the ground, then the force may be transmitted to the occupant.

Occupant Ejection

- Clearly, during this rather violent rollover event, occupants may be ejected from the passenger compartment to land somewhere outside the vehicle.
- The ejection portal may be any opening in the passenger compartment – side windows, the sunroof, open doors, hatchbacks, a windshield opening, etc.
- An ejection is an event that takes time, because the occupant must first move to the ejection portal and then must move through the portal.

Occupant Ejection

- The occupant will almost always become entangled or caught by vehicle structure or components.
- For example, consider a 5’7” occupant being ejected through the center of a two foot wide window opening. Let us say the ejection velocity is on the order of 50 feet per second.
- The time required for the occupant to transit the window opening is thus 0.11 seconds.
- If the passenger has six inches of clearance on either side of the window frame, the vehicle will have to rotate about 10 degrees to entangle the occupant in the window frame. At 360 degrees per second, this amount of rotation will take about 0.03 seconds. Thus, the occupant will interact with the window frame.

Occupant Ejection

- This interaction will do a couple of things –
  - It will alter the velocity vector of the ejected occupant
  - The interaction will probably be energetic enough to leave trace evidence of the path of ejection.

Occupant Ejection

- Once the occupant leaves the vehicle, he will travel in a straight path until landing on the ground.
- If the ejection is on the up side of the rolling vehicle, then the occupant will often land in front of the rolling vehicle.
- This is a bad thing!
- Partial ejections are also possible, which often lead to fatal crushing injuries for the occupant.

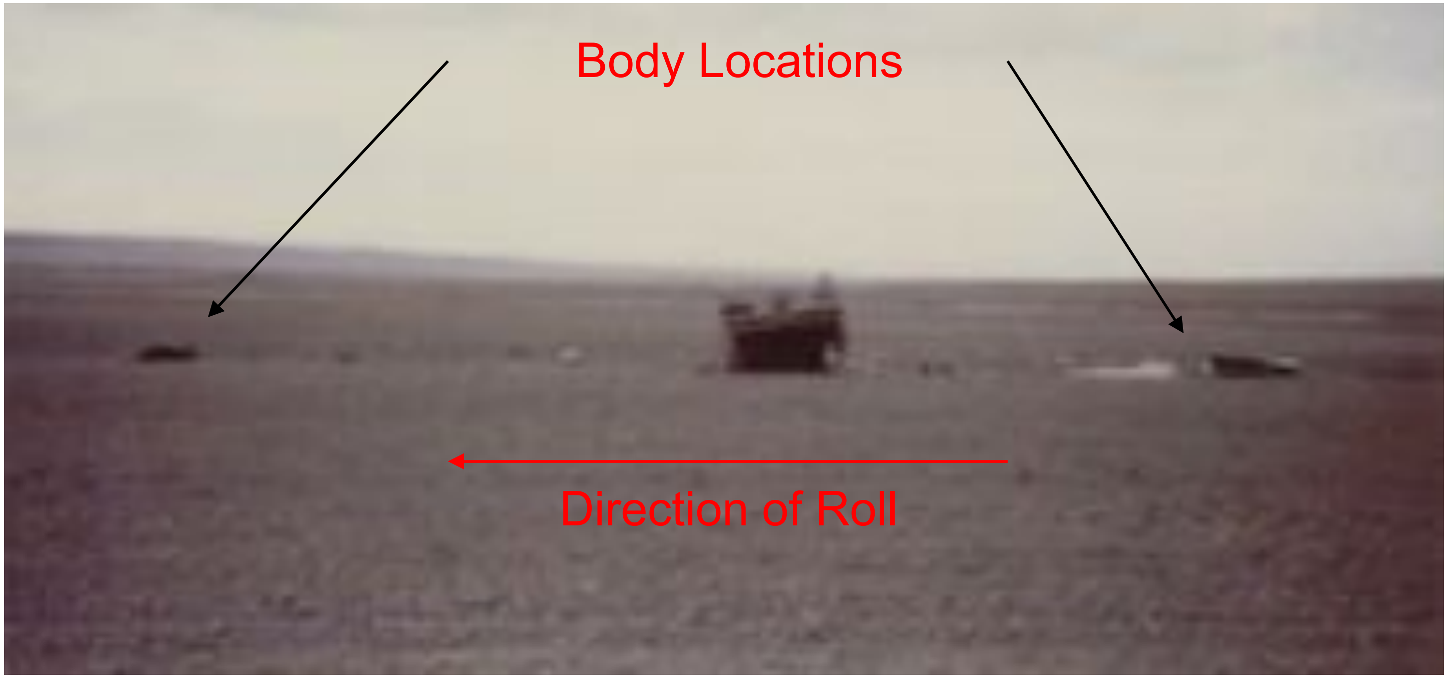
Section 5

Case Study

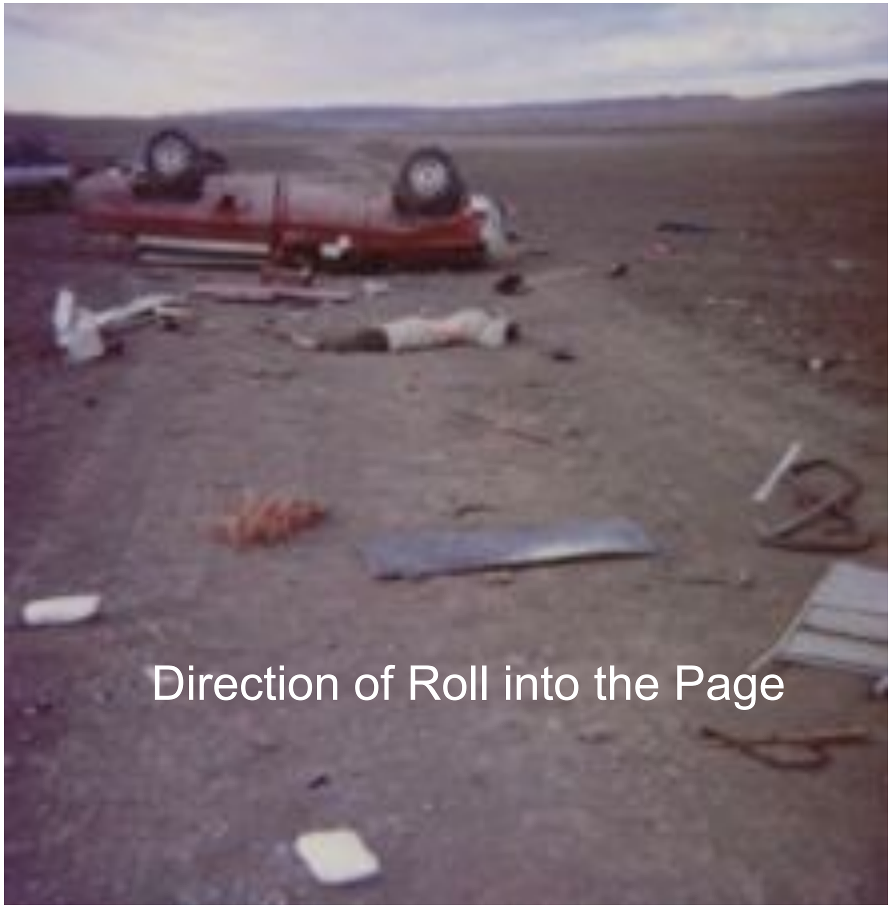
Case Study

- We will put our discussion to use in determining the driver of a rollover crash.
- This rollover occurred December 24, 1998 in a Western state.
- It occurred on a field access road. The adjacent field had been harvested.
- There were two occupants in the vehicle, both of whom were dead at the scene.
- Our task, some six years later, is to determine who was driving.

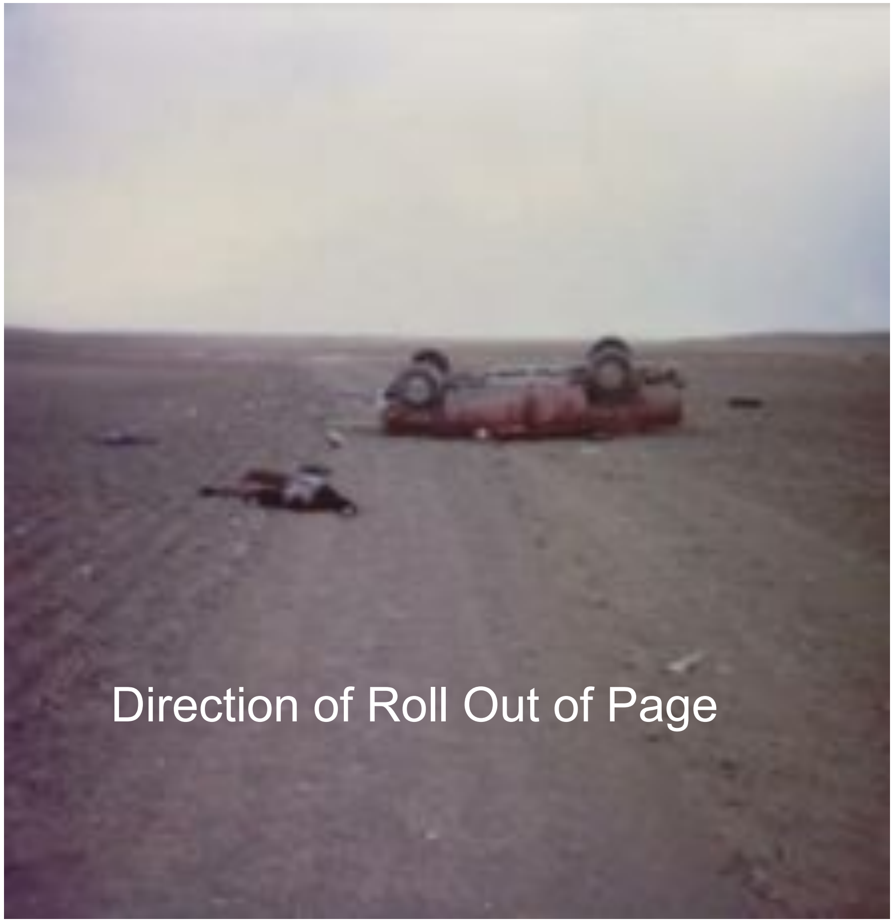
Case Study - Scene



Case Study - Scene



Case Study - Scene

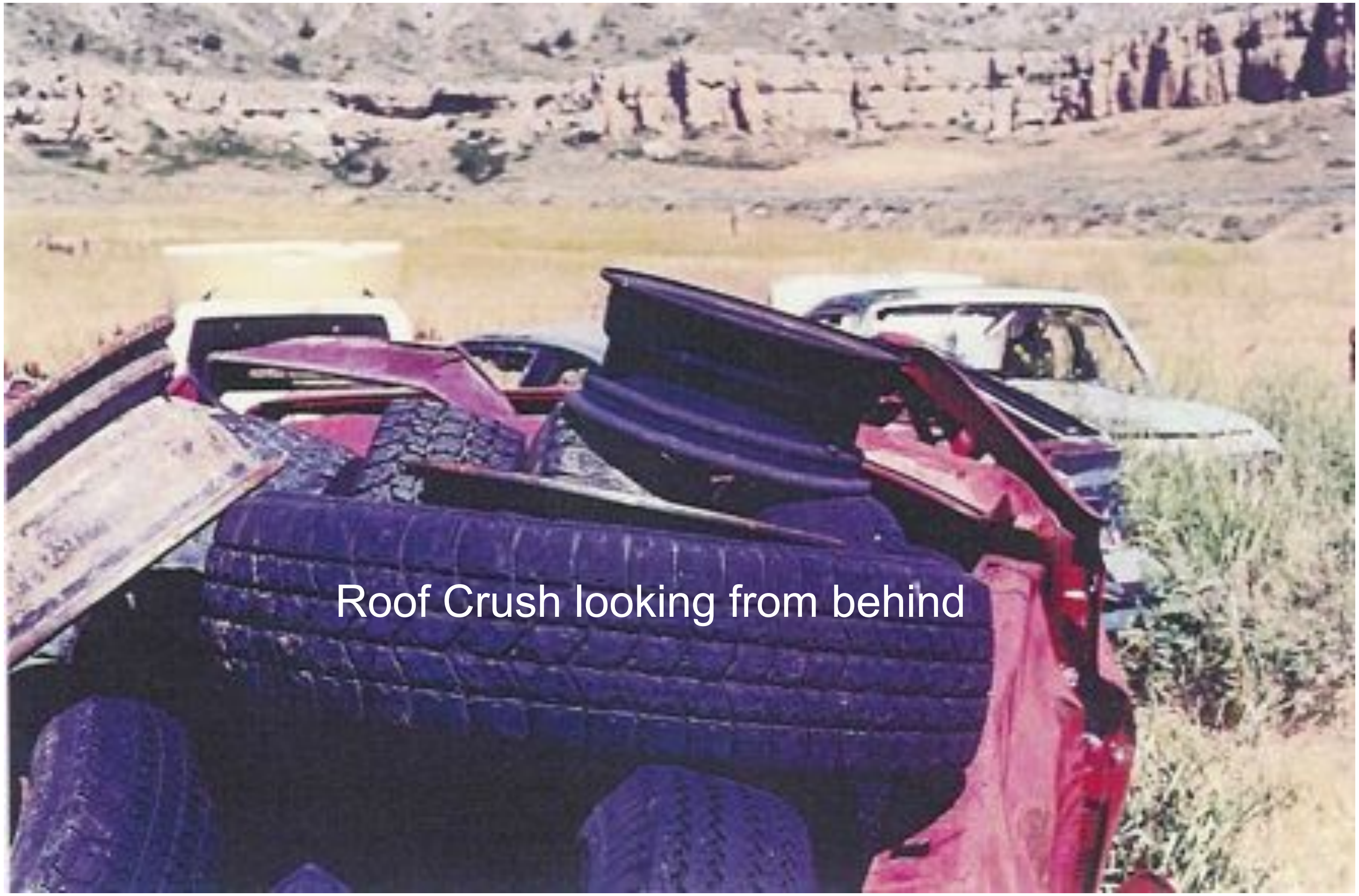


Case Study - Scene

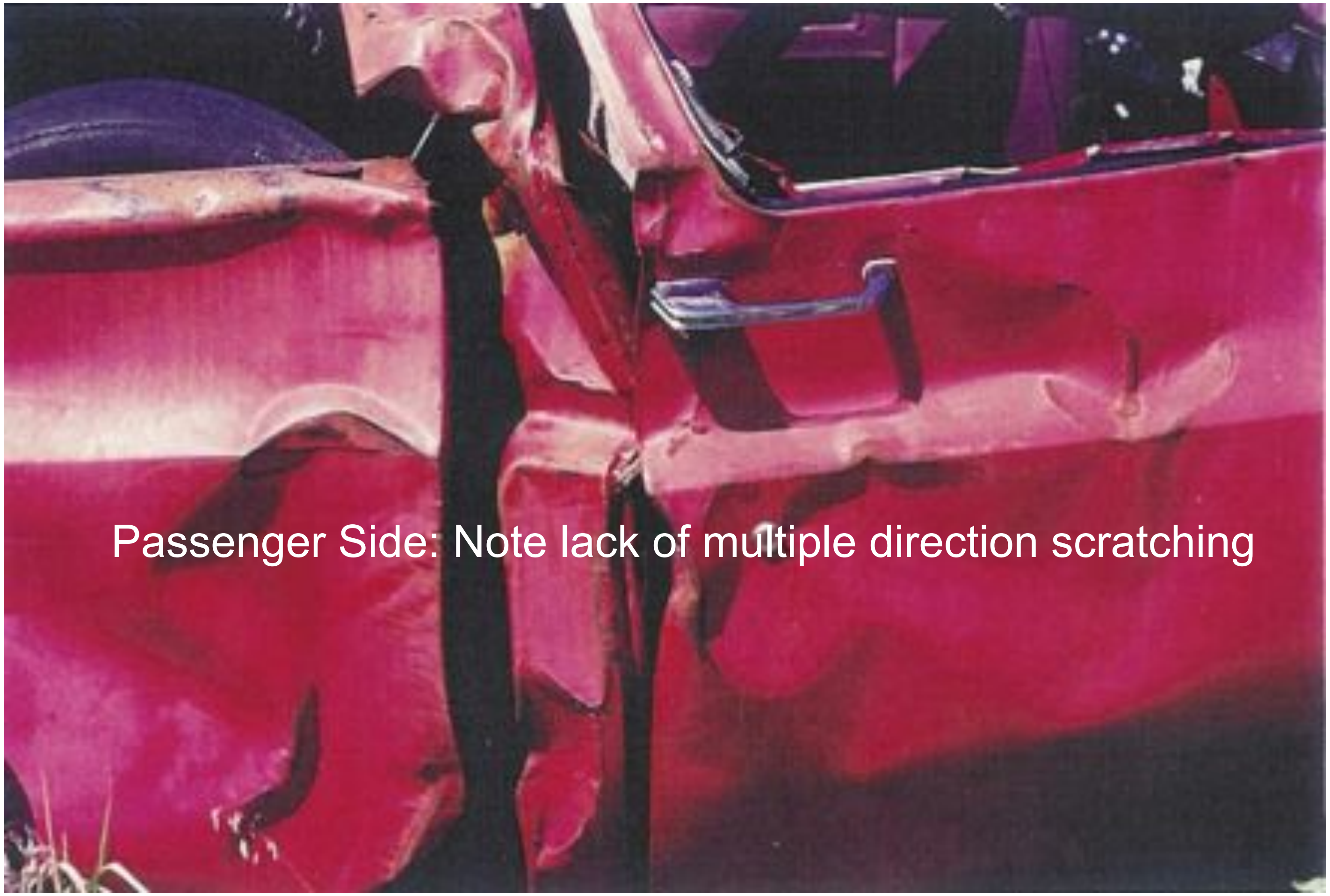
- From the point of trip to final rest for the pickup is about 89 feet.
- The speed range, using Orlowski's f values, would be between 31 mph and 40 mph.
- On this surface, the likely f value would be on the high side of this range – and could be even higher, considering the roof crush.
- The roll was with the driver's side leading.

Case Study - Pickup

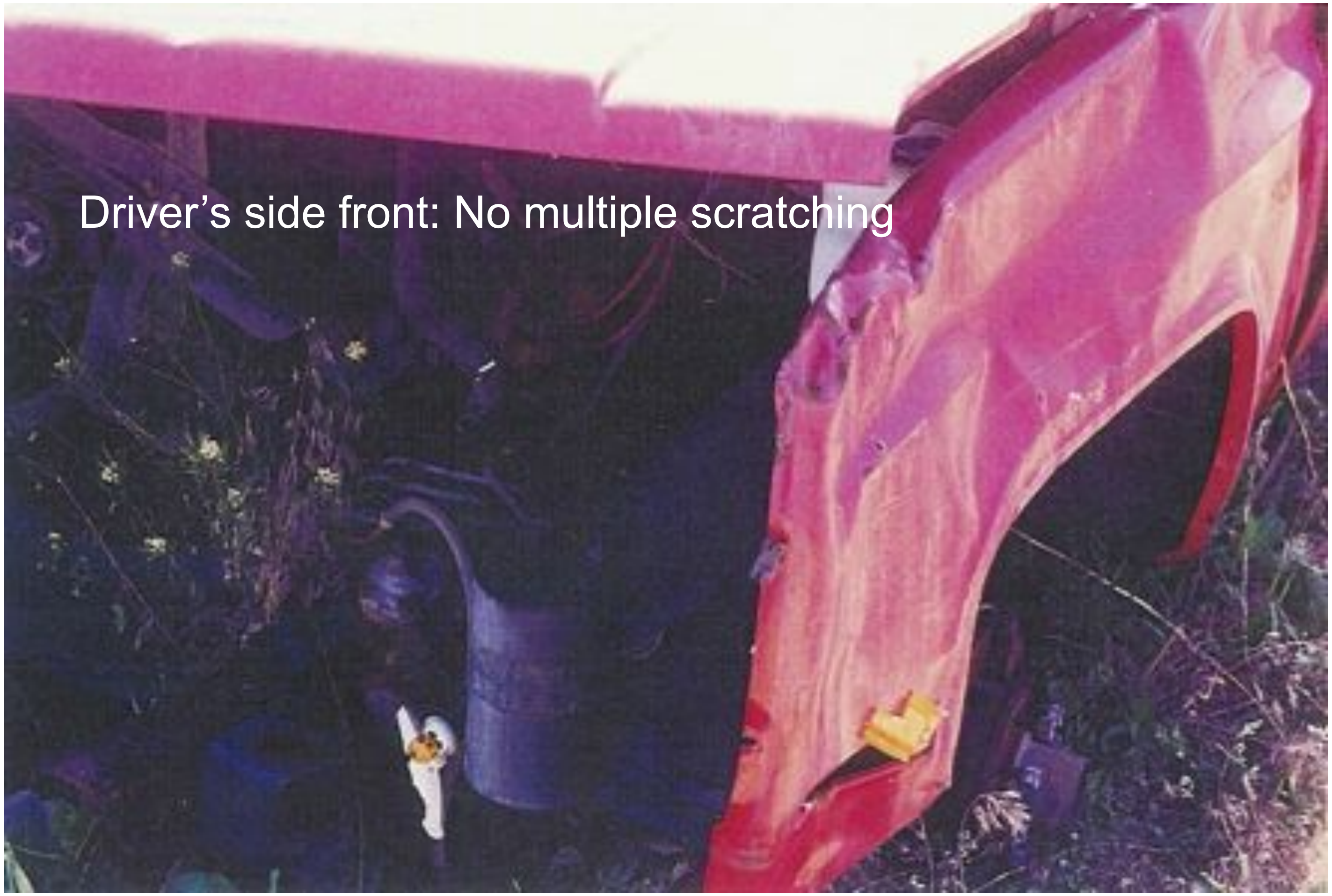
Case Study - Pickup



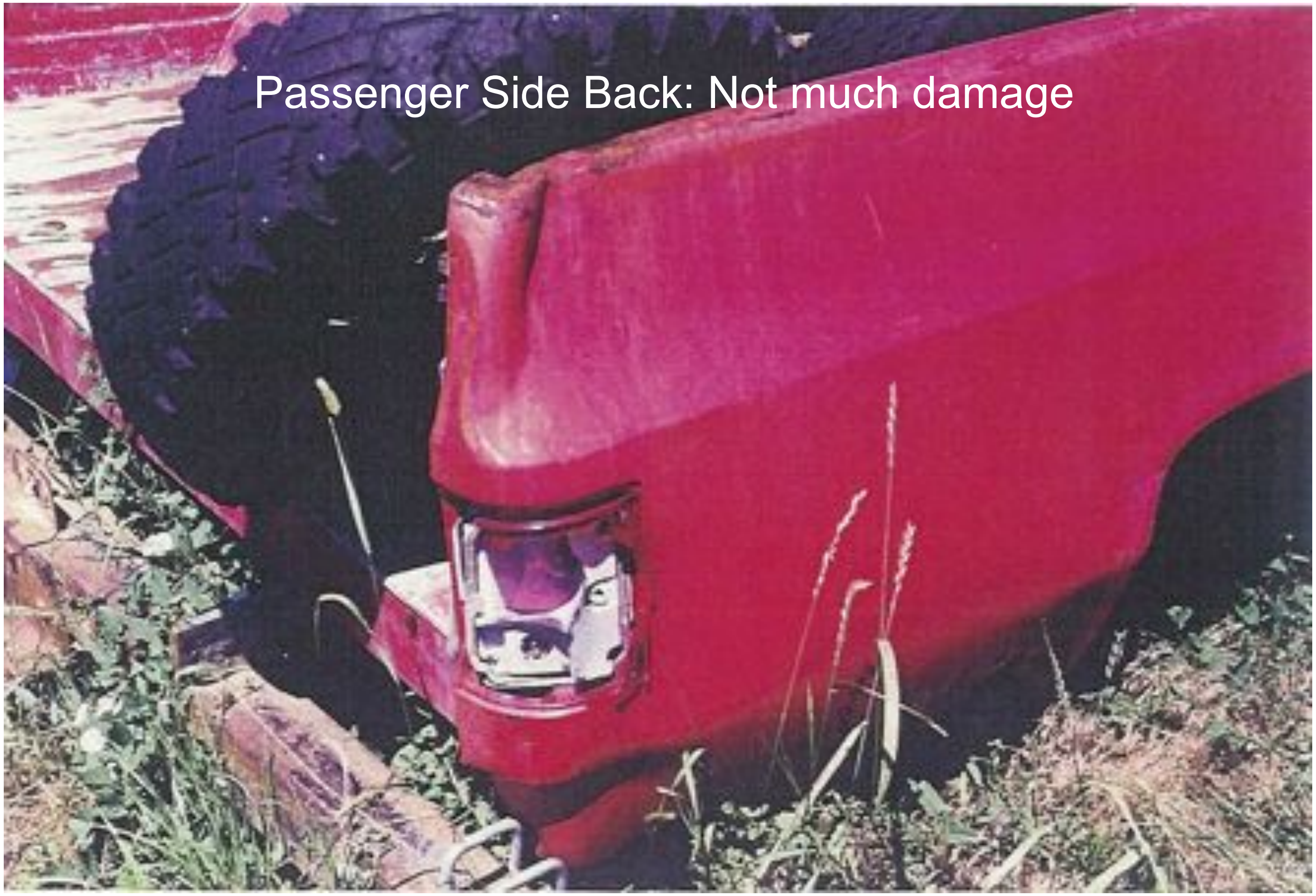
Case Study - Pickup



Case Study - Pickup



Case Study - Pickup



Case Study – How Many Rolls?

- We know the vehicle rolled “x” and ½ times, because it is on its top with the roof crushed.
- Because of the roof crush, there was probably no rolling after the roof caved in.
- There is a debris path, including one occupant, between the trip and the final rest.
- This means that “x” is probably not zero.

Case Study – How Many Rolls?

- We cannot find evidence of multiple overlapping scratching on the vehicle.
- There are areas on the pickup with little damage.
- If the pickup rolled multiple times, then we would expect to see more damage.
- With the evidence available to us, we may expect that $x = 1$.
- It is likely the pickup rolled 1½ times in coming to final rest.

Case Study – Roll Dynamics

- The pickup tripped over its driver's side wheels.
- It rolled a bit over two quarter turns in the air and first impacted on the passenger side roof edge.
- This probably broke out the glass in the passenger side window.
- The passenger would have moved to the right and up toward the force application.
- It is likely to expect the passenger would receive a head injury from this impact.
- The driver would begin to move to the right also, even for a short time.

Case Study – Roll Dynamics

- The driver’s legs would be in a position to interact with the four speed transmission floor shift lever.
- It is not clear if the driver’s window was open or shut, or if this first impact caused the window glass to break.
- The centripetal acceleration will cause both occupants to move toward their respective sides after this first impact.
- The occupant on the driver’s side will have the opportunity to be ejected from the driver’s side window.
- His velocity will be higher than the translational velocity of the center of mass of the pickup.
- The magnitude and angle of this velocity is not known specifically.

Case Study – Roll Dynamics

- If the driver is ejected first, then the pickup will have the opportunity to roll over him.
- The pickup continues to roll. When it is wheels down, it still has ½ turn to go.
- After 5/4 rotation, the passenger side is now facing up and the passenger has the opportunity to be ejected out the passenger side window.
- The passenger will have a higher velocity than the center of mass of the pickup, and will land ahead of the pickup's path.
- Again, we do not know the specific magnitude or angle of this velocity vector.

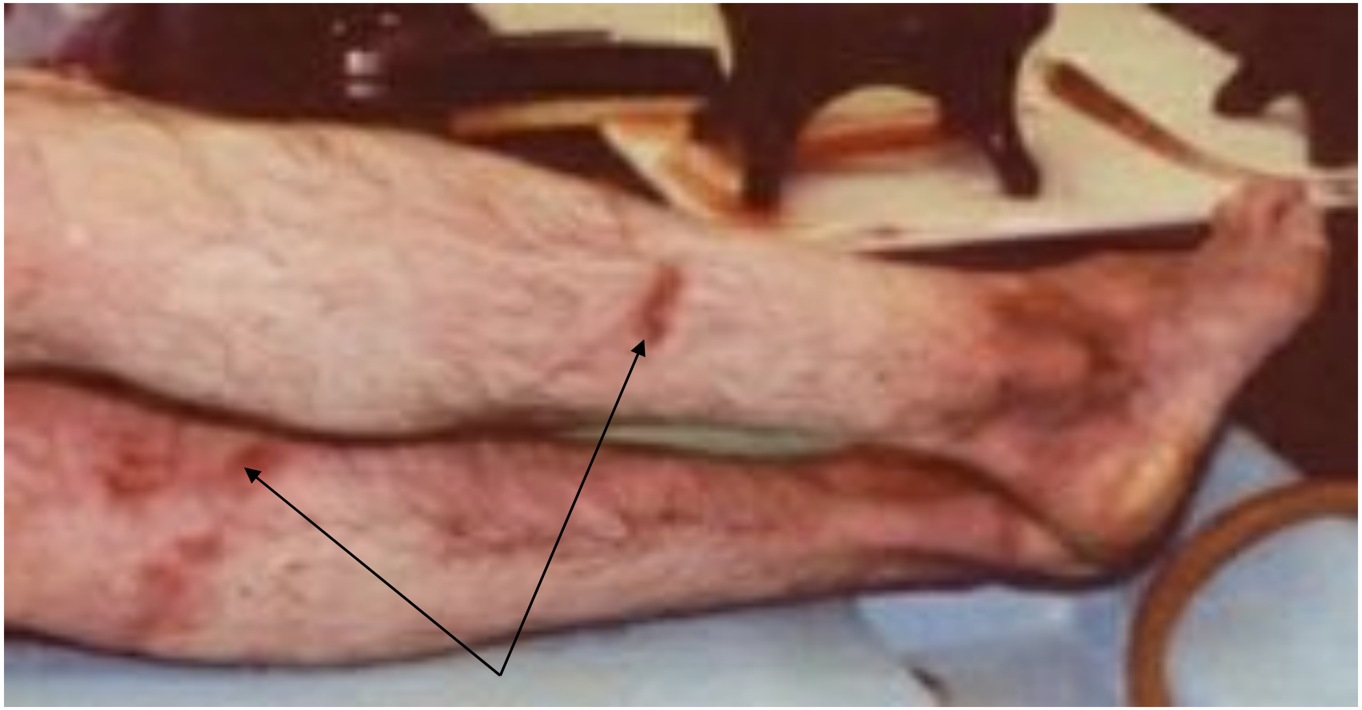
Case Study – Roll Dynamics

- The pickup rolls the final quarter-turn, and lands on its roof.
- This crushes the roof and causes any subsequent rolling to cease.
- Neither occupant left documented evidence as to their respective ejection portals.
- From the analysis of the roll dynamics, we might then expect the driver to be on the near side of the pickup and the passenger to be on the far side of the pickup.

Case Study – Occupant Injuries

- The person lying on the far side of the pickup had suffered fatal head injuries.
- The head impact had been on the right parietal area of the skull.
- The person lying on the near side of the pickup had suffered crushing chest injuries on the right side.
- He also had bruising on both lower legs consistent with shift lever impact.

Case Study – Occupant injuries



Case Study – Occupant Injuries

- We may see the injuries to the occupants are consistent with the positions ascribed to them by means of the roll analysis.

Summary

- Although, as we have seen, rollover events are violent and complex.
- However this doesn't mean they can't be analyzed.
- As with any event, analyzing in segments simplifies the problem and allows overall conclusions to be reached.
- In rollover events where occupant positioning is one of the issues to be determined, accurate and detailed evidence gathering is imperative.
- It's not sufficient to merely say the vehicle rolled *x* feet to a stop.
- It must be determined how the vehicle rolled and the orientation of the vehicle as it struck the ground or other major objects.
- Without this information a proper dynamics analysis cannot be performed and in turn a proper kinematics analysis cannot be completed. Thus, no seating determination can be obtained.
- Thus, careful attention to detail will allow us to properly analyze the rollover event.

End

- Thank you for your attention!!

Ike says "Bye!"