Considerations In Investigating Traffic Crashes Involving Rollovers

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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 becomes much 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 very 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.

Definition and Concepts

- **Kinematics**
  - The analysis of the motion of objects without regard to the cause of the motion.
- **Dynamics**
  - The analysis of the motion of objects and the forces involved in putting the object into motion.
- Hence the terms "Occupant Kinematics" and "Vehicle Dynamics."
- In crash investigation, the analysis of occupant movement is a marriage of kinematics and dynamics.

Definitions and Concepts (cont.)

- **Newton's First Law of Motion**
  - A body in motion will remain in motion and a body at rest will remain at rest until acted upon by an outside, net force.
- If an object is in motion the motion will be straight line motion.
- Also known as the "Law of Inertia."

Definitions and Concepts (cont.)

- **Newton's Second Law of Motion**
  - The acceleration of an object is directly proportional to the force applied and inversely proportional to its mass.

$$F = Ma$$

Definitions and Concepts (cont.)

- **Angular Displacement**
  - Denoted by *2* (theta) and is measured in radians.
  - Angular displacement is analogous to translational displacement measured in feet or meters.

Definitions and Concepts (cont.)

- **Angular Velocity**
  - Change in angular displacement with respect to a change in time.
  - Denoted by *T* (omega) and is measured in radians per second.
  - Angular velocity is analogous to translational velocity measured in ft/sec or m/sec.

Definitions and Concepts (cont.)

- **Angular Acceleration**
  - Change in angular velocity with respect to a change in time.
  - Denoted by ″ (alpha) and is measured in radians per second^2.
  - Angular acceleration is analogous to translational acceleration measured in ft/sec^2 or m/sec^2.

Definitions and Concepts (cont.)

- **Moment of Inertia**
  - A measure of the resistance a body has to angular acceleration.
  - A function of both the mass and shape of the body.
  - Denoted by *I* (uppercase i) and is measured in slug-ft^2 or lb-ft-sec^2 in the English system and kg-m^2 in the metric system.
  - Moment of inertia is analogous to mass, which is a measure of a body's resistance to translational acceleration.

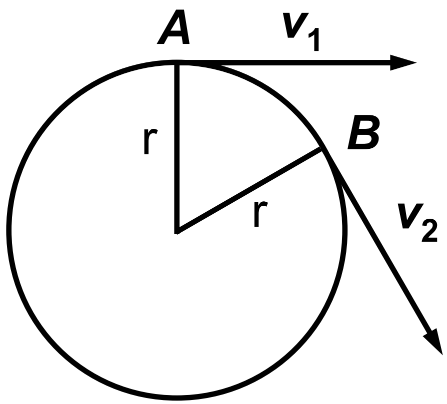
Definitions and Concepts (cont.)

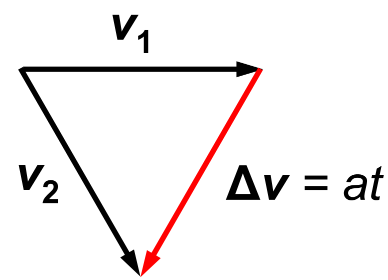
- **Torque**
  - Torque is produced by a force multiplied by the length of the lever arm, or moment arm, against which the force is acting.
  - Denoted by J (tau) and is measured in ft-lbs or N-m.
  - Torque is analogous to force.

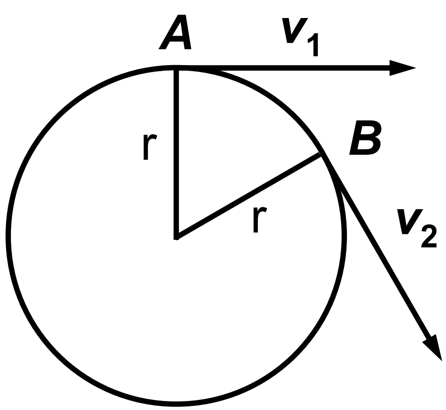
Occupant Ejection

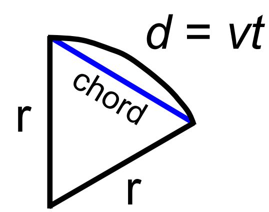
- Many times in a rollover situation, the occupants of the vehicle become ejected.
- This is due to the high forces involved which are produced by the rotational motion.
- All occupants are subjected to these forces.
- However, it is the unrestrained occupants that generally become victims to these forces.
- 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









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

$$rat = vvt$$

$$rat = v^2 t$$

$$ra = v^2$$

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

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?

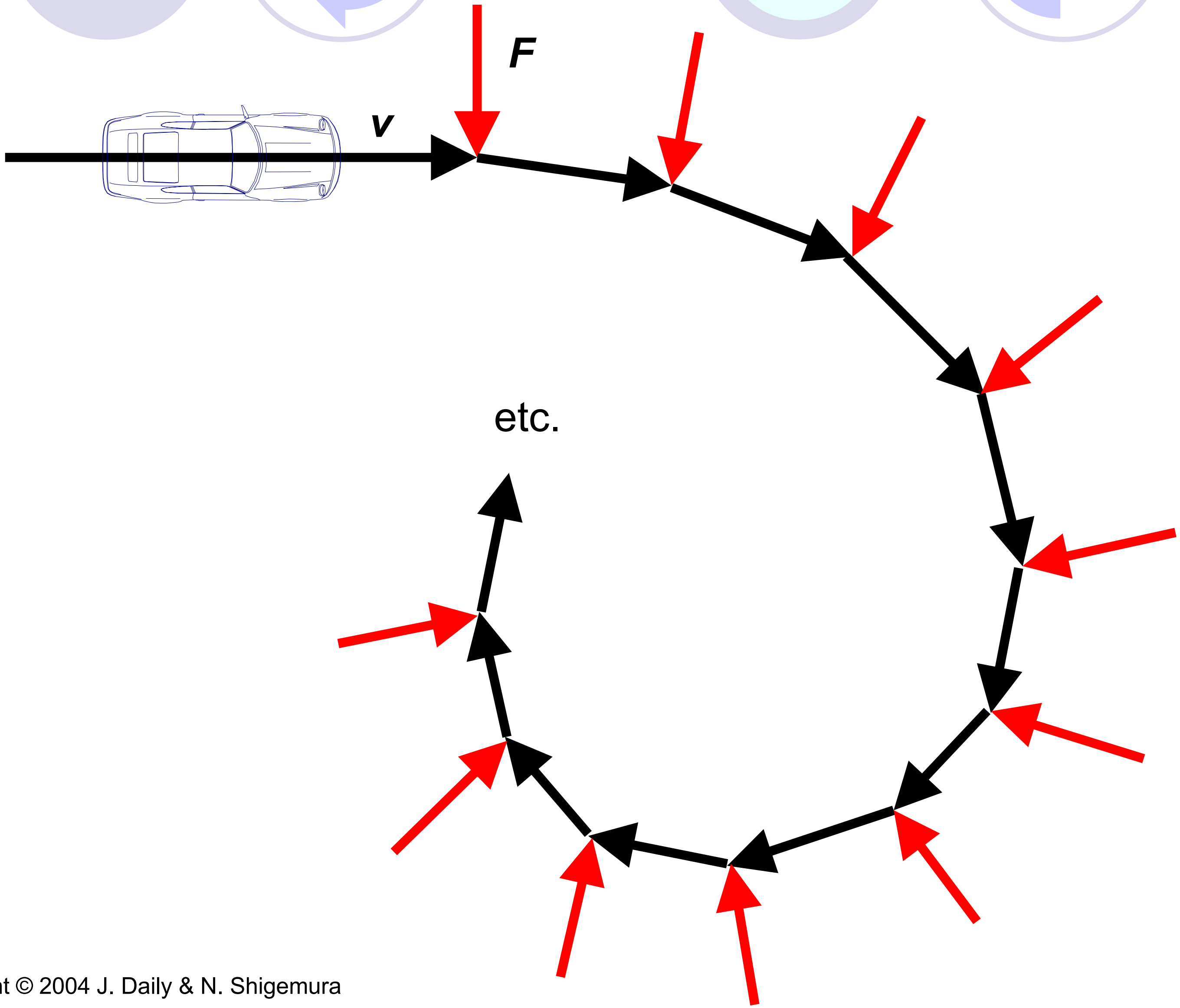
Friction

- 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.)

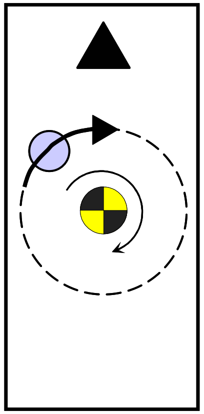


Rotational Dynamics (cont.)

- 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, *T*, 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:

$$v_t = r\omega$$

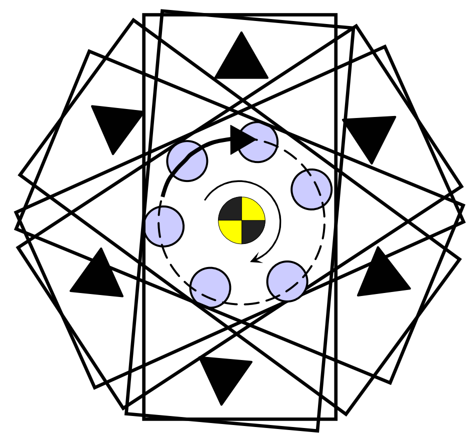


Fig. 1

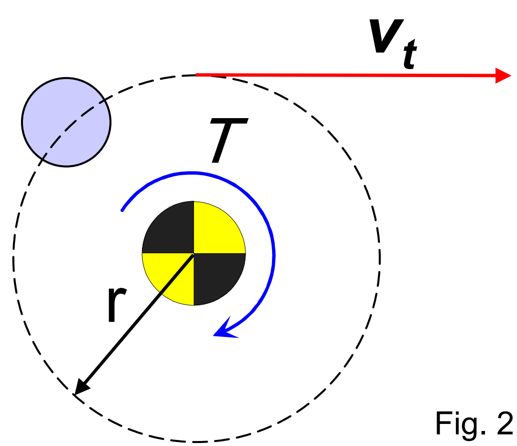


Fig. 2

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.)

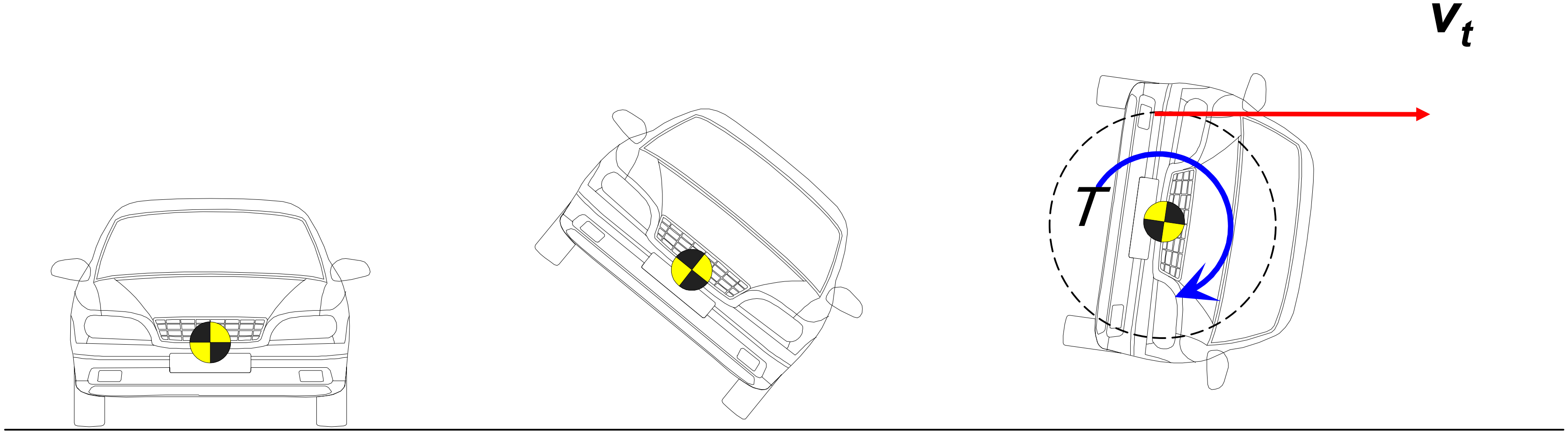
- Finally, calculate the force the driver experiences:

$$F = wf$$
$$= 200(1.66)$$
$$= 332 \text{ lbs.}$$

- This is the centripetal force the car body places on the driver. (This is not 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 very fast.



Rollovers

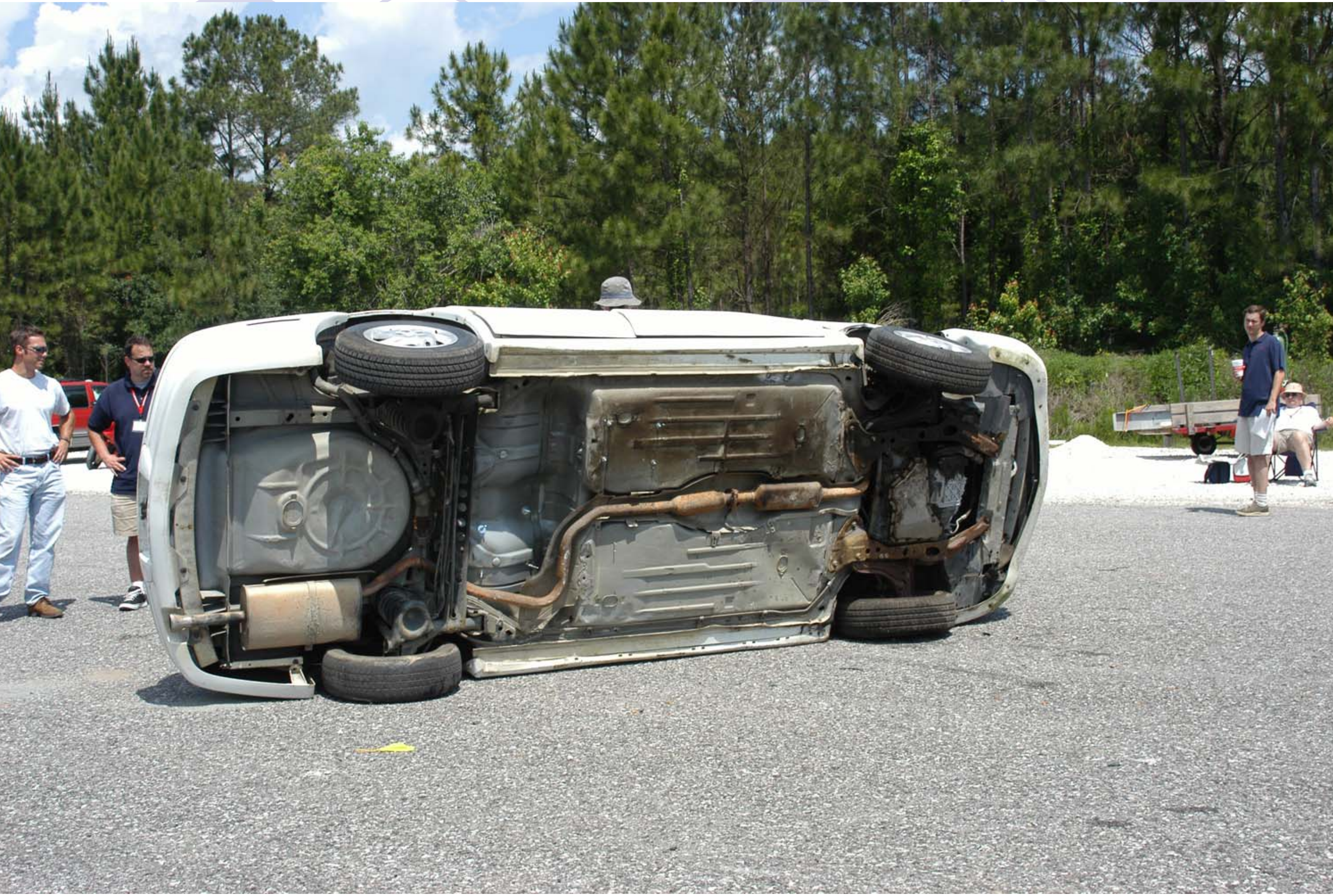
- Rollover tests at IPTM's Special Problems 2003

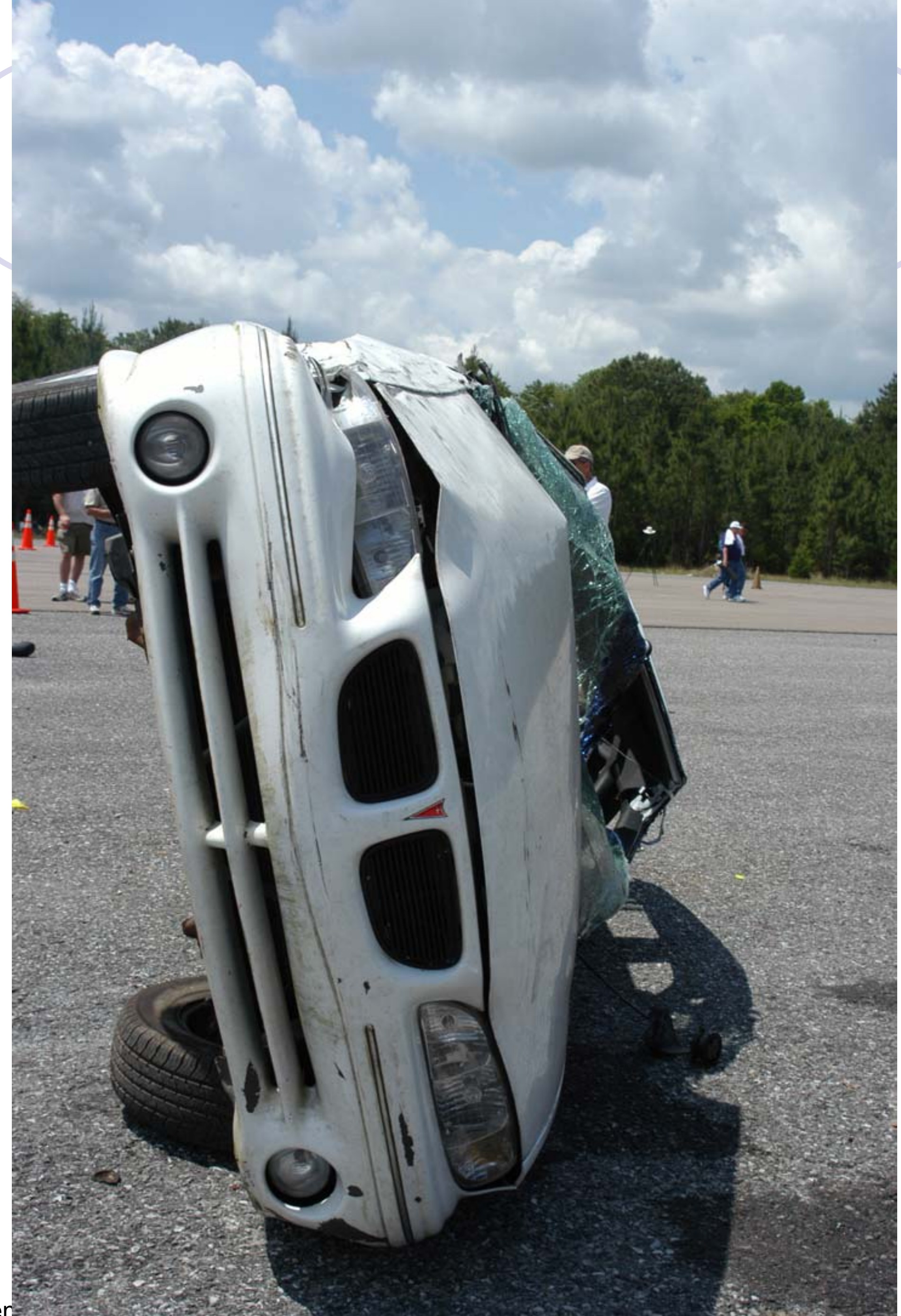
Rollovers (cont.)

- Rollover tests at IPTM's Special Problems 2003

Rollovers (cont.)

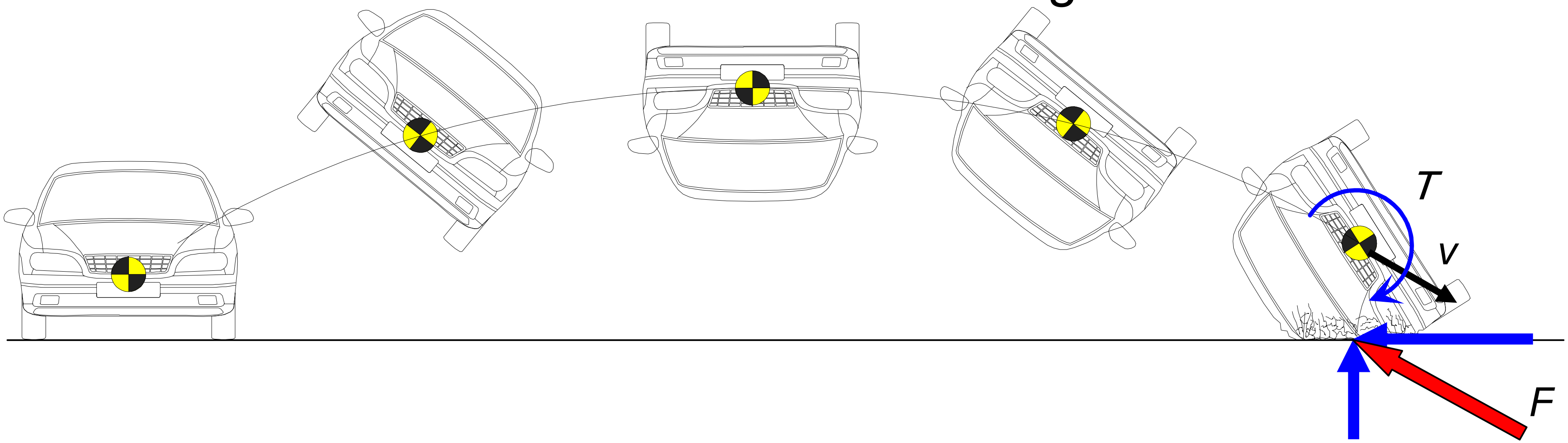
- As seen in the previous videos, rollover events are very violent.
- Vehicles can bound, attaining vertical distances and increase in angular velocities.





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 kinematics analysis require 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”.
- Sometimes, in spite of our best efforts, there is little evidence left behind:

Rollover Event, cont'd.

- In the previous slide, this Ford pickup was involved in a head-on collision with a Dodge pickup.
- The Ford rolled once down a steep embankment, coming to rest on its wheels.
- It subsequently burned, which effectively destroyed any trace evidence that may have been left behind.
- Unfortunately, the passenger was trapped, so the driver was easy to determine.

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.

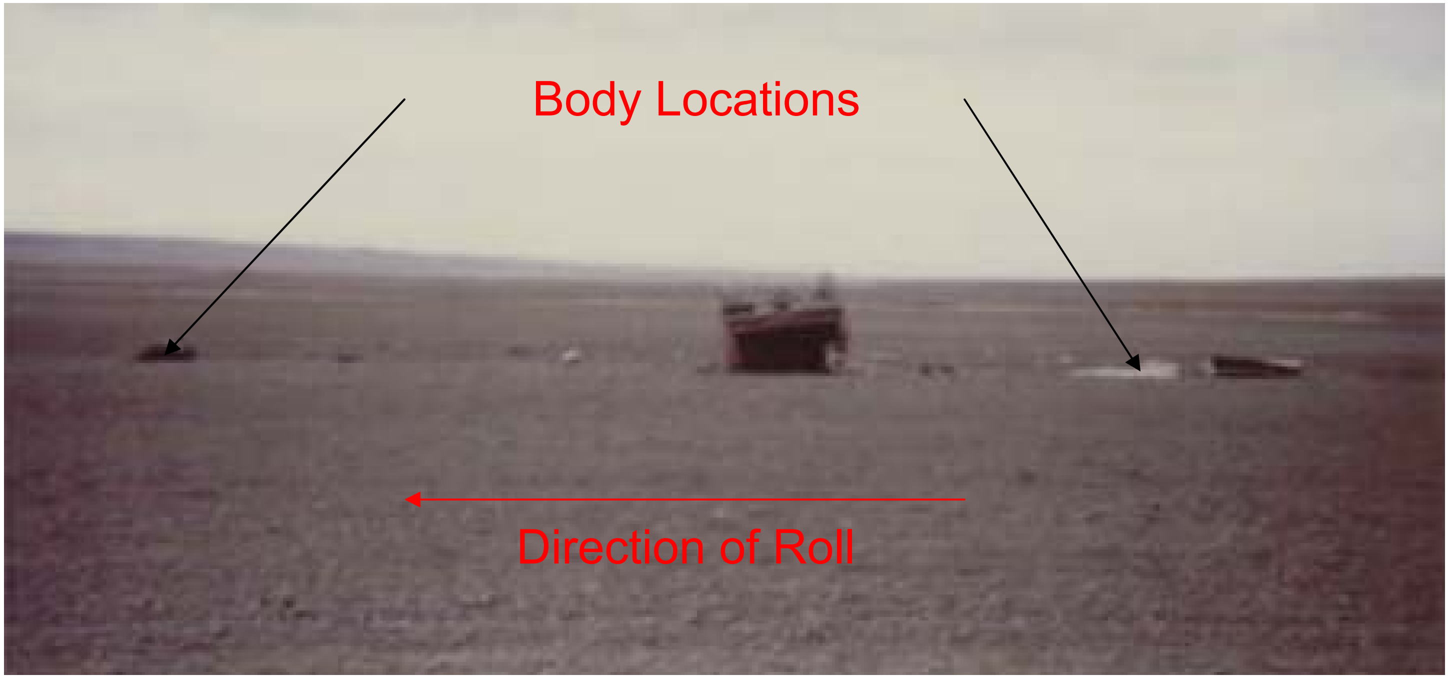
Case Studies

Case Study 1

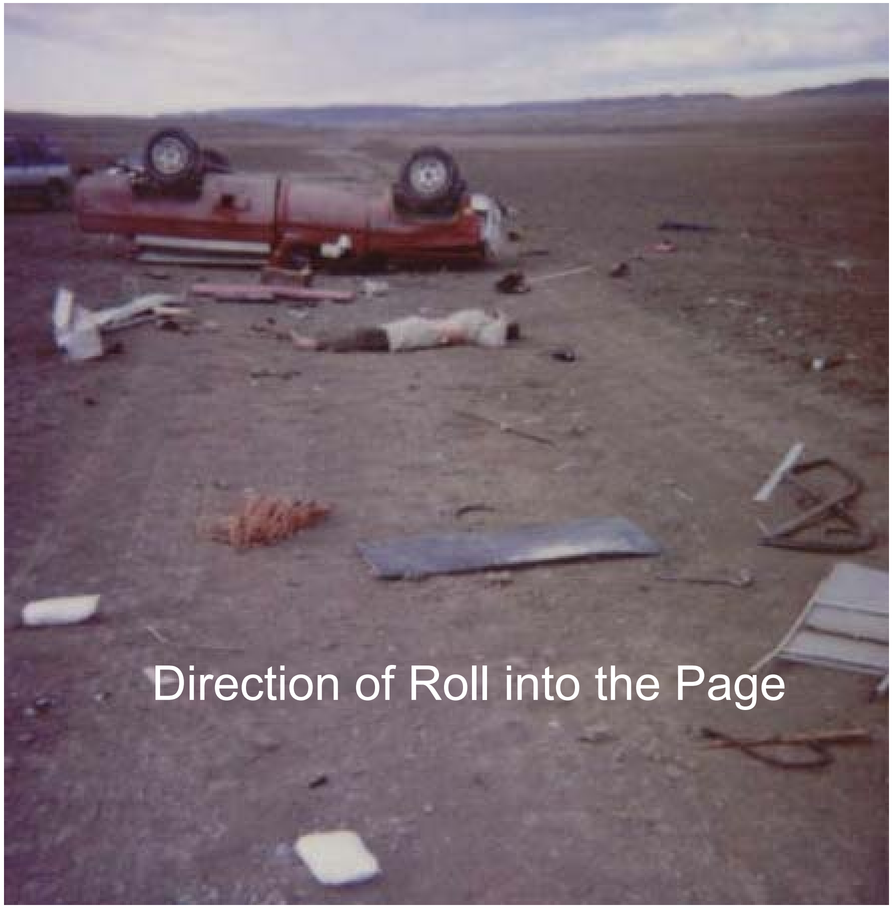
Case Study 1

- 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.

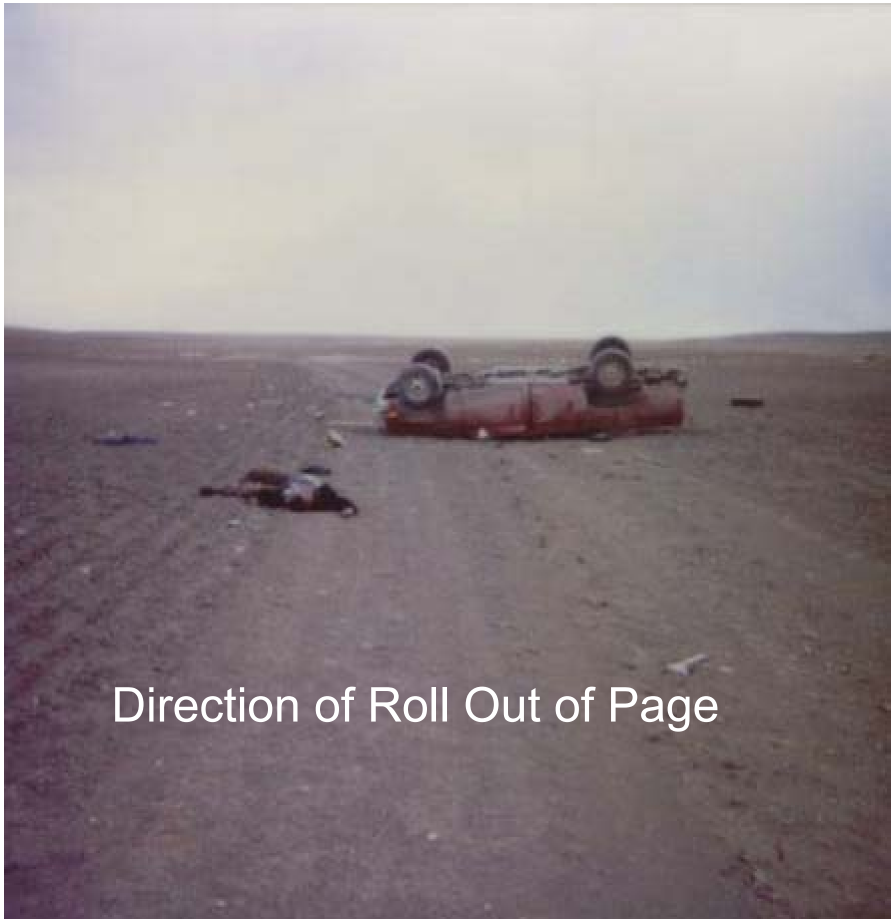
Case Study 1 - Scene



Case Study 1 - Scene



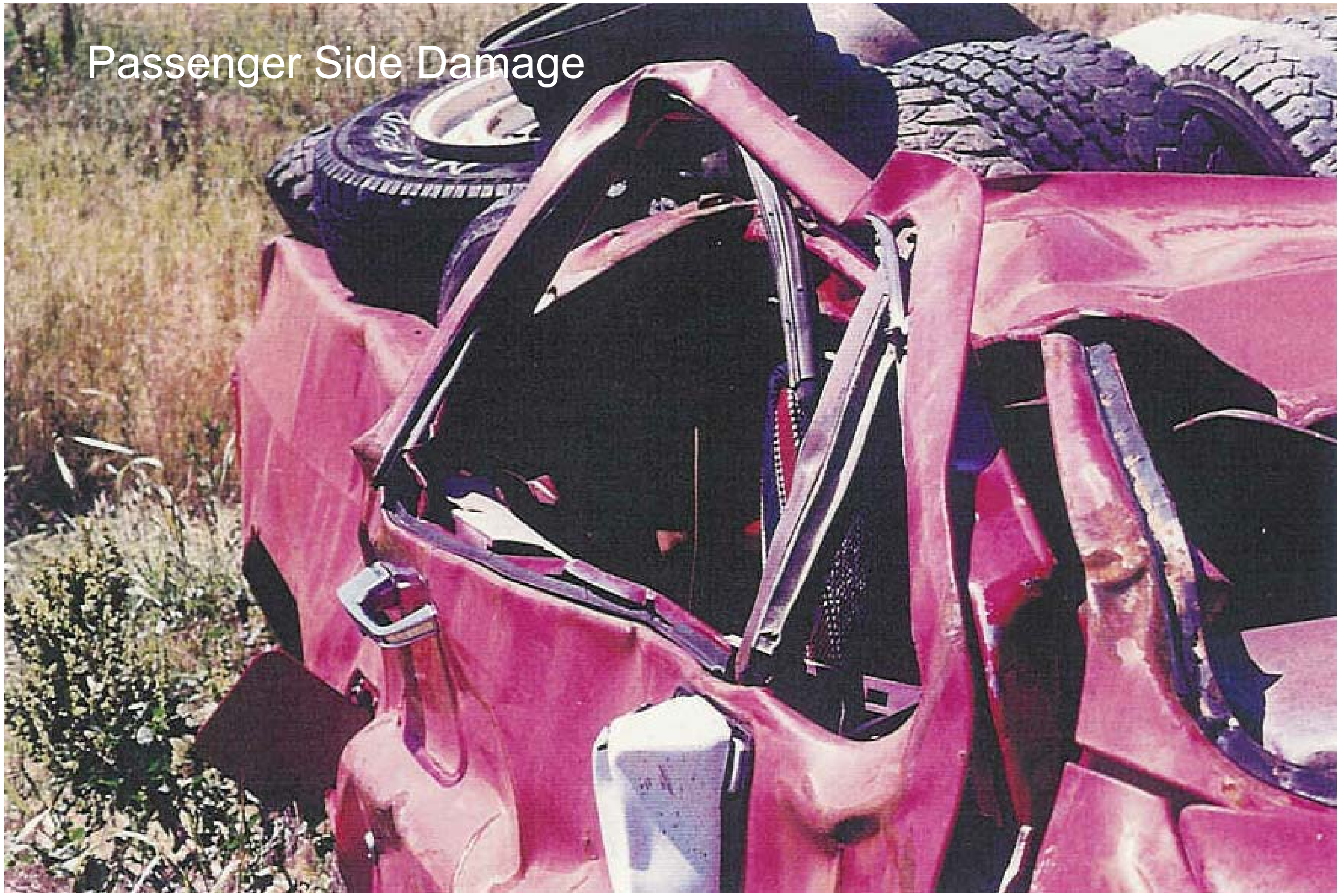
Case Study 1 - Scene



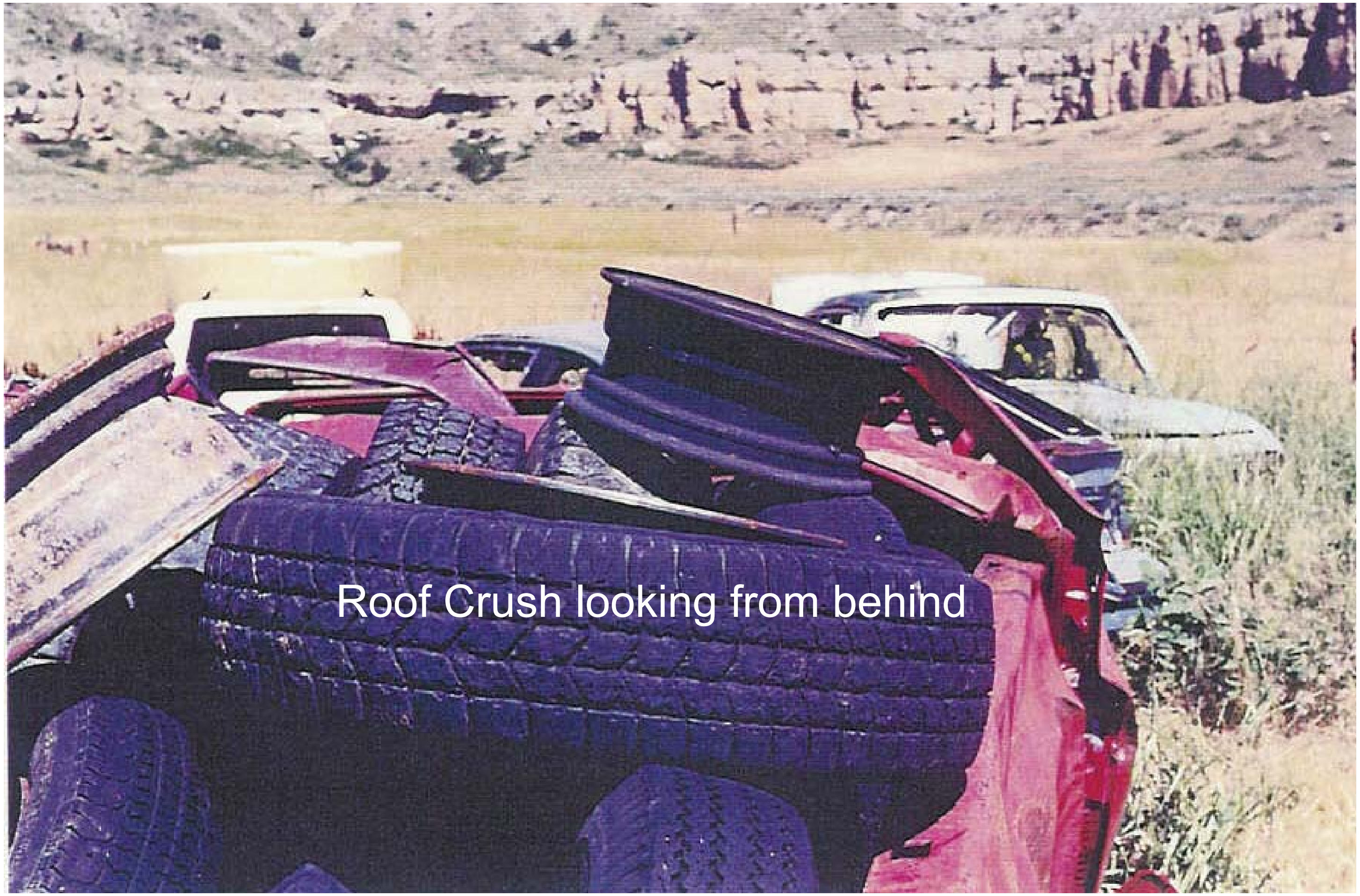
Case Study 1 - Scene

- 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 1 - Pickup



Case Study 1 - Pickup



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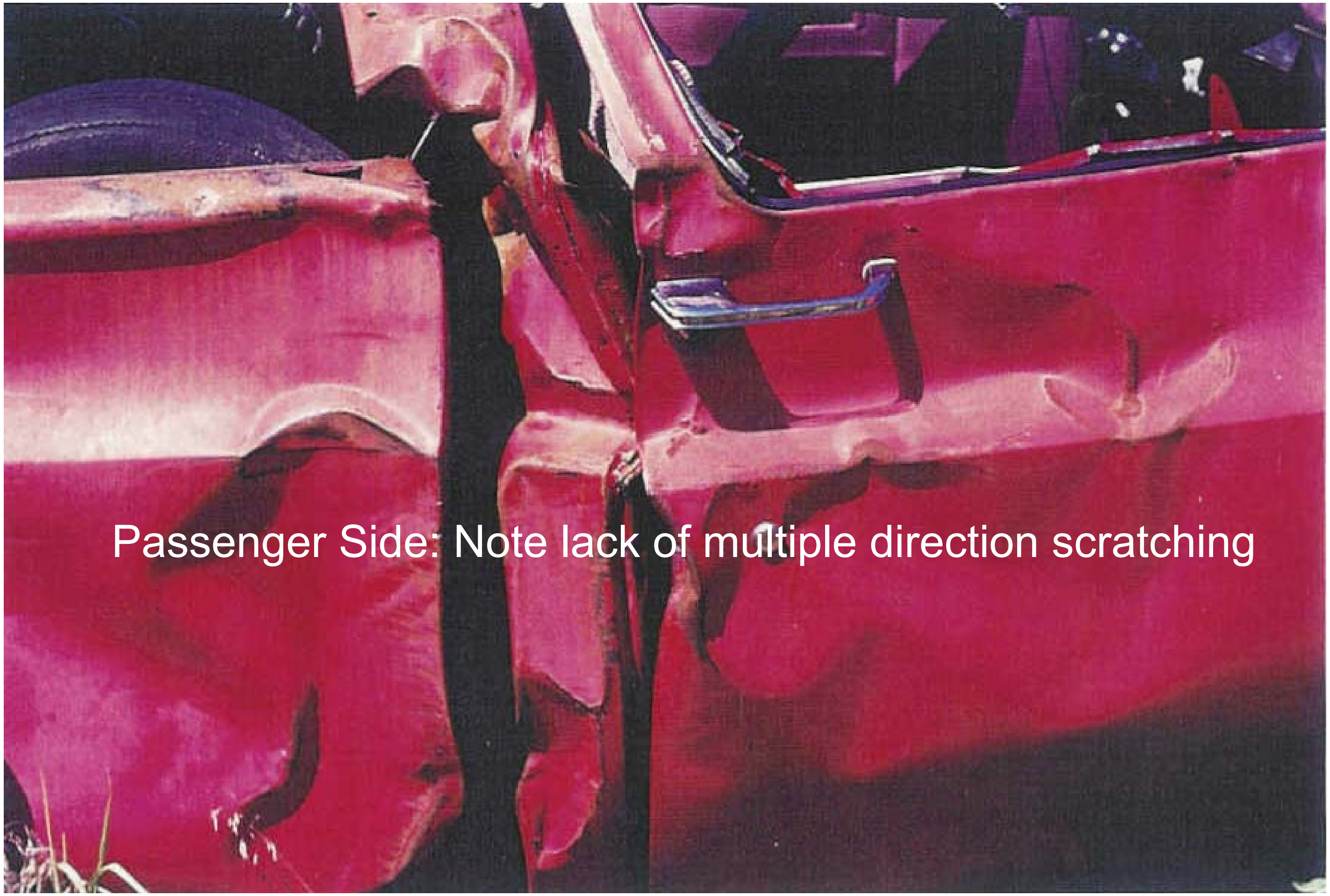
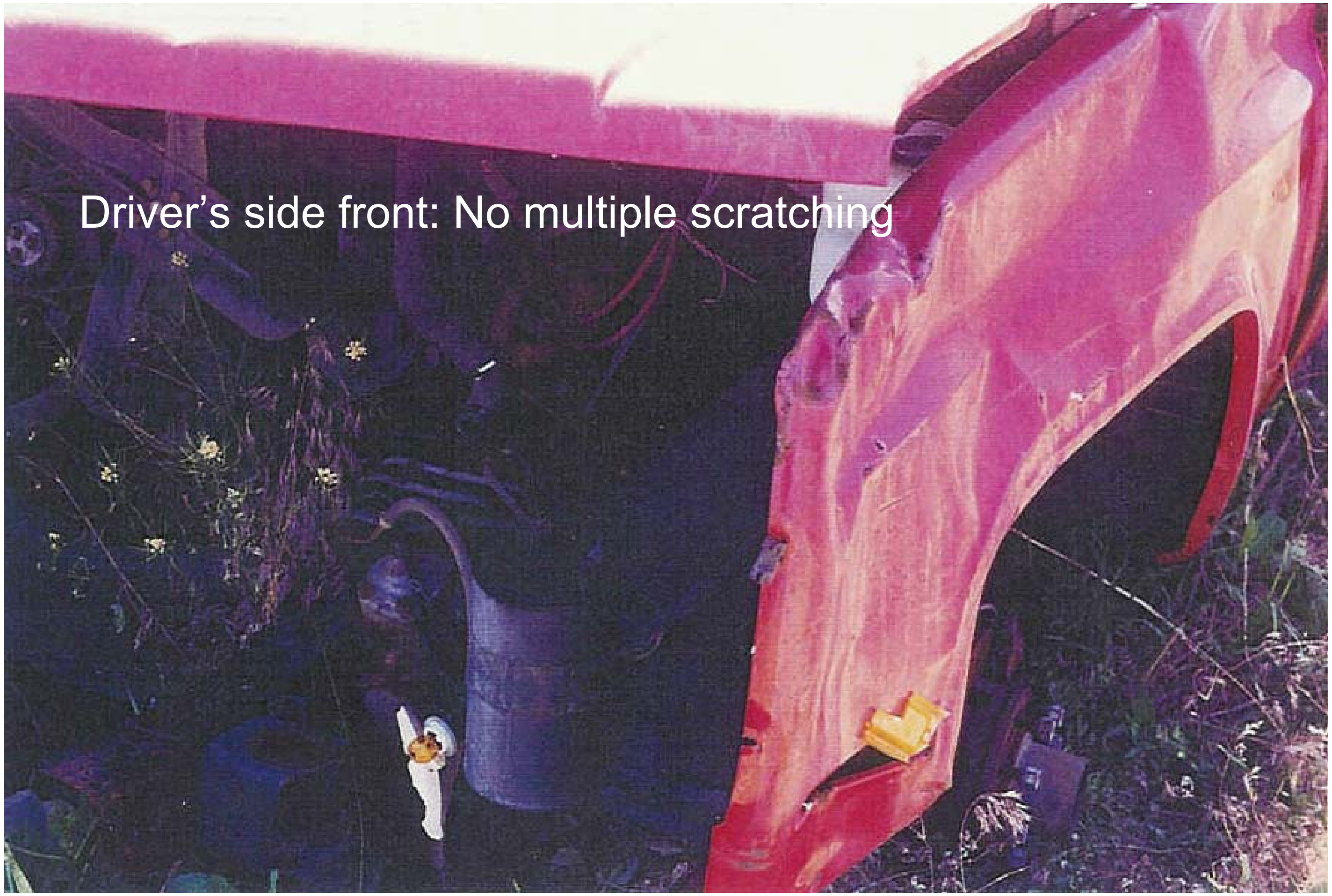


Case Study 1 - Pickup



Case Study 1 - Pickup

Case Study 1 – 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 1 – 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 1 – 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 1 – 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 1 – 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.

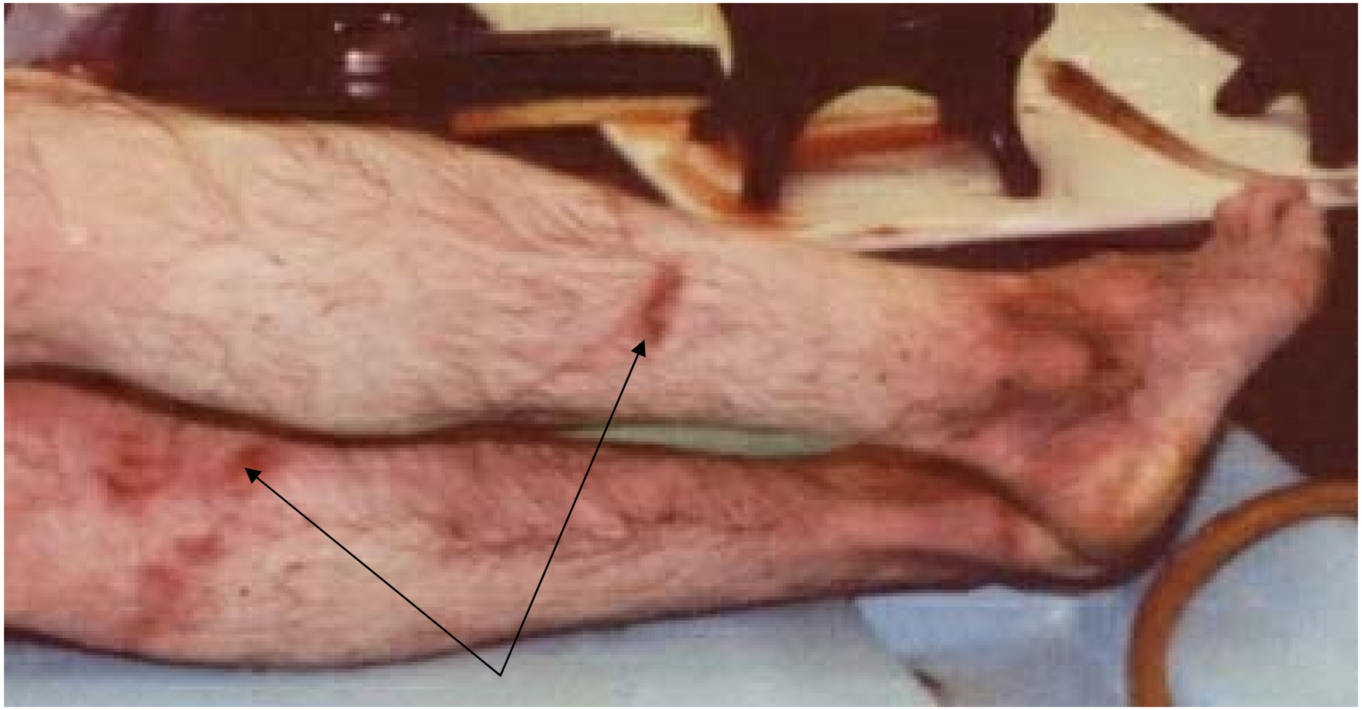
Case Study 1 – Roll Dynamics

- 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 1 – 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.

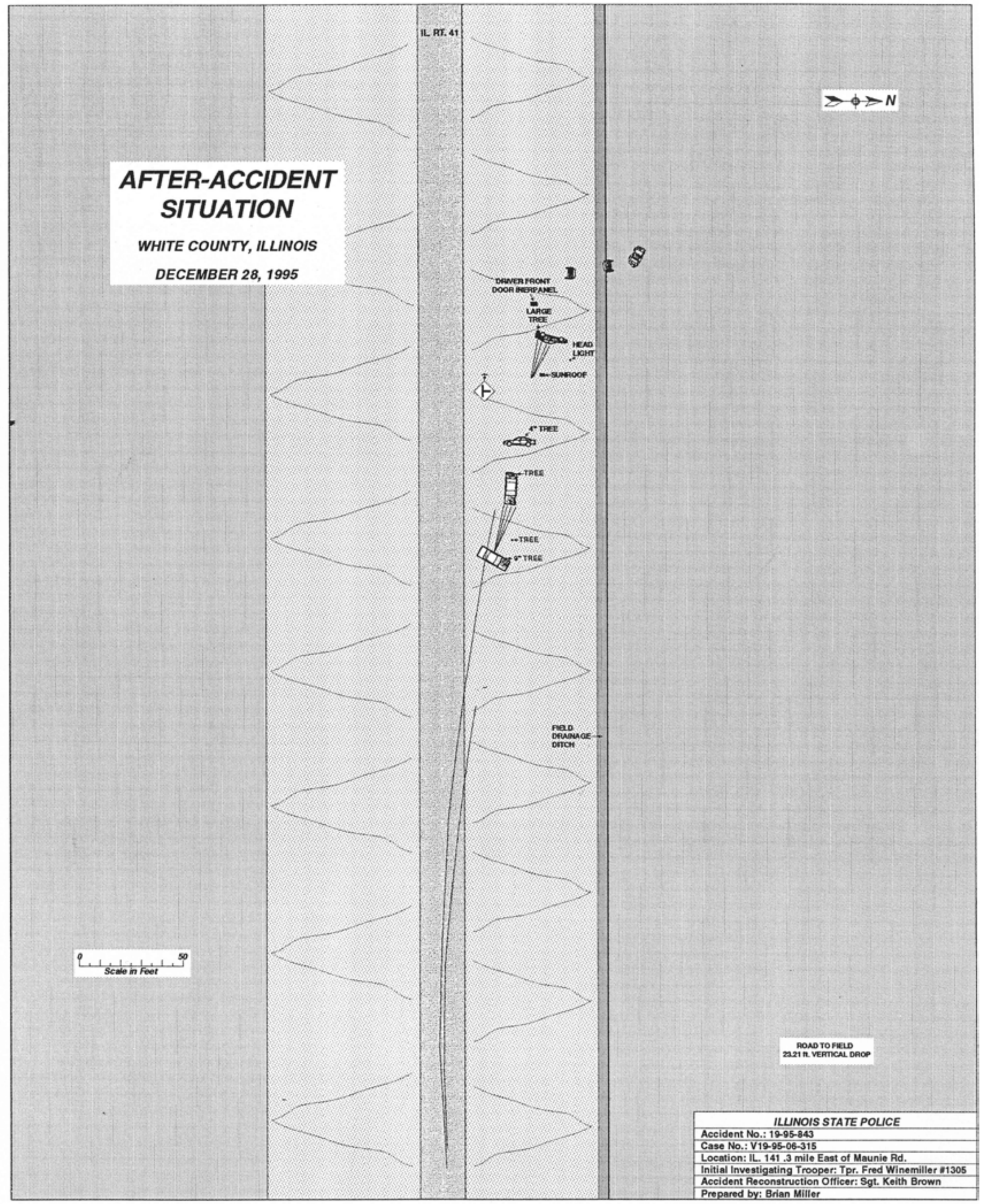
Case Study 1 – Occupant injuries

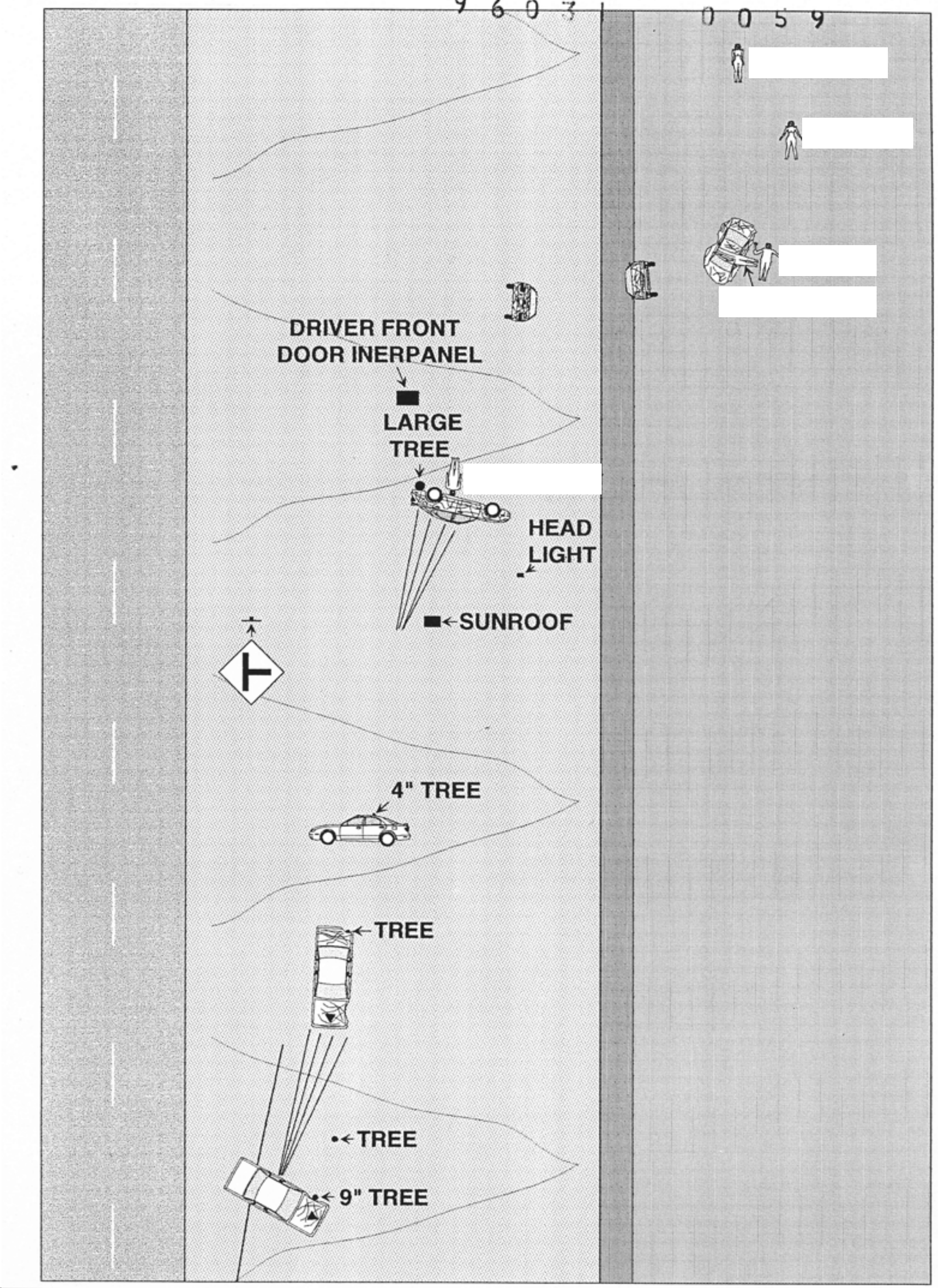


Case Study 1 – Occupant Injuries

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

Case Study 2


AFTER-ACCIDENT SITUATION
WHITE COUNTY, ILLINOIS
DECEMBER 28, 1995
IL. RT. 41
N
DRIVER FRONT DOOR INERPANEL
LARGE TREE
HEAD LIGHT
SUNROOF
4" TREE
TREE
TREE
9" TREE
FIELD DRAINAGE DITCH
0
50
Scale in Feet
ROAD TO FIELD
23.21 ft. VERTICAL DROP
ILLINOIS STATE POLICE
Accident No.: 19-95-843
Case No.: V19-95-06-315
Location: IL. 141 .3 mile East of Maunie Rd.
Initial Investigating Trooper: Tpr. Fred Winemiller #1305
Accident Reconstruction Officer: Sgt. Keith Brown
Prepared by: Brian Miller


DRIVER FRONT DOOR INERPANEL
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HEAD LIGHT
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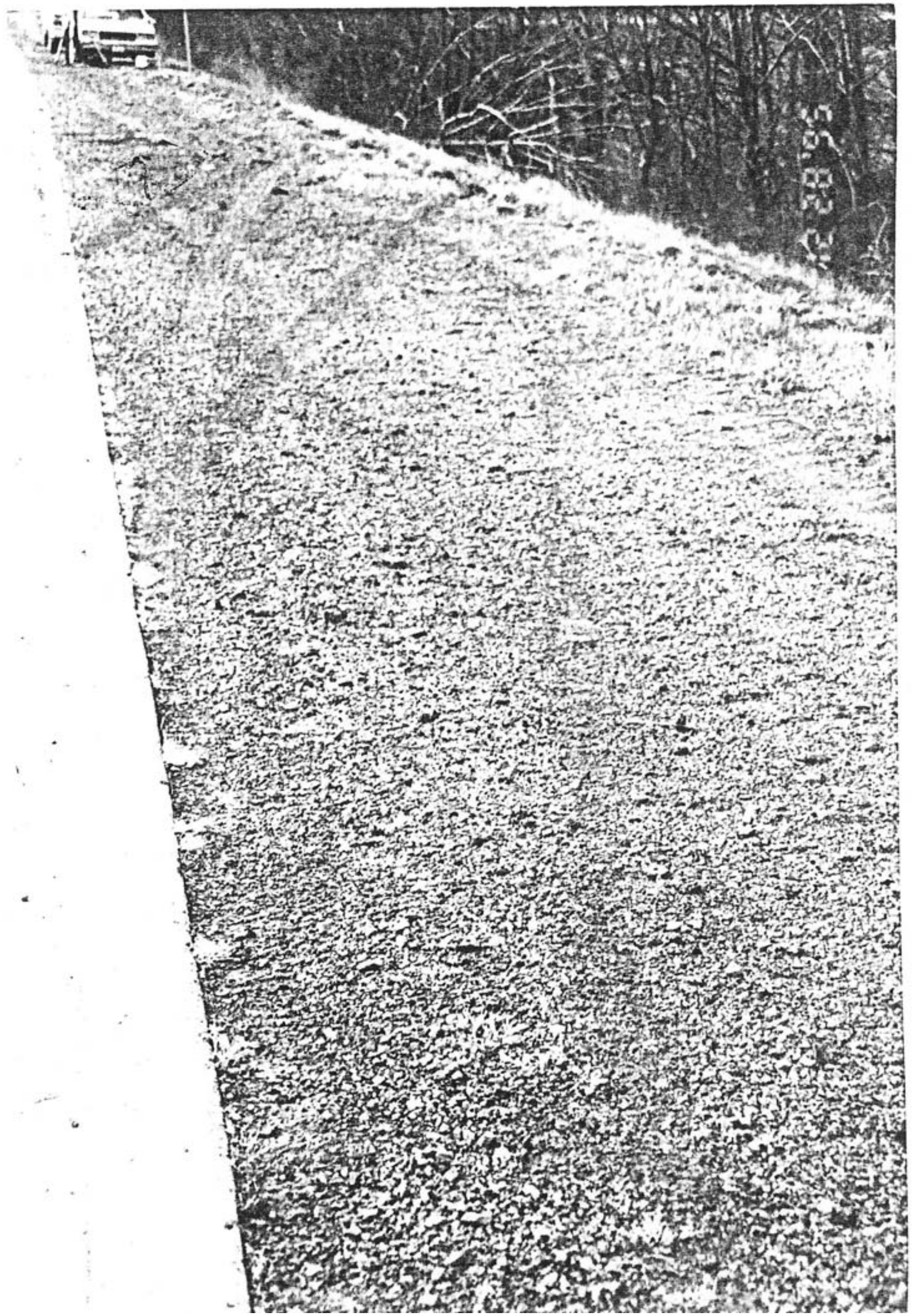
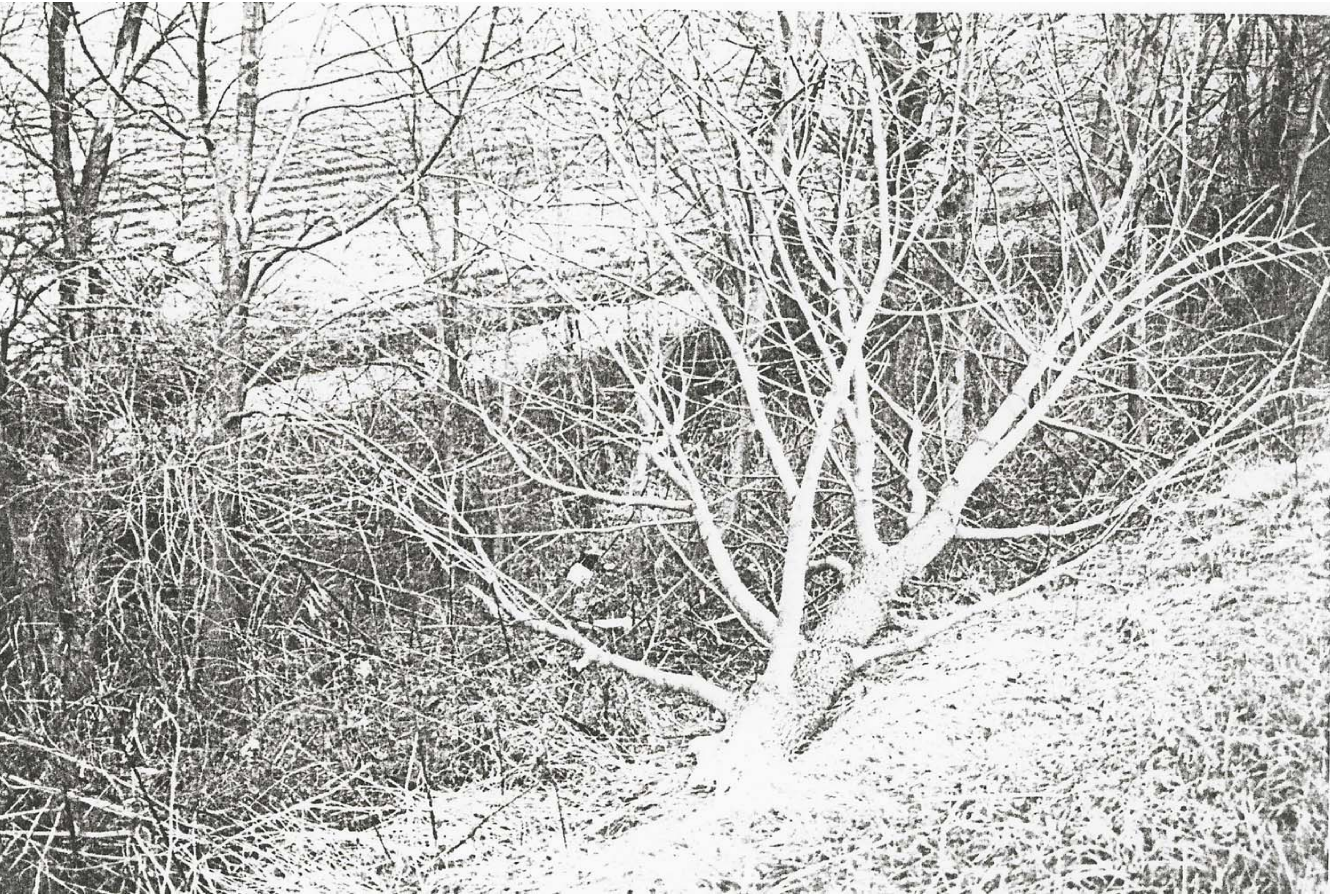
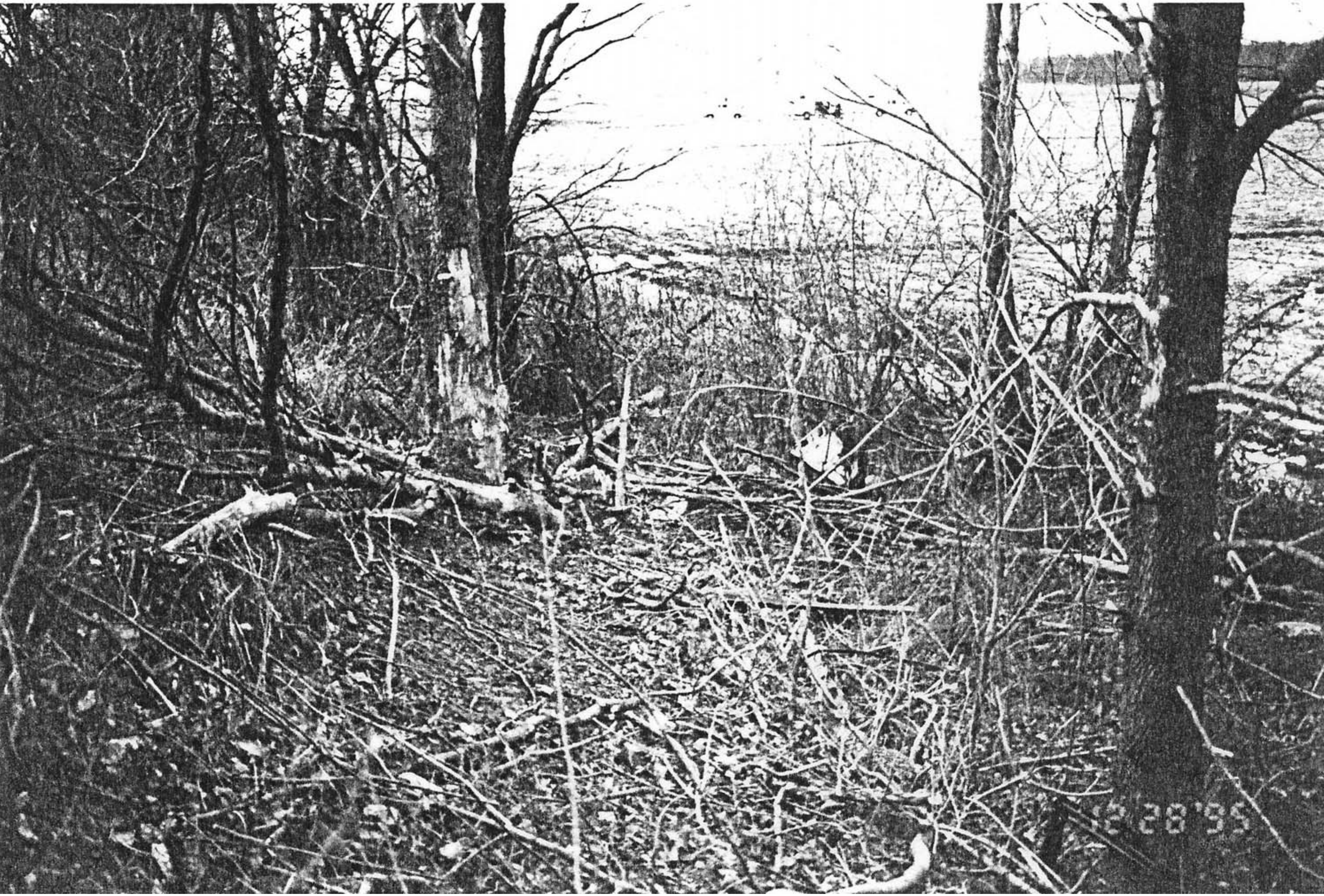
TREE
TREE
9" TREE






12 28 '95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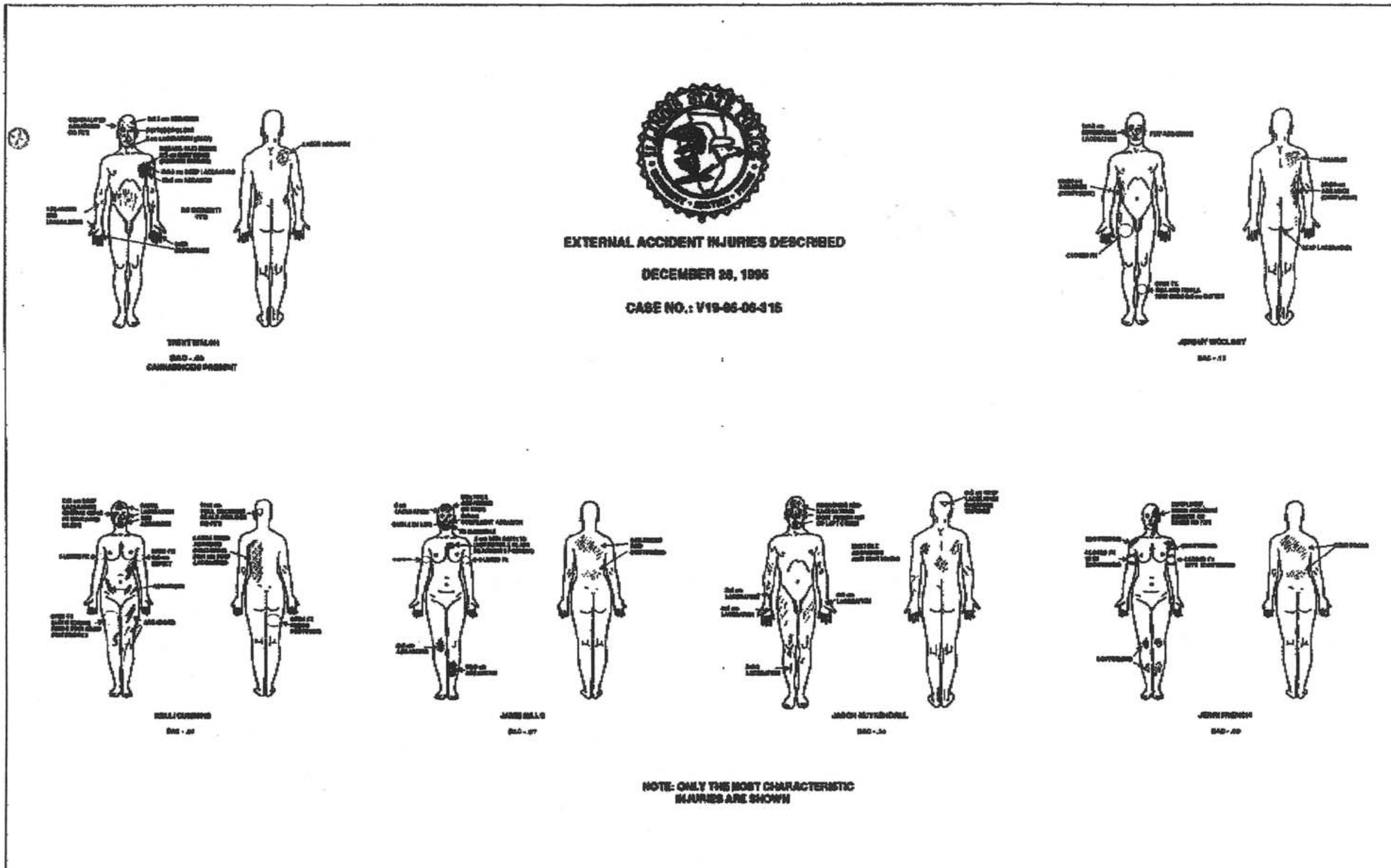
VOTE
JERRY



Drawing Prepared by: Brian Miller

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!"