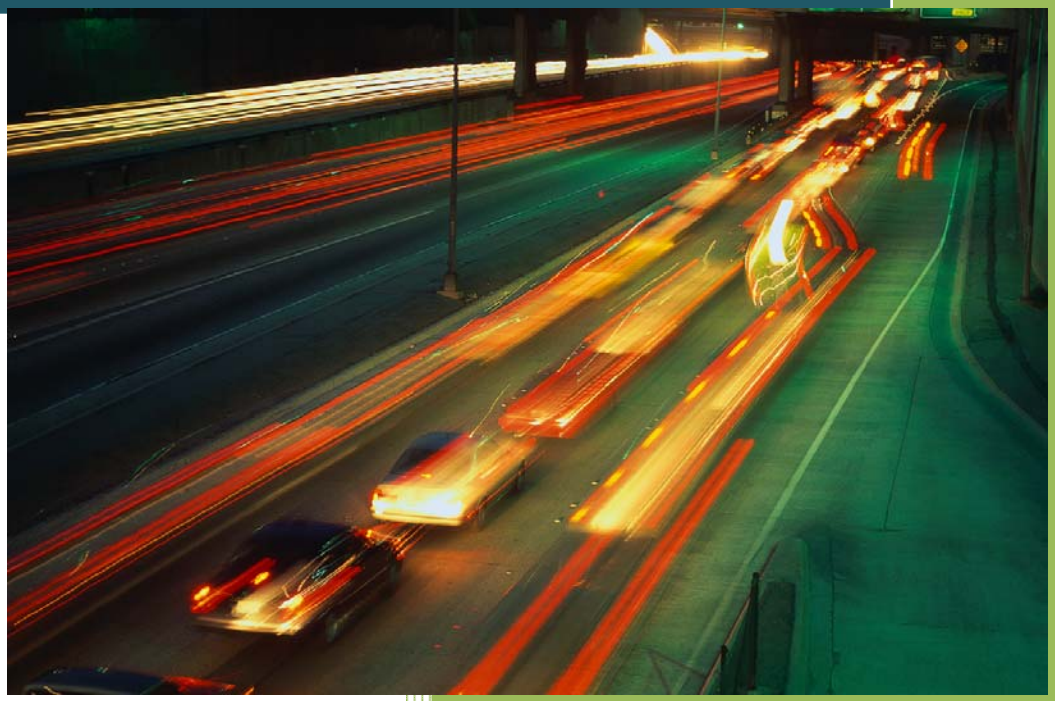
2010

Traffic Accident Reconstruction



References
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Elvin Aycock, PE, ACTAR, I-ENG-A Advisor
Investigative Engineers Association

Traffic Accident Reconstruction

Investigative Engineers Association, Inc. and Atlanta Engineering Services, Inc.

Accident Reconstruction Reference Books

- **Traffic Accident Reconstruction,** Lynn B. Fricke, Northwestern University Traffic Institute, 1990.

- **The Traffic-Accident Investigation Manual, At-Scene Investigation and Technical Follow-Up,** J Stannard Baker and Lynn B. Fricke, Northwestern University Traffic Institute, 1986.

- **Highway Collision Analysis,** James C. Collins and Joe L. Morris, Charles C. Thomas Publisher, 1967.

- **Accident Reconstruction,** James C. Collins, Charles C. Thomas Publisher, 1979.

- **Introduction to Forensic Engineering,** Randall Noon, CRC Press, 1992.

- **Engineering Analysis of Vehicular Accidents,** Randall Noon, CRC Press, 1994.

- **Motor Vehicle Accident Reconstruction and Cause Analysis,** Rudolf Limpert, The Michie Company, 1978.

- **Brake Design and Safety,** Rudolf Limpert, Society of Automotive Engineers, Inc., 1999.

- **The Automotive Handbook,** Society of Automotive Engineers, Inc. 2000.

- **Fundamentals of Vehicle Dynamics,** Thomas D. Gillespie, Society of Automotive Engineers, Inc., 1999.

- **Low Speed Automobile Accidents,** Watts, Atkinson, and Hennessy, Lawyers & Judges Publishing Co., 1996.

- **Low Speed Automobile Accidents: Investigation, Documentation and Case Preparation,** Peter H. Rast and Robert E. Stearns, Lawyers & Judges Publishing Co., 2000.

- **The Investigation's Guide to Tire Failures,** R. J. Grogan, Institute of Police Technology and Management, 1999.

- **A Format for Successful Accident Reconstruction Report Writing,** George L. Ruotolo, Institute of Police Technology and Management, 1993.

- **Insurance Fraud and Motor Vehicle Collisions,** Robert A. KuBois, Institute of Police Technology and Management, 1993.

- **Lamp Examination for Traffic Collision Investigators,** Tony L. Becker, Institute of Police Technology and Management, 1995.

- **Inspection of Motorcycles After Impact,** Neil F. Robar, Institute of Police Technology and Management, 1996.

- **Photographing Vehicles for Litigation,** Jack Murray, Institute of Police Technology and Management, 1997.

- **The Investigation of Automobile Collisions with Wooden Utility Poles and Trees,** Joseph N. Cofone, Institute of Police Technology and Management, 1996.

- **Accident Reconstruction: Automobiles, Tractor-Semitrailers, Motocycles, and Pedestrians,** SAE Reports, Society of Automotive Engineers, 1987.

- **Conservation of Linear Momentum Using Vector Sum Analysis (for the Traffic Accident Reconstructionist),** Walter A. Kennedy, Institute of Police Technology and Management, 1989.

- **Traffic Accident Reconstruction, Legal Issues in the 1990's,** Carol H. Garcia and Craig J. Trocino, Institute of Police Technology and Management.

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- **Impact Velocity from Conservation of Linear Momentum for the Traffic Accident Investigator and Reconstructionist,** Walter A. Kennedy, Institute of Police Technology and Management, 1993.

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- **Accident Investigation in the Private Sector,** Volume One, Jack Murray, Thomas Investigative Publications, 1993.

- **Accident Investigation in the Private Sector,** Volume Two, Jack Murray, Thomas Investigative Publications, 1997.

- **The Expert Witness Handbook, A Guide for Engineers,** Professional Publication, Inc., 1985.

- **Expert Guide to Successful Legal Testimony,** Jack Murray and Jay Murray, Thomas Investigative Publications, Inc. 1999.

- **Marketing & Management Maximizer for your Investigative Agency Practice,** Jack Murray, Thomas Investigative Publications, Inc., 1999.

- **Accident Reconstruction Fundamentals, A Guide for Understanding Vehicle Collisions,** Elvin Aycock, A Pro Seminar Publication, 1999.

Vehicle Data: Dimensions, Weights, & Specification Sources

- Neptune Engineering, Inc.
  Jim Neptune
  P. O. Box 1597
  Clovis, CA 93613
  559-297-1593

  Provides Motor Vehicle Data, Vehicle Crush Coefficients, Motor Vehicle Manufacturers Specifications documents, NHTSA Crash Test Reports, and Sister & Clone Listing.
  Cost is based on per each vehicle data. $40.00

- **Motor Vehicle Data**
  12106 Waywood Drive
  Twinsburg, Ohio 44087
  330-963-0130

  Standard Data Sheet: $48.00
  Mini Data Sheet (12 data points): $28.00

- **4N6XPRT Systems**
  8387 University Avenue
  La Mesa, CA 91941
  7-800-266-9778

  Computer program with more than 27,000 cars, pickups, vans, and utility vehicles.
  1945 thru 1998 model years. $495.00.

- **J2 Engineering, Inc.**
  7636 North Ingram Avenue
  Fresno, CA 93711
  557-437-3884

Excel based CD-ROM package. Crush Calculations, Vehicle Specifications, Crash Data, Inertia Values, Exemplar Vehicle diagram, Vehicle Interchange List. $499.00

- **Data Touch, Inc.**
  1845 Anaheim Avenue
  Suite 3B
  Costa Mesa, CA 92627
  1-800-777-4481

  NHTSA Recalls, Technical Service Bulletins, and Consumer Complaint Letters.
  $20.00 per each.

Tools for Traffic Accident Reconstruction

- **35mm SLR Camera**
- **and/or Digital Camera**
- **25-foot Tape Measures (6 each)**
- **100-foot Tape Measure**
- **Rolatape**
- **Plumb Bob**
- **Carpenter's Level**
- **Tire Depth Gage**
- **Compass**
- **Basic Mechanic's Tool Set**
- **Tire Pressure Gage**
- **Flashlight**
- **Inspection Mirrors**
- **Reflective Vest**
- **Computer System**

Computer Software

- **Engineering Dynamics Corporation**
  8625 S. W. Cascade Boulevard
  Suite 200
  Beaverton, Oregon 97008
  503-644-4500

  EDCRASH - is an analysis of single or two-vehicle collisions. Provides accident history such as velocities at each path position: begin braking, impact, separation, final/rest, delta-V, PDOF.

  EDSMAC - is used to predict and visualize vehicle responses before, during and after impact. Provides the simulation model of automobile collisions: Vehicle kinematics such as position, velocity, acceleration vs. time, and tire data.

  EDVDB - is a vehicle database with vehicle type, make, model, year, and body style.

  EDVTS - is a simulation of the response of a vehicle-trailer system to driver throttle, braking and steering inputs.

  EDSVS - is a simulation of the response of a motor vehicle to driver throttle, braking and steering inputs.

  $1,995.00 to $3,500.00

  HVE-3D - provides an analysis of multi-vehicle collisions in three dimension on a PC environment.
  Starts at $17,000.00

- Macinnis Engineering Associates
  1-800-565-3040 (Canada)
  604-277-3040

  PC-Crash - performs 3D collisions & 3D trajectory simulation. Provides vehicle speeds, at pre-impact, collision, and post-impact positions. It has 3D

road tool for constructing or importing 3D scenes and automatic calculation of secondary impacts including sustained contact.

2D Version - $1,995.00
3D Version - $4,895.00

PC-Rect - is a stand-alone photogrammetry program which rectifies accident scene photographs. It extracts dimensional information captured in your photographs and lets you print scaled plan views or import the rectified image directly into the PC-Crash.

$995.00

- ARSoftware
  2703 152nd Avenue
  Redmond, WA 98052
  425-861-4666

  WinCRASH and WinSMAC can work together or separately to analyze vehicle collision. WinCRASH models the collision providing vehicle speeds and positions and WinSMAC takes the initial speeds and positions and predicts the collision interaction and the post-impact motion of the vehicles.

  WinCRASH - $469.00
  WinSMAC - $769.00

  Other programs from ARSoftware:

  AITools-Equations - $129.00
  AITools-Linear Momentum - $129.00
  AITrucks-Brake Efficiency - $369.00

- Fonda Engineering Associates
  558 Susan Drive
  King of Prussia, PA 19406
  215-337-3311

  Crashex - is based on the SAE paper 870044. It is a DOS based operating

system for the analysis of a vehicle collision. The windows version should be out later this year. When sufficient data is available, it will calculation results of the collision using the conservation of momentum and the conservation of energy. When only crush data is available, it uses the conservation of energy and when only site data is available it uses the conservation of momentum. According the Mr. Fonda, it is a superior program for vehicles in rotation.

DOS Version - $295.00
Windows Version - $1,195.00 (Estimated by Mr. Fonda)

Reconstruction Schools

- **The Traffic Institute - Northwestern University**
  Evanston, Illinois
  1-800-323-4011

- **Texas Engineering Extension Service - Texas A & M University**
  Classes held at Various Locations
  1-800-423-8433

- **Institute of Police Technology & Management - University of North Florida**
  Jacksonville, Florida
  904-646-2700

- **University of California Riverside**
  Riverside, CA
  909-787-3806

- **Canadian Traffic Education Centre**
  Edmonton, Alberta
  780-468-CTEC

- **Society of Automotive Engineers**
  Troy, MI
  724-772-7148

TRAFFIC ACCIDENT RECONSTRUCTION INSPECTION TECHNIQUES

1. Be aware of the issues and familiar with the (alleged) accident scenarios before your inspections of the vehicles or scene.

2. Use your eyes & imagination.

3. Do not rush an inspection. Every minute you-spend with the physical evidence will pay off.

4. Visualize the vehicle(s) in motion during the collision.

5. Imagine what the driver(s) may have seen, and what they may have done in reaction.

6. Don't be shy with film, or with extra or redundant measurements.

7. A broken car or a group of broken cars is no different from any other type of failure or accident you have investigated. The patient application of sound engineering and investigative principals will yield the answer(s) - assuming there is enough evidence to work with.

8. The inspection techniques that we will discuss have direct applicability to a wide range of accident types, but are selected because of their usefulness in computer - assisted accident reconstruction. Do not consider this discussion of inspection techniques and procedures to be exhaustive.

VEHICLES - EXTERIOR

Use a System. Develop and use the "same" procedure on every case. Develop specific procedures for automobiles, motorcycles, bicycles, light trucks, heavy trucks, and articulated vehicles.

Use Inspection Forms. Using forms ensures that all pertinent information is recorded. Development and use of detailed inspection forms will often bring to light aspects of an accident which otherwise would have been overlooked.

Document All Vehicle Damage. Start at a specific location and proceed around the vehicle perimeter, recording all visible damage. Note any paint, plastic or tire rubber transfer on vehicle surface. Note direct and induced damage.

Photographic Documentation.

General views of vehicle exterior. Using a 1:1 lens (e.g., 55mm - 60mm macro), take full-vehicle shots from 12:00, 1:30, 3:00, 4:30, 6:00, 7:30, 9:00, 10:30. Photographer's eye should be approximately in the plane of the hood / trunk for these views.

Undercarriage views. If a lift, or floor jacks are available, take shots to document the condition of the vehicle chassis.

INSPECTION TECHNIQUES (CON'T)

Photographic Documentation (con't)

Specific close-up views.

- License plate
- Door frame nameplate(s)
- Tire tread - each tire

Detailed views documenting all vehicle damage. Take sufficient shots that each detail view can be easily located on the vehicle exterior. Use scales as appropriate. Start at one location (12:00) and proceed around vehicle. Document all undercarriage damage as well.

Crush Damage Profiling - Grid Method

This method uses a set of tape measures as a coordinate system to map the damage to the vehicle. This method can be used almost anywhere, as long as the ground surface is "reasonably" flat and level.

1. Establish the reference lines.

Lay two tape measures approximately parallel to the longitudinal axis of the vehicle. Align the zero marks on the tape measures with each other. Lay two more tape measures perpendicular to the first set at either end of the vehicle. Position each tape measure such that each parallel pair intersects the other parallel pair at the same marks on the tape. Square the four-tape system by diagonal measurements or using a T-square.

2. Reference Lines to Known Points.

Determine the location of the reference lines with reference to "known" vehicle reference points (corners of bumpers, extension of axle center lines, base of A-pillar, edge of door, etc.). Suspend a plumb bob from the vehicle reference point until it almost touches the ground. Measure the perpendicular distance from the nearest two reference lines to the suspended plumb bob tip.

3. Profile the crush damage.

Using the same technique described in (2), measure the perpendicular distance from the reference lines to the crushed vehicle profile. Make sure that two orthogonal measurements are made for each point on the profile. Profile the entire damaged perimeter of the vehicle. Record enough points on the undamaged perimeter to allow referencing of the undeformed portion of the vehicle to the reference lines (2-above), and to facilitate the accurate overlay of an undeformed vehicle profile for comparison and for crush depth determination.

Crush Damage Profiling - Notes

In accidents where there is significant override of one vehicle on another, or in the case of narrow object impacts, there is often more than one "crush depth" at a given point on the perimeter. In other words, the crush is not uniform with elevation. In these cases, it is important to profile the nominal deformed profile (along the rocker panel or bumper), and the maximum crush depth profile. This can be accomplished for either profiling technique described using a system of tripods, levels, plumb bobs, and tape measures.

Filament Inspection.

A complete discussion of vehicle light filament inspection and analysis is beyond the scope of this seminar. Suffice to say - there are inspection techniques which can in many cases determine whether a light was burning at the time of impact. The techniques can be applied to both headlights and brake lights.

Two excellent resources are (1) The Traffic-Accident Investigation Manual by J. Stannard Barker and Lynn B. Ficke, Northwestern University Traffic Institute and (2) Lamp Examination for Traffic Collision Investigators by Tony L. Becker, Institute of Police Technology & Management, University of North Florida.

Newton’s Laws of Motion

In 1687 Isaac Newton first presented the three basic laws governing the motion of a particle. These laws gave insight into the effects of forces acting on bodies in motion. The three laws of motion are as follows:

(1) Newton's first law of motion, the law of inertia,

(2) Newton's second law of motion, the law of constant acceleration,

(3) Newton's third law of motion, the law of momentum.

Newton's First Law of Motion, the Law of Inertia

A particle originally at rest, or moving in a straight line with a constant velocity, will remain in this state provided the particle is not subjected to an unbalanced force.
The law of inertia describes the fundamental property of matter or a particle. Every object (body) remains in a state of rest or of uniform motion in a straight line unless acted upon by outside forces. This law states that motion is as natural a condition as rest. Just as an object at rest is in equilibrium, so is an object moving in a straight line at a constant speed in equilibrium.

For example, a car that is going along a level road at constant speed is balanced by the supporting forces of the pavement. The forward pull of the engine counterbalances the retarding forces of friction and air resistance. The resultant force is zero; thus, the car is in equilibrium.

Newton's Second Law of Motion, The Law of Constant Acceleration:

A particle acted upon by an unbalanced force F experiences an acceleration that has the same direction as the force and a magnitude that is directly proportional to the force.
The law of constant acceleration describes what happens to a body when an external force is applied to a body. That body acted upon by a constant force will move with constant acceleration in the direction of the force; the amount of acceleration will be directly proportional to the acting force and inversely proportional to the mass of the body. This law can be expressed by:
$F = ma$ or $a = F/m$

Remember what happens when an object falls. It is accelerated by the force of gravity. In this example, the force is any applied force that is equal to the weight of the object, and the acceleration is that of gravity. Any weight unit can be used for F and W, and any acceleration unit (such as ft/sec/sec) can be used for a and g. For example, a car weighing 3200 lbs. accelerates at a rate of 5 ft/sec/sec. Ignoring friction, what is the effective forward force exerted by the engine? W equals 3200 lb. (the weight of the car); a equals 5 ft/sec/sec (the acceleration of the car) and g equals 32

ft/sec/sec (the acceleration of gravity).

F=W a/g

500 lb. force = 3200 x 5/32

This law explains why pilots and astronauts experience G forces. The weight of a person at rest is the force exerted by the acceleration of gravity, 1 G, or 32 ft/sec/sec. If someone is being accelerated at a rate greater than 1 G, he will feel heavier. For example, if he is accelerated at 65 ft/sec/sec, he will feel as though his weight had doubled. An easy way to say this is that he is feeling a 2 G (2 x 32.2 = 64.4) force. If accelerated at 96 ft/sec/sec, he will feel a 3-G force, and so on.

Newton's Third Law of Motion, the Law of Momentum:

The mutual forces of action and reaction between two particles are equal, opposite, and collinear.

$$P = \frac{w}{g}\bar{v}$$

Often in a momentum analysis the weights of the vehicles are used in place of the vehicle's mass. The weight is not divided by the acceleration of gravity when the calculations are made.

P = wv

Because the acceleration of gravity is a constant, it can be seen that the momentum is directional proportional to an object's weight and velocity. That is, if you double the weight of an object and keep the

velocity the same, the momentum is twice as much. Or if you double the velocity with the weight held constant, the momentum is doubled.

Therefore, if you had a 3,000 lb car traveling eastbound at 40 ft/sec, it would have the same momentum as a 6,000 lb. vehicle traveling eastbound at 20 ft/sec.

P=wv
P = 3000 lbs. (40 ft /sec) P =120,000 ft - lbs. /sec
P=wv
P = 6000 lbs. (20 ft /sec) P =120,000 ft - lbs. /sec

The law of conservation of momentum can be stated as: In any group of objects that act upon each other, the total momentum before the action equals the total momentum after the action. In traffic accident reconstruction, the action is the collision between two vehicles and the objects are the two vehicles. Using Newton's Second and Third Laws of Motion, an equation for conservation of momentum can be developed as follows:

$$\vec{v}_1 m_1 + \vec{v}_2 m_2 = \vec{v}_1' m_1 + \vec{v}_2' m_2$$

The subscripts refer to vehicles one and two. The arrows above the velocity indicate that each term is a vector quantity. The symbol ' above the velocity is read "velocity prime" and refers to the after-collision velocity. The left side of the equation is the momentum before the collision and the right side is the momentum after the collision.

Because the equation has mass in each term and the mass is equal to the weight divided by the acceleration of gravity (m = w/g), w/g can replace the value for m in each term of the equation. Drop the g from each term and the equation becomes:

$$\vec{v}_1 w_1 + \vec{v}_2 w_2 = \vec{v}_1^{\,'} w_1 + \vec{v}_2^{\,'} w_2$$

This is the equation used in making momentum calculations. It is a vector equation and is not a simple algebraic equation. The arrows over the terms are indicative of a vector equation. This equation states that the momentum before the collision is equal to the momentum after the collision.

TRAFFIC ACCIDENT RECONSTRUCTION FORMULAS

TO FIND	WHEN GIVEN	EQUATION TO USE
ACCELERATION a (ft/sec/sec)	$t \quad v_i \quad v_e$ $t \quad v_i \quad d$ $v_i \quad v_e \quad d$	1. $a = \frac{v_e - v_i}{t}$ 2. $a = \frac{2d - 2v_i t}{t^2}$ 3. $a = \frac{v_e^2 - v_i^2}{2d}$
INITIAL VELOCITY v_i (ft/sec)	$t \quad a \quad v_e$ $t \quad a \quad d$ $a \quad v_e \quad d$	4. $v_i = v_e - at$ 5. $v_i = \frac{d}{t} - \frac{at}{2}$ 6. $v_i = \sqrt{v_e^2 - 2ad}$
END VELOCITY v_e (ft/sec)	$t \quad a \quad v_i$ $a \quad v_i \quad d$	7. $v_e = v_i + at$ 8. $v_e = \sqrt{v_i^2 + 2ad}$
DISTANCE d (ft)	$t \quad a \quad v_i$ $a \quad v_i \quad v_e$ $t \quad v_i \quad v_e$	9. $d = v_i t + \frac{1}{2} a t^2$ 10. $d = \frac{v_e^2 - v_i^2}{2a}$ 11. $d = \frac{t(v_i + v_e)}{2}$
TIME t (sec)	$a \quad v_i \quad v_e$	12. $t = \frac{v_e - v_i}{a}$

Traffic Accident Reconstruction Formulas

FALL VELOCITY

$$v = d\sqrt{\frac{g}{2(dG - h)}}$$

SIDESLIP VELOCITY

$$v = \sqrt{\frac{g\,r\,(\mu + G)}{(1 - \mu G)}}$$

VAULT/FLIP VELOCITY

$$v = d\sqrt{\frac{g}{(d - h)}}$$

$$W_s = E_s = f\,w\,d$$

SLIDING ENERGY

$$KE = \tfrac{1}{2} m v^2 \quad or \quad KE = \frac{w v^2}{2g}$$

KINETIC ENERGY

$$v = \sqrt{\frac{2gE}{w}}$$

VELOCITY

MOMENTUM

$$v_1 w_1 + v_2 w_2 = v_1' w_1 + v_2' w_2$$

Yaw

$$V = \sqrt{gr\mu} = \sqrt{grf}$$

or

$$V = \sqrt{\frac{gr(\mu + G)}{1 - \mu G}}$$

r = radius
G - grade

Momentum

$$v_1 = \frac{w_1 v_1' \cos\theta_1' + w_2 v_2' \cos\theta_2' - w_2 v_2 \cos\theta_2}{w_1 \cos\theta_1}$$

$$v_2 = \frac{w_1 v_1' \sin\theta_1' + w_2 v_2' \sin\theta_2'}{w_2 \sin\theta_2}$$

Case Studies

Vehicle 2: 1992 Nissan Stanza traveling West on Highway 120 collides with Vehicle 1, a 1997 Toyota Camry traveling East and making a left turn onto a local street to the Post Office. Speed limit on Highway 120 is 45 MPH

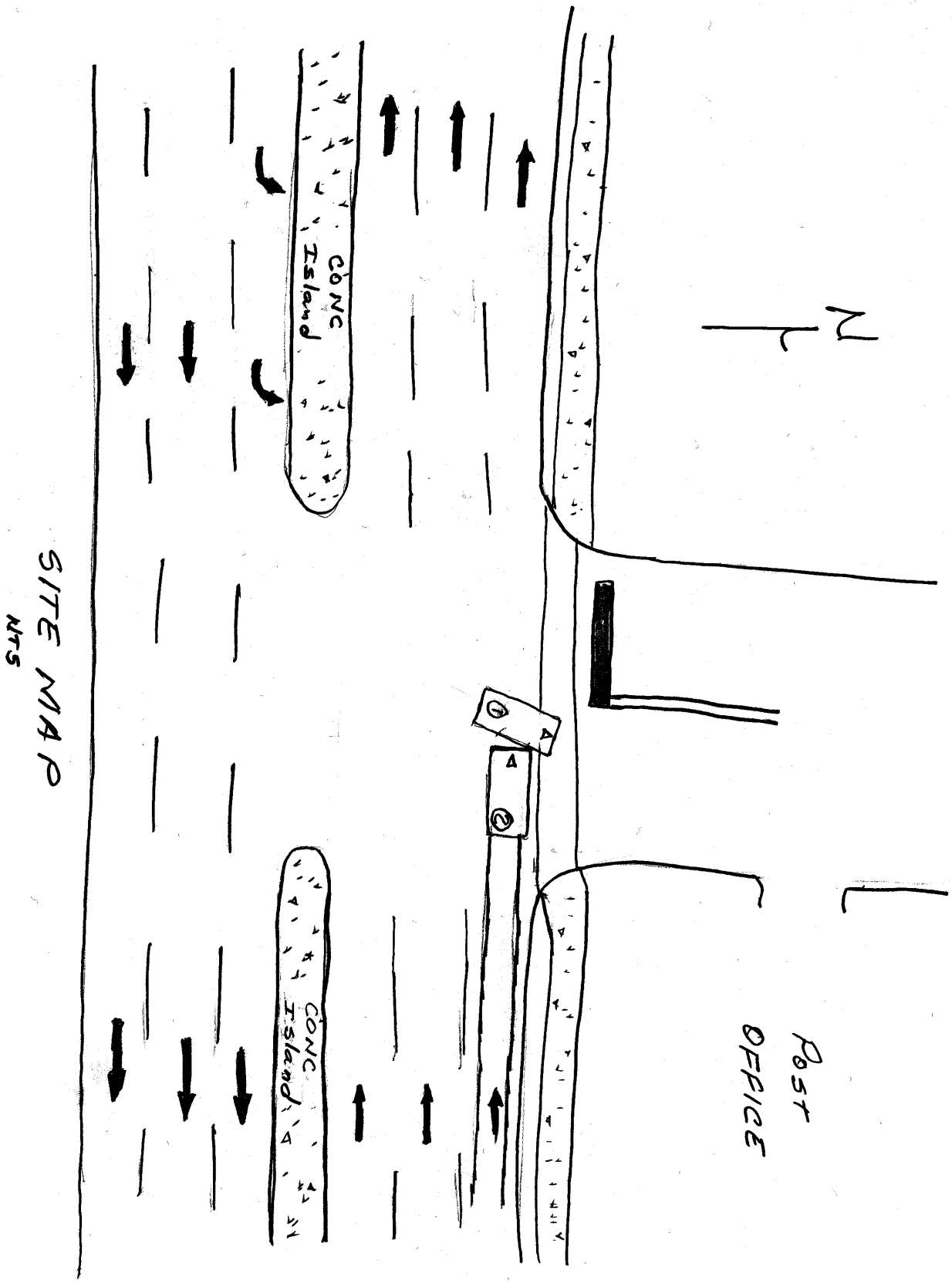
Approximately 9:20 A.M.
Weather was sunny
Location: Highway 120 and Local Street to Post Office
Asphalt Street, paved approximately 4 year ago

Damage
Vehicle 1: Right rear passenger' door panel crushed approximately 5 inches.
Vehicle 2: Damage to front bumper, hood, and turn signal. The bumper had minimum damage.

Injuries: No physical injuries

Site Evidence:
Vehicle 2: 60 feet of skid marks. Appeared that all wheel were locked.
Vehicle 2's skid marks made an abrupt turn to the right at end of skid.
Vehicle 1: Left no skid marks.
Broken glass found at the point of impact.

From statements to the Police, the driver of Vehicle 1 said that the driver of Vehicle 2 was speeding. What was the speed of Vehicle 2 at the time of impact?



SITE MAP
NTS

Vehicle 1

Vehicle 2

Skid Marks

$$V_i = \sqrt{V_e^2 - 2ad}$$

where

V_i = initial velocity

V_e = ending velocity V_e = 5mph (estimated from crush)

a = acceleration = 7.35 fps

a = drag factor × g

drag factor on asphalt = 0.75

$g = -32.2$

d = distance of skid = 60'

$$V_i \sqrt{(7.35)^2 - 2(-32.2)(.75)(60')}$$

$$V_i = \sqrt{54 + 2898}$$

$$V_i = 54.3 \text{ fps} = 37 \text{ mph}$$

∴ The estimated speed of the Nissan Stanza was 33 mph to 41 mph

Recalculate the speed assuming that the Nissan Stanza came to a stop just before hitting the Toyota Camry.

Discovered that the skid was really 66 feet instead of 60 feet.
Recalculate the speed of the Nissan Stanza using the 66 feet.

Use 54 feet.

A few days later, we were able to take the Nissan Stanza to the scene of the accident to run skid test to determine the drag factor. Three trials were ran with following results:

1. 0.69
2. 0.68 Average drag factor = 0.68
3. 0.67

Recalculate the speed using the drag factor of 0.68 and skid distance of 60 feet.

Recalculate using a drag factor of 0.80.

Simple Falls

The definition of a fall is when the vehicle is no longer supported by the roadway surface underneath it. All bodies in free fall near the earth's surface have the same downward acceleration of 32.2 ft/sec/sec. A body in free fall has the same downward acceleration whether it starts from rest or has an initial velocity.

The presence of air affects the motion of falling bodies partly through buoyancy and partly through air resistance. In vehicle reconstruction buoyancy and air resistance are negligible and can be neglected in the calculations.

The formulas for straight-line motion can be used to analyze the horizontal and vertical aspects of a vehicle's flight. The horizontal velocity component remains constant during flight and the effect of gravity on the vertical velocity component is to provide a downward acceleration.

The formula for calculating the velocity at the beginning of a simple fall is:

$$v = d\sqrt{\frac{g}{2(dG - h)}}$$

Where :

***v* - velocity (fps)**

***d* - horizontal distance traveled in the air (ft)**

h **- vertical distance, the difference in the elevation from take off to landing, an elevation higher at touchdown than at takeoff is (+) (feet), and elevation lower at touchdown than at takeoff is (-) (feet),**

G - grade of the traveled surface at take off

Upgrade is positive and downgrade is negative, (ft/ft)

g - acceleration of gravity, 32.2 ft/sec².

The horizontal distance is the distance the center of mass traveled from an unsupported location to the point of first contact with ground measured horizontally. The final position of the vehicle may not be the point of first contact. Caution should be taken to ascertain the accurate location of first contact and not be misled by the final rest location of the vehicle.

The vertical distance is the distance the center of mass traveled vertically from the unsupported location to the point of first contact. Again care should be exercised in determining the point of first contact and not assume that the final position of the vehicle is the point of landing.

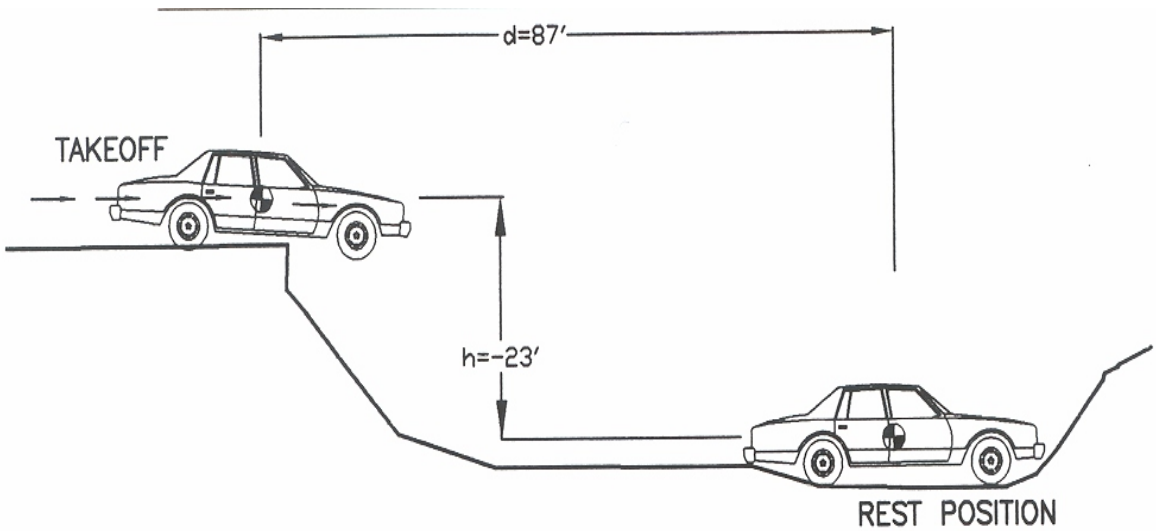


Figure 2-4. The horizontal distance is 87 feet and the vertical distance is 23 feet.

$$v = d\sqrt{\frac{g}{2(dG - h)}} \qquad \text{Formula 2-1}$$

Where: d = 87 feet

h = -23 feet, the vehicle landed below the takeoff location

G = 0 ft/ft, the roadway was level at the takeoff location

g = 32.2 ft/sec²

$$v = 87\sqrt{\frac{32.2}{2[87(0) - (-23)]}}$$

$$v = 87\sqrt{\frac{32.2}{2[0 + 23]}}$$

$$v = 87\sqrt{\frac{32.2}{46}}$$

$$v = 87\sqrt{.7}$$

v = 87(.83667)

v = 72.8fps **To change fps to mph multiply by 0.68**

v = 49.5 mph

Which would increase the speed the most?

- **Increase the horizontal distance (d) 10 feet**

  or

- **Increase the vertical distance (h) 10 feet.**

Increase Horizontal Distance	**Increase Vertical Distance**
d = 97 feet	**d = 87 feet**
h = 23 feet	**h = 33 feet**
g = 32.2 ft / sec²	**g = 32.2 ft / sec²**
G = 0 %	**G = 0 %**

Conservation of Momentum

Law of Conservation of Momentum states that in any group of objects that act upon each other, the total momentum before the action equals the total momentum after the action.

In traffic accident reconstruction:

- **Action is the collision**
- **Objects are the vehicles**

Using Newton's 2nd and 3rd Laws of Motion, the equation for the conservation of momentum is derived:

$$m_1\vec{v}_1 + m_2\vec{v}_2 = m_1\vec{v}_1' + m_2\vec{v}_2'$$

this equation replaces the mass with weight

$$w_1\vec{v}_1 + w_2\vec{v}_2 = w_1\vec{v}_1' + w_2\vec{v}_2'$$

Types of Collisions:

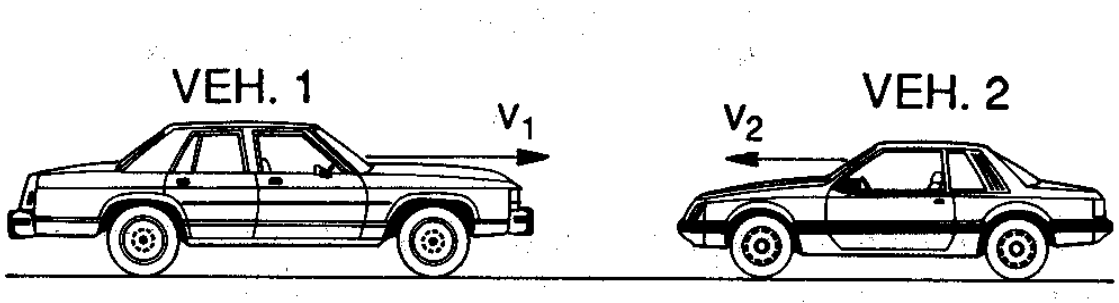
1. Collinear Collisions:

   Examples are head-on collisions, rear-ended collisions, and collisions with the angle of impact of less than 10 degrees.

2. Angled Collisions:

Examples are T-bone (impact angle is 90°) and collisions with angle of impacts greater than 10°.

Solving a Collinear Collision



Vehicle 1	Vehicle 2
w_1 = 3850 lbs.	w_2 = 2480 lbs.
v_1 = 20 mph eastbound (29.1fps)	v_2 = 20 mph westbound (29.1 fps)

Assume east is positive

After the collision the vehicles stay together and move eastbound

Calculation the post-collision velocity of the vehicles.

$$v_1' = v_2'$$

The above momentum equation can be rewritten as:

$$w_1\vec{v}_1 + w_2\vec{v}_2 = \vec{v}'(w_1 + w_2)$$

3850 (29.1) + 2480 (-29.1) = v' (3850 + 2480)

112,035 - 72,168 = v' (6690)

$v' = 5.96$ fps

$v' = 4$ mph Positive 4 mph which indicates the vehicles moved in an easterly direction.

Four Methods to solve Angled Collisions

- Graphical Method
- Mathematical Method
- General Momentum Equation
- Computer Software

Using the General Momentum Equations

The task of the reconstructionist is to determine how the vehicles came together from the evidence. These are:

- **The point of impact**
- **Pre-Collision angle of each vehicle**
- **Post-Collision angle of each vehicle**
- **Weights of each vehicle**
- **Post-Collision velocity of each vehicle (Usually from the vehicle skid marks at the scene)**

Equation for the Velocity of Vehicle 1:

$$v_1 = \frac{v_1' w_1 \cos \theta_1' + v_2' w_2 \cos \theta_2' - v_2 w_2 \cos \theta_2}{w_1 \cos \theta_1}$$

Equation for the Velocity of Vehicle 2:

$$v_2 = \frac{v_1' w_1 \sin \theta_1' + v_2' w_2 \sin \theta_2'}{w_2 \sin \theta_2}$$

To use the General Momentum Equations a standard definition of the angles must be used. They are as follows:

- If none of the before- or after-collision momentum vectors are on the x-axis, rotate the vectors until the before-collision vector for Vehicle 1 is on the x-axis. Make sure that all vectors retain the same relationship to each other.

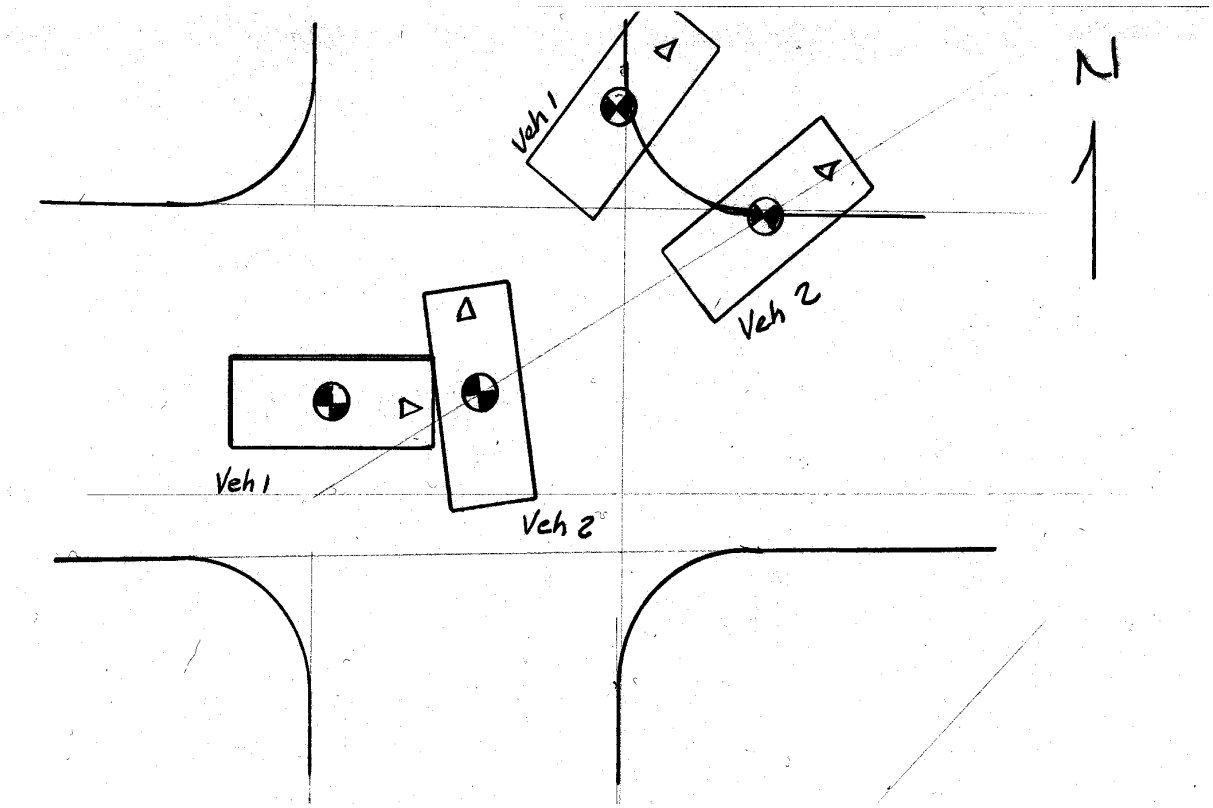
- To measure the angles, move to the origin any vector whose tail is not at the origin.

- Measure the angles counterclockwise from the positive x-axis.

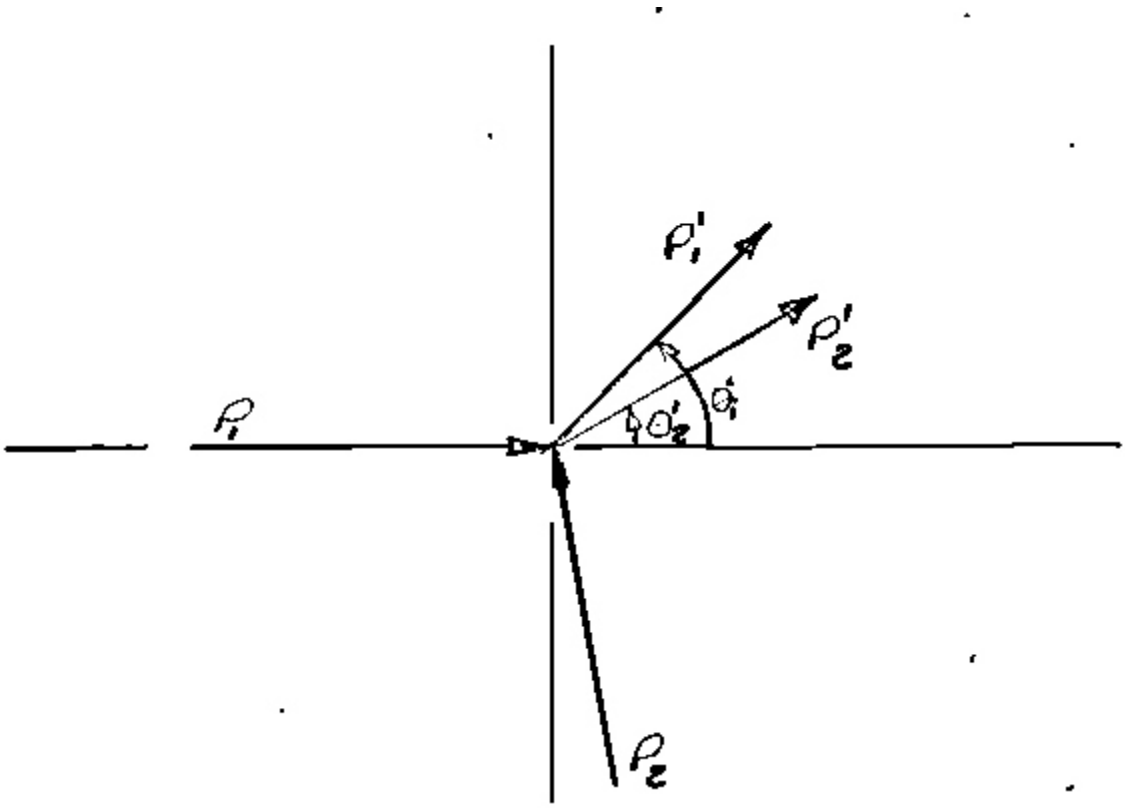
- θ_1 and θ_2 are the before-collision angles for vehicles 1 and 2.

- θ_1' and θ_2' are the after-collision angles for vehicles 1 and 2.

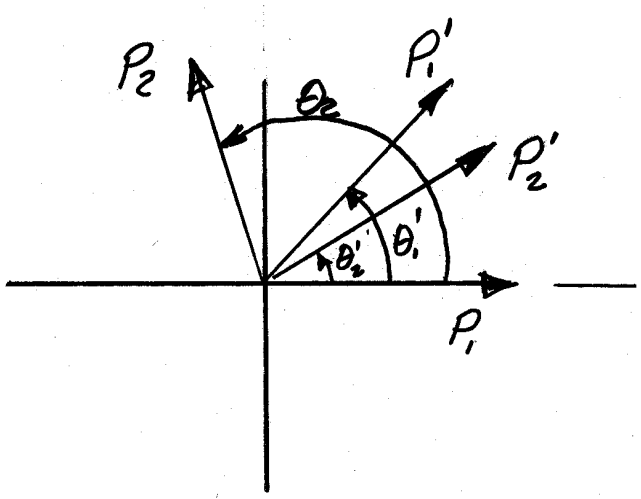
Vehicle 1 was traveling eastbound when vehicle 2 attempting to make a left turn when the vehicles collide. A site scene map was prepared locating the point of impact and the resting position of the vehicles. Pre-impact angles and post-impact angles of the vehicles were determined. The post-collision speeds were determined from the skid marks found at the scene. The weights of the vehicles were determined from data obtained from Neptune Engineering. Calculate the pre-collision impact speeds of both vehicles using the general momentum equations.



The next step is to determine the angles of the vehicles before and after impact.



Move the tails of the vectors to the origin to determine angles. Measure counterclockwise from the positive x-axis.



$\theta_1 = 0°$

$\theta_2 = 100°$

$\theta_1' = 45°$

$\theta_2' = 30°$

Vehicle 1

w_1 = **3100 lbs**

v_1' = **38 fps**

θ_1 = **0°**

θ_1' = **45°**

Vehicle 2

w_2 = **3770 lbs.**

v_2' = **38 fps**

θ_2 = **100°**

θ_2' = **30°**

Solving for the Velocity of Vehicle 2 first:

$$v_2 = \frac{v_1' w_1 \sin\theta_1' + v_2' w_2 \sin\theta_2'}{w_2 \sin\theta_2}$$

$$V_2 = \frac{38\,(3100)\ \text{SIN}\ 45° + 38(3770)\ \text{SIN}\ 30°}{3770\ \text{SIN}\ 100°}$$

$$V_2 = \frac{83297 + 71630}{3713}$$

$$V_2 = 41.7\ \text{fps}$$

$$V_2 = 28\ \text{mph}$$

The pre-collision velocity of vehicle 2 is now known, solve for the velocity of vehicle 1.

$$v_1 = \frac{v_1' w_1 \cos\theta_1' + v_2' w_2 \cos\theta_2' - v_2 w_2 \cos\theta_2}{w_1 \cos\theta_1}$$

$$V_1 = \frac{38(3100)\cos 45° + 38(3770)\cos 30° - 41.7(3770)\cos 100}{3100 \cos 0°}$$

$$V_1 = \frac{83297 + 124067 - (-27299)}{3100(1)}$$

$$V_1 = \frac{234663}{3100}$$

$$V_1 = 75.7 \text{ fps}$$

$$V_1 = 51 \text{ mph}$$

APPENDIX 1

Delta-V from Linear Momentum and Crush Damage

Accidents are assessed as to the severity of a collision in terms of the injuries suffered by the occupants of the vehicles. Injuries in a particular accident depend on a number of factors. The crashworthiness of a vehicle is the ability of a vehicle to be subjected to a collision and sustain less damage than a vehicle that isn't as crashworthy. The vehicle speeds and the change in vehicle speeds affect the severity of an accident. Also, factors are the usage of restraint such as seat belts and the occupant characteristics such as health, age, etc.

Most reconstructionist routinely determine speeds from skid marks. The most critical factor is to determine the correct coefficient of friction. Plug the coefficient of friction and the skid distance into the skid formula and out pops the velocity of the vehicle at the beginning of the skid.

Determination of speeds from crush damage is similar in that the stiffness coefficients can be compared to coefficient of friction. The stiffness coefficients are used with the distance or in this case, the length of deformation to determine speed. Just as accurate skidmark lengths are needed to obtain accurate speeds, so are accurate deformation lengths needed to determine accurate speeds from crush damage. Skidmarks have only length while deformation has both length and width.

Delta-V from Linear Momentum

Two Definitions

1. **The Law of Conservation of Momentum:** The total momentum of a system before the collision is equal to the total momentum of the system after the collision.

   $\mathbf{P_1 + P_2 = P_1' + P_2'}$ **where P = Momentum before impact and P' = Momentum after impact**

2. **Linear Momentum:** A vector quantity which is the product of a body's mass and its velocity. The direction is that of the velocity.

3. **Vector Momentum Analysis:** A method of solving linear momentum problems for the post-impact data resulting from known, or given, impact information.

Collision Example:

A red eastbound vehicle weighting 4,000 pounds was stopped in the lane of traffic when it was struck in the rear by a second eastbound vehicle. The second vehicle was blue and

weighted 3,000 pounds. The driver of the blue vehicle applied the vehicle brakes at the moment of impact. After impact, both vehicles slid as a unit for 66 feet to rest on a roadway with a drag factor of 0.65. Each vehicle left four skid marks from impact to rest. The pre-collision speed of the red vehicle was 0. What was the pre-collision speed of the blue vehicle?

Figure 1.

Blue Car⇒Red Car
3,000# 4,000#
V_{Blue} = ?
f ' = 0.65
g = 32.2 fps/s

Blue Car⇔Red Car
3,000# 4,000#
V_{Blue} = fps = V_{Red} = fps

The post-impact velocity of the vehicles as a unit was:

$$v_1' = \sqrt{v_e^2 - 2ad}$$

$$v_1' = \sqrt{0^2 - 2 * -32.2 * 0.65 * 66}$$

$$v_1' = \sqrt{2762.76}$$

$$v_1' = 52.56\,fps = 35.85\,mph$$

Where a = gf = 32.2fps/s * 0.65 = 20.93 fps/s

The post impact velocity of the red vehicle and the blue vehicle was 52.56 fps.

Delta-V from Crush Damage

The CRASH3 software program is used to calculate delta-v. CRASH3 is an acronym for "Calspan Reconstruction of Accident Speeds on the Highway - version 3." CRASH3 uses two separate and independent methods to estimate the speed change in a vehicle collision. First, trajectory analysis which involves a work-energy relationship for the spinout and conservation of linear momentum for the collision. Second, damage analysis which uses detailed measurements of the structural deformation of each vehicle to calculate the estimate of the energy required to deform each vehicle.

Stiffness coefficients are determined by crashing an exemplar vehicle into a fixed barrier.

Deformation of the vehicle is divided into crush zones. In some cases individual crush zones have to be adjusted to compensate for higher or lower stiffness coefficients. The actual vehicle specifications of the crashed vehicles are used in the calculations.

The CRASH3 Technical Manual lists five basic assumptions used in the software.

4. The driver's control of the vehicle ceases at impact.

5. At some time during the interaction both vehicles achieve a common velocity at the collision interface.

6. The program is two dimensional: therefore vertical effects such as rollover, steep grades, and curb mountings cannot be modeled directly.

7. Vehicle properties are average properties for a vehicle class. The properties used may or may not adequately represent a particular vehicle.

8. Crush stiffnesses are assumed to be uniform over the side, front, or back of the vehicle.

CRASH3 was developed as a research tool for identifying trends in crash severity parameters such as the change in velocity in highway accidents. Delta-V, change in velocity, is very useful data in identifying crash severity in an impact. CRASH3 is a consistent, uniform method of judging accident severity in terms of the change in velocity.

The definition of Delta-V is the change in velocity. Does the change in direction constitute a Delta-V? Yes, because Delta-V is a vector quantity with direction. In vehicle analysis of Delta-V, the change in the velocity vector is at the center of mass of the vehicle. The change in velocity can result in the change in speed, or a change in direction, or both.

APPENDIX 2

Project #: _____ Project Name:_____

Page____ of ____

Vehicle Description

Make_____ Year_____ Model_____

License Plate No._____

State of Registration_____ Date of Registration_____

VIN_____

GVWR_____ Curb Wt._____

Odometer Mileage_____ 2WD or 4WD_____

Overall Vehicle Measurements

Overall length (in.)_____ Wheelbase (in.)_____

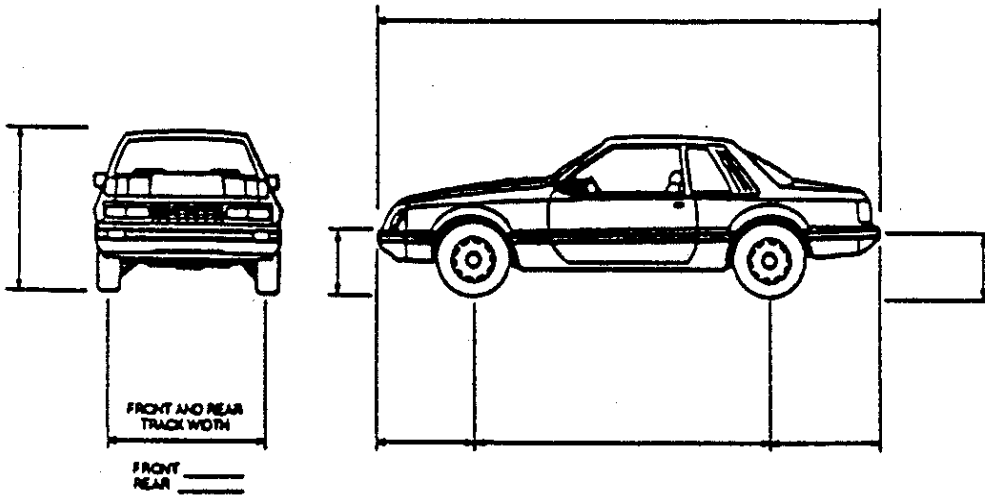
Front overhang (in.)_____ Rear overhang (in.)_____

Overall width (in.)_____ Track width (in.)_____

Bumper height: front (in.)_____ rear (in.)_____

Vehicle overall height (roof - in.)_____

Height of seat cushion from ground (in.)_____



Project #_____ Project Name:_____

Page_____ of _____

Description of Vehicle Damage

Location and description of all damage to vehicle exterior:

_____

_____

_____

_____

_____

Vehicle Undercarriage

Damage to muffler and tailpipe_____

_____

Evidence of frame damage_____

_____

Scrapes on undercarriage components _____

_____

Dirt and debris picked up by undercarriage components _____

_____

Damage to drive shaft _____

_____

Damage to differential(s) _____

_____

Transmission Damage _____

_____

Rear axle and suspension damage _____

_____

Front axle and suspension damage _____

_____

Project #:_____ Project Name:_____

Page_____ of _____

Tires and Wheels

Right Rear:

Make _____ Name _____

Size _____ Pressure (recommended/actual) _____

Ply (bias, radial) _____ Load capacity _____

Tread type (summer, all-season, mud/snow, recap, chains) _____

Tread depth (outside/center/inside) _____

General condition (cuts, scrapes, wear) _____

_____

Rim damage? _____

Locate tire and rim damage relative to each other and tire serial number location

_____

_____

Condition of wheel lugs _____

Wheel rotation restricted? Explain _____

_____

Right Front:

Make _____ Name _____

Size _____ Pressure (recommended/actual) _____

Ply (bias, radial) _____ Load capacity _____

Tread type (summer, all-season, mud/snow, recap, chains) _____

Tread depth (outside/center/inside) _____

General condition (cuts, scrapes, wear) _____

_____

Rim damage? _____

Locate tire and rim damage relative to each other and tire serial number location

_____

_____

Condition of wheel lugs _____

Wheel rotation restricted? Explain _____

_____

Project #:_____ Project Name:_____

Page_____ of _____

Tires and Wheels

Left Rear:

Make _____ Name _____

Size _____ Pressure (recommended/actual) _____

Ply (bias, radial) _____ Load capacity _____

Tread type (summer, all-season, mud/snow, recap, chains) _____

Tread depth (outside/center/inside) _____

General condition (cuts, scrapes, wear) _____

_____

Rim damage? _____

Locate tire and rim damage relative to each other and tire serial number location

_____

_____

Condition of wheel lugs _____

Wheel rotation restricted? Explain _____

_____

Left Front:

Make _____ Name _____

Size _____ Pressure (recommended/actual) _____

Ply (bias, radial) _____ Load capacity _____

Tread type (summer, all-season, mud/snow, recap, chains) _____

Tread depth (outside/center/inside) _____

General condition (cuts, scrapes, wear) _____

_____

Rim damage? _____

Locate tire and rim damage relative to each other and tire serial number location

_____

_____

Condition of wheel lugs _____

Wheel rotation restricted? Explain _____

_____

Project #:_____ Project Name:_____

Page_____ of _____

Brakes

Type (hydraulic, power assisted, air) _____

Anti-lock? (Two-wheel, four-wheel, not equipped) _____

Disk brakes? (Front, rear, all, drums) _____

Pedal travel _____ Pedal tread condition _____

Master cylinder fluid level _____ leaks? _____

Lines (leaks, brakes) _____

_____

General comments_____

_____

_____

Steering / Suspension

Type of Steering (power, manual) _____ 4W steering?_____

Describe any damage to tie rods, idler arm, drag links, Pitman arm, steering box, king pins, ball joints, and steering linkage in general:

_____

_____

_____

If steering wheels are locked in position by damage, measure wheel lock angle relative to vehicle axis_____

Describe suspension (springs, control arms, torsion bars, leaf springs, shocks) and damage _____

_____

_____

_____

Project #:_____ Project Name:_____

Page_____ of _____

_____

Interior

General condition and appearance _____

_____

Seat type: front_____ **rear**_____

Seat damage? Describe _____

_____

Front seat adjustment:

Driver _____

Passenger _____

Front seat headrests? _____

Headrest position above seat: driver _____ **pass.** _____

Seat belt type (lap, lap + shoulder, none) _____

Seat belt retractors operable? _____

Steering wheel description (stock, custom) _____

Steering wheel damage (rim bent, column stroked) _____

_____

Steering wheel orientation (turned how far which way) _____

Transmission type (std., auto.) _____

Transmission left in what gear? _____

Headlights/parking lights on? _____ **High beam?** _____

Side and rear view mirrors in correct position? _____

2WD/4WD selector position _____

Other observations _____

_____

_____

Project #:_____ Project Name:_____

Page_____ of _____

Engine Compartment

General description of damage _____

_____

_____

_____

No. cylinders in engine _____ Turbo/supercharged_____

Engine stock? _____ Description modifications _____

_____

_____

Fuel injected or carburetor? _____ CID _____

Gas/Diesel _____ Tank capacity (gal.) _____

Fuel pump mechanical or electrical _____

Electronic ignition? _____

Radiator punctured? _____

Any lines or hoses broken or disconnected? Describe _____

_____

_____

_____

Project #:_____ Project Name:_____

Page_____ of _____

Lights

Highlights broken? _____ Taillights broken? _____

Side marker lights broken or missing? _____

Any lights inoperable at time of accident (filaments broken not as a result of impact)_____

Headlights adjusted properly? _____

Windshield and Window Glass

Describe damage to windows _____

Any windows rolled down? _____

