Lesson 7 -- Forensic Engineering - Vehicular accident reconstruction

Pre-lesson Reading:

Introduction

Vehicular accident reconstruction is the scientific process of investigating, analysing, and drawing conclusions about the causes and events of a vehicular collision. Forensic investigators are employed to conduct in-depth collision analysis to identify the causes of collision, including the role of the drivers, vehicles, road's conditions and the environment.

The laws of physics such as the conservation of linear momentum, work-energy and kinematics are the basis for the analysis and may be employed to handle the different variables. Accident reconstructions are done in court cases involving death and personal injury. Results from accident reconstructions are also useful in developing recommendations for making roads and highways safer, as well as improving safety aspects of motor vehicle designs.

Investigation. The purpose of Accident scene inspection is to recover data for further investigation of all of the vehicles involved in the collision. The investigations include collection of evidence such as scene photographs, videos of the collision, measurements of the scene and eyewitnesses' confessions. Additional information such as steering angles, braking distance (with / without braking), use of signal lights/ hazard lights, car speed and acceleration will also be obtained. Witnesses are interviewed to get more evidence for accident reconstruction. Physical evidence such as skid marks of tires is also examined. The length of a skid mark can often allow calculation of the original speed of a vehicle. Vehicle speeds are frequently under-estimated by a driver, so an independent estimate of speed is often essential in accident investigations. Inspection of the road surfaces is also vital - icy road, oil spill from a vehicle or obstacles such as road debris may affect the friction of the road surfaces.

Analysis. The process of vehicular accident reconstruction includes data processing and analysis as well as evaluation of different possible hypotheses according to test results / modeling result from software simulations. Accident reconstruction software is regularly used by law enforcement personnel and consultants to analyse a collision and to demonstrate what may have happened in an accident.
A short video on car crashes:
http://www.metacafe.com/watch/2382492/car_crash_compilation/

Worksheet 7.2 Accident Scene Investigation

A serious traffic accident happened on 19 March, 2010 on the highway at North Lantau Island. A black Rolls Royce stopped on the highway because of a flat tyre. The driver got off the car and walked to the rear of the car to check the luggage inside the car boot. Unfortunately, a white car driving on the same lane crashed into the Rolls Royce. Both cars damaged seriously and the driver of the Rolls Royce was killed.

7

Figure 1

5 , 6

2

1

3 , 4

Source: Tai Kung Pao (20-3-2010)

Figure 2

Suppose you were a forensic investigator and arrived at the location after the accident. According to the above photos, what would you do in order to identify the causes of the accident?

Things you would do	WHY ?

(This is an open-ended question and there are a lot of possible answers. Write as much as you can with your common sense and justify your answers with reasons.)

Worksheet 7.3 Reaction time of the driver

Reaction time is the lapse of time between stimulation and the beginning of response.

Suppose you were driving on the high way and listening to the music you like most, suddenly, you saw the brake light of the car in front of you blinking, you tried to hit the brake to slow down your car. **But**, there is a small time delay before you can really do that - your reaction time. During that period of time, your car is still moving at the same HIGH speed!

Typical reaction time of driver under different conditions:

Conditions	Reaction time
Normal	~ 1 sec
Having telephone conservation / Listening music	~1.5 – 2 sec
Drunk or under medication	~ 2 – 5 sec

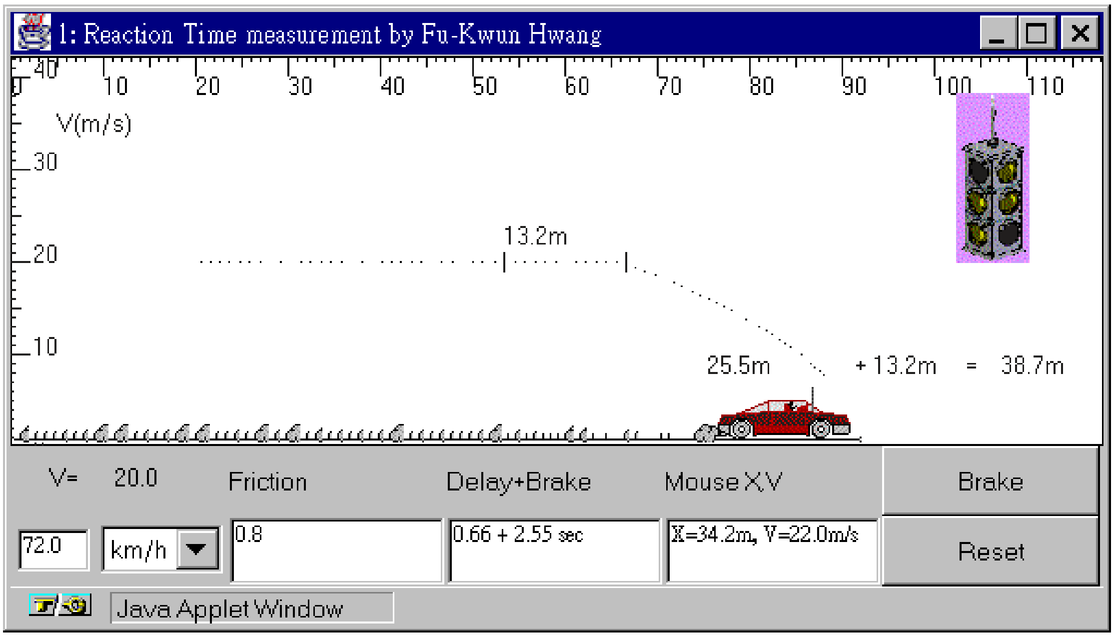
The total stopping distance (停車距離) is divided into 2 parts :

- Thinking distance(思考距離) :
  the distance travelled by the car in your reaction time

- Braking distance(剎車距離) :
  the distance skidded by the car after the brake is hit.

Total stopping distance = Thinking distance + Braking distance

The following 'Reaction time" animation demonstrates how the reaction time affects the total stopping distance of the car:



Reference websites for the reaction time :
http://www.shep.net/resources/curricular/physics/java/javaReaction/index.html
http://www.humanbenchmark.com/tests/reactiontime/index.php

Simulated conditions:

1. Listen to loud music when you take the test on reaction time;
2. Answer a phone call when you take the test on reaction time;
3. Turn your body around for ten times and then take the test on reaction time immediately.

What can you imply from the results of your tests ?

Notes : The reaction time tested in this animation may be much faster than the real situation. Real drivers use their feet to hit the brake which may need a longer time for the signal communication with the brain. Besides, real driver are easily distracted by different conditions on the road while the students are highly concentrated on the test.

Worksheet 7.4 Features of skid marks

In a car accident, a skid mark is the mark a tire makes when a vehicle wheel stops rolling and slides on the surface of the road, much like that of an eraser leaving pieces of rubber on a paper, and is an important aspect of trace evidence analysis in forensic science and forensic engineering.

Different inflation of tyres will lead to different appearances of the skid marks. Try to finish the matching game below and give reasons for your choices.

Normal inflation

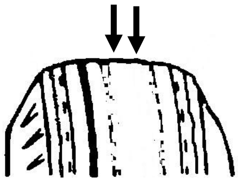
Under-inflation

Rapid wear at edges

Over-inflation

Rapid wear at centre

Tyres' conditions



◎ ◎ ◎

◎ ◎ ◎

Contacts with road

(diagrams showing vertical sections of tyres contacting with road surface)

◎ ◎ ◎

◎ ◎ ◎

Appearances of the skid marks

Note: Tyre wear may not lead to total disappearance of the striation (輪胎條紋). The striation may become shallower when compared to that of the normal area.

Actually, there are numerous patterns of skid marks due to the different situation of the vehicles (e.g. accelerating, turning round, drifting, moving backward and sideslipping). The appearance of each skid mark pattern is special but an experienced forensic engineer can obtain much valuable information by examining the marks left by the tire.

References on skid marks:

http://en.wikipedia.org/wiki/Skid_mark
http://www.harristechnical.com/articles/errors.pdf
http://www.donan.com/Services/Vehicle-Accident-Reconstruction/Passenger-Vehicles.aspx
http://collisionanalysis.co.uk/introduction.htm
http://www.easts.info/on-line/journal_06/3441.pdf

Worksheet 7.5 START and STOP

The acceleration of a vehicle

The manufacturer of BMW quotes that the model BMW 530i can accelerate from rest to a speed of 100 kmh^{-1} (27.8 ms^{-1}) in 6.5 seconds, while a Collora E140 can have the same acceleration in 9.8 seconds. It is obvious that BMW has a higher power to start the car. We can calculate the acceleration of both cars to make a clearer comparison.

Source: http://www.bmwhk.com/com/en/newvehicles/modelfinder/modelfinder.html (BMW Concessionaires (HK) Ltd.)

BMW 530i

Acceleration = the rate of change of the speed

$$a = \frac{v - u}{t}$$

(v = final speed of the car)

(u = initial speed of the car) (* 1 kmh^{-1} = 0.278 ms^{-1})

In the above example, u = 0 since the cars start from rest. The acceleration of BMW and Collora are 4.28 ms^{-2} and 2.84 ms^{-2} respectively.

Besides, we can also calculate the distance travelled by the car during the process of acceleration by the equation of motion:

$$v^2 - u^2 = 2as$$

(s = distance traveled)

Apply the equation to complete the following table:

Car type	BMW 530i	Collora E140
Acceleration	4.28 ms^{-2}	2.84 ms^{-2}
Distance travelled (start from rest to 100 kmh^{-1})		

The braking of a vehicle

When a car is moving on a road without applying the brake, the tyres are rolling on the ground and no significant mark will be left on the road. Once the brake is applied, the wheels are locked without rolling and the tyres will slip on the road causing skid marks on the road surface. The length of the skid marks begins when the brake is applied and ends when the car stops.

Actually, it is the friction between the tyres and the road surface that causes the car to decelerate and stop. The following experiment allows you to investigate the relationship between the friction of an object and its weight.

Experiment

Place a wooden board on a rough surface, add several weights on the wooden board. Then attach a spring balance to the wooden board and pull the wooden horizontally (Figure 1). Observe and record the reading on the spring balance when the board JUST starts to slide on the rough surface. This is the friction between the wooden board and the rough surface.

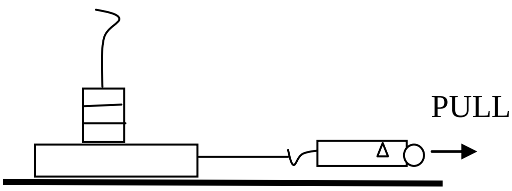


Figure 1

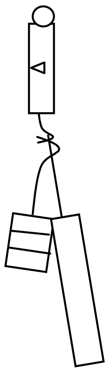


Figure 2

Measure the total weight of the wooden board and the weights. (Figure 2)

Repeat the above steps with more weights adding on the wooden board. Tabulate your data in the table below:

	Trial 1	Trial 2	Trial 3
Friction *F* *(N)*			
Total weight *W (N)*			
Ratio *F / W*			

You will find that the ratios *F / W* are more or less the same so that we can express the relation as

$$\frac{F}{W} = \text{constant} \qquad \text{OR}$$

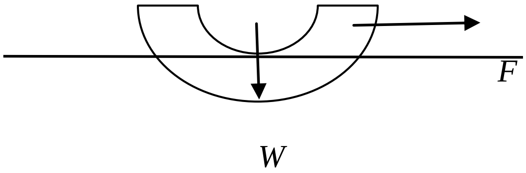
$$(F = constant \times W)$$

In forensic science, we define the constant as *f*, the **drag factor (阻力係數)** for the road surface. We can conclude that *f* is a factor which depends on the nature of the tyre and the road surface but independent to the weight of the vehicles. (In physics, f is called the coefficient of friction 摩擦力係數)

In many car accidents, forensic investigator will make an on-site test about the tyre/road condition. It is known as the “drag test”.

http://www.musclemustangfastfords.com/tech/mmfp_0610_bolt_on_performance_parts/index.html

As we have proved in our experiment, the drag factor does not depend on the weight of the vehicle. Only a part of the tyre is needed for measuring the ratio F/W.



For normal tyre’s condition, the drag factor depends on the nature of the road surface. Here are some examples:

Cement : 0.55 – 1.22
Asphalt (柏油) : 0.50 - 0.90
Gravel (沙礫) : 0.40 – 0.80
Snow : 0.10 – 0.50

HK Police commonly uses 0.7 for the drag factor in normal condition.

The higher the speed of the car before braking, the longer the distance needed for the car to stop. By measuring the length of skid marks, it is possible to estimate the vehicle speed just before sliding by the following formula:

$$speed = \sqrt{254 D f}$$

Where speed the speed just before sliding (measured in kmh^{-1})
f: drag factor

D: length of the skid mark (measured in m)

(assume the braking efficiency of the car is 100 %)

$$\frac{1}{2}mv^2 = F \times D$$
$$v = \sqrt{\frac{2FD}{m}} = \sqrt{2fgD} = \sqrt{19.6Df} \quad measured\ in\ ms^{-1}$$
$$v = \sqrt{254Df} \quad measured\ in\ kmh^{-1}$$

Example:

A car skids to a stop on a road in Mongkok, leaving four skid marks with an average length of 45 m. Skid tests reveal a drag factor of 0.70. Estimate the speed of the car just before sliding.

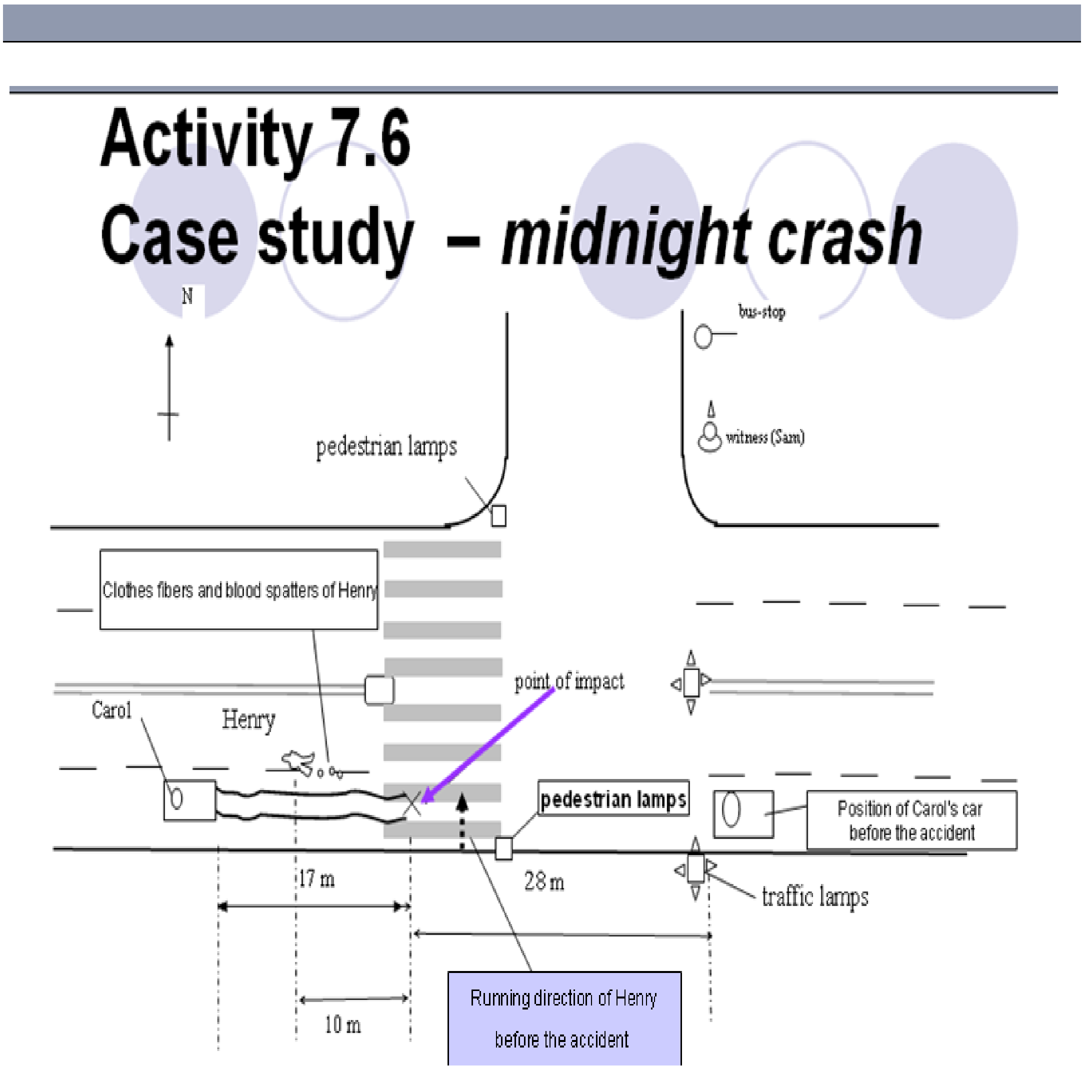
Answer: ________________________________

Notes:

- It is important to understand that this is the MINIMUM speed of the vehicle at the beginning of the skid.
- It is not possible to find all of the skid marks – skid marks start out as light shadow marks but would become progressively darker (→ more difficult to see).
- This formula assumes that the vehicle comes to a stop at the end of the skid without hitting anything such as another car or a tree.
- If there is a speed value at the end of the visible skid, as when the car strikes something, the residual speed value must be combined with the calculated minimum skid speed.

Worksheet 7.6 Case study-Midnight Crash

Your group is the investigation team providing expert testimony at an automobile accident case in the court. The case involves a lady driver (Carol) driving a red car which knocked down a young male pedestrian (Henry) around midnight at a road junction in Yuen Long. The driver was not injured and passed the alcohol test. However, the pedestrian was hurt badly. An eyewitness (Sam) reported to the police that he saw part of the accident. The following sketch was drawn by your colleague 1 hour after the accident:



(The positions of Carol , Henry, and Sam in the above sketch are predicted positions during the accident)

After thorough investigation you get the following information:

- mass of the car and Carol: 1100 kg
- mass of Henry: 60 kg
- speed limit at the location: 50 km/h
- drag factor $f = 0.7$
- point of impact: 28 m from the nearby traffic lamps
- 17 m long skid marks from the point of impact
- Henry lay on the ground
- clothes fibers and some blood spatters were found near Henry’s body
- a few street lamps were out of order during the accident
- the manufacturer of Carol’s car claimed that the maximum acceleration of the car is 2.4 ms^{-2}

Q1. From the above information, can you estimate the minimum speed of Carol’s car during the crash?
(Since the mass of car is much heavier than that of Henry, we can assume the speed of the car didn’t change after the collision)

Answers:

In order to reveal the truth and provide evidence in the court, your team had interviewed Carol, Henry and Sam respectively and got the following confessions.

<u>Carol (the driver, a nurse, 40, mother of 3 kids)</u>

When I was hurrying to the hospital for work that night, I stopped my car before the red traffic light. The road was dark. After the traffic light turned green and making sure that the road ahead was clear, I drove across the road junction. Suddenly, I saw a person wearing dark clothes appearing in front of me. I swear that I couldn’t see him until the last moment. I pressed my horn sharply but he didn’t seem to have any response. Everything was too late and my car knocked him down. I applied the brake immediately to stop my car. I was so scared that I stayed in my car until the police came.

Henry (the injured person, a salesman, 26, single)

After drinking with my friends, I left the bar around midnight. I intended to catch the last bus home. The pedestrian lamp was green and flashing when I was running across the road. Suddenly, without sounding its horn a car at high speed came to me from my right hand side and knocked me unconscious.

Sam (witness, a financial planner, 33, married)

That was a quiet night. When I was walking towards the bus-stop after meeting with a client, I heard very loud sound of horn from behind suddenly. I turned to my left and saw a car knocking down a person. I remember that the pedestrian lamp near the crash scene was still red at that moment. I ran quickly across the road to see what I could help. I saw a man wearing black clothes lying on the road with some bloodstains around him. A car stopped about 10 m away from the injured person. The driver, who was a lady, got off her car. She was very scared. I called 999 with my mobile phone for her.

Q2. Comparing the confessions of Carol, Henry and Sam list out some points that you think are contradictory.

Answers:

Q3. Comment on the confessions and discuss whether they are trustworthy “(✓)” or doubtful “(?)”.

Notes for teacher to guide the discussion:

Carol:

( ) The road was dark.

( ) I had pressed the horn.

( ) I had braked the car after knocking down Henry.

( ) I stayed in the car until the police came

Henry:

( ) I was running when I was knocked down by the car.

( ) The pedestrian lamp was green / flashing.

( ) The car did not sound its horn.

Sam:

( ) I heard the horn before the collision.

( ) The car stopped about 10 m from the body (quite consistent with the site measurement)

( ) The pedestrian lamp was red during the collision.

( ) The driver got off the car.

Worksheet 7.7 Animation of vehicle's accident

Nowadays, computer generated animations can be used to pool together all the relevant evidences from forensic investigations and the confessions of the people involved in the accident and give a visual demonstration of related events logically and clearly. Very often such animations are used in attending meetings or providing courtroom presentation.

Here are some examples of Accident Animation (Multiple Animated Objects):

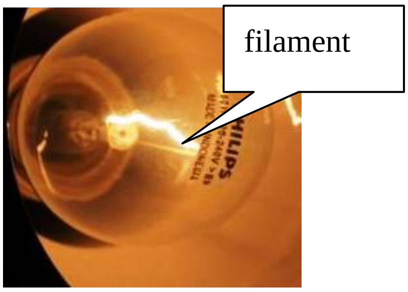
The animation is based on the footage of a real accident. The animation includes the Jogger View, Second Pedestrian View and Car Across Intersection View. Luckily, the person run over in the animation did survive in the accident!
Reference for the animation:
http://www.mapscenes.com/software/capture/samples/index.htm

Lesson 7 Follow-up activities

<u>ON or OFF ? Lamp Examination after a Collision</u>

In many traffic accident cases, witnesses or drivers will claim that one of the accident vehicles did not have its lights on during a night time accident or the taillights and hazard lamps are off when the vehicle stops suddenly, which can account for the responsibility of the accident.

Vehicle lamps can be examined to determine if they were on or off at the moment of impact. The majority of lamps used in vehicle tail lights are incandescent (白熾). They are the same as household light bulbs. The filaments, the tightly coiled wires running between two upright support posts, are made from tungsten, a very hard metal.



When electric current passes through a filament coil, the temperature of the wire is raised to 2000°C and white light is produced (incandescence).

At normal environmental temperatures, tungsten does not react with oxygen in the air. However, tungsten can be oxidised rapidly at incandescent temperatures in the presence of air. In standard lamps, the air inside was removed and replaced with nitrogen, an inert gas that will not have oxidation reaction with tungsten. When the filament reaches incandescence, the nitrogen gas prevents oxidation. Light will be produced continuously.

Figure 1 and 2 show the tungsten filaments of two lamps. One of them was broken due to collision when the lamp was on. Which one is it? Explain your answers.

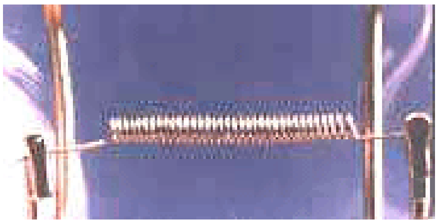


Figure 1

Figure 2

Answers:

<u>Yaw marks (偏航胎痕) and rotation of vehicles</u>

There are various types of tire marks; the two most common ones are <u>straight-line skid marks</u> (discussed in previous section) and <u>yaw marks</u>. The presence of straight-line skid marks indicates that a tire is not rotating, either due to braking or as a result of damage sustained during a collision.

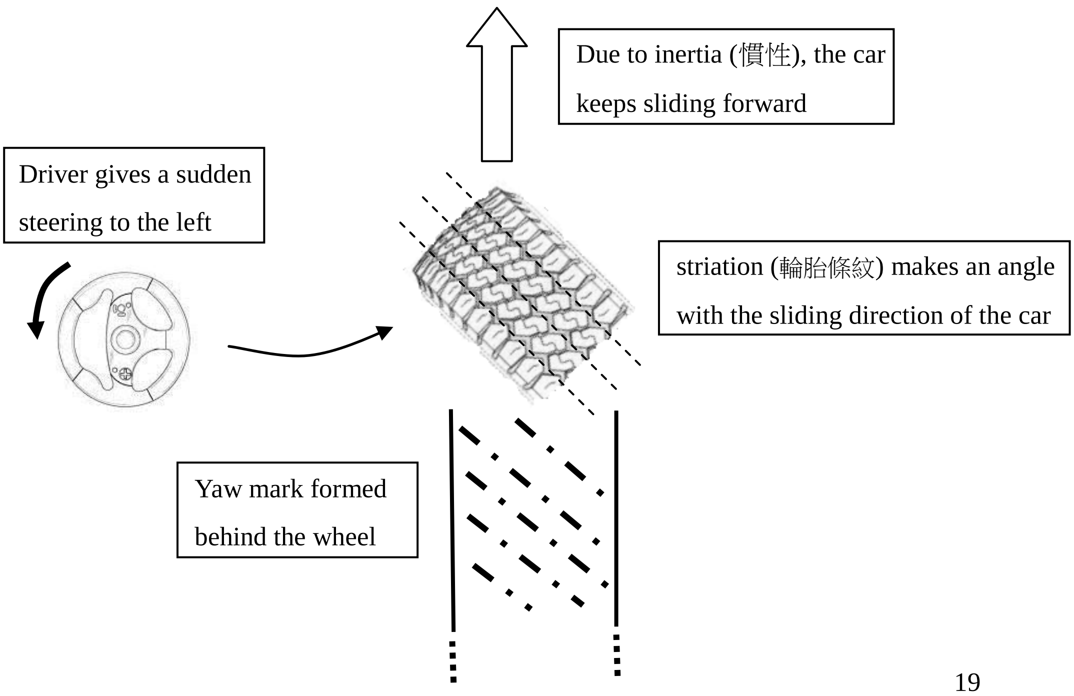
Yaw marks often occur when a driver makes a hurried steering (a) to avoid an object on the road, or (b) to remain on the pavement while entering a curve too fast or (c) while overcorrecting a previous situation. A yaw mark is that physical mark on the roadway caused by the rotating tires of a vehicle slipping in a direction parallel to the axle of the wheel during a maximum rate of change of direction.

Figure 3

Source:
http://www.donan.com/Services/Vehicle-Accident-Reconstruction/Passenger-Vehicles.aspx

(Donan Engineering Company, Inc.)

Yaw mark indicates rotation of a vehicle, as would occur when a vehicle "spins out". Yaw marks are generally curved, and the striations are at an angle to the marks.



Use of Newton's 3rd Law in Vehicular Accident Reconstruction (a Hong Kong case) (in Chinese)

Reference:
http://hk.apple.nextmedia.com/template/apple/art_main.php?iss_id=20100924&sec_id=4104&art_id=14483256

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3. Nickell, J. & Fisher, J.F. (1999). *Crime Science: Methods of Forensic Detection.* Kentucky: The University of Press of Kentucky.
4. Wong, S.S. & Pang W.C. (2009). *Physics at Work: Force and Motion (Teacher's Edition).* Hong Kong: Oxford University Press (China) Ltd.
5. 李昌鈺、提姆西・龐巴、瑪琍琳・米勒 (2004)：《犯罪現場（李昌鈺刑事鑑定指導手冊）》，台北：商周出版社。
6. http://www.metacafe.com/watch/2382492/car_crash_compilation/
7. http://en.wikipedia.org/wiki/Skid_mark
8. http://www.harristechnical.com/articles/errors.pdf
9. http://www.donan.com/Services/Vehicle-Accident-Reconstruction/Passenger-Vehicles.aspx
10. http://collisionanalysis.co.uk/introduction.htm
11. http://www.easts.info/on-line/journal_06/3441.pdf
12. http://www.shep.net/resources/curricular/physics/java/javaReaction/index.html
13. http://www.humanbenchmark.com/tests/reactiontime/index.php
14. http://www.donan.com/Services/Vehicle-Accident-Reconstruction/Passenger-Vehicles.aspx