The Physics of Tailgating

Outcomes:
1. Analyze and describe vertical motion as it applies to kinematics. (116-2)
2. Describe and evaluate the design of technological solutions and the way they function, using scientific principles. (116-6)
3. Analyze and describe examples where scientific understanding was enhanced or revised as a result of the invention of technology. (116-2)
4. Analyze mathematically the relationship among displacement, velocity and time. (325-2)

Introduction

Have you ever been in a rush to get somewhere and wished that the car ahead of you would just hurry up? Have you ever driven a little too close in an attempt to hurry the driver along? If so, you are guilty of tailgating. Tailgating is a dangerous and usually futile practice: "It only takes one crash in a tailgating line to produce a chain reaction" (Frank, n.d.). The laws of physics and of common sense dictate that you cannot go any faster than the slowest car ahead. Also driving too close forces stronger reactions to everything done by the car in front, making the drive much harder on your nerves and your car. An understanding of the physics of tailgating may be crucial in ensuring road safety and in helping tailgaters slow down and enjoy the ride. It might even result in less 'road rage'.

Theory

Tailgating can lead to multiple car crashes if even one car in a line suddenly slows down. The critical question is "how close is too close?" When learning to drive you are usually told to keep a safe distance of at least two seconds behind the car in front of you. As you observe the car ahead of you pass a fixed point, your own car should pass that same point at least two seconds later. This safe distance can also be expressed as one car length per 22 km/h of speed travelled. These rules of thumb are usually given since it is assumed that most people learning to drive do not understand basic physics. But without an understanding of some simple physics, we may all be at increased risk from tailgating. The physics of tailgating is related to motion and the kinematics equations, and includes principles like stopping distance and reaction time.

Reaction Time

If you are driving along the highway at 95 km/h and the car ahead of you suddenly applies the brakes, you must react quickly. Variables like response time become very important. When you first observe that the car ahead of you is stopping, it takes time for the brain to process this information. Reaction time includes the time taken for this processing plus the time for your foot to move to the brake. Reaction time can be determined by utilizing acceleration due to gravity principles (see activity). Typical reaction times are between 0.2 and 0.7 seconds. Nicklin (1997) tested reaction time with 64 students using computer trials of simulated brake and gas pedals, to find average reaction times of 0.3 to 0.6 seconds.

The reaction times stated above are typically obtained under ideal circumstances where the person being tested is paying attention to the task at hand.

In a real situation the driver could possibly be distracted (eg. having a conversation with a friend, or singing along to the radio). Testing reaction time under these conditions might give a more realistic representation of reaction time. An even more realistic estimate would include adding on an estimation of the time it would take to move your foot from the gas pedal to the brake pedal (Alternative Homework Assignment: Tailgating). Since the foot is farther away from the brain than the hand, the reaction time calculation will be increased slightly.

Stopping Distance

A person's reaction time is important in calculating a stopping distance for the vehicle they are driving. Initially you are travelling along at some constant velocity before your foot hits the brake. The distance travelled during the reaction time is given by, $d = v_i t$ where v_i is the initial velocity. When the brakes are applied the vehicle begins to decelerate.

During this period of deceleration the distance travelled is given by,

$$2ad = v_f^2 - v_i^2$$

$$d = \frac{v_f^2 - v_i^2}{2a}$$

where $v_f = 0$, so

$$d = \frac{-v_i^2}{2a}$$

where a is negative since the car is decelerating. Thus the total stopping distance for the car is given by,

$$d = v_i t + \frac{-v_i^2}{2a}$$

The following data, originally published in Popular Science and AutoWeek magazines (Nicklin, 1997, p. 78), can be used to solve 'tailgating problems'.

Vehicle	Deceleration (m/s^2) (from 97 km/h)
BMW M3	9.8
Toyota Celica GT	9.2
Lincoln Continental	9
Nissan Maxima	8.3
Chevrolet Blazer	7.5
Dodge Colt GL	7.1

Identical Braking Capacity

Assume that two Lincoln Continentals are travelling along a highway at 97 km/h. The front car slams on its brakes. Knowing the reaction time of the driver we can determine the minimum distance that the second Lincoln should have been behind the first to avoid a rear end collision.

The following calculation shows that the front car will stop in a distance of 41 m.

$$d = \frac{-v_i^2}{2a}$$

$$d = \frac{-(27\ \mathrm{m/s})^2}{2(-9.0\ \mathrm{m/s^2})}$$

$$d = 41m$$

The second car (using a reaction time of 0.45 s) will stop over a distance of,

$$d = v_i t + \frac{-v_i^2}{2a}$$

$$d = (27\, {}^{m}\!/_{s})(0.45s) + \frac{-(27\, {}^{m}\!/_{s})^2}{2(-9.0\, {}^{m}\!/_{s^2})}$$

$$d = 12m + 41m$$

$$d = 53m$$

Note that 12 m of this distance is travelled before applying the brakes, and the other 41 m is required to stop. Thus a safe distance behind the first car would be at least 12 m. Given that the average car length is about 5.0 m, this safe distance translates into about 2.4 car lengths behind. A constant speed of 27 m/s over this 12 m translates into a 'safe time' that is equal to the reaction time.

$$t = \frac{d}{v}$$

$$t = \frac{12m}{27\, {}^{m}\!/_{s}}$$

$$t = 0.44s$$

The only factor affecting the required separation distance is the reaction time (when both cars are travelling at the same speed and have the same deceleration).

At this point it might appear that the two second rule is overly cautious. However the situation described is an idealized one where both cars have the same braking ability and the tailgater has a reasonably good reaction time. The situation could be much worse if the tailgater had a poor reaction time, if the road conditions were wet or icy, if the lead car were travelling slower than the tailing car, or if the braking capacity of the cars were different.

Different Braking Capacity

The situation with different braking capacities can also be illustrated using data from the table given (Nicklin, 1997). Nicklin describes a situation where two cars are travelling at 121 km/h with a separation distance of 5 car lengths (?24.38 m). Car A decelerates at $9.8\, {}^{m}\!/_{s^2}$ (a BMW), while car B decelerates at $7.5\, {}^{m}\!/_{s^2}$ (a Chevrolet Blazer). If the driver of car B has a reaction time of 0.45 s, the following calculations show that car B will in fact hit car A even at 5 car lengths away.

Stopping distance of car A:

$$2ad = v_f^2 - v_i^2 \quad \text{where } v_f = 0$$

$$d = \frac{-v_i^2}{2a}$$

$$d = \frac{-(33.6\, {}^{m}\!/_{s})^2}{2(-9.8\, {}^{m}\!/_{s^2})}$$

$$d = 57.6m$$

Stopping distance of car B:

$$d = v_i t + \frac{-v_i^2}{2a}$$

where the $v_i t$ portion corresponds to the distance travelled during the reaction time.

$$d = (33.61\, {}^{m}\!/_{s})(0.45s) + \frac{-(33.61\, {}^{m}\!/_{s})^2}{2(-7.5\, {}^{m}\!/_{s^2})}$$

$$d = 15.1m + 75.3m$$

$$d = 90.4m$$

Thus when car A has stopped, it would be 24.38 m (5 car lengths) + 57.6 m = 81.98 m from where car B started. If Car A has come to a complete stop, it will still be hit by Car B since Car B requires 90.4 m to stop (it can be shown that Car B will actually collide with Car A 3.4 s after Car A starts to brake). Car B would have been decelerating for 81.98 - 15.1 m = 66.88 m before reaching car A. The final velocity of car B at 66.88 m is,

$$v_f^2 = 2ad + v_i^2$$
$$v_f^2 = 2(-7.5\,{}^{m}\!/_{s^2})(66.88m) + (33.61\,{}^{m}\!/_{s})^2$$
$$v_f^2 = -1003.2\,{}^{m^2}\!/_{s^2} + 1129.63\,{}^{m^2}\!/_{s^2}$$
$$v_f = 11.2\,{}^{m}\!/_{s}$$

Under these conditions when car A has better brakes and can stop faster, car B will collide with car A even with a good reaction time and a separation distance of five car lengths.

The situation is even more complicated when there is a line of tailgating cars. If the car ahead of you is also tailgating, you have no way of knowing how much they have reduced their own safety margin. As a driver you can roughly tell your own reaction time, velocity, and braking ability. Unfortunately you know nothing about the other driver's reaction time or braking conditions. This lack of knowledge further increases the risk of tailgating.

Getting Ahead?

Traffic lights can be particularly frustrating especially when trying to reach a destination in a hurry. Many drivers think that tailgating and driving as fast as possible between lights will get them there faster than somebody who obeys the speed limit. However this is not necessarily the case. In the case of heavy traffic, tailgating can actually slow you down. How many times have you observed a car whiz by you by weaving in and out of traffic, only to find that four or five lights later they are still only slightly ahead of you? Traffic lights are timed to ensure easy flow of traffic. One way of doing this allows a person following the speed limit to get every green light (once they get one). Tailgaters however are forced to slow down or stop every time a car ahead slows or takes a turn. Getting back up to speed leaves a larger gap in front of the car than if they had been travelling along at a constant speed at a safe distance. This gap is quickly filled in heavy traffic, so the tailgater doesn't get much further ahead. Also, having to get up to speed at every red light causes the slowdown of trailing lines of traffic that would ordinarily have made the light, thus contributing to traffic congestion.

Conclusion

In our fast paced world it is often difficult to slow down when there is so much to do in so little time. Tailgating may give the perception of getting ahead, but a basic understanding of motion shows that this is not the case. So, how close is close enough? In the case of tailgating the answer to this question is 'too close for comfort'.

Questions

1. In a realistic model of tailgating what factors should be considered that would increase the safe stopping distance?
2. What is the stopping distance of a Toyota Celica ($a = -9.2\ m/s^2$) from 97 km/h where the driver has a reaction time of 0.55 s?
3. A Chevrolet Blazer travelling at 97 km/h can stop in 48 m. Given that the actual stopping distance for a certain driver is 54 m, what was the driver's reaction time?
4. An automobile is travelling at 25 m/s on a country road when the driver suddenly notices a cow in the road 30 m ahead. The driver attempts to brake the automobile but the distance is too short. With what velocity would the car hit the cow if the car decelerated at $7.84\ m/s^2$ and the driver's reaction time was 0.75 s?
5. Research: Look in car magazines to determine stopping distances and deceleration rates for your own or family car.

References

Alternative Homework Assignment: Tailgating. http://www.physics.umd.edu/rgroups/ripe/perg/abp/aha/tail.htm

Frank, L.: http://www.leefrank.com/books/margins/asides/keepaway.htm

Kinematics of Driving: Some "Real" Traffic Considerations. http://www.dctech.com/physics/features/physics_0700a.htm

Kinematics of Tailgating: http//www.ecu.edu/si/cd

Nicklin, R.C. (1997). Kinematics of tailgating. The Physics Teacher, 35, p. 78-79.

Activities

Reaction Time

Purpose: To determine a person's reaction time.

Materials: • Meter stick

Procedure:

1. Have a partner hold a meter stick while you position your thumb and forefinger just at the 0 mark. Have your partner release the ruler while you try to catch it as quickly as possible. You can then record the distances of several trials and take an average distance.
2. The meter stick will fall at a rate of 9.8 m/s^2 toward the ground from an initial velocity of 0 m/s. Given this data, reaction time can be calculated from the kinematics formula,

$$d = v_i t + \tfrac{1}{2} a t^2$$

where $v_i = m$ 0 so,

$$d = \tfrac{1}{2} a t^2$$

$$at^2 = 2d$$

$$t^2 = \frac{2d}{a}$$

$$t = \sqrt{\frac{2d}{a}}$$

This activity can be repeated under more realistic conditions by having your partner distract you as you try to catch the ruler.