Forces Applied to Automotive Technology

Throughout this unit we have addressed automotive safety features such as seat belts and headrests. In this section, you will learn how forces apply to other safety features in cars. Some of these features involve increasing friction with different types of road surfaces. For example, you will learn why different tires are used for specific applications and road conditions, and how antilock brakes and electronic stability controls help drivers maintain control of vehicles on slippery surfaces. Another car safety feature is crumple zones that become crushed when a car collides with another object (Figure 1). These different technologies have advantages, but they also have limitations. By understanding the physics involved in these safety features, you will become a safer driver and a more informed car consumer.

The Physics of Car Tires

In Investigation 4.2.1, you learned that for many pairs of materials the force of static friction or kinetic friction acting on an object is not affected by the amount of surface area in contact with a surface. Instead, the coefficients of friction depend on the types of materials in contact. The magnitude of static friction or kinetic friction only depends on the coefficient of friction and the magnitude of the normal force. However, rubber is an exception. For example, the magnitude of static friction acting on a rubber tire on a road surface depends on the surface area of the tire that is in contact with the road. That is one reason why race cars have very wide tires with no treads. These types of tires are designed to maximize the surface area in contact with the road, which increases the magnitude of static friction acting on the tires, and also dissipates heat more quickly. This, in turn, helps race cars move along curved paths without slipping. If it starts raining during a race, the event is sometimes postponed because these types of tires have no treads.

Unlike race car tires, the tires on passenger vehicles need to provide good traction (force of friction) on road surfaces under all weather conditions. The tread area on a tire has small and large grooves (Figure 2). Grooves provide pathways for water, such as rain and snow, to pass beneath the tire as it rolls over a wet road. This helps the tire maintain contact with the road. As a result, the magnitude of friction acting on the tires is usually large enough for safe driving.

When driving at a low safe speed on a wet road, the water level in front of a passenger car tire is low (Figure 3(a)). The water has time to move through the grooves in the tire tread and be squeezed out behind the tire. In this situation, friction from the road still acts on the tire. If the driver starts to speed up, some of the water in front of the tire will not have enough time to pass through the grooves toward the back of the tire (Figure 3(b)). This causes the water level in front of the tire to increase. This excess water causes the tire to start to lose contact with the road. If the driver’s speed continues to increase, the water level in front of the tire will increase to the point where the tire no longer directly touches the road surface (Figure 3(c)).

Figure 1 A typical crash test

Figure 2 The tread on tires is designed to work under various road conditions. Beneath the rubber tread are layers that provide added safety and strength.

Figure 3 (a) When a car travels at low speeds on a wet road, water levels are low in front of and high behind the tire (the normal stage). (b) If the speed of the car increases, water levels increase in front of the tire (the transition stage). (c) If the speed of the car continues to increase, water levels in front of the tire increase to the point where the tire no longer makes direct contact with the road surface (the hydroplane stage).
Now the tire experiences no friction from the road and very little friction from the water. As you learned in Chapter 3, an object experiencing no net external force will continue to move at constant velocity. The two materials in contact are now rubber and water, not rubber and the wet road. This situation is called hydroplaning and is very dangerous. It results in the driver losing control of the vehicle and being unable to slow down due to the very low friction acting on the tires. The only way to avoid hydroplaning is to drive slowly when the roads are wet.

The tread depth on passenger car tires is usually 7 mm to 8 mm for a new tire. As the tires wear, the tread depth decreases and less water is able to move through the grooves. Driving with worn tires increases the chance of hydroplaning. When the tread depth gets too low, the tires should be changed.

The Physics of Car Brakes

There is no perfectly safe car crash, but engineers continually work at protecting car occupants as much as possible. Even though vehicles are becoming safer every year, many people across the world still die in car crashes.

The best way to survive an accident is to avoid one. Nothing will ever replace sensible driving at the proper speed. However, sooner or later every driver gets into a situation where an accident might occur. One safety feature found in many cars is antilock brakes. A disc brake on a car is very similar to the brakes on a bicycle. However, in disc brakes, a piston squeezes the brake pads against a rotor (Figure 4). Braking harder increases the magnitude of the normal force, which in turn increases the force of friction acting on the rotor. The rotor is attached to the wheel, and as the rotor slows down so does the wheel.

One problem with disc brakes on cars is that the brake can stop the wheel from turning a lot faster than the friction from the road can stop the car from moving. This results in the wheels becoming locked and sliding across the road. So the car skids and the driver is unable to steer the car. The antilock braking system (ABS) on cars helps solve this problem.

An ABS uses a computer to monitor the readings of speed sensors on the wheels of the car. If a wheel experiences a sudden large decrease in speed, the computer quickly reduces the force on the brake pads until the wheel moves at an acceptable speed again. The computer can change the force on the brake pads very rapidly, which allows the car to slow down as fast as possible without the tires skidding. This helps to slow down the car rapidly while allowing the driver to maintain control and steer the car.

One problem with ABS is that drivers feel a chattering action in the brake pedal when slowing down to avoid an accident. Drivers often think this means something is wrong and lift their foot off the brake pedal or, even worse, start pumping the brakes. However, this chattering action is normal for ABS and drivers should continue to apply firm pressure to the brake pedal. Under no circumstances should the driver pump the brakes in a car with ABS. Pumping the brakes will make the car travel farther before it stops. There is some evidence that ABS technology does not actually improve the safety of car crashes because drivers do not use it properly. In some cases drivers who maintain control due to ABS actually steer off the road to avoid an accident, which often results in more serious injuries.

Electronic Stability Controls on Cars

Another safety system on cars very similar to ABS is traction control. Traction control is actually the reverse of ABS. ABS comes into play when a car is slowing down and the tires start sliding on the road. Traction control is used when the car is speeding up, especially when starting from rest, and the tires start sliding. If the driver presses down hard on the accelerator, one or more of the wheels may start turning faster than the car is moving. The force of friction on the fast-turning wheels decreases and the driver can lose control of the vehicle and have an accident.

Traction control involves sensors that detect the sliding tires. This information is sent to a computer, which decreases the amount of fuel to the engine. The computer may even
use ABS to slow the wheels down. The main thing is that traction control helps the driver maintain control of the vehicle while accelerating.

Electronic stability control (ESC) uses both traction control and ABS to help increase the safety of a vehicle. The sensor for ESC is usually located at the centre of the car. Its purpose is to detect if the car is tilting too much one way or another when making a sharp turn. The two scenarios where ESC comes into play are when the car is experiencing understeering or oversteering (Figure 5). Understeering occurs when the force of friction acting on the front wheels is not enough to prevent the car from travelling in a straight line while the driver is trying to turn. Oversteering is the opposite. When oversteering occurs, the car turns more than the driver intended and the back wheels start to slide sideways, spinning the car around.

To help prevent both of these situations, ESC can activate one or more brakes using ABS or adjust the speed of the car using traction control. The end result is that the driver has a better chance of controlling the motion of the car with ESC than without it. However, ESC does not actually drive the car for you. Only responsible driving can keep the driver and passengers safe. A driver who is driving too fast or faster than road conditions allow can easily create a dangerous situation, whether the car has ESC or not.

### Crash Testing

Crash tests are all about making sure cars are safe and helping to make them even safer. Yet car crashes are still one of the leading causes of death and injury in North America. One of the most important tools used during a crash test is a crash test dummy. A crash test dummy is designed to accurately simulate what will happen to a person during an accident. To collect data during a car crash, the dummy has three different kinds of sensors. The dummy is typically covered with accelerometers that measure the acceleration of different parts, like the head and torso. A motion sensor in the chest measures how much it gets compressed during the crash. This information can be used to estimate the severity of injuries to the torso. Load sensors all over the dummy are used to measure other forces acting on it. This extra information helps engineers determine the nature and severity of injuries.

### Seat Belts

Possibly the most important way to protect a person during an accident is to use the seat belt. You have already studied how the seat belt is involved in keeping a person in a car seat. However, early seat belt designs actually caused injuries due to the tremendous force exerted by the belt on the person. Today two design features for seat belts are used to help prevent these types of injuries.

The first seat belt design feature is called a pretensioner. The pretensioner pulls in on the belt when a computer detects a crash (Figure 6). During a sudden stop or a mild crash, the seat belt is reeled in, causing the person to be pulled into the optimal crash position in the seat. This reduces the forces acting on the person and helps keep the person in the car seat. However, if the accident is very violent, the forces exerted by the seat belt on the person may cause serious injury, even if the
person is sitting in the optimal position. A safety feature to help in this situation is a load limiter. Load limiters release some of the belt if a tremendous force starts to pull on it. One simple way to do this is to sew a fold into the belt material. When a person in an accident pushes forward on the seat belt with a large force, the stitching breaks and a greater length of seat belt material becomes available. This decreases the force acting on the person. Another way of making a load limiter is to use a torsion bar. This bar keeps the belt in place by restricting the turning of the spool that is used to wind up the belt material. If a large force acts on the belt, the torsion bar can twist slightly, releasing some of the material and reducing the force acting on the person.

**Car Body Design**

The most noticeable safety feature during a crash test is the crumple zones of the car. At one time, cars were built with rigid frames that were inflexible even during severe accidents. With these cars, drivers and passengers experienced huge accelerations as the car stopped almost immediately during the collision. Crumple zones on cars are designed to crush during an accident. This crushing action increases the time it takes to stop the car during a collision. By increasing the time interval during the crash, the acceleration of the people within the car and the forces acting on those people are significantly reduced. Lower forces mean that it is more likely that the people in the car will survive the accident uninjured.

Another car safety feature involves some parts of the car body being made of plastic. The plastic body parts serve two main purposes during a collision. First, they will not interfere with the crumple zones since plastic is very flexible. Second, the lightweight plastic keeps the mass of the car low enough to make the car easier to stop to avoid a collision.

**Airbags**

Another car safety feature is airbags. These devices are deployed during a car accident to help prevent the people inside a car from hitting a hard surface like the dashboard or steering wheel (Figure 7). A thin nylon airbag is folded in the steering wheel or dashboard. A sensor that detects a collision causes sodium azide to react with potassium nitrate to produce nitrogen gas. The reaction happens so fast that the airbag is pushed out at over 300 km/h. During a car crash, a driver or passenger continues to move forward even though the car comes to a sudden stop. With a deployed airbag, the person collides with the airbag instead of the steering wheel or dashboard. As the person collides with the airbag, it compresses. This increases the time interval of the collision, which further reduces the magnitude of the force acting on the person.

Even when an airbag is deployed, a person can still become injured. If a person is sitting too close to the airbag, the rapidly inflating airbag can cause serious injury to the head and arms. It is for this reason that children should never sit on the passenger seat. Instead, children are more protected from injury when seat belted in the back seat. It is important to keep in mind that a seat belt should be worn at all times, whether or not the vehicle has airbags.
4.4 Summary

- The force of friction acting on rubber tires depends on the surface area in contact with a road surface. For most other substances, the force of friction depends only on the coefficient of friction and the magnitude of the normal force.
- Hydroplaning occurs when a tire loses direct contact with the road surface. This situation occurs when a driver is moving too fast on a very wet road.
- The antilock braking system (ABS) uses a computer to adjust the braking on each car wheel to prevent the wheels from locking up. This helps a driver maintain control of a vehicle when slowing down quickly.
- Electronic stability control (ESC) uses both ABS and traction control to help prevent oversteering or understeering.
- The crumple zones of a car are designed to crush during an accident. The crushing action increases the time it takes the car to come to a stop during the collision. This longer time interval, in turn, decreases the magnitude of both the acceleration and the forces acting on the people inside the car.

4.4 Questions

1. Tire X has treads 8 mm deep. Tire Y has the same design but the treads are 2 mm deep.
   (a) Which tire is more likely to experience hydroplaning when driving on a wet road? Explain your reasoning.
   (b) What happens to the force of friction acting on the tire as the surface area decreases during the transition stage of hydroplaning? Explain your reasoning.

2. In Figure 8, the red marks show where tire wear has occurred for improperly inflated tires. Describe what effect, if any, these wear patterns might have on a car travelling on a wet road.

   ![Figure 8](image)

3. Describe what happens to the water levels near a tire as it travels on a wet road at ever-increasing speeds. Explain how these water levels affect the force of friction acting on the tires.

4. Compare the disc brake on a car to the brakes on a bicycle. How are the two braking systems different?

5. Some stationary exercise bikes have a control that adjusts the amount of friction on the wheel.
   (a) What is the purpose of this device?
   (b) Describe a possible design for this device. Include a diagram in your description.
   (c) Describe how you would perform an investigation to determine the relationship between the setting on the control and the maximum force of static friction acting on the wheel.

6. Explain how disc brakes work in terms of forces and Newton's laws.

7. Discuss the validity of the statement, “Car brakes slow the wheels down but friction from the road slows the car down.” Explain your reasoning and give examples to support your arguments.

8. Explain how ABS helps to achieve each result listed below, even though it periodically reduces the friction on the wheel.
   (a) reduce the stopping distance
   (b) help the driver maintain control of the car

9. (a) Compare and contrast ABS and traction control.
   (b) Explain how and when ESC uses ABS and traction control.

10. Explain how crumple zones help to reduce the force on people inside a car during an accident.

11. Describe two new safety innovations involving seat belts.

12. (a) What is the purpose of an airbag?
    (b) Explain how an airbag works.
    (c) Explain how airbags help protect people in cars during a collision.

13. Tires are rated according to their traction, temperature, and tread wear. Research this rating system and briefly describe the meaning of each rating characteristic.