4.5 Forces Applied to Sports and Research

Newton's laws of motion and the principles of gravity and friction are involved in many activities and technologies all around us. Some of these applications involve reducing forces, such as Teflon coatings on frying pans or applying wax to skis or snowboards. Others involve increasing forces, as in the design of golf clubs (**Figure 1**) or running shoes. In this section, you will learn about many new applications for forces in sports and research. To understand these applications, you will use everything you have learned in this unit.

Figure 1 A stroboscopic photograph of a typical golf swing. What forces are involved in making the golf ball move as far as possible?

Forces Applied to Sports

In many different sports, there are times when you want to increase forces and other times when you want to decrease forces. We will examine a few examples of these applications of forces.

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Golf Club Design

In many sports, a player has to move a ball or puck as quickly as possible by striking it. In volleyball, basketball, and football, players use their arms to do this. In soccer, players use their legs. In hockey, cricket, baseball, and golf, players use another object such as a stick, bat, or club. Here we will examine the physics of a typical golf club.

The typical golf swing for a long-distance shot involves making the head of the club hit the ball as fast as possible without twisting the head of the club. The faster the club head is moving when it strikes the ball, the farther the ball will travel. However, if you swing the club harder, it does not always work. If the centre of the head (called the sweet spot) does not make contact with the ball, the head may twist and the ball will travel in the wrong direction. A better-designed club can typically increase distance and control, but it cannot make an inexperienced golfer into a good one.

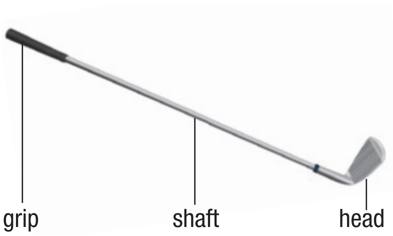

Figure 2 The parts of a golf club

The different parts of a golf club are shown in **Figure 2**. The grip is made of either leather or rubber. Its purpose is to increase the force of static friction acting on the player's hands, increasing control. The shaft connects the grip to the head and is made of steel or a carbon-fibre resin composite. The carbon fibre is lighter but more expensive. The length of the shaft varies with the type of club. Clubs that are designed to move the ball over long distances have a longer shaft and are called woods. Clubs that are meant for shorter distances have shorter shafts and are called irons. The shafts vary in stiffness as well. A less flexible shaft is meant for players who can move the club quickly. More flexible shafts are meant for players who tend to whip the head of the club around to gain speed. The head of the club is the part that makes direct contact with the ball. Heavier heads tend to twist less when they hit the ball off centre, but they are harder to swing and hit the ball more slowly.

In other sports, a player must also use good technique to hit a ball or puck as fast as possible, as in the case of a good hit in baseball, a hard shot in hockey, or a hard spike in volleyball. In the end, a better hockey stick helps, but nothing replaces skill and practice.

Footwear Design

In many sports, the footwear worn by an athlete is just as important as any other piece of equipment used in the game. Sometimes the footwear is designed to decrease the force of friction, as with skates. At other times, the frictional forces must be increased to help athletes stop and start quickly, as with running shoes.

The coefficient of kinetic friction of a skate blade on ice may be as low as 0.005, when the ice is perfectly smooth. Physicists thought that this very low coefficient of friction was due to a very thin layer of water forming between the blade and the frozen ice. They thought that the pressure of the skate pushing down on the ice caused the ice to melt, making it more slippery. Physicists now know that this is only a factor when the ice is at exactly 0 °C. Ice that is colder than 0 °C will not become more slippery due to this effect.

Physicists have found that a thin liquid layer of slushy water exists naturally on the surface of ice rinks. It is this slushy layer that reduces the coefficient of kinetic friction. The layer is usually very thin (10^{-8} m) and it gets thinner as the ice is cooled. At –25 °C, the slushy layer does not exist at all, and the coefficient of kinetic friction of a steel skate blade on ice is 0.6, which is comparable to most other coefficients of friction. Modern skate blades are slightly curved at the bottom (**Figure 3**). This allows the skater to dig the edge of the blade into the ice and use the normal force to push forward when accelerating.

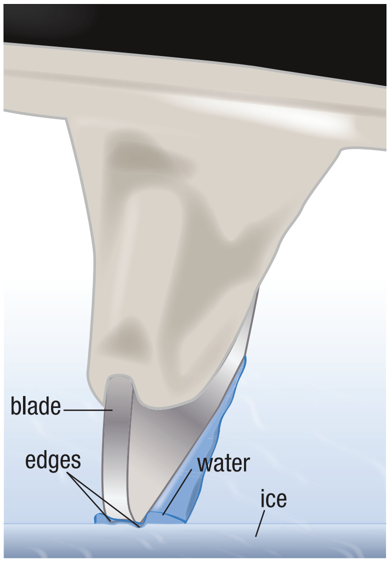

Figure 3 A layer of slushy water that forms between the bottom of a skate blade and the ice reduces the force of friction. The bottom of the blade is curved to help a skater dig into the ice to accelerate.

Running shoes are designed to increase the force of static friction exerted by the ground on the athlete. This allows the athlete to accelerate at greater rates. This design is extremely important in sports where quick starts and stops are required. It also helps an athlete have greater manoeuvrability. Running shoes are also designed to protect ankles and knees from injuries during strenuous activities. They are also designed to be as light as possible to reduce weight and help increase speed.

The typical design of a running shoe is shown in **Figure 4**. The bottom tread of the shoe (called the outsole) is made from a durable carbon-rubber compound to help increase the coefficient of static friction. The midsole is made from foam to help reduce the magnitude of forces acting on the ankles and knees as a person is running. The inner part of the midsole is often made of a harder material to provide stability, while the outer part is made of a softer material to help cushion the impact. It is not unusual for the magnitude of the normal force to triple during various sports activities. The cushion helps absorb some of this impact. Some midsoles include air or gels to help further absorb the impacts when running.

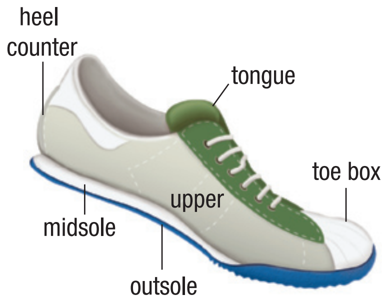

Figure 4 The parts of a running shoe

The upper part of the shoe is designed for comfort and to decrease movement of the foot within the shoe. The heel counter is a hard cup-shaped device used to promote stability and the movement of the heel. The forces exerted by an athlete on the ground while running can be very large in magnitude, but from Newton's third law, a force of equal magnitude is exerted by the ground on the feet in the opposite direction. The best running shoes allow an athlete to quickly accelerate, while at the same time absorbing some of these forces to protect the athlete from injury.

Bearing Design

One way to reduce friction and increase efficiency of devices such as generators, motors, and fans is to use bearings. Bearings are devices that allow surfaces to slide or roll across each other while reducing the force of friction. Many different types of bearings can be used under different circumstances. A plain bearing involves sliding two surfaces across each other while they are lubricated with oil or graphite. A rolling element bearing uses balls or rollers to reduce friction (**Figure 5**). The balls or rollers are usually lubricated with oil. Both of these types of bearings have been used for years and can have very low coefficients of friction.

Some newer types of bearings can reduce friction to negligible levels in some cases. For example, fluid bearings use a film of fluid, such as air or oil, to separate two surfaces (**Figure 6**). The fluid film reduces the force of friction drastically in a similar way that a thin layer of water separates a skate blade on ice. Fluid bearings require a seal to keep the fluid in place and a pump to replace the fluid when it leaks. These bearings can be made cheaply, and they create less noise when operating than rolling element bearings. However, they can fail suddenly without warning if the seal breaks. These types of bearings also use energy to keep the lubricant in place. A typical use for fluid bearings is in the hard drive of a computer.

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Figure 5 A typical rolling element bearing

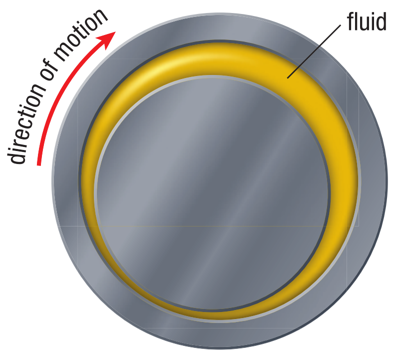

Figure 6 A typical fluid bearing

Magnetic bearings use magnetic fields, instead of fluids, to keep two surfaces separated. The two surfaces do not make direct contact with each other, so this technology is often called magnetic levitation. Magnetic bearings often require a backup bearing system in case they fail. Electricity is required to operate the electromagnets that keep the surfaces separated. So energy is required to keep the bearings working. However, the bearings need no maintenance and have no known upper limit on speed. Typical uses of magnetic bearings are in motors, turbines, generators, Maglev trains, and household meters.

Forces Applied to New Innovations

One area of interest in current physics involves the design of artificial limbs. Another area of current research is in developing materials that have very low coefficients of friction.

Prosthesis Design

A prosthesis is an artificial device that replaces a missing body part. This application of forces involves replacing parts of the body that have been damaged by accident or disease or are the result of birth defects. These artificial body parts could be dentures, hip replacements, heart valves, or even artificial hearts. In this section, we will examine artificial limbs.

Artificial limbs have seen many recent improvements, involving new materials that are lighter, more durable, and more flexible than previous materials. Some claim that these new materials and designs actually give an amputee a physical advantage over other athletes. For example, a newly designed artificial leg is lighter and stronger than a human leg. This might allow an athlete to run faster and longer than they normally could. For example, Oscar Pistorius of South Africa (**Figure 7**) was not eligible to compete in the 2008 Summer Olympic games because it was believed that his artificial legs gave him an unfair advantage. The ruling was eventually overturned; however, Oscar did not end up qualifying. He did very well, though, in the Paralympics.

The design of artificial limbs has progressed even further. Scientists and engineers are working on making them look and act more like real limbs. One technique involves targeted muscle reinnervation (TMR). This method uses a robotic arm or leg that is connected to different muscles in the body. When the patient thinks about moving the artificial limb, the muscles contract and the sensors detect the contraction, making the limb move. The U.S. Pentagon's research division, Defense Advanced Research Projects Agency (DARPA) is funding work on connecting the artificial limb directly to the human nervous system.

The Proto 1 is the prototype that uses TMR to control an artificial mechanical arm (**Figure 8**). These artificial limbs are designed for people who have lost a limb. The Proto 1 can complete tasks previously thought impossible by a mechanical arm. The arm can perform complex tasks such as taking a credit card out of a wallet or stacking cups using sensory feedback from the arm rather than vision. One of the main advantages of this type of arm over other similar devices is the ability to closely monitor the force of the grip of the hand and to easily make adjustments to the amount of force.

New designs are expected to have greater degrees of freedom and behave even more like a human arm. The next Proto design will have 80 different sensors that provide feedback about touch, position, and even temperature.

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Figure 7 Oscar Pistorius has been referred to as the "blade runner" from South Africa.

Figure 8 The Proto 1 mechanical arm

Near-Frictionless Carbon

One of the major problems in mechanical devices is wear and loss of efficiency due to friction. At one time, Teflon seemed to be the answer to this problem. Teflon has a low coefficient of friction and can be used as a coating on non-stick frying pans and pots to help reduce the amount of oil required when cooking. However, near-frictionless carbon is now the frontrunner in the race to produce a solid substance with the lowest coefficient of friction.

Near-frictionless carbon has a coefficient of friction less than 0.001, whereas Teflon has a coefficient of 0.04 when tested under the same conditions (**Figure 9**). The coating of near-frictionless carbon is very hard and resists wear from sliding and rolling. It can be applied to many different types of surfaces and reduces the need to replace and repair moving parts in many different types of machines. High-tech applications are being researched in the space program and in aircraft design, for example. However, any type of bearing could make use of this new carbon coating. This technology may eventually become cheap enough to be used in automobiles and compressors such as air conditioners.

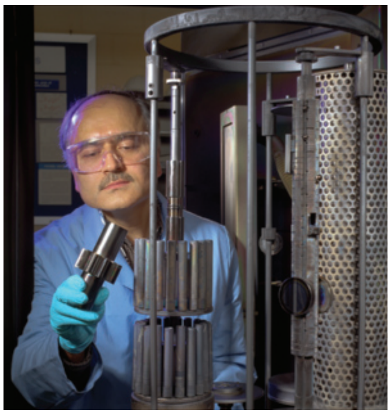

Figure 9 A researcher examining a coating of near-frictionless carbon

4.5 Summary

- The study of forces can be applied to improve sports technology.
- Bearings are used to decrease the force of friction and improve efficiency.
- New research into innovations with forces involves fields of study such as prosthesis design and materials such as near-frictionless carbon.

4.5 Questions

1. The physics involved in striking a golf ball and making it move as fast as possible is similar in many ways to the physics involved in striking a puck or ball in many other sports. K/U A
   (a) Describe how a spike in volleyball is similar to hitting a golf ball.
   (b) How is a slapshot in hockey similar to striking a golf ball?
2. A baseball bat has a sweet spot when it strikes a baseball. K/U T/I A
   (a) What does the term "sweet spot" imply about the motion of the ball after the swing?
   (b) Research what happens to the motion of the bat and the batter if the ball hits the bat at positions other than the sweet spot.
3. Examine the typical golf swing in **Figure 1** on page 184. What evidence do you have from this photograph that the golfer is using good technique when striking the golf ball? K/U
4. At one time physicists thought that the blade of a skate pushing down on the ice created a thin layer of slushy water that decreased the force of friction acting on the blade. K/U
   (a) Explain why physicists now know this is not true.
   (b) Why do skates actually slide so easily over ice?
   (c) Why will blades not slide easily over extremely cold ice?
5. The Therma Blade uses a small battery to heat the skate blade when the player is on the ice. This type of skate blade experiences significantly less friction than a normal hockey blade. T/I C A
   (a) Explain why the Therma Blade experiences less friction than a normal hockey blade on ice.
   (b) A battery must be inserted into the hollow plastic above the top of the blade. Why might this be considered a disadvantage?
   (c) Research the Therma Blade. Describe how it works and its current level of use. Discuss the advantages and disadvantages of the blade.
   (d) In your opinion, should the Therma Blade be allowed in hockey leagues across Canada? Explain your reasoning.
6. The ancient Egyptians used rolling logs to move large blocks of stone when building the pyramids. How is the physics of a rolling element bearing similar to this ancient method of reducing friction? A
7. (a) Describe a typical fluid bearing, and explain how it reduces the force of friction acting on two surfaces.
   (b) Compare the physics of a fluid bearing to that of the blade of a skater on ice. K/U
8. (a) Describe how a magnetic bearing works.
   (b) What disadvantages do magnetic bearings have over rolling element bearings? K/U
9. Some people with artificial limbs want to compete with athletes in the Olympics and in other sports events. C A
   (a) Give three reasons why this should be allowed and even encouraged.
   (b) As technology improves, artificial limbs may provide a significant advantage to people using them. Should professional athletes using artificial limbs be allowed to compete with those who do not use these limbs? Explain your reasoning.
10. There has been some debate recently that some people might wish to replace properly working parts of the body with prostheses. This may become more prevalent as the technology begins to improve and prostheses become better at performing tasks than the actual human body. T/I A
    (a) Research some of the new advances in prostheses.
    (b) How do you feel about this possible trend in the use of this technology? Should governments get involved with this issue? What kind of legislation should be passed, if any? Explain your reasoning.
11. A common use of prostheses today is the artificial hip. What characteristics do you think the materials used in a hip replacement must have to be able to function properly? A
12. Describe the properties of near-frictionless carbon and discuss how it might be used in the future. K/U

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