LEGO® Spybotics™
Secret Agent Training Manual

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LEGO® Spybotics™ Secret Agent Training Manual

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SPYBOT MECHANICAL SYSTEMS TRAINING

Your choice of Spybot can make the difference between mission success and failure. This chapter covers some of the features common to all Spybots and the features that make each Spybot unique. You'll also find some ideas to consider when you develop your own Spybots.

This chapter covers the following topics:

- Identifying the common features of each Spybot
- Determining the relative speed and strength of a Spybot
- Describing the special features of each Spybot

One of the techniques I use to explain the Spybot features and operation is simple exercises designed to help you understand what's going on by thinking and acting like a Spybot. Experienced designers and engineers will often do this to get a better grasp of the problems they might have with their projects.

Common Spybot Features

The basic LEGO Spybot brick is the same (except for the color of the transparent domes) on all of the Spybots. Chapter 3 goes into more detail about the electronic systems in your Spybot. In this section, I just talk about the mechanical aspects of the Spybot brick.

Each Spybot brick has a battery compartment, a touch sensor, and two motors, as shown in Figure 2-1. Each of these mechanical features either provides input to or is controlled by the computer inside the Spybot brick.

Touch Sensor

Battery Compartment on Bottom

Left Motor Drive Shaft
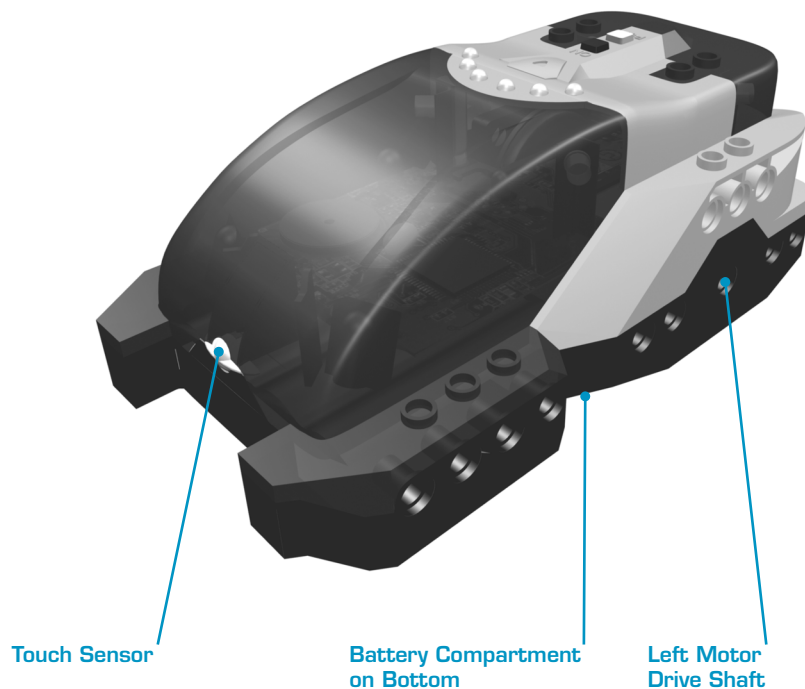
▲ **Figure 2-1.**
Spybot brick mechanical features

If you look closely at your Spybot and/or the Spybot in Figure 2-1, you'll notice the following additional features:

● **Two buttons on top:** The black button is the power button, and the silver/gray button is the Run button to run the current downloaded program.

● **Six lights in an arc:** These lights are for display. During missions, various lights display for the S.M.A.R.T. agent to make appropriate responses. The lights also indicate the status of a mission. When you first turn the Spybot on, the number of lights displayed indicates your current Spybotics security clearance.

● **Center yellow light:** This light displays information during missions and shows you that the Spybot is ready to start a mission.

You will learn more about these additional features in the appropriate sections of Chapter 3.

The Battery Compartment

On the underside of the Spybot brick, you'll see a panel with beveled edges and an arrow molded into the part. Gently push the panel in the direction of the arrow and lift it clear of the battery compartment. There is room for three AA (LR-06) batteries. For more information on batteries, see the "Choosing Among Battery Alternatives" section in Chapter 4.

When you insert batteries into the compartment, be careful to ensure that the "button" on the top of each battery is pointing in the right direction. There is a picture molded into the bottom of the compartment that will help you get it right. Remember, you can't hurt the Spybot by inserting the batteries the wrong way, but it won't work if you do so.

When you replace the panel, make sure the arrow is pointing to the front of the Spybot (see Figure 2-2). You should also make sure that the front of the panel is in line with the front of the Spybot. Then gently push the panel back to seal the battery compartment.
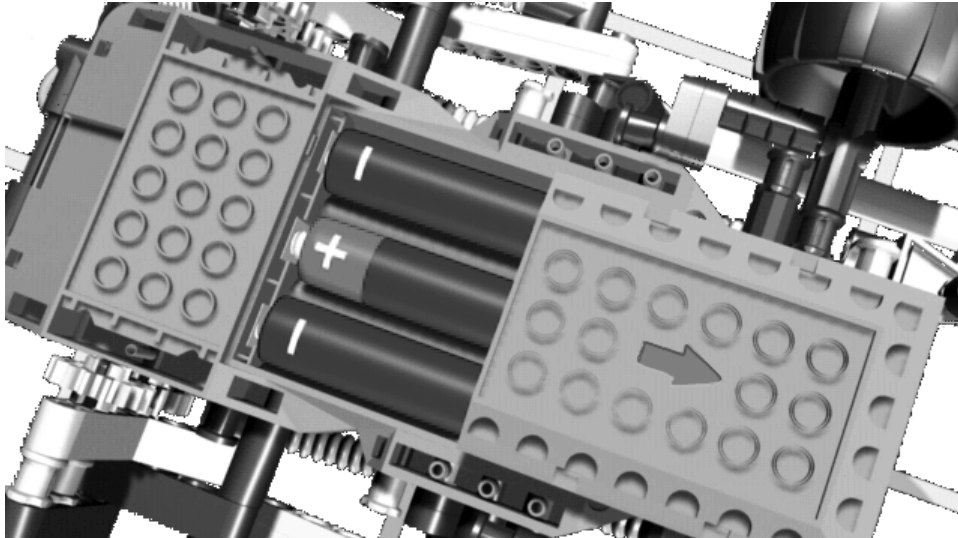
▲ **Figure 2-2.**
Spybot brick battery placement

If you're thinking about building a custom Spybot, it's good to keep the access to the battery compartment free of any obstructions. Avoid running bracing or suspension parts across the battery compartment.

The Touch Sensor

The Spybot *touch sensor* is used to detect when the Spybot has hit something. It looks simple by itself, but it can be quite a challenge to build a good bumper for the sensor. Although the sensor is designed with a "shock absorber" to minimize damage when it is fully pressed, it's not a good idea to allow your Spybot to simply crash into things.

For one thing, the touch sensor is very narrow. This means you have to be pretty lucky to hit anything at all. Another thing to watch out for is that the Spybot models generally have wheels or tracks that extend past the front of the brick. This makes it even harder to activate the touch sensor.

All Spybots have a bumper, and as you might expect, S.M.A.R.T. has gone to a lot of trouble to design bumpers that are easy to activate and yet protect the Spybot brick. Here's an exercise you can do to prove to yourself that a flexible yet strong bumper is a good thing to have.

EXERCISE

Spybot Bumper Design

Imagine that your nose is a touch sensor. What will happen if your target is the wall and you have no bumper to protect your nose? You probably don't need to do this part of the experiment to come up with the answer, right?

Now put your arms straight out in front of you and lock your elbows (see Figure 2-3A). If you walk toward the wall, your hands will hit the wall and the shock will be transmitted right back to your shoulders. This time your nose is protected, but your arms are not flexible enough to prevent possible damage to the rest of your body.

A   **B**

▲ **Figure 2-3.**
Experimenting with bumper designs

Now put your arms in front of you and bend your elbows slightly (see Figure 2-3B). When you get to the wall, your arms flex, which takes up almost all of the impact. As your arms flex, your nose gets closer to the wall and will eventually touch the wall gently.

As you can see, even something as simple as a bumper needs careful design. The "Individual Spybot Features" section later in this chapter describes each bumper in more detail.

The Drive Motors

There are two motors on each Spybot. You can direct each motor individually from the handheld controller. On a normal remote control car, you have one motor that drives the vehicle forward and backward, and another that steers the vehicle. Why don't the Spybots use this arrangement?

The answer is simplicity and cost. The S.M.A.R.T. design team realized that a conventional steering system would have more parts and would be more likely to break. Like all good designers, they looked around for a system that was simple to build and operate. The system they decided to use is called a *differential drive* mechanism—one motor moves one side of the vehicle, and the other motor moves the other side. You'll most often see this kind of mechanism on construction equipment, where strength and reliability are important.

You can find the differential drive system in all kinds of equipment, including bulldozers (see Figure 2-4), skid-steer loaders, huge excavators, and even commercial lawn mowers. This type of system has the advantages of being very simple to build and easy to control. But there is one disadvantage—can you think of what it is?
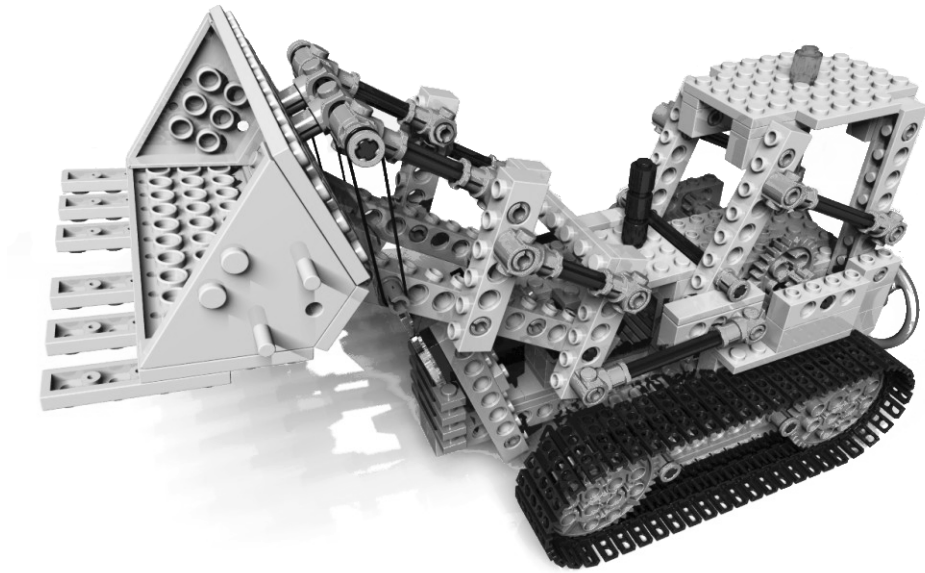
▲ **Figure 2-4.**
LEGO Set 914 bulldozer (courtesy of Coby at http://tubafrog.com/lego)

If you guessed *friction*, you're right. If you guessed another exercise is coming up, you're right again.

EXERCISE

Friction

To understand how differential drive works and how it's affected by friction, stand on a smooth floor with just socks on your feet. When you move, take small steps by taking some weight off one foot and shifting that foot forward or backward slightly before putting it down again. Try to keep your feet about shoulder-width apart and parallel.

Moving forward and backward is no problem. To turn to the left, keep your left foot on the ground and move your right foot forward a few times. See how your left foot spins on the smooth floor? This is where the friction comes from. You've got socks on, and the floor is smooth, so it's easy for your foot to skid in the turn. If you've ever run down a long hall in socks and skidded, you know what I'm talking about.

Now put clean sneakers on your feet and try to turn. Remember to keep your shoes flat on the floor. Don't lift the heels or toes of the shoes. The rubber soles on the sneakers have better contact with the smooth floor, so they have more friction. It's actually hard to turn one of your feet unless you reduce the contact patch by raising the heel or toe. That's why basketball players lift their heels when they pivot to look for some-one to pass the ball to. Friction is also the reason you can't slide down that long hallway with new sneakers on your feet.

The main idea here is that a machine with differential drive steers by turning only the drive wheels or tracks on one side. You don't actually point the wheels in the direction of the turn like you do with a bicycle or a car. Now that you have an idea of how differential drive or skid steer-ing works, you can probably find other examples of machines that use this control method.

Determining Spybot Speed and Strength

Each LEGO Spybot has a different arrangement of gears, wheels, and tracks that allow it to move freely. All of the Spybots except for Snaptrax use gears to transfer motion from the motor to the drive wheels.

But how do the gears affect the speed and strength of the Spybot? This section of the book will help you understand how gears work, and it will also provide design information that Spybot builders can use for their own creations.

The Spybots use the simplest possible gear train. The motor shaft drives the input gear, which drives the output gear, which is connected to the wheels (see Figure 2-5). The Shadowstrike, Technojaw, and Gigamesh units each have a small gear driving a larger one. The Snaptrax drives its output wheel right from the motor.

12-Tooth Output Gear

Drive Shaft from Motor

Output Shaft to Wheel

This simple drive train uses a 12-tooth gear on the input shaft to drive the 20-tooth gear on the output shaft. The gear ratio is 12:20 or 3:5.

20-Tooth Output Gear
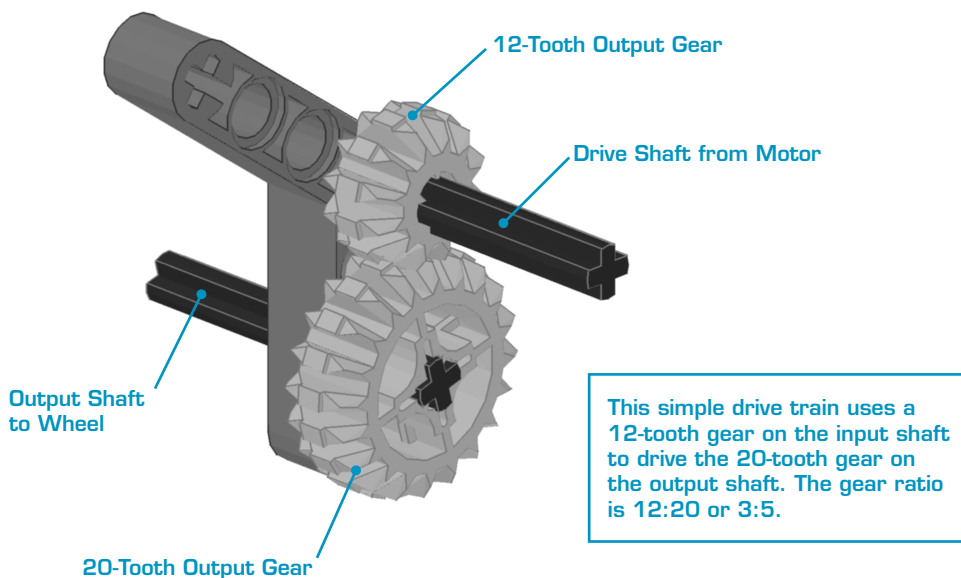
▲ Figure 2-5.
Simple Spybot gear train

Before you can figure out how fast the Spybots will go, you need to do a bit of background work using simple math. Don't worry if you think you're not good at math. By the time you finish this section, you'll be an expert on measuring circles and figuring out gear ratios.

Measuring Circles

The time has come to do another exercise. This time, you're going to figure out the relationship between the distance across a circle and the distance around a circle. If you already know the answer, you can skip this exercise.

EXERCISE

Distance Across a Circle vs. Distance Around a Circle

For this exercise, you'll need the following items:

- A few round household items (soda can, coffee mug, CD, and so on)
- A piece of string large enough to go around the biggest item
- A ruler
- A calculator

First, write down the names of the household items you selected in the Household Item column in Table 2-1. Wrap the string around each of the household items and keep track of where the string overlaps. This distance is the *circumference* (the distance around) the object.

Measure the distance from the end of the string to this overlap point and write down the result in the Circumference column in Table 2-1.
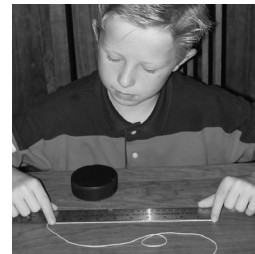
Then measure across the widest part of the item to get the *diameter* of the item and write that number down in the Diameter column in Table 2-1. Don't worry about the Ratio column just yet. I've filled the first row in to get you started.

▼ **Table 2-1.**
Circle Measurement Results

HOUSEHOLD ITEM	CIRCUMFERENCE	DIAMETER	RATIO
Dessert plate	20.875 in. (530 mm)	6.625 in. (168 mm)	3.154
_____	_____	_____	_____
_____	_____	_____	_____
_____	_____	_____	_____

It's a little easier if you use millimeters (mm) for the measurement. If you use inches (in.), you might need to get a grownup to help you convert the fractions into decimal numbers. For example, if you measure 8 3/4 inches for the circumference of an item, write down **8.75 in.** in the Circumference column.

Now, to fill in the Ratio column, divide the circumference by the diameter using your calculator. Write down the result for each row in the last column. The interesting result is that the numbers should all be pretty much the same, depending on how carefully you measured the circumference and diameter.

What you have just done is figured out an approximate (rough) answer for the value of π (pi). Without getting into a lot more detail than you need right now, the real value of π is about 3.14159.

No matter what the size of the circle, you can always figure out the distance around if you know the diameter by multiplying it by π. On the other hand, if you know the distance around the circle and you want to know the diameter, you just divide by π. Figure 2-6 shows you how to calculate the circumference and diameter of a circle with π.

$$D = C/\pi$$

C is the circumference
D is the diameter
π is about 3.14159

$$C = D \times \pi$$
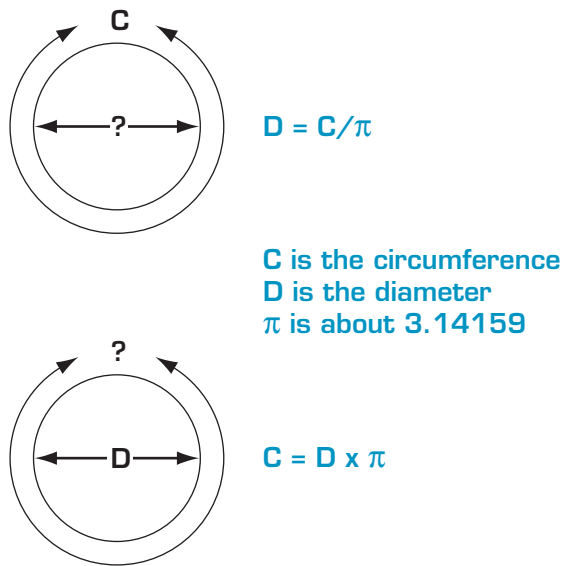
▲ **Figure 2-6.**
Calculating the circumference and diameter of a circle

So what does all this have to do with how fast a Spybot can travel? Read on to find out.

Speed and Wheel Size

Now that you have a simple way of figuring out how big around a circle is (its circumference), you can move on to calculating speed. Have a look at the small wheel (the wheel at the top of the diagram) shown in Figure 2-7. If the small wheel has a diameter of 10 inches, how far will it travel in one revolution? (Hint: The distance around the wheel [circumference] is how far the wheel will travel in one revolution.)
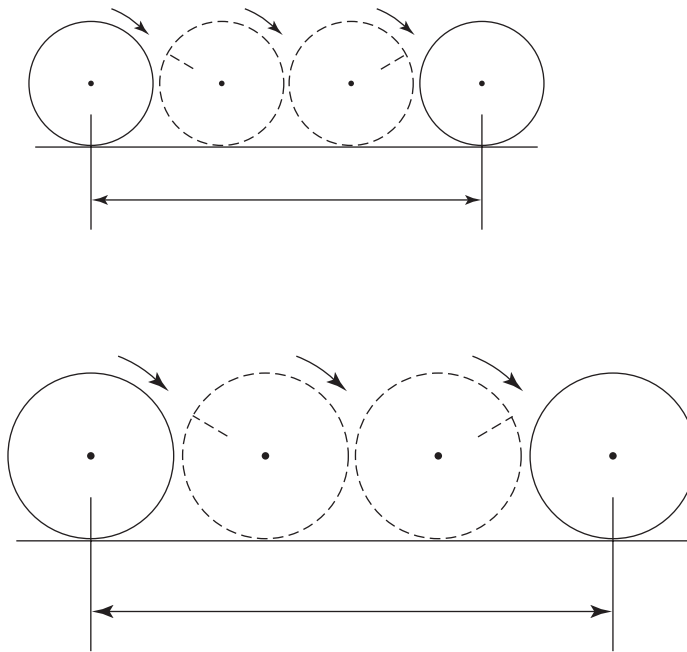
▲ **Figure 2-7.**
Which wheel moves farther in one turn?

If you answered 31.4159 inches, you're right! Now look at the big wheel (the wheel at the bottom of the diagram) in Figure 2-7. It has a diameter of 15 inches, so it will travel 47.1239 inches in one revolution. OK, this is the cool part. Let's say each wheel turns at the same speed of one revolution per second. An engineer would say that each of the wheels has an *angular velocity* (turning speed) of one rotation per second. If you put these wheels side by side, how far does each one travel in 1 second?

The small wheel goes 31.4159 inches in 1 second, and the big wheel goes 47.1239 inches in 1 second. So not only does the big wheel go further in one turn, it also goes forward faster!

Hang on, you're almost ready to put this all together to calculate Spybot speed. You just need one more bit of information, and that's how the gears change the speed of rotation of the motors to the wheels.

Spybot Gear Trains

All of the Spybots use a simple arrangement called a *gear train* to translate the rotation of each motor's axle to the drive wheel. The Spybot sets use the newer LEGO gears that can be used inline or at right angles to each other. If you have any of the LEGO BIONICLE sets, you're probably familiar with this already.

The gear trains used in Spybots are very easy to understand. If you have a bicycle that has adjustable gears, you already have a good idea of how they work. Let's say you have a bike with a six-speed block on the back wheel and a single fixed gear on the chain ring (see Figure 2-8). To go faster, you make the chain go on the smaller gears, but then it's harder to turn the pedals. To go up a hill, you put the chain on the bigger gears, but then you travel more slowly.

Output Gear (6 Speeds)   Input Gear

▲ **Figure 2-8.**
Parts of a bicycle gear train

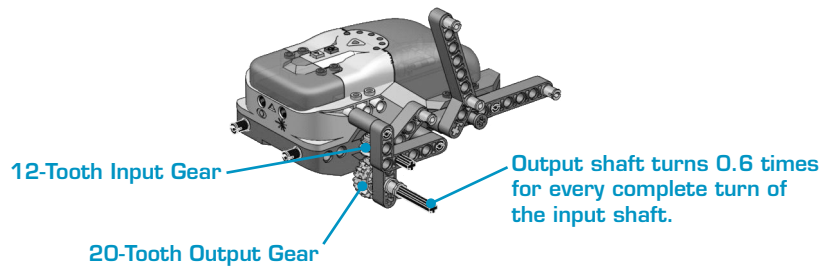**NOTE** Engineering is the art of trading one property for another to achieve a goal. When you ride your bicycle and change gears to go faster or to climb hills, you are making decisions about trading speed for power. The more you understand how these things work, the better your ability to make these kinds of engineering decisions.

It's time for another exercise. This time you'll use the Technojaw gear train as your example.

Calculating a Simple Gear Ratio

As you can see in Figure 2-9, Technojaw's 12-tooth gear is attached to the motor drive shaft, and its 20-tooth gear is attached to the wheel axle.

12-Tooth Input Gear

Output shaft turns 0.6 times for every complete turn of the input shaft.

20-Tooth Output Gear

▲ **Figure 2-9.**
The Technojaw gear train

A bit of thought will help you figure out how far the axle turns for every motor revolution. Let's say that the gear on the motor axle turns by one gear tooth. How many teeth does the gear on the wheel axle turn by? Also one tooth. So after the motor gear turns by one full revolution (12 teeth), the wheel gear has also rotated by 12 teeth. But the wheel gear has 20 teeth, so it has only turned by 12 out of 20 teeth. That's 12/20 or 3/5 or 0.60 revolutions for every revolution of the motor.

Calculating Spybot Speed

Now you can combine your work on circles, wheel speed, and gear trains to figure out the relative speeds of the Spybots. Because I'm an engineer, I like to make tables for this kind of calculation because then I can see all of my work. Creating a table also helps because the calculations are basically the same for all the Spybots.

You're going to figure out the relative speeds of the Spybots, so you start by assuming that the motors are all the same and turn at one revolution per second. Then you use the gear-train ratio to figure out the drive axle speed. Finally, you multiply by the wheel circumference to get the relative speed of the Spybot. I've worked out the answer for Shadowstrike in Table 2-2 to get you started.

▼ **Table 2-2.**
Spybot Speed Calculation Results

SPYBOT	MOTOR GEAR	AXLE GEAR	RATIO	WHEEL CIRCUM-FERENCE	SPEED
Technojaw	12	20	_____	_____	_____
Snaptrax	direct drive	direct drive	1	3.125 in. (80 mm)	3.125 in. (80 mm) per motor rev
Gigamesh	12	36	_____	5.44 in. (138 mm)	_____
Shadowstrike	12	20	0.60	6.25 in. (158 mm)	3.75 in. (94.8 mm) per motor rev

The wheel circumference is a bit tricky to calculate for some of the Spybots. The easiest way to get the wheel circumference is to make a little mark on one of the tires and place the mark on the tire at the end of a line drawn on a sheet of paper. Roll the tire until the mark touches the paper again and measure the distance between the marks. That's the circumference. The Snaptrax wheel circumference is difficult to calculate because it's a track, so I've filled that in for you in Table 2-2 also.

If you assume that all of the motors spin at the same speed, you can already see that Technojaw is slightly faster than Snaptrax. Can you figure out the speed of the rest of the Spybots? After you've filled out the table, check to see if your answers are correct by looking at the http://www.hempeldesigngroup.com/lego/spybotics Web site.

As you'll see in the next section, speed isn't everything. Each Spybot has its own special features that make it suited to particular tasks.

Individual Spybot Features

The Spybots are all capable of detecting light, moving in all directions, and figuring out when they have hit an obstacle with their front bumper. But sometimes you'll need special features that give your Spybot the edge. Let's look at each Spybot and figure out what makes it unique.

I start by describing the simpler designs, Snaptrax and Gigamesh, and then I move on to Technojaw and Shadowstrike.

Snaptrax S45 Features

The Snaptrax Spybot is simplest of all of the Spybots (see Figure 2-10). It has no gearing between the motors and the drive track, just a special drive axle that has a shoulder to keep it in place. The axle is unique because it is made of a softer plastic than the normal LEGO axles. This helps to protect the motor from shocks.
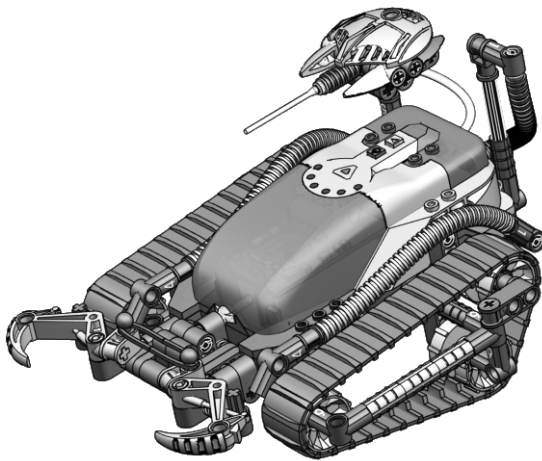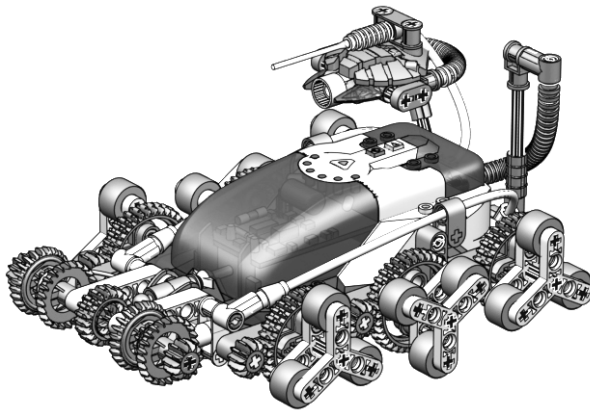

▲ **Figure 2-10.**
The Snaptrax S45 Spybot

The Snaptrax is relatively narrow and is well protected against attack from other forces. The tracks have guardrails to keep obstacles away, and the snapping claw arrangement on the front is combined with a simple but effective bumper to protect the main brick.

Just about the only disadvantage to Snaptrax is that you have to be careful about how you control it. If you drive backward and then quickly change to driving forward, you can make Snaptrax "pop a wheelie," which makes it more difficult to control and also more vulnerable to attack.

Gigamesh G60 Features

The Gigamesh Spybot is certainly a powerful-looking device (see Figure 2-11). With its strange, three-pronged wheels, it can find traction on even the bumpiest terrain. Because of its extremely low gear ratio, it is also the slowest Spybot, but it makes up for its slow speed in brute strength.
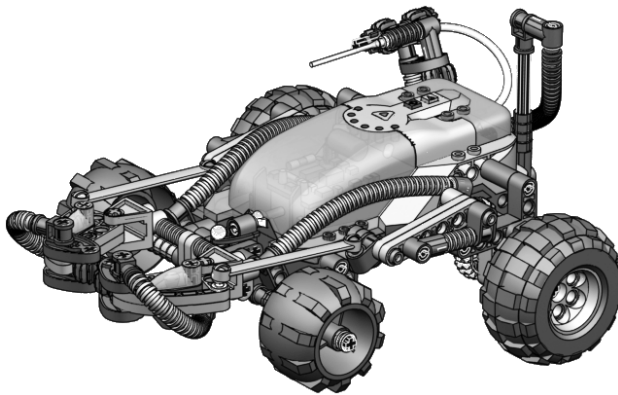

▲ **Figure 2-11.**
The Gigamesh G60 Spybot

The Gigamesh is also a narrow Spybot, and it is very stable because it is low to the ground. It has a simple bumper arrangement, and it has an intimidating set of grinding gears along its front edge. With all of the gears that come with Gigamesh, you can be assured that other building ideas will come to you.

One of the disadvantages of Gigamesh is the complexity of its gears. One or two times, I've had loose LEGO elements get caught between Gigamesh's Y-shaped wheel holders. The only way I found to clear the blockage was to reverse direction and twist away from the obstacle(s).

Technojaw T55 Features

Technojaw is a very interesting Spybot because it combines speed with an unusual "pinching" action of its front claws (see Figure 2-12). If you look closely at the drive mechanism, you'll see that if you drive Technojaw forward, the drive train pulls the jaws open. If you stop Technojaw, the jaws close automatically.
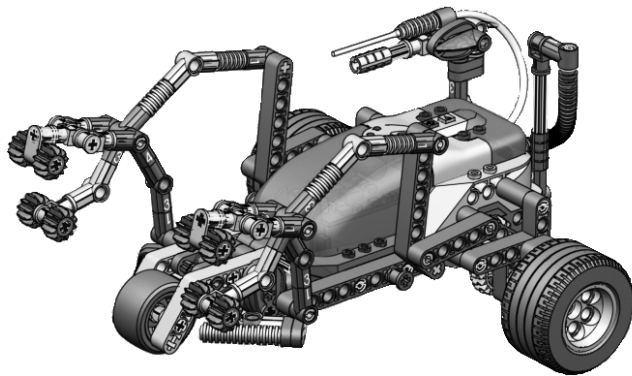

▲ **Figure 2-12.**
The Technojaw T55 Spybot

Technojaw is quite wide. This is to make it easier to accommodate the pincher mechanism within the protection of the balloon tires. The plastic tires at the front seem a bit out of place, but an experienced Spybot agent will soon figure out why the designers didn't use rubber. The reason is because the tires act as skids when Technojaw turns. The rubber wheels would have too much friction and it make it very difficult to turn Technojaw.

Technojaw has a great assortment of parts that are useful in other Technic creations. If Technojaw has one disadvantage, it's width. The width of this Spybot makes it difficult to maneuver in tight situations.

Shadowstrike S70 Features

Shadowstrike is a very cool Spybot (see Figure 2-13). It has the same type of pinching action as Technojaw, but it's much more exaggerated. Shadowstrike also has an unusual three-wheeled configuration that combines a skidding wheel with a bumper. The very narrow bumper and deflection beams make Shadowstrike less likely to hit obstacles and register them on the touch sensor.

▲ **Figure 2-13.**
The Shadowstrike S70 Spybot

Shadowstrike is also a wide robot, but its narrow front profile makes up for it. Shadowstrike has a good assortment of beams and axle connector parts, which makes for interesting secondary models.

If there is one disadvantage to Shadowstrike, it's the complexity of the gripper mechanism. In close combat with another Spybot, there is always the danger that Shadowstrike's gripper will get caught on something.

Summary

In this chapter, I went over the basic physical and mechanical features in each LEGO Spybot and gave you some detailed engineering calculations that you can use to compare Spybot speeds. Along the way, you've learned a few things about gears and drive trains too. I compared the individual Spybots so that you can make the important decision of which should be your first Spybot. If you already have one, then you have more information for deciding which Spybot will be the *next* member of your Spybot team!