Basic Machines – Part 1

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CHAPTER 1

LEVERS

CHAPTER LEARNING OBJECTIVES

Upon completion of this chapter, you should be able to do the following:

- *Explain the use of levers when operating machines afloat and ashore.*
- *Discuss the classes of levers.*

Through the ages, ships have evolved from crude rafts to the huge complex cruisers and carriers of today's Navy. It was a long step from oars to sails, another long step from sails to steam, and another long step to today's nuclear power. Each step in the progress of shipbuilding has involved the use of more and more machines.

Today's Navy personnel are specialists in operating and maintaining machinery. Boatswains operate winches to hoist cargo and the anchor; personnel in the engine room operate pumps, valves, generators, and other machines to produce and control the ship's power; personnel in the weapons department operate shell hoists and rammers and elevate and train the guns and missile launchers; the cooks operate mixers and can openers; personnel in the CB ratings drive trucks and operate cranes, graders, and bulldozers. In fact, every rating in the Navy uses machinery sometime during the day's work.

Each machine used aboard ship has made the physical work load of the crew lighter; you don't walk the capstan to raise the anchor, or heave on a line to sling cargo aboard. Machines are your friends. They have taken much of the backache and drudgery out of a sailor's lift. Reading this book should help you recognize and understand the operation of many of the machines you see about you.

WHAT IS A MACHINE?

As you look about you, you probably see half a dozen machines that you don't recognize as such. Ordinarily you think of a machine as a complex device-a gasoline engine or a typewriter. They are machines; but so are a hammer, a screwdriver, a ship's wheel. A machine is any device that helps you to do work. It may help by changing the amount of force or the speed of action. A claw hammer, for example, is a machine. You can use it to apply a large force for pulling out a nail; a relatively small pull on the handle produces a much greater force at the claws.

We use machines to *transform* energy. For example, a generator transforms mechanical energy into electrical energy. We use machines to *transfer* energy from one place to another. For example, the connecting rods, crankshaft, drive shaft, and rear axle of an automobile transfer energy from the engine to the rear wheels.

Another use of machines is to multiply force. We use a system of pulleys (a chain hoist, for example) to lift a heavy load. The pulley system enables us to raise the load by exerting a force that is smaller than the weight of the load. We must exert this force over a greater distance than the height through which the load is raised; thus, the load will move slower than the chain on which we pull. The machine enables us to gain force, but only at the expense of speed.

Machines may also be used to multiply speed. The best example of this is the bicycle, by which we gain speed by exerting a greater force.

Machines are also used to change the direction of a force. For example, the Signalman's halyard enables one end of the line to exert an upward force on a signal flag while a downward force is exerted on the other end.

There are only six simple machines: the lever, the block, the wheel and axle, the inclined plane, the screw, and the gear. Physicists, however, recognize only two basic principles in machines: those of the lever and the inclined plane. The wheel and axle, block and tackle, and gears may be considered levers. The wedge and the screw use the principle of the inclined plane.

When you are familiar with the principles of these simple machines, you can readily understand the

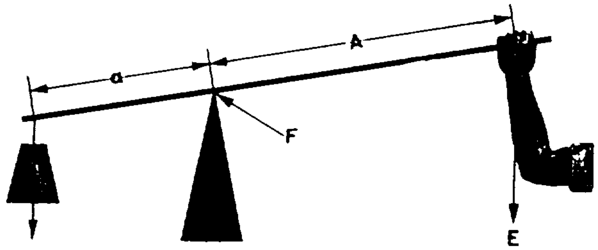


Figure 1-1.-A simple lever.

operation of complex machines. Complex machines are merely combinations of two or more simple machines.

THE LEVER

The simplest machine, and perhaps the one with which you are most familiar, is the lever. A seesaw is a familiar example of a lever in which one weight balances the other.

You will find that all levers have three basic parts: the fulcrum (F), a force or effort (E), and a resistance (R). Look at the lever in figure 1-1. You see the pivotal point (fulcrum) (F); the effort (E), which is applied at a distance (A) from the fulcrum; and a resistance (R), which acts at a distance (a) from the fulcrum. Distances A and a are the arms of the lever.

CLASSES OF LEVERS

The three classes of levers are shown in figure 1-2. The location of the fulcrum (the fixed or pivot point) in relation to the resistance (or weight) and the effort determines the lever class.

First Class

In the first class (fig. 1-2, part A), the fulcrum is located between the effort and the resistance. As mentioned earlier, the seesaw is a good example of a first-class lever. The amount of weight and the distance from the fulcrum can be varied to suit the need.

Notice that the sailor in figure 1-3 applies effort on the handles of the oars. An oar is another good example. The oarlock is the fulcrum, and the water is the resistance. In this case, as in figure 1-1, the force is applied on one side of the fulcrum and the resistance to be overcome is applied to the opposite side; hence, this is a first class lever. Crowbars, shears, and pliers are common examples of this class of levers.

Second Class

The second class of lever (fig. 1-2, part B) has the fulcrum at one end, the effort applied at the other end, and the resistance somewhere between those points. The

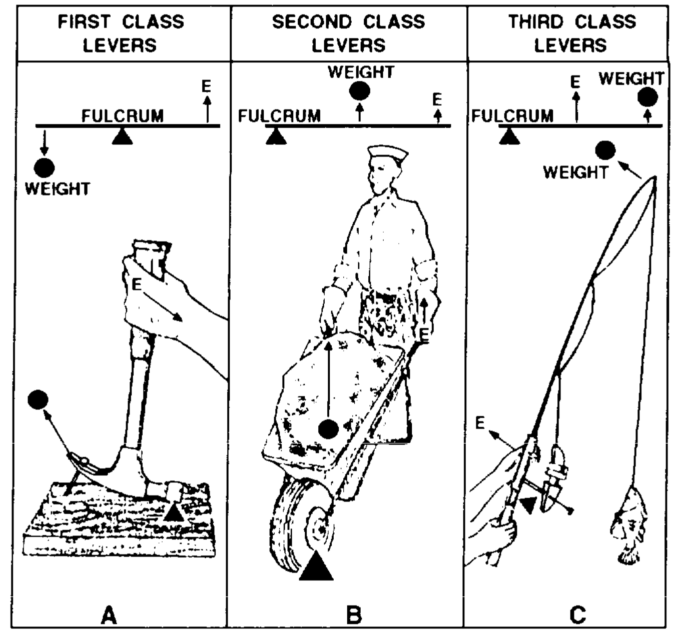


Figure 1-2.-Three classes of levers.

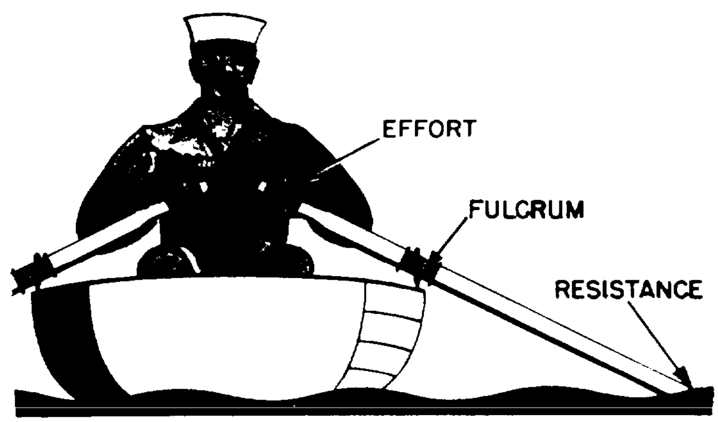


Figure 1-3.-Oars are levers.

wheelbarrow in figure 1-4 is a good example of a second-class lever. If you apply 50 pounds of effort to the handles of a wheelbarrow 4 feet from the fulcrum (wheel), you can lift 200 pounds of weight 1 foot from the fulcrum. If the load were placed farther away from the wheel, would it be easier or harder to lift?

Levers of the first and second class are commonly used to help in overcoming big resistances with a relatively small effort.

Third Class

Sometimes you will want to speed up the movement of the resistance even though you have to use a large amount of effort. Levers that help you accomplish this are in the third class of levers. As shown in figure 1-2, part C, the fulcrum is at one end of the lever, and the

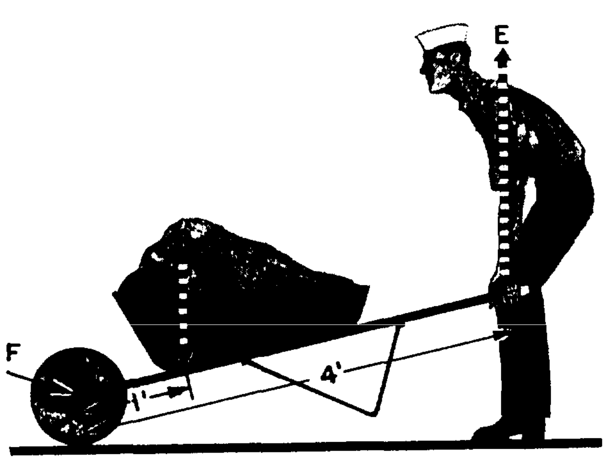


Figure 1-4.-This makes it easier.

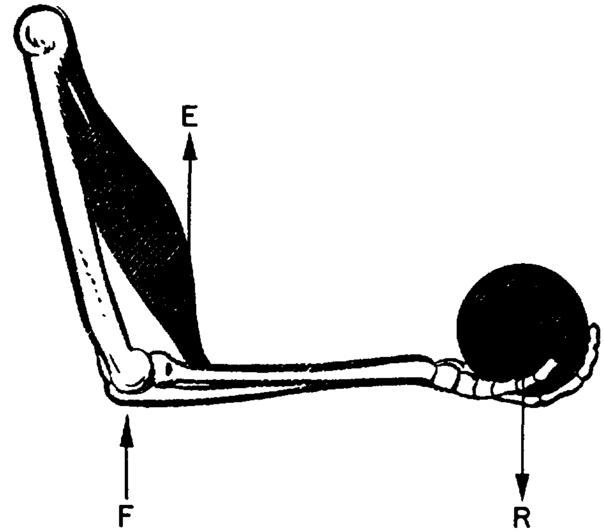


Figure 1-6.-Your arm is a lever.

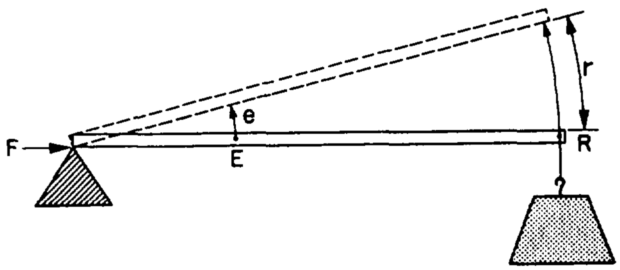


Figure 1-5.-A third-class lever.

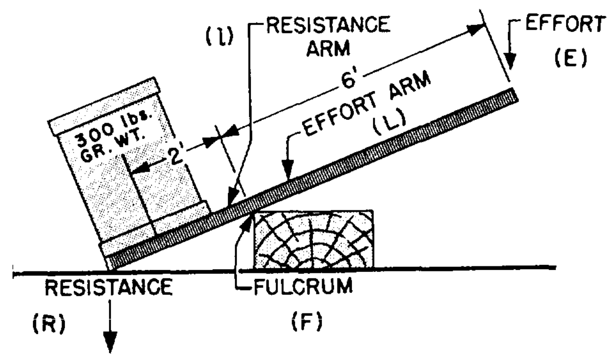


Figure 1-7.-Easy does it.

weight or resistance to be overcome is at the other end, with the effort applied at some point between. You can always spot the third-class levers because you will find the effort applied <u>between</u> the fulcrum and the resistance. Look at figure 1-5. It is easy to see that while E moved the short distance (e), the resistance (R) was moved a greater distance (r). The speed of R must have been greater than that of E, since R covered a greater distance in the same length of time.

Your arm (fig. 1-6) is a third-class lever. It is this lever action that makes it possible for you to flex your arms so quickly. Your elbow is the fulcrum. Your biceps muscle, which ties onto your forearm about an inch below the elbow, applies the effort; your hand is the resistance, located about 18 inches from the fulcrum. In the split second it takes your biceps muscle to contract an inch, your hand has moved through an 18-inch arc. You know from experience that it takes a big pull at E to overcome a relatively small resistance at R. Just to experience this principle, try closing a door by pushing on it about 3 or 4 inches from the hinges (fulcrum). The moral is, you don't use third-class levers to do heavy jobs; you use them to gain speed.

One convenience of machines is that you can determine in advance the forces required for their operation, as well as the forces they will exert. Consider for a moment the first class of levers. Suppose you have an iron bar, like the one shown in figure 1-7. This bar is 9 feet long, and you want to use it to raise a 300-pound crate off the deck while you slide a dolly under the crate; but you can exert only 100 pounds to lift the crate. So, you place the fulcrum-a wooden block-beneath one end of the bar and force that end of the bar under the crate. Then, you push down on the other end of the bar. After a few adjustments of the position of the fulcrum, you will find that your 100-pound force will just fit the crate when the fulcrum is 2 feet from the center of the crate. That leaves a 6-foot length of bar from the fulcrum to the point where you pushdown. The 6-foot portion is three times as long as the distance from the fulcrum to the center of the crate. And you lifted a load three times as great as the force you applied (3 x 100 = 300 pounds).

Here is a sign of a direct relationship between the *length of the lever arm and the force acting on that arm.*

You can state this relationship in general terms by saying: the length of the effort arm is the same number of times greater than the length of the resistance arm as the resistance to be overcome is greater than the effort you must apply. Writing these words as a mathematical equation, we have

$$\frac{L}{l} = \frac{R}{E},$$

where

L = length of effort arm,

l = length of resistance arm,

R = resistance weight or force, and

E = effort force.

Remember that all distances must be in the same units, such as feet, and that all forces must be in the same units, such as pounds.

Now let's take another problem and see how it works out. Suppose you want to pry up the lid of a paint can (fig. 1-8) with a 6-inch file scraper, and you know that the average force holding the lid is 50 pounds. If the distance from the edge of the paint can to the edge of the cover is 1 inch, what force will you have to apply on the end of the file scraper?

According to the formula,

$$\frac{L}{l} = \frac{R}{E},$$

here,

L = 5 inches

l = 1 inch

R = 50 pounds, and

E is unknown.

Then, substituting the numbers in their proper places, we have

$$\frac{5}{l} = \frac{50}{E}$$

and

$$E = \frac{50 \times 1}{5} = 10 \text{ pounds}$$

You will need to apply a force of only 10 pounds.

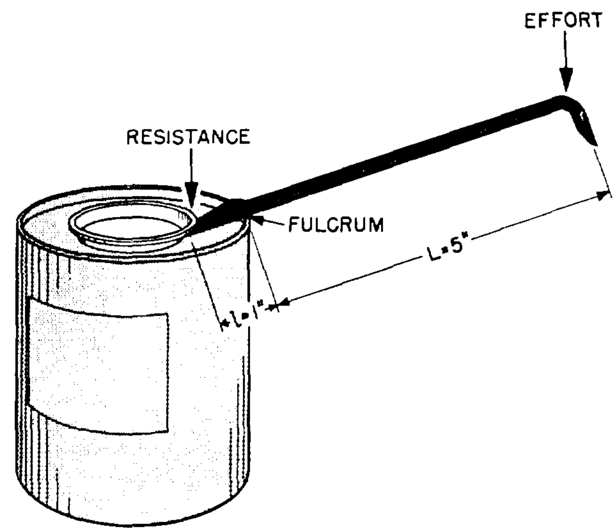


Figure 1-8.-A first-class job.

The same general formula applies for the second class of levers; but you must be careful to measure the proper lengths of the effort arm and the resistance arm. Looking back at the wheelbarrow problem, assume that the length of the handles from the axle of the wheel—which is the fulcrum-to the grip is 4 feet. How long is the effort arm? You're right, it's 4 feet. If the center of the load of sand is 1 foot from the axle, then the length of the resistance arm is 1 foot.

By substituting in the formula,

$$\frac{L}{l} = \frac{R}{E},$$

$$\frac{4}{l} = \frac{200}{E},$$

and

E = 50 pounds.

Now for the third-class lever. With one hand, you lift a projectile weighing approximately 10 pounds. If your biceps muscle attaches to your forearm 1 inch below your elbow and the distance from the elbow to the palm of your hand is 18 inches, what pull must your muscle exert to hold the projectile and flex your arm at the elbow?

By substituting in the formula,

$$\frac{L}{l} = \frac{R}{E},$$

it becomes

$$\frac{l}{18} = \frac{10}{E}$$

and

$$E = 18 \times 10 = 180 \text{ pounds.}$$

Your muscle must exert a 180-pound pull to hold up a 10-pound projectile. Our muscles are poorly arranged for lifting or pulling-and that's why some work seems pretty tough. But remember, third-class levers are used primarily to speed up the motion of the resistance.

Curved Lever Arms

Up to this point, you have been looking at levers with straight arms. In every case, the direction in which the resistance acts is parallel to the direction in which the effort is exerted. However, not all levers are straight. You 'll need to learn to recognize all types of levers and to understand their operation.

Look at figure 1-9. You may wonder how to measure the length of the effort arm, which is represented by the curved pump handle. You do not measure around the curve; you still use a straight-line distance. To determine the length of the effort arm, draw a straight line (AB) through the point where the effort is applied and in the direction that it is applied. From point E on this line, draw a second line (EF) that passes through the fulcrum and is perpendicular to line AB. The length of line EF is the actual length (L) of the effort arm.

To find the length of the resistance arm, use the same method. Draw a line (MN) in the direction that the resistance is operating and through the point where the resistance is attached to the other end of the handle. From point R on this line, draw a line (RF) perpendicular to MN so that it passes through the fulcrum. The length of RF is the length (l) of the resistance arm.

Regardless of the curvature of the handle, this method can be used to find lengths L and l. Then, curved levers are solved just like straight levers.

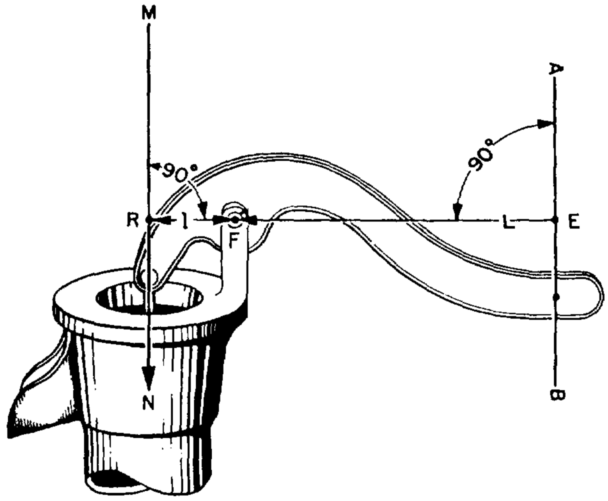


Figure 1-9.-A curved lever arm.

MECHANICAL ADVANTAGE

There is another thing about the first and second classes of levers that you have probably noticed by now. Since they can be used to magnify the applied force, they provide positive mechanical advantages. The third-class lever provides what is called a fractional mechanical advantage, which is really a mechanical disadvantage—you use more force than the force of the load you lift.

In the wheelbarrow problem, you saw that a 50-pound pull actually overcame the 200-pound weight of the sand. The sailor's effort was magnified four times, so you may say that the mechanical advantage of the wheelbarrow is 4. Expressing the same idea in mathematical terms,

$$\text{MECHANICAL ADVANTAGE} = \frac{\text{RESISTANCE}}{\text{EFFORT}}$$

or

$$\text{M.A.} = \frac{R}{E}$$

Thus, in the case of the wheelbarrow,

$$\text{M.A.} = \frac{200}{50} = 4$$

This rule—mechanical advantage equals resistance divided by effort —applies to all machines.

The mechanical advantage of a lever may also be found by dividing the length of effort arm A by the length of resistance arm a. Stated as a formula, this reads:

$$\text{MECHANICAL ADVANTAGE} = \frac{\text{EFFORT ARM}}{\text{RESISTANCE ARM}}$$

or

$$\text{M.A.} = \frac{A}{a}$$

How does this apply to third-class levers? Your muscle pulls with a force of 1,800 pounds to lift a 100-pound projectile. So you have a mechanical advantage of

$$\frac{100}{1{,}800}, \text{ or } \frac{1}{18},$$

which is fractional-less than 1.

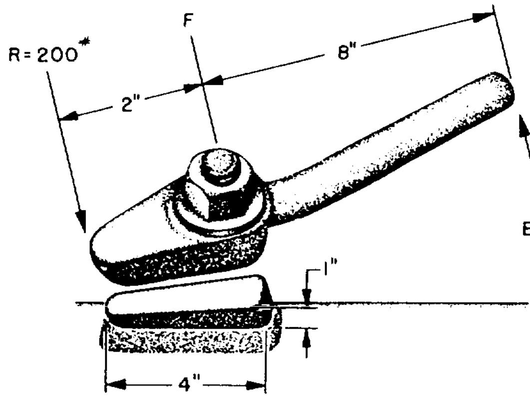


Figure 1-10.-It's a dog.

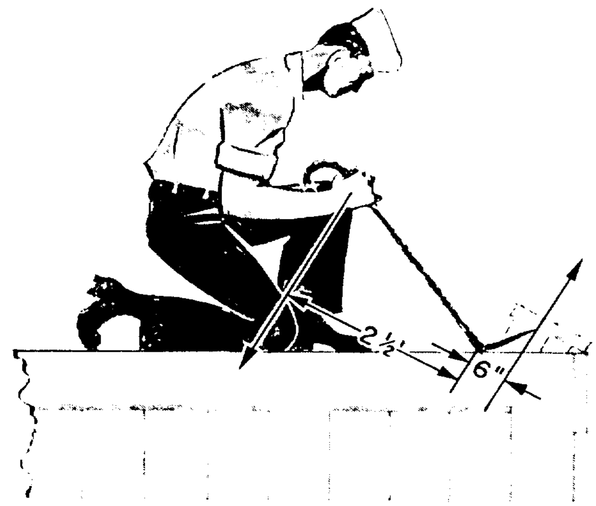


Figure 1-12.-Using a wrecking bar.

APPLICATIONS AFLOAT AND ASHORE

Doors, called hatches aboard a ship, are locked shut by lugs called dogs. Figure 1-10 shows you how these dogs are used to secure the door. If the handle is four times as long as the lug, that 50-pound heave of yours is multiplied to 200 pounds against the slanting face of the wedge. Incidentally, take a look at the wedge—it's an inclined plane, and it multiplies the 200-pound force by about 4. Result: Your 50-pound heave actually ends up as a 800-pound force on each wedge to keep the hatch closed! The hatch dog is one use of a first-class lever in combination with an inclined plane.

The breech of a big gun is closed with a breech plug. Figure 1-11 shows you that this plug has some interrupted screw threads on it, which fit into similar interrupted threads in the breech. Turning the plug part way around locks it into the breech. The plug is locked and unlocked by the operating lever. Notice that the connecting rod is secured to the operating lever a few inches from the fulcrum. You'll see that this is an application of a second-class lever.

You know that the plug is in there good and tight. But, with a mechanical advantage of 10, your 100-pound pull on the handle will twist the plug loose with a force of a half ton.

If you've spent any time opening crates at a base, you've already used a wrecking bar. The sailor in figure 1-12 is busily engaged in tearing that crate open.

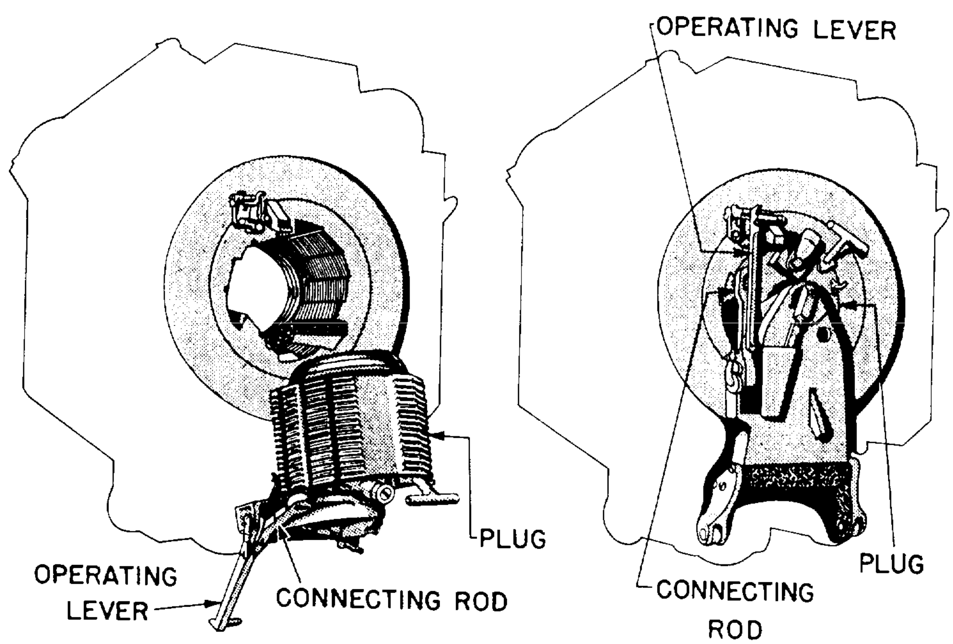


Figure 1-11.-The breech of an 8-inch gun.

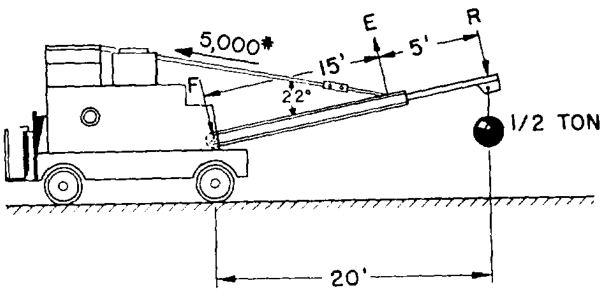


Figure 1-13.-An electric crane.

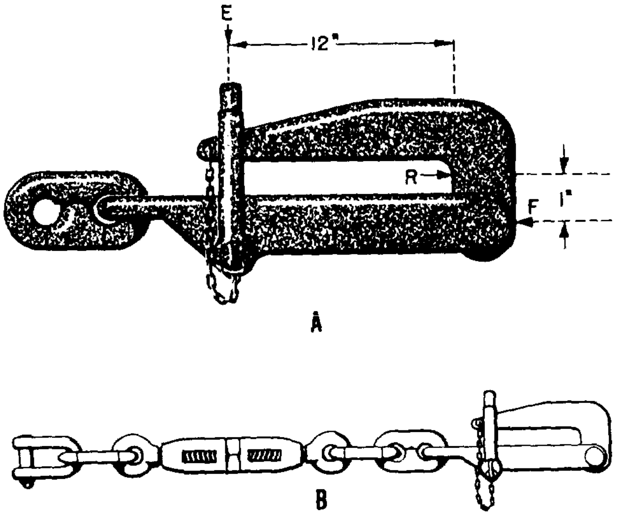


Figure 1-14.-A. A pelican hook; B. A chain stopper.

The wrecking bar is a first-class lever. Notice that it has curved lever arms. Can you figure the mechanical advantage of this one? Your answer should be M.A. = 5.

The crane in figure 1-13 is used for handling relatively light loads around a warehouse or a dock. You can see that the crane is rigged as a third-class lever; the effort is applied between the fulcrum and the load. This gives a mechanical advantage of less than 1. If it's going to support that 1/2-ton load, you know that the pull on the lifting cable will have to be considerably greater than 1,000 pounds. How much greater? Use the formula to figure it out:

$$\frac{L}{l} = \frac{R}{E}$$

Got the answer? Right. . . E = 1,333 pounds

Now, because the cable is pulling at an angle of about 22° at *E*, you can use some trigonometry to find that the pull on the cable will be about 3,560 pounds to lift the 1/2-ton weight! However, since the loads are generally light, and speed is important, the crane is a practical and useful machine.

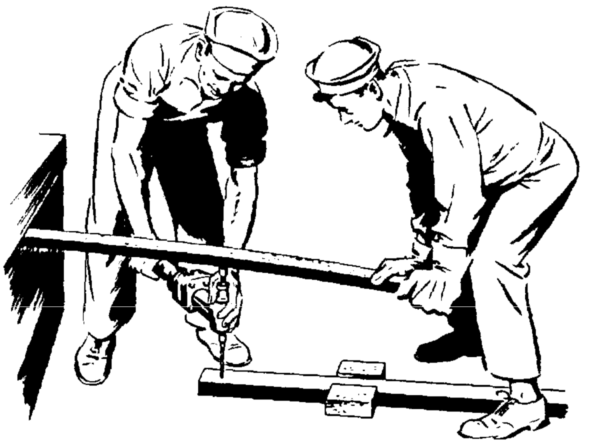


Figure 1-15.-An improvised drill press.

Anchors are usually housed in the hawsepipe and secured by a chain stopper. The chain stopper consists of a short length of chain containing a turnbuckle and a pelican hook. When you secure one end of the stopper to a pad eye in the deck and lock the pelican hook over the anchor chain, the winch is relieved of the strain.

Figure 1-14, part A, gives you the details of the pelican hook.

Figure 1-14, part B, shows the chain stopper as a whole. Notice that the load is applied close to the fulcrum. The resistance arm is very short. The bale shackle, which holds the hook secure, exerts its force at a considerable distance from the fulcrum. If the chain rests against the hook 1 inch from the fulcrum and the bale shackle is holding the hook closed 12 + 1 = 13 inches from the fulcrum, what's the mechanical advantage? It's 13. A strain of only 1,000 pounds on the base shackle can hold the hook closed when a 6 1/2-ton anchor is dangling over the ship's side. You'll recognize the pelican hook as a second-class lever with curved arms.

Figure 1-15 shows you a couple of guys who are using their heads to spare their muscles. Rather than exert themselves by bearing down on that drill, they pick up a board from a nearby crate and use it as a second-class lever.

If the drill is placed halfway along the board, they will get a mechanical advantage of 2. How would you increase the mechanical advantage if you were using this rig? Right. You would move the drill in closer to the fulcrum. In the Navy, a knowledge of levers and how to apply them pays off.

SUMMARY

Now for a brief summary of levers:

Levers are machines because they help you to do your work. They help by changing the size, direction, or speed of the force you apply.

There are three classes of levers. They differ primarily in the relative points where effort is applied, where the resistance is overcome, and where the fulcrum is located.

First-class levers have the effort and the resistance on opposite sides of the fulcrum, and effort and resistance move in opposite directions.

Second-class levers have the effort and the resistance on the same side of the fulrum but the effort is farther from the fulcrum than is the resistance. Both effort and resistance move in the same direction.

Third-class levers have the effort applied on the same side of the fulcrum as the resistance but the effort is applied between the resistance and the fulcrum, and both effort and resistance move in the same direction.

First- and second-class levers magnify the amount of effort exerted and decrease the speed of effort. First-class and third-class levers magnify the distance and the speed of the effort exerted and decrease its magnitude.

The same general formula applies to all three types of levers:

$$\frac{L}{l} = \frac{R}{E}$$

Mechanical advantage (M.A.) is an expression of the ratio of the applied force and the resistance. It may be written:

$$\text{M.A.} = \frac{R}{E}$$

CHAPTER 2

BLOCK AND TACKLE

CHAPTER LEARNING OBJECTIVES

Upon completion of this chapter, you should be able to do the following:

- *Describe the advantage of block and tackle afloat and ashore*

Blocks—pulleys to a landlubber—are simple machines that have many uses aboard ship, as well as onshore. Remember how your mouth hung open as you watched movers taking a piano out of a fourth story window? The guy on the end of the tackle eased the piano safely to the sidewalk with a mysterious arrangement of blocks and ropes. Or, you've been in the country and watched the farmer use a block and tackle to put hay in a barn. Since old Dobbin or the tractor did the hauling, there was no need for a fancy arrangement of ropes and blocks. Incidentally, you'll often hear the rope or tackle called the fall, block and tack, or block and fall.

In the Navy you'll rig a block and tackle to make some of your work easier. Learn the names of the parts of a block. Figure 2-1 will give you a good start on this. Look at the single block and see some of the ways you can use it. If you lash a single block to a fixed object-an overhead, a yardarm, or a bulkhead-you give yourself the advantage of being able to pull from a convenient direction. For example, in figure 2-2 you haul up a flag hoist, but you really pull down. You can do this by having a single sheaved block made fast to the yardarm. This makes it possible for you to stand in a convenient place near the flag bag and do the job. Otherwise you would have to go aloft, dragging the flag hoist behind you.

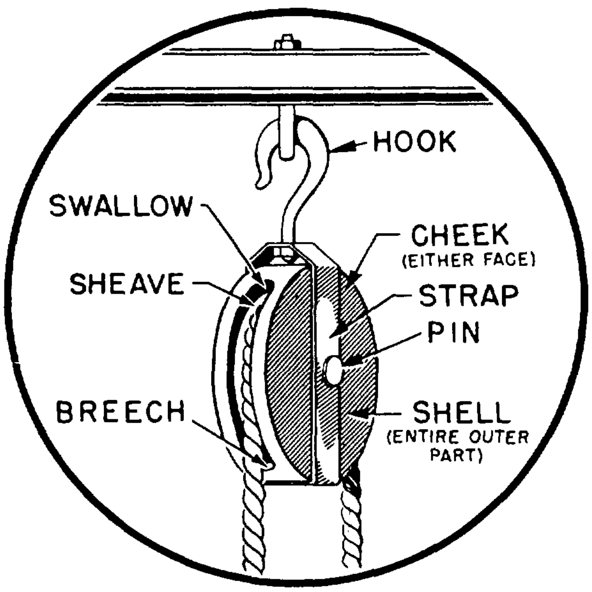


Figure 2-1.-Look it over.

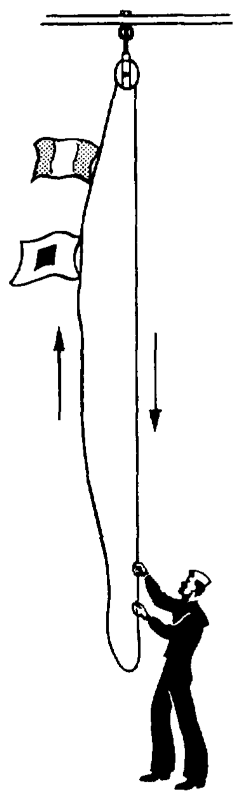


Figure 2-2.-A flag hoist.

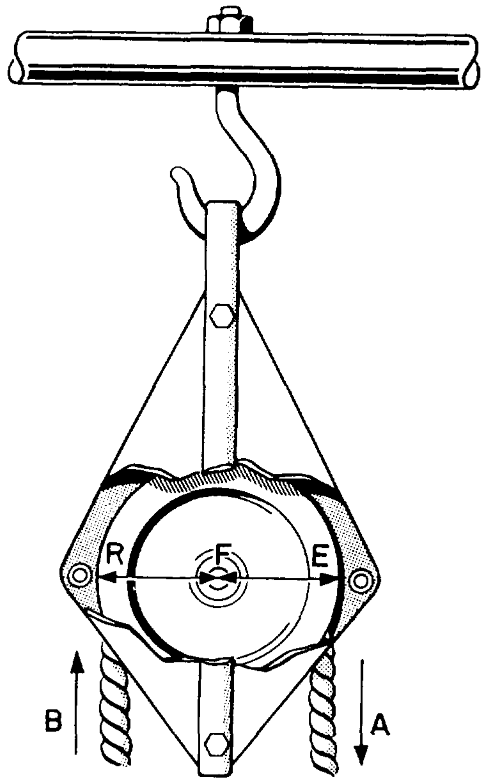


Figure 2-3.-No advantage.

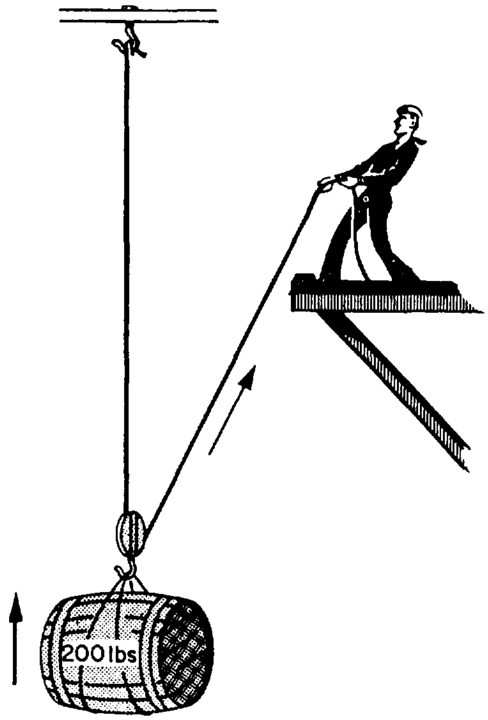


Figure 2-4.-A runner.

MECHANICAL ADVANTAGE

With a single fixed sheave, the force of your down pull on the fall must be equal to the weight of the object hoist. You can't use this rig to lift a heavy load or resistance with a small effort-you can change only the direction of your pull.

A single fixed block is a first-class lever with equal arms. The arms (EF and FR) in figure 2-3 are equal; hence, the mechanical advantage is 1. When you pull down at A with a force of 1 pound, you raise a load of 1 pound at B. A single fixed block does not magnify force nor speed.

You can, however, use a single block and fall to magnify the force you exert. Notice in figure 2-4 that the block is not fixed. The fall is doubled as it supports the 200-pound cask. When rigged this way, you call the single block and fall a runner. Each half of the fall carries one-half of the total bad, or 100 pounds. Thus, with the runner, the sailor is lifting a 200-pound cask with a 100-pound pull. The mechanical advantage is 2. Check this by the formula:

$$\text{M.A.} = \frac{R}{E} = \frac{200}{100}$$

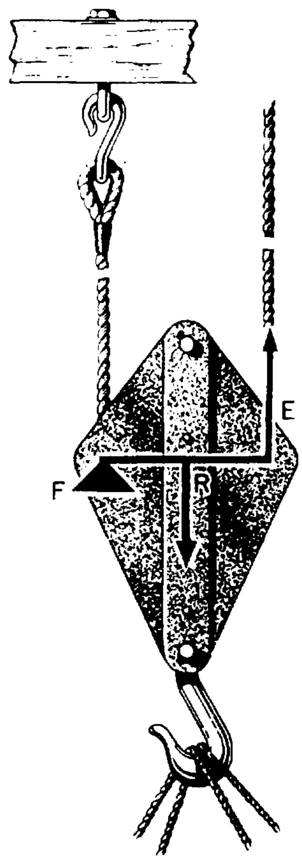


Figure 2-5.-It's 2 to 1.

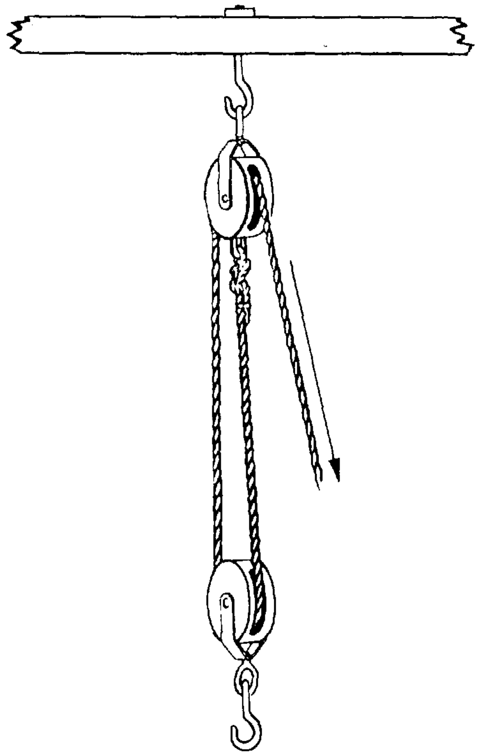


Figure 2-6.-A gun tackle.

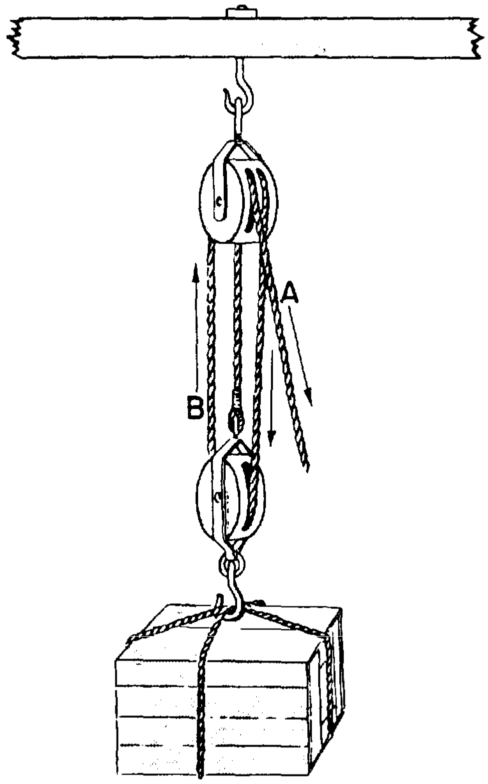


Figure 2-7.-A luff tackle.

The single movable block in this setup is a second-class lever. See figure 2-5. Your effort (E) acts upward upon the arm (EF), which is the diameter of the sheave. The resistance (R) acts downward on the arm (FR), which is the radius of the sheave. Since the diameter is twice the radius, the mechanical advantage is 2.

When the effort at E moves up 2 feet, the load at R is raised only 1 foot. That's something to remember about blocks and falls—if you are actually getting a mechanical advantage from the system. The length of rope that passes through your hands is greater than the distance that the load is raised. However, if you can lift a big load with a small effort, you don't care how much rope you have to pull.

The sailor in figure 2-4 is in an awkward position to pull. If he had another single block handy, he could use it to change the direction of the pull, as in figure 2-6. This second arrangement is known as a gun tackle. Because the second block is fixed, it merely changes the direction of pull—and the mechanical advantage of the whole system remains 2.

You can arrange blocks in several ways, depending on the job to be done and the mechanical advantage you want to get. For example, a luff tack consists of a double block and a single block, rigged as in figure 2-7. Notice that the weight is suspended by the three parts of rope that extend from the movable single block. Each part of the rope carries its share of the load. If the crate weighs 600 pounds, then each of the three parts of the rope supports its share—200 pounds. If there's a pull of 200 pounds downward on rope B, you will have to pull downward with a force of 200 pounds on A to counterbalance the pull on B. Neglecting the friction in the block, a pull of 200 pounds is all that is necessary to raise the crate. The mechanical advantage is:

$$\text{M.A.} = \frac{R}{E} = \frac{600}{200} = 3$$

Here's a good tip. If you count the number of parts of rope going to and from the movable block you can figure the mechanical advantage at a glance. This simple rule will help you to approximate the mechanical advantage of most tackles you see in the Navy.

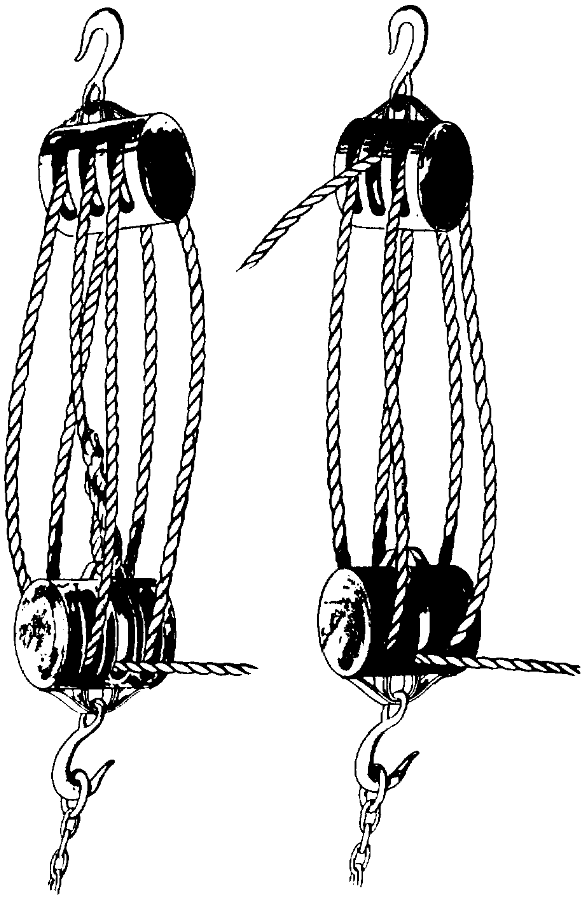


Figure 2-8.-Some other tackles.

Many combinations of single-, double-, and triple-sheave blocks are possible. Two of these combinations are shown in figure 2-8.

You can secure the dead end of the fall to the movable block. The advantage is increased by 1. Notice that this is done in figure 2-7. That is a good point to remember. Remember, also, that the strength of your fall—rope—is a limiting factor in any tackle. Be sure your fall will carry the load. There is no point in rigging a 6-fold purchase that carries a 5-ton load with two triple blocks on a 3-inch manila rope attached to a winch. The winch could take it, but the rope couldn't.

Now for a review of the points you have learned about blocks, and then to some practical applications aboard ship:

With a single fixed block the only advantage is the change of direction of the pull. The mechanical advantage is still 1.

A single movable block gives a mechanical advantage of 2.

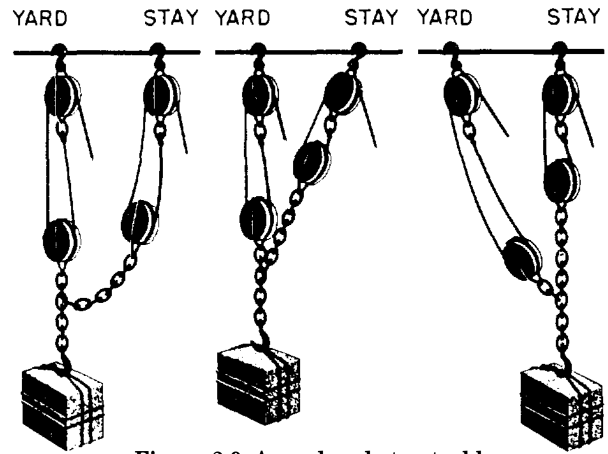


Figure 2-9.-A yard and stay tackle.

Many combinations of single, double, and triple blocks can be rigged to give greater advantages.

Remember that the number of parts of the fall going to and from the movable block tells you the approximate mechanical advantage of the tackle.

If you fix the dead end of the fall to the movable block you increase the mechanical advantage by one 1.

APPLICATIONS AFLOAT AND ASHORE

We use blocks and tackle for lifting and moving jobs afloat and ashore. The five or six basic combinations are used over and over in many situations. Cargo is loaded aboard, and depth charges are stored in their racks. You lower lifeboats over the side with this machine. We can swing heavy machinery, guns, and gun mounts into position with blocks and tackle. In a thousand situations, sailors find this machine useful and efficient.

We use yard and stay tackles aboard ship to pick up a load from the hold and swing it onto the deck. We use yard and stay tackles to shift any load a short distance. Figure 2-9 shows you how to pick a load by the yard tackle. The stay tackle is left slack. After raising the load to the height necessary to clear obstructions, you take up on the stay tackle and ease off on the yard fall. A glance at the rig tells you that the mechanical advantage of each of these tackles is only 2. You may think it's hard work to rig a yard and stay tackle when the small advantage is to move a 400-pound crate along the deck. However, a few minutes spent in rigging may save many unpleasant hours with a sprained back.

If you want a high mechanical advantage, a luff upon luff is a good rig for you. You can raise heavy loads with this setup. Figure 2-10 shows you what a luff upon

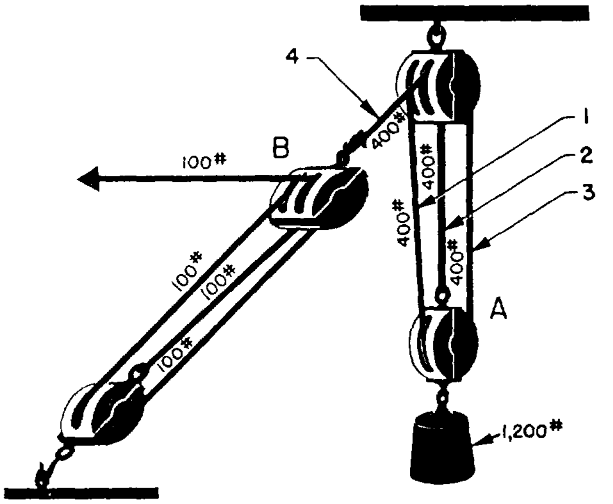


Figure 2-10.-Luff upon luff.

luff rig looks like. If you apply the rule by which you count the parts of the fall going to and from the movable blocks, you find that block A gives a mechanical advantage of 3 to 1. Block B has four parts of fall running to and from it, a mechanical advantage of 4 to 1. The mechanical advantage of those obtained from A is multiplied four times in B. The overall mechanical advantage of a luff upon luff is the product of the two mechanical advantages—or 12.

Don't make the mistake of adding mechanical advantages. Always multiply them.

You can easily figure out the mechanical advantage for the apparatus shown in figure 2-10. Suppose the load weighs 1,200 pounds. The support is by parts 1, 2, and 3 of the fall running to and from block A. Each part must be supporting one-third of the load, or 400 pounds. If part 3 has a pull of 400 pounds on it, part 4—made fast to block B—also has a 400-pound pull on it. There are four parts of the second fall going to and from block B. Each of these takes an equal part of the 400—pound pull. Therefore, the hauling part requires a pull of only 1/4 x 400, or 100 pounds. So, here you have a 100-pound pull raising a 1,200-pound load. That's a mechanical advantage of 12.

In shops ashore and aboard ship, you are almost certain to run into a chain hoist, or differential pulley. Ordinarily, you suspend these hoists from overhead trolleys. You use them to lift heavy objects and move them from one part of the shop to another.

To help you to understand the operation of a chain hoist, look at the one in figure 2-11. Assume that you grasp the chain (E) and pull until the large wheel (A) has

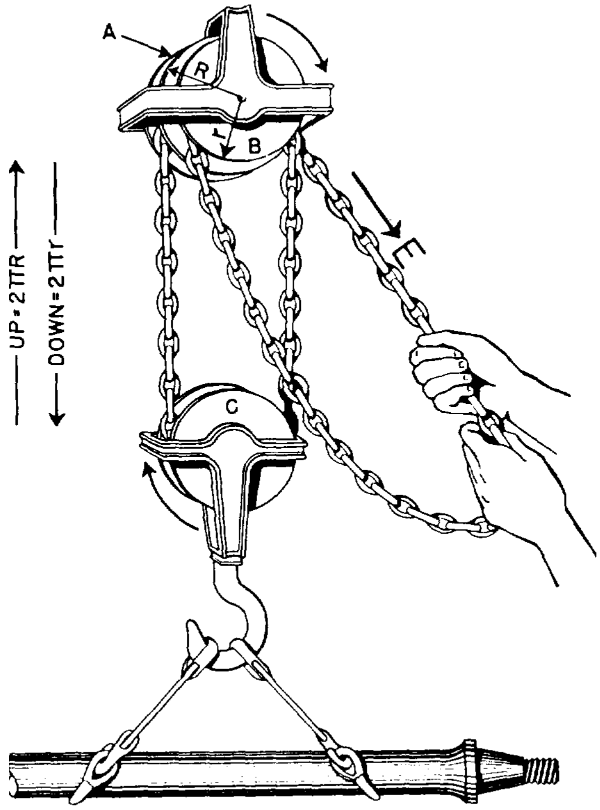


Figure 2-11.—A chain hoist.

turned around once. Then the distance through which your effort has moved is equal to the circumference of that wheel, or $2\pi r$. Again, since C is a single movable block the downward movement of its center will be equal to only one-half the length of the chain fed to it, or πr.

Of course, C does not move up a distance πR and then move down a distance πr. Actually, its steady movement upward is equal to the difference between the two, or $(\pi R - \pi r)$. Don't worry about the size of the movable pulley (C). It doesn't enter into these calculations. Usually, its diameter is between that of A and that of B.

The mechanical advantage equals the distance that moves the effort (E). It's divided by the distance that moves the load. We call this the velocity ratio, or theoretical mechanical advantage (T.M.A.). It is theoretical because the frictional resistance to the movement of mechanical parts is left out. In practical uses, all moving parts have frictional resistance.

The equation for theoretical mechanical advantage may be written

$$\frac{\text{Distance effort moves}}{\text{Distance resistance moves}};$$

and in this case,

$$T.M.A. = \frac{2\pi R}{\pi R - \pi r} = \frac{2R}{(R - r)}.$$

If A is a large wheel and B is a little smaller, the value of *2R* becomes large and then *(R – r)* becomes small. Then you have a large number for

$$\frac{2R}{(R - r)}$$

which is the theoretical mechanical advantage.

You can lift heavy loads with chain hoists. To give you an idea of the mechanical advantage of a chain hoist, suppose the large wheel has a radius *(R)* of 6 inches and the smaller wheel a radius *(r)* of 5 3/4 inches. What theoretical mechanical advantage would you get? Use the formula

$$T.M.A. = \frac{2R}{R - r}.$$

Then substitute the numbers in their proper places, and solve

$$T.M.A. = \frac{2 \times 6}{6 - 5\frac{3}{4}} = \frac{12}{\frac{1}{4}} = 48$$

Since the friction in this type of machine is considerable, the actual mechanical advantage is not as high as the theoretical mechanical advantage. For example, that theoretical mechanical advantage of 48 tells you that with a 1-pound pull you can lift a 48-pound load. However, actually your 1-pound pull might only lift a 20-pound load. You will use the rest of your effort in overcoming the friction.

SUMMARY

The most important point to remember about block and tackle is that they are simple machines. And simple machines multiply effort or change its direction. You should also remember the following points:

A pulley is a grooved wheel that turns by the action of a rope in the groove.

There are different types of pulleys. Pulleys are either fixed or movable.

You attach a fixed pulley to one place. The fixed pulley helps make work easier by changing the direction of the effort.

You hook a movable pulley to the object you are lifting. As you pull, the object and the pulley move together. This pulley does not change the direction of the effort, but it does multiply the effort.

You can use fixed and movable pulleys together to get a large mechanical advantage (M.A.).

CHAPTER 3

THE WHEEL AND AXLE

CHAPTER LEARNING OBJECTIVES

Upon completion of this chapter, you should be able to do the following:

- *Explain the advantage of the wheel and axle.*

Have you ever tried to open a door when the knob was missing? If you have, you know that trying to twist that small four-sided shaft with your fingers is tough work. That gives you some appreciation of the advantage you get by using a knob. The doorknob is an example of a simple machine called a wheel and axle.

The steering wheel on an automobile, the handle of an ice cream freezer, and a brace and bit are all examples of a simple machine. All of these devices use the wheel and axle to multiply the force you exert. If you try to turn a screw with a screwdriver and it doesn't turn, stick a screwdriver bit in the chuck of a brace. The screw will probably go in with little difficulty.

There's something you'll want to get straight right at the beginning. The wheel-and-axle machine consists of a wheel or crank rigidly attached to the axle, which turns with the wheel. Thus, the front wheel of an automobile is not a wheel-and-axle machine because the axle does not turn with the wheel.

MECHANICAL ADVANTAGE

How does the wheel-and-axle arrangement help to magnify the force you exert? Suppose you use a screwdriver bit in a brace to drive a stubborn screw. Look at figure 3-1, view A. You apply effort on the handle that moves in a circular path, the radius of which is 5 inches. If you apply a 10-pound force on the handle, how much force will you exert against the resistance at the screw? Assume the radius of the screwdriver blade is 1/4 inch. You are really using the brace as a second-class lever—see figure 3-1, view B. You can find the size of the resistance by using the formula

$$\frac{L}{1} = \frac{R}{E}.$$

In that

L = radius of the circle through which the handle turns,

1 = one-half the width of the edge of the screwdriver blade,

R = force of the resistance offered by the screw,

E = force of effort applied on the handle.

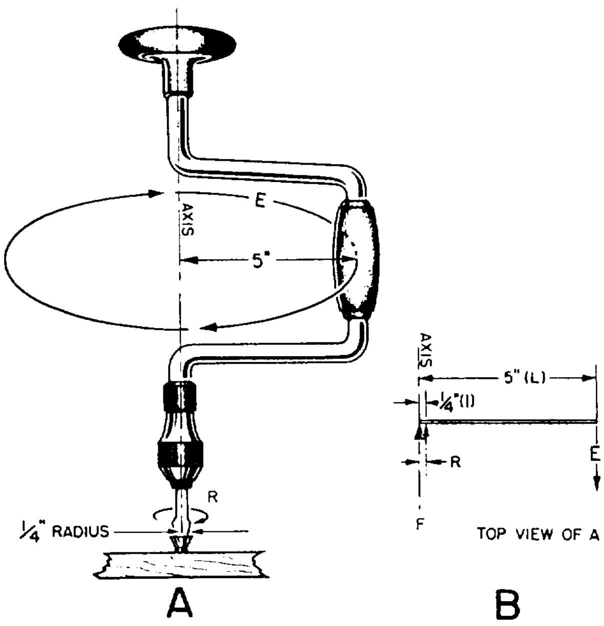


Figure 3-1.-It magnifies your effort.

Substituting in the formula and solving:

$$\frac{5}{\frac{1}{4}} = \frac{R}{10}$$

$$R = \frac{5 \times 10}{\frac{1}{4}}$$

$$= 5 \times 10 \times 4$$

$$= 200 \text{ lb.}$$

This means that the screwdriver blade will turn the screw with a force of 200 pounds. The relationship between the radius of the diameters or the circumferences of the wheel and axle tells you how much mechanical advantage you can get.

Take another situation. You raise the old oaken bucket, figure 3-2, using a wheel-and-axle arrangement. If the distance from the center of the axle to the handle is 8 inches and the radius of the drum around which the rope is wound is 2 inches, then you have a theoretical mechanical advantage of 4. That's why these rigs were used.

MOMENT OF FORCE

In several situations you can use the wheel-and-axle to speed up motion. The rear-wheel sprocket of a bike, along with the rear wheel itself, is an example. When you are pedaling, the sprocket is attached to the wheel; so the combination is a true wheel-and-axle machine. Assume that the sprocket has a circumference of 8 inches, and the wheel circumference is 80 inches. If you turn the sprocket at a rate of one revolution per second, each sprocket tooth moves at a speed of 8 inches per second. Since the wheel makes one revolution for each revolution made by the sprocket, any point on the tire must move through a distance of 80 inches in 1 second. So, for every 8-inch movement of a point on the sprocket, you have moved a corresponding point on the wheel through 80 inches.

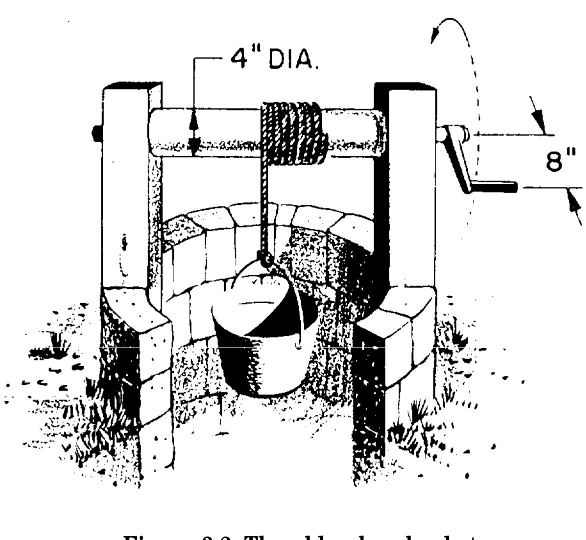


Figure 3-2.-The old oaken bucket.

Since a complete revolution of the sprocket and wheel requires only 1 second, the speed of a point on the circumference of the wheel is 80 inches per second, or 10 times the speed of a tooth on the sprocket.

(NOTE: Both sprocket and wheel make the same number of revolutions per second, so the speed of turning for the two is the same.)

Here is an idea that you will find useful in understanding the wheel and axle, as well as other machines. You probably have noticed that the force you apply to a lever starts to turn or rotate it about the fulcrum. You also know that a sheave on a fall starts to rotate the sheave of the block. Also when you turn the steering wheel of a car, it starts to rotate the steering column. Whenever you use a lever, or a wheel and axle, your effort on the lever arm or the rim of the wheel causes it to rotate about the fulcrum or the axle in one direction or another. If the rotation occurs in the same direction as the hands of a clock, we call that direction clockwise. If the rotation occurs in the opposite direction from that of the hands of a clock, we call that direction of rotation counterclockwise. A glance at figure 3-3 will make clear the meaning of these terms.

The force acting on the handle of a carpenter's brace depends not only on the amount of that force, but also on the distance from the handle to the center of rotation. This is known as a moment of force, or a torque (pronounced tork). Moment of force and torque have the same meaning.

Look at the effect of the counterclockwise movement of the capstan bar in figure 3-4. Here the amount of the effort is designated E_1 and the distance from the point where you apply the force to the center

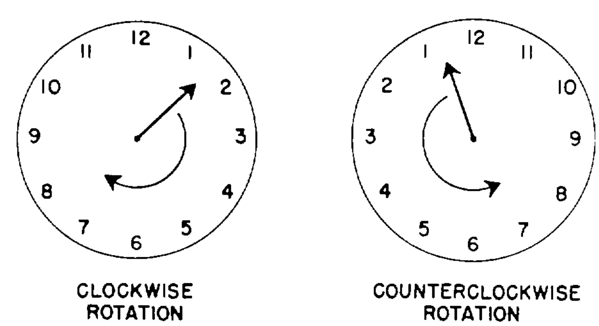


Figure 3-3.-Directions of rotation.

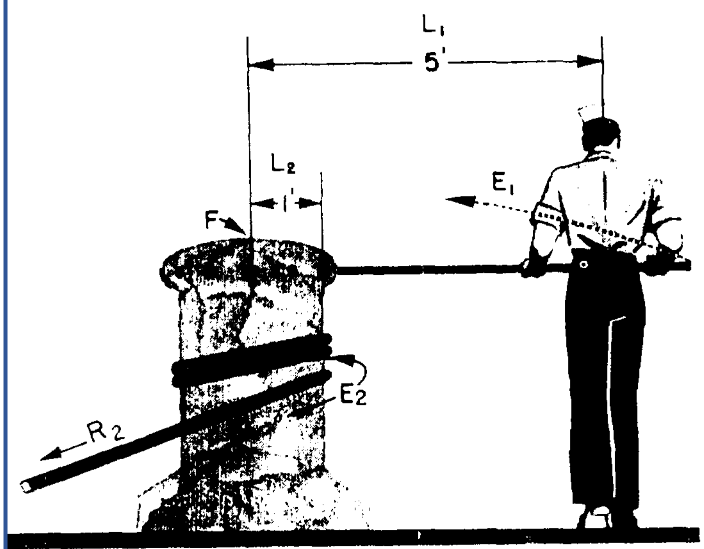


Figure 3-4.-Using the capstan.

of the axle is L_1. Then, $E_1 \times L_1$ is the moment of force. You'll notice that this term includes both the amount of the effort and the distance from the point of application of effort to the center of the axle. Ordinarily, you measure the distance in feet and the applied force in pounds.

Therefore, you measure moments of force in foot-pounds (ft-lb). A moment of force is frequently called a moment.

By using a longer capstan bar, the sailor in figure 3-4 can increase the effectiveness of his push without making a bigger effort. If he applied his effort closer to the head of the capstan and used the same force, the moment of force would be less.

BALANCING MOMENTS

You know that the sailor in figure 3-4 would land flat on his face if the anchor hawser snapped. As long as nothing breaks, he must continue to push on the capstan bar. He is working against a clockwise moment of force that is equal in magnitude, but opposite in direction, to his counterclockwise moment of force. The resisting moment, like the effort moment, depends on two factors. In the case of resisting moment, these factors are the force (R_2) with which the anchor pulls on the hawser and the distance (L_2) from the center of the capstan to its rim. The existence of this resisting force would be clear if the sailor let go of the capstan bar. The weight of the anchor pulling on the capstan would cause the whole works to spin rapidly in a clockwise direction—and good-bye anchor! The principle involved here is that whenever the counterclockwise and the clockwise moments of force are in balance, the machine either moves at a steady speed or remains at rest.

This idea of the balance of moments of force can be summed up by the expression

$$\text{CLOCKWISE MOMENTS} = \text{COUNTERCLOCKWISE MOMENTS}$$

Since a moment of force is the product of the amount of the force times the distance the force acts from the center of rotation, this expression of equality may be written

$$E_1 \times L_1 = E_2 \times L_2,$$

in that

E_1 = force of effort,

L_1 = distance from fulcrum or axle to point where you apply force,

E_2 = force of resistance, and

L_2 = distance from fulcrum or center axle to the point where you apply resistance.

EXAMPLE 1

Put this formula to work on a capstan problem. You grip a single capstan bar 5 feet from the center of a capstan head with a radius of 1 foot. You have to lift a 1/2-ton anchor. How big of a push does the sailor have to exert?

First, write down the formula

$$E_1 \times L_1 = E_2 \times L_2.$$

Here

L_1 = 5

E_2 = 1,000 pounds, and

L_2 = 1.

Substitute these values in the formula, and it becomes:

$$E_1 \times 5 = 1{,}000 \times 1$$

and

$$E_1 = \frac{1{,}000}{5} = 200 \text{ pounds}$$

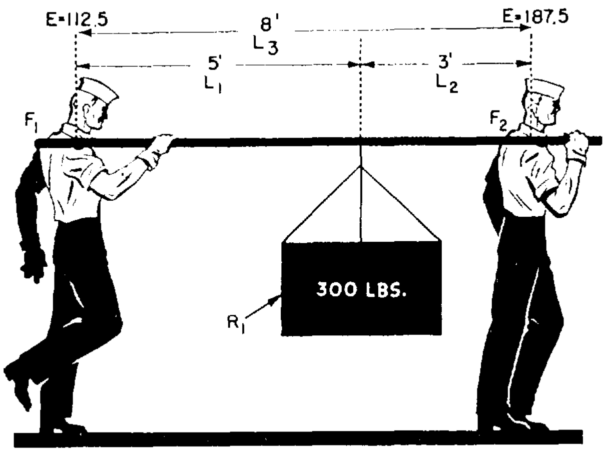


Figure 3-5.-A practical application.

Example 2

Consider now the sad case of Slim and Sam, as illustrated in figure 3-5. Slim has suggested that they carry the 300-pound crate slung on a handy 10-foot pole. He was smart enough to slide the load up 3 feet from Sam's shoulder.

Here's how they made out. Use Slim's shoulder as a fulcrum (F_1). Look at the clockwise movement caused by the 300-pound load. That load is 5 feet away from Slim's shoulder. If R_1 is the load, and L_1 the distance from Slim's shoulder to the load, the clockwise moment (M_A) is

$$M_A = R_1 \times L_1 = 300 \text{ x } 5 = 1{,}500 \text{ ft-lb.}$$

With Slim's shoulder still acting as the fulcrum, the resistance of Sam's effort causes a counterclockwise moment (M_B) acting against the load moment. This counterclockwise moment is equal to Sam's effort (E_2) times the distance (L_3) from his shoulder to the fulcrum (F_1) at Slim's shoulder. Since L_2 = 8 ft, the formula is

$$M_B = E_2 \text{ x } L_3 = E_2 \times 8 = 8E_2$$

There is no rotation, so the clockwise moment and the counterclockwise moment are equal. $MA = M_B$. Hence

$$1{,}500 = 8E_2$$

$$E_2 = \frac{1{,}500}{8} = 187.5 \text{ pounds.}$$

So poor Sam is carrying 187.5 pounds of the 330-pound load.

What is Slim carrying? The difference between 300 and 187.5 = 112.5 pounds, of course! You can check your answer by the following procedure.

This time, use Sam's shoulder as the fulcrum (F_2). The counterclockwise moment (M_c) is equal to the 300-pound load (R_1) times the distance (L_2 = 3 feet) from Sam's shoulder. M_c 300 x 3 = 900 foot-pounds. The clockwise moment (m_D) is the result of Slim's lift (E_1) acting at a distance (L_3) from the fulcrum. L_3 = 8 feet. Again, since counterclockwise moment equals clockwise moment, you have

$$900 = E_1 \times 8$$

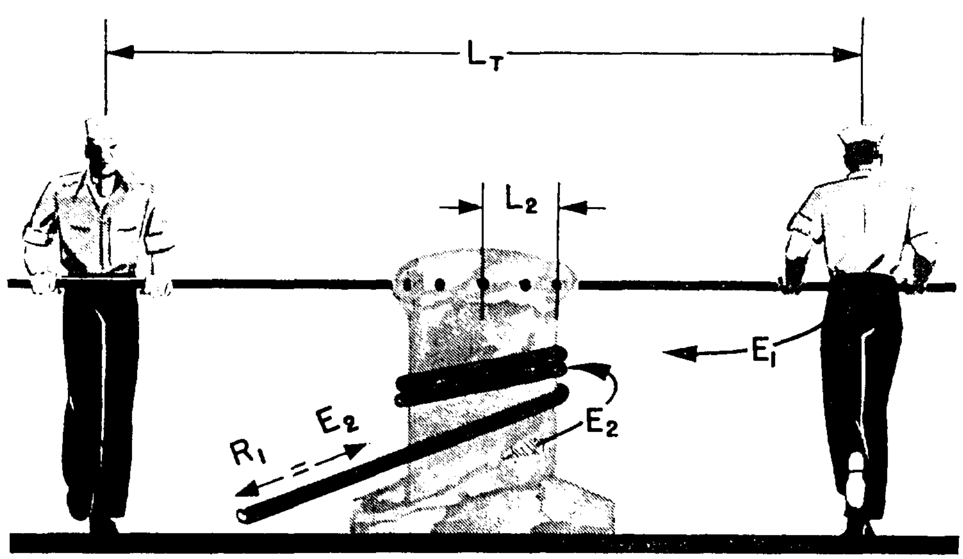


Figure 3-6.-A couple.

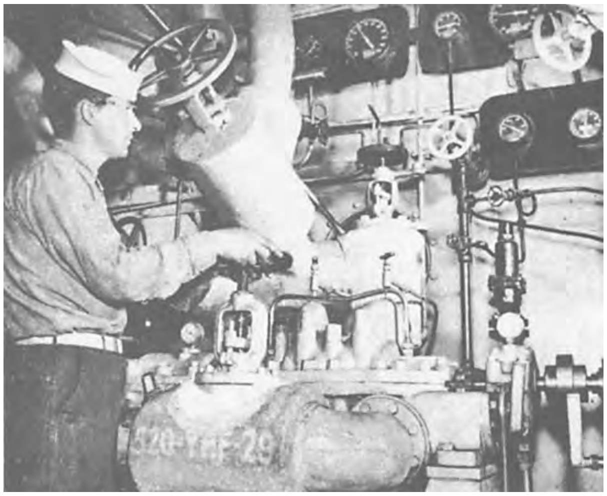


Figure 3-7.-Valves.

and

$$E_1 = \frac{900}{8} = 112/5 \text{ pounds}$$

Slim, the smart sailor, has to lift only 112.5 pounds. There's a sailor who really puts his knowledge to work.

THE COUPLE

Take a look at figure 3-6. It's another capstan-turning situation. To increase an effective effort, place a second capstan bar opposite the first and another sailor can apply a force on the second bar. The two sailors in figure 3-6 will apparently be pushing in opposite directions. Since they are on opposite sides of the axle, they are actually causing rotation in the same direction. If the two sailors are pushing with equal force, the moment of force is twice as great as if only one sailor were pushing. This arrangement is known technically as a couple.

You will see that the couple is a special example of the wheel and axle. The moment of force is equal to the product of the total distance (L_n between the two points and the force (E_1) applied by one sailor. The equation for the couple may be written

$$E_1 \times L_T = E_2 \times L_2$$

APPLICATIONS AFLOAT AND ASHORE

A trip to the engine room important the wheel and axle makes you realize how is on the modern ship.

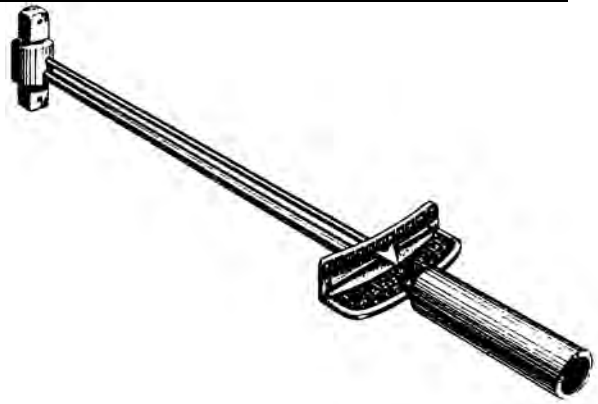


Figure 3-8.—A simple torque wrench.

Everywhere you look you see wheels of all sizes and shapes. We use most of them to open and close valves quickly. One common type of valve is shown in figure 3-7. Turning the wheel causes the threaded stem to rise and open the valve. Since the valve must close watertight, airtight, or steamtight, all the parts must fit snugly. To move the stem on most valves without the aid of the wheel would be impossible. The wheel gives you the necessary mechanical advantage.

You've handled enough wrenches to know that the longer the handle, the tighter you can turn a nut. Actually, a wrench is a wheel-and-axle machine. You can consider the handle as one spoke of a wheel and the place where you take hold of the handle as a point on the rim. You can compare the nut that holds in the jaws of the wrench to the axle.

You know that you can turn a nut too tight and strip the threads or cause internal parts to seize. This is especially true when you are taking up on bearings. To make the proper adjustment, you use a torque wrench. There are several types. Figure 3-8 shows you one that is very simple. When you pull on the handle, its shaft bends. The rod fixed on the pointer does not bend. The pointer shows on the scale the torque, or moment of force, that you are exerting. The scale indicates pounds, although it is really measuring foot-pounds to torque. If the nut is to be tightened by a moment of 90 ft-1b, you pull until the pointer is opposite the number 90 on the scale. The servicing or repair manual on an engine or piece of machinery tells you what the torque—or moment of force—should be on each set of nuts or bolt.

The gun pointer uses a couple to elevate and depress the gun barrel. He cranks away at a handwheel that has two handles. The right-hand handle is on the opposite side of the axle from the left-hand handle—180° apart.

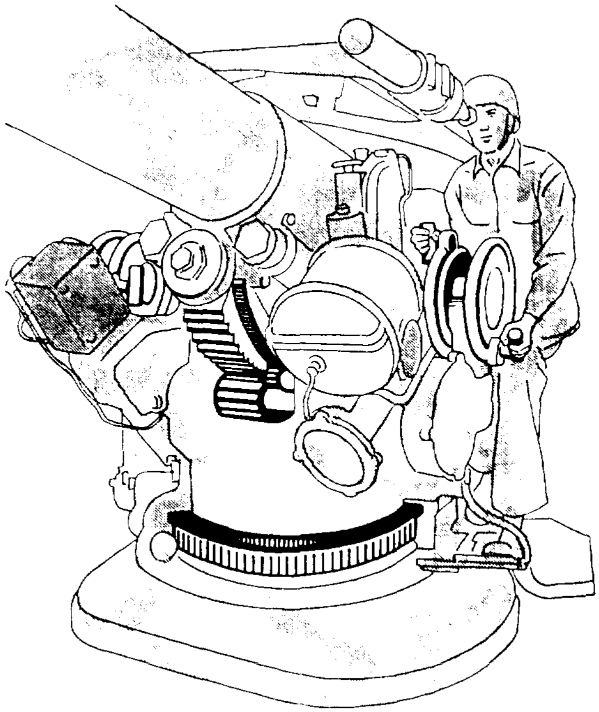


Figure 3-9.-A pointer's handwheel.

Look at figure 3-9. When this gun pointer pulls on one handle and pushes on the other, he's producing a couple. If he cranks only with his right hand, he no longer has a couple—just a simple first-class lever! And he'd have to push twice as hard with one hand.

A system of gears-a gear train-transmits the motion to the barrel. A look at figure 3-10 will help you to figure the forces involved. The radius of the wheel is 6 inches—1/2 foot-and turns each handle with a force of 20 pounds. The moment on the top that rotates the wheel in a clockwise direction is equal to 20 x 1/2 = 10 ft-lb. The bottom handle also rotates the wheel in the same direction with an equal moment. Thus, the total twist or torque on the wheel is 10 + 10 = 20 ft-lb. To get the same moment with one hand, apply a 20-pound force. The radius of the wheel would have to be twice as much—12 inches—or one foot. The couple is a convenient arrangement of the wheel-and-axle machine.

SUMMARY

Here is a quick review of the wheel and axle-facts you should have straight in your mind:

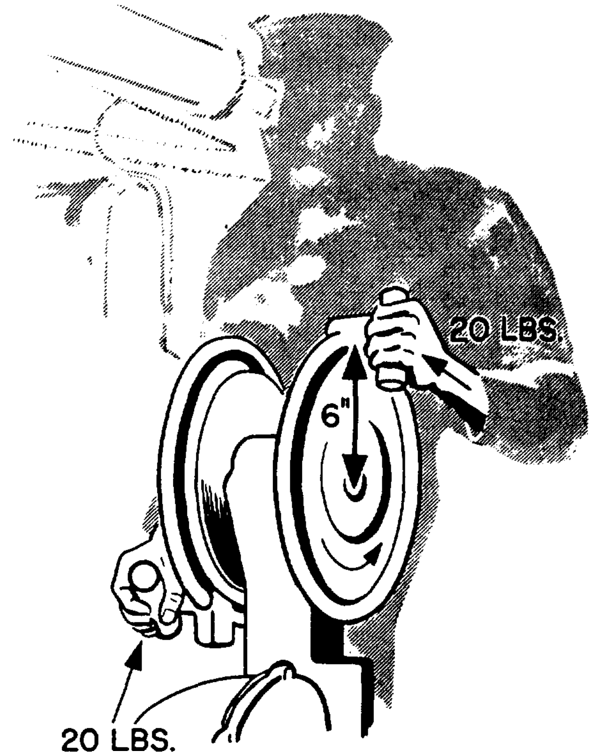


Figure 3-10.-Developing a torque.

A wheel-and-axle machine has the wheel fixed rigidly to the axle. The wheel and the axle turn together.

Use the wheel and axle to magnify your effort or to speed it up.

You call the effect of a force rotating an object around an axis or fulcrum a moment of force, or simply a moment.

When an object is at rest or is moving steadily, the clockwise moments are just equal and opposite to the counterclockwise moments.

Moments of force depend upon two factors: (1) the amount of the force and (2) the distance from the fulcrum or axis to the point where the force is applied.

When you apply two equal forces at equal distances on opposite sides of a fulcrum and move those forces in opposite directions so they both tend to cause rotation about the fulcrum, you have a couple.

CHAPTER 4

THE INCLINED PLANE AND THE WEDGE

CHAPTER LEARNING OBJECTIVES

Upon completion of this chapter, you should be able to do the following:

- *Summarize the advantage of the barrel roll and the wedge.*

You have probably watched a driver load barrels on a truck. He backs the truck up to the curb. The driver then places a long double plank or ramp from the sidewalk to the tailgate, and then rolls the barrel up the ramp. A 32-gallon barrel may weigh close to 300 pounds when full, and it would be a job to lift one up into the truck. Actually, the driver is using a simple machine called the inclined plane. You have seen the inclined plane used in many situations. Cattle ramps, a mountain highway and the gangplank are familiar examples.

The inclined plane permits you to overcome a large resistance, by applying a small force through a longer distance when raising the load. Look at figure 4-1. Here you see the driver easing the 300-pound barrel up to the bed of the truck, 3 feet above the sidewalk. He is using a plank 9 feet long. If he didn't use the ramp at all, he'd have to apply 300-pound force straight up through the 3-foot distance. With the ramp, he can apply his effort over the entire 9 feet of the plank as he rolls the barrel to a height of 3 feet. It looks as if he could use a force only three-ninths of 300, or 100 pounds, to do the job. And that is actually the situation.

Here's the formula. Remember it from chapter 1?

$$\frac{L}{1} = \frac{R}{E}$$

In which

L = length of the ramp, measured along the slope,

1 = height of the ramp,

R = weight of the object to be raised, or lowered,

E = force required to raise or lower the object.

Now apply the formula this problem:

In this case,

L = 9ft,

1 = 3 ft, and

R = 300 lb.

By substituting these values in the formula, you get

$$\frac{9}{3} = \frac{300}{E}$$

$$9E = 900$$

$$E = 100 \text{ pounds.}$$

Since the ramp is three times as long as its height, the mechanical advantage is three. You find the theoretical mechanical advantage by dividing the total distance of the effort you exert by the vertical distance the load is raised or lowered.

THE WEDGE

The wedge is a special application of the inclined plane. You have probably used wedges. Abe Lincoln used a wedge to help him split logs into rails for fences. The blades of knives, axes, hatchets, and chisels act as wedges when they are forced into apiece of wood. The wedge is two inclined planes set base-to-base. By

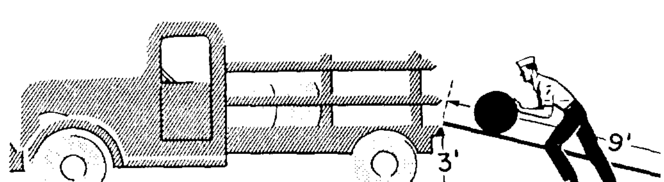


Figure 4-1.—An inclined plane.

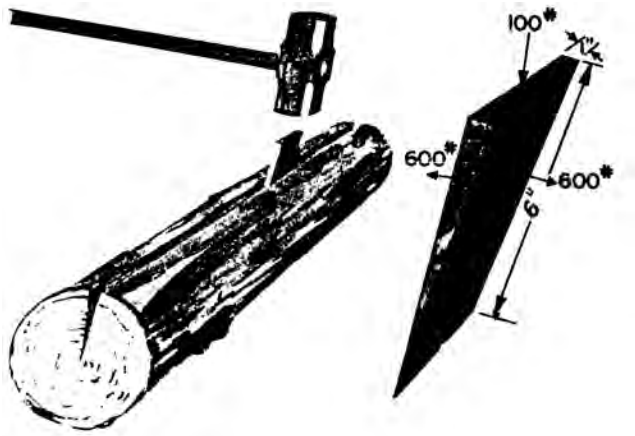


Figure 4-2.-A wedge.

Figure 4-3.—The gangplank is an inclined plane.

driving the wedge full-length into the material to cut or split, you force the material apart a distance equal to the width of the broad end of the wedge. See figure 4-2.

Long, slim wedges give high mechanical advantage. For example, the wedge of figure 4-2 has a mechanical advantage of six. The greatest value of the wedge is that you can use it in situations in which other simple machines won't work. Imagine the trouble you'd have trying to pull a log apart with a system of pulleys.

APPLICATIONS AFLOAT AND ASHORE

A common use of the inclined plane in the Navy is the gangplank. Going aboard the ship by gangplank illustrated in figure 4-3, is easier than climbing a sea ladder. You appreciate the mechanical advantage of the gangplank even more when you have to carry your seabag or a case of sodas aboard.

Remember that hatch dog in figure 1-10? The use of the dog to secure a door takes advantage of the lever principle. If you look sharply, you can see that the dog seats itself on a steel wedge welded to the door. As the dog slides upward along this wedge, it forces the door tightly shut. This is an inclined plane, with its length about eight times its thickness. That means you get a theoretical mechanical advantage of eight. In chapter 1, you figured that you got a mechanical advantage of four from the lever action of the dog. The overall mechanical advantage is 8 x 4, or 32, neglecting friction. Not bad for such a simple gadget, is it? Push down with 50 pounds heave on the handle and you squeeze the door shut with a force of 1,600 pounds on that dog. You'll find the damage-control parties using wedges by the dozen to shore up bulkheads and decks. A few sledgehammer blows on a wedge will quickly and firmly tighten up the shoring.

Chipping scale or paint off steel is a tough job. How-ever, you can make the job easier with a compressed-air chisel. The wedge-shaped cutting edge of the chisel gets in under the scale or the paint and exerts a large amount of pressure to lift the scale or paint layer. The chisel bit is another application of the inclined plane.

SUMMARY

This chapter covered the following points about the inclined plane and the wedge:

The inclined plane is a simple machine that lets you raise or lower heavy objects by applying a small force over a long distance.

You find the theoretical mechanical advantage of the inclined plane by dividing the length of the ramp by the perpendicular height of the load that is raised or lowered. The actual mechanical advantage is equal to the weight of the resistance or load, divided by the force that must be used to move the load up the ramp.

The wedge is two inclined planes set base-to-base. It finds its greatest use in cutting or splitting materials.

CHAPTER 5

THE SCREW

CHAPTER LEARNING OBJECTIVES

Upon completion of this chapter, you should be able to do the following:

- *State the uses of the screw.*
- *Explain the use of the jack.*
- *Discuss the use of the micrometer*

The screw is a simple machine that has many uses. The vise on a workbench makes use of the mechanical advantage (M.A.) of the screw. You get the same advantage using glued screw clamps to hold pieces of furniture together, a jack to lift an automobile, or a food processor to grind meat.

A screw is a modification of the inclined plane. Cut a sheet of paper in the shape of a right triangle and you have an inclined plane. Wind this paper around a pencil, as in figure 5-1, and you can see that the screw is actually an inclined plane wrapped around a cylinder. As you turn the pencil, the paper is wound up so that its hypotenuse forms a spiral thread. The pitch of the screw and paper is the distance between identical points on the same threads measured along the length of the screw.

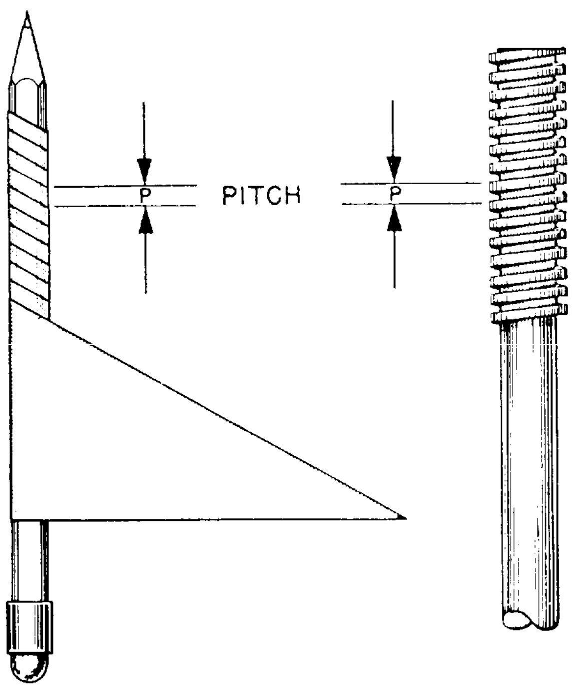


Figure 5-1.—A screw is an inclined plane in spiral form.

THE JACK

To understand how the screw works, look at figure 5-2. Here you see the type of jack screw used to raise a house or apiece of heavy machinery. Notice that the jack has a lever handle; the length of the handle is equal to *r*.

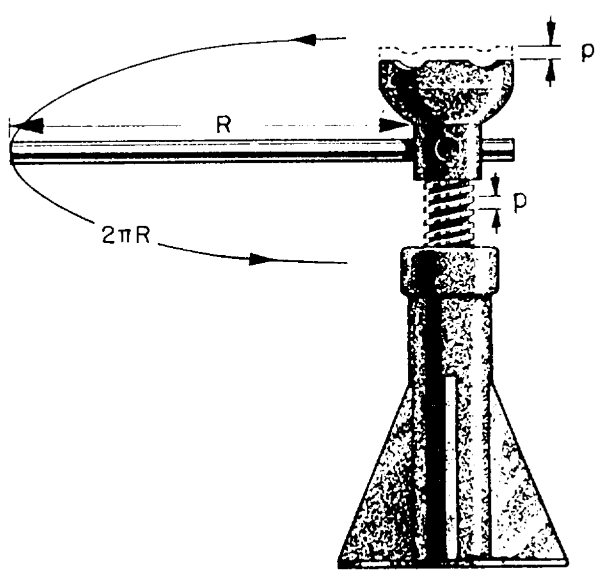


Figure 5-2.-A jack screw.

If you pull the lever handle around one turn, its outer end has described a circle. The circumference of this circle is equal to 2π. (Remember that π equals 3.14, or $^{22}/_{7}$) That is the distance you must apply the effort of the lever arm.

At the same time, the screw has made one revolution, raising its height to equal its pitch (p). You might say that one full thread has come up out of the base. At any rate, the load has risen a distance p.

Remember that the theoretical mechanical advantage (T.M.A.) is equal to the distance through which you apply the effort or pull, divided by the distance and resistance the load is moved. Assuming a 2-foot, or 24-inch, length for the lever arm and a 1/4-inch pitch for the thread, you can find the theoretical mechanical advantage by the formula

$$\text{T.M.A.} = \frac{2\pi r}{P}$$

in that

r = length of handle = 24 inches

p = pitch, or distance between corresponding points on successive threads = 1/4 inch.

Substituting,

$$\text{T.M.A.} = \frac{2 \times 3.14 \times 24}{1/4} = \frac{150.72}{1/4} = 602.88.$$

A 50-pound pull on the handle would result in a theoretical lift of 50 x 602 or about 30,000 pounds—15 tons for 50 pounds.

However, jacks have considerable friction loss. The threads are cut so that the force used to overcome friction is greater than the force used to do useful work. If the threads were not cut this way and no friction were present, the weight of the load would cause the jack to spin right back down to the bottom as soon as you released the handle.

THE MICROMETER

In using the jack you exerted your effort through a distance of $2\pi r$, or 150 inches, to raise the screw 1/4 inch. It takes a lot of circular motion to get a small amount of straight line motion from the head of the jack. You will use this point to your advantage in the micrometer; it's a useful device for making accurate small measurements—measurements of a few thousandths of an inch.

In figure 5-3, you see a cutaway view of a micrometer. The thimble turns freely on the sleeve, rigidly attached to the micrometer frame. The spindle attaches to the thimble and is fitted with screw threads that move the spindle and thimble to the right or left in the sleeve when you rotate the thimble. These screw threads are cut 40 threads to the inch. Hence, one turn of the thimble moves the spindle and thimble 1/40 of inch. This represents one of the smallest divisions on the micrometer. Four of these small divisions make 4/40 of an inch, or 1/10 inch. Thus, the distance from 0 to 1 or 1 to 2 on the sleeve represents 1/10, or 0.1, inch.

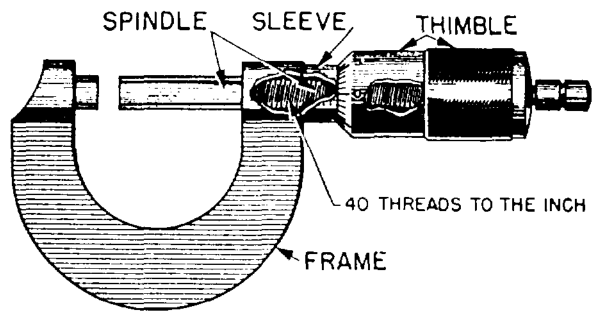


Figure 5-3.-A micrometer.

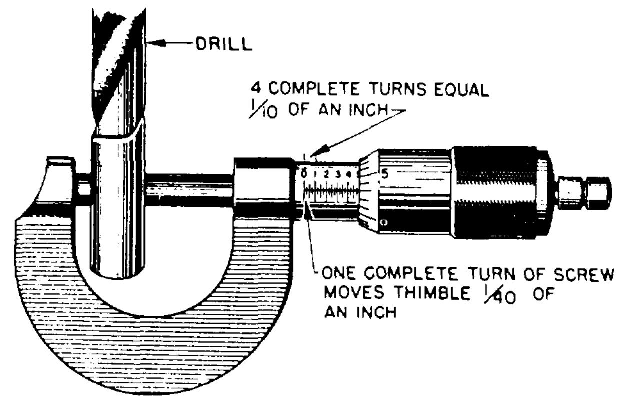


Figure 5-4.—Taking turns.

To allow even finer measurements, the thimble is divided into 25 equal parts. It is laid out by graduation marks around its rim, as shown in figure 5-4. If you turn the thimble through 25 of these equal parts, you have made one complete revolution of the screw. This represents a lengthwise movement of 1/40 of an inch. If you turn the thimble one of these units on its scale, you have moved the spindle a distance of 1/25 of 1/40 inch, or 1/1000 of an inch—0.001 inch.

The micrometer in figure 5-4 reads 0.503 inch, that is the true diameter of the half-inch drill-bit shank measured. This tells you that the diameter of this bit is 0.003 inch greater than its nominal diameter of 1/2 inch—0.5000 inch.

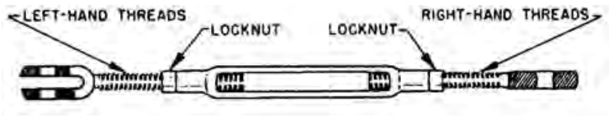


Figure 5-5.—A turnbuckle.

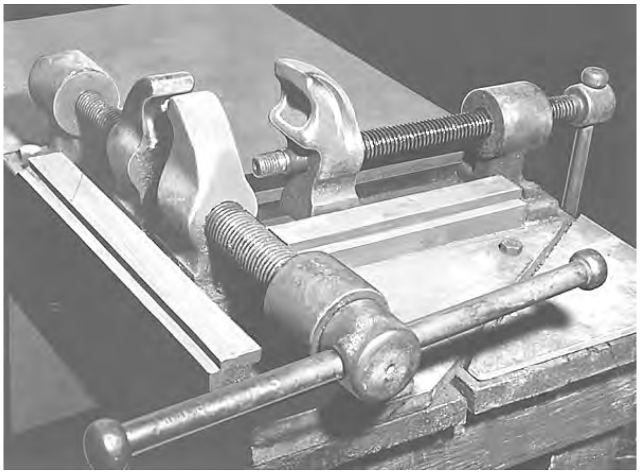


Figure 5-6.-A rigger's vice.

Because you can make accurate measurements with this instrument, it is vital in every machine shop.

APPLICATIONS AFLOAT AND ASHORE

It's a tough job to pull a rope or cable tight enough to get all the slack out of it. However, you can do it by using a turnbuckle. The turnbuckle (fig, 5-5) is an application of the screw. If you turn it in one direction, it takes up the slack in a cable. Turning it the other way allows slack in the cable. Notice that one bolt of the turnbuckle has left-hand threads and the other bolt has right-hand threads. Thus, when you turn the turnbuckle to tighten the line, both bolts tighten up. If both bolts were right-hand thread-standard thread-one would tighten while the other one loosened an equal amount. That would result in no change in cable slack. Most turnbuckles have the screw threads cut to provide a large amount of frictional resistance to keep the turnbuckle from unwinding under load. In some cases, the turnbuckle has a locknut on each of the screws to prevent slipping. You'll find turnbuckles used in a hundred different ways afloat and ashore.

Ever wrestled with a length of wire rope? Obstinate and unwieldy, wasn't it? Riggers have dreamed up tools to help subdue wire rope. One of these tools-the rigger's vise-is shown in figure 5-6. This rigger's vise uses the mechanical advantage of the screw to hold the wire rope in place. The crew splices a thimble-a reinforced loop—onto the end of the cable. Rotating the handle causes the jaw on

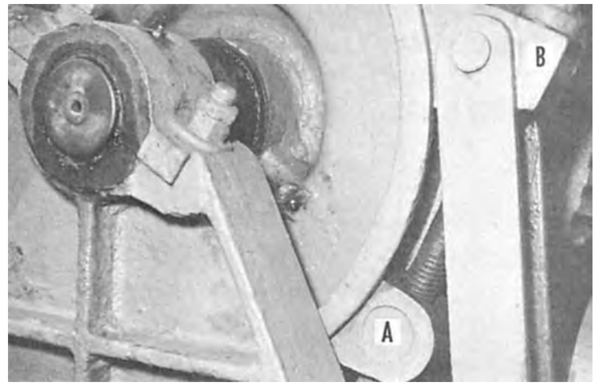


Figure 5-7.—A friction brake.

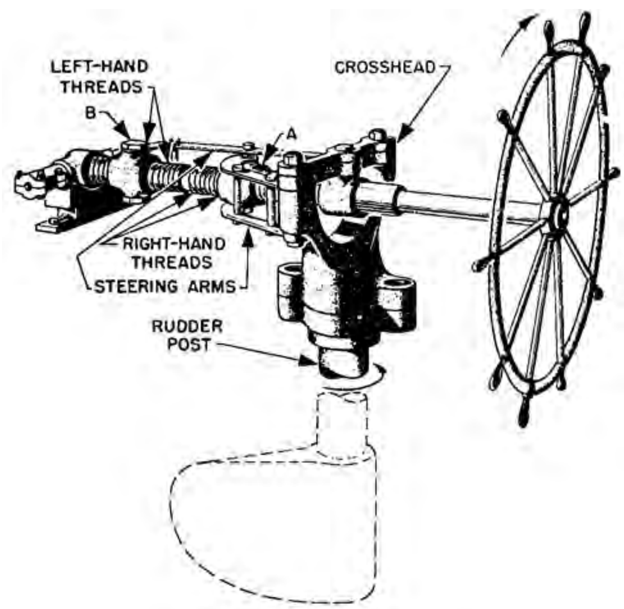


Figure 5-8.—The screw gives a tremendous mechanical advantage.

that screw to move in or out along its grooves. This machine is a modification of the vise on a workbench. Notice the right-hand and left-hand screws on the left-hand clamp.

Figure 5-7 shows you another use of the screw. Suppose you want to stop a winch with its load suspended in mid-air. To do this, you need a brake. The brakes on most anchor or cargo winches consist of a metal band that encircles the brake drum. The two ends of the band fasten to nuts connected by a screw attached to a handwheel. As you turn the handwheel, the screw pulls the lower end of the band (A) up toward its upper end (B). The huge mechanical advantage of the screw puts the squeeze on the drum, and all rotation of the drum stops.

One type of steering gear used on many small ships and as a spare steering system on some larger ships is the screw gear. Figure 5-8 shows you that the

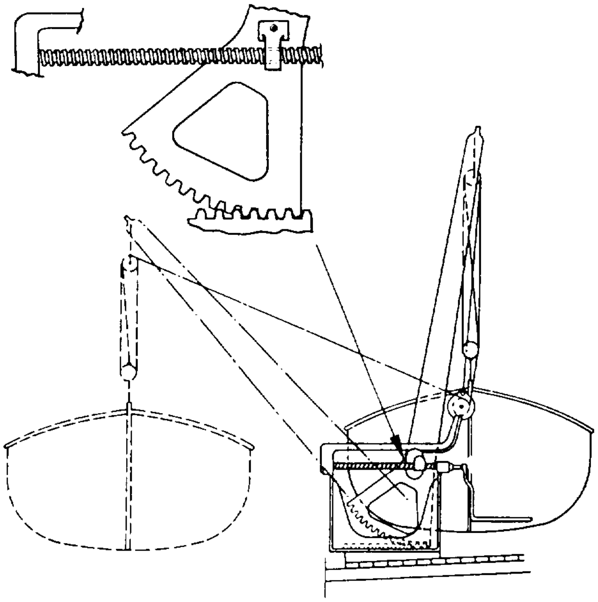


Figure 5-9.—The quadrant davit.

wheel turns a long threaded shaft. Half the threads—those nearer the wheel end of this shaft-are right-hand threads. The other half of the threads-those farther from the wheel—are left-hand threads. Nut A has a right-hand thread, and nut B has a left-hand thread. Notice that two steering arms connect the crosshead to the nuts; the crosshead turns the rudder. If you stand in front of the wheel and turn it in a clockwise direction—to your right—arm A moves forward and arm B moves backward. That turns the rudder counterclockwise, so the ship swings in the direction you turn the wheel. This steering mechanism has a great mechanical advantage.

Figure 5-9 shows you another practical use of the screw. The quadrant davit makes it possible for two men to put a large lifeboat over the side with little effort. The operating handle attaches to a threaded screw that passes through a traveling nut. Cranking the operating handle in a counterclockwise direction (as you face outboard), the nut travels outward along the screw. The traveling nut fastens to the davit arm by a swivel. The davit arm and the boat swing outboard as a result of the outward movement of the screw. The thread on that screw is the self-locking type; if you let go of the handle, the nut remains locked in position.

SUMMARY

You have learned the following basic information about the screw from this chapter; now notice the different ways the Navy uses this simple machine:

The screw is a modification of the inclined plane—modified to give you a high mechanical advantage.

The theoretical mechanical advantage of the screw can be found by the formula

$$\text{T.M.A.} = \frac{2\pi r}{p}.$$

As in all machines, the actual mechanical advantage equals the resistance divided by the effort.

In many applications of the screw, you make use of the large amount of friction that is commonly present in this simple machine.

By using the screw, you reduce large amounts of circular motion to very small amounts of straight-line motion.

CHAPTER 6

GEARS

CHAPTER LEARNING OBJECTIVES

Upon completion of this chapter, you should be able to do the following:

- *Compare the types of gears and their advantages.*

Did you ever take a clock apart to see what made it tick? Of course you came out with some parts left over when you got it back together again. And they probably included a few gear wheels. We use gears in many machines. Frequently the gears are hidden from view in a protective case filled with grease or oil, and you may not see them.

An eggbeater gives you a simple demonstration of the three jobs that gears do. They can change the direction of motion, increase or decrease the speed of the applied motion, and magnify or reduce the force that you apply. Gears also give you a positive drive. There can be, and usually is, creep or slip in a belt drive. However, gear teeth are always in mesh, so there can be no creep and slip.

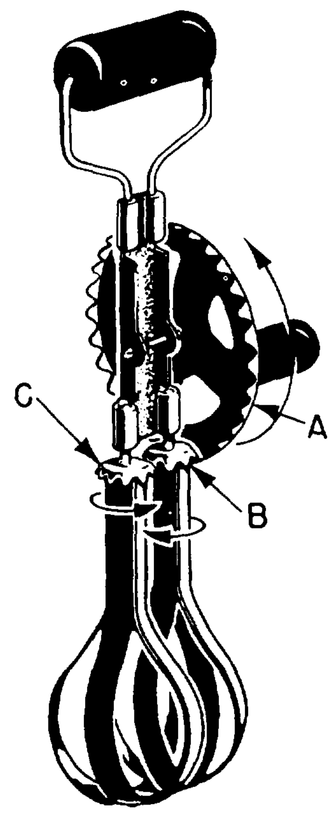
Follow the directional changes in figure 6-1. The crank handle turns in the direction shown by the arrow—clockwise—when viewed from the right. The 32 teeth on the large vertical wheel (A) mesh with the 8 teeth on the right-hand horizontal wheel (B), which rotates as shown by the arrow. Notice that as B turns in a clockwise direction, its teeth mesh with those of wheel C and cause wheel C to revolve in the opposite direction. The rotation of the crank handle has been transmitted by gears to the beater blades, which also rotate.

Now figure out how the gears change the speed of motion. There are 32 teeth on gear A and 8 teeth on gear B. However, the gears mesh, so that one complete revolution of A results in four complete revolutions of gear B. And since gears B and C have the same number of teeth, one revolution of B results in one revolution of C. Thus, the blades revolve four times as fast as the crank handle.

In chapter 1 you learned that third-class levers increase speed at the expense of force. The same happens with the eggbeater. The magnitude of force changes. The force required to turn the handle is greater than the force applied to the frosting by the blades. This results in a mechanical advantage of less than one.

TYPES OF GEARS

When two shafts are not lying in the same straight line, but are parallel, you can transmit motion from



Figurc 6-1.—A simple gear arrangement.

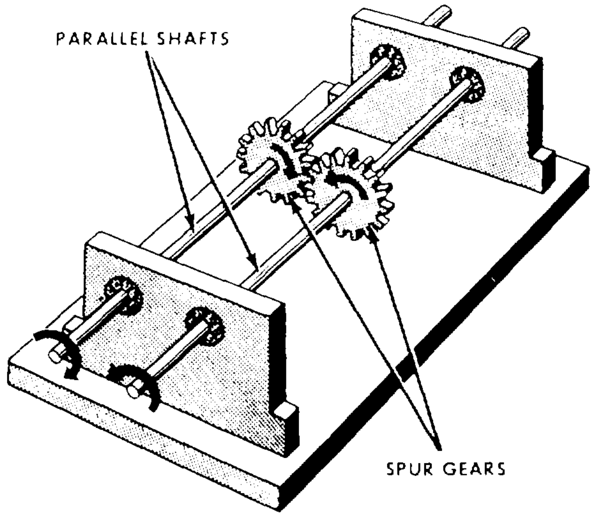


Figure 6-2.4-Spur gears coupling two parallel shafts.

one to the other by spur gears. This setup is shown in figure 6-2.

Spur gears are wheels with mating teeth cut in their surfaces so that one can turn the other without slippage. When the mating teeth are cut so that they are parallel to the axis of rotation, as shown in figure 6-2, the gears are called straight spur gears.

When two gears of unequal size are meshed together, the smaller of the two is usually called a pinion. By unequal size, we mean an unequal number of teeth causing one gear to be a larger diameter than the other. The teeth, themselves, must be of the same size to mesh properly.

The most commonly used gears are the straight spur gears. Often you'll run across another type of spur gear called the helical spur gear.

In helical gears the teeth are cut slantwise across the working face of the gear. One end of the tooth, therefore, lies ahead of the other. Thus, each tooth has a leading end and a trailing end. Figure 6-3, view A, shows you the construction of these gears.

In the straight spur gears, the whole width of the teeth comes in contact at the same time. However, with helical (spiral) gears, contact between two teeth starts first at the leading ends and moves progressively across the gear faces until the trailing ends are in contact. This kind of meshing action keeps the gears in constant contact with one another. Therefore, less lost motion and smoother, quieter action is possible. One disadvantage of this helical spur gear is the tendency of each gear to thrust or push axially on its shaft. It is necessary to put a special thrust bearing at the end of the shaft to counteract this thrust.

You do not need thrust bearings if you use herringbone gears like those shown in figure 6-4. Since the teeth on each half of the gear are cut in opposite directions, each half of the gear develops a thrust that counterbalances the other half. You'll find herringbone gears used mostly on heavy machinery.

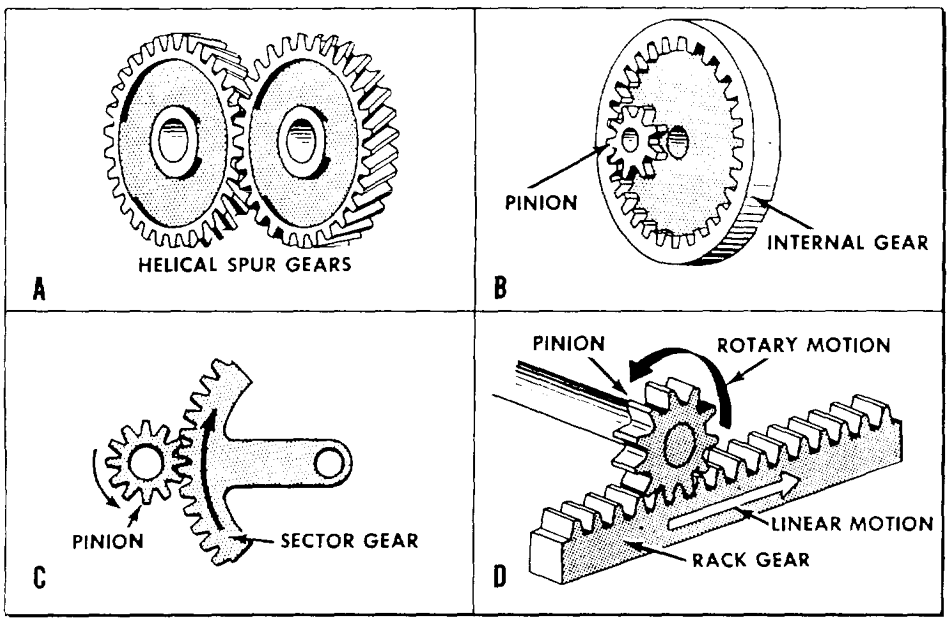


Figure 6-3.-Gear types.

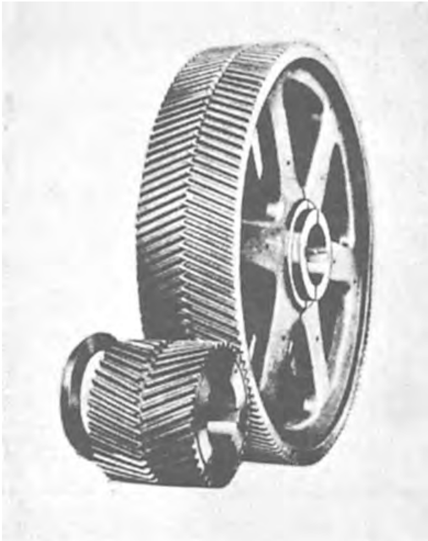


Figure 6-4.—Herringbone gear.

Figure 6-3, views B, C, and D, also shows you three other gear arrangements in common use.

The internal gear in figure 6-3, view B, has teeth on the inside of a ring, pointing inward toward the axis of rotation. An internal gear is meshed with an external gear, or pinion, whose center is offset from the center of the internal gear. Either the internal or pinion gear can be the driver gear, and the gear ratio is calculated the same as for other gears—by counting teeth.

You only need a portion of a gear where the motion of the pinion is limited. You use the sector gear shown in figure 6-3, view C, to save space and material. The rack and pinion in figure 6-3, view D, are both spur gears. The rack is a piece cut from a gear with an extremely large radius. The rack-and-pinion arrangement is useful in changing rotary motion into linear motion.

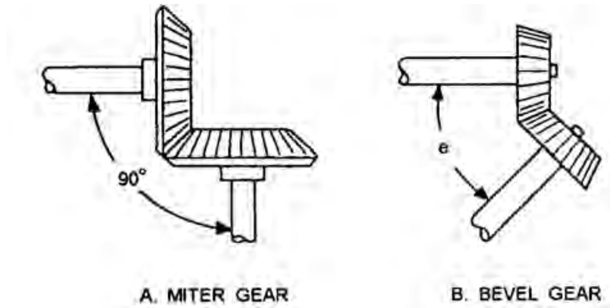


Figure 6-5.-Bevel gears.

THE BEVEL GEAR

So far most of the gears you've learned about transmit motion between parallel shafts. However, when shafts are not parallel (at an angle), we use another type of gear called the bevel gear. This type of gear can connect shafts lying at any given angle because you can bevel them to suit the angle.

Figure 6-5, view A, shows a special case of the bevel gear-the miter gear. You use the miter gears to connect shafts having a 90-degree angle; that means the gear faces are beveled at a 45-degree angle.

You can see in figure 6-5, view B, how bevel gears are designed to join shafts at any angle. Gears cut at any angle other than 45 degrees are bevel gears.

The gears shown in figure 6-5 are straight bevel gears, because the whole width of each tooth comes in contact with the mating tooth at the same time. However, you'll run across spiral bevel gears with teeth cut to have advanced and trailing ends. Figure 6-6 shows you what spiral bevel gears look like. They have the same advantage as other spiral (helical) gears—less lost motion and smoother, quieter operation.

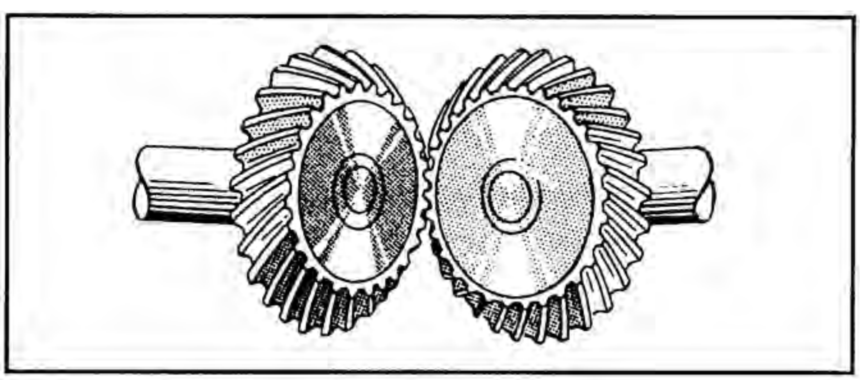


Figure 6-6.-Spiral bevel gears.

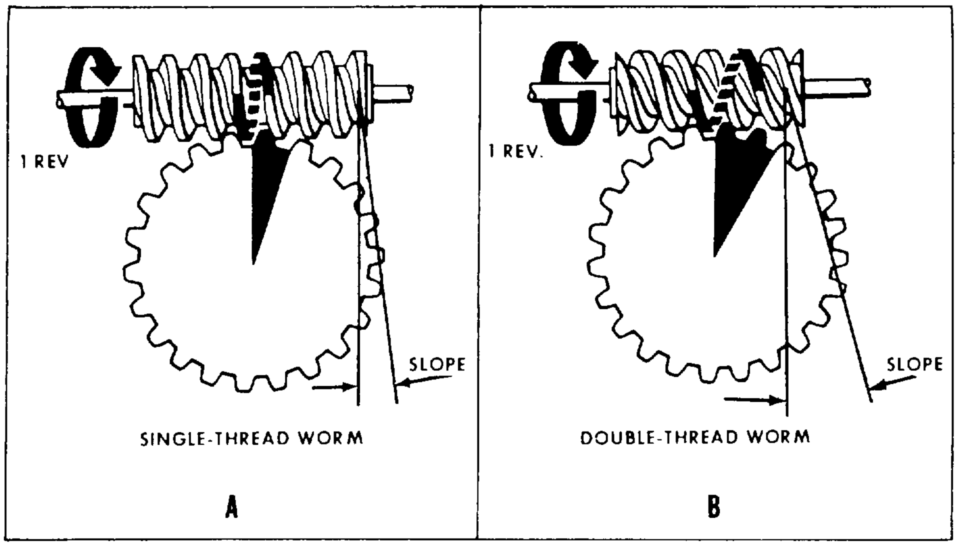


Figure 6-7.—Worm gears.

THE WORM AND WORM WHEEL

Worm and worm-wheel combinations, like those in figure 6-7, have many uses and advantages. However, it's better to understand their operating theory before learning of their uses and advantages.

Figure 6-7, view A, shows the action of a single-thread worm. For each revolution of the worm, the worm wheel turns one tooth. Thus, if the worm wheel has 25 teeth, the gear ratio is 25:1.

Figure 6-7, view B, shows a double-thread worm. For each revolution of the worm in this case, the worm wheel turns two teeth. That makes the gear ratio 25:2 if the worm wheel has 25 teeth.

A triple-thread worm would turn the worm wheel three teeth per revolution of the worm.

A worm gear is a combination of a screw and a spur gear. You can obtain remarkable mechanical advantages with this arrangement. You can design worm drives so that only the worm is the driver-the spur cannot drive the worm. On a hoist, for example, you can raise or lower the load by pulling on the chain that turns the worm. If you let go of the chain, the load cannot drive the spur gear; therefore, it lets the load drop to the deck. This is a nonreversing worm drive.

GEARS USED TO CHANGE DIRECTION

The crankshaft in an automobile engine can turn in only one direction. If you want the car to go backwards, you must reverse the effect of the engine's rotation. This is done by a reversing gear in the transmission, not by reversing the direction in which the crankshaft turns.

A study of figure 6-8 will show you how gears are used to change the direction of motion. This is a schematic diagram of the sight mounts on a Navy gun. If you crank the range-adjusting handle (A) in a clockwise direction, the gear (B) directly above it will rotate in a counterclockwise direction. This motion causes the two pinions (C and D) on the shaft to turn in the same direction as the gear (B) against the teeth cut in the bottom of the table. The table is tipped in the direction indicated by the arrow.

As you turn the deflection-adjusting handle (E) in a clockwise direction, the gear (F) directly above it turns

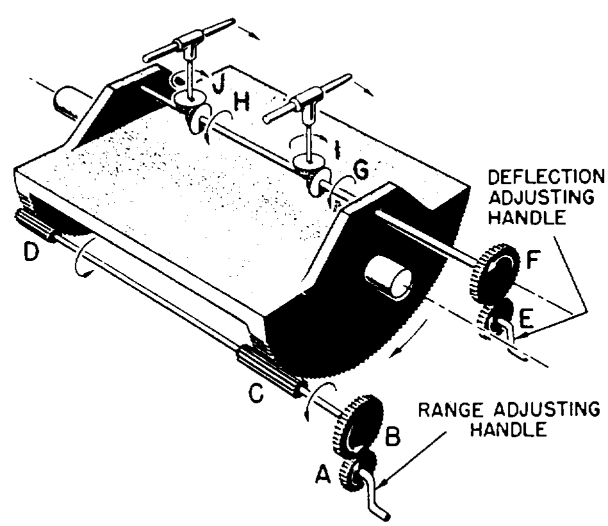


Figure 6-8.-Gears change direction of applied motion.

in the opposite direction. Since the two bevel gears (G and H) are fixed on the shaft with F, they also turn. These bevel gears, meshing with the horizontal bevel gears (I and J), cause I and J to swing the front ends of the telescopes to the right. Thus with a simple system of gears, it is possible to keep the two telescopes pointed at a moving target. In this and many other applications, gears serve one purpose: to change the direction of motion.

GEARS USED TO CHANGE SPEED

As you've already seen in the eggbeater, you use gears to change the speed of motion. Another example of this use of gears is in your clock or watch. The mainspring slowly unwinds and causes the hour hand to make one revolution in 12 hours. Through a series-or train-of gears, the minute hand makes one revolution each hour, while the second hand goes around once per minute.

Figure 6-9 will help you to understand how speed changes are possible. Wheel A has 10 teeth that mesh with the 40 teeth on wheel B. Wheel A will have to rotate four times to cause B to make one revolution. Wheel C is rigidly fixed on the same shaft with B. Thus, C makes the same number of revolutions as B. However, C has 20 teeth and meshes with wheel D, which has only 10 teeth. Hence, wheel D turns twice as fast as wheel C. Now, if you turn A at a speed of four revolutions per second, B will rotate at one revolution per second. Wheel C also moves at one revolution per second and causes D to turn at two revolutions per second. You get out two revolutions per second after having put in four revolutions per second. Thus, the overall speed reduction is 2/4—or 1/2—that means you got half the speed out of the last driven wheel you put into the first driver wheel.

You can solve any gear speed-reduction problem with this formula:

$$S_2 = S_1 \times \frac{T_1}{T_2},$$

where

S_1 = speed of first shaft in train

S_2 = speed of last shaft in train

T_1 = product of teeth on all drivers

T_2 = product of teeth on all driven gears

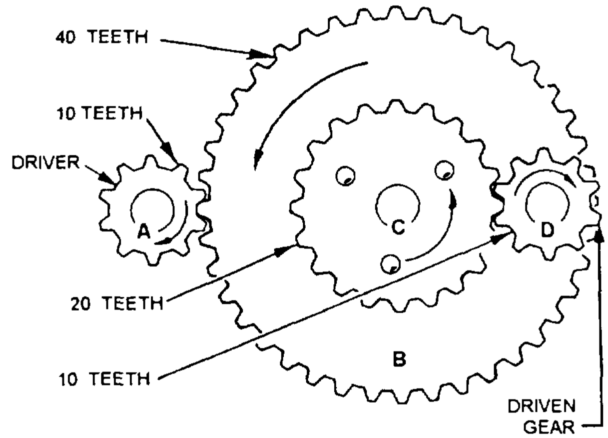


Figure 6-9.-Gears can change speed of applied motion.

Now use the formula on the gear train of figure 6-9.

$$S_2 = S_1 \times \frac{T_1}{T_2} = 4 \times \frac{10 \times 10}{40 \times 10}$$

$$= \frac{800}{400} = 2 \text{ revs. per sec.}$$

To obtain any increase or decrease in speed you, must choose the correct gears for the job. For example, the turbines on a ship have to turn at high speeds-say 5,800 rpm—if they are going to be efficient. The propellers, or screws, must turn rather slowly—say 195 rpm—to push the ship ahead with maximum efficiency. So, you place a set of reduction gears between the turbines and the propeller shaft.

When two external gears mesh, they rotate in opposite directions. Often you'll want to avoid this. Put a third gear, called an idler, between the driver and the driven gear. Don't let this extra gear confuse you on speeds. Just neglect the idler entirely. It doesn't change the gear ratio at all, and the formula still applies. The idler merely makes the driver and its driven gear turn in the same direction. Figure 6-10 shows you how this works.

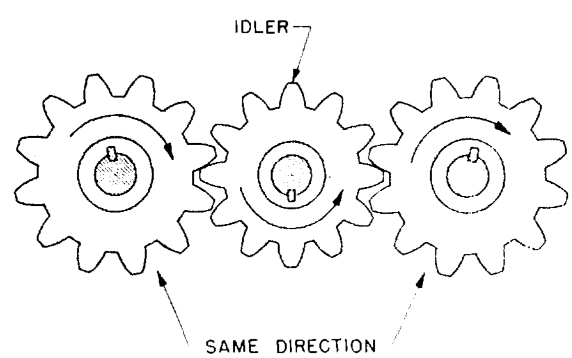


Figure 6-10.-An idler gear.

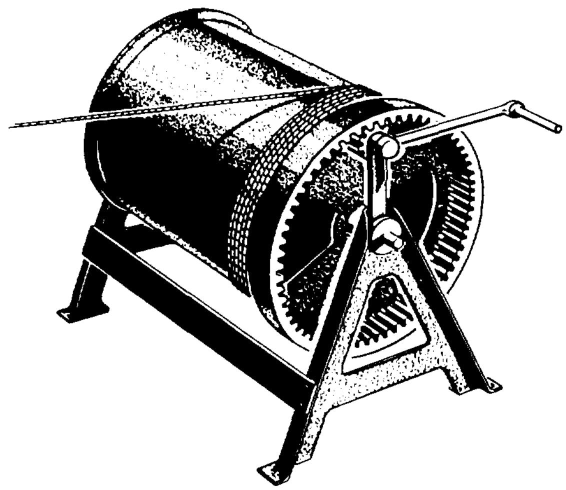


Figure 6-11.-Cable winch.

GEARS USED TO INCREASE MECHANICAL ADVANTAGE

We use gear trains to increase mechanical advantage. In fact, wherever there is a speed reduction, you multiply the effect of the effort. Look at the cable winch in figure 6-11. The crank arm is 30 inches long, and the drum on which the cable is wound has a 15-inch radius. The small pinion gear has 10 teeth, which mesh with the 60 teeth on the internal spur gear. You will find it easier to figure the mechanical advantage of this machine if you think of it as two machines.

First, figure out what the gear and pinion do for you. You find the theoretical mechanical advantage (T.M.A.) of any arrangement of two meshed gears by using the following formula:

$$\text{T.M.A.} = \frac{T_o}{T_a}$$

In which,

T_o = number of teeth on driven gear;

T_a = number of teeth on driver gear.

In this case,

T_o = 60 and T_a = 10.

Then,

$$\text{T.M.A.} = \frac{T_o}{T_a} = \frac{60}{10} = 6$$

Now, figure the mechanical advantage for the other part of the machine-a simple wheel-and-axle arrangement consisting of the crank arm and the drum. Divide the distance the effort moves $(2\pi R)$ in making one complete revolution by the distance the cable is drawn up in one revolution of the drum $(2\pi r)$.

$$\text{T.M.A.} = \frac{2\pi R}{2\pi r} = \frac{R}{r} = \frac{30}{15} = 2$$

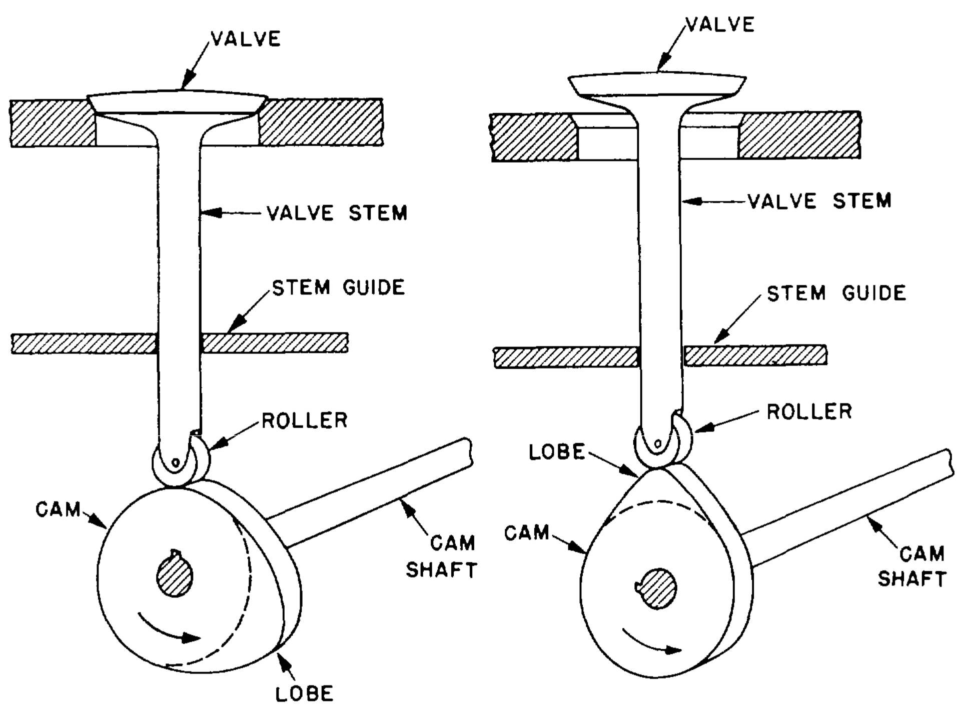


Figure 6-12.-Camdriven valve.

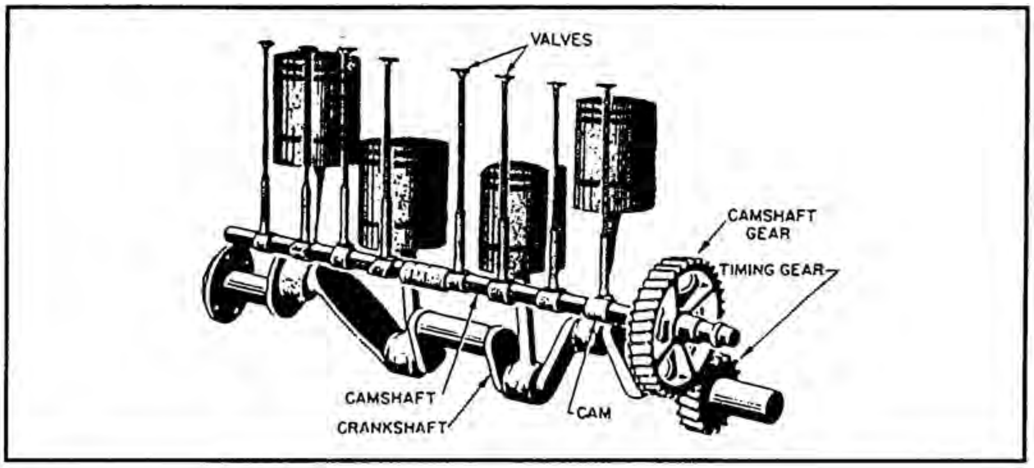


Figure 6-13.—Automobile valve gear.

The total, or overall, theoretical mechanical advantage of a compound machine is equal to the product of the mechanical advantages of the several simple machines that make it up. In this case you considered the winch as two machines—one having a mechanical advantage of 6 and the other a mechanical advantage of 2. Therefore, the overall theoretical mechanical advantage of the winch is 6 x 2, or 12. Since friction is always present, the actual mechanical advantage may be only 7 or 8. Even so, by applying a force of 100 pounds on the handle, you could lift a load of 700 to 800 pounds.

CAM

You use gears to produce circular motion. However, you often want to change rotary motion into up-and-down, or linear, motion. You can use cams to do this. For example, in figure 6-12 the gear turns the cam shaft. A cam is keyed to the shaft and turns with it. The design on the cam has an irregular shape that moves the valve stem up and down. It gives the valve a straight-line motion as the cam shaft rotates.

When the cam shaft rotates, the high point (lobe) of the cam raises the valve to its open position. As the shaft continues to rotate, the high point of the cam passes, lowering the valve to a closed position.

A set of cams, two to a cylinder, driven by timing gears from the crankshaft operate the exhaust and intake valves on the gasoline automobile engine as shown in figure 6-13. We use cams in machine tools and other devices to make rotating gears and shafts do up-and-down work.

ANCHOR WINCH

One of the gear systems you'll get to see frequently aboard ship is that on the anchor winch. Figure 6-14 shows you one type in which you can readily see how the wheels go around. The winch engine or motor turns the driving gear (A). This gear has 22 teeth, which mesh with the 88 teeth on the large wheel (B). Thus, you know that the large wheel makes one revolution for every four revolutions of the driving gear (A). You get a 4-to-1 theoretical mechanical advantage out of that pair. Secured to the same shaft with B is the small spur gear (C), covered up here. The gear (C) has 30 teeth that mesh with the 90 teeth on the large gear (D), also covered up.

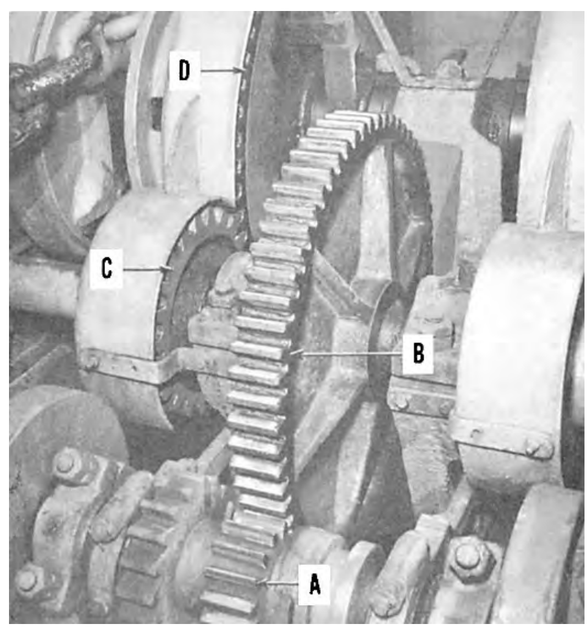


Figure 6-14.—An anchor winch.

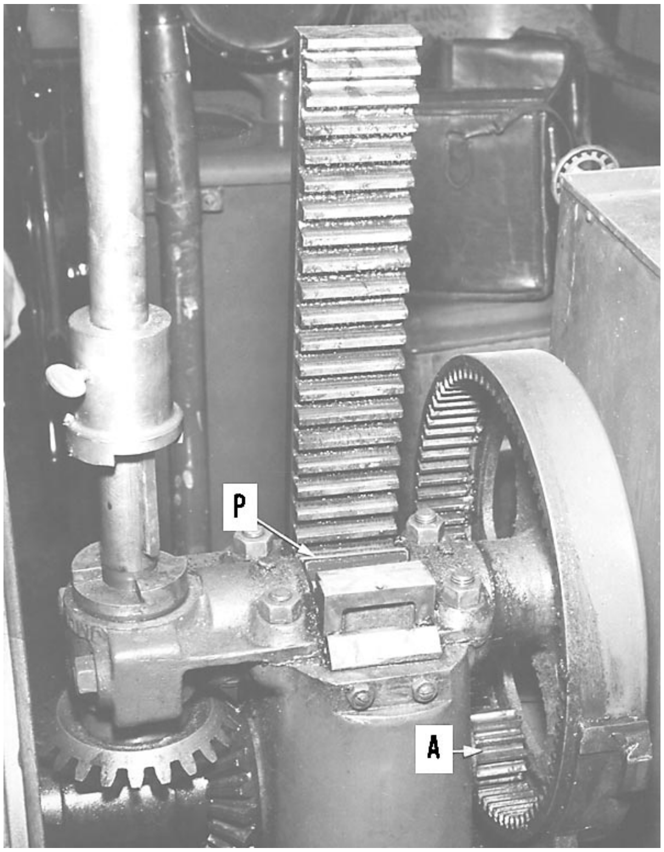


Figure 6-15.—A steering mechanism.

The advantage from C to D is 3 to 1. The sprocket wheel to the far left, on the same shaft with D, is called a wildcat. The anchor chain is drawn up over this. Every second link is caught and held by the protruding teeth of the wildcat. The overall mechanical advantage of the winch is 4 x 3, or 12 to 1.

RACK AND PINION

Figure 6-15 shows you an application of the rack and pinion as a steering mechanism. Turning the ship's wheel turns the small pinion (A). This pinion causes the internal spur gear to turn. Notice that this arrangement has a large mechanical advantage.

Now you see that when the center pinion (P) turns, it meshes with the two vertical racks. When the wheel turns full to the right, one rack moves downward and the other moves upward to the position of the racks. Attached to the bottom of the racks are two hydraulic pistons that control the steering of the ship. You'll get some information on this hydraulic system in a later chapter.

SUMMARY

These are the important points you should keep in mind about gears:

Gears can do a job for you by changing the direction, speed, or size of the force you apply.

When two external gears mesh, they always turn in opposite directions. You can make them turn in the same direction by placing an idler gear between the two.

The product of the number of teeth on each of the driver gears divided by the product of the number of teeth on each of the driven gears gives you the speed ratio of any gear train.

The theoretical mechanical advantage of any gear train is the product of the number of teeth on the driven gear wheels, divided by the product of the number of teeth on the driver gears.

The overall theoretical mechanical advantage of a We compound machine is equal to the product of the theoretical mechanical advantages of all the simple machines that make it up.

We can use cams to change rotary motion into linear motion.