

Objective:

To apply the principles of hydraulics in building a working model of a hydraulic lift.

Introduction

What do a wheelchair lift, an excavator at a construction site, and a dentist's chair have in common? The ability to lift a heavy load. And in all of these examples, the ability is due to the power of hydraulics.

Hydraulics is the study of liquids and their mechanical properties: for instance, how they move, resist movement, act when subject to pressure, and so forth. In engineering, one application of hydraulics is using liquids, like water and oil, to move things. Why use a liquid to move things, instead of, say, air? One important reason is that a liquid is **incompressible**, which means that if you press on it, you cannot change its volume. For example, if you have a cup filled with marshmallows, you can fit even more marshmallows into the cup by compressing (squeezing) the marshmallows together. But if the glass is full of water, there is no way you can fit more water into the cup - no matter how hard you squeeze! Since liquid is incompressible, applying a **force** (for example, a push or a pull) to one end of a hydraulic system transmits (passes along) the force through the liquid to the other end.

A force spread out over an **area**, or a force divided by an area, is called **pressure**. Pushing on the top of a glass of water is putting pressure on the water. Another way of thinking about pressure is to imagine yourself pushing on an object with your finger or with the palm of your hand. In both cases, you are applying the same force, but the *pressure* is different because the *area* of the tip of your finger is much smaller than the palm of your hand. Figure 1 below shows a simple hydraulic system that uses the concepts of force and pressure.

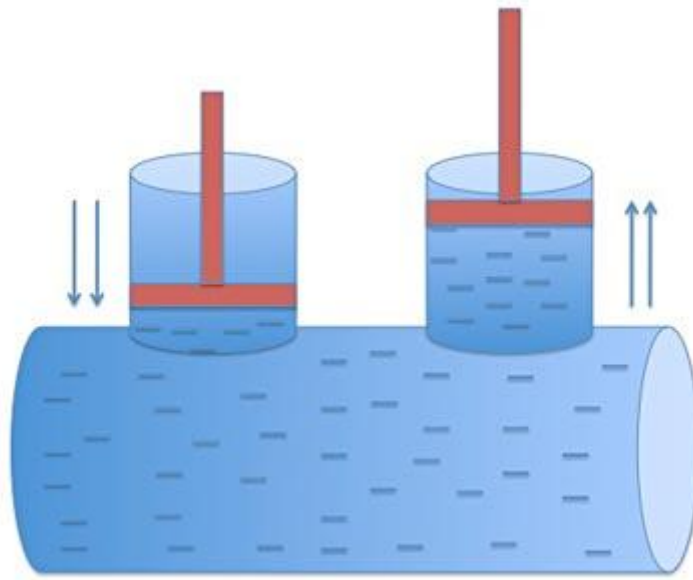


Figure 1. This simple hydraulic system has two pistons in cylinders on the top.

The hydraulic system in Figure 1 is made up of a liquid-filled tube topped with two **pistons**. Applying a downward force on this closed system (in this case, pushing down on the left-hand piston) causes the liquid to move against the right-hand piston and, because the liquid is incompressible, push the piston up. Since the liquid is incompressible, the pressure in the liquid is the same at every point within the liquid. When the **energy** from the force applied to one piston is transferred to the liquid and gives its energy to move the second piston, we say that **work** has been done to the liquid by the first piston. Hydraulic machinery, like wheelchair lifts and car jacks, use liquids to do work. That work can be applied to performing big jobs like lifting heavy loads.

An advantage of hydraulic tools is the concept of **force multiplication**. Force multiplication enables the force you apply to one piston to be multiplied, by a multiplicative factor, to make a larger force acting on the second piston. This only works if the first piston is smaller in area than the second piston. If we take the simple hydraulic system mentioned above and alter it to use force multiplication, it will look like Figure 2 below.

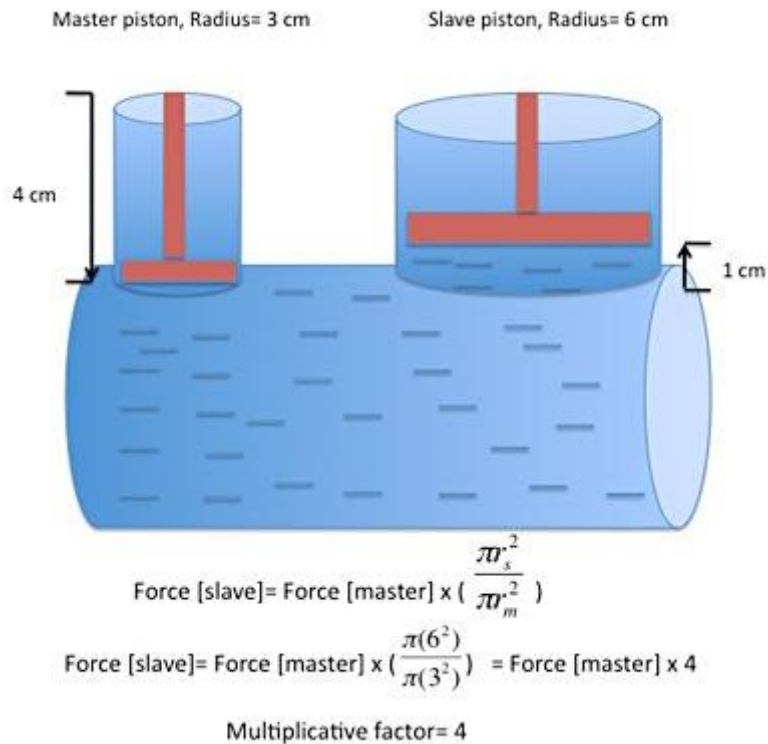


Figure 2. Simple hydraulic system with pistons of different areas. The piston with the smaller area is called the master and the piston with the larger piston is called the slave. The difference in areas enables force multiplication.

When the *master* (smaller) piston is pushed in, the amount of force applied to the *slave* (larger) piston by the liquid is multiplied by the ratio of the area of the slave piston to the area of the master piston. This relationship is derived below in Equations 1-3.

Materials and Equipment

- 20 ml syringe
- 50 ml syringe
- Utility knife
- Waste CD
- Silicone fuel tubing
- Card boxes

Experimental Procedure

Building the Model Hydraulic Lifts

1. In this project, you will build three model hydraulic lifts using syringes with pistons of different areas and metal wall plates. The syringes act as hydraulic cylinders.
 - a. First you will build the model lifts, which involves attaching the top of a slave syringe's piston to the back of a metal plate with epoxy and then connecting the master syringe to the slave syringe with tubing.
 - b. Every lift will have a 12 cubic centimeter (cc) master hydraulic cylinder but each will have one of three different slave hydraulic cylinders: 12 cc, 35 cc, and 60 cc.
 - c. You will use water as the hydraulic fluid.
2. Prepare the metal plates. The metal plates will hold the weights while the slave piston will lift the plate and the weights. Using the Phillips screwdriver, remove the screws from both ends of all three of the blank wall plates. Discard the screws.
3. Prepare the syringes to attach to the metal plates. Make sure that the tops of the pistons in the syringes are flat because they will be epoxied to the back of the metal plates, and they need to be flush against the plates.
 - a. Larger syringes may have rings on the piston. If a piston has a ring on it, then use the hacksaw to remove it. File down the remains of the ring, so that the top of the piston is as flat as possible, as shown in Figure 4. Ask an adult volunteer to help you remove the ring.
 - b. If the 12 cc syringes have a curved tip, then cut the curved tip off with the utility knife so that the remaining tip is straight. Cutting off the curved tip makes it easier to push into the tubing.



Figure 4. Two 60 cc syringes, one shown with the original ring (left) and one shown with the ring

removed (right).

4. Epoxy the top of one 12 cc, 35 cc, and 60 cc syringe each to a separate metal plate, as shown in Figure 5 below, to create half of the model lift. The syringes that you epoxy to the metal plates are the slave syringes (or slave hydraulic cylinders).
 - a. Following the safety recommendations and directions on the epoxy package, mix up enough epoxy to make one lift at a time. Use a paper plate and a disposable spoon to mix the epoxy. You may want to have an adult help you with this.
 - b. Place a small dollop of epoxy in the middle of one of the metal plates.
 - c. Epoxy the top of one of the 12-cc syringe pistons to the metal plate. Follow the directions on the epoxy package, and allow the epoxy to cure for the recommended amount of time. Throw away the paper plate and spoon.
 - d. Repeat steps 4a to 4c with one 35-cc syringe and one 60-cc syringe.



Figure 5. This image shows the three slave syringes and wall plates used in the experiment. Each slave syringe/metal plate pair comprises half of a model hydraulic lift.

5. You will next use another 12 cc syringe and tubing to make the master syringe (or master hydraulic cylinder).
 - a. Cut a 30 centimeter (cm) piece of tubing.
 - b. Push the tip of a 12 cc syringe (that is not epoxied to a wall plate) into one end of the tubing.
 - c. The master syringe is now ready to attach to the slave syringe (slave hydraulic cylinder) to create the hydraulic lift.
6. Fill the master syringe and its tubing with water and prepare to attach it to the slave syringe to create the hydraulic lift. Water will serve as the hydraulic fluid in the hydraulic lifts.
 - a. Push the piston in the master syringe all the way down so that it is fully depressed into the cylinder.

- b. Place the free end of the tubing into the glass of water and pull the piston up (while firmly holding the rest of the syringe). This will suck water into the tubing and syringe. Pull the piston slowly and smoothly so that you avoid getting bubbles in the tubing.
 - c. Pull the master syringe's piston up as far as it can go without falling out of the cylinder of the syringe.
 - d. Depress the master syringe's piston a tiny bit to remove any bubbles at the end of tubing.
7. Insert the tip of the 12 cc slave syringe into the free end of the tubing that is attached to the master cylinder. See Figure 6 below to view how to put these two parts together.
 - a. Confirm that the 12 cc hydraulic lift works by pushing and pulling the water into and out of the slave syringe by pushing and pulling the master syringe's piston. *Note* If the tubing pops off the syringes, simply refill the tubing and master syringe with water, as in step 6, and reattach the tubing to the slave syringe, sealing the connection with plumber's putty.
 - b. End your practice by pulling on the master piston and bringing the water from the slave syringe back into the tubing and master syringe.



Figure 6. This image shows the master syringe attached to a slave syringe and its metal plate.

8. Repeat steps 6 and 7 using the 35 cc slave syringe/metal plate assembly and a 12 cc master syringe/tubing assembly, to create the 35 cc model hydraulic lift.
9. Repeat steps 6 and 7 using the 60 cc slave syringe/metal plate assembly and a 12-cc master syringe/tubing assembly, to create the 60 cc model hydraulic lift.

Testing the Model Hydraulic Lifts

1. You are now ready to test the 12 cc model hydraulic lift, the 35 cc model hydraulic lift, and the 60 cc model hydraulic lift (all with a 12 cc master syringe, or master hydraulic cylinder). All three model hydraulic lifts should have a master and slave syringe, and hydraulic fluid, or water, in the master syringe and tubing.
 - a. Make sure that the hydraulic fluid, or water, is in the tubing and master syringe. The slave piston must be depressed in its cylinder.
2. Place the vise on a sturdy table. The vise will be used to support and hold the lifts while they are lifting.
3. Use a set of light weights (such as the metric weights in the Materials list) or several types of materials of various weights to test the model hydraulic lift.
 - a. For example, you can use books, bottles of water, or cans of food. You can combine a couple of different items to make heavier weights.
4. To prepare the 12 cc model lift for testing, insert the 12 cc slave syringe and its metal plate vertically into the vise. Mount the lift so that the collar of the syringe is sitting on the vise's jaws and the metal plate is above its jaws, as shown in Figure 7 below. Mount the slave syringe cylinder high in the vise so that the piston does not stick as it moves up and down. Mount each slave syringe that you test the same way in the vise.
 - a. Tighten the vise enough to hold the syringe but not so tight that the piston cannot move up and down within the barrel.
 - b. The lift should be held firmly enough so that when you place weight on the plate, the lift does not fall over.



Figure 7. Here is a completed 12 cc model hydraulic lift, where the lift is properly held and supported by the vise.

5. The 12 cc model lift is now ready for testing. Use the weights that you collected and determine the heaviest weight that the 12 cc lift can support. Start with a small weight and try increasingly heavy weights. Record all data in a data table in your lab notebook.
 - a. If you are using your own materials for testing (not a set of standard weights) then weigh the material on the digital scale before placing it on the lift. Record the weight of the material in your lab notebook.
 - b. Set the materials on the plate. Smoothly depress the master piston, delivering all of the hydraulic fluid, or water, from the master syringe to the slave syringe. As the master piston is depressed, and the hydraulic fluid is delivered, the slave piston and the metal plate will rise.
 - c. Wait to see if the lift supports the weight. If the lift supports the weight, the weight and the plate will not move and will stay in the lifted position. Record that the lift is successful in supporting the weight in your lab notebook.
 - d. If the lift *cannot* support the weight, the weight will depress the slave piston, and the hydraulic fluid will flow out of the slave syringe and back into the master syringe. Record that the lift is unsuccessful in supporting the weight in your lab notebook.

- e. If your lift successfully lifted the weight, pull the master piston and bring the weight back down. Then increase the weight by about 100 grams, using different materials, until you find the maximum weight the lift can support. Record all data in your lab notebook.
 - f. You may find that with heavier weights, with the piston fully extended, the vise may start to tumble. In this case, have your volunteer hold the vise.
 - g. Repeat steps 5a through 5f two more times for a total of three trials. Redoing your experiments ensures that your data is repeatable and accurate. Before each trial, pull the master piston out and bring the hydraulic fluid back into the master syringe and tubing.
- 6. Repeat steps 3 to 5 with the 35 cc hydraulic model lift. Remember to record all data in a data table in your lab notebook.
 - 7. Repeat steps 3 to 5 with the 60 cc hydraulic model lift. Remember to record all data in a data table in your lab notebook.