environment. Since gases readily expand, minor leaks in a pneumatic system do not significantly affect the system's performance. **Hydraulic systems** are generally **more precise** due to liquid incompressibility and the components of the system are often kept **well lubricated** by the liquid used. Water and oil are typically used in hydraulic systems.

Other Questions to Consider:

- Can you name some examples of pneumatic/hydraulic systems?
- Why would fluid powered systems be favorable?

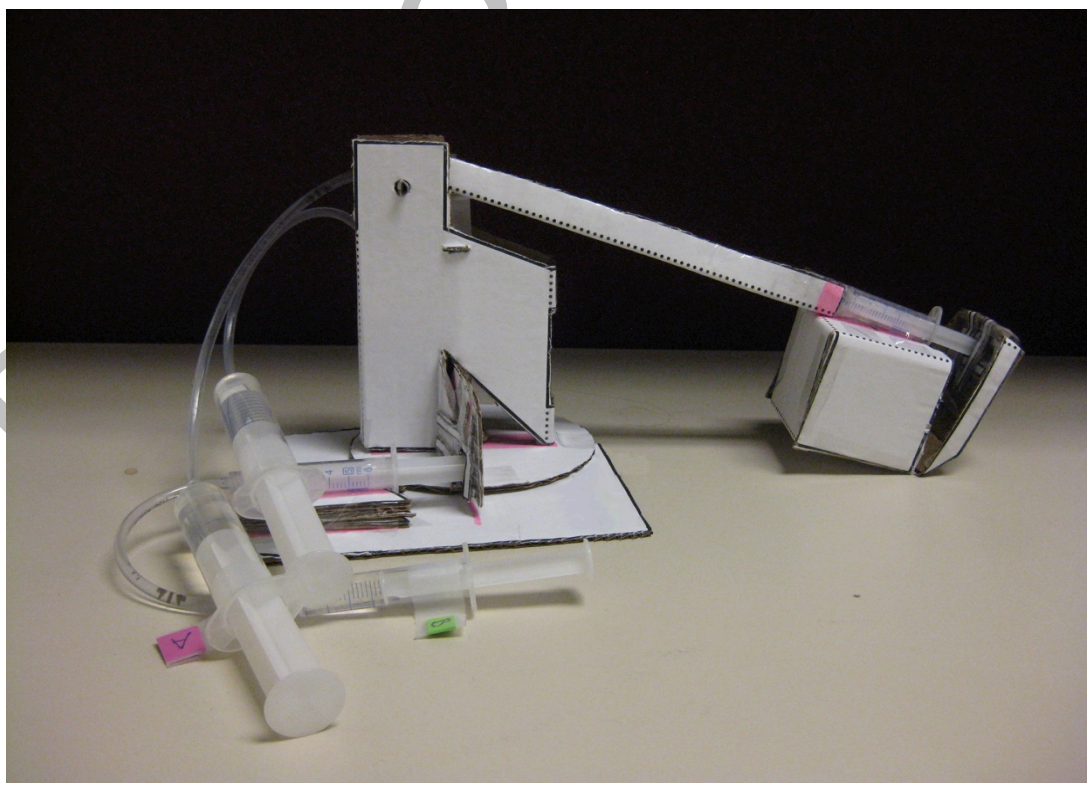
See Appendix B for the solutions!

Design Activity: Making a Mechanical Arm

Overview

Now that you understand the background behind fluid power, you can construct your very own mechanical arm from a few simple materials! The overall construction of the mechanical arm is separated into several parts, each generating a different type of motion. Tips for constructing the mechanical arm and advice for troubleshooting common issues are included in Appendix C. Printable cardboard templates are included in Appendix D.

- In Part 1, you will build a system that uses fluid power to generate horizontal motion for opening and closing a scoop attached to the mechanical arm.
- In Part 2, you will build a system that uses fluid power to generate rotational motion for swinging the mechanical arm left and right.
- In Part 3, you will build a system that uses fluid power to generate vertical motion for lifting and dropping the mechanical arm.
- In Part 4, you will integrate the three systems you have built to create a working mechanical arm.ater



Complete Materials List

In order to build a mechanical arm, you will need:

- 4 small (5mL) plastic syringes
- 2 large (20mL) plastic syringes
- 3ft (90cm) of plastic tubing
- Bucket of water
- Cardboard
- Cardboard Templates
- Scissors
- Ruler
- Tape
- Glue Stick
- Pencil

Note: The bucket should be large enough to fully submerge a pair of syringes and tubing for connecting them.

Safety Considerations

Before you begin, make sure you are aware of the following safety considerations:

- Since you will be working with water, make sure your workspace is far away from any sources of electricity (i.e. electrical outlets, electronic devices, etc.). Otherwise, you could experience an electric shock.
- Take your time. This will help you avoid making mistakes and accidental injuries from working with scissors and sharp paper edges.
- Protect the surfaces you will be working on from damage by covering them with layers of cardboard or newspaper before you begin.
- Have a towel handy to clean up any water that spills while you are working and be sure to warn everyone working nearby if you have spilled water on the ground to avoid slips and falls

Syringe Preparation

Objective

In this section, you will prepare three sets of syringes and tubing underwater to power your mechanical arm using hydraulics. Although you could alternatively prepare the syringes in air to power the mechanical arm pneumatically, but hydraulics is ideal in this case to avoid the delay in pneumatic force transfer due to the compressibility of air.

Materials

From the materials list above, for this section you will need:

- 4 small (5mL) plastic syringes
- 2 large (20mL) plastic syringes
- Bucket of water
- 3ft (90cm) of plastic tubing
- Scissors
- Ruler

Procedure

1. 3 sets of tubing will be assembled:
    a. 1 large syringe, 1 small syringe, 30 cm tubing
    b. 2 small syringes, 5 cm tubing
    c. 1 large syringe, 1 small syringe, 20 cm tubing
2. For syringe set A, remove the syringe plungers from the two syringes (1 large, 1 small).
3. Connect the 30 cm tubing between the two syringes.
4. Optional: apply hot glue to the connection.
5. Submerge all materials underwater and ensure no air bubbles are trapped inside.
6. Secure the large plunger back in the syringe and set to 0 mL.
7. Replace the small plunger back in the other syringe.

8. Remove Set A from the water and dry.
9. Repeat for Sets B and C.

Now you should have three different syringe sets:

- **Syringe Set A**: a large and small syringe connected by 30 cm of plastic tubing.
- **Syringe Set B**: two small syringes connected by 5 cm of plastic tubing.
- **Syringe Set C**: a large and small syringe connected by 20cm of plastic tubing.

Part 1: Making the Scoop (Horizontal Motion)

Objective

In this section, you will construct the object scooping section of the mechanical arm and use fluid power to generate the horizontal motion needed to operate the opening and closing of the scoop lid.

Materials

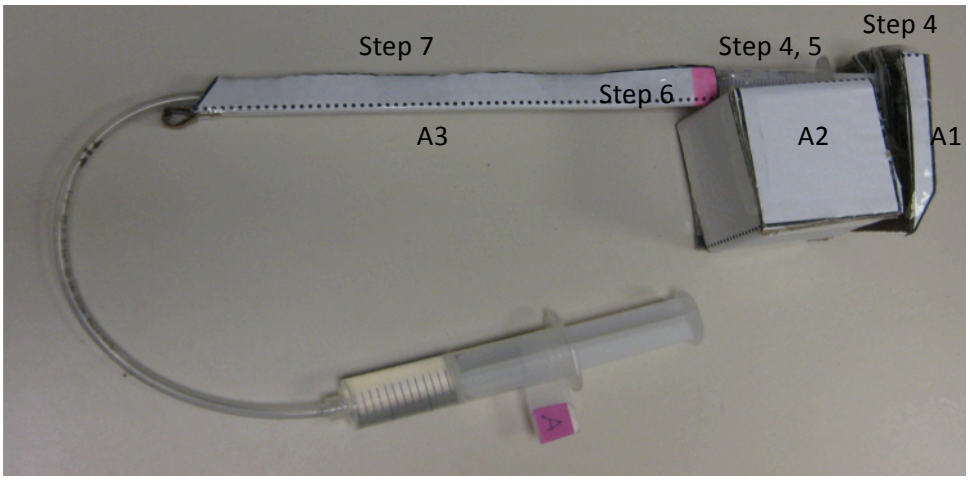
For this section, you will need:

• Syringe Set A	• Scissors
• Cardboard	• Tape
• Cardboard Templates	• Glue Stick

Before we start, glue all templates to cardboard and cut out all parts along the solid lines

Procedures

1. Fold the lid (A1) and apply tape to form the lid of the scoop.
2. Glue the small syringe plunger from Set A to the inside of the lid as shown.
3. Alternatively, use trips of cardboard and tape to secure the plunger (right).
4. Fold and tape together the body of the scoop (A2) to form a box.
5. Place the (small) syringe handle in the notch of the box (A2) and secure with tape.
6. Place the shaded area of the arm (A3) between the syringe and the box (A2) to form the "arm".
7. Fold the arm (A3) longitudinally with the tubing inside, and secure with tape.
8. At the narrow end of the arm (A3), bend the cardboard to form a loop. Tape or glue to secure such that there is a hole inside the loop.
9. Pump the large syringe to check if the lid opens and closes over the scoop.



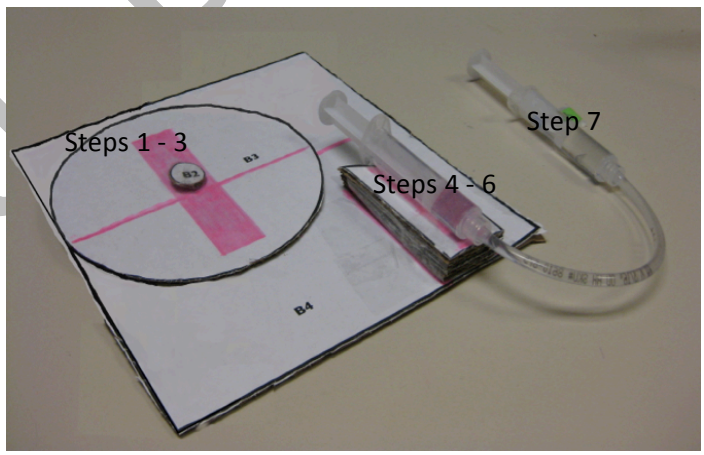
Now you should have an "arm" with a scoop on one end that you can open and close by manipulating the large syringe to move the scoop lid horizontally.

Part 2: Making the Base (Rotational Motion)
Objective
In this section, you will construct a rotating base for the mechanical arm that will use fluid power to generate the rotational motion needed to control the left and right swing of the disk on which the arm will sit.

Materials
For this section, you will need:

- Syringe Set B
- Cardboard
- Cardboard Templates
- Scissors
- Tape
- Glue Stick
- Button fastener

Procedures



1. Puncture a hole through the dot indicated on the disk (B2).
2. Place the disk (B2) in the shaded region on the base (B1) and puncture a hole through the base in the same location as B2.

3. Place a button fastener through the hold and secure. The disk should be free to rotate on its centre.
4. Align and stack B3, B4, B5, and B6, placing B3 on the top. Apply tape to secure the stack as one unit.
5. Tape the stack to the base (B1).
6. Place a small syringe from Set B on the stack, with the syringe handle placed in the notch. Secure with tape or glue.
7. Pump the free syringe to check that you can control the plunger of the fixed syringe and set the syringe to 2.5mL.

Now you should have a square base and rotating disk for your mechanical arm to sit on and a syringe that is ready to be connected for manipulating the left and right rotation of the disk and arm.

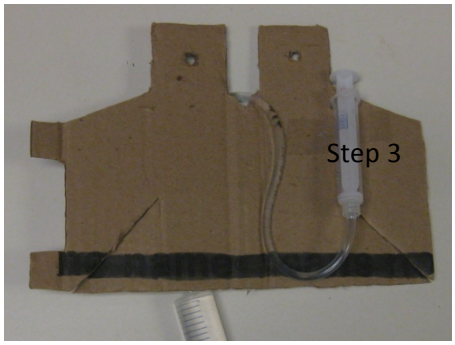
Part 3: Making the Lift (Vertical Motion)
Objective
In this section, you will construct a lift system for the mechanical arm and use fluid power to generate the vertical motion needed to lift and drop the arm.

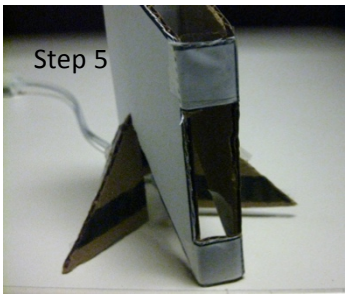
Materials
For this section, you will need:

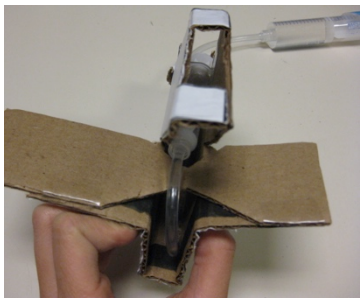
- Syringe Set C
- Cardboard
- Cardboard Templates
- Scissors
- Tape
- Hot glue

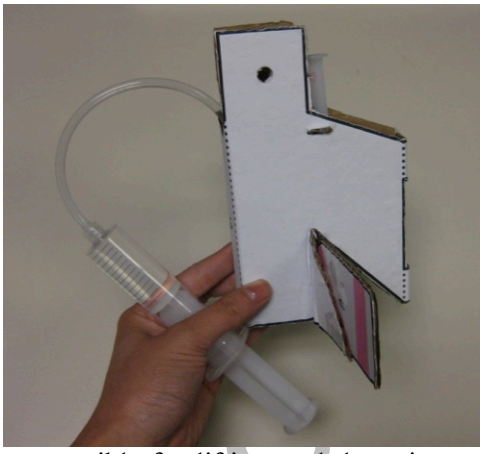
Procedures

1. Fold the body (C1) to form a frame.
2. Puncture the two hole and slice the two small lines in the centre of the template.
3. From inside the frame (C1), tuck the handle of small syringe into one of the slit lines. Tape to secure.
4. Close the frame and secure the other side of the syringe handle in the other slit.
5. Tape frame shut.
6. Tuck C2 through the triangular openings in C1 and apply tape to form the wings. Note the notch in C2 faces downwards.
7. Pump the large syringe to check that you can control the small syringe in the lift and set the small syringe to 0mL.









Now you should have a frame housing a syringe that will be responsible for lifting and dropping a mechanical arm, which you will be able to control using the larger syringe.

Part 4: System Integration

Objective

In this section, you will assemble the scoop, base, and lift you constructed in the previous sections to form a functional mechanical arm powered by fluids.

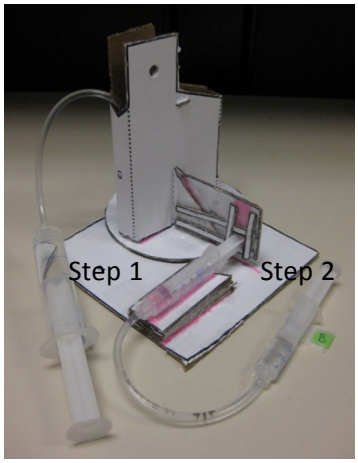
Materials

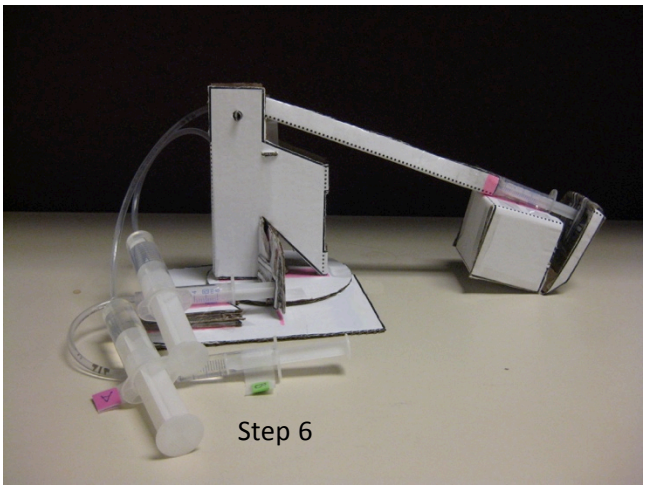
For this section, you will need:

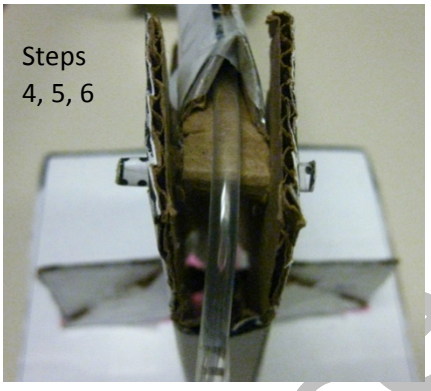
• Scoop from Part 1	• Tape
• Base from Part 2	• Hot glue
• Lift from Part 3	• Button fastener

Procedures

1. Place the body (C1) on the disk (B2) and align the wing (C2) with the shaded region on B2. Use hot glue to secure.
2. For the syringe attached to the stack (B3), secure the plunger to the wing (C2) using hot glue.
3. Check that you can rotate the disk by pumping the small syringe connected to the base.
4. Place the arm (A3) between the top part of the body (C1) where there are two small holes.
5. Pass a button fastener or paperclip through the holes in the body (C1) and the loop in the arm (A3). The arm should not be able to pivot from the fastener.
6. Check that you can lift the scoop arm by pumping the large syringe connected to the lift. Optional: glue to the top of the vertical syringe pump to the arm.







Now you should have a working mechanical arm controlled by fluid power. Add extra tape to secure any weak spots in your design and prepare your mechanical arm for a design challenge that will test its abilities!

Appendix A: Design Challenges

Challenge #1: Speed Test

In this challenge, we will test the reliability and speed of your hydraulic arm by trying to transport as many objects as possible in 3 minutes.

Materials:

- Mechanical arm
- Flat surface
- Clock
- Package of gumballs
- Cup
- Tape

Procedure

1. Tape the cup to the flat surface.
2. Scatter the gumballs over the flat surface.
3. Use the hydraulic arm to pickup gumballs and drop them into the cup.
4. After 3min, count the number of gumballs in the cup.

Try to get the highest score possible in 3 minutes!
Each gumball in the cup is equal to 1 point.
You can substitute the gumballs with similarly small objects.
If there are several mechanical arms available, some variations to try include:

- Repeating this procedure for each mechanical arm and tally the points