Engineering the Future
Science, Technology, and the Design Process

Engineer's Notebook: Project 3.0

Improve a Patented Boat Design

National Center for Technological Literacy®
Museum of Science, Boston

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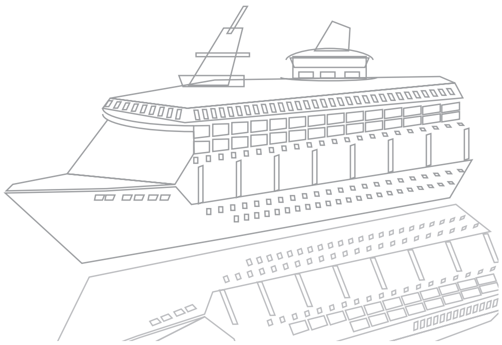
Project 3.0



Improve a Patented Boat Design

Most problems that engineers encounter involve the improvement of things that already exist. In order to redesign something, the first step is to figure out how it works. This process is called "reverse engineering," and it usually begins when an engineer takes a very close look at how something operates, makes some good guesses about how it works, then builds a model to test these initial ideas. If the model works, then it's possible to modify the model to improve its performance. Cars, planes, cell phones, and just about all of the technologies that we depend on daily have been improved again and again through this process.

For this project, you will redesign the "putt-putt boat," a toy that was invented over a hundred years ago! These boats are still being manufactured today in India, and shipped all over the world for people to buy.

In order to redesign something, you first have to figure out how it works. Several of the tasks in this project will help you learn how the putt-putt boat transforms heat energy into sound and motion. When you have completed your redesign, you will write a patent application, which will include drawings and a detailed description of how the boat works, and the changes you have made. If you file your patent with the government, you'll protect your new design so it cannot be copied by one of your competitors.

Teamwork

Engineers most often work in teams. A team shares resources, information, and talent to develop the best solutions to problems. In this course, you will frequently work as a member of a team. According to working engineers, you will be expected to:

1) Organize your team by designating co-leaders and specialists for critical objectives.

2) Apply the seven teamwork behaviors listed below, amending them as agreed.

3) Jointly agree upon your mission, objectives, and motivation to accomplish the challenge.

4) Schedule your team effort by setting a time line of tasks, and delegate responsibilities.

5) Carry out your plan on schedule, documenting procedure and results as you go.

6) Prepare for presentation of your conclusions and results.

There are seven behaviors that should be displayed by members of a team. They are the following:

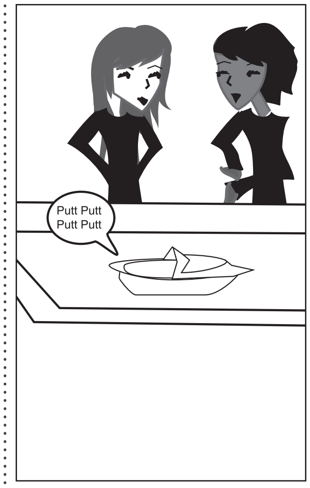
Helping, offering assistance to others.	**Questioning,** interacting, discussing, and posing questions to all members of the team.
Listening, working from each others' ideas.	**Respecting,** encouraging and supporting the ideas and efforts of others.
Participating, contributing to the project.	**Sharing,** offering ideas, and reporting findings to each other.
Persuading, exchanging, defending, and rethinking ideas.	

You will also need to keep in mind the eight steps of the Engineering Design Process.

TASK 3.1 Putt-Putt Boats and Patents

- Identify the goals of the project.
- Describe what is required in a patent.

A patent is a protection for an invention meant to keep other people from copying it. There are several different kinds of patents. Patents are given for new inventions, including new processes, machines, and products. Improvements on existing inventions can also be patented, provided they are new and useful. Patent protection lasts for 20 years, but during that time detailed descriptions and drawings of the invention are made available to the public, so that others may make improvements.



Your Patent

For this project, you will first build a boat according to specifications. Then you'll be free to decide how to redesign the putt-putt boat, in its form (appearance) or function (performance). After learning some engineering principles about fluids, energy, and motion, you will be asked to design a new boat. You will have, as your final product, your original boat, your redesigned boat, and a **patent,** which will include:

Declaration identifying the designers.

Specifications or a complete description, including:

- Re-design criteria and constraints
- Decision-making process and chart
- Description of how the putt-putt boat works
- Design improvement claims
- Drawing of the design

Background

Thomas Piot first patented the putt-putt boat in 1891 in the United Kingdom. As you review Piot's original patent for "Improvements in Steam Generators" on the next two pages, see if you can match his descriptions in the section called "Complete Specification" with his drawings on the second page.

Piot Engine

Because Thomas Piot's boat engine is a unique design, it is called "the Piot Engine" in this *Engineer's Notebook.*

N° 20,081 A.D. 1891

Date of Application, 19th Nov., 1891
Complete Specification Left, 18th Aug., 1892—Accepted, 15th Oct., 1892

PROVISIONAL SPECIFICATION.

Improvements in Steam Generators.

I, DESIRE THOMAS PIOT, of No. 71, Bolsover Street, Euston Road, in the County of Middlesex Electrician do hereby declare the nature of this invention to be as follows :—

The object of my invention is to produce a steam generator in which the operation of feeding with water is continuous and depends upon the vaporization of the water in the heating chamber.

In carrying my invention into effect I use two or more tubes, opening into a common chamber so that the orifices thereof, and the ports or slots formed in the sides or circumference may be close to the sides of said chamber. I prefer to charge the tubes and chamber with water, and to generate steam by heating said chamber. The exit of the steam under pressure and consequent condensation by contact with the atmosphere or other surrounding medium causes a reverse current by which the water of condensation or other water may be drawn into the generator.

The chief feature of my said invention is to place a small volume of fluid in direct contact with a source of heat, and to utilise the pressure for producing mechanical work, the volume of liquid under action being always supplied by its own condensation either by using the water thereof or utilising the attenuated pressure to draw in water from other sources and produce a continuous action.

My said invention is especially useful in the case of toy boats, where the propulsion depends upon the pressure of steam acting directly upon the water, and the consequent condensation serves to supply the feed by convection.

Dated this 18th day of November 1891.

FREDK. WALKER,
11, Furnival Street, Holborn, London, E.C., Agent for the Applicant.

COMPLETE SPECIFICATION.

Improvements in Steam Generators.

I DESIRE THOMAS PIOT of No 71 Bolsover Street Euston Road in the County of Middlesex, Electrician do hereby declare the nature of this invention and in what manner the same is to be performed, to be particularly described and ascertained in and by the following statement :—

The object of my invention is to produce a steam generator in which the operation of feeding with water is continuous and depends upon the vaporization of the water in the heating chamber.

In order that my invention may be the better understood I have appended the accompanying sheet of drawings in which

Figure 1 is a side elevational view of a model boat having my improved steam generator adapted thereto.

Figure 2 is a plan of the same and

Figure 3 is a transverse section of my improved generator.

In carrying my invention into effect I employ two or more tubes A A^1 one of said tubes A^1 may be slightly longer than the other, one end of the tubes opening into a chamber B common to the two so that the orifices, ports or slots which may be formed in the sides or circumference may be close to the sides of the above mentioned chamber B, I prefer to charge the tubes and chamber with water and to generate steam by heating said chamber in any suitable manner.

The exit of steam under pressure and consequent condensation by contact with

[*Price* 8*d*.]

Piot's Improvements in Steam Generators.

the atmosphere or other surrounding medium causes a reverse current by which the water of condensation or other water may be drawn into the generator.

The chief feature of my invention is to place a small quantity or volume of fluid in direct contact with a source of heat and to utilise the pressure for producing mechanical work, the volume of liquid under action being always supplied by its own condensation either by using the water thereof or utilising attenuated pressure to draw in water from other sources and produce a continuous action.

Figures 1 and 2, in which the body or hull C of the vessel is utilised as a reservoir for liquid fuel, and has adapted to the deck thereof a suitable burner *b* and wick *c* both wick and burner being shielded from the influences of the external atmosphere by means of a funnel *d*.

The chamber B is supported in any suitable manner inside the aforementioned funnel immediately over the flame *e* and the tubes A A^1 are led therefrom to the stern of the boat as shewn by the dotted lines in Figure 1. Water having been injected by any suitable manner into the chamber B, on lighting the lamp steam is generated, and issuing through the tube A^1 causes a partial vacuum in the said chamber and water is drawn up the tube A when again coming into contact with the heated surface of the chamber is converted into steam thus keeping up a constant flow of water to the chamber B and at the same time propelling the vessel C by the pressure of steam acting upon the water in which the vessel floats. A screwed tap e^1 or other suitable device is provided for the purpose of supplying the oil to the body of the boat.

Having now particularly described and ascertained the nature of my said invention, and in what manner the same is to be performed, I declare that what I claim is:—

In a steam generator the combination of two pipes or tubes terminating in a chamber heated by a lamp or other source of heat in which steam is generated and a constant supply of water created by convection substantially as herein described with reference to the accompanying drawings.

Dated this 18th day of August 1892.

FREDK. WALKER,
11, Furnival Street, London, E.C., Agent for the Applicant.

London: Printed for Her Majesty's Stationery Office, by Darling & Son, Ltd.—1892

Fig II

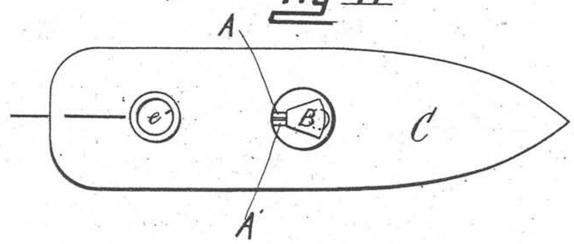


Fig I

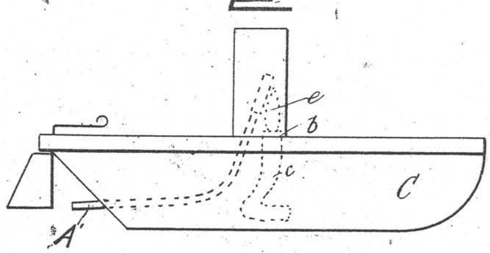
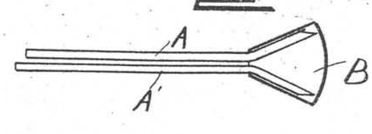


Fig III



Name ______________________________

Watch the Putt-Putt Boat

Watch the putt-putt boat in action. Write down your answers to the following questions on a separate sheet of paper. Insert your notes at this point in the *Engineering Notebook*.

1) What do you hear?

2) What do you see?

3) How do you think it runs?

4) What do you think it looks like inside?

5) Write some questions that you have about the putt-putt boat.

Starting the Patent Process

1) **Brainstorm:** How would you like to improve the boat?

Divide your ideas into two lists, one for form (appearance) and one for function (performance).

Form	Function

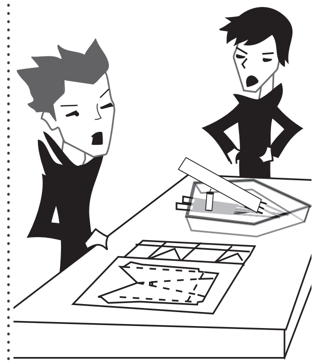
2) What concepts do you need to learn more about to be able to achieve some of your improvement ideas?

Initial ______________ Date ___________

TASK 3.2 Manufacture a Putt-Putt Boat

- Fabricate a working device to specifications.
- Explain why quality control is important in manufacturing.

In this task you will build a boat using an existing putt-putt boat design. The design and the process for manufacturing it were invented by Slater Harrison, who runs a website with instructions for many toys at <www.sciencetoymaker.com>. For this first boat, be careful not to deviate from these instructions unless your instructor tells you to. In manufacturing, the original design is reproduced many times, and each copy must be an almost-exact replica of the original. A copy that is too different from the original might not function as it's supposed to. Sloppy manufacturing can be expensive for a company, so care and quality are important!



Before You Start

Safety Check

In this task you will be using sharp cutting tools and adhesives for gluing that may have some strong fumes. Think about safety at all times and pay attention to the safety instructions. Keeping an organized and clean working area is good practice for a safe working environment.

::QUALITY CONTROL::

- Steps labeled "QUALITY CONTROL" require extra care and precision. Be sure to read these instructions carefully before beginning!
- Some quality control steps require a test. Be sure your product passes the test before continuing. In some of the tests you will need your instructor to sign off before you continue. This is to increase the likelihood that your product will work as intended.

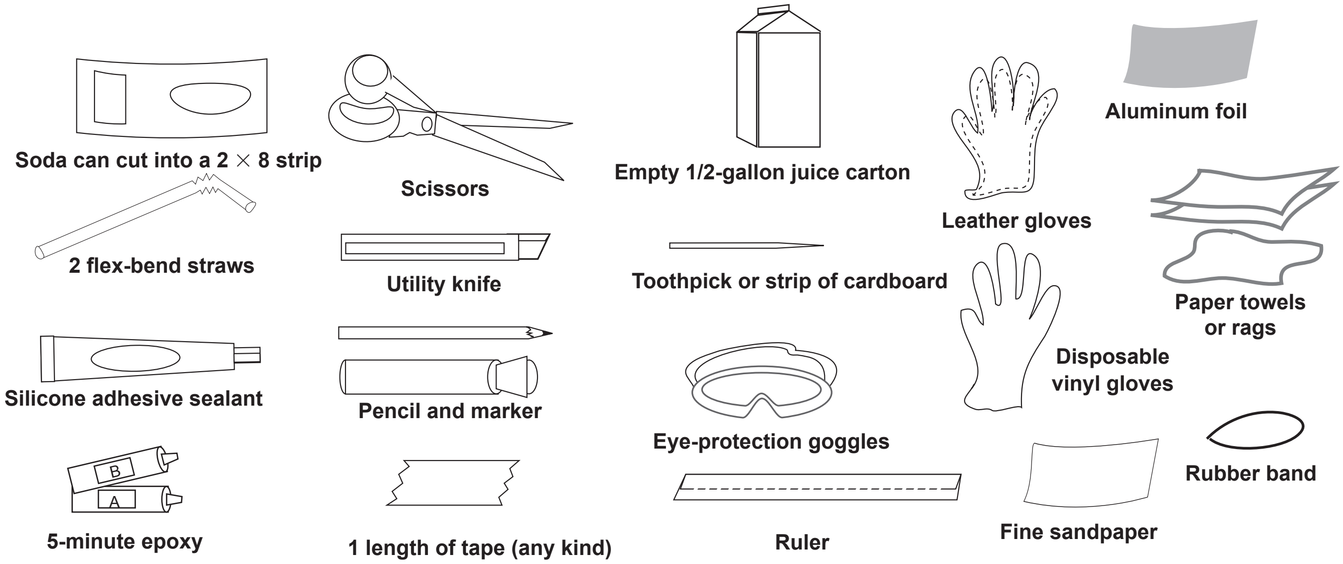
The Process

Here is an outline of the process of building the putt-putt boat. Read through all steps for Part 1 before beginning. Then read through all steps for Part 2 before starting that part; and so on.

Part 1: Build the Boiler
Part 2: Seal the Edges of the Boiler
Part 3: Make a Candle Holder
Part 4: Glue in Exhaust Pipes
Part 5: Seal the Boiler
Part 6: Build a Cardboard Hull
Part 7: Install the Boiler
Part 8: Test Your Boat

Part 1: Build the Boiler

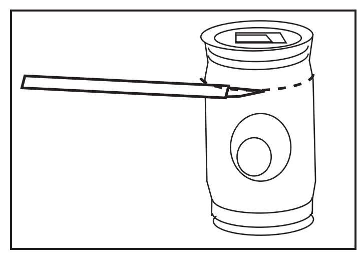
You Will Need



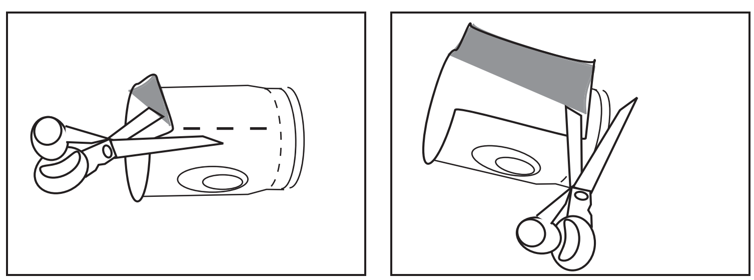
Separate the Metal

::SAFETY CHECK::
Put on leather gloves before cutting the can. Beware of jagged edges.

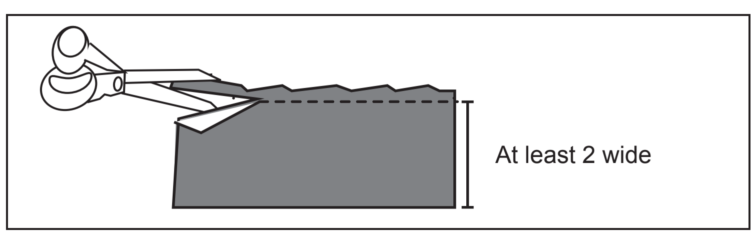
1) Use a utility knife to make a 1" cut where the can reaches its full diameter near the top. If you are not using an aluminum can and you have a 2" × 8" strip of aluminum, skip to step 4.



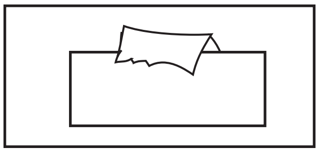
2) Switch to scissors and use them to finish cutting off the top of the can. Then use the scissors to cut straight to the bottom of the can. Finally, cut the bottom off just above where the can starts to narrow. Recycle the can top and bottom.



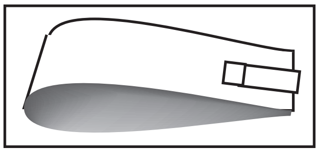
3) Carefully trim the jagged edge of your aluminum, but make sure the aluminum sheet is **AT LEAST 2" wide.**



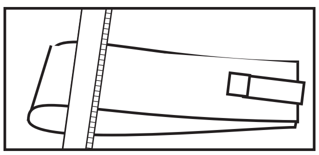
Form the Boiler "Pocket"



4) Shape this piece of aluminum into a "pocket" by first using sandpaper to gently sand the silver side of the aluminum. This will help the adhesives stick better when they are applied later.



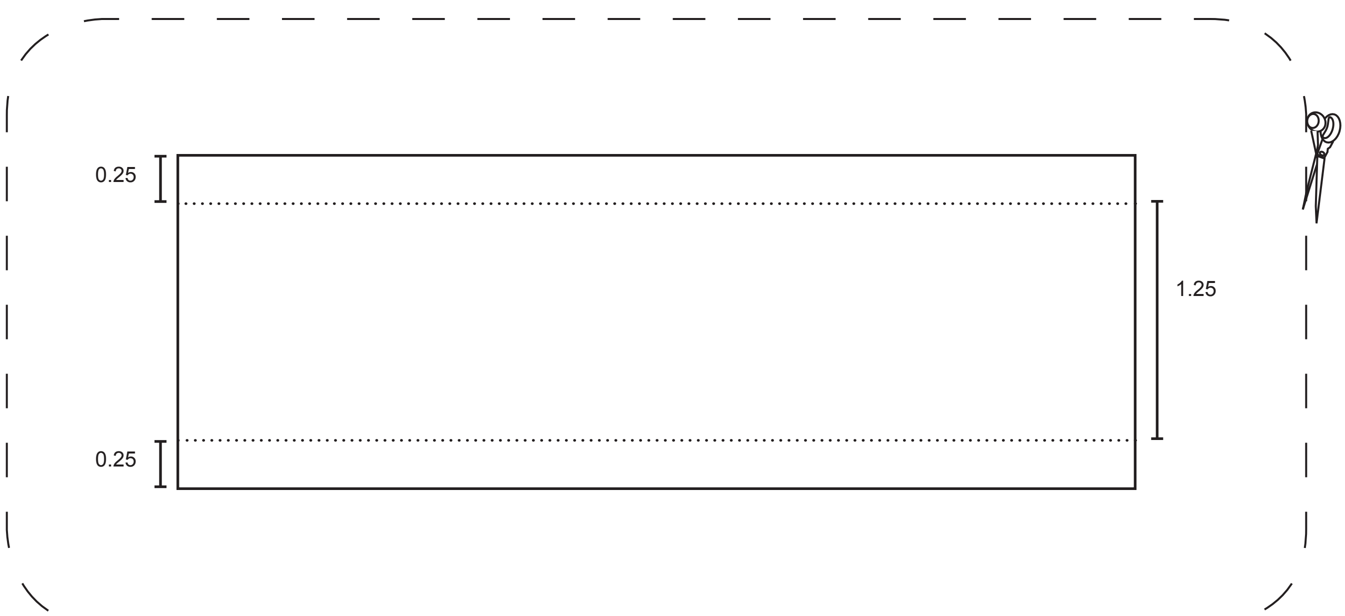
5) Obtain a 3" length of tape and fold the last 1/2" of tape onto itself so it will be easy to remove. Gently round the aluminum in half. Line up the two straight edges at the end, and tape them together as shown. The folded length should be about 4" long. This tape will keep the edges together while you fold the metal. (If using a soda can, keep the silver side in and label side out.)



6) Using a ruler, carefully press the metal strip at the bend to make a neat crease. You can give the ruler a single pound with your fist, but not too hard. Use about the same force you would use to break an egg.

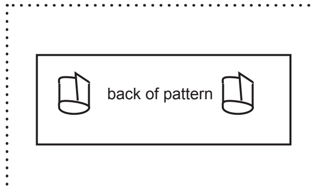
::QUALITY CONTROL::
If you pound too hard or slide the ruler across the crease, tiny cracks may form that prevent your engine from working.

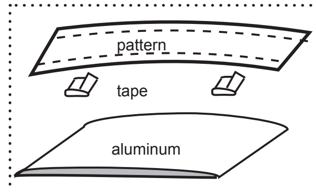
7) Shown here is a full-scale pattern for the boiler. You will want to "rough" cut this out—meaning, cut it OUTSIDE the dimension lines. The solid lines will give you the width of the boiler, but the length of your folded aluminum will be shorter. The dotted lines are the guides for folding in the next steps. What is the total width of the boiler pattern? _____________



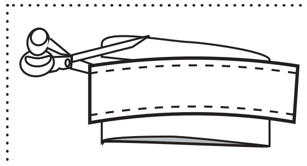
::QUALITY CONTROL::
Check the measurements to make sure that the pattern is full-scale.

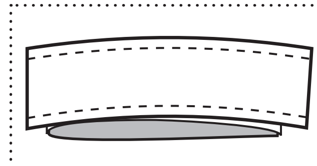
8) Use tape "donuts" to tape the pattern to the folded aluminum as shown. Make sure the long edge of the pattern follows the long end of the aluminum.





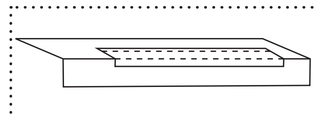
9) Once the pattern is taped on, cut along the solid black lines of the pattern—not the dotted lines! Save a piece of the aluminum for applying epoxy in a later step.





::QUALITY CONTROL::
Be careful NOT to accidentally cut along the dotted lines.

10) To bend the aluminum, carefully align the dotted line of the pattern with the sharp (not rounded) edge of a desk or table. You can also use a stiff ruler as a bending guide. Use your hand and ruler or table edge to form bends in the aluminum. This simulates a machine called a "brake" that is used to form bends in metal.



::QUALITY CONTROL::
Try to make the bend EXACTLY along the dotted line. Push hard enough to make a well-defined bend in the aluminum.

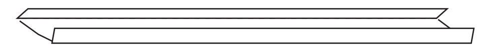
11) Remove the paper pattern and tape holding the aluminum together.

NOTES:

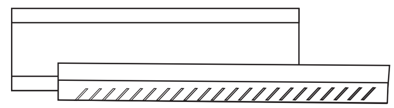
Initial ______________ Date ___________

12) With the paper pattern and tape removed, finish bending both sides of the aluminum so that it is flat.

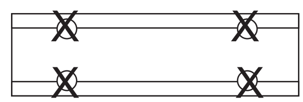
First push both side flaps down with all of your fingers.



Then cover one edge completely with the flat ruler and give two pounds with your fist in two different places on the fold. Repeat for the other side.



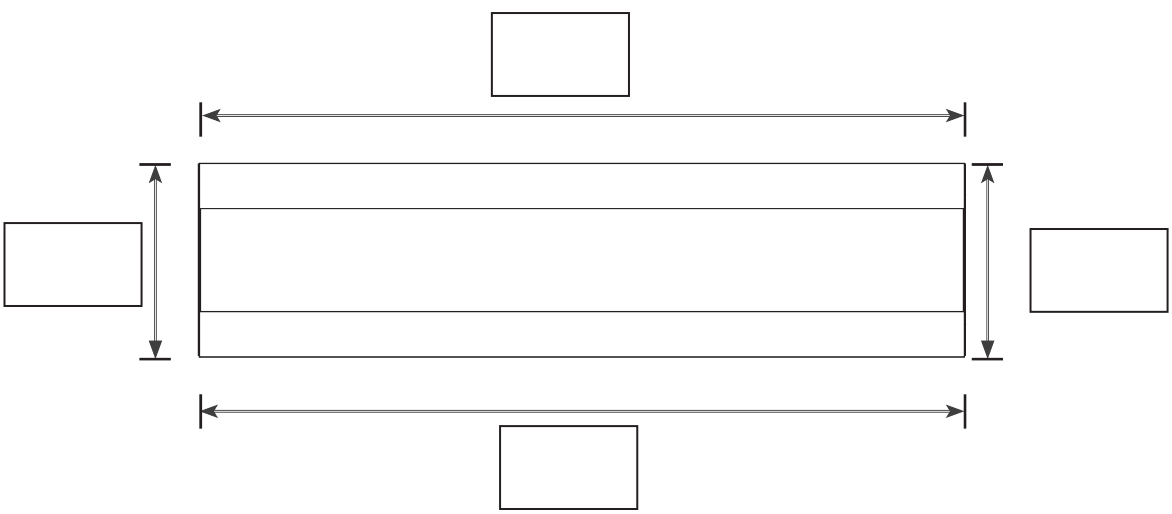
In this diagram the places to push on are marked with an X.



::QUALITY CONTROL::
As before, if you pound too hard or slide the ruler across the crease, tiny cracks may form that prevent your engine from working.

Evaluate Your Work

Measure the edges of your aluminum pocket after you have folded it, and record your measurements below. Then have your instructor sign off on this step.

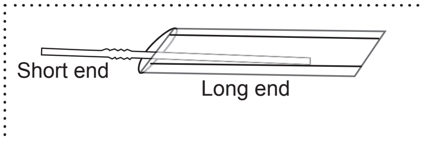


INSTRUCTOR SIGNATURE ______________________

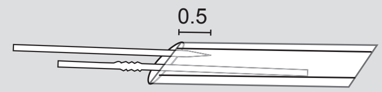
Name ______________________________

Part 2: Seal the Edges of the Boiler

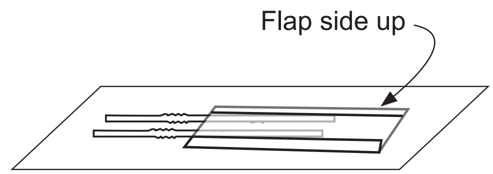
13) Get two bendy straws. Each bendy straw has a long end and a short end, relative to the bend. Do not extend the bendy part until told to. Insert the long end of both straws into the open end of the aluminum pocket, and push the straws in as far as they will go.



::QUALITY CONTROL::
If it is difficult to get the pocket open to insert the straws, you can use the pointed end of a pencil to help, but do NOT insert more than a half-inch (0.5) of the pencil—it can dent the aluminum pocket and ruin it.



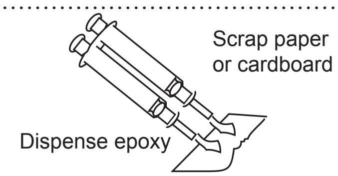
14) Make enough tape "donuts" to cover the side of the boiler that does NOT have the narrow fold-over flaps. With the tape donuts, stick the boiler to a piece of cardboard or paper.

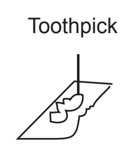


15) **Read steps 16–18 carefully before proceeding.** Your instructor will provide either epoxy or silicone adhesive to seal the seams of the boiler.

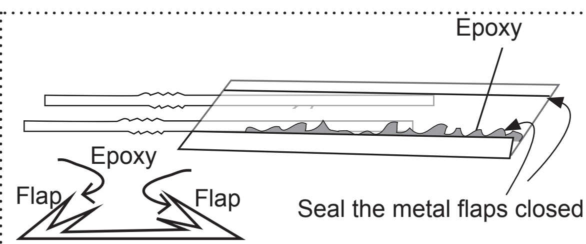
::SAFETY CHECK::
While using adhesives, put on gloves and open windows to ventilate fumes.

16) Your instructor will dispense small, equal amounts of the two parts of epoxy onto a piece of paper or cardboard. Then use a toothpick or metal nail to THOROUGHLY but QUICKLY mix the two parts together. Unequal or unmixed epoxy will not set properly. You will share epoxy with others to reduce waste, as the epoxy starts to set quickly.





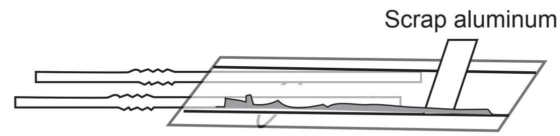
17) Use the toothpick or nail to apply a skinny bead of epoxy to seal the two bent aluminum flaps. You are not trying to epoxy the flaps to the top of the boiler, but rather to **epoxy the flaps closed** so as to seal the boiler sides.



::QUALITY CONTROL::
Do NOT use more epoxy than necessary to get an even layer of epoxy along the edges to seal the flaps closed. Try not to miss any spots. Do NOT glue the straws in place yet.

Initial ______________ Date __________

18) Before the epoxy sets, run the piece of scrap aluminum you saved earlier between the metal flaps on each side to spread the epoxy evenly and make a tight seal. Allow the epoxy to set for 20 minutes.



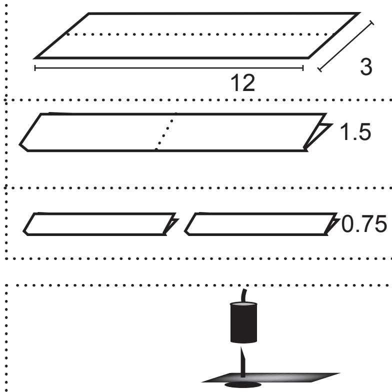
Part 3: Make a Candle Holder

19) While the epoxy is setting, make the candle holder for the boat. Obtain a 3" wide piece of aluminum foil that is about 12" long.

Fold it in half lengthwise, then fold it in half again, so that the final width is 0.75".

Then cut the strip in half so you have a backup holder. You should now have two strips that are 6" × 0.75".

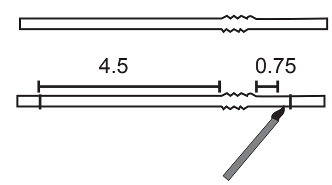
Stick a thumbtack through one end of the strip. Carefully cut a small candle to about 0.5" high and place it on the tack that is through the end of the holder.



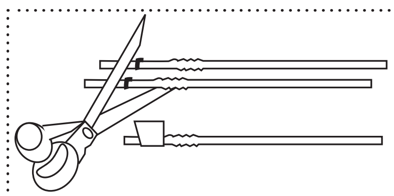
Part 4: Glue in Exhaust Pipes

Read steps 20–24 before proceeding.

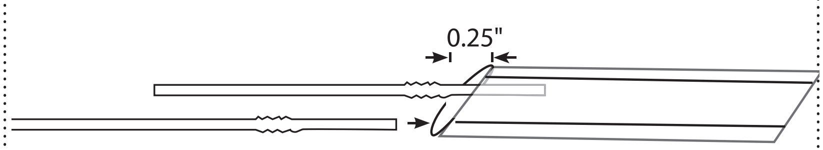
20) After the epoxy has hardened, you can remove the straws—the pocket should maintain its open shape. Use a marker to mark the straws at the distances shown, measured from the bendy section, so the long part of the straw will be 4.5" and the short part will be 0.75" from the bendy part.



21) Cut the straws at the four marked locations, and save all of the extra cut-off straw pieces. Use sandpaper to scuff the short ends of both straws, creating small scratches for the epoxy to adhere to.

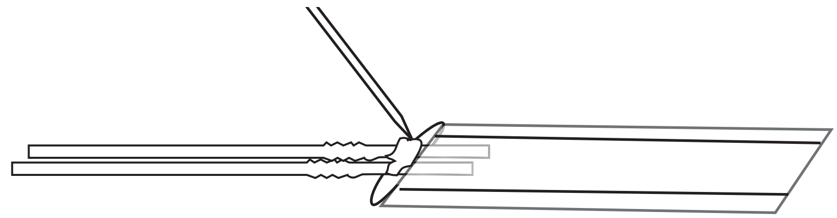


22) Insert the short ends of the straws into the boiler so that a quarter of an inch (0.25") of straw sticks out before the bendy part starts.

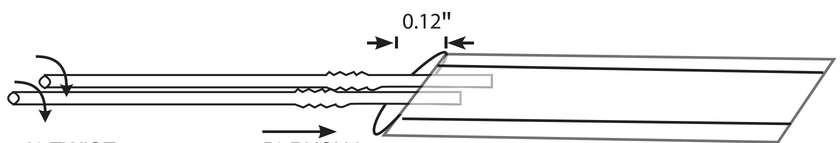


::QUALITY CONTROL::
Do NOT extend the bendy part of the straws, and do NOT get epoxy on the bendy part.

23) Thoroughly mix another batch of epoxy that will be used to secure the straws in the boiler. You are not filling all the space around the straws. Apply a small amount to the exposed 1/4" of straw as shown in the picture, then turn the boiler over and apply another small amount in the same spot on the other side.

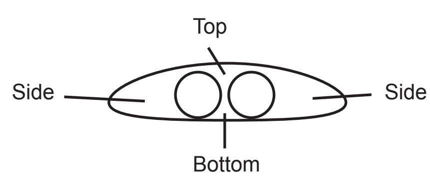


24) Rotate the straws back and forth three times to spread the epoxy. Then push the straws into the boiler so that around one-eighth inch (0.12") is still exposed before the bendy part. Wipe off any epoxy that gets on the still-collapsed part of the bendy straws. Keep the boiler flat and allow the epoxy to set for 20 minutes. **While it is setting, read over the rest of the steps.**



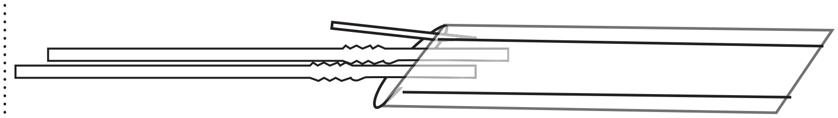
Part 5: Seal the Boiler

25) Use 100% silicone sealer to seal the four main gaps in the open end of the pocket.



::SAFETY CHECK::
While using adhesives, wear gloves and open windows to ventilate any fumes.

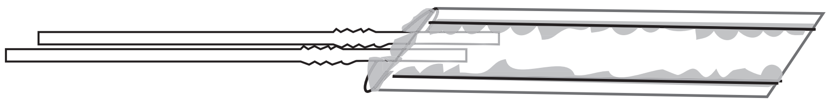
For the top and bottom gaps, as labeled in the diagram, use a toothpick or nail to push silicone into the gap, filling any spots the epoxy missed. For the two side gaps, fill them with about 1/2" of silicone and then stir the toothpick or nail around to make sure the silicone fills all spots.



Fill gaps with silicone using a toothpick.

::QUALITY CONTROL::
The straws stick into the boiler a little less than 3/4, so don't go too deep with the silicone or you might start to cover the ends of the straws.

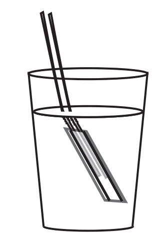
26) For the two seams in the flaps you earlier filled with epoxy, apply a thin layer of silicone over the epoxy layer to seal any holes. Also apply some to the corners, which are common leak points. Leave the silicone to set for at least 8 hours.



::QUALITY CONTROL::

After the silicone has set, TEST the boiler for leaks before proceeding. Submerge the boiler so that the metal is completely under water in a cup or bucket. Gently blow through both straws, and take note of any bubbles coming from the boiler.

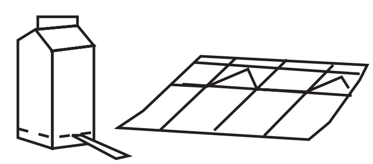
If there are leaks anywhere along the boiler seams or the corners, you should remove the boiler from the water, pat the area dry, apply a thin layer of silicone, and wait at least one hour for the silicone to set before retesting. Demonstrate underwater testing for your instructor to obtain a sign-off signature.



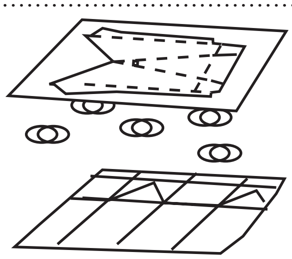
INSTRUCTOR SIGNATURE ____________________

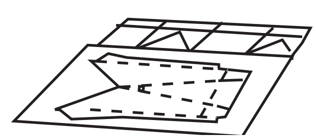
Part 6: Build a Cardboard Hull

27) Use a knife to cut off the bottom of a half-gallon milk or juice carton. Open the folded-in top part. Then cut the carton open lengthwise along the edge where the carton overlaps with itself. Don't cut through the double-layer; cut just next to it. Lay the carton flat.



28) Shown on the next page is a full-scale pattern for the boat hull. Attach the pattern to the carton using five tape loops located as shown in the picture.



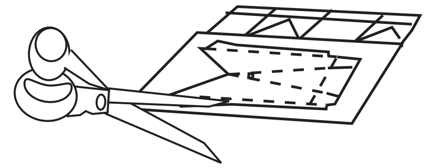


::QUALITY CONTROL::

Make sure the dashed line labeled "STERN" is aligned with one of the folds in the carton, and that the pattern is NOT on the spout section with all of the extra folds.

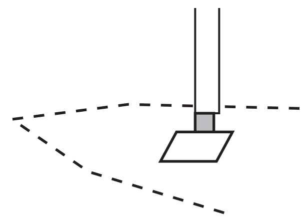
29) Use scissors to carefully cut out the outline of the boat along the solid lines.

::QUALITY CONTROL::
Do NOT cut along any dashed lines. Also make sure to cut the two short solid lines off of the dashed stern line.

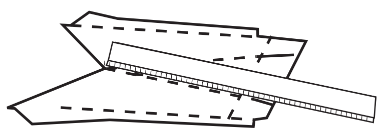


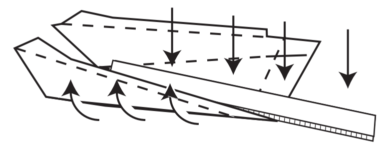
30) **Place a sheet of cardboard under the carton to protect the desk or table.** Use a knife to carefully cut the small rectangle near the center of the hull. This is where the boiler will be mounted.

::SAFETY CHECK::
Handle knives carefully!

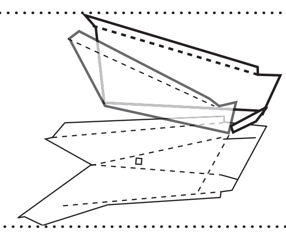


31) Position a ruler along one of the dashed lines in the middle that forms a *V*. Push down on the ruler with one hand and pull up on the carton with your other hand. This simulates a brake used for forming bends in flat material. Repeat for the other dashed lines.

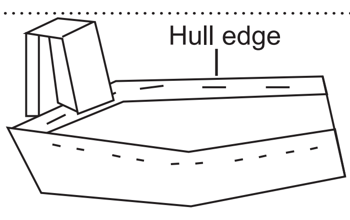


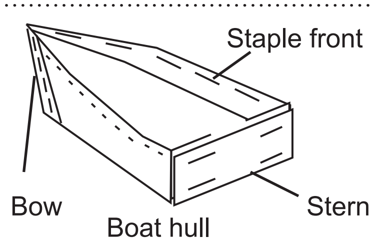


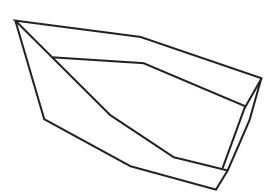
32) Remove the paper pattern from the carton after all bends have been made.

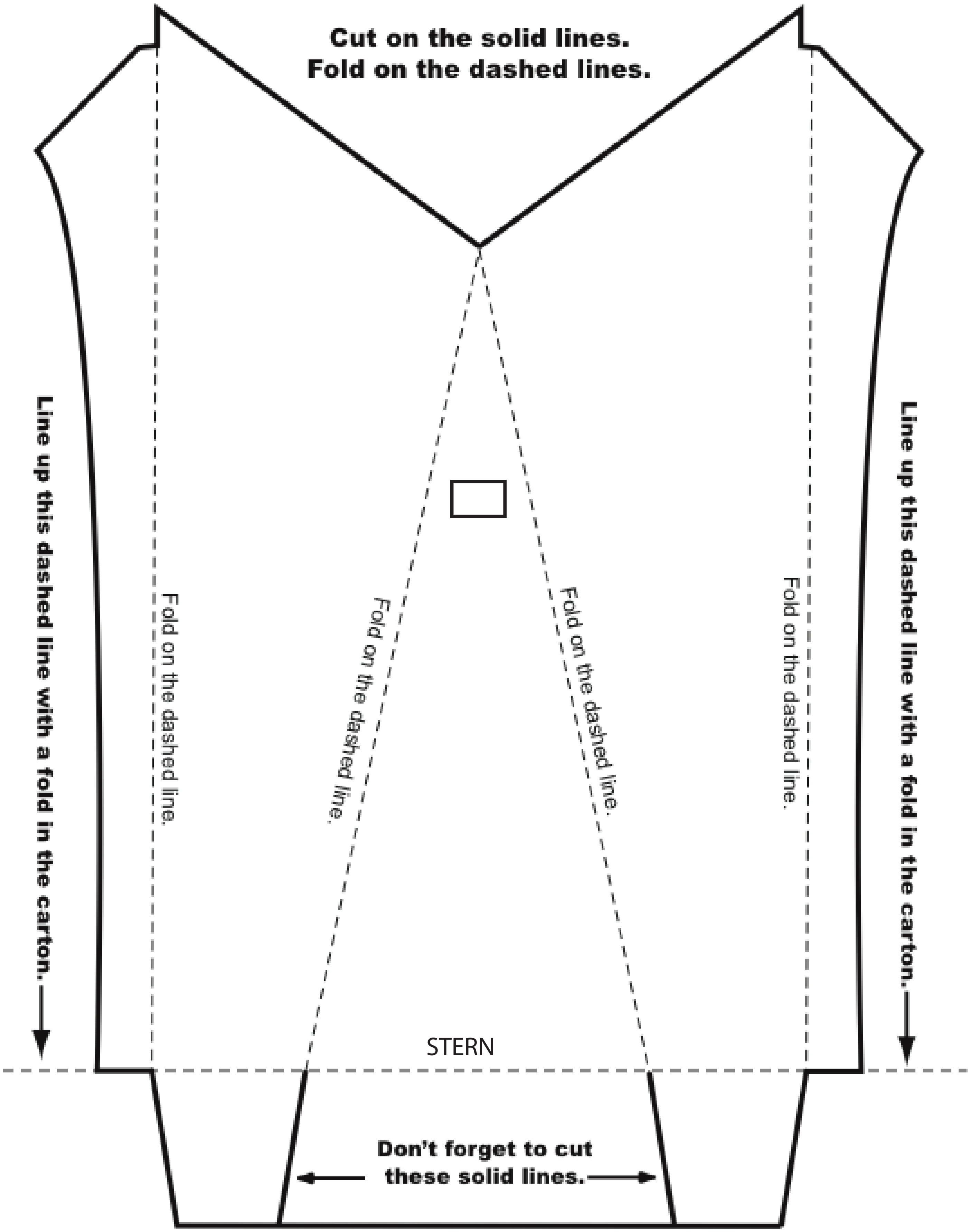


33) Staple the boat together. For the narrow flaps along the hull edges, use five evenly spaced staples on each flap. For the front bow of the boat, use four evenly spaced staples about 1/8" in from the edge, then turn the stapler 180 degrees and use four more stapes in the same locations as the first four but coming in from the other side of the hull. For the back stern of the boat, fold the two side flaps in and then the rear flap up, and use two evenly spaced staples through each side flap.





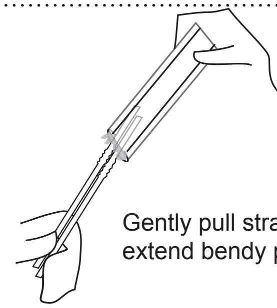



Cut on the solid lines.
Fold on the dashed lines.
Line up this dashed line with a fold in the carton.
Fold on the dashed line.
Fold on the dashed line.
Fold on the dashed line.
Fold on the dashed line.
Line up this dashed line with a fold in the carton.
STERN
Don't forget to cut
these solid lines.

Part 7: Install the Boiler

34) Before installing the boiler, inspect it for any epoxy or silicone on the metal bottom side (the side without the flaps). This is the side the candle flame will touch. If there is any epoxy or silicone on the metal, clean it off using steel wool or sandpaper

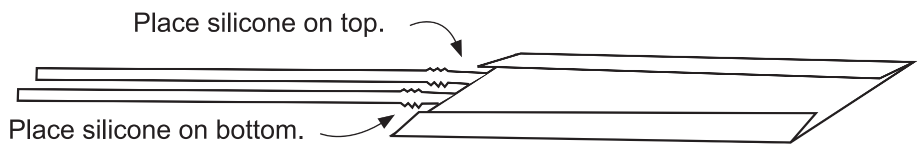
35) Hold the base of the boiler where the straws enter the metal with one hand, and gently pull and lengthen the bendy part of the straw.



Gently pull straws to extend bendy part.

::QUALITY CONTROL::
Don't pull so hard that the straws come out, and try not to damage the bendy part of each straw by denting or crushing it. If a straw does come out, sand it with sandpaper and use a small amount of epoxy to glue it back in place.

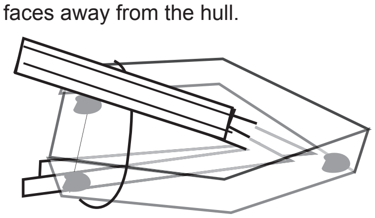
Read steps 36–40 before proceeding. You should have some paper towels or rags and several pieces of tape ready during this step.



36) Put a medium-sized amount of silicone on both the top and bottom side of the bendy part of the straws. Then insert the straws into the boat hull through the small rectangle you cut out, so that the bottom of the boiler (no flaps) faces the boat hull.

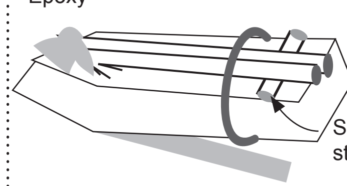
::QUALITY CONTROL::
The clean metal surface without the flaps and adhesives MUST face the BOTTOM of the boat, as this is the side the candle will be touching!

Top of boiler (flaps, epoxy, silicone) faces away from the hull.

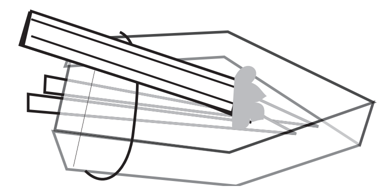


Bottom of boiler faces boat hull.

37) Insert a short scrap piece of straw as a spacer between the bottom of the hull and the long part of the straws and hold the straws in place with a rubber band or a piece of tape while the silicone dries.



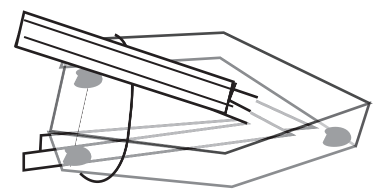
38) Turn the boat back over and check to make sure the boiler is centered in the boat and the top edge of the boiler is about 2 from the floor of the boat.



39) Add silicone to the bottom of the boat so the hole is sealed.

40) Add silicone to the three inside corners of the hull where the stapes join the flaps of the boat together. This will help prevent leaks in the hull.

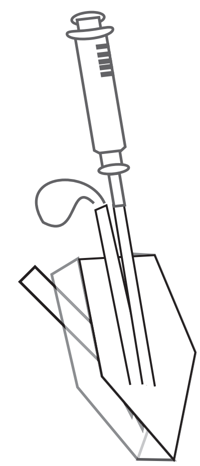
Allow the silicone to set for 24 hours.



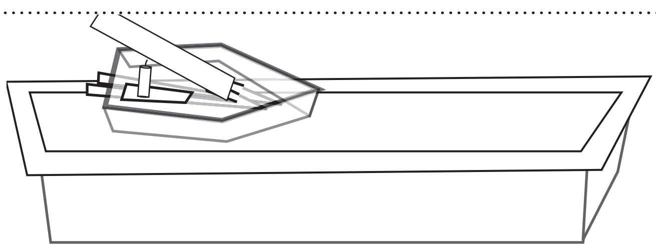
Part 8: Test Your Boat

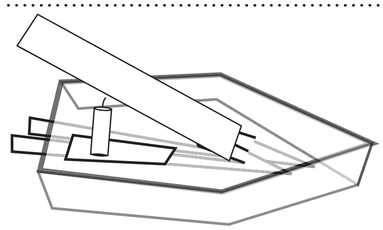
41) Remove the spacer straw and rubber band. Prime the boiler with water. Hold the boat vertically and use a syringe to inject water into one of the straws of the boiler, as shown. Keep adding water until it starts to come out of the other straw.

For the first test, you should prime it twice. Turn the boat over so that the water runs all around the inside of the boiler. Empty the boiler of water. Prime it with water again.



42) Put the boat in the test track or boat basin, being careful to not let the water come out of the boiler. Light the candle and place the candle holder so the flame is around the middle of the boiler. You can fix the candle in place by hooking the aluminum foil over the back of the boat. Watch and wait a minute or two.





43) If your boat works, congratulations! You have successfully manufactured a putt-putt boat! If it doesn't work, see your instructor for troubleshooting help.

::QUALITY CONTROL::
Obtain a final signature from your instructor after successfully demonstrating your functioning boat.

INSTRUCTOR SIGNATURE ____________________

Benchmark

In this task you have manufactured a putt-putt boat. Manufacturing processes can be broken down into a few major categories:

Forming: Using pressure or force to shape a material

Separating: Removing unwanted materials

Conditioning: Any process that changes the properties of a material using heat, chemicals, or mechanical force

Assembling: Joining the various parts of a product

Finishing: Any process done to the surface of a product to make the product more attractive to a consumer

1) Identify at least one step in the boat construction that can be classified into each category of the manufacturing process:

Forming

Separating

Conditioning

Assembling

Finishing

2) What do you think causes the putt-putt sound of the boat?

Initial ______________ Date __________

Name ____

3) Write your explanation of how you think the boat works. Draw pictures and label parts of the boat to help you explain your ideas. You will be able to reflect back on your initial understanding later, so don't worry about being "correct" in your explanation. Just take your best guess for now.

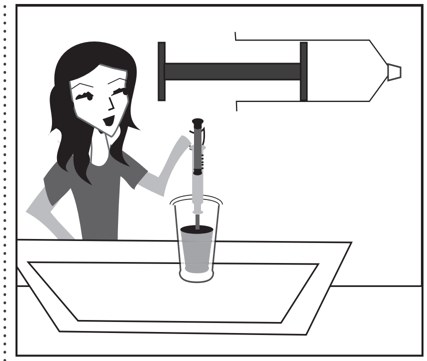
Read Chapter 17, "In Deep," in the textbook *Engineering the Future.* Underwater design engineers like Bob Brown need to know a lot about fluids in order to make vehicles that can withstand the conditions in the ocean. Use notebook paper to answer the questions at the end of the chapter. Sign, date, and number each page. Insert the pages at this point in your *Engineer's Notebook.*

Initial ______________ Date __________

TASK 3.3 Investigate Fluid Systems

- Explore the similarities and differences between liquids and gases.

There are many kinds of fluid systems. In the natural world there are open systems like rivers and streams, where the fluid (water) continuously flows in and out. For instance, water evaporates out, and rain water is added in to the system. There are also closed systems like the human circulatory system, in which the fluid (blood) is contained inside veins and arteries. In this task, and the next, you'll explore two kinds of closed systems—hydraulic and pneumatic systems—that can be used to manufacture boat hulls. Later you'll apply these same ideas to how the boiler works in the putt-putt boat.



The engineer studies color coding in fluids.

Exploring Fluids

You can use syringes with moveable pistons to make fluids move. You will learn more about this later, when making a machine press move. But what is a fluid?

Fluid: A material or substance that can flow, including liquids and gases.

You already know that a liquid like water is a "fluid," but a gas, like air, is also considered a fluid. Both liquids and gases can be used in a system for making things move. A system may be named according to the type of fluid it uses:

Hydraulic System: Liquid is the fluid that flows in the system.

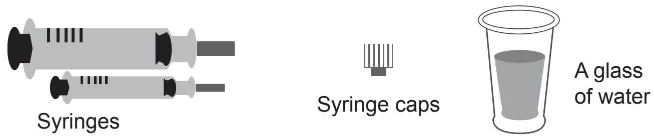
Pneumatic System: Gas is the fluid that flows in the system.

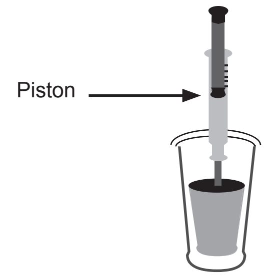
It's important to remember these two terms. Where have you heard or seen the prefixes "hydra" or "pneum" before? Think of some associations that will help you remember which has to do with liquid (water, oil, etc.) and which with gas (air, oxygen, etc.). Write some clues to help you remember.

Name ______________________________

Fluids in Syringes

Your instructor will provide you with syringes, along with caps for the syringes to seal them shut.





- Try putting air and water in the syringes.
- Push and pull the piston to see how the trapped fluids respond.
- Try to note differences you observe between pneumatics and hydraulics.

Record your observations:

Pneumatic Systems	Hydraulic Systems

Color-Coding Gas Pressure

What Is Gas Pressure?

Gases are difficult to understand because they are impossible to see with the naked eye. Luckily, there are some things you can learn about a gas by experimenting. Using the plunger on a syringe, you can change the amount of space (volume) in the syringe and see what happens. Because the gas can't escape when you push the plunger in, if the cap is on, it is squeezed into a smaller space. Squeezing a gas into a smaller space increases the pressure of the gas. So the volume and the pressure change inside the syringe.

Pressure: A measure of what you perceive as the "squeezedness" of a fluid. Pressure is defined as how hard the fluid pushes on the walls of its container. It is similar to how temperature is a measure of what you perceive as an object's "hotness."

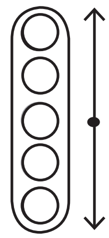
A fluid has a pressure that can be measured, just as it has a temperature that can be measured. As you pull the piston out in a syringe that is full of air, the volume inside the syringe will increase. The gas trapped in the syringe expands to fill the whole syringe. It is even less squeezed than normal. When a gas expands into a larger volume, its pressure decreases.

Initial ______________ Date ___________

Color Coding Chart

You can color-code pressure in a way similar to how you color-coded temperature. Just as the air all around you has a “normal” temperature, it also has a “normal” pressure, so you can color it yellow. You can color a “high-above-normal pressure” red and a “low-below-normal pressure” blue.

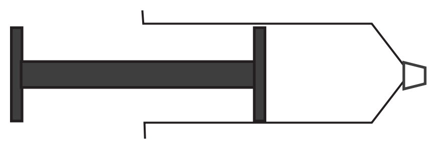
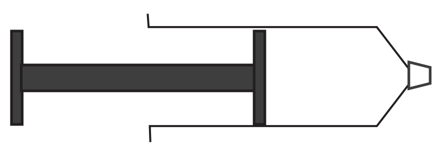
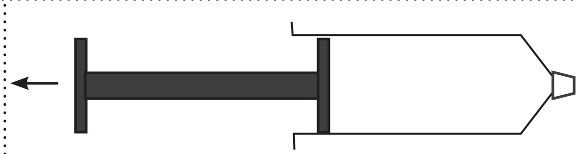
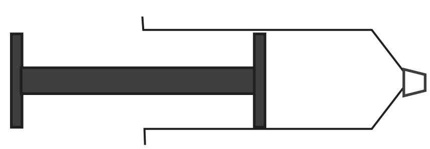
Color Key



RED	High-above-normal
ORANGE	Above-normal
YELLOW	Normal
GREEN	Below-normal
BLUE	Low-below-normal

Color Coding Exercise

Fill a syringe about halfway with air and screw the cap on. Try the actions as indicated in the left column, and observe what happens. In the diagrams below, indicate the pressure inside the syringe with the correct color. Assume that the air around each syringe is always colored yellow.

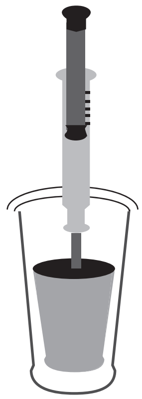
ACTION	PISTON POSITION	PRESSURE IN THE SYRINGE
Syringe at rest		**Normal** pressure
Push in piston		**High-above-normal** pressure
Release piston		**Normal** pressure
Pull on piston		**Low-below-normal** pressure
Release piston		**Normal** pressure

Explain why, after you push in a piston of a syringe filled with air and then release it, the piston will be pushed back out to its starting point. Use the phrase “differences drive change” in your answer.

Name ____________________

Color-Coding Liquid Pressure

What Is Liquid Pressure?



Fill a syringe about half full with water and try to get all of the air bubbles out. Screw on the cap.

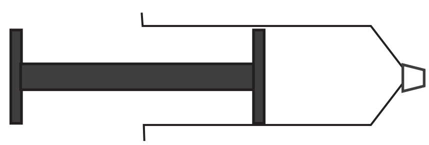
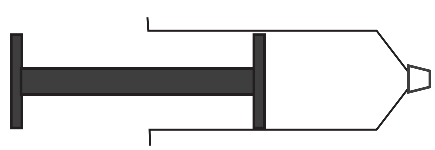
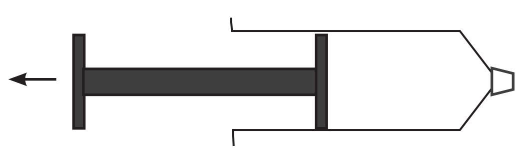
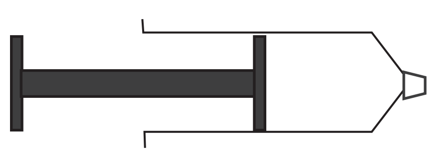
Push in the piston. What happens? Can you compress water like air? Probably not as much, yet the water is still more squeezed when you're pushing on it than when you're not pushing on it, so the pressure of the liquid does increase. When you stop pushing, the pressure returns to normal, but the piston doesn't move.

If you pull the piston out, the volume inside the syringe increases, but the volume of the water doesn't change; it just has more room to flow around. The space between the water and the container is filled with very little air, because you tried to get all the air out before. This trapped air has a low-below-normal pressure, which is why the normal air outside pushes the syringe back in.

How is this different from the air-filled syringes?

Color Coding Exercise

The following diagrams show syringes filled with water. Try the actions as indicated in the left column, and observe what happens. In the diagrams below, indicate the pressure inside the syringe with the correct color. Assume that the air around each syringe is always colored yellow.

ACTION	PISTON POSITION	PRESSURE IN THE SYRINGE
Syringe at rest		**Normal** pressure
Push in piston		**High-above-normal** pressure
Release piston		**Normal** pressure
Pull on piston		**Low-below-normal** pressure
Release piston		**Normal** pressure

Initial ____________ Date __________

Energy Stored in Fluids

- When air is in a syringe, it acts like a spring. If you push in to compress the air, it pushes back when you let go. That indicates that the compressed air must store energy, like a mechanical spring.
- When water is in a pistion, it does not act like a spring. The piston does not move when it is released. That indicates that the water doesn't store energy, even though you can change its pressure.
- You'll learn more about this in the next task.

Comparing Gases and Liquids

Use this chart to summarize what you've learned so far about liquids and gases trapped in a syringe. Circle the best answer for each one and then be prepared to discuss your answer with the class.

	Liquids	Gases
Name of system that uses this fluid	Hydraulic Pneumatic	Hydraulic Pneumatic
Mass of trapped fluid	Constant (Stays the same) Variable (May change)	Constant (Stays the same) Variable (May change)
Volume of fluid	Constant (Stays the same) Variable (May change)	Constant (Stays the same) Variable (May change)
Density $Density = \frac{mass}{volume}$	Constant (Stays the same) Variable (May change)	Constant (Stays the same) Variable (May change)
Energy can be stored in fluid	Yes No	Yes No

NOTES:

Benchmark

1) A regular-sized car might have tires that are filled to around 60 pounds per square inch (psi). What characteristic of pneumatic systems makes air a good choice when considering ride comfort in a car? What would it feel like to ride in a car that had liquid-filled tires? Why?

2) Explain what happens when a 4x4 vehicle drives over a big rock in terms of the pressure inside and outside the tire.

3) Is the putt-putt boat a hydraulic system, a pneumatic system, or both? Explain.

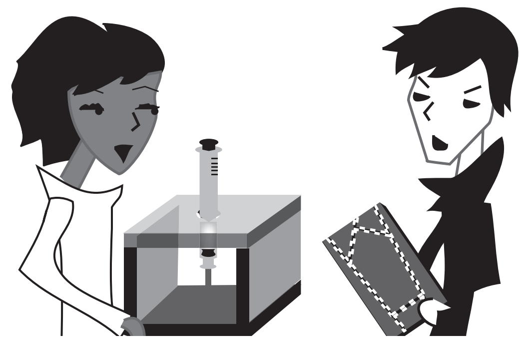
4) When transferring energy with a syringe, you pushed on the piston. How is energy transferred in the putt-putt boat to get it moving forward?

Read Chapter 18, "Shooting for the Moon," in the textbook *Engineering the Future.* Astronautical engineers like Aprille Ericsson use properties of fluids to make rockets move through space. Use notebook paper to answer the questions at the end of the chapter. Sign, date, and number each page. Insert the pages at this point in your *Engineer's Notebook.*

TASK 3.4 Develop a Manufacturing Press

- Learn how pressure, volume, force, and area are used for designing fluid systems.

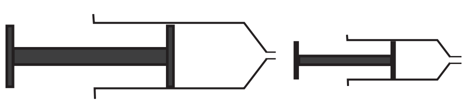
In this task you will investigate how pneumatic and hydraulic systems transfer energy. Remember that in order for something to happen, such as energy transfer, you must create a difference. In this case you will create a pressure difference using two different fluids: air and water. You will test several combinations of syringes, big to small, filled with water and air, and actually feel these principles in action. Then you will decide which system to use for a machine press for manufacturing boat hulls from thin sheets of metal.



What system will you use for your machine press?

Pneumatic Systems

You will need:



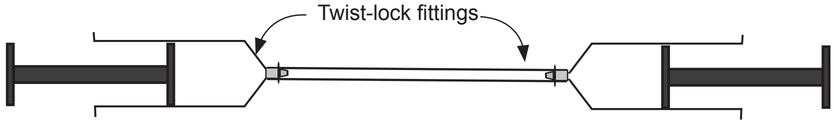
Large and small syringes

Female 1/8 twist-lock fittings

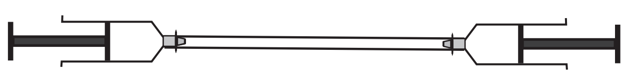
Syringe cap

Tubing

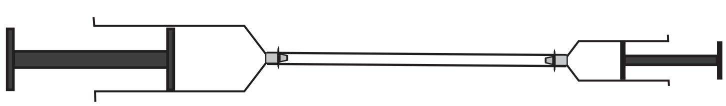
Big-to-big syringes



Small-to-small syringes



Big-to-small syringes



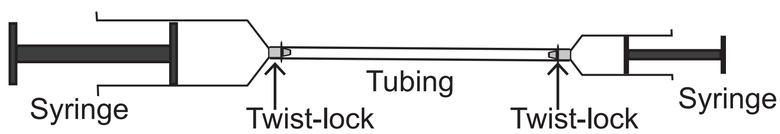
Longer tube with syringes

Experimenting with Pneumatic Systems

Take two syringes and connect them to a section of tubing using twist-lock fitings to create a **pneumatic** system. Different teams should connect different combinations of syringes. Some teams will connect two syringes of the same size, while other teams will connect syringes of different sizes.

Pull the piston of one of the syringes out nearly all the way, and push the other syringe in nearly all the way. Take turns pushing on each piston so the air moves back and forth through the tube and compare how hard or easy it is to push on each syringe. This is a **closed system** because no fluids enter or leave the syringes and tubing.

Record your observations below, indicating the sizes of the syringes connected together, which one is easier to push, and anything else you notice. Then trade pneumatic systems with another team that has a system with syringes of different sizes. Do this with at least three different sets of syringes, and record your results.



1) Record your observations of **pneumatic** systems:

Syringe Sizes	Which Is Easier to Push?	Other Observations

2) If you can, state a general rule that would allow someone to predict how a pneumatic system would behave based on the relative sizes of the two syringes.

Boyle's Law/Pressure in Gases

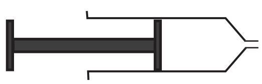
In the 1600's Robert Boyle found that if he kept a gas at constant temperature and compressed it slowly by decreasing the volume of the container, the gas pressure increased. When he increased the volume of the container, its pressure decreased. (That may not be surprising to you, as that is probably what you found in the previous activity involving syringes with trapped air.) Expressing this idea with a simple equation can be very useful.

Expressed as an equation, Boyle's Law states that if you take a trapped gas at a certain pressure (P_1) and volume (V_1), and then change the volume (V_2) by expanding or compressing the container, you can find the new pressure (P_2). Keep in mind that Boyle's Law is only true if the temperature is kept the same, and it is a closed system, so no gas escapes.

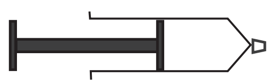
$$P_1 V_1 = P_2 V_2$$

Sample Problem

The pressure of air at sea level is 14.7 pounds per square inch (psi). This pressure is due to the weight of the air, and is the weight of the air above one square inch of surface. That is "normal" air pressure. Take an open syringe and move the piston to any measured volume of air—say, 10 mL. The air inside the syringe is the same as the pressure of the air outside—14.7 psi.

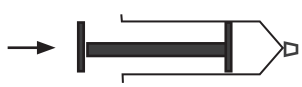


Open syringe
V_1 = 10 mL
P_1 = 14.7 PSI



Closed syringe
V_1 = 10 mL
P_1 = 14.7 PSI

Now put a cap on the syringe and push the piston in so that the volume is just half what it was before. (If it was 10 mL before, it should be just 5 mL now.)



Closed syringe
V_2 = 5 mL
P_2 = ?

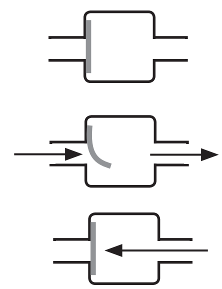
1) Use the equation above to calculate the new air pressure in the syringe. Show your work below.

2) Would Boyle's Law hold for hydraulic systems? Why or why not?

Build a Pneumatic Pump

A great many machines work by connecting tubes in various ways to manipulate the pressure of fluids—including both liquids and gases. One of the simplest is the syringe itself used by doctors to inject medicines or extract blood samples. Here's a more complex machine that you can build, a pneumatic pump.

A key component of a pneumatic pump is a one-way valve, which may be as simple as a flap of plastic covering a hole. As air flows from left to right, because of the pressure difference, the flap is pushed open and air can flow through the tube. If the pressure is reversed, the flap is pushed closed.



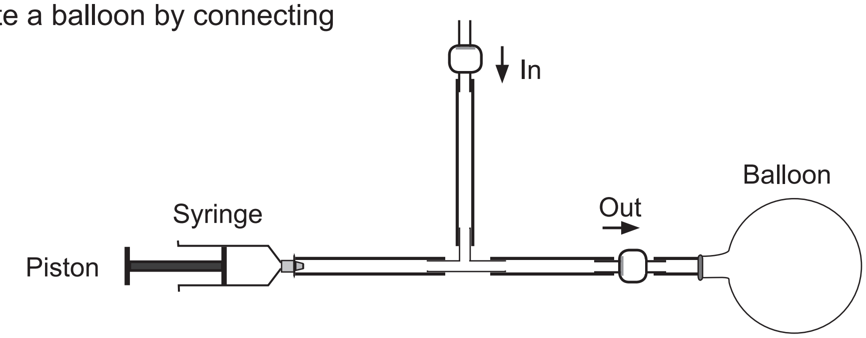
No pressure difference= Valve Closed

More pressure on left= Valve Open

More pressure on right= Valve Closed

Build a pneumatic pump to inflate a balloon by connecting the following parts as shown:

- 1 syringe
- 1 balloon
- 1 plastic "T"
- 2 one-way valves
- 4 short lengths of tubing
- 1 twist-lock fitting



1) How many times do you need to operate the piston in the syringe to inflate the balloon to about four inches in diameter?

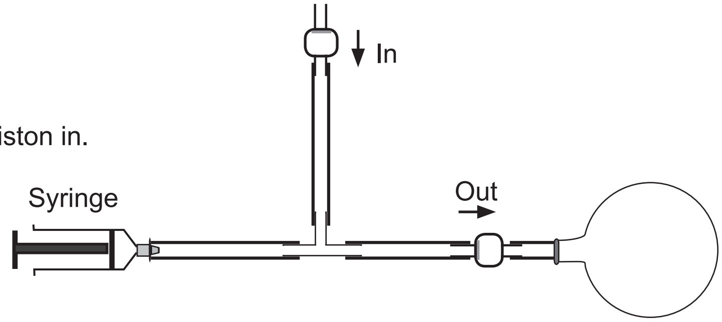
2) Compare your results with another group who built their pneumatic pump with a different size syringe. What did you find out and what can you conclude about how the size of the piston affects the operation of the pump?

3) In your own words, explain how the pump works.

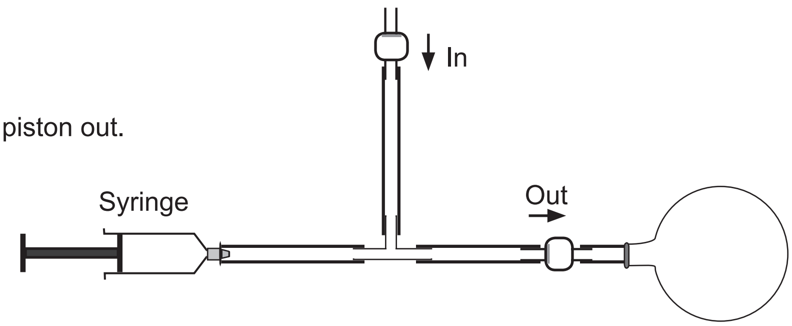
Pressure and Energy

4) Show how the pressure changes in the pneumatic pump by coloring the syringe, tubing, and balloon to show the air pressure while you are pushing the piston into the syringe (top), and when you are pulling it back out (bottom). If necessary, refer back to the color key in Task 3.3 to recall which colors to use for above and below normal pressure. Assume the surrounding air is colored yellow.

Push piston in.



Pull piston out.



5) A pneumatic pump is a kind of air compressor. That is, it creates a volume of air (inside the balloon) that is at a higher pressure than normal air. As you work the pump, you are adding energy to the system. Your body turns chemical energy from the food you have eaten into **mechanical energy**—energy of motion. The balloon stores that energy in the form of pressurized air. What can you do to release the stored energy and turn it back into mechanical energy?

6) The pneumatic pump demonstrates an important concept about pressure and energy in fluids: **A difference in pressure drives the flow of energy. When the pressure is equalized, energy stops flowing.** Below, list some examples you can think of in the everyday world where a difference in pressure drives the flow of energy.

Boyle's law relating the pressure and volume of a gas does not apply to liquids, since the volume of a liquid does not change. However, as you'll see in the next few pages, hydraulic systems can still be very useful.

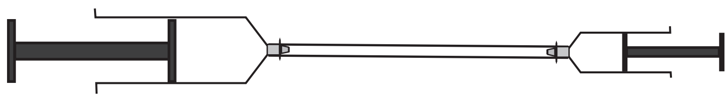
Read Chapter 19, "Fuel from the Fields," in the textbook *Engineering the Future.* Joshua Tickell uses his understanding of engines to make a system that runs using fuel made from vegetable oil. Use notebook paper to answer the questions at the end of the chapter. Sign, date, and number each page. Insert the pages at this point in your *Engineer's Notebook.*

Initial ______________ Date ___________

Experimenting with Hydraulic Systems

Connect two syringes with a tube as before. Different teams should connect different combinations of syringes. This time you will fill your syringes with water, so they will be hydraulic systems. Take care to fill the system completely with water, eliminating bubbles. You may need to submerge the system in a pan of water to get all of the bubbles out. As before, you will want each syringe to be about half full with water so you can push the water back and forth between the two syringes.

Take turns pushing on each piston so the water moves back and forth through the tube and compare how hard or easy it is to push on each syringe. Record your observations below. Then trade with another team that has a system with syringes of sizes that are different from yours. Do this with at least three different sets of syringes, and record your results.



1) Record your observations of **hydraulic** systems:

Syringe Size	Which Is Easier to Push?	Other Observations

2) If you can, state a general rule that will allow someone to predict how a hydraulic system would behave based on the relative sizes of the two syringes.

3) It takes a difference in pressure for energy to flow from one place to another. You can change the pressure in both pneumatic and hydraulic systems by pushing in a piston, which reduces the volume. Pneumatic systems are better than hydraulic systems for storing energy. Which system is better at immediately transferring energy from one place to another? How do you know?

Pascal's Law/Pressure in Liquids

Blaise Pascal invented the syringe. He also helped to develop some of the first equipment to help divers breathe under water and, as a result, he became very interested in how fluids behave. One of Pascal's most useful discoveries is now known as **Pascal's Law:**

When a force is applied to a liquid in a container, the pressure will increase equally throughout the liquid.

This is different from applying a force to a solid, which acts in just one direction, or to a gas, which can be compressed.

You may have noticed in the previous activity that if a small and large syringe are connected in a hydraulic system, the force needed to push the small syringe is less than the force needed to push the large syringe. If the pressure is the same throughout the system, consider why the force is different.

Remember that pressure and force are not the same thing. **Pressure** (*P*) is the force (*F*) applied to a given area (*A*) as shown. In the case of two syringes, the area is the part of the piston in contact with the liquid. If these areas are different, the force that must be applied to push the liquid back and forth is different, even though the pressure is the same.

$$P = \frac{F}{A}$$

Sample Problem

Select one of the hydraulic systems from your experiments recorded on the previous page, in which the syringes were different sizes. Your task in this problem is to figure out how much harder it is to push the piston in the large syringe than in the small syringe.

Because the two syringes are part of the same hydraulic system, the pressure exerted on both pistons is the same. So if you use a subscript to indicate the large piston and the small piston, the equation above implies that:

$$\frac{F_{Large}}{A_{Large}} = P = \frac{F_{Small}}{A_{Small}} \qquad \text{It's also true that:} \qquad \frac{F_{Large}}{F_{Small}} = \frac{A_{Large}}{A_{Small}}$$

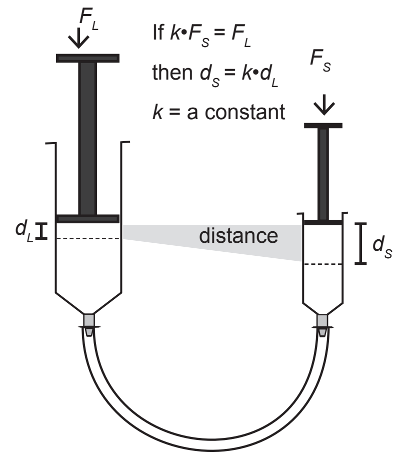
In other words, the ratio of forces on two pistons is the same as the ratio of the areas of the two pistons. Suppose, for example, that you had to exert a force of 5 pounds on the small piston. Determine the area of the ends of the pistons and find out how much more force you need to exert on a connected large piston to get the water to move back. Answer below.

(Area of a circle is $A_{circle} = \pi r^2$ where $\pi \approx 3.14$ and *r* is the radius. The radius, *r*, is one half of the diameter or one half of the distance across the circle through the center.)

Name ____________________

Distance-Force Trade Off

As shown on the previous page, a hydraulic system can multiply force when you have pistons of different sizes, but the additional force is not free. You have to pay for less force used by pushing the smaller piston farther. The additional distance is proportional to the force multiplier. If the increase in force from the small piston to the large is ten times greater, then the small piston must be pushed ten times farther than the large piston.



The system also works in reverse. Pushing the small piston ten inches will move the large piston one inch, and the force to move the small piston ten inches is 1/10 the force needed to move the large piston 1 inch. In other words, a hydraulic system allows you to trade off force for distance, or distance for force.

Hydraulic Lift

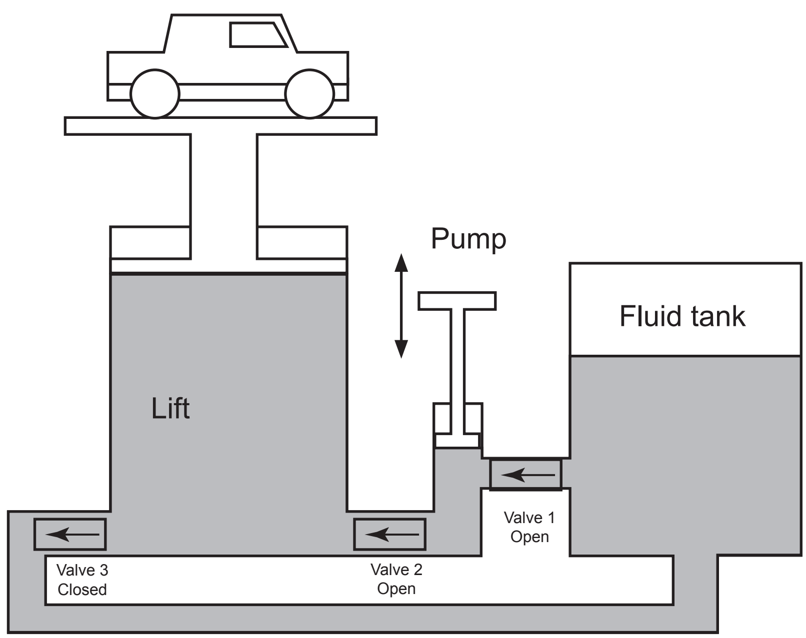
The hydraulic press, based on Pascal's Law, was invented by British engineer Joseph Bramah in 1795. The same principle applies to the hydraulic lift, which can be found in just about every garage where cars are repaired. If you pay attention to just the pump (small piston) and the lift (large piston), you'll see that it is like the hydraulic system you have already experimented with.

In addition to the simple hydraulic system, you'll see that the hydraulic lift includes three one-way valves and a tank for extra fluid. The one-way valves only allow fluid to pass in the direction of the arrows. The fluid used for these systems is almost always oil, but it works the same way as the water hydraulic system. From your experience, you should be able to figure out how it works. See if you can fill in the steps below. Remember, fluid can only move in the direction of the arrows in the system.

Step 1: Valves one and two are open and valve three is closed. What happens to the fluid and lift when you push down on the pump?

Step 2: What happens when you pull up on the pump?

Step 3: What happens when you close valves one and two and open valve three?



Initial ____________ Date __________

DESIGN CHALLENGE

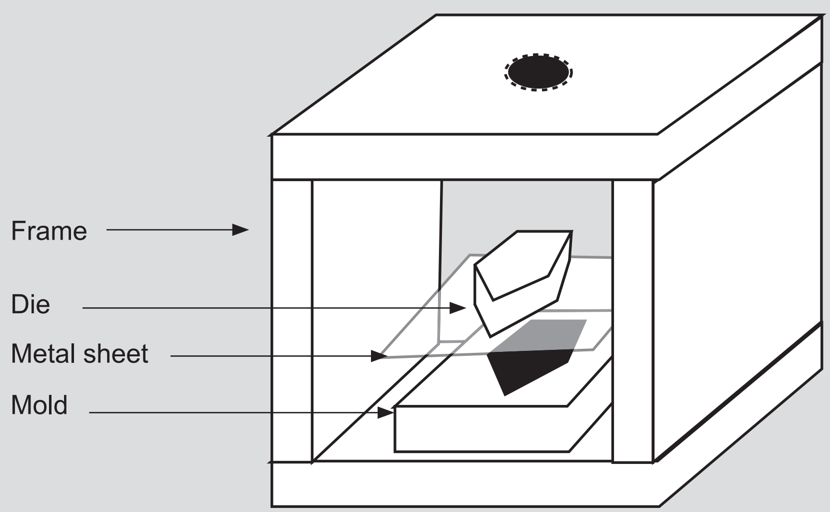
Design a Brake Press

A great many of the metallic objects that you use every day were probably formed with a brake press. A brake press can make large numbers of objects quickly and inexpensively.

The basic idea of such a press is very simple. A thin sheet of metal is placed between a mold and a die. The die fits into the mold loosely so there is room for the piece of metal to be squeezed in between.

The major design question is whether it is best to use a pneumatic system to press the die into the mold, or to use a hydraulic system. You are welcome to try both systems to see which is better.

Below is a drawing of a frame, die, and mold for a simple brake press. Draw in the parts you would add so that it is operated by a fluid system to increase the pressure on the die. Use labels to indicate the parts you are adding. Then explain your system in writing, including why you chose the system that you did.



Name ______________________________

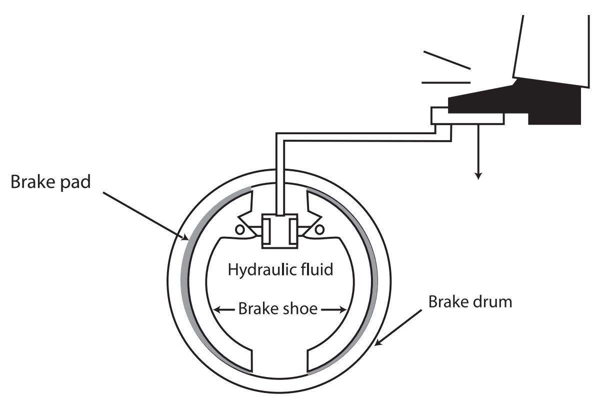
Benchmark

1) Which type of system do you think robotic arms use—pneumatic or hydraulic? Why?

2) Following are some pneumatic and hydraulic systems. For each one circle “closed” or “open” to indicate if it is a closed or open system:

Pneumatic Systems		Hydraulic Systems	
Bicycle pump	(closed or open)	City water system	(closed or open)
Hot air balloon	(closed or open)	Human circulatory system	(closed or open)
Auto tire	(closed or open)	Auto brake system	(closed or open)

3) The brakes in a car consist of brake drums that are attached to all four wheels. Inside the drums are brake shoes that are attached to the axle. In order for the car to stop, the brake shoes in all four wheels must push outward against the brake drums. Look at the simplified diagram for the hydraulic system of drum brakes below and explain how stepping on the brake pedal causes the brake shoes to push outward.



Drum brakes

4) When new brake fluid is put into the brake system, it’s usually necessary to “bleed” the system, which means to remove all of the air bubbles. What do you think would happen if that were not done?

Read Chapter 20, “An Ingenious Engine,” in the textbook *Engineering the Future.* Chris Langenfeld tells the story of how his team of engineers designed a new kind of engine to power a wheelchair. Use notebook paper to answer the questions at the end of the chapter. Sign, date, and number each page. Insert the pages at this point in your *Engineer’s Notebook.*

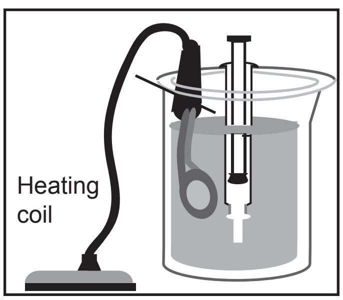
Initial ____________ Date __________

TASK 3.5 Investigate Heat Engines

- Explain the relationship between temperature, pressure, and volume in an engine.
- Compare different types of engines.

It's not an exaggeration to say that heat engines are one of the most important technologies of the modern world. Increase the temperature of a gas in a confined space and the pressure goes up dramatically. In engine design this relationship between temperature, pressure, and volume is key. By examining how various engines work, you'll have a better understanding of the putt-putt boat engine as well as the fundamental principles that underlie all engines.

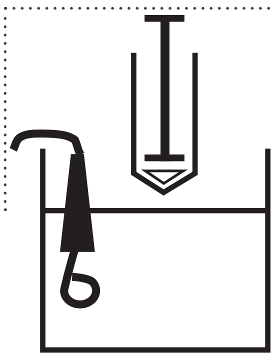
Observing the Acetone Engine



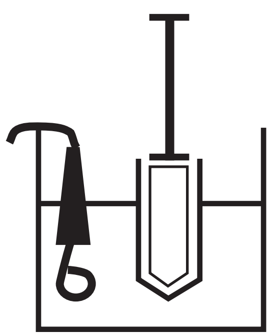
Watch the demonstration of an acetone engine. A beaker is filled with water, and a syringe filled with acetone is submerged in water. The water is heated by a heating coil. After some time the syringe is removed from the hot water and put into ice water. (A clothes pin can be used to remove the syringe.) Watch how the piston is affected by the changes in temperature.

What do you observe? How can you explain what happened? Write your ideas below each picture and share them with a partner. Use arrows to show the syringe movement and color-coding to help you explain.

1 Syringe is at room temperature.

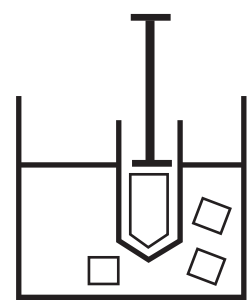


2 Syringe is immersed in hot water.



Heating phase

3 Syringe is immersed in cold water.



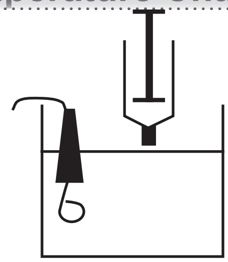
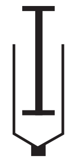
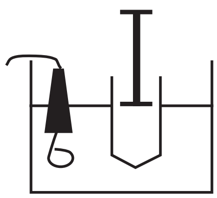
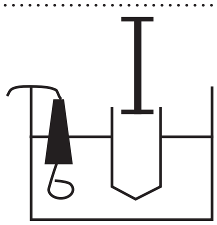
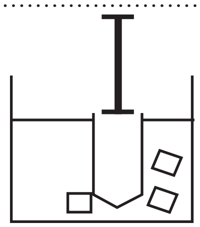
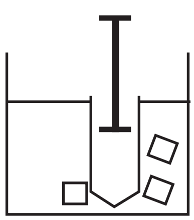
Cooling phase

Name ______________________________

Pressure and Temperature in the Acetone Engine

In the previous tasks, you worked with fluid systems. By pushing on the fluid in the fluid system, energy was transferred. This task is about more complex systems that are driven by changes in temperature, which cause changes in states of matter, from liquid to gas and gas to liquid.

The diagrams on this page ask you to compare what is happening with the temperature in the acetone engine to what is happening with the pressure. Color-code the following pictures, and describe what is happening to the temperature and pressure at each step.

	Temperature Change (ΔT)	Pressure Change (ΔP)
1 Syringe at room temperature.		
2 Syringe in hot water, piston starts moving out.		
3 Syringe in hot water, piston is out as far as it can go.		
4 Syringe just placed into ice water.		
5 Syringe in ice water, piston moves back in.		
6 Draw what the next step would be.		

Initial ______________ Date __________

Temperature, Pressure, and Volume—Putting It All Together

1) The acetone engine demonstrates key ideas about how heat engines work. What are your ideas about the acetone engine? Compare your ideas with another student to see if you agree. If not, discuss your answers. If you change your mind about anything, insert a sheet of notebook paper at this point, explaining how you changed your ideas.

2) A **heat engine** is a device that converts thermal energy into mechanical energy. What is the mechanical energy in an acetone engine?

3) As mentioned in previous tasks, it takes a difference to make a difference; or difference drives change. Below, explain what that means in terms of the acetone engine.

When steam engines were starting to be used in factories, scientists and engineers wanted to better understand the relationship between temperature (*T*), pressure (*P*), and volume (*V*) so they could build better steam engines. The following people made some important discoveries.

Boyle's Law

In the 1600s, Robert Boyle discovered the relationship between the volume and pressure of a gas kept at constant temperature.

$$P_1 V_1 = P_2 V_2$$

Charles' Law

In the 1700s, Jacques Alexandre César Charles discovered the relationship between the temperature and volume of a gas at constant pressure.

$$\frac{V_1}{T_1} = \frac{V_2}{T_2}$$

Guy-Lussac's Law

In the 1800s, Joseph Louis Gay-Lussac discovered the relationship between the temperature and pressure of a gas kept at constant volume.

$$\frac{P_1}{T_1} = \frac{P_2}{T_2}$$

If you combine these relationships, you have the combined gas law for a closed system.

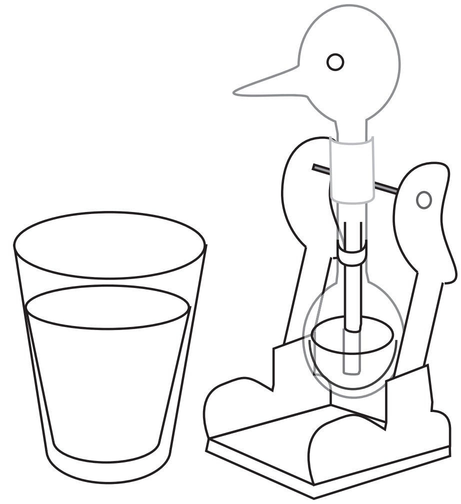
$$\frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2}$$

4) The labels of many spray cans say "Contents under pressure. Do not place in hot water or near radiators." Of course, you should **never** do this, as it is very dangerous. However, you can use the *P*, *V*, *T* relationship, above, to describe what would happen if you did put a spray can in a place where it would heat up. Please explain what would happen and how you know.

Extra Challenge: Observing the Drinking Bird Engine

Another kind of heat engine is the “drinking bird.” To start the engine, make sure the bird is balanced so that it is upright but it can tip easily. Then tip it once so that its bill is completely wet. Finally, let it go and it should bob back and forth and “drink” on its own.

The fluid inside the bird is methylene chloride. Both methylene chloride and acetone evaporate very quickly and can expand to many times their liquid volume.



1) When you think you’ve figured it out, explain how the drinking bird works by drawing sketches below. Showing each step in the drinking bird engine cycle, explain what is occurring to the temperature, pressure, and volume at that point. You may compare ideas with other students, but sketch and explain it in your own words.

2) Recall the combined gas law equation for a closed fluid system on the previous page. If you take 1 to be the state when the drinking bird is upright, and 2 to be the state when the bird has tipped over to “drink,” explain which terms (P, V, and T) have increased and which have decreased when the bird moves from state 1 to state 2.

$$\frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2}$$

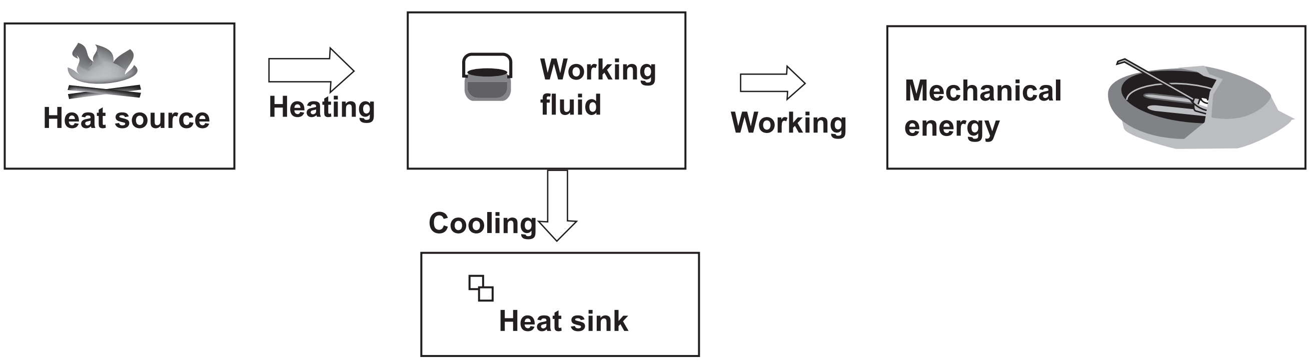
Efficiency of a Heat Engine

In 1824, when Nicholas Leonard Sadi Carnot was just 28 years old, he published a book about his life in which he discussed heat engines. At that time, steam engines were driving the industrial revolution. Carnot discussed the science behind these technological devices and how more of the energy that was being put into the engines could be used to do something useful besides just warming up the environment.

Carnot realized that engines not only need a heat source (a way to get hot), but also a heat sink (a way to get cool again). It's the difference in temperature between source and sink that determines the maximum efficiency of any engine. The drinking bird engine is an excellent example because it's not how hot you make the engine that makes it work efficiently, but how cool you can make it by dunking the absorbent bill into the water, so that it can be cooled by the air. So heat alone does not drive a heat engine—it's the difference between the hot side and the cool side of the engine that matters. The efficiency of an engine is defined as the following:

$$Efficiency = \frac{\text{Amount of energy doing what you want}}{\text{Total energy put in}} = \frac{\text{useful output}}{\text{input}}$$

It is impossible for the efficiency of an engine to be 100%, because no matter how hot you get the engine, you still need to cool it back down. This idea is illustrated by the following diagram showing what happens to the energy in a heat engine. Notice that some of the energy must be lost in cooling the working fluid so that it can be heated again, then the process starts over again.



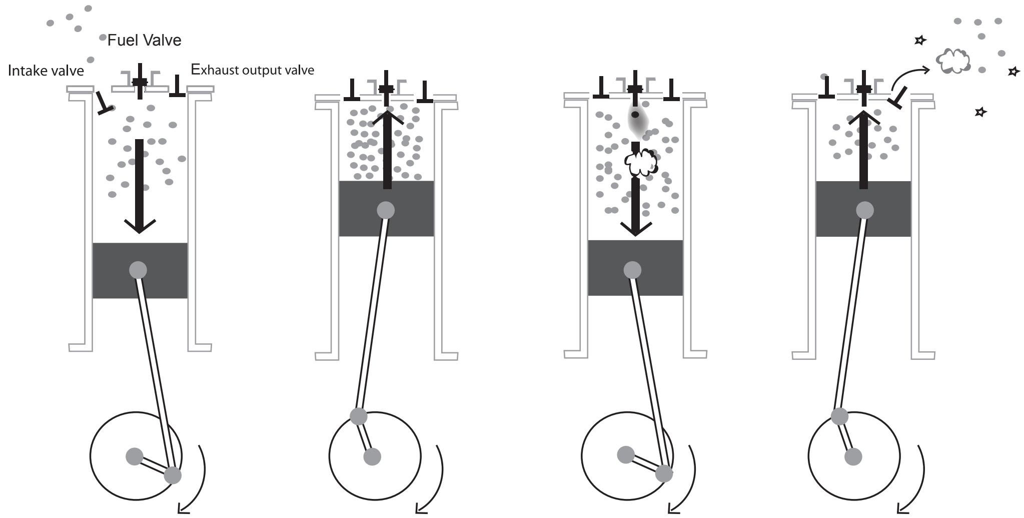
1) What is the **heat source** for the drinking bird? For the putt-putt boat?

2) What is the **heat sink** for the drinking bird? For the putt-putt boat?

Name ______________________________

Otto Heat Engine Cycle

1) Most automobile engines are based on the four-stroke Otto cycle. Refer to Chapter 20 in the *Engineering the Future* textbook and fill in the four parts of the engine cycle below.



1.____________ **2.**____________ **3.**____________ **4.**____________

In an automobile engine, as the piston rises it increases the pressure in the cylinder, and the temperature of the gas-air mixture increases slightly. Then a spark plug sends an electrical charge into the cylinder and ignites the fuel, which violently increases the pressure and thrusts the piston downward.

2) Draw a spark plug into the above Otto Cycle where it would ignite the fuel in a gasoline engine.

Spark plug cross-section

3) What is the difference between a diesel engine and the gasoline engine? (You'll find the answer in *Engineering the Future.*)

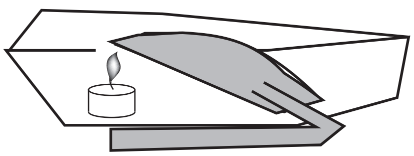
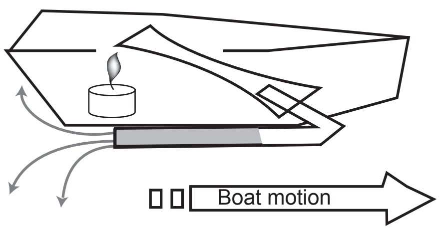
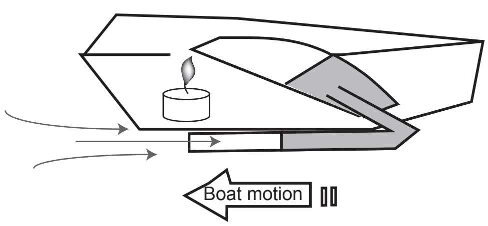
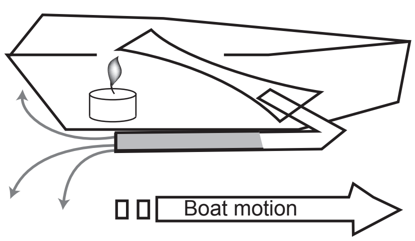
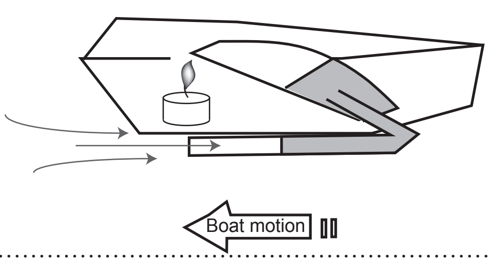
Read Chapter 21, "Energy from the Earth," in the *Engineering the Future* textbook. Professor of thermodynamics Ron DiPippo describes how geothermal wells might provide a solution to some of the world's energy problems. Use notebook paper to answer the questions at the end of the chapter. Sign, date, and number each page. Insert the pages at this point in your *Engineer's Notebook*.

Initial ______________ Date __________

Piot Engine Cycle

Now you are ready to think about the putt-putt boat's engine cycle. It is a bit tricky because the pressure, temperature, and volume are all changing at the same time. Look at the diagrams below and write a few sentences for each set of pictures that describes how you think the putt-putt boat engine works. You may use color-coding to help you.

Be sure to consider how differences in **pressure** and **temperature** are causing changes such as the flow of fluids and the motion of the boat.

Steps in the Cycle	What Is Happening?
1 	
2 	
3 	
4 	
5 	

Benchmark

Acetone Engine

1) Why is acetone, not hot water, used in the syringe?

2) If you keep the syringe in the hot water, is it possible that the piston will be pushed completely out of the syringe as the acetone continues to boil? Why or why not?

3) What if you took the piston out of the hot water but did not put it in the ice bath? Would it still cool down? What would happen to the position of the piston? Why?

Drinking Bird Engine

4) Explain why the liquid moves up the tube in terms of the combined gas law. $\frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2}$

5) Where do conduction, convection, and radiation come into play in the drinking bird engine?

6) What are the main thermal transfers that are occurring in the drinking bird heat engine?

Otto Engine

7) The Otto engine is an **internal combustion engine** because fuel is burnt inside the engine. In the Stirling engine heat is provided by a source outside of the engine, so it's called an ____________________ combustion engine.

Piot Engine

8) At what point in the Piot engine cycle does cooling occur?

9) What would happen if the Piot engine didn't include a cooling cycle?

10) What are the sources of inefficiency for the Piot engine cycle?

All Engines

11) What do all of these engines have in common?

12) What are some ways that engine efficiency can be improved?

Initial ______________ Date ___________

TASK 3.6 The Rocket Effect

- Explore the rocket effect.
- Examine the relationship between force, mass, and acceleration in a rocket.

You have probably noticed bubbles escaping out of the tubes from the putt-putt boat's engines Do these bubbles push the boat forward? Or is it the water that is pushed out by the bubbles? Even more important, why does a fluid expelled from the back of the boat make it go forward at all? In this activity you'll find the answers to these questions as you investigate the propulsion system of a rocket and compare it to the putt-putt boat.

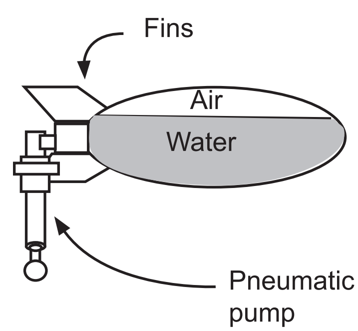
The Rocket Engine

Just about everyone has observed the rocket effect by blowing up a balloon and then letting go. The balloon flies all over the room as the air escapes from the hole in the balloon, which pushes the balloon forward.

As in the engines you've looked at previously, it's the difference in pressure that drives the transfer of energy. When you blow up a balloon you are storing energy in the pressurized air. When you let it go, the air flows from the region of high pressure (inside the balloon) to low pressure (outside the balloon), until the pressure is equalized.

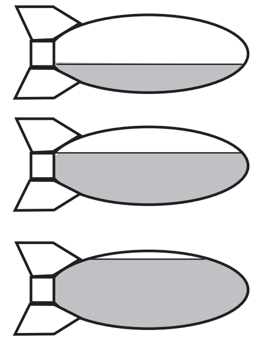
1) How do you think a rocket engine is different from the heat engines you observed in the previous task?

2) A water rocket is like a balloon, except it has fins to keep it flying straight. It is pressurized by a pneumatic pump. When released it is propelled by escaping air (like the balloon) or water. Observe the rocket as it is propelled with air, and then with water. What does this tell you about the rocket effect?



The Rocket Effect

1) Experiment with loading the rocket with different amounts of water. Is there an optimal amount of water to make it travel the farthest? If so, what is the optimal percentage of the rocket that should be filled with water? (Show the results of your experiments below.)



2) Remember that because air is a gas, it is compressible, so it can store energy. However, water is a liquid, so it is not compressible. You can increase the pressure of water and use it to transfer energy, but it cannot store energy. Explain how a water rocket takes advantage of the properties of both liquids and gases.

Newton's Laws of Motion

Sir Isaac Newton (1642–1727)

The rocket effect is best described by Sir Isaac Newton, whose three laws of motion, which he published in 1687, have been among the most important scientific findings of all time.

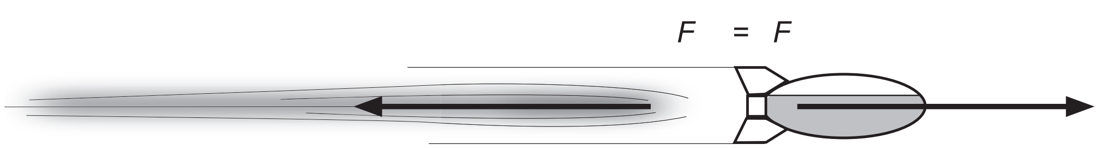
First Law: An object in motion remains in motion unless acted on by an outside force. This means that a rocket in space, with its engine turned off, will keep going with the same speed and direction because there is no air in space to slow it down. But if its engine is fired, it will speed up or change direction.

Acceleration is the scientific term for speeding up or changing direction.

Second Law: Force equals mass times acceleration: *F = ma.*

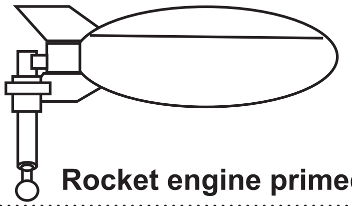
This means that the force provided by the rocket exhaust equals the mass of the exhaust material (water and/or air) times its acceleration. Water has a lot more mass than air, so it gives the water rocket a much bigger push.

Third Law: Every action has an equal and opposite reaction. The water and air pushed out of the back of the rocket gives the rocket a push in the opposite direction.

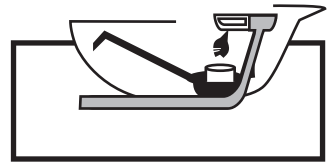


mass of EXHAUST × acceleration of EXHAUST = mass of ROCKET × acceleration of ROCKET

The Rocket Effect and the Piot Engine



Rocket engine primed with water



Piot engine primed with water

1) Both the rocket engine and the Piot engine are primed with water. What happens to the water

A. in the rocket engine?

B. in the Piot engine?

2) Some people think the bubbles drive the putt-putt boat forward and others think that it's water pushed by the bubbles that drive the putt-putt boat forward. Who do you think is right, and why?

3) Is the water rocket a pneumatic system, a hydraulic system, or both? Explain your answer.

4) Is the Piot engine a pneumatic system, a hydraulic system, or both? Explain your answer.

5) Is the water rocket an open system or a closed system? Explain your answer.

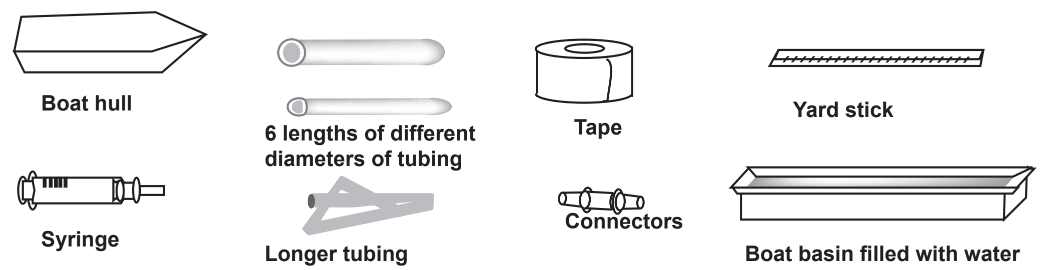
6) Is the Piot engine an open system or a closed system? Explain your answer.

7) How is the Piot engine similar to a rocket engine?

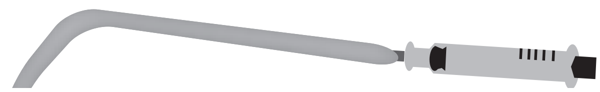
Name ______________________________

Explore the Rocket Effect

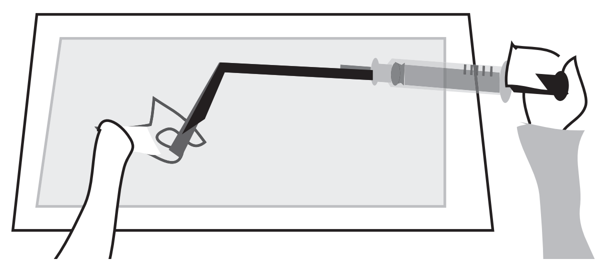
In order to investigate different arrangements for a possible engine redesign, you can make a working model of the fluid part of the Piot engine.



1) Connect a syringe to a length of tubing and fill the syringe and tubing completely with water.



2) Submerge the tubing and move the piston of the syringe to pump water in and out of the tubing. Have a partner move the piston in and out while you put your finger by the open end of the tubing under water. Describe what you feel. Does it feel different if you push the piston slowly or quickly?



3) Try different diameter tubing with the same syringe. Again, feel the water as it is flows in and out of the tubing. Describe any difference you feel and explain why it feels different.

4) Tape the larger tubing to the bottom of a hull. Move the piston in and out of the syringe and observe the motion of the boat. Does it move more forward or backward? Why?

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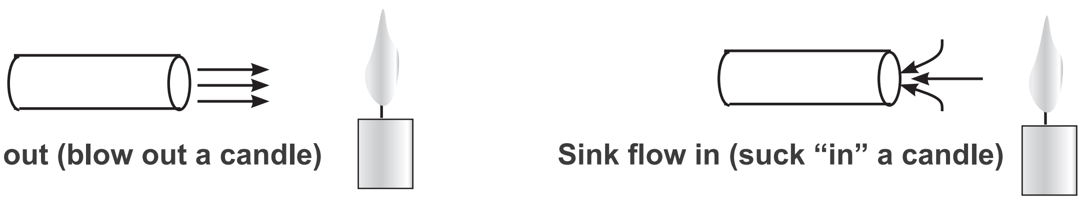
Jet Flow and Sink Flow

Why does the boat move slightly backward? Because the water flows into the boat in a different way than it flows out of the boat. The water being ejected backward is what's known as a "jet" flow, all moving in the same direction. This is the same kind of flow that happens when you blow out a candle. The air comes out almost entirely directed in line with your mouth. But when the water is pushed back in, it is a "sink" flow, coming equally from all directions. You would find it difficult to "suck" out a candle, as the air comes from all around your mouth, and not from behind the candle. The amount of air (volume) flowing in and out is the same, but the way it flows is different.

1) Use a straw to blow out a candle flame. Then try blowing out the candle by sucking the air in through the straw.

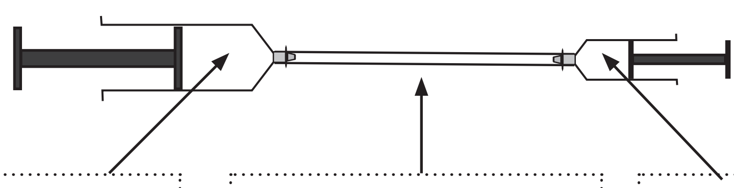


Jet flow out (blow out a candle) **Sink flow in (suck "in" a candle)**

Trade Off of Mass vs. Acceleration

Remember Newton's second law: *F = ma.* If you can increase the mass (amount) of water that flows out of the back of the putt-putt boat, you can increase the force driving it forward. And if you can get the water to flow faster, that will increase the force on the putt-putt boat too. Unfortunately, it's not easy to do both. To see why, connect a small and large syringe with a tube, and fill the entire system with water or some other liquid that has small particles suspended in it, so that you see how quickly the fluid flows.

1) Push the fluid back and forth and record what you observe below.



How quickly does the fluid flow in the large syringe?	How quickly does the fluid flow in the tube?	How quickly does the fluid flow in the small syringe?

2) Why is there a trade off between mass and acceleration when designing an engine that uses the rocket effect?

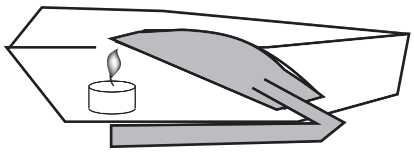
Name ______________________________

Benchmark

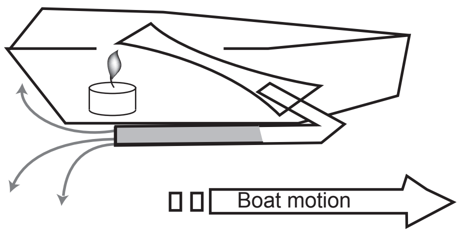
Review how you explained the Piot engine cycle in the previous task, and improve it in light of what you know now about heat engines and the rocket effect.

Steps in the Cycle | **What Is Happening?**

1



2



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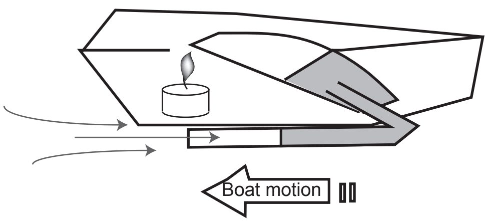

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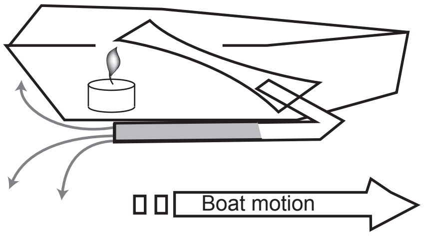

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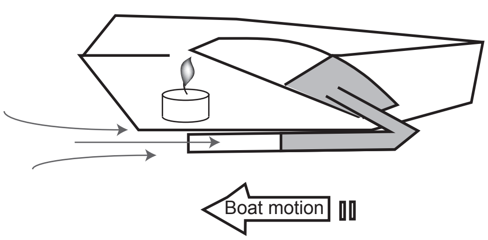


Read Chapter 22, "Good Chemistry," in the textbook *Engineering the Future.* Rebecca Steinman, a nuclear engineer, explains how a nuclear reactor is designed to provide electric power safely without creating air pollution. Use notebook paper to answer the questions at the end of the chapter. Sign, date, and number each page. Insert the pages at this point in your *Engineer's Notebook.*

Initial ______________ Date ___________

TASK 3.7 Investigate Resistance in Pipes

- Explain how resistance in pipes changes with area and length.

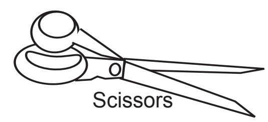
No engine is 100 percent efficient. In the putt-putt system there are energy losses due to **radiation** and **convection** of heat to the surrounding air, as well as several other sources of energy loss such as resistance to the hull as it moves through the water. In this task you will investigate the effects of resistance on fluids that flow through pipes so that you can consider what might happen if you use different straws in the Piot engine.

The engineers investigate resistance in pipes.

What You Will Need

3 flex-bend straws, 3/16 diameter

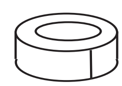
3 stirrer straws, 1/8 diameter



Scissors

3 flex-bend juice box straws (optional)

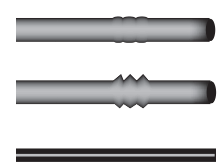
3 drinking straws, 1/4 diameter



Tape

Trade Off of Mass vs. Acceleration

1) Extend the bendy section of the flex-bend drinking straws so that they are at their maximum length. Trim the longer straws so they are all the same length as the shortest straw.



2) Take a deep breath and exhale through each straw individually. Try to maintain a similar effort blowing through the straw. Record how long it takes to fully exhale through each straw.

3) Record the results in the table.

4) What do you notice about the resistance to blowing air through the straws as the diameter of the straws decreases?

Single Straw	Time(s)
Straight drinking	
Flex-bend drinking	
Stirrer	

Name ______________________________

Effect of Quantity

1) Try exhaling through a single stirrer straw, then two stirrer straws next to each other, then three. Take a deep breath and try to maintain the same constant pressure as you did for individual straws. Record how long it takes to fully exhale through each combination of straws.

Parallel Straw	Time(s)
Single stirrer	
Two stirrer	
Three stirrers	

2) What do you conclude about the effect of the number of straws on the resistance to fluid flow?

3) Summarize, in a single sentence, what you learned about how fluids flow through different-sized straws and a different number of straws.

Effect of Length

1) Carefully tape the ends of two straight drinking straws together. Try to seal the joints to prevent leaks while not obstructing the openings.

2) Take a deep breath and exhale through the two drinking straws taped together. Trying to maintain a similar effort blowing through the straws. Record how long it takes to fully exhale through the two straws, and through the single straw.

Series Straws	Time(s)
Single drinking	
Two drinking	

3) Summarize what happens to the resistance when you increase the length of the straws.

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Direct and Inverse Relationships

The resistance (*R*) of a pipe is **directly proportional** ($\propto$) to its length (*L*).

$$R \propto L$$

As the length of a straw increases, the resistance to the fluid flow also increases. Taping several pipes together, end to end, is called a series arrangement. When pipes are arranged in series, the fluid must flow through all of them.

The resistance (*R*) of a pipe is **inversely proportional** ($\propto$) to its cross-sectional area (*A*).

$$R \propto \frac{1}{A}$$

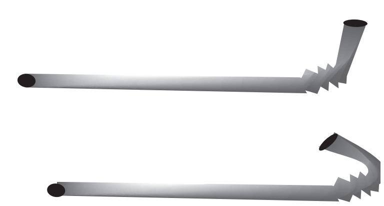
As the cross-sectional area of the straws increases, the resistance decreases. Taping two or more straws next to each other so you blow through all of them at once is called a parallel arrangement. When straws are arranged in parallel, it is like having a single straw with a larger cross section.

Based on the amount of time it took you to exhale with a constant pressure difference, which combination of straws has more resistance, two drinking straws in series, or two stirrer straws in parallel?

Resistance Effects of Bends

1) Carefully tape the ends of three flex-bend drinking straws together. Try to seal the joints to prevent leaks while not obstructing the openings.

2) Take a deep breath and exhale through the three flex-bend straws taped together so that they are all in a straight line. Then repeat while changing the number of bends in the straws, and the angles of the bends.



3) Summarize your observations about the effect of bends in pipes on the resistance to fluid flow. Be specific.

Name ____________________

Benchmark

1) Think about the boiler and pipe system in the putt-putt boat. There must be a build-up of pressure in order for the water to flow out the back.

A. What if the pipes (straws) gave no resistance? How well would the engine work?

B. What if the pipes (straws) gave too much resistance?

2) Describe the changes in the pipes that you think might improve the putt-putt boat's performance. Would you make them longer? Shorter? Increase the diameter?

3) Which of these pipes and combinations of pipes has the least resistance? Which has the most resistance? Explain your choices.

- Three drinking straws in series
- Two drinking straws in parallel
- One bendy straw bent at a 45-degree angle
- One bendy straw bent at a 90-degree angle
- A single drinking straw
- A single stirrer straw

4) How is fluid flow similar to the flow of thermal energy? How is it different?

Read Chapter 23, "Down the Pipes," in the textbook *Engineering the Future.* Lisa Bina uses environmental engineering and knowledge about fluids in pipes to redesign a major city's sewage system. Use notebook paper to answer the questions at the end of the chapter. Sign, date, and number each page. Insert the pages at this point in your *Engineer's Notebook.*

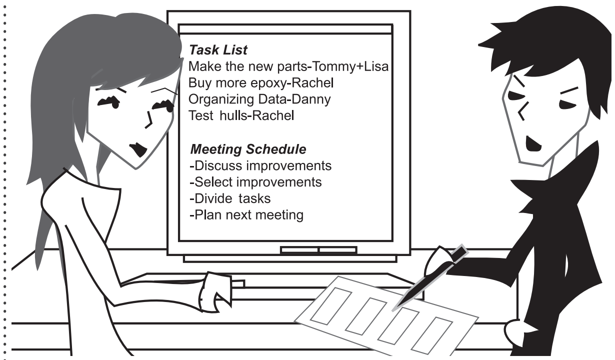
Initial ____________ Date __________

TASK 3.8 Redesign the Putt-Putt Boat

- Apply knowledge to implement a design change.

It's now time to redesign the putt-putt boat. Your team is free to change any aspects of the boat design; at least one change should affect the boat's performance. Following are some ideas about what you could change:

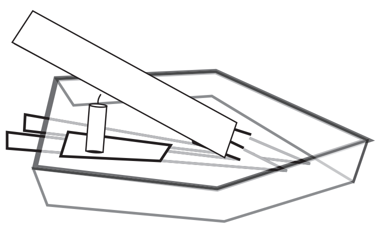
- Boiler (size, shape, material)
- Pipes (length, area, bends)
- Hull (material, shape)
- Appearance (color, decoration)
- Manufacturing (methods, machines)



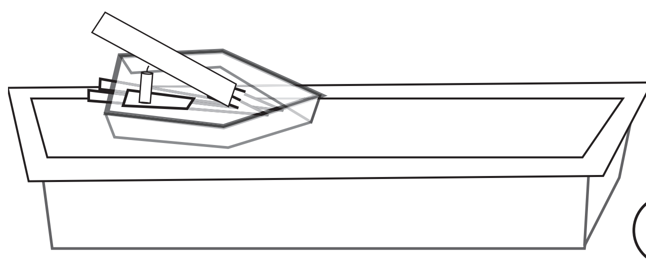
Teammates discuss their plans for redesign.

Getting Started

You will need the following:



Your putt-putt boat prototype



Boat test channel or basin

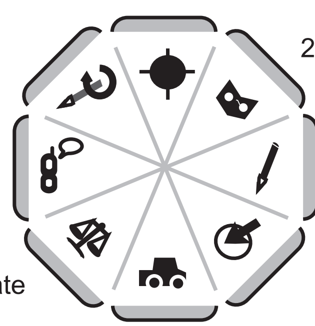
?

Other items as determined by project team

The Engineering Design Process

You will also need to review the engineering design process. Work with your teammates to go through each step.

On the next few pages, take notes of your team's progress each step of the way. These notes will be evaluated as an important part of your work on this project.



Define the Problem

Like most engineering problems, this one is only partly defined. Discuss with your teammates what you are trying to accomplish and how you'll know when you succeed. Make up one sentence that clearly defines what you are trying to do. List two or more criteria (requirements) for success. And list two or more constraints (limits) such as cost and/or materials.

Problem statmement:

Criteria:

1)

2)

3)

Constraints:

1)

2)

Research the Problem

Up to this point, this project has been about researching the problem. Think back to what you have learned and list one or two key points for each task.

3.1 Putt-Putt Boats and Patents

3.2 Manufacture a Putt-Putt Boat

3.3 Investigate Fluid Systems

3.4 Develop a Manufacturing Press

3.5 Investigate Heat Engines

3.6 The Rocket Effect

3.7 Investigate Resistance in Pipes

Develop Possible Solutions

1) Think about the customer

Discuss with your teammates who you think will purchase your new toy putt-putt boat. Will it be a parent or grandparent? Or might a child buy it for herself? How old should someone be before he uses a putt-putt boat? List your ideas about the possible customers and what each might be looking for below.

Possible Customer	What the Customer May Be Looking For

2) Brainstorm ideas

for improving the boat so that one or more of the customers would want to buy it. It's helpful if everyone comes up with one or two ideas first, then share ideas, and come up with more (or a combination of ideas) as a team. Make a list of your own ideas and sketches and insert it at this point in your *Engineer's Notebook.*

Choose the Best Solution

Discuss the pros and cons of each idea with your teammates. Look for ways of combining two or more ideas so that the result will be better than the ideas any one individual might come up with. If you have difficulty deciding, narrow it down to just two or three choices, and make a Pugh chart as described in Project 1. Sketch or describe this idea below, or on a separate sheet of paper inserted here.

Create a Prototype

Construct a functioning putt-putt boat based on the best design idea that your team selected. Decide on roles so that everyone contributes. For example, two people might start making the model, while someone makes up a poster about the product and why people should buy it. Someone else on your team might search the web for toy boats to see how much they cost and how they are marketed. You can use these things later to communicate your ideas.

Initial ______________ Date __________

Test and Evaluate

1) Test your team's putt-putt boat to see if it works. Troubleshoot any problems. Report the results below.

2) Ask people who might be potential customers if they would buy the boat, and if so, how much they would pay for it. Report the results below.

Communicate

Engineers usually have to present their ideas in a convincing manner to the manufacturer, or whoever will support the project financially. Communicating clearly and persuasively is as important as developing a good design, because if nobody wants it, even the best design will never be built.

Redesign

Most of the time engineers do not design entirely new products or processes. Instead they improve upon something that had been designed by someone else. This entire project is a re-design of something that was first patented more than 100 years ago. Even if your design turns out to be a "best seller," you can be sure that someday someone will redesign it so that it will be even better. That's the way technology improves over the years.

TASK 3.9 Present Your Patent

- Write a patent application to explain your design change.

Present your team's boat design in the form of a written patent application and oral presentation that demonstrates how your putt-putt boat performs, how it is different from previous patented versions, and why you think people will buy it. The patent application requires a scaled drawing labeled to demonstrate how your design should be constructed.

The engineer finally mails the patent application.

Drawing Exercise

- The following page provides guidelines for writing a patent application. These guidelines were adapted from guidelines found at the United States Patent and Trademark Office. Although intended as a final project to show what you have learned, these guidelines are similar to the requirements given for actual patent applications, which are intended to give inventors protection from people who might copy their creations.

- Because this is a team project, and you and your teammates will all be describing the same invention, feel free to share ideas. However, each of you should write your own patent application—in your own words—and make your own scale drawings.

- A very important part of the application will be to explain how the older putt-putt boat works, giving full credit to its inventor, Thomas Piot. Your description of how to build it should be clear enough for someone who has never seen a putt-putt boat to make a working model. And your description of how it works should show that you fully understand the scientific explanation for how the boat functions.

- After you describe how the older boat works, you will describe what improvement efforts worked and why. For this course, it is not essential that the prototype boat worked as expected. What is most important is that you describe what you attempted to do and what you found when you tested it.

- Before you start, look at the rubric on the last page of this task to see how your application will be evaluated.

Name ______________________________

Patent Application

Patent Application Guidelines

Name of Applicant: ______________________ Date Submitted: ______________

Title of Invention: ____
(The title should be as short as possible, no more than 500 characters.)

1) Abstract of Disclosure

Provide a one-paragraph overview of the invention in 150 words or less.

2) Declaration

A. Give Appropriate Credit
Describe your role and give appropriate credit to others on your team.

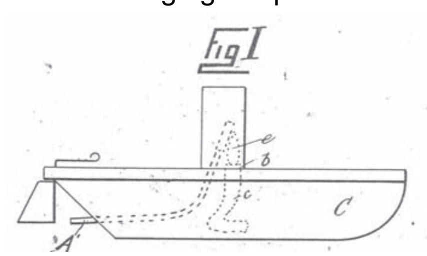
B. Oath of Originality
This is a statement that, to your knowledge, the part of the invention or improvement covered by the patent is original and does not copy an idea patented by anyone else. Conclude this section with your signature, including your first, middle, and last name.

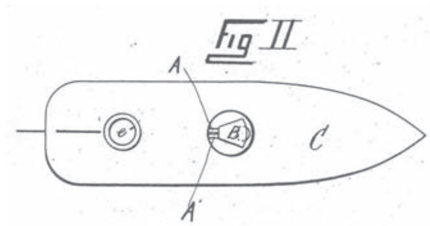
3) Specification

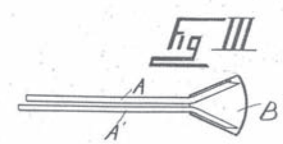
A. Describe Prior Work
Describe the basic putt-putt boat design and explain clearly how it works, using diagrams to show the engine cycle. Refer to previous patents and give credit to previous inventors.

B. Drawing and Explanation
Provide at least three orthographic views and one isometric view of your complete design. Drawings should be to scale. Explain how to build the device so that someone who has not seen one before could construct a working model. Illustrations should use numbers or letters to label parts mentioned in your explanation.

C. Design Improvement Claims
Describe how your modification affects the performance, use, or look of a previously patented or published boat design. (You must have at least one new design feature that is aimed at changing the performance of the boat.)







Illustrations are from Thomas Piot's 1891 putt-putt boat application, which was titled "Improvements in Steam Generators." Additional information on patent applications can be found at the website of the United States Patent and Trademark Office (www.uspto.gov).

Initial ____________ Date __________

Rubric for Patent Application

	⌖⌖⌖⌖	⌖⌖⌖	⌖⌖	⌖
Communication	Clearly explains scientific and engineering concepts. The report consistently uses correct terms, as well as good spelling and grammar. Report includes required drawings, background information, and modifications. All format specs met.	The general idea of the inventon is clear. However, there are some mistakes in writing, and some requirements are not met.	The idea of the invention is vague. The report includes several mistakes in writing and it is difficult to interpret the meaning. Few requirements are met.	Some attempt is made, but the report does not communicate how the putt-putt boat works or the idea for the new invention.
Knowledge and Understanding	The report shows a strong knowledge of the concepts and demonstrates a thorough understanding of concepts such as manufacturing, engineering design, fluid flow, resistance in pipes, heat engines, pressure, energy and forces, temperature differences, energy conduction, convection and radiation, and properties of liquids and gases.	The report shows a basic understanding of most concepts. However, there are missed opportunities to include important concepts related to the boat operation.	The report shows little knowledge of the concepts. Topics are touched upon but not expanded enough to show understanding.	The report indicates minimal effort to communicate understanding of how the boat works, or of engineering or scientific principles.
Application and Reasoning	The report demonstrates creative thinking in the application of scientific principles to solving a practical problem. The proposed invention is original and may affect the boat's performance.	Some creative thinking was used in the modification. However, the modifications are not based on sound application of scientific principles.	Suggested improvements concern appearance only. Scientific concepts have not been applied to the redesign.	The report shows very little understand-ing of the problem or reasoning about how to solve it.

Teacher Comments

Total Points: ______