NEXT ENGINEERS

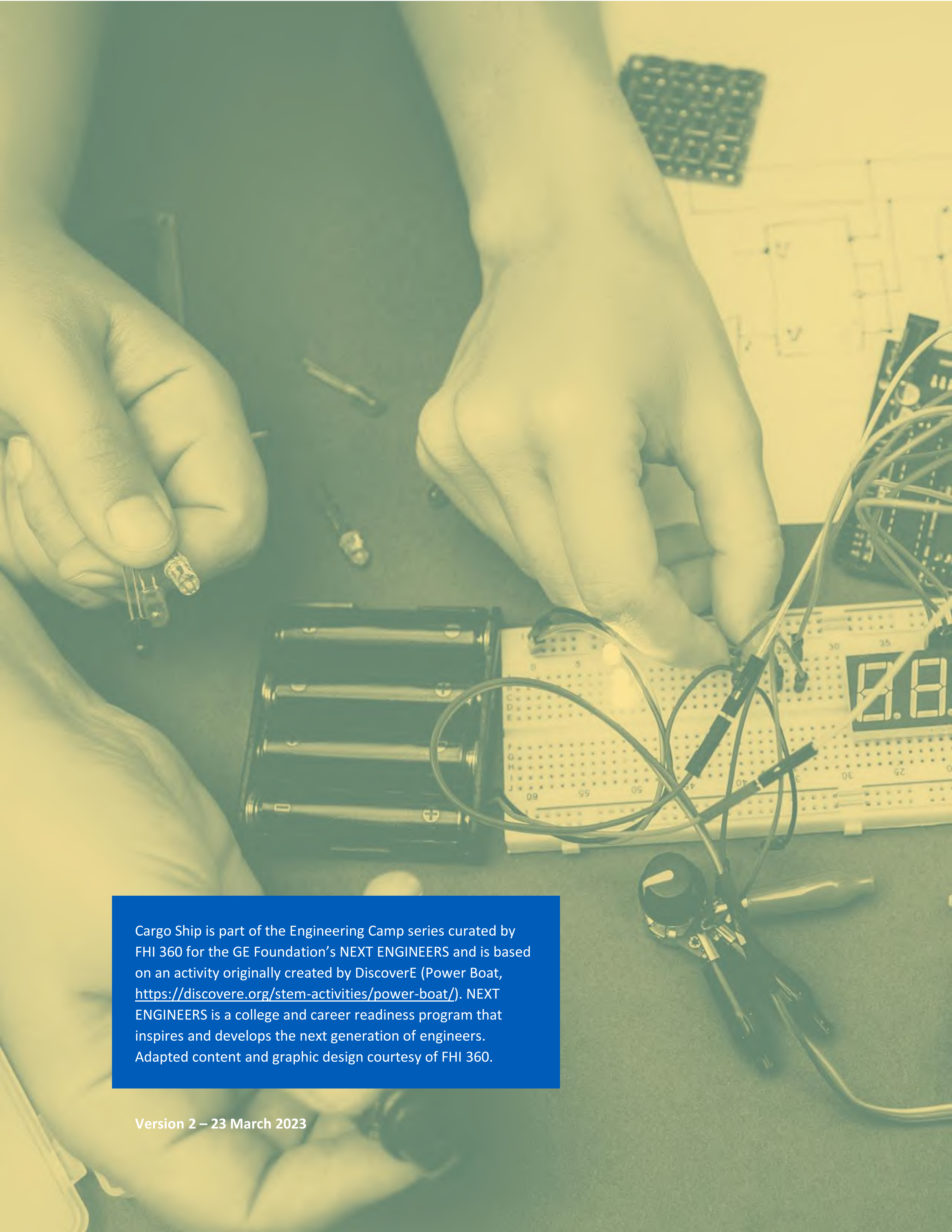
ENGINEERING CAMP

Difficulty Level 2

Cargo Ship

Mechanical Engineering
Hydrodynamic Engineering

GE Foundation



Cargo Ship is part of the Engineering Camp series curated by FHI 360 for the GE Foundation's NEXT ENGINEERS and is based on an activity originally created by DiscoverE (Power Boat, https://discovere.org/stem-activities/power-boat/). NEXT ENGINEERS is a college and career readiness program that inspires and develops the next generation of engineers. Adapted content and graphic design courtesy of FHI 360.

Version 2 – 23 March 2023

Cargo Ship

DESIGN CHALLENGE

Time	Cost	Group size (teams)	Activity type
4.5 hours	Medium	3 - 4 students	Design Challenge
Engineering Areas			
• Mechanical Engineering • Hydrodynamic Engineering	• Engineering Design Process		

Challenge Description

In this design challenge, students design and build their own elastic/rubber band-powered boat to carry a load of cargo a specific distance. This challenge provides an opportunity for students to explore the concepts of buoyancy, stability, energy conversion, and motion and forces.

About the Engineering Design Challenge

Students will design and build a boat able to transport a given mass over a specific distance powered only by elastic bands.

Success Criteria

- The boat must be stable in the water without assistance.
- The boat should cover a distance of at least 2 m (6.5 ft).
- The boat should carry a cargo of mass about 200 g (0.4 lbs) over this distance.
- The boat must stay afloat for the entire distance.

Constraints

- The boat may only be powered by elastic bands. No blowing, splashing, or pulling/pushing is allowed.

Materials

Students will need blank paper and pens/pencils to draw their designs.

The following materials will be required for a **group of 50 students** for this challenge and should form a central store of materials:

- About 100 paper or polystyrene cups (250 ml (8 oz) or larger)
- 10 sheets of 25 mm – 40 mm (1 in – 1.5 in) thick polystyrene (A3)
- About 100 plastic spoons
- A box of paper clips
- About 30 empty plastic soda bottles with lids (different shapes and sizes)
- An assortment of elastic bands of varying lengths and thickness (about 50)

STUDENT DISCOVERIES

Students will:

- Learn the about the Engineering Design Process
- Participate in a team-based learning experience
- Learn about buoyancy, potential energy and kinetic energy
- Have fun experiencing engineering

Materials, continued

- About 100 drinking straws
- About 100 wooden skewers
- About 200 popsicle sticks or tongue depressors
- 2 – 3 glue guns and about 10 glue sticks for the group to share (if it is not possible for each team to have its own)
- 2 – 3 craft, utility, or box cutter knives (if it is not possible for each team to have its own)
- A roll of cotton or string

The following materials are required **per team** for this activity:

- 5 elastic bands to start with (more are available in the central store)
- Waterproof or water-resistant tape (like duct tape or electrical tape)
- Scissors
- 1 copy of the Engineering Design Process Summary (below)
- 1 copy of the Student Worksheet (below)

The following additional materials will be required for **testing** the boats:

- A swimming pool or pond for final testing
- A large container of water (storage bin, shallow tub, kiddie pool) for interim testing if teams cannot build and test by the pool or pond
- A measuring tape
- A 200 g (0.4 lbs) mass (waterproof and with a recovery string in case of mishaps) – a Ziplock bag of sand or a 175 g (6 oz) tin of tuna would work well.

FACILITATOR NOTE

This challenge is best done with access to a swimming pool or pond. Make sure that all teams tie a piece of cotton or string to their boats so that they are able to retrieve them from the middle of the pool if necessary.

Time required

This design challenge will require approximately **4.5 hours** to complete. You may decide how to structure and organize this time.

Activity	Duration
1. Introduction	**15 min**
2. Identify the problem and gather information	**30 min**
3. Generate possible solutions	**45 min**
4. Create, test and redesign	**2.25 hours**
5. Present the solution and reflect	**45 min**

KEY WORDS

- Buoyancy
- Density
- Displacement
- Kinetic Energy
- Potential Energy
- Water resistance

Facilitation Principles

These documents contain helpful advice for anyone facilitating a Next Engineers engineering activity or challenge.

- **Working with Youth: Facilitation Tips** (https://www.nextengineers.org/resource/working-youth-facilitation-tips) is a handy summary of the key facilitation principles that facilitators need to keep in mind when facilitating any activity with students.

Facilitation Principles, continued

- **Ten Guidelines for Building New Engineers** (https://www.nextengineers.org/resource/ten-guidelines-building-new-engineers) gives ten practical guidelines on how to facilitate all Next Engineers engineering activities and challenges to build new engineers.

Facilitator Preparation

1. Read through this facilitation guide.
2. Collect the materials and secure access to a swimming pool or pond if possible.
3. Practice doing the activity yourself to identify where students may struggle. In particular, experiment with two main ways of storing elastic potential energy (twisting vs. stretching) and with how this energy can be used to rotate a paddlewheel or propeller.
4. Think how you could share your story and career journey in a relevant and personal way during the challenge. Find the following resources for how to tell your story on the Next Engineers website:
    a. **I'm an Engineer! Storytelling Worksheet** (https://www.nextengineers.org/resource/im-engineer-storytelling-worksheet)
    b. **I Work with Great Engineers! Storytelling Worksheet** (https://www.nextengineers.org/resource/i-work-great-engineers-storytelling-worksheet)
5. Practice asking and answering questions students may ask. See **Frequently Asked Student Questions** (https://www.nextengineers.org/resource/frequently-asked-student-questions).

Activity 1: Introduction

15 MIN

1. Welcome students to the activity and, if necessary, briefly introduce yourself, noting what kind of engineer or engineering student you are. Say a little about why you decided to pursue engineering and why you enjoy it.
2. Ask the group if anyone has ever travelled on a boat or ship before. What kind of vessel was it? How big was it? Where did it sail? How was it powered? What was the experience like?
3. From the various descriptions of different boats given, lead students to identify some of the basic characteristics that all boats share.
   a. They float.
   b. They stay upright (they're stabilized to keep from tipping over).
   c. They move via some source of energy, such as wind (captured by sails), fuel (to run a motor), or human (paddling with oars or paddles).
4. Ask the group if, in the age of airplanes and electric cars, boats are still important. What jobs do boats do?
5. Explain that even though boats can be very simple and may be the oldest vehicles we know of, they are still the lifeblood of the modern economy. Modern container ships, bulk goods ships, and tankers are responsible for almost 80% of all the goods that are shipped between countries. Without these ships, we would not have many of the foods and goods we enjoy.
6. Tell students that in this challenge they will work as teams of engineers to design and build a boat able to transport a load of cargo over a specific distance powered only by elastic or rubber bands.
7. Explain that the success criteria are:
   a. The boat must be stable in the water without assistance.
   b. The boat must cover a distance of at least 2 m (6.5 ft).
   c. The boat must carry a cargo of mass 200 g (0.4 lbs) over this distance.
   d. The boat must stay afloat for the entire distance.
8. Explain that the only constraint is that their boat may only be powered by elastic bands. No blowing, splashing, or pulling/pushing is allowed.
9. Note that nothing in the challenge defines how quickly their boats need to cover this distance.

TOP TIP

Remember that you can adjust the criteria and the constraints to suit the capability of the group. If you think carrying a load of about 200 g over 2 m will be too challenging, reduce the load, lessen the distance, or both. If you want to give your group more of a challenge, increase the load and/or distance.

You can also set intermediate criteria and incrementally challenge teams to meet the 2 m / 200 g goal or set up the activity as a competition.

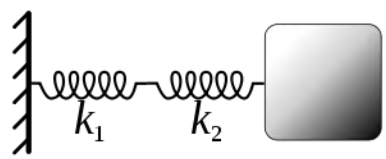
Activity 2: Identify the problem and gather information

30 MIN

1. Break the group up into their teams and give each team their materials (i.e., those not from the central materials store). Explain that during this part of the challenge, teams will have the opportunity to:
   a. Investigate the materials available to them in the materials store to determine their properties and to start thinking about how they could be used in the challenge.
   b. Think about some possible solutions (e.g., how the energy in a stretched elastic or rubber band could be used to power their boat).
   c. Use the Internet to search for design ideas that they might like to explore further or build on.
2. Remind students that in this challenge it is not sufficient to just build a boat that can float or even carry a load. The boat needs to be propelled a distance of at least 2 m (6.5 ft) without sinking or capsizing along the way. The boat does not have to travel in a straight line so long as it is 2 m (6.5 ft) away from where it started.
3. Explain, therefore, that besides creating a buoyant craft, students also need to find a way of moving it forward. The only source of energy available to them is the elastic potential energy stored in a deformed elastic or rubber band.
4. Ask teams to spend a few minutes thinking about the following questions:
   a. What can they do with their elastic bands to make them store energy (called **elastic potential energy**)? Students should realize that the bands need to be **deformed** and this can be done in one of two ways - by stretching them and by twisting them.
   b. In what ways might they be able to combine the energy stored in multiple elastic bands? If necessary, lead students to see that bands can be combined either into a bunch or connected end-to-end. Ask students which combination they think might be more effective.
   c. How can students convert the elastic potential energy in their deformed elastic bands into **kinetic energy** (moving energy) of their boat? Based on experience, most students will hit on using a paddlewheel or a propeller. As these spin and push against the water, the water pushes back in the opposite direction and the boat is propelled forward.
   d. Would it be better to design around a paddlewheel or a propeller? In this context, paddlewheels are easier to design, construct, and operate but they are also less efficient than propellers.
   e. How can students control the release of the energy from their elastic bands? A sudden or explosive release of energy will be unlikely to propel the boat the full distance. Most of the energy will be lost. Students will need to control the release of this energy so that it turns the paddlewheel or propeller for as long as possible. This will help the boat to cover the greatest possible distance.
   f. What kind of boat or hull design will be the most efficient? The lower a boat sits in the water or the wider and flatter the hull is, the more water resistance (or drag) the boat will experience, and the more energy will need to be expended to move it. However, boats with wider flatter hulls tend to be more stable.

CREATING TEAMS

- As far as possible, keep teams to no more than four students. Three students per team is ideal.
- Make sure there is a good mix of students in each team.
- Assign roles or allow teams to determine and designate their own roles. Some roles you can suggest teams consider are Project Lead, Research Lead, Design Lead, Resource Manager, and Finance Manager.



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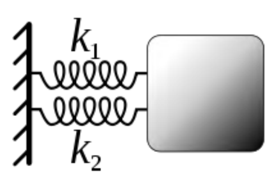

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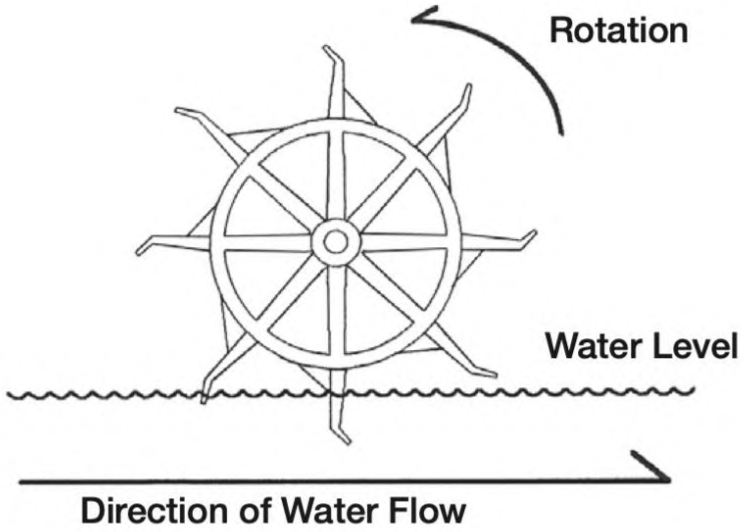

Diagram of a paddlewheel by Pentair is used under fair use
https://pentairaes.com/media/docs/2hp_paddlewheel_aerator_manual.pdf

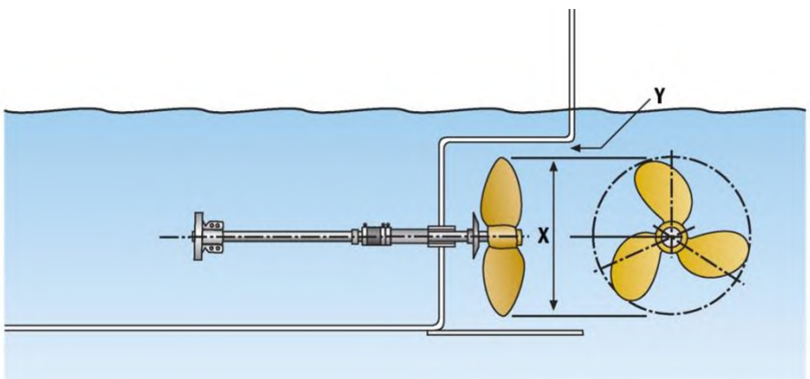

Diagram of a propeller by Beta Marine is used under fair use
https://betamarine.co.uk/inland-propellers/

5. Invite teams to investigate the materials in the materials store and to use the Internet to search for design ideas that might be helpful. As teams do this, have them consider the following questions:
   a. How heavy is 200 g (0.4 lbs) really? Have teams feel the weight of the load they will need to carry.
   b. How big does their boat need to be to be able to support this load?
   c. How far is 2 m (6.5 ft) really?
   d. How many paddlewheels or propellers might they need?
   e. How can they make sure that as much of the energy in the elastic band is converted to the forward motion of their boat? They need to remember that it does not matter how quickly their boats cover the distance.
   f. How can they make sure that their boat is stable and that the load does not fall out? Would it be better to position the cargo as close to the water as possible or higher up?
   g. Where would the best place for the load be – the front, middle, or back of the boat? How will this position affect the performance of the paddlewheel or propeller?

DID YOU KNOW?

Draft (draught in the U.K.) is the distance between the waterline and the bottom of a boat.

h. How can they make sure that their boats move in a straight line? Can they use fins? Does the length of their boat matter? Does the position of the propulsion system matter (in the front, at the back, or on the side)? What is the effect of having more than one paddlewheel or propeller?
i. What forces will try and stop their boat moving forward and how can these be reduced?

TIPS FOR MAKING CONNECTIONS

- **Give constructive feedback** to help students grow and improve.
- **Ask open-ended questions** to better understand what and how students are thinking.
- **Be respectful** by listening actively and responding openly and authentically. Give students your undivided attention and the respect you want them to give you.
- **Be honest** about what you know. Say if you don't know something. Encourage students to keep trying by sharing some of your own failures and the lessons you learned.

Activity 3: Design phase

45 MIN

1. It is now time for teams to start generating possible design solutions for their boats. Teams need to consider the following factors in their design.
   a. How to design and build a boat that is large and buoyant enough to support a load of 200 g (0.4 lbs).
   b. How to store the maximum amount of energy possible in an elastic band.
   c. How the stored elastic potential energy in the rubber band can best be converted into the kinetic energy of a propellor or a paddlewheel.
   d. What the best shape and position of the propellor or paddlewheel might be to maximize the force pushing the boat forward in a straight line.
   e. What the best shape of the hull might be to minimize the water resistance experienced by the boat.
   f. How to make sure that the boat travels straight.
   g. How to make sure that the boat does not capsize.
2. Encourage team members to make their own design sketches first and then to share their ideas with the rest of their team. Teams should use the process of sharing design ideas as a brainstorming exercise to arrive at the best ideas possible. Teams need to produce a combined set of final sketches that describe and explain how their boat will work and what materials they are going to need from the store. Remind teams that they will be able to change part or all of their design as they start testing and redesigning.
3. Many teams will understand how to design a paddlewheel with the materials provided. If necessary, you can point them in the direction of how to design a propeller by using the method described in the video *Build a Submarine* (3:21) (https://www.youtube.com/watch?v=DP4t99DTBmo).
4. Once each team has a sketch or set of sketches of the idea they want to prototype, have them compile a list of materials from the store that they require. Only when they have completed their sketches and list should you allow them to take materials from the store and start building.

Screenshot of a propeller made from the bottom of a plastic bottle from Build a Submarine available at https://commons.wikimedia.org/wiki/File:SpringsInParallel.svg

TIPS FOR WORKING WITH STUDENTS

- **Be prepared** by practicing the activity beforehand. Being prepared is the best start to leading confidently and having fun.
- **Facilitate like an engineer** by reflecting during and after each session. What worked? What could be improved? How could you do things differently next time?
- **Teamwork is critical** in engineering so encourage it among students. Make sure no one dominates and that everyone gets to play.
- **Give one instruction at a time** to keep a large group on task and doing what you need them to do.
- **Give regular time updates** to keep students on track.

Activity 4: Create, test, and redesign

2.25 HOURS

1. This is the part of the challenge when teams get to build, test, evaluate, and redesign all or part of their designs. Encourage teams to test early and often, and to test different aspects of their designs individually. Before teams do any testing, ask them to think about what aspects of their design they are testing, how they will record and evaluate the results of the test, and how they will use these results to inform further iterations.
2. As teams design and build, remind them to attach a piece of string to their boats so that they can easily be retrieved from the middle (or bottom) of the pool if necessary.
3. During this part of the challenge, it is important that you circulate constantly around the teams and ask them to describe and explain what they are doing, what tests they have done, what they have learned from these tests, and how this has informed or changed their designs.
4. As needed, you can challenge teams to think differently about their designs. For example, ask them if they have tried:
   a. Twisting multiple elastic bands together to increase the energy available per second.
   b. Stringing elastic bands together end-to-end so that they can have more twists.
   c. Cutting an elastic band to make a stretchy string.
   d. Changing the shape or size of their propellor or paddlewheel to make it push more water.
   e. Changing the position of their paddlewheel or propeller to make it push more water.
   f. Changing the number of paddlewheels or propellors their boat has.
   g. Changing the shape of their hull to reduce water resistance.
   h. Adding ballast to make their boat more stable.
   i. Slowing down the rate of rotation of any paddlewheel or propeller to extract the energy more efficiently from the elastic or rubber band.

Activity 5: Present the solution and reflect

45 MIN

1. It is now time for teams to put their boats through an official test. Each boat will get at most three attempts to complete the challenge. Should teams wish, they can adjust their designs between tests.
2. After the tests, bring the whole group together to discuss the following questions.
   a. How well was your boat able to meet all the criteria while working within the constraints?
   b. What features of your boat do you think are the most unique? What are you most proud of?
   c. How similar was your original design to the actual boat your team eventually built and tested?
   d. If you found you needed to make changes during the construction phase, what were the most significant changes you made and why did you decide to make these changes?
   e. Which boat that another team developed was the most effective or interesting to you? Why?
   f. If you could have used one additional material, what would you choose and why?
   g. Do you think that this challenge was more rewarding to do as a team, or would you have preferred to work alone on it? Why?
   h. What did you learn about engineering?
   i. How do you think the challenge relates to a career in engineering?

Extension

This activity can be extended in the following ways:

- Increase the distance that the boats need to travel.
- Require boats to carry a greater load.
- Impose a time restriction under which the boats need to travel the given distance.

Key Words

- **Buoyancy:** Also called upthrust or the buoyant force, buoyancy is the upward force that acts on an object when it is placed in a fluid which results from the difference in the pressure of the fluid at the bottom of the object and the pressure of the fluid at the top of the object. The magnitude of this force is equal to the weight of the fluid displaced by the object.
- **Density:** The mass per unit volume of an object or substance.
- **Elastic potential energy:** The energy stored in a deformed (stretched or twisted) object like an elastic band or spring. When the deforming force is released, this potential energy is released as the kinetic energy of the object regaining its normal shape and size.
- **Force:** A push or pull upon an object which causes the object to change its motion (accelerate or decelerate).
- **Kinetic energy:** A form of energy that an object has by virtue of its motion.
- **Potential energy:** The energy held by an object because of its position relative to other objects, stresses within itself, or its electric charge.

- **Constraints**: Limitations of materials, time, budget, size of team, etc.
- **Criteria**: Conditions that the design must satisfy to be considered successful.
- **Design**: a plan or drawing made before something is built to show and explain what it will look like, and how it will work.
- **Engineering Design Process (EDP)**: The iterative process of researching, designing, prototyping, and testing engineers use to solve problems and design solutions.
- **Engineering Habits of Mind (EHM)**: Six unique ways that engineers think.
- **Engineers**: Inventors and problem-solvers of the world. Twenty-five major specialties are recognized in engineering (have a look at the infographic at https://tryengineering.org/wp-content/uploads/18-EA-381-InfographicEngineering_R2-6.pdf).
- **Iteration**: The process of gradual improvement through repeated design, testing, and redesign.
- **Prototype**: A working model of the solution to be tested.

Challenge Background

Boats have been around since the earliest times of human civilization. The oldest boats found are between 7 000 and 10 000 years old.[1]

Even though they are such an old form of transportation, it can be argued that they are more important than ever, facilitating about 80% of all international trade.[2]
Some boats are extremely small and simple, like a hollowed-out log forming a wooden raft. Others are enormous and complex, like aircraft carriers and oil tankers. The largest and heaviest ship ever built was the oil tanker, Seawise Giant. It was over 450 m in length (that is almost half a kilometer or a third of a mile – almost as tall as the Sears Tower in Chicago) and weighed 564 650 tons (657 019 tons when fully loaded).

"Seawise Giant" by Nils Koch is released under CC BY SA 4.0 https://commons.wikimedia.org/wiki/File:%22Seawise_Giant%22_-_Singapore,_1990.jpg

No matter how big or small they are, all boats are surprisingly similar.

- They float (meaning they are buoyant). When you're floating in water, the water exerts an upward buoyant force that cancels out the downward force of gravity. The buoyant force on the object is equal to the weight of fluid displaced by that object. So, anything that is less dense than water – that is, lighter than the volume of water they displace – will float, while anything denser than water will sink. Today, engineers are designing even bigger, lighter ships that take advantage of buoyancy to use less fuel.
- They stay upright (they're stabilized to keep from tipping over, or capsizing). Many large ships use ballast to help keep them stabilized. Ballast is extra mass (usually in the form of water pumped into special tanks) that lowers the ship's center of gravity so that it does not roll over.
- They move via some source of energy, such as wind (captured by sails), fuel (to run a engine or motor), or human (paddling with oars or paddles). In the case of motors and oars, potential (stored) energy is converted into kinetic (moving) energy to turn a propellor or move an oar through the water.

Stored energy is called potential energy. It is not doing any work but can be converted into another form of energy that does do work. Holding an object off the ground gives it a kind of potential energy called gravitational potential energy. If you let go of the object, it will fall and could do work on your toe! The object's gravitational potential energy gets converted into the moving energy – also called kinetic energy – of the object when it is dropped.

The energy in petrol (gasoline) has chemical potential energy. If you set it on fire, that potential energy is converted into heat energy.

Elastic bands and springs, when they are stretched, compressed, or twisted, can store elastic potential energy. If you release them, this elastic potential energy is converted into kinetic energy as the elastic or spring assumes its normal shape.

[1] https://en.wikipedia.org/wiki/Boat
[2] https://en.wikipedia.org/wiki/Maritime_transport

Additional Resources

- ***Biggest Ships on Earth*** (10:53)
  https://www.youtube.com/watch?v=w0eqqmCHB18
- ***Types of hull design***
  https://www.boaterexam.com/boating-resources/boat-hull-types-designs.aspx
- ***How to Make a Rubber Band Powered Boat - Simple Elastic Band Paddle Boat*** (2:51)
  https://www.youtube.com/watch?v=LDNgV_RVPO0
- ***4 Amazing ideas for Fun or Simple Ways to Make a Boats*** (7:33)
  https://www.youtube.com/watch?v=qncATegYpeM
- ***How to make rubber band powered BOAT*** (4:20)
  https://www.youtube.com/watch?v=C9IRZ4QYXg8

References

This activity is based on **Power Boat** originally created by **DiscoverE** and available at: https://www.discovere.org/our-activities/single-activity-detail/Power%20Boat.

Visit the **DiscoverE** (https://www.discovere.org/) website for a host of other great engineering activities and resources.