Olin College of Engineering

Teacher's Guide for Vertical Wind Tunnels

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Would your students be excited about interacting with a roaring blast of wind?

In this workshop, students will learn about air resistance while building hovercrafts that sink, float, or fly out of the top of the wind tunnel! They'll practice being engineers by experimenting with weights and surface area to build their hovercrafts, as well as recording their variables, graphing their results, and making hypotheses (guesses).

Materials and Pre-Workshop Preparation

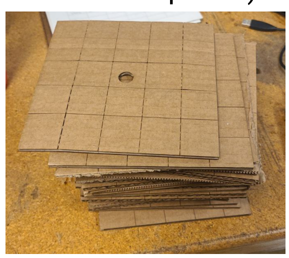
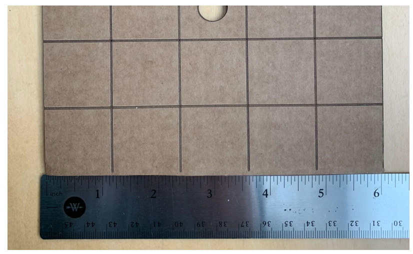
Disclaimer: We implemented this workshop with tools and materials that are not universally available (wind tunnel, laser cutting machine, etc.) and understand that not every educator will have the same access. In this Teacher's Guide, we suggested more accessible alternatives where applicable, but feel free to take inspiration from or personalize the lessons!

This workshop can be run independently

- **Suggested ages/grades:** Grades 3-5 but can be upgraded for grades (6-8)
- **Time required:** One hour
- **Required materials:**
    - **Wind Tunnel**

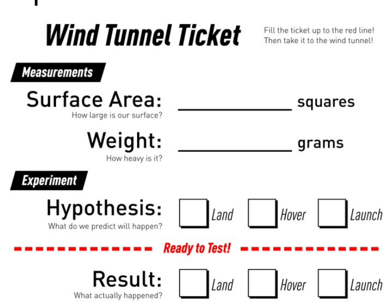
- Wind tunnel with ~10x10” internal area (see instructions for building a DIY wind tunnel)
- Pole (~¼” diameter, height should be same as wind tunnel)
- Mounting for the pole in the center of the wind tunnel (see this file for laser cutting)

- **Hovercraft construction**
  - 6x6in gridded sheets of cardboard (3 for each student). Laser cut 6” x 6” cardboard squares with grid lines etched on them and a hole in the middle using these cutsheets. We recommend having gridded sheets to make it easier for students to determine the surface area of their hovercraft by simply counting the number of squares. It also allows them to practice using units (documenting that their hovercraft uses *x* amount of squares).

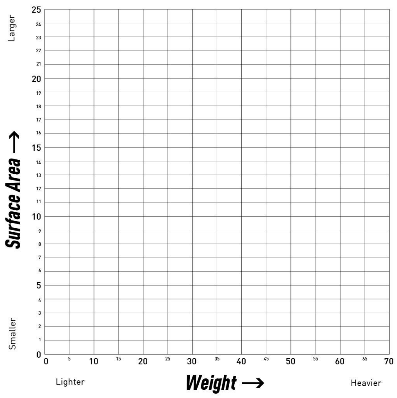
    - Alternatively to using a laser cutter, these cardboard sheets and the hole in the center can be cut out by hand using a box-cutter and the grid lines can be drawn on instead of etched.
    - An alternative to using cardboard is using cardstock with a gridded pattern or grid lines drawn on.
  - Use this STL file (linked) to 3D-print one bushing per student. The bushing is used to hold the washers in place.
  - 200 Washers w/ ½” inner diameter (must be larger than pole outer diameter). This will be a stock of weights that students can
  - 30 Zip ties
  - Scissors (one for each student)
  - Tape (for decorating)
  - Markers (for decorating)

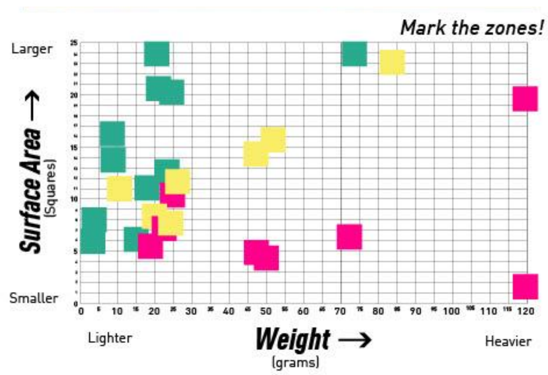
- **Documentation**
  - 3 printed copies of this Wind Tunnel ticket (linked) for each student.



  - Printed poster of weight-surface area graph (linked).

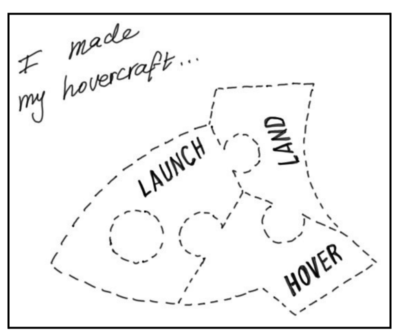
- The axes should be scaled according to how strong the wind produced from your wind tunnel is. As the graph fills up with data points throughout the workshop, students should be able to identify a line of points that represents hovercrafts that floated and regions of data points that represent hovercrafts that sank and flew out.





  - Colored sticky notes
  - Weight scale (reliable up to 0.01g, such as [this](#) one)
  - Pens
  - Signs for Construction, Weighing Station, Graphing, Testing

➢ **Optional Materials (highly recommended):**
  - Puzzle pieces to collect throughout the activity (one each for sink, hover, and fly)
    - This motivates students to try achieving all three outcomes with their designs as well helping them realize that there are multiple ways to succeed
    - Files for launch, land, hover puzzle pieces for laser cutting. We used 1/8" colored acrylic
    - Alternatively, the PDF files for the launch, land, hover puzzle shapes can be printed and cut out on standard paper for students to collect and stick into a 'logbook'.



➢ **Pre-workshop preparation:**
  - **Prepare a demo**

        - Educators should begin the activity with a demo of a hovercraft sinking, another hovering and another flying out. This will help set up the activity and introduce students to the three different outcomes (sink, hover and fly) that they are trying to achieve
        - This will involve figuring out surface area and weight combos for each of the three cases, and creating those hovercrafts to test in the wind tunnel and show how they behave. In presenting this demo, educators should note the differences between the three hovercrafts to get students thinking about the relationship between surface area, weight, and air resistance.
    - **Physical room set up**
        - We suggest moving tables and chairs into pods with a pod dedicated to each of the 4 workshop stations. You can also print signs for each of the stations to make the distinction between different zones clearer and also to space out the flow of kids to the wind tunnel to avoid restless waiting in line.
        - If possible, orient your stations in the room in this order to help with traffic flow: Construction → Surface Area Estimation → Weighing → Wind tunnel + graphing.
        - We suggest putting the wind tunnel in an open space as children are likely to want to gather around it.
    - **Usage of materials**
        - We suggest creating a "pack" of materials for each student before the workshop starts. Each "pack" should include 3 tickets, 3 sheets of cardboard, 1 bushing, a stack of weights, and a writing tool.

- ➢ **Prerequisite Knowledge:**
    - Having seen decimals before is helpful.

Learning Goals

- ➢ Become comfortable with plotting and understanding graphs
- ➢ Build intuition for how air resistance interacts with different shapes
- ➢ Make students feel like real engineers

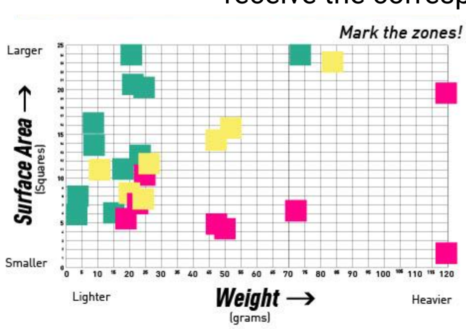
Connections to Common Core/Next Generation Science Standards

- Surface Area:
    - Geometry 6.G (Common Core)
    - Geometry 2.G (Common Core)
- Measurements and Data
    - 3.MD (Common Core)
- Forces

- K-PS2-1 (Next Gen Science)
    - K-PS2-2 (Next Gen Science)
- Prediction
    - 3-PS2-2 (Next Gen Science)
- Graphing
    - Geometry 5.G (Common Core)
    - Expressions and Equations 6.EE (Common Core)
    - K-2-ETS1-3 (Next Gen Science)

Activity Description

➢ **Goals and Outcomes**
- The goal of the activity is to build 2D hovercrafts that sink, hover and fly using the gridded cardboard. This is done through the following steps:
    - **Construction**: Students cut cardboard into a shape of their choice based on what they want the hovercraft to do (sink, hover, fly). They will also add weights to it
    - **Surface Area Estimation**: Students will then estimate the surface area of their hovercraft by counting squares. They will write this value on their ticket.
    - **Weighing**: Students will weigh their hovercraft on a scale and write this value down on their ticket
    - **Hypothesis**: Students will make a hypothesis about what their hovercraft will do and write this down on the ticket
    - **Wind tunnel**: Students will test out their hovercraft by placing it in the tunnel
    - **Graphing**: Students will add their result to the graph with a colored sticky note. The color of sticky will indicate whether the craft sank, flew or hovered. If it worked according to their hypothesis, students will receive the corresponding puzzle piece.




➢ **Guiding questions.** These questions can be helpful to ask when students are stuck and/or to help students connect this fun activity to the STEM content lurking beneath the surface.
- Why do you think this one sank/floated?
- What do you think would happen if you made the shape smaller?

- Why did you add that many weights?
- What might happen if we added more weights?
- What did you change from last time and why?

➢ **Intentional commentary.** Comments such as the following can help students build and recognize STEM-related mindsets and skills
- “Wow, that was a great iteration.”
- “Woah, that hovercraft caught the wind so well!”

Closing Questions and Student Reflections

➢ A closing activity is to have students look and interpret the resulting graph. At the end of the activity, it would be good to have all the students sit around the graph and understand the trends shown. A short handout shown below to fill out at the same time is a good activity to help them interpret the graph.

It would LAUNCH (FLY) if it was: ____________________

It would LAND (SINK) if it was: ____________________

It would HOVER if it was: ____________________

Extensions and Enrichments

- Whenever civil, mechanical, and structural engineers design structures such as towers, they take high winds and other lateral forces into account in order to create as much stability and strength as possible. Wind tunnel testing allows engineers to see what happens to different shapes and materials when subjected to the many kinds of wind any building will eventually have to withstand. Wind tunnel testing averts disasters such as the collapse of the Tacoma Narrows Bridge. Wind tunnel testing also enabled engineers to design a special shape for the Shanghai Towers. This shape reduced the wind load that typical rectangular skyscrapers have to bear and shaved millions of dollars off the price tag of materials. This is no small accomplishment: at over 2,000 feet tall, with 128 stories, the Shanghai Tower is often subjected to very powerful winds. It's not just the structure itself that has to survive, it's the different elements of the structure as well. Think about roofs ripping off of houses, or shingles getting torn off a house in a bad storm.
- Some online resources with activities:
    - Hovercraft activity
    - Icarus challenge
- Some ideas to use as expansions:
    - Doing a similar activity but using objects instead. Having students explore how different objects sink/float
    - Have students investigate how different shapes spin in the tunnel

Educational Design Principles Used to Create this Workshop

We are Olin College undergraduate engineering students who are practicing the engineering design cycle through the iterative design, development, testing, and improvement of STEM workshops for elementary school students. We began our "user research phase" by visiting our partner students. We engaged our partner students with standard engineering design challenges as a way to get to know what they like, what motivates them, their fine motor building skills, their teaming skills, etc. This informed our creation of custom workshops for our partner students, which we then improved and tailored to work with a second class of students.

Our work has also been guided by our learnings about some educational design theories/principles. In this section, we provide information about how these educational design theories/principles have been used in the design of our workshop. We hope this will help teachers understand our motivations and therefore be more able to modify our workshops to work better for their students in their unique educational context.

Throughout our design work, we practiced keeping a tight loop between our goals (i.e., our learning objectives related to STEM content, social-emotional learning, and the development of confidence and belonging in STEM) and the activities we designed to achieve these goals.

- Goal #1: **Help students think about math/science concepts like surface area and weight as they are creating their hovercraft**
- We used tickets described earlier to accomplish this goal. This part of the activity explicitly forced students to weigh their hovercrafts with a scale as well as count/estimate the squares of surface area in their hovercraft. The relationship between surface area and weight was the main math/science learning in our activity and the tickets helped emphasize that by having *surface area*, *weight*, and *hypothesis* sections that had to be filled out before testing in the wind tunnel. Specifically, the *hypothesis* section encouraged students to build intuition around thinking of surface area and weight as variables that they can tweak to affect how their hovercraft will behave in the tunnel. After testing in the wind tunnel, filling out the *result* section furthers this learning by either:
    - A. Confirming their hypothesis, which validates their intuition and creates a sense of accomplishment → "I hypothesized that it would sink, and it did!!"
    - B. Rejecting their hypothesis, which prompts questions around why it didn't behave the way they expected, and what they can change about the surface area and weight on their next iteration.

  Having tickets was also a way of incorporating Universal Design for Learning Guidelines (UDL) principles into our workshop by offering multiple ways for students to comprehend and follow the activity instructions [1]. Paper tickets provided additional scaffolding to the activity by serving as written guidelines to help students remember/understand what we had verbally explained at the beginning of the workshop. During the workshop, it also helped students remember the task that they are trying to accomplish by visually seeing which section of the ticket (representing a specific section of the activity) they're trying to complete next.

- Goal #2: **Emphasize the design, build, and iterate engineering process by giving students the opportunity to build, test and observe their hypotheses about their craft.** We did this by allowing students to build and test their hovercrafts. Testing with the vertical wind tunnel is an exciting way to give students agency over their learning: they must observe the performance of their own hand built craft, classify it into one of the 3 regimes, and compare it against their hypothesis.

  This aspect of our workshop is guided by discovery-based learning which encourages engagement and motivation and helps students better retain information that they're learning. This "self-directed learning" has the effect of "boost[ing] students' perceptions of their own capabilities" which works towards our overarching goal of empowering students to see themselves as engineers and feel a sense of belonging in STEM [2].

This is also guided by hands-on learning which gives students practice in problem solving and critical thinking. It also leaves them with a physical creation that they can take home to remember the activity they did and, hopefully, what they learned from it.

➢ Goal #3: **Get students comfortable with graphs: understanding axes & labels, plotting data points, interpreting collective data and trends.**

We did this by having students plot the ratio of surface area and weight on a large graph. This was in an effort to get students comfortable with plotting a point on a graph and to introduce them to making sense of a graph. Graphing is a concept that students often struggle with and this is to help build familiarity.

Please use these materials and tailor them to your students!

We encourage you to use these materials, editing and modifying them as appropriate for your students in your particular context! When you use, share, incorporate, or modify these materials, please keep the credit and license notice from the footer. We also humbly request that you email sarah.adams@olin.edu if you use these materials, as we are tracking their impact and how far they travel!

References

References used in the motivation and design of our workshop and/or extensions.

[1] "The UDL Guidelines." UDL, https://udlguidelines.cast.org/

[2] "Instruction vs. Discovery Learning." AACSB, https://www.aacsb.edu/insights/articles/2021/07/instruction-vs-discovery-learning-in-the-business-classroom