SeaGlide_TEAM	Fluid Dynamics Unit Plan	Lesson #2 - 3 (60 minutes each)

Description:
Students will take the role of a naval engineer. Recently, their supervisor challenged the department to design a submarine that was capable of maneuvering through the water, similar to a plane, and be piloted by a single person. As a reward, those that design this submarine will receive a large stipend and promotion. With their team, the student will design a submarine that can maintain its depth in the water, that can be piloted by a single person, and that can glide in the water similarly to an airplane.

Lesson #2: Thrust & Drag was adapted from TeachEngineering: May the Force Be with You: Thrust & TeachEngineering: May the Force Be with You: Drag

Students will be able to:
- Describe the effects of weight, lift, thrust, and drag on an airplane
- Compare and contrast the fluid characteristics of air and water
- Explain how Bernoulli's Principle allows for planes to fly and submarines to glide in water
- Design a submarine that functions similarly to an airplane using Bernoulli's Principle and fluid dynamics forces

Students will understand:
Through this unit plan, students will gain an understanding of two of the four forces affect an object flying through a liquid: lift, weight, thrust and drag. Students should already have an understanding of weight, but not necessarily of lift. In the first lesson, students discover Bernoulli's Principle and explore the effects that it has on an object's ability to be "lifted" by increased air pressure. In the second lesson, students discover the effects that object design have on its thrust and drag properties. Students are also learning to develop and argue solutions by using concepts learned from this lesson and applying them to a submarine's functionality.

Key Definitions & Concepts: [1]
- **Lift**: the resulting net upward force when the air pressure below a wing is greater than the air pressure above the wing
- **Bernoulli's Principle**: states that an increase in the speed of a fluid occurs simultaneously with a decrease in pressure or with a decrease in the fluid's potential energy.
- **Fluid**: any liquid or gas (generally any material that cannot sustain a tangential, or shearing, force when at rest) that undergoes a continuous change in shape when subjected to such a stress.
- **Thrust**: a reaction force described quantitatively by Newton's third law. When a system expels or accelerates mass in one direction, the accelerated mass will cause a force of equal magnitude but opposite direction on that system.
- **Drag**: air resistance; a force acting opposite to the relative motion of any object moving with respect to a surrounding fluid.

Standards: [Copied from: 2]

MS-PS2-2: Plan an investigation to provide evidence that the change in an object's motion depends on the sum of the forces on the object and the mass of the object.

- Students will be using a Fluid Dynamics simulator to test how wing shape affects lift capability. The speed of air directly connects to Bernoulli's Principle, allowing it to generate a force greater than that of gravity and lifting an object. Students are directly investigating and discovering this through the exploration activities.
- Students will be performing experiments to test how an object's shape and force affects the fluid dynamics properties. The experiments look at how fluid movement impacts the force of thrust and object shape affects its drag, or air resistance. Students are directly investigating and discovering this through the exploration activities.

MS-ETS1-2: Evaluate competing design solutions using a systematic process to determine how well they meet the criteria and constraints of the problem.

- Through the elaboration of this lesson, students design a submarine that meets the demands of the students' supervisor. Students communicate the science behind their submarine's design in the form of a proposal and an email, demonstrate their knowledge of the material and defend the effectiveness of their designed solution.

Background Information

Prior Knowledge:

- Gravity is the driving force for an object's weight
- All objects are subject to gravity
- Density is the amount of mass occupying a given volume or space
- Buoyancy is a measure of how much force is required for an object to be suspended inside a liquid

Science Practices: [Copied from: 3]	Core Ideas: [Copied from: 4]	Cross Cutting Concepts: [Copied from: 5]
• Planning & Carrying Out Investigation • Engaging in Argument from Evidence	• Forces & Motion • Developing Possible Solutions	• Stability & Change

Possible Preconceptions/Misconceptions: Lesson #1: Lift & Weight

Students may experience difficulty understanding that fast moving wind exhibits low pressure while slow moving wind exhibits high pressure. Students will assume that fast-moving particles have high amounts of kinetic energy, causing it to exhibit greater pressure when interacting with an object. However, because we are discussing airplanes and submarines, the fluid particles are constantly and excessively surrounding the object. This allows for fluid particles that are fast-moving to move away from the object, creating an absence of particles. Whereas with slow-moving particles, they quickly accumulate together. This can be explained because of the process of diffusion. Recall that areas containing higher concentrations of molecules will move to areas of lower concentrations of molecules. Hence, the fluid particles that are slow-moving and under high pressure will want to move to the absent area created by the fast-moving fluid particles. This process causes an object to be "lifted."

Possible Preconceptions/Misconceptions: Lesson #2: Thrust & Drag
Students will experience difficulty understanding that thrust is a direct result of Newton's third law. The object is moving forward because the surrounding fluid molecules are exerting an equal force. This force is pushing the object forward. Once students grasp this concept, they will have a much easier time continuing through the lesson.

Lesson Plan - 5E(+) Model

Engage: Lesson #1: Lift & Weight [6]
The instructor will distribute the worksheet *Air is a Fluid* and show students the complementary video *Air is a Fluid*. This video introduces students to the topic of air fluidity and airplane flight, which connects to submarine movement in water. Hence, students will discover that air behaves like a fluid through completing this activity. Students should work individually to answer the questions on the worksheet while watching the video. The instructor should take up to 5 minutes to correct any misconceptions as necessary by reviewing the students' responses as a whole class. This activity should take up to 10 minutes.

Engage: Lesson #2: Thrust & Drag
The instructor will begin the lesson by distributing a pre-quiz to test students' recollection of the previous lesson. The pre-quiz prompts students to explain Bernoulli's Principle in their own words and relate Bernoulli's Principle to buoyancy. The quiz also features a bonus question that is meant to challenge students and gauge their prior knowledge of aerodynamics. The students should be given 5 minutes to complete and turn-in the pre-quiz for grading.

Explore: Lesson #1: Lift & Weight
Part I: Introduction
The instructor will break up the students into groups of 3 and distribute the *Fluid Dynamics* worksheet. The instructor will also explain the directions of the worksheet and guide students to the simulation. It is recommended to have one computer or tablet accessible for each group. This preparatory step should take less than 5 minutes.

Part II: *Benchmark Lesson:* Fluid Dynamics Simulation [7]
Students will work on the *Fluid Dynamics Simulation* and answer the questions on the complimentary worksheet. Working in groups of 2 to 3, students will learn about the movement of air. Students will be engaged in a simulation-based activity, where they can adjust variables and explore air movement in a controlled setting. Through the simulations and associated worksheet, students will be identifying and analyzing patterns between the movement of air molecules and the design of a shape. This allows for students to choose how they want to observe the data, as well as come up with and test hypotheses. This activity is designed so that students take initiative in gaining understanding of fluid movement through active investigation and observation of how wing shape can both impact and benefit from Bernoulli's Principle. This activity should take up to 15 minutes to complete.

Part III: *Investigation Lesson:* Bernoulli's Principle [8]
Students will watch the video *Bernoulli's Principle: Demonstrated*, which connects the relationship between pressure and velocity to their observations from the Fluid Dynamics simulation. During the video, students should work on answering the questions on the *Bernoulli's Principle* half sheet. Upon completion, the instructor will engage the class in an open discussion to correct any misconceptions based on the students' responses. The instructor will then lead the students through an open discussion (reference the *Instructor's Guide* in the attachment section) to connect the idea that Bernoulli's Principle is similar to that of buoyancy. This will help students connect airplane flight to a submarine in water. This activity and discussion should take up to 10 minutes.

Explore: Lesson #2: Thrust & Drag
Part I: Introduction [9]
The instructor will begin by leading the students to understanding *What is thrust?* (Reference the *Instructor's Guide* in the attachment section for details). It is highly recommended that the instructor write down key details (and prompt students to take notes) of this discussion on the board for students to reference during the activity (i.e. definition of thrust, illustration of the forces of flight, Newton's Third Law of Motion).

The instructor will then lead the students to understanding *What is drag?* (Reference the *Instructor's Guide* in the attachment section for details). It is highly recommended that the instructor write down key details (and prompt students to take notes) of this discussion on the board for students to reference during the activity (i.e. definition of drag, definition of cross-sectional area, definition of streamlined).

These discussions should last no longer than a total of 10 minutes.

Be sure to leave these details on the board throughout the thrust activity of the exploration

Part II: *Benchmark Lesson:* Thrust versus Drag [9], [10]
After the discussion, students will complete the *You're a Pushover* activity and the corresponding worksheet in parts. In this activity, students will be engaged through active learning to discover the third force acting on airplanes: thrust. Students should work individually to complete the worksheet. The instructor will be guiding students through the activity, prompting them to reflect on their experiences throughout the activity to answer questions.

In part one of the worksheet, students will consider the actions and reactions of forces when they push on a wall. It should take students a couple minutes to answer the questions; however, the instructor should emphasize the first question, and prompt the students to think about how Newton's Third Law of Motion applies. Part one should take less than 5 minutes.

In part two of the worksheet, students will consider the forces acting and reacting of the forces on a moving balloon. The associated questions prompt students to make connections to Newton's Third Law of Motion. Expect students to incorrectly answer the first question during part two of the *You're a Pushover* activity, and guide them to understand that the balloon is moving forward because the surrounding air molecules are exerting an equal force. As air molecules are exiting the balloon, those molecules are exerting an equal force on the surface of the balloon. This process propels the balloon forward. Note: the balloon is not propelling itself forward. Rather, the air is exerting a force on the balloon; that force is the active propeller for the balloon's movement. Part two should take about 5 minutes to complete.

In part three of the worksheet, students will extend their understanding of Newton's Third Law of Motion into mathematics. They will utilize a given formula to calculate and determine the missing variable values. It is recommended that the instructor complete the example with the whole class on the board and allow 5 minutes for the students to complete the table.

In total, the *You're a Pushover* activity should take up to 15 minutes to complete.

Students will then complete the *What a Drag* activity in groups of three. In this activity, students will be exploring the fourth and final force acting on airplanes: drag. Prior to the experiment, the instructor must assign each group a specific weight (10 grams, 20 grams, 30 grams, or 40 grams). It is recommended that these designations are distributed as evenly as possible between the groups. The instructor will then guide students to complete the experiment-based activity, where students are testing different paper shapes to see how drag is affected by the shape and/or weight of an object. Students will be engaged through inquiry and actively learning by writing down their observations, making inferences, and answering questions associated with the lesson topic. The students will be instructed to put their shapes together and weigh them up to their group's designated weight. The students will use clay to adjust the weight of their shapes. While the students are setting up their experiments, it is recommended that the instructor clear the board of all information from the thrust versus drag discussion and from the thrust activity. The student groups should be able to complete through number 7 of the experiment without needed help. For question 8, prompt the students to write out (on the classroom's board) their calculated average fall times for the large cube and label their calculation by their group number and weight designation. The students will need to take an average of those averages to fill in the chart for number 8 of the experiment. This experiment should take up to 15 minutes to complete.

Once the class has finished through the experiment, the instructor will prompt the class to work individually on the analysis questions and the challenge question. This analysis prompts the students to utilize the class data to make inferences and draw evidence-based conclusions. The challenge question describes the formula for calculating drag based on given variables and prompts the students to completing a calculation. Allow the students up to 10 minutes to answer the analysis questions and the challenge question, and to turn in their lab report. It is recommended to collect all of the *What a Drag!* worksheets for grading.

In total, the *What a Drag!* activity should take up to 25 minutes to complete.

Part III: *Investigation Lesson:* Submarine Design Revision

The instructor will distribute the letter from the *Director of the Engineering Division* and the *Submarine Design Revision* worksheet. Through this activity, students must refer back to their submarine designs and proposals from the prior lesson on thrust and drag. Students will be working individually to revise their submarine designs with the knowledge they learned about thrust and drag from this lesson. Afterward, they must write to their captain about their design revision, explaining how thrust and drag will be reduced, in the format of an email. This gives the students an additional opportunity to verbalize their understanding of the unit as a whole. Allow the students any remaining class time to begin working on their revisions. Students should return their revision email during the start of the next class meeting for grading.

Explain:

Throughout the exploration of this lesson, students will engage in discussions and activities that seek to discover their understanding of the topic at-hand as it relates to fluid dynamics. Instructors should informally ask questions to promote thoughtful discussion that is designed to aid in addressing any questions or concerns that some students may have. Students are expected to formalize their answers throughout the entirety of the lesson via the worksheets, the activities and the exit ticket.

Elaborate: Lesson #1: Lift & Weight

Students will take the role of a naval engineer through the *Submarine Design: Proposal* activity sheet. Through this activity, students will write a proposal to their immediate supervisor that provides a drawing of their uniquely designed submarine and an explanation that includes details about their submarine's functionality and success capability when compared to an airplane. The students must meet the requirements given on the *Submarine Design: Proposal* activity sheet and explain how the submarine meets said requirements. The activity requires students to think critically about how the forces behind airplane flight relates to how a submarine functions underwater. They also must apply their prior knowledge of buoyancy to how airplanes maneuver in a fluid. Depending on the remaining class time, it is recommended to let the students begin individually working on this activity **after** the 5 minute exit ticket is completed. Students should return their proposal for grading at the start of the next class meeting.

Elaborate: Lesson #2: Thrust & Drag

Students will take the role of a naval engineer through the *Submarine Design: Revision* activity sheet. Through this activity, students will individually write an email to their immediate supervisor that provides a drawing of their revised submarine and an explanation that includes details about their submarine's functionality and success capability when considering fluid dynamics. The students must meet the requirements given on the *Submarine Design: Revision* activity sheet and explain how the submarine meets said requirements. The activity requires students to think critically about how fluid dynamics relates to an airplane's functionality and to use this analysis as a means of revising their submarine design from Lesson #1: Lift & Weight.

Evaluate:

Students will complete an exit ticket relevant to Lesson #1: Lift & Weight, prompting them to answer questions pertaining to Bernoulli's Principle and how it connects to buoyancy. This allows the instructor to gauge how well students are connecting the idea of airplane flight to that of a submarine, which is an idea that is important for their SeaGlide design. The exit ticket should take up to 5 minutes and should be completed after the exploration, but before the *Submarine Design: Proposal* activity.

Throughout the entirety of this unit, there are both formal and informal evaluations. The informal evaluations occur throughout the exploration portions via leading and open-ended questioning, as well as through the open class discussions. The informal evaluations will allow for the teacher to gauge surface-level understanding of the students. By surveying the students during completion of the worksheets and activities, teachers will be able to hear and to address any misconceptions or misunderstandings as necessary. The formal evaluations of this unit are the compilation of the worksheets, the *Submarine Design* activity and revision, and the exit ticket.

Enrich:

This lesson can be extended to an aeronautical engineering class. The concepts of fluid dynamics can be expanded on, as well as the physics background supporting it. Fluid dynamics is a unique phenomenon that relies heavily on the logical and mathematical properties described in physics. Oftentimes, these mathematical properties require advanced knowledge of the Calculus series, like derivatives. Because this lesson makes use of a simulation that allows for custom shape design, engineering design can be focused on and discussed in detail.

All associated documents are attached below

Reference *Annotated Bibliography* on the very last page of this packet

Worksheets for Lesson #1: Lift & Weight

Instructor's Guide [9]

Background Information:

The four forces of flight are *lift, weight, thrust* and *drag*. Lift and weight are opposing forces, which means they act in opposite directions. Likewise, thrust and drag are opposing forces. All airplanes are subject to these four forces. Thrust is what moves the aircraft forward and also creates air speed, which is part of what creates lift. Lift is what pushes the airplane up, while gravity is the force that pulls the airplane down. Drag is a force that acts against thrust and slows the airplane down. When the thrust is greater than the drag, the plane moves forward. When weight is greater than lift, the plane descends.

The wings are the parts of an airplane that create lift. If we look at a wing from the side, we can see that it is shaped somewhat like a teardrop, with a thick, rounded front end and a thin, pointed back end. The curve on the top of the wing is longer than the bottom, which means that the air traveling across the top of the wing has to move faster to keep up with the air moving under the wing. According to Bernoulli's principle, there must be less pressure on the top of the wing than on the bottom of the wing.

The result of this difference in air pressure is a net upward force called *lift*. The air moving under the wing moves slower and exerts more pressure/force on the wing than does the air moving over the wing. Since there is more force under the wing than above it, the net result is that the wing rises up; hence, lift. This principle forms the basis of winged flight.

Flaps are present on the front and back edges of wings. During takeoff and landing, pilots extend the flaps on the back edge of the wing. The flaps increase the *camber* (curve) of the wing, which maintains the lift at slower speeds. After takeoff, the pilot retracts the flaps for normal flight. Engineers use wind tunnels and computers to continuously test wing designs to determine their lift.

Discussion Topics & Expectations:

In the *Exploration: Part 3: Investigation Lesson*, the class will engage in a discussion on what Bernoulli's Principle is and how it connects to buoyancy. When guiding the discussion, the instructor should ask the following probing questions:

- Based on the video, how would you describe Bernoulli's Principle?
    - Expectation: Bernoulli's Principles states that the faster a fluid moves, the lower its pressure. But, the slower a fluid moves, the greater its pressure.
- How does this allow an airplane to fly?
    - Expectation: Because the wing is curved, it slows down the air. This causes high pressure underneath the wing and lower pressure above the wing. This then causes the wind to lift the plane up until the pressure cannot lift the plane any higher.
- This sounds very similar to another idea we learned previously, where the pressure underneath an object allows it to no longer sink but instead remain suspended in a fluid. What is this called?
    - Expectation: Buoyancy.
- Theoretically, if air and water are both fluids, what can we assume about an underwater object, like a submarine?
    - Expectation: It would experience the same forces that an airplane experiences in air.

Name:____ Date:_________________

Air is a Fluid

1. What do you predict is going to happen when the beakers are inserted into the tank?

2. Describe the demonstration. What is happening?

3. Does the result support or reject your hypothesis? Explain your answer.

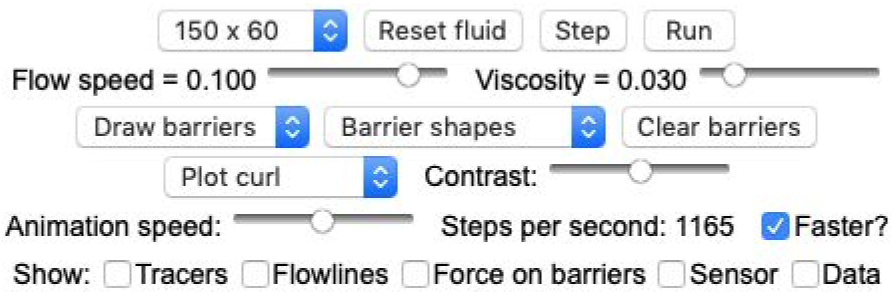
4. Using your observations from the video, explain how both air and water are fluids.

Name:_______________________________________ Date:______________

Fluid Dynamics [7]

Directions:

Go to the Fluid Dynamics Simulator from Weber State University. Once there, edit the settings to be the following:



Go through the worksheet and answer the questions based on the required settings. After each question, “Pause” the simulation and “Reset fluid.”

Questions:

1. Click “Barrier shapes” and select “Long line.” Check the “Tracers” and “Force on barriers” buttons.
    a. What do you notice about the movement of air?
    b. Is the air movement constant or fluctuating?
2. Click “Barrier shapes” and select “Diagonal.” Check the “Tracers” and “Force on barriers” buttons.
    a. What do you notice about the movement of air?
    b. Is there air movement fluctuating more or less than before from Question 1b?

3. Click “Barrier shapes” and select “Shallow diagonal.” Check the “Tracers” and “Force on barriers” buttons.
    a. What do you notice about the movement of air?

    b. Is the air movement fluctuating or remaining constant?

4. Click “Barrier shapes” and select “Airfoil.” Check the “Tracers” and “Force on barriers” buttons.
    a. What does this shape remind you of?

    b. What do you notice about the movement of air?

Name:____ Date:________________

Bernoulli's Principle [8]

1. State and explain Bernoulli's Principle.

2. What does the color red represent?

3. What does the color blue represent?

4. When the air interacts with the ball, what happens? Detail your response.

Name:____ Date:________________

Bernoulli's Principle [8]

1. State and explain Bernoulli's Principle.

2. What does the color red represent?

3. What does the color blue represent?

4. When the air interacts with the ball, what happens? Detail your response.

Name:____ Date:________________

Submarine Design Proposal

Prompt:

You are a naval engineer. Recently, your supervisor challenged your department to design a submarine that was capable of maneuvering through the water, similar to a plane, and to be piloted by a single person. As a reward, those that design this submarine will receive a large stipend and promotion. With your team, design this submarine, allowing it maintain its depth in the water.

Design Requirements:

- Can remain at a constant depth by adjusting accordingly via wing design
- One person must be able to man the submarine
- Must be based off of an airplane

Proposal Requirements:

- Detailed drawing of the design
- Explanation of the design including:
    - How the submarine meets the design requirements
    - How the submarine is comparable to an airplane
- Scientific evidence to support explanations

Rubric:

Points	0 - 1	2 - 3	4 - 5
Design	The submarine does not meet any of the design requirements **and** does not share any of the characteristics with an airplane	The submarine meets some of the design requirements **AND/OR** shares some of the characteristics with an airplane.	The submarine meets all design requirements and shares the characteristics of an airplane to move through the water.
Explanation	The proposal offers no factual scientific evidence to support the design requirements.	The proposal offers some factual scientific evidence to support the design requirements.	The proposal offers factual scientific evidence to support how it will meet the design requirements.
Grammar/ Spelling	The proposal has many grammatical/spelling mistakes that negatively impacts the proposal.	The proposal has some grammatical/spelling mistakes that negatively impacts the proposal.	The proposal has little to no grammatical/spelling mistakes that negatively impacts the proposal.
Creativity (**BONUS**)	The design has little to no unique designs or decals, or does not combine an airplane to the submarine.	The design is unique, contains decals, and combines the best parts of an airplane to a submarine.	

Name:____ Date:________________

Submarine Design Proposal: Grade

Comments:

Design:__________

Explanation:__________

Grammar/Spelling:__________

Creativity (**BONUS**):__________

TOTAL:_________

Name:____ Date:________________

Submarine Design Proposal: Grade

Comments:

Design:__________

Explanation:__________

Grammar/Spelling:__________

Creativity (**BONUS**):__________

TOTAL:_________

Name:____ Date:_________________

Exit Ticket

1. In your own words, explain Bernoulli's Principle. Be sure to include the following ideas: high pressure, low pressure and fluid velocity.

2. Connect the idea of Bernoulli's Principle to Buoyancy.

Name:____ Date:_________________

Exit Ticket

1. In your own words, explain Bernoulli's Principle. Be sure to include the following ideas: high pressure, low pressure and fluid velocity.

2. Connect the idea of Bernoulli's Principle to Buoyancy.

Worksheets for Lesson #2: Thrust & Drag

Instructor's Guide [10]

What is Thrust?

Imagine you are floating in space holding a huge bowling ball. If you were to throw the bowling ball in one direction, you would move in the opposite direction. The same is true with jets, rockets and propellers. However, jets, rockets and propellers *throw* air or another gas. This movement of gas (air) is called thrust: the force that causes an airplane to move forwards. Not only does thrust push the airplane forwards, but that movement also allows the wings to create lift. Remember from the lesson prior, Lesson #2, we learned that lift is created when air moves faster over the top of the wing. Figure 1 illustrates the four forces of flight.

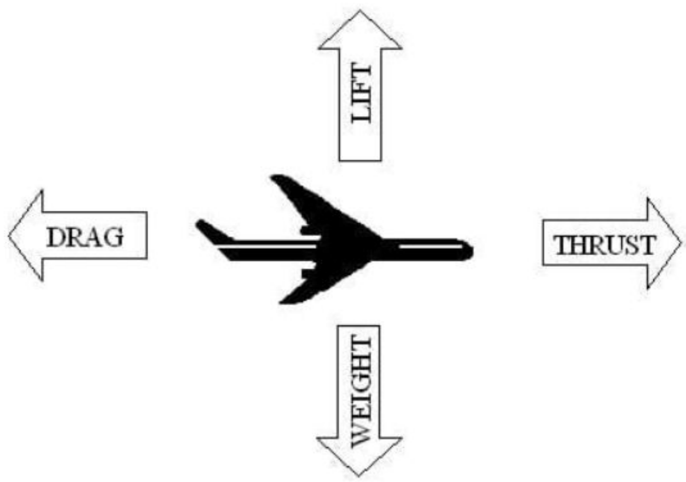


Figure 1. The four forces of flight: lift, weight, thrust and drag.

Airplane thrust is created by three principle mechanisms: propellers, jet engines and rocket engines. All three engine types take advantage of the physical behaviors described by Newton's third law of motion, which states that for every action, there is an equal and opposite reaction. All airplane engines push air backwards. Newton's third law predicts that an airplane will move forward with an equal and opposite force. This reaction force is known as thrust.

What is Drag?

The type of drag that we are most familiar with is *form drag*. This is the resistance (or pushing) sensation you feel when you walk into the wind. It is caused by all of the air molecules running into your body. Form drag is dependant on the shape of an object, the cross-sectional area of an object, and the speed of an object. In the case of drag, the cross-sectional area is the area of an object that is facing the direction of its movement. For example, if you hold your hand out of a car's window with your palm down, you do not feel much push from the wind. If you turn your hand right, so that your palm faces the direction the car is moving, the wind will push your hand back much harder. This increase in resistance (push) is due to the increase of the cross sectional area of your hand, not the overall size of your hand.

Engineers often consider drag in designing things like airplanes and cars. They try to design these things as *streamlined* as possible. Streamlined means that the shape of the object, airplane or car can reduce the drag of the object (reduce the force opposing forward motion). This is why airplanes have rounded nose cones and why they pull up their landing gear after liftoff (to remove the wheels from being in the way and creating unnecessary drag). In this activity, we will demonstrate how shape and size affect the drag on something as simple as a piece of paper.

Name: ____ Date: ____________________

Pre-Quiz

1. What is Bernoulli's Principle? Explain it in terms of air as a fluid.

2. The formula for determining Buoyant Force is B = d x g x V. If we apply this to an airplane and assume that volume displaced (v) is negligible, what force does this leave?

BONUS Draw and label a picture of a plane with arrows indicating the following forces: lift, weight, drag, and thrust.

Name: ____ Date: ____________________

Pre-Quiz

1. What is Bernoulli's Principle? Explain it in terms of air as a fluid.

2. The formula for determining Buoyant Force is B = d x g x V. If we apply this to an airplane and assume that volume displaced (v) is negligible, what force does this leave?

BONUS Draw and label a picture of a plane with arrows indicating the following forces: lift, weight, drag, and thrust.

Name: ____ Date: ______________________

You’re a Pushover Worksheet [10]

Part 1: You’re a Pushover

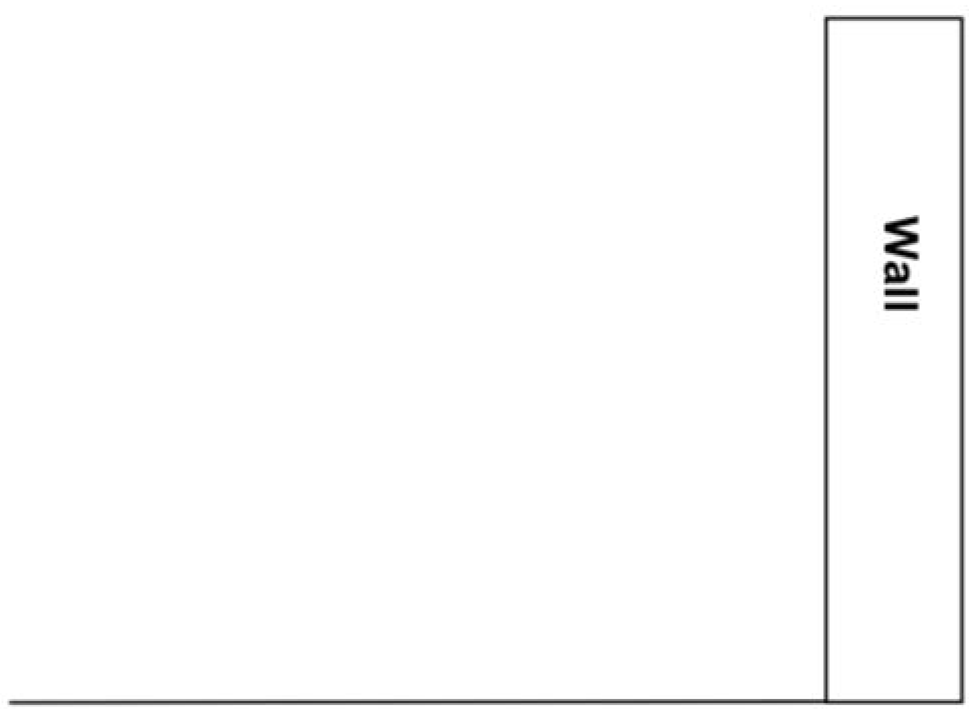
1. What does a wall do when you push on it?

On the diagram below:

2. Draw yourself pushing on the wall.

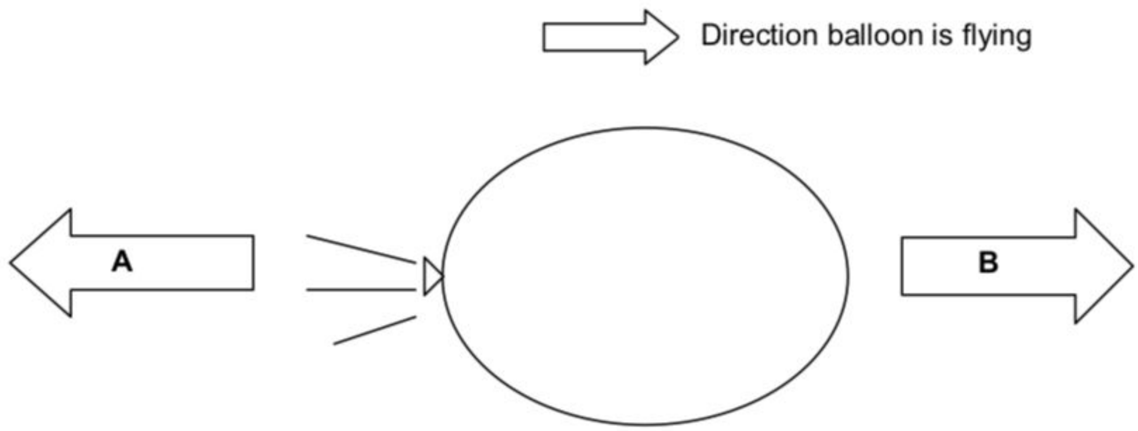
3. Draw and label an arrow indicating the force you are applying to the wall.

4. Draw and label an arrow indicating the force the wall is applying to you.



Part 2: Pushing on Air!

Observe the figure of a balloon below, and answer the following questions.



1. Which force arrow, A or B, is the force of the balloon on the air? ______

2. What is Newton's 3rd Law of Motion?

3. How do airplanes make use of Newton's 3rd Law?

Part 3: Gotta be Equal

Newton's 3rd Law can be written as :

the mass of object 1 x the acceleration of object 1 =
the mass of object 2 x the acceleration of object 2

Or more specifically as:

$$m_1 \times a_1 = m_2 \times a_2$$

This means that if we know information about 3 of the 4 pieces, we can calculate the fourth. For example if:

Mass1 = 3 and Acceleration1= 2;
Mass2 = 1 and Acceleration2 = *a*

Using our equation for Newton's 3rd Law, we know that 3 x 2 = 1 x *a*. Since 3 x 2 = 6, then 1 x *a* = 6 must be true. So, what is *a* then? 6! Hence, Acceleration 2 must be 6.

Complete the chart below by finding the missing variables:

Mass1 (kg)	**x**	**Acceleration 1 (m/s^2)**	**=**	**Mass 2 (kg)**	**x**	**Acceleration 2 (m/s^2)**
2	x	10	=		x	5
10	x	10	=		x	5
	x	10	=	10	x	5
	x	25	=	2	x	50
10	x		=	2	x	25
4	x		=	2	x	6
4	x	4	=	2	x	
6	x	6	=	4	x	

Name: ____ Date: ____________

What a Drag! [10]

Introduction:

Engineers often consider drag in designing things such as airplanes and cars. They try to design these objects as *streamlined* as possible. Streamlined means that the shape of the object, an airplane or a car can reduce the drag of the object (reduce the force opposing forward motion). This is why airplanes have rounded nose cones and why they pull up their landing gear after lift-off (to remove the wheels from being in the way and creating unnecessary drag). In this activity, we will demonstrate how shape and size affect the drag on something as simple as a piece of paper.

Materials:

- One *What a Drag! Shapes* worksheet per group
- One roll of scotch tape and pair of scissors per group
- Clay for each group
    - 40 g for the 10 gram designated groups
    - 80 g for the 20 gram designated groups
    - 120 g for the 30 gram designated groups
    - 160 g for the 40 gram designated groups
- Two meter sticks per group
- One stopwatch per group
- One balance per group

Procedure:

1. Cut out the four shapes: small cube, large cube, small cone and large cone.
2. Tape clay to the bottom (inside the shape) of the cubes so that they are all the same mass. For the cones, tape the clay inside the point. (The cone will remain open like a party hat).
3. Tape the shapes together, ensuring that the clay is secure (i.e., non-moving)
4. Use the balance to ensure the weight of each shape (designated by the instructor) and to ensure that each shape has the same weight (be as accurate as possible).
   Each shape has a mass of: _______________ grams.
5. Select one person to stand on a chair and drop the objects from a height of 2 meters. (A second person needs to hold the meter sticks together).
6. The third person should use the stopwatch to record how long it takes each shape to fall the same distance. Each time, be sure to drop the cones with the pointy side facing down! Do three trials for each shape.
7. Calculate the average time to fall for each shape and complete the following table.

Average Time Chart:

Object	Mass (grams)	Attempt	Time to fall (seconds)
Small Cube		1	
Small Cube		2	
Small Cube		3	
Large Cube		1	
Large Cube		2	
Large Cube		3	
Small Cone		1	
Small Cone		2	
Small Cone		3	
Large Cone		1	
Large Cone		2	
Large Cone		3	

Small Cube Average Time (seconds): ____ **Large Cube Average Time (seconds): ____**

Small Cone Average Time (seconds): ____ **Large Cone Average Time (seconds): ____**

8. Fill in the table below using the overall average time taken for the large cubes to fall. (Hint: calculate the average of the class' Large Cube Average Time for each weight. Use the area next to the table to show your work).

Object	Mass (grams)	Average Time (seconds)
Large Cube	10	
Large Cube	20	
Large Cube	30	
Large Cube	40	

Analysis Questions:

1. Did mass affect how long each shape took to fall? Use data to backup your answer.

2. Make a bar graph showing the different shapes on the horizontal axis and the average dropping times on the vertical axis. Be sure to clearly label your axes!

3. Which object fell the fastest? Why?

4. Which object fell the slowest? Why?

5. What is drag (in your own words)?

Challenge Question

The equation for drag is:

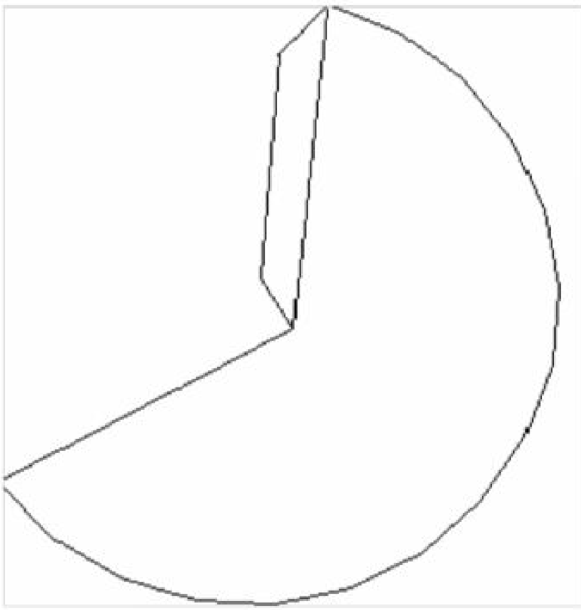
$$F_D = \frac{1}{2}\rho v^2 C_D A$$

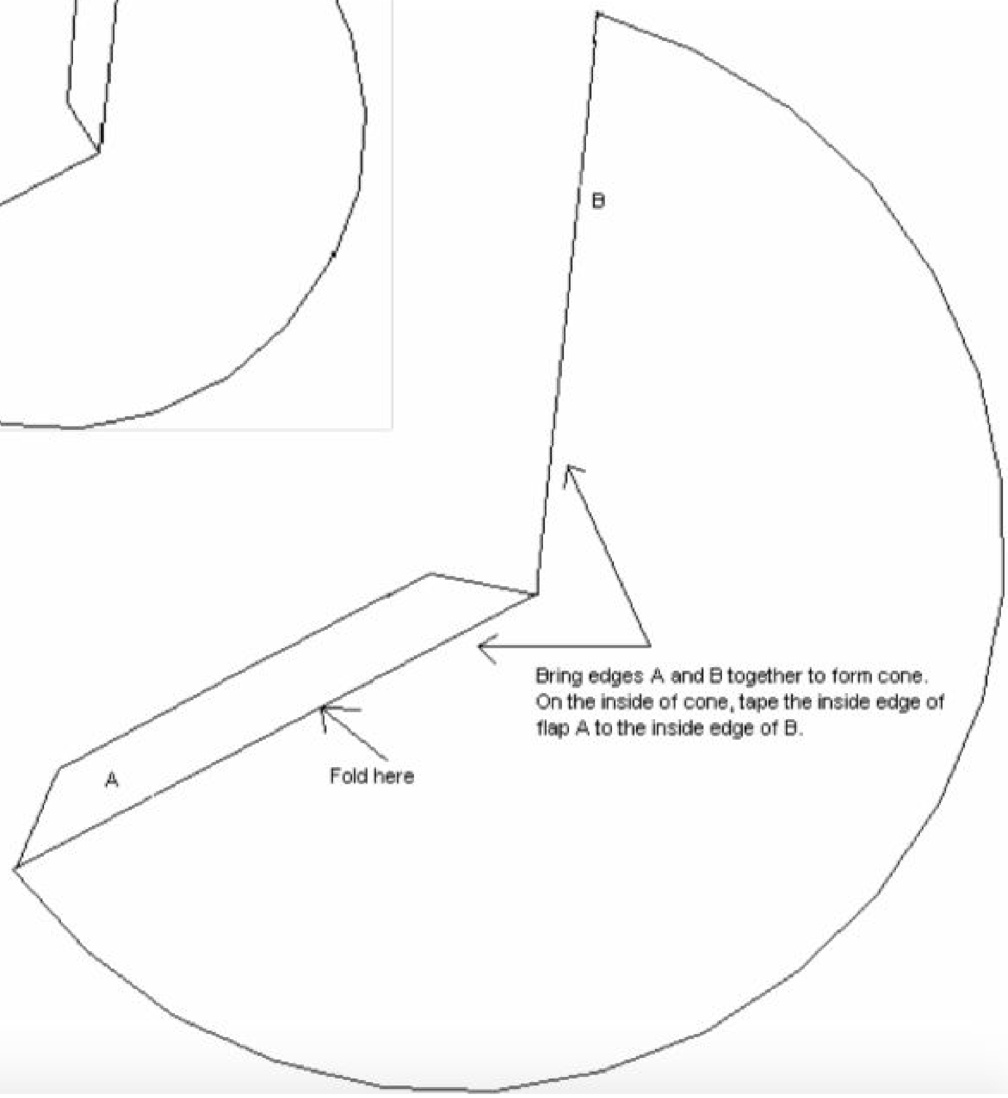
where F_D = force of drag, C_D = drag coefficient, ρ = density of the fluid (in this instance, air), v = velocity of the object relative to the fluid, and A = area of the object (facing its direction of motion).

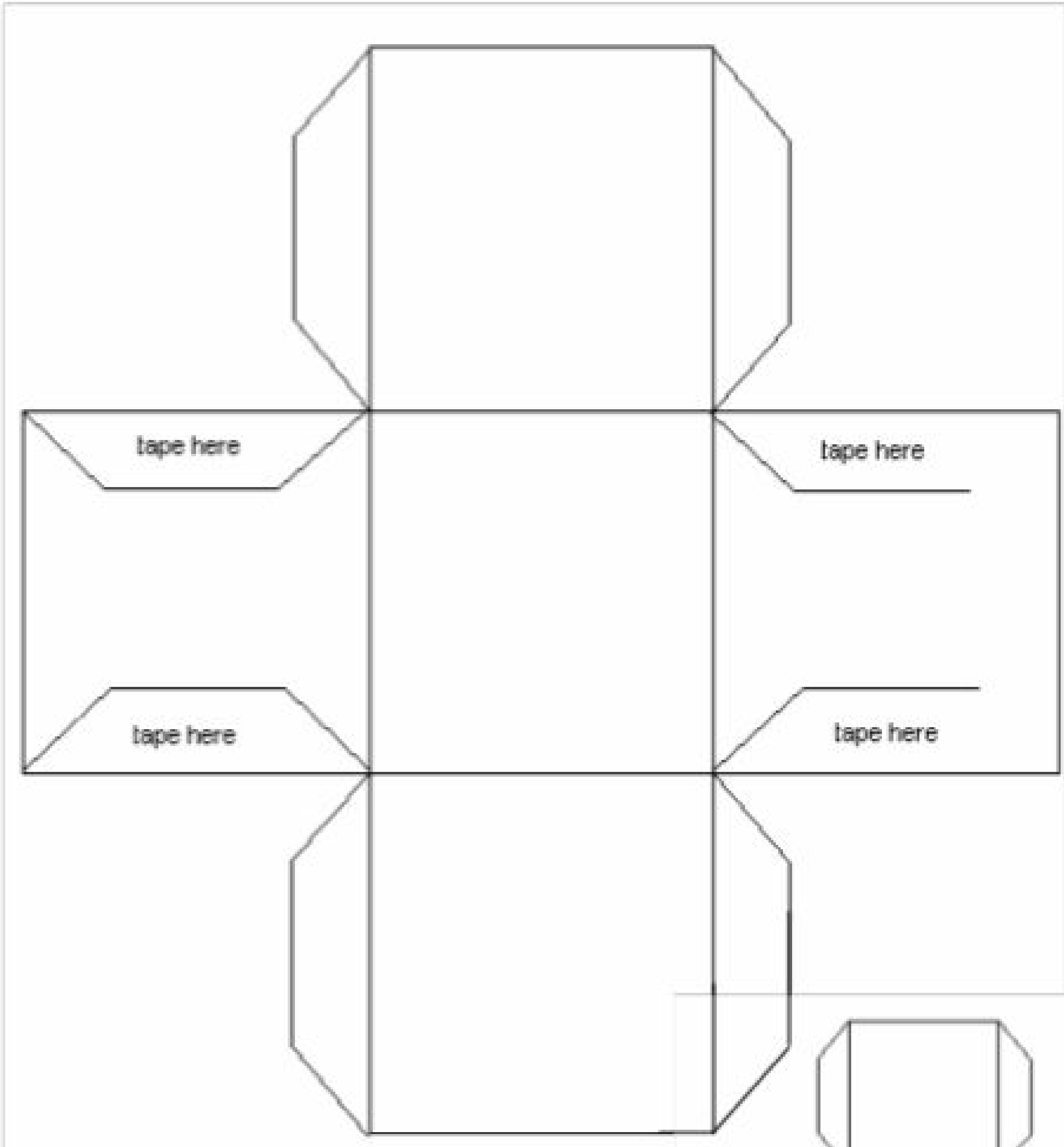
After opening her parachute and obtaining a constant velocity, a parachutist has a velocity of 3 m/sec. The density of the air is 0.95 kg/m^3; the drag coefficient of the parachute is 0.75, and the total area of the parachute is 58 m^2.

What is the drag force?

What a Drag! Shapes [10]



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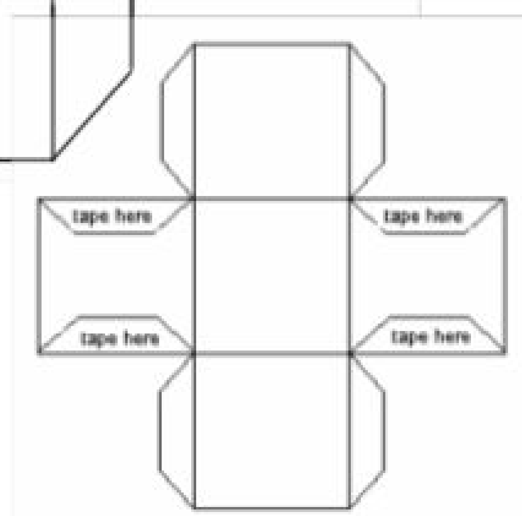
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DEPARTMENT OF THE NAVY
NAVAL SEA SYSTEMS COMMAND
2531 JEFFERSON DAVIS HWY
ARLINGTON, VA 2242-5160

Congratulations Cadet!

Your underwater submarine design far surpassed that of my expectations of this department. Well done. This friendly design competition was meant to find who in the department had the expertise and creativity to build an underwater submarine that could be manned by one individual. You successfully determined how that could be done, but the real challenge is ensuring it will glide through the water similar to an airplane.

Using your knowledge of aerodynamics, refer back to your original submarine design and elaborate on its speed and control within the water. I need you to address the following concerns:

- Forward acceleration in the water
- Reduction of velocity by the water
- Submarine material (can we use heavy materials or should we not?)

Contact me in an email, stating how you would address the above concerns and defend your answers. The NAVY needs the best and safest ships possible to ensure our missions are successful.

Thank you for everything you're doing, Cadet. You make a fine addition to the Armed Forces!

Director, Engineering Division

Name:____ Date:_________________

Submarine Design Revision Email

Directions:

Your team designed a submarine that meets the requirements your captain put in place. Now, you must write an email to them, stating how the submarine operates and meets the requirements by incorporating your new knowledge of fluid dynamics. Below is a rubric for your revision.

Design Requirements:

- Forward acceleration in the water is prioritized
- Reduction of velocity by the water is greatly reduced or negligible
- Heavy versus non-heavy materials in the design of the submarine

Revision Email Requirements:

- Explanation of the design including:
  - What aspects were changed, and why
  - How the submarine meets the design requirements
  - How the submarine is comparable to an airplane
- Scientific evidence to support explanations
- Incorporation of new topics learned about fluid dynamics

Points	0 - 1	2 - 3	4 - 5
Design	The submarine does not meet any of the design requirements **and** does not share any of the characteristics with an airplane	The submarine meets some of the design requirements **AND/OR** shares some of the characteristics with an airplane.	The submarine meets all design requirements and shares the characteristics of an airplane to move through the water.
Explanation	The email offers no factual scientific evidence to support the design requirements **and** does not provide proper logic for changes made.	The email offers some factual scientific evidence to support the design requirements **AND/OR** provides logic for changes made partially correct.	The email offers factual scientific evidence to support how it will meet the design requirements and provides proper logic for changes made.
Grammar/ Spelling	The proposal has many grammatical/spelling mistakes that negatively impacts the proposal.	The proposal has some grammatical/spelling mistakes that negatively impacts the proposal.	The proposal has little to no grammatical/spelling mistakes that negatively impacts the proposal.
Creativity (**BONUS**)	The design has little to no unique designs or decals, or does not combine an airplane to the submarine.	The design is unique, contains decals, and combines the best parts of an airplane to a submarine.	

Name:____ Date:________________

Submarine Design Revision Email: Grade

Comments:

Design:__________

Explanation:__________

Grammar/Spelling:__________

Creativity (**BONUS**):__________

TOTAL:__________

Name:____ Date:________________

Submarine Design Revision Email: Grade

Comments:

Design:__________

Explanation:__________

Grammar/Spelling:__________

Creativity (**BONUS**):__________

TOTAL:__________

Answer Keys for Lesson #1: Lift & Weight

Name:___________Answer Key______________________________ Date:___________________

Air is a Fluid [6]

1. What do you predict is going to happen when the beakers are inserted into the tank?

   Answers will vary based on student hypothesis.

2. Describe the demonstration. What is happening?

   The teacher is "pouring" the air from one cup to another while underwater.

   Notice that, when initially inserted, the beakers contained mostly air. Tilting a beaker sideways allowed for air to escape and for water to rush in. Consider beaker A to be the initial beaker with mostly air, and consider beaker W to be the initial beaker with mostly water. By tilting beaker A underneath beaker W, we notice that beaker A becomes filled with mostly water (from the tank) and that beaker W becomes mostly filled with air (from beaker A).

3. Does the result support or reject your hypothesis? Explain your answer.

   Answers will vary based on student hypothesis in Question 1.

4. Using your observations from the video, explain how both air and water are fluids.

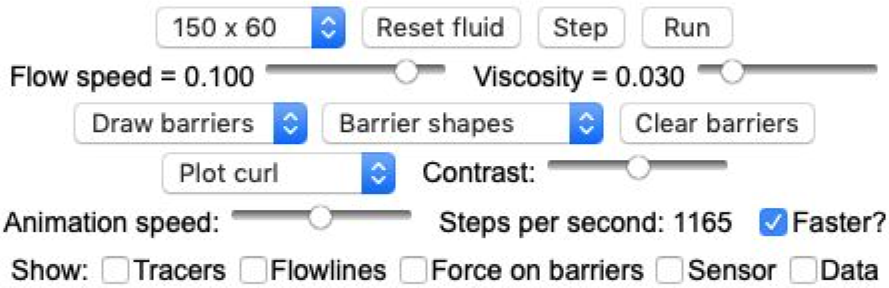
   Air and water are both fluids because they can be poured. In the case of water, we can pour water from one cup to another in a room full of air. Under water, we can pour air from one cup to another.

Name:______________Answer Key_________________________ Date:__________________

Fluid Dynamics [7]

Directions:

Go to the Fluid Dynamics Simulator from Weber State University. Once there, edit the settings to be the following:



Go through the worksheet and answer the questions based on the required settings. After each question, "Pause" the simulation and "Reset fluid."

Questions:

1. Click "Barrier shapes" and select "Long line." Check the "Tracers" and "Force on barriers" buttons.
    a. What do you notice about the movement of air?

       The air is getting trapped behind the long line.

    b. Is the air movement constant or fluctuating?

       The air is fluctuating from the top of the long line to the bottom.

2. Click "Barrier shapes" and select "Diagonal." Check the "Tracers" and "Force on barriers" buttons.
    a. What do you notice about the movement of air?

       The air is getting trapped behind the diagonal line.

    b. Is there air movement fluctuating more or less than before from Question 1b?
       The air is fluctuating a little bit, but not much.

3. Click “Barrier shapes” and select “Shallow diagonal.” Check the “Tracers” and “Force on barriers” buttons.
    a. What do you notice about the movement of air?

       The air is getting trapped behind the shallow diagonal line and remaining there.

    b. Is the air movement fluctuating or remaining constant?

       The air is barely fluctuating and remaining relatively constant.

4. Click “Barrier shapes” and select “Airfoil.” Check the “Tracers” and “Force on barriers” buttons.
    a. What does this shape remind you of?

       The shape reminds me of an airplane wing.

    b. What do you notice about the movement of air?

       The air is moving past the wing and getting trapped underneath the wing.

Name:_______________Answer Key_________________________ Date:__________________

Bernoulli's Principle [8]

1. State and explain Bernoulli's Principle.

   As the velocity of a fluid increases, the pressure exerted by that fluid decreases. Hence, pressure and velocity in a moving fluid are inversely proportional. This means that, when pressure is high, then velocity is low and vice versa.

2. What does the color red represent?

   The color red represents high-pressure and slow-moving air.

3. What does the color blue represent?

   The color blue represents low-pressure and fast-moving air.

4. When the air interacts with the ball, what happens? Detail your response.

   The object gains "lift" and rises until the high pressure cannot support the height.

Name:______________Answer Key______________________ Date:________________

Submarine Design Proposal

Prompt:

You are a naval engineer. Recently, your supervisor challenged your department to design a submarine that was capable of maneuvering through the water, similar to a plane, and to be piloted by a single person. As a reward, those that design this submarine will receive a large stipend and promotion. With your team, design this submarine, allowing it maintain its depth in the water.

Design Requirements:

- Can remain at a constant depth by adjusting accordingly via wing design
- One person must be able to man the submarine
- Must be based off of an airplane

Proposal Requirements:

- Detailed drawing of the design
- Explanation of the design including:
  - How the submarine meets the design requirements
  - How the submarine is comparable to an airplane
- Scientific evidence to support explanations

Expectations:

The wing shape allows for Bernoulli's Principle to take effect, thereby allowing the submarine to increase and decrease in depth from high and low pressure fluid molecules. The angle of the wings can be adjusted to allow for depth control. All of the submarine's controls are localized to one area, allowing for one person to command the ship.

The submarine design should appear similar to an airplane, with a hull, propeller, and wings. Depending on student design, it can have stripes or decals. These provide bonus points for students in the creativity category.

Name:______________Answer Key__________________________ Date:__________________

Exit Ticket

1. In your own words, explain Bernoulli's Principle. Be sure to include the following ideas: high pressure, low pressure and fluid velocity.

   Answers will vary based on student response.

   Expect something similar to the following: Bernoulli's Principle is the concept that a fluid moving at a high velocity is under low pressure whereas a fluid moving at a low velocity is under high pressure.

2. Connect the idea of Bernoulli's Principle to Buoyancy.

   Bernoulli's Principle is directly related to Buoyancy in that slow moving fluid molecules are compact, generating a high pressure. This allows slow-moving fluid molecules to lift an object. Likewise, fast moving fluid molecules are dispersed, generating a low pressure. When under these two pressures, the object can "float" at a height that the high pressure can support.

Answer Keys for Lesson #2: Thrust & Drag

Name: ______________Answer Key_____________________ Date: ______________________

Pre-Quiz

1. What is Bernoulli's Principle? Explain it in terms of air as a fluid.

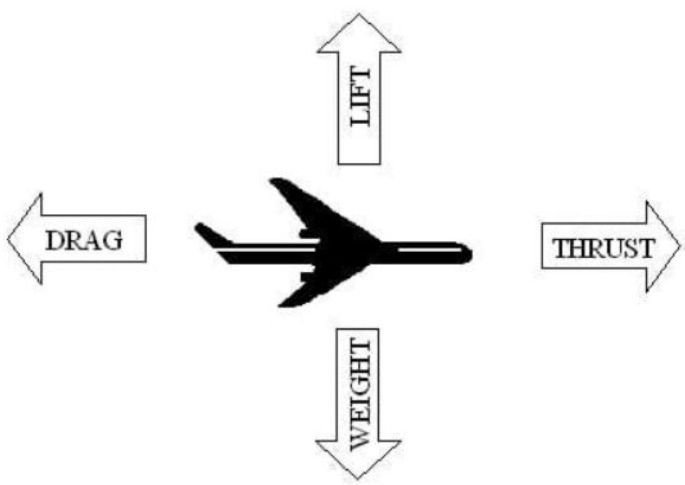
   Bernoulli's Principle states that high velocity fluid molecules will exhibit low pressure and low velocity fluid molecules will exhibit high pressure.

2. The formula for determining Buoyant Force is B = d x g x V. If we apply this to an airplane and assume that volume displaced (v) is negligible, what force does this leave?

   This leaves us with weight.

BONUS Draw and label a picture of a plane with arrows indicating the following forces: lift, weight, drag, and thrust.

Answers will vary based on student drawing. Expect the following: the force pushing the plane upward is lift and the force pushing the plane down is weight. See Figure 1 below:



[10]

Figure 1. The four forces of flight: lift, weight, thrust and drag.

Students will be learning about thrust and drag in this lesson; however, this serves as a pre-assessment to gauge any prior knowledge.

Name: ____________Answer Key______________________ Date: ______________________

You're a Pushover Worksheet [10]

Part 1: You're a Pushover

1. What does a wall do when you push on it?

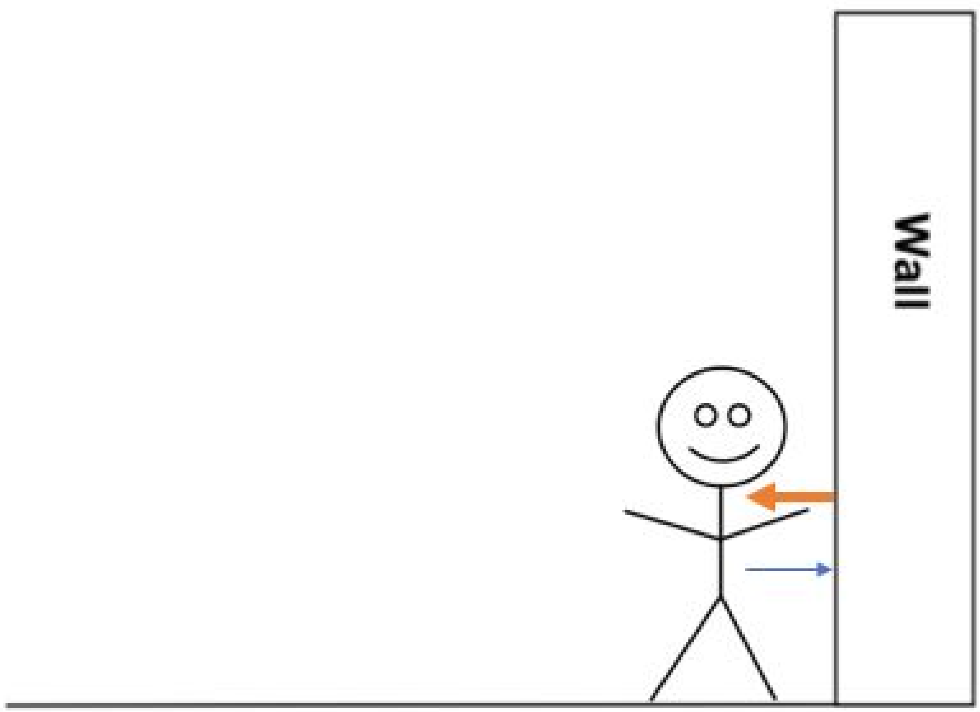
   The wall exerted an equal force, so neither I nor the wall moved.

On the diagram below:

2. Draw yourself pushing on the wall.

3. Draw and label an arrow indicating the force you are applying to the wall.

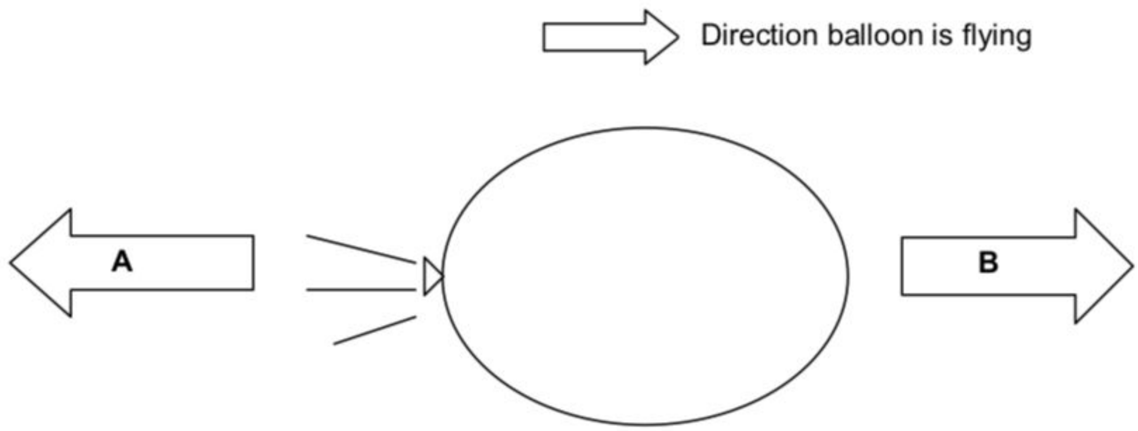
4. Draw and label an arrow indicating the force the wall is applying to you.



Orange is the force exerted by the wall; blue is the force exerted by the person

Part 2: Pushing on Air!

Observe the figure of a balloon below, and answer the following questions.



1. Which force arrow, A or B, is the force of the balloon on the air? __A___

2. What is Newton's 3rd Law of Motion?

   For every action, there is an equal and opposite reaction.

3. How do airplanes make use of Newton's 3rd Law?

   When airplanes fly, they are displacing air molecules. When these air molecules are displaced and pushed behind the airplane, the molecules exert an opposite force on the plane, pushing it forward. This allows airplanes to move forward and exhibit thrust.

Part 3: Gotta be Equal

Newton's 3rd Law can be written as :

the mass of object 1 x the acceleration of object 1 =
the mass of object 2 x the acceleration of object 2

Or more specifically as:

$$m_1 \times a_1 = m_2 \times a_2$$

This means that if we know information about 3 of the 4 pieces, we can calculate the fourth. For example if:

Mass1 = 3 and Acceleration1= 2;
Mass2 = 1 and Acceleration2 = *a*

Using our equation for Newton's 3rd Law, we know that 3 x 2 = 1 x *a*. Since 3 x 2 = 6, then 1 x *a* = 6 must be true. So, what is *a* then? 6! Hence, Acceleration 2 must be 6.

Complete the chart below by finding the missing variables:

Mass1 (kg)	**x**	**Acceleration 1 (m/s^2)**	**=**	**Mass 2 (kg)**	**x**	**Acceleration 2 (m/s^2)**
2	x	10	=	4	x	5
10	x	10	=	20	x	5
5	x	10	=	10	x	5
4	x	25	=	2	x	50
10	x	5	=	2	x	25
4	x	3	=	2	x	6
4	x	4	=	2	x	8
6	x	6	=	4	x	9

Name: ______________Answer Key__________________________ Date: ______________

What a Drag! Worksheet [10]

Introduction:

Engineers often consider drag in designing things such as airplanes and cars. They try to design these objects as *streamlined* as possible. Streamlined means that the shape of the object, an airplane or a car can reduce the drag of the object (reduce the force opposing forward motion). This is why airplanes have rounded nose cones and why they pull up their landing gear after lift-off (to remove the wheels from being in the way and creating unnecessary drag). In this activity, we will demonstrate how shape and size affect the drag on something as simple as a piece of paper.

Materials:

- One *What a Drag! Shapes* worksheet per group
- One roll of scotch tape and pair of scissors per group
- Clay for each group
  - 40 g for the 10 gram designated groups
  - 80 g for the 20 gram designated groups
  - 120 g for the 30 gram designated groups
  - 160 g for the 40 gram designated groups
- Two meter sticks per group
- One stopwatch per group
- One balance per group

Procedure:

1. Cut out the four shapes: small cube, large cube, small cone and large cone.
2. Tape clay to the bottom (inside the shape) of the cubes so that they are all the same mass. For the cones, tape the clay inside the point. (The cone will remain open like a party hat).
3. Tape the shapes together, ensuring that the clay is secure (i.e., non-moving)
4. Use the balance to ensure the weight of each shape (designated by the instructor) and to ensure that each shape has the same weight (be as accurate as possible).
   Each shape has a mass of: ___**Designated by the instructor**__ grams.
5. Select one person to stand on a chair and drop the objects from a height of 2 meters. (A second person needs to hold the meter sticks together).
6. The third person should use the stopwatch to record how long it takes each shape to fall the same distance. Each time, be sure to drop the cones with the pointy side facing down! Do three trials for each shape.
7. Calculate the average time to fall for each shape and complete the following table.

Average Time Chart: <u>**ALL answers on this page will vary per group based on their measurements**</u>

Object	Mass (grams)	Attempt	Time to fall (seconds)
Small Cube		**1**	
Small Cube		**2**	
Small Cube		**3**	
Large Cube		**1**	
Large Cube		**2**	
Large Cube		**3**	
Small Cone		**1**	
Small Cone		**2**	
Small Cone		**3**	
Large Cone		**1**	
Large Cone		**2**	
Large Cone		**3**	

Small Cube Average Time (seconds): ____ **Large Cube Average Time (seconds): ____**

Small Cone Average Time (seconds): ____ **Large Cone Average Time (seconds): ____**

8. Fill in the table below using the overall average time taken for the large cubes to fall. (Hint: calculate the average of the class' Large Cube Average Time for each weight. Use the area next to the table to show your work).

Object	Mass (grams)	Average Time (seconds)
Large Cube	**10**	
Large Cube	**20**	
Large Cube	**30**	
Large Cube	**40**	

Analysis Questions:

1. Did mass affect how long each shape took to fall? Use data to backup your answer.

   Answers will vary based on student observations and data.
   The goal answer is anything related to the following: mass does not affect the rate at which an object falls. The only factor affecting a falling object is the acceleration due to gravity (i.e. 9.8 m/s^2).

2. Make a bar graph showing the different shapes on the horizontal axis and the average dropping times on the vertical axis. Be sure to clearly label your axes!

   Answers will vary based on student data collected.

3. Which object fell the fastest? Why?

   Answers will vary based on student data collected.
   The goal answer is anything related to the following: the small cone (at 40 g) is expected to fall the fastest because it has the least amount of surface area and the greatest amount of weight. As the small cone falls, it creates a zone of slow-moving high pressure molecules as explained by Bernoulli's Principle. According to Newton's Third Law of Motion, the forces exerted by the air molecules are equal to that of the falling cone. Because of the small cone's low surface area, the air molecules move towards the lower pressure end of the cone at a faster rate. Hence, the small cone should fall the fastest.

4. Which object fell the slowest? Why?

   Answers will vary based on student data collected.
   The goal answer is anything related to the following: the large cube (at 10 g) is expected to fall the fastest because it has the greatest amount of surface area and the least amount of weight. As the large cube falls, it creates a zone of slow-moving high pressure molecules as explained by Bernoulli's Principle. According to Newton's Third Law of Motion, the forces exerted by the air molecules are equal to that of the falling cone. Because of the large cube's high surface area and flat bottom, the air molecules move towards the lower pressure end of the cone at a slower rate. Hence, the large cube should fall the slowest.

5. What is drag (in your own words)?

   Answers will vary based on student response. Expect students to relate paper shape to drag.
   The goal answer is anything related to the following: air resistance, or a force acting opposite to the relative motion of any object moving with respect to a surrounding fluid.

Challenge Question

The equation for drag is:

$$F_D = \frac{1}{2}\rho v^2 C_D A$$

where F_D = force of drag, C_D = drag coefficient, ρ = density of the fluid (in this instance, air), v = velocity of the object relative to the fluid, and A = area of the object (facing its direction of motion).

After opening her parachute and obtaining a constant velocity, a parachutist has a velocity of 3 m/sec. The density of the air is 0.95 kg/m^3, the drag coefficient of the parachute is 0.75, and the total area of the parachute is 58 m^2.

What is the drag force?

$F_D = (\frac{1}{2})(0.95\ kg/m^3)(3\ m/s)^2(0.75)(58m^2)$

$F_D = 185.96\ kg/s^2$

F_D = 185.96 lbs.

Name:_______________Answer Key_________________________ Date:__________________

Submarine Design Revision Email

Directions:

Your team designed a submarine that meets the requirements your captain put in place. Now, you must write an email to them, stating how the submarine operates and meets the requirements by incorporating your new knowledge of fluid dynamics. Below is a rubric for your revision.

Design Requirements:

- Forward acceleration in the water is prioritized
- Reduction of velocity by the water is greatly reduced or negligible
- Heavy versus non-heavy materials in the design of the submarine

Revision Email Requirements:

- Explanation of the design including:
  - What aspects were changed, and why
  - How the submarine meets the design requirements
  - How the submarine is comparable to an airplane
- Scientific evidence to support explanations
- Incorporation of new topics learned about fluid dynamics

Expectations:

Students are expected to have designs that are very similar to their previous design. However, greater emphasis on hull design should be present in the explanation.

The streamlined shape of the hull allows for the least amount of impact from the water molecules, and therefore less drag. A sharper point in the front of the submarine allows for water molecules to flow from the front of the submarine to the back with greater ease, which further decreases the amount of drag. The use of heavy materials is not necessarily important because water allows for a decreased force of weight on the submarine.

The submarine design should appear similar to an airplane, with a hull, propeller, and wings. Depending on student design, it can have stripes or decals. These provide bonus points for students in the creativity category.

Annotated Bibliography

[1] Hall, N. (2015, May 5). What is Thrust? Retrieved March, 2019, from https://www.grc.nasa.gov/WWW/k-12/airplane/thrust1.html

This reference was used for resource purposes and content inspiration. It was used in the development of the necessary vocabulary used throughout the unit. This reference was neither adapted nor excerpted.

[2] Nsta. (n.d.). Access the Next Generation Science Standards by Topic. Retrieved January 18, 2019, from https://ngss.nsta.org/AccessStandardsByTopic.aspx

This website was used in each lesson in the Ocean Conditions module to select proper national set standards for science subjects that each lesson is centered around.

[3] Nsta. (n.d.). Science and Engineering Practices. Retrieved January 18, 2019, from https://ngss.nsta.org/PracticesFull.aspx

This website used in every lesson in the Ocean Conditions module to find Standards for Science and Engineering Practices that are applicable in each lesson.

[4] Nsta. (n.d.). Disciplinary Core Ideas. Retrieved from https://ngss.nsta.org/DisciplinaryCoreIdeasTop.aspx

This website was used in each lesson in the Ocean Conditions module to select appropriate disciplinary core ideas set forth by the NSTA that are at the center of each lesson.

[5] Nsta. (n.d.). Crosscutting Concepts. Retrieved from https://ngss.nsta.org/CrosscuttingConceptsFull.aspx

This website was used in each lesson in the Ocean Conditions module to selecting appropriate crosscutting concepts set forth by the NSTA that apply to each science lesson.

[6] Sealy, K. (2015, March 04). Air is a fluid! Retrieved March, 2019, from https://www.youtube.com/watch?v=_d4sQQShDH4

This reference was used as an educational tool to demonstrate the fluid properties of both air and water. This video is used in the engagement portion of this lesson.

[7] Schroeder, D. (n.d.). Fluid Dynamics Simulation. Retrieved March, 2019, from https://physics.weber.edu/schroeder/fluids/

This reference was used as an educational tool to be used in the exploration portion of lesson #1. This tool served to demonstrate how the movement of fluid molecules and object shape can generate high and low pressure zones. The simulation was directly used in this lesson.

[8] UltimateScienceProductions. (2012, March 12). Bernoulli's Principle: Demonstrated. INCREDIBLE!!! Retrieved March, 2019, from https://www.youtube.com/watch?v=8vqMotb6m3c

This reference was used an educational tool to demonstrate Bernoulli's Principle. This video is used in the exploration portion of lesson #1 and has an associated half sheet with questions.

[9] Rutkowski, T., Conner, A., Hill, G., Zarske, M. S., & Yowell, J. (2018, March 9). May the Force Be with You: Thrust - Lesson. Retrieved from https://www.teachengineering.org/lessons/view/cub_airplanes_lesson04

This reference was used for excerption purposes. This reference aided in the completion of the instructor's guide for this lesson. Also, the introduction portion of the TeachEngineering website's lesson was directly excerpted for the instructor's guide. The introduction provided the necessary science knowledge for an instructor to teach the lesson topic and answer any student questions. TeachEngineering is useful in executing and adapting inquiry-based activities that require students to employ NGSS science practices and e gage in hands-on learning.

[10] Rutkowski, T., Conner, A., Hill, G., Zarske, M. S., & Yowell, J. (2019, February 11). You're a Pushover! Activity – Worksheet. Retrieved March, 2019, from https://www.teachengineering.org/activities/view/cub_airplanes_lesson05_activity1

This reference was used for excerption purposes within the unit plan. This reference aided in the You're A Pushover! and What a Drag! activities and their analysis questions, as well as the instructor's guide. Also, this reference was used in the exploration portion of lesson #2. This reference served to provide a hands-on activities where students are observing natural phenomenon that they will be learning about. These activities and their associated worksheets are directly excerpted from TeachEngineering. TeachEngineering is useful in implementing and adapting activities that involve hands-on and inquiry-based learning in STEM topics.