

Future Fleet

Science Topic: Buoyancy, Density, and Volume

Grades: 9th – 12th

Essential Questions:

Big ideas

- Anything will float if its shape displaces its own weight of water before it reaches the point it will submerge.
- The stability of a ship is judged on the relationships between buoyancy and center of gravity.
- The ships of the future must be versatile, efficient, and cost effective.
- The design of future ships is an engineering task and a scientific process that requires much planning and innovation.
- Ships are built within a budget; therefore accurate predictions of costs and high probability of success are critical outcomes of a prototype design.

Big questions

- How do ships stay afloat?
- Why is there not one best design for the fastest, most stable, most maneuverable ship?

Guiding questions

- How can 3,000 mega tons of steel float?
- Why does the shape of the ship hull affect stability?
- Why do some ships sink almost immediately after launch?
- How does the accuracy of design affect the economics of a shipbuilding project?
- Historically, have ships always been designed using a scientific process?
- Why did the Navy design the Littoral class ships?
- Why did the Navy use two 2 different designs?

Lesson Overview:

Students will watch a video about the design of the Navy fleet of the future. Using the design process, students will design prototypes of ships of the future. Students will take economics, size, geography, resources, and defense issues into account when they design their ships. The prototypes should be seaworthy. As part of the evaluation, the prototypes will be tested to see if they float.

Learning Objectives:

Students will be able to calculate the displacement mass of a given hull design. Students will be able to discuss the stability of ships by comparing metacenter and center of gravity. Students will build a

prototype ship out of clay based upon a theoretical design of theirs. Students will defend their ship designs by using accurate science and calculations.

Knowledge

- Students will know the definitions of the vocabulary words: density, displacement mass, displacement volume, buoyancy, volume, center of gravity, center of buoyancy, metacenter
- Students will know the calculations for displacement mass and metacenter.
- Students will know the procedure to find the center of gravity of a thin object.

Comprehension

- Students will be able to calculate the volume of a rectangular prism, volume of a irregular shaped prism, and displacement mass of a volume.
- Students will be able to find experimentally the center of gravity of a thin shape.
- Students will be able to find the metacenter given the center of gravity and multiple centers of buoyancy.

Application

- Students will use the concepts they learned to design a prototype ship.

Analysis

- Students will create a brief presentation on the design of their prototype.
- Students will predict the success of their prototype based on the scientific principles.

Synthesis

- Students will build a prototype based on their design

Evaluate

- Students will evaluate their prototypes and that of the others to determine points of success and points of failure.
- Students will come up with improvements to their prototype based on analysis of the float test.

Next Generations Science Standards Framework

- PS2: Motion and Stability: Forces and Interactions
- PS2.B: Types of Interactions- Math -Create equations that describe numbers or relationships 4. Rearrange formulas to highlight a quantity of interest, using the same reasoning as in solving equations. For example, rearrange Ohm's law $V = IR$ to highlight resistance R.
- PS2.C: Stability and Instability in Physical Systems

Common Core Math Standards

- HSN-Q.A.1. Use units as a way to understand problems and to guide the solution of multi-step problems; choose and interpret units consistently in formulas; choose and interpret the scale and the origin in graphs and data displays.
- HSN-Q.A.2. Define appropriate quantities for the purpose of descriptive modeling.
- HSN-Q.A.3. Choose a level of accuracy appropriate to limitations on measurement when reporting quantities.
- HSA-CED.A.1. Create equations and inequalities in one variable and use them to solve problems. Include equations arising from linear and quadratic functions, and simple rational and exponential functions.
- HSA-CED.A.4. Rearrange formulas to highlight a quantity of interest, using the same reasoning as in solving equations. For example, rearrange Ohm's law $V = IR$ to highlight resistance R.

- HSA-REI.B.3. Solve linear equations and inequalities in one variable, including equations with coefficients represented by letters.

Time Frame:

This lesson is designed to be completed in three 90-minute sessions.

Vocabulary:

- Density - The degree of compactness of a substance. Density is equal to mass divided by volume
- Displacement mass – the mass of a fluid (as water) displaced by a floating body (as a ship) of equal mass
- Displacement volume - the volume of a fluid (as water) displaced by a floating body (as a ship)
- Buoyancy - is the upward force a fluid exerts on an object
- Volume – a cross sectional area multiplied by its length. The number of cubic units in an object
- Center of gravity- the geometric property that represents the average location of the weight of an object
- Center of buoyancy - the center of gravity of the displaced water
- Metacenter – intersection of the lines of force created by different centers of buoyancy

Background for the Teacher:

Common misconceptions

- Heavy things sink
 - This is addressed in the buoyancy video
- A ship that floats will continue to float
 - This is addressed in the article “The History of Failed Ships” and in the instruction on metacenter.
- Modern ships are unsinkable
 - This is addressed in the guiding questions on “The History of Failed Ships”
- Mass is a measure of weight
 - This is addressed in the displacement of mass instruction.

The students will start the lesson with a discussion about an article “The History of Failed Ships.” They should have read this article the previous night and completed the active reading worksheet. Through this article students will gain knowledge about the consequences of poorly designed ships including, loss of life and resources.

Density is defined as mass divided by volume. Salinity, temperature and depth all affect density.

Displacement volume is the volume of fluid an object displaces. Displacement mass is volume times density. This volume can be calculated by finding a cross sectional area and multiplying by the length of the ship. The calculation for displacement is volume of water (cm^3) x density (g / cm^3) The volume of water must be converted from m^3 to cm^3 in the example provided. When the students make their prototypes the units of volume will be in cm^3 . In addition it is important to mention that mL is another name for cm^3 . The volume of an irregular shape must also be calculated. There are two ways to do this. The first is to approximate the cross sectional area using graph paper. One can then multiply the length of the model ship as is done with the rectangular prism. The second way is a connection to calculus. One can find the area between two curves. The hull shape must match to a function. The deck height is chosen to be the top curve. Next integrate to find the cross sectional area and then multiply by the length. This calculation can be done by hand or can be done on wolframalpha.com:

Ex.

- 1) Find the intersections of the deck and the hull curve

Type into wolframalpha.com

Intersection $y=51$ and $y=(11*10^{-12})(x+35)^4(x-35)^4$

- 2) Find the area between the two curves

Type into wolfram alpha.com

Integrate $y=(51 - [(11*10^{-12})(x+35)^4(x-35)^4])$ from $[-51.8882, 51.8882]$

The area would be 4284.59

Weight is a force and must be calculated as acceleration due to gravity times mass. Often mass in grams is mistaken for weight. The mass of an object does not change, but its weight will change with gravity. Using the example of how far Alan Shepard was able to hit a golf ball on the moon, one can see how one can change weight but still have mass. Mass in grams is converted to both Newton’s the SI unit of force (by multiplying by $(1\text{kg}/1000\text{ g}) * 9.8\text{ m}/\text{s}^2$) and pounds the common unit of force (by multiplying by $(1\text{kg}/1000\text{ g}) * 2.2\text{lbs}/\text{kg}$). The buoyant force is the displacement force. Archimedes principle states,

“An object immersed in a fluid is buoyed up by a force equal to the weight of the fluid displaced by the object.”

One can demonstrate the concept of center of gravity by considering a thin cross sectional area of an object. A flat paper object works well. Suspend the object from a point and drop a weighted string from the same point. Trace a line on the object for the full length of the string. Repeat this process from another point on the object. The intersection of the two lines locates the surface expression of the center of gravity. One can demonstrate the center of gravity of a volume by tracing a cross sectional area of the volume onto a thin sheet of paper. Then find the center of gravity as above. The center of gravity of the volume of the object will be at the center of the perpendicular line to the plane of the cross sectional area as it passes through the center of gravity of the cross sectional area. Students do not need to find the center of gravity of their prototype. They only need to find the center of gravity of the cross sectional area to calculate the metacenter. We are only interested in roll stability for this prototype. There is a second **calculus** connection here that is optional for students in calculus or above: Calculate the center of mass of a region using an integral

Where $f(x)$ = the deck height and $g(x)$ = the hull shape

X coordinate = Integral from a to b of $x [f(x) - g(x)]$ divided by the area of the region

Wolframalpha.com

1) X coordinate =

Integrate $y=x (51 - [(11 \cdot 10^{-12})(x+35)^4(x-35)^4])$ from $[-51.8882, 51.8882]$

RESULT is zero

2) Then divide the answer by 4284.59

RESULT is zero

X coordinate at zero

(Which is where we expect it because of symmetry)

Y coordinate = Integral from a to b of $f^2(x) - g^2(x)$ divided by the area of the region

Wolframalpha.com

1) y coordinate =

Integrate $y=(51^2 - [(11 \cdot 10^{-12})(x+35)^4(x-35)^4]^2)$ from $[-51.8882, 51.8882]$

Result 248643

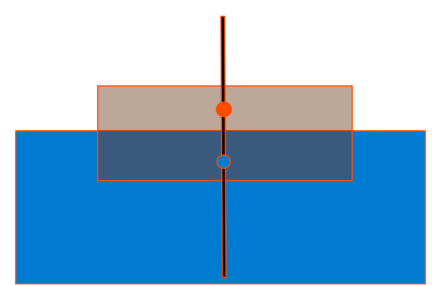
2) Divided by 4284.59

This gives us about 58

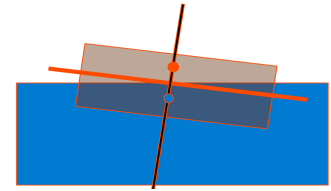
This will be the center of gravity well about the deck line in the center of the ship

Similar calculations to find the center of buoyancy for the part of the ship below the water (we are using 14 foot draft) can be done.

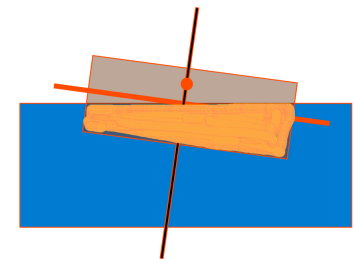
Metacenter is also found experimentally. Start by finding the center of gravity and the center of buoyancy. Then draw a line connecting the lines of force. (Hopefully this falls in the middle if the design is symmetrical)



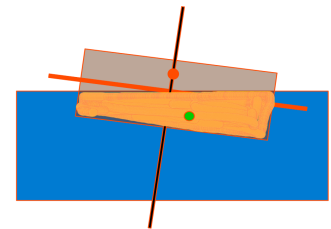
Next roll their ship



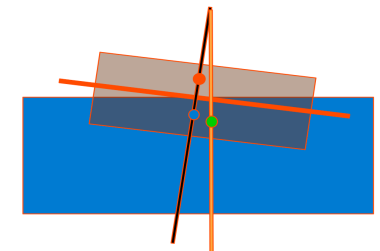
This will create a new cross sectional area that demonstrates the new displacement.



Find the center of buoyancy of the new area.



Draw in the line of force for the new center of buoyancy. This is the line that passes through the new center of buoyancy and is perpendicular to the water line.



The intersection of these lines of force is the metacenter. The metacenter will dictate the stability of the ship. The higher the metacenter is above the center of gravity the more stable the ship will be. However, there is a trade off. The more stable the ship is the faster it will recover from a roll. This could cause a very uncomfortable ride for passengers. This should be mentioned but students will not have to compensate for comfort in their prototypes.

The third connection to calculus is to find the center of buoyancy of a rolled ship and then calculate the metacenter. The top line should be changed to $y = -.1x + 51$ to represent a rolled ship and calculate the center of buoyancy of that. Finding a perpendicular line through the new center of buoyancy to the line $y = -.1x + 51$ (the new water line) will give the line of force. The intersection point of that line and the line through the first center of buoyancy and center of mass will give the metacenter.

Classroom Activities:

Materials

For each group of/individual students:

Session one lab materials

- How Metal "Boats" Float
 1. Large bowl
 2. Water
 3. Aluminum foil
 4. Metric ruler
 5. Pen
 6. Scissors
 7. Permanent marker
 8. Hammer or mallet

- Liquid Density and Lava Lamp
 1. Water bottle
 2. Vegetable oil
 3. Water
 4. Food coloring
 5. Alka-Seltzer

- Soda can Pirouette
 1. Empty soda can

Session two prototype creation

- Scissors
- Cardboard
- String and weight (pendulum)
- Cornstarch Clay
 - 1 c. cornstarch
 - 1 1/2 c. baking soda
 - 1 c. cold water
 - Combine ingredients in saucepan, cook on medium heat until clay forms. Knead when cool. Put the dough in refrigerator till needed. It will last a few days. Bring back to room temperature and knead until smooth. Form figures and let harden overnight or bake for 1 hour at 250 degrees
- Index cards
- Some container to float the prototypes in
- Pencil
- Mass balance

Engage 10 min

Presentation Slides 2-8

The students should have read the article “The History of Failed Ships” and the active reading worksheet for homework the night before the lesson starts.

Ask the students the following guiding questions for “The History of Failed Ships”

What is the economic cost of a failed ship design?

What is the human cost of a failed ship design?

How can the tragic losses in the article be prevented?

Is it possible to know how much a ship will cost before you build it?

Can an unsinkable ship be designed?

Is it possible for a tragedy at sea to happen today even with current technology? (Costa Concordia should be addressed here)

Use the smart board and write the student responses to this question in the box provided. You can save the notes the students take by one of the following two methods:

-Press Print Screen button on keyboard and paste into a word document

-Use the screen capture feature of notebook software that comes with the smart board to add the screen to a set of notes to be shared with the class later.

(Note: presentation best viewed with PowerPoint 2010 download the free viewer at <http://www.microsoft.com/en-us/download/details.aspx?id=13>)

Explore 25 min

Presentation Slides 10-17

Students will work through lab stations on density, buoyancy, volume and center of gravity.

LABS

Students will move through the following stations

1. How Metal "Boats" Float (5 min)

Procedure

- Pull the corners of the aluminum foil square together and crumple the square into a loose ball that is approximately six cm in diameter. Rump the aluminum such that the corners stay together and are visible in one spot.

- Set the ball gently in the bowl of water, placing it so that the corners are at the top of the ball, as this will help prevent the ball from filling up with water. Immediately observe the ball.
Does it sink or float?
- Get down low so that you are at eye level with the aluminum foil ball and quickly observe how much of the ball is below the surface of the water.
Approximately what percent of the ball is underwater?
- Remove the ball from the bowl, shake out any water and dry it on the towel.
- Crumple the ball a little more tightly, until it is approximately 3 cm in diameter. If you crumple it too much, just carefully pull apart some of the aluminum foil to get the desired size.
- Set the ball gently in the water, placing the marked corners at the top.
Does it sink or float?
What percentage of the ball is below the top of the water?
Remove it, shake out any water and dry it.
- Do it one more time and compress the ball as much as possible
Does it sink or float? What percentage of the ball is below the top of the water?
As the ball gets smaller what can you say about its density?

2. Liquid Density and Lava Lamp (5 min)

- Fill the water bottle most of the way with vegetable oil.
- Fill the rest of the bottle with water. The water will sink to the bottom under the oil.
- Add a few drops of food coloring. The food coloring is water-based, so it will also sink and color the water that is now at the bottom of the flask.
- Break an Alka-Seltzer tablet into a few small pieces, and drop them in the flask one at a time.
- Watch your lava lamp erupt into activity! As the reaction slows down, simply add more Alka-Seltzer.
- The Alka-Seltzer reacts with the water to produce carbon dioxide gas bubbles. These stick to the water droplets. The water/gas combination is less dense than the oil, so it rises to the top of the flask. At the top, the gas bubbles pop and escape into the air, allowing the dense water to sink back to the bottom again.

3. Soda can Pirouette (5 min)

- Students will balance a soda can on its edge trying to find the center of gravity. (the can will fall over)
- Students will fill the can up about 1/3 (100ml) with water to change the center of gravity
- Then try to balance again and gently tap to have the can spin on its edge.

Students will do this in design teams (4 – 5) using the following roles

- Task manager- Keep group members focused
- Activity recorder - records what they do & what questions the group has
- Life Line (can be doubled)- can leave the group to seek help
- Evaluator - judge the effectiveness of the group and report only to the group..

Explain 30 min

Presentation Slides 18-41

Reconvene the groups to discuss their findings before the concepts are formally presented in the power point. This discussion and the presentation of concepts are scheduled to take place for 30 min.

Students will see what density is and how it's calculated

Students will look at the Salinity map and Temperature map to see the different combinations of Salinity and Temperature that a ship designer would have to contend with.

The students will learn to use density and volume to calculate displacement

The students will learn what the center of gravity is and how to find it experimentally.

The students will learn how to find the center of buoyancy

The students will learn how to use the center of mass and buoyancy to calculate metacenter.

Elaborate 15 min

Presentation Slide 42

Students will write the general guidelines for ship design based on their exploration today. The students should do this by making a list of the most important aspects of ship design. The instructor will move from team to team-emphasizing stability and buoyancy.

Evaluate 10 min

Presentation Slides 43

Teams will reconvene to work on their exit ticket and evaluate the group dynamics

SESSION 2

Engage 15 min

Presentation Slides 45-51

The students will watch the video on Navy ships of the future.

The students will go through the following guiding questions with the instructor

- 1) Why did the navy use two different designs (looking for the idea of different companies bidding on the same project within the budget available and different solutions to the same problem)?
- 2) What need is the Navy trying to address? (Keep America safe from its inherent threats at a reduced cost while still being very flexible and able to reach more ports than ever before)
- 3) What aspects of the design of the ships address the needs of the Navy (fast, highly maneuverable, 14 foot draft, and automation)? The automation allows for half crew size of most ships. This reduces the cost of man power which is the highest cost to the Navy)
- 4) Why do you think using all new 21st century technology was important to these features?

The instructor will then show the clip of At-Sea-Ep-2-1-11.14.2012.12.47.48.wmv with regard to pirates that operate off the coast of Somalia. A link to Google earth will show the students the coast.

(<http://goo.gl/maps/7R37J>)

Guiding question:

1) How could the LCS class ships help support operations in the region?

Explore 30 min

Presentation Slides 52-53

Students will work together to come up with the design of their new Littoral class ships. Students will be presented with the technical specifications of the Littoral class ship that they must design. (5 min)

Students will work in their design teams to sketch different hull designs to fit the specifications of a new Littoral class. They can choose from any combination of hull design elements. They must consider the scale of their drawing in relation to the full size ship. They will apply the following to each section of their hull design:

- The students will make three cardboard cutouts of their hull design section. The first will be the full deck height. The second will be just the bottom cut off at the water line. The third will be the bottom cut off at an angled water line (used later to find center of buoyancy when ship is at an angle).
- The students will use graph paper to approximate the area of their hull below the water line.
- They will then calculate the volume of the hull by multiplying the area by the length. If their hull narrows in front they can approximate the volume further by multiplying the cross sectional area by the length of the front and dividing by 6 (similar to how one would measure half a cone).
- These calculations will give the teams the volume of their displaced water. Multiplying this volume by the density of salt water will give them the mass they can displace.
- The students should find the mass of the clay they are given and compare it to the displacement to see if they are displacing enough water to make their boat float. The students who use multiple hull designs combined will have to divide their clay for each section to make sure the displacement for each section is correct.
- If their design will not displace the correct amount of water they are to modify their design and try again.

Students must also check the stability of the ship by making sure the metacenter is above the center of mass. They will perform this calculation by:

- Finding the center of mass of all three cut outs.
- The two shapes that represent the displaced water will represent the buoyant centers (one level and one at an angle).
- Students will stack the three shapes one on top of another and find the metacenter. Stacking the three shapes with the original hull on the bottom and the displaced mass shape on top, the students will determine the metacenter. They will draw the line of force through the center of buoyancy and the center of mass. Then they will roll their ship and put the new displacements cut out on top. The students should draw a perpendicular line through the new center of buoyancy to

the new water line (see illustrations in PowerPoint). The metacenter will be the intersection of those lines.

- The Students will have to make a guess at the stability if they use multiple sections. For example: A back that is very stable with a front that is not as stable may balance out.

Instructor will act as coach and move among the teams.

Explain 35 min

Presentation Slides 53

Students will build their prototypes. To accomplish this they will shape cardboard or card-stock (index cards) using tape to fit the curve of their design to the length they calculated. Then they will press the cornstarch clay onto the curve, connecting all sections and smoothing all seams. They may need to support the weight of the clay by positioning toothpicks under the cardstock. Students should mark on the prototype where they believe the water line will be when it is tested. The model must be left to air-dry overnight in the classroom before testing the next day. To speed up the drying process they can be cooked in an oven at very low temperature to keep the paper from combusting. The ignition point of paper is 451F; the instructor can safely heat them to about 200F for 15 minutes. (Students should cook the prototypes only under adult supervision.)

Evaluate 10 min

Presentation Slides 54

The students will work in their design team on a brief description of their prototype. In this description the students should address the aspects of their prototype that are most closely related to a real ship (displacement and buoyancy). Students should then give themselves a confidence rating. This should represent how successful the ship will be in a full-scale prototype. Focusing only on aspects related to a real ship, students should answer the question "Is the design of their prototype worth spending several million dollars to test at full scale"

SESSION 3

Explore: 45 min

Presentation Slides 56-57

Each group will have 3 minutes to present their design to the class using the evaluation from Session 2.

Each team will put their prototype in the water tank and have it tested by the instructor.

All Students will record data on a rubric for each prototype. There are three categories:

- 1) Percentage error between predicted water line and actual water line (tank can have dye or food coloring in it to help denote the actual water line for measurement)
- 2) Stability test under wave conditions. Dropping different weights in the water a short distance from the ship will create three different conditions.
- 3) Overall design appeal and creativity – This is subjective

Explain: 20 min

Presentation Slides 58

Teams should reconvene and reevaluate their calculations to determine the following:

- 1) Explanations for percentage error
- 2) Stability of their prototype and propose solutions.
- 3) If they were to make another prototype what would they do differently?

Elaborate: 20 min

Presentation Slides 59-61

The class will come back as a whole to work through the following guiding questions:

- 1) We only looked at stability and buoyancy, what other variables might have to be addressed in building of a prototype?
- 2) How will designing versatile and flexible ships prepare us to handle the future?

Discussion Topic:

Given the safety concerns about some modern cruise ships, how might one prevent future accidents like the Costa Concordia?

EVALUATION OPPORTUNITIES

- 1) Participation
- 2) Lab sheets
- 3) Exit ticket
- 4) Presentation at beginning of session 3
- 5) Design packet
- 6) Summary of student rubric scores
- 7) Design improvement worksheet

Re-teaching – As you proceeded through the lesson

- During the labs the teacher can move around the room and demonstrate the labs for the students having difficulty.
- In Presentation Slides 18-41 students are asked to reconvene the groups to discuss their findings before the concepts are formally presented in the power point. This is the opportunity to confirm they have gotten out of the labs the concepts that were intended.
- While the students are working on the Exit ticket the instructor can correct any misconceptions with struggling students.
- While students are working on the section after session two “Evaluate”, Presentation Slide 54, the instructor can help students tweak their designs.
- While students are working on Session 3 “Explain”, Presentation Slide 58, the instructor can take this time to re-teach any concepts that lead to a team’s failure.

Additional resources

Science Buddies.(April 12, 2012).Buoyant Science: How Metal "Boats" Float:A watery wager from Science Buddies.*Scientific America*.Retrived November 23, 2012, from <http://www.scientificamerican.com/article.cfm?id=bring-science-home-how-metal-boats-float>.

No author.(n.d.).Liquid Density and Lava Lamps. *Home training tools*. Retrieved November 23, 2012, from <http://www.hometrainingtools.com/homemade-lava-lamp-project/a/1736/>

Carrie. (July 13, 2011). Center of Gravity – Fork on Glass. *Indianapolis Public Library Kids Blog*. Retrieved November 23,2012 from <http://www.imcpl.org/kids/blog/?p=8933>

No author. (n.d.). Cornstarch Clay. *Cooks.com*. Retrieved November 29, 2012, from <http://www.cooks.com/rec/view/0,199,147183-241204,00.html>

Stuart Cameron.(n.d.). ss DAPHNE. *Shipping Times* Retrieved on November 23, 2012 from <http://www.clydesite.co.uk/clydebuilt/viewship.asp?id=3340>

AP, Associated Press(June 7 1986) Study Showed Pride Of Baltimore Was An Unstable Ship. *AP News Archive*. Retrieved on November 23,2012 from <http://www.apnewsarchive.com/1986/Study-Showed-Pride-Of-Baltimore-Was-An-Unstable-Ship/id-8d91408f405441838d6d25abff86ea63>

Fairley, R. & Willshire, R. (2003, March). Why the Vasa Sank: 10 problems and Some Antidotes for Software Projects. *IEEE Software*, 20(2), 18.

Miller, H., McIntire, J., & Southerland, J. (2001). Retrieved November 23, 2012. from NAVAL EDUCATION AND TRAINING PROFESSIONAL DEVELOPMENT AND TECHNOLOGY CENTER website: http://www.globalsecurity.org/military/library/policy/navy/nrtc/14057_ppr_ch12.pdf



STEM for the CLASSROOM



Hoffman, D.(June 25, 2012) 5.4 MOMENTS & CENTERS OF MASS. *Contemporary Calculus*. Retrieved November 23, 2012 from http://scidiv.bellevuecollege.edu/dh/Calculus_all/Calculus_all.html

Active Reading worksheet

Instructions: Fill out following worksheet as you read the article "A History of Failed Ships."

Before you read

Read the title and first sentence or two and answer the following questions:

1. What is the purpose of this article?
2. Predict what you might find in this article
3. What questions might this article answer?

While you read

1. Read the article all the way through once, underlining any words you do not know the meaning of and keeping in mind the purpose of the article.
2. After looking up the words you did not know, read the article again looking for the author's main ideas and underline them.
3. As you read both times, jot down interesting, confusing, troubling, or noteworthy ideas.

After you read

1. Write a brief summary of the article.
2. Write your reaction to the article. How did it make you feel? (This should be more than just I "liked it" or "did not like it.")

A History of Failed Ships

A quick search of YouTube for the key words “ship launch fail” will yield what at first seems like a funny compilation of failed ship designs. However, when the financial and human costs are taken into account, the comic turns tragic. January 13, 2012 the Costa Concordia ran aground and eventually sank. These tragic event costs 30 people their lives. The European Union initiated an investigation into the safety standards of cruise ships that operate under its jurisdiction. One of the main questions they were forced to ask was “Do the current stability rules on passenger ships need further updating?” (Baldacchino, November 22, 2012). Throughout history ship designers have been struggling to build safe, swift, strong ships. Countless ships have been successful, but enough have failed to warrant a look into the history of the failures. A purposeful investigation may shed light onto the design of a future unsinkable ship.

On August 10th, 1628 the warship Vasa set sail in Stockholm harbor. After sailing about 1300 meters, a light gust of wind caused the Vasa to heel over on its side. Water poured in through the gun portals and the ship sank with a loss of 53 lives. It was the most expensive project ever undertaken by Sweden at the time. (Fairley, 2003) The ship sat on the bottom of the harbor for 333 years.(Fairley, 2003) In 1628 no one knew why the Vasa sank and took the lives of 53 crew members. After its salvage in 1961 and a subsequent study of historical records, several conclusions were drawn. Richard Fairley (2003) lists them as follows:

1. Excessive schedule pressure: The Vasa was completed under strong time constraints to meet a pressing need.
2. Changing needs: Many changes to operational characteristics were made during construction of the ship.
3. Lack of technical specifications: The (non-existent) specifications were not revised as the operational requirements changed.
4. Lack of a documented project plan: During a yearlong transition in leadership it was difficult for the assistant to manage the project. This resulted in poor supervision of the various groups working on the ship (i.e., the shipwright, the ship builder, and the numerous subcontractors). There is no evidence that the new project manager (the former assistant) prepared any plans after the original shipwright died.
5. Excessive innovation: No one in Sweden, including the shipwright, had ever built a ship having two gun decks.
6. Secondary innovations: Many secondary innovations were added during construction of the Vasa to accommodate the increased length, the additional gun deck, and other changes.
7. Requirements creep: It seems that no one was aware of the degree to which the Vasa had evolved during the 2 ½ years of construction.
8. Lack of scientific methods: There were no known methods for calculating center of gravity, stiffness, and the resulting stability relationships of the Vasa.
9. Ignoring the obvious: The Vasa was launched after failing a stability test.

10. Possible mendacity: Results of the stability test were known to some but were not communicated to others. (p 5-6)

The loss of the Vasa was a tragedy, but the wealth of knowledge gained from studying its history honors the 53 crew members that died on that day.

On July 3rd 1883 the SS Daphne was launched from Alexander Stephen's Linthouse yard. (Cameron, n.d.) There was a work crew of 200 men and boys aboard who would finish the ship after it was afloat. (Cameron, n.d.) During the launch one of the ship's chains got caught on the bottom of the river and the ship overturned in deep water. (Cameron, n.d.) There were only 76 survivors. (Cameron, n.d.) A dragging chain should not overturn a ship. It was later found that the initial stability of the ship was flawed and there were excessive loose gear and personnel aboard. (Cameron, n.d.) The ship sank because the center of gravity and the center of buoyancy were not properly aligned. Since the ship was not finished, the placement of the weight on the ship was not properly distributed. Furthermore, when the ship was tipped by the dragging of the chain, the equipment slid across the deck. This increased the imbalance between the centers of gravity and buoyancy. The tragedy led to new regulations limiting the number of people allowed on a ship at launch. (Cameron, n.d.)

On May 14th 1986 the Pride of Baltimore sank off the coast of Puerto Rico killing 4 people. The ship was a 90-foot replica of an early 1800's Baltimore clipper. When it was struck by an unexpected blast of wind that knocked the ship on its side, it filled with water and sank within two minutes. (AP, 1986) According to the Associated Press (1986) a study was conducted in 1984 that showed the ship was "unstable and prone to tipping." (p.1) The study said that the Pride of Baltimore would lose its ability to naturally right itself once the ship passed beyond an angle of 30 degrees to the water. Furthermore, the ship was predicted to sink if it went beyond 76 degrees. (AP, 1986). Other ships in the 1984 study could tip more than 120 degrees and still right themselves. (AP, 1986) Information existed to support limiting the travel of this ship to harbor only but was ignored. The loss of life could have been prevented in this case.

The lessons learned by these tragic losses can guide us in the design of future ships. The science, engineering, and technological information exist to build ships that can minimize, perhaps even eliminate, the possibility of a ship sinking. On the other hand, exploring our planet and our universe has always had its risks and always will. No matter how much we try to mitigate loss it will still occur. The ultimate goal is to make our explorations as safe as we can and keep learning from the mistakes of the past.

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Let's Explore

You will now work in teams to explore the concepts of buoyancy, density, volume, and center of gravity.

The Team Members (4 - 5):

List your team members here

_____ is the Task Manager
My job is to keep group members focused.

_____ is the Activity recorder
My job is to record what the team does & what questions the team has.

_____ is the Evaluator
My job is to judge the effectiveness of the team (shared only within the team).

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The Stations:

Check off the stations as you do them:

How Metal "Boats" Float

Liquid Density and Lava Lamp

Soda can Pirouette

Station Instructions:

HOW METAL BOATS FLOAT (5 min)

Verify the materials you need are at the station

- Large bowl
- Water
- Aluminum foil (25 cm square)
- Metric ruler
- Pen

Procedure

Pull the corners of the aluminum foil square together and crumple the square into a loose ball that is approximately six cm in diameter. Rump the aluminum such that the corners stay together and are visible in one spot.

Set the ball gently in the bowl of water, placing it so that the corners are at the top of the ball, as this will help prevent the ball from filling up with water. Immediately observe the ball.

- *Does it sink or float?*

Get down low so that you are at eye level with the aluminum foil ball and quickly observe how much of the ball is below the surface of the water.

- *Approximately what percent of the ball underwater?*

Remove the ball from the bowl, shake out any water and dry it on the towel.

Crumple the ball a little more tightly, until it is approximately 3 cm in diameter. If you crumple it too much, just carefully pull apart some of the aluminum foil to get the desired size.

Set the ball gently in the water, placing the marked corners at the top.

- *Does it sink or float?*
- *What percentage of the ball is below the top of the water?*
- *Remove it, shake out any water and dry it.*

Do it one more time and compress the ball as much as possible

- *Does it sink or float?*
- *What percentage of the ball is below the top of the water?*
- *As the ball gets smaller what can you say about its density?*

LIQUID DENSITY AND LAVA LAMP (5 min)

-Verify the materials you need are at the station

1. An empty water bottle
2. Vegetable oil
3. Food coloring

4. Alka-Seltzer tablet
5. Index card used as a funnel

Procedure

- Fill the water bottle 1/2 full with vegetable oil.
- Slowly add water so the bottle is about 2/3 full. The water will sink to the bottom under the oil.
- Add a few drops of food coloring; your choice of color. The food coloring is water-based, so it will also sink and color the water that is now at the bottom of the bottle.
- Break an Alka-Seltzer tablet into a few small pieces, and drop them in the bottle one at a time.
- Watch your lava lamp erupt into activity! As the reaction slows down, simply add more Alka-Seltzer.

SODA CAN PIROUETTE (5 min)

Verify the materials you need are at the station

1. Empty soda can
2. Water

Procedure

- Try to balance the can on its bottom edge.
- Fill the can about 1/3 of the way full (about 100ml or 4oz) of water.
- Now balance the can on its edge and give it a little tap to see it spin.

Explore Summary

How Metal "Boats" Float

- *As the ball gets smaller what can you say about its density?*

Liquid Density and Lava Lamp

-What scientific principal makes the water rise to the top of the bottle and then drop back down?

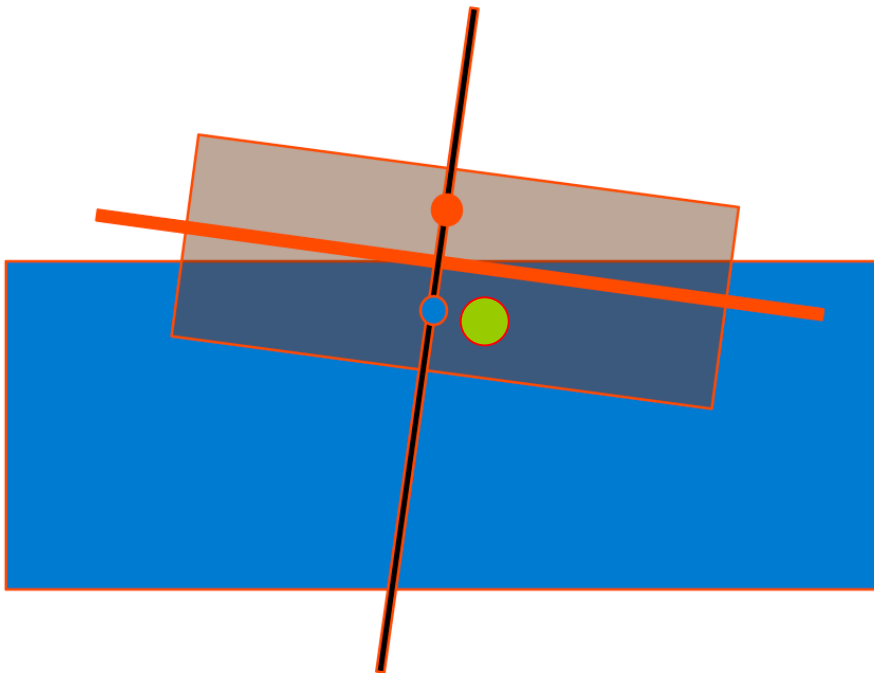
Soda Can Pirouette

-What changed about the can that allowed it to spin?

Exit Ticket

1) Find the displacement of mass of a ship section with cross sectional dimensions of 30m by 8 m and a length of 10m.

2) Use the diagram to find the metacenter



Design Packet

Students will work in their design teams to sketch different hull designs to fit the specifications of a new Littoral class. Teams can choose from any combination of the hull design elements. Teams must consider the scale of their drawing in relation to the full size ship.

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The prototype design

The engineering design process involves a series of steps that lead to the development of a new product or system. In this design challenge, students are to complete each step and document their work as they develop their littoral class ship.

Your ship must have the following specifications:

- Length must be 128 cm
- Width 32 cm
- Displacement depth 4.3 cm
- Hull shape up to the designers but ship must be stable and must displace its weight in water

SESSION ONE

Your team has one hour to work through the design process below.

<p>Define the Problem-State the challenge problem in your own words. Ex. How can I design a _____ that will _____?</p>
<p>Identify Criteria and Constraints -- Specify the design requirements (criteria). Example: Our growth chamber must have a growing surface of 10 square feet and a delivery volume of 3 cubic feet or less. List the limits on the design due to available resources and the environment (constraints). Example: Our growth chamber must be accessible to astronauts without the need for leaving the spacecraft.</p>
<p>Brainstorm Possible Solutions -- Each student in the team should sketch his or her own ideas as the team discusses ways to solve the problem. Labels and arrows should be included. These drawings should be quick and brief.</p>
<p>Generate Ideas -- In this step, each student should develop two or three ideas more thoroughly. Students should create new drawings that are multiple views showing the top, front and one side, and three-dimensional depiction drawings. These are to be drawn neatly, using rulers to draw straight lines and to make parts proportional. Parts and measurements should be labeled clearly.</p>
<p>Explore Possibilities -- The developed ideas should be shared and discussed among the team members. Students should record pros and cons of each design idea directly on the paper next to the drawings.</p>
<p>Select an Approach -- Students should work with the team and identify the design that appears to solve the problem best. Students should write a statement that describes why they chose the solution. This should include some reference to the criteria and constraints identified above.</p>
<p>Build a Model or Prototype -- Students will construct a full-size or scale model based on their drawings. The teacher will help identify and acquire appropriate modeling materials and tools. See the design brief for a sample list.</p>

SESSION 2

Test and Refine the Design -- Students will examine and evaluate their prototypes or designs based on the criteria and constraints. Groups may enlist students from other groups to critique the solution and help identify changes that need to be made. Based on criteria and constraints, teams must identify any problems in their design and propose solutions to resolve the problems.

PROJECT NOTES

- The students will make three cardboard cutouts of their hull design section. The first will be the full deck height. The second will be just the bottom below the water line. The third will be the bottom cut off at an angled water line (used later to find center of buoyancy when ship is at an angle).
- The students will use graph paper to approximate the area of their hull below the water line.
- They will then multiply the area by the length of hull they plan to use, resulting in volume. If their hull narrows in the front they can approximate that volume further by multiplying their cross sectional area by the length of the front divided by 6 (similar to how one would measure half a cone).
- These calculations will give the teams the volume of their displaced water. Multiplying this volume by the density of salt water will give them the mass they can displace.
- The students are to find the mass of the clay they are given and compare it to the displacement mass to see if they are displacing enough water to make their boat float. The students who combine multiple hull designs will have to divide their clay for each section to make sure the displacement for each section is correct.
- If their design will not displace the correct amount of water they should modify it and try again.

Students must also check the stability of the ship by making sure the metacenter is above the center of mass. They will perform this calculation by:

- Finding the center of mass of all three cut outs.
- The two shapes that represent the displaced water will represent the buoyant centers (one level and one at an angle).
- The students will stack all three shapes on top of each other and find the metacenter (will be demonstrated in PowerPoint).
- The Students will have to make a guess at the stability if they use multiple sections. For example: A back that is very stable with a front that is not as stable may balance out.

Instructor will act as coach and move among the teams.

Students in their design teams will evaluate the prototypes

Evaluation of team number #

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Rubric

1) Percentage error between predicted water line and actual water line.

Predicted distance from water line to bottom of ship

Actual distance from water line to bottom of ship

Percent error:

2) Stability test under wave conditions.

Weight one success or fail

Weight two success or fail

Weight three success or fail

3) Overall design appeal and creativity – 1 to 10(10 being best)

Students in their design teams will evaluate their prototypes to determine redesign
The Team Members (4 - 5):

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Teams are to reconvene and reevaluate their calculations to determine the following:

- Explanations for percentage error
- Discussion on the stability of their prototype and what improvements could be made.
- If they were to make another prototype, what would they do differently?