Incorporating Systems Thinking/Systems Engineering Topics into an Introduction to Mechanical Engineering Course through a Course Project

"The Wave Tank Project"

SOUTH DAKOTA MINES
An engineering, science and technology university

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The Wave Tank Project

Overview

This wave tank project was conducted in a freshman level Introduction to Mechanical Engineering course at the end of the semester to demonstrate the importance of systems thinking. Students were assigned the task of designing a boat using materials provided in a kit. The boat was to be designed to withstand the addition of weights, either in the form of glass marbles or steel spheres, with a stated goal to the students of designing the most buoyant boat.

To incorporate systems thinking into the project, the tank used to test boat buoyancy included wave pumps to create a turbulent water environment. As the instructors accurately predicted, the freshmen students did not think to consider the environment in which the boats would be tested, and most students were not prepared for the turbulence during the preliminary testing. The goal of the preliminary test was to serve as an eye-opening experience, to encourage curiosity about system context. Teams were given a second chance to redesign their boats for a second official test to account for the complexity that the turbulent water added. In addition, the second test was also made to be competitive with the ‘best team’ defined as the one that could hold the most weight relative to the boat’s weight. To rank the teams according to performance, a buoyancy score was used. The buoyancy score is defined as:

$$\text{Buoyancy Score} = \frac{Ballast\ Weight}{Boat\ Weight}$$

This project was assigned to both the Fall 2019 and Fall 2020 sections of the Introduction to Mechanical Engineering course at the South Dakota School of Mines and Technology. This document serves as a guide to others wishing to implement the project. The instructions document that was provided to the students is also attached within and specifies the constraints and objectives of the project.

Wave Tank Equipment and Setup

The test setup is easily replicated with components from online shopping sites like Amazon. The tank itself should be obtainable from a pet store that sells aquariums. The parts that were used and an estimate of the cost of the setup are given in Table 1.

Table 1. Wave tank test setup parts list.

Product	Name	Qty	Unit Price	Link
Tank				
20-gal fish tank	Aqueon Standard Glass Aquarium Tank 20 Gallon (purchased locally in store)	1	$39.99	https://www.petco.com/20-gallon-tank
Wave Pumps				
Wave pump kit (1050 GPH)	Current USA eFlux Wave Pump Kit	2	$104.22	https://www.amazon.com/e-flux-wave-pump-kit
Accessory wave pump (1050 GPH)	Current USA eFlux Accessory Wave Pump	2	$71.13	https://www.amazon.com/wave_pump_accessory
Additional				
Steel Spheres (0.75" dia.)	PGN - 3/4" Inch (0.75") Precision Chrome Steel Bearing Balls G25 (10 PCS)	1	$6.99	https://www.amazon.com/PGN-Precision-Chrome-Steel-Bearing/
Steel Spheres (0.5" dia.)	Ten 0.5" chrome ball bearings	5	$5.90	https://www.amazon.com/PGN-Precision-Chrome-Steel-Bearing/
Water Preserver	55 Gallon Water preserver Concentrate	1	$13.99	https://www.amazon.com/Water-Preserver
Power Strip	AmazonBasics 6-Outlet Surge Protector Power Strip, 6-Foot Long Cord, 790 Joule - Black	1	$9.98	https://www.amazon.com/AmazonBasics-SurgeProtector
Go Pro (optional)				
Go Pro Hero 7 Black	GoPro Hero 7 Black Edition with Two Extra GoPro USA Batteries + Sandisk Extreme 64GB MicroSD + Free Polaroid 16GB MicroSD (80GB Total)	1	$339.99	https://www.amazon.com/GoPro-Batteries
Go Pro battery Charger	GoPro Dual Battery Charger + Battery for HERO7/HERO6 Black/HERO5 Black (GoPro Official Accessory)	1	$37.75	https://www.amazon.com/GoPro-Battery-Charger
Suction Mount	GoPro Suction Cup Mount (GoPro Official Mount)	1	$33.96	https://www.amazon.com/GoPro-Suction-Cup-Mount
Total setup cost			$451.15 $862.85	*cost without GoPro *cost with GoPro

Notes on Setup

In addition to the materials listed in Table 1, a few other components and tools were required to conduct the experiment. Most notably, a scale was required to assess the ballast weight. Other miscellaneous components like tape and double-sided tape were also useful. Glass spheres (playing marbles) were used as the preliminary test weights. Most of these materials were already available in the lab in which the experiment was conducted and are therefore not listed in Table 1.

The items listed in "additional materials" of Table 1 may or may not be required. The water preserver didn't have much influence on the water quality in the wave tank and may not be required if the tank is prepared just before the test and cleaned afterwards. The power strip helped keep all the wave tank power cables organized, but again may not be required depending on the location and configuration of the setup.

The GoPro was an interesting addition to the setup as it let the teams watch their boats from a surface level point of view. An additional GoPro under the water level would have been an interesting addition to see how the boats behave just after taking on water and sinking. The GoPro items may be excluded to fit a budget if required.

Instructions for Setup

Once the equipment for the wave tank is acquired, the instructions below can be followed for set up. Most of the components of the wave tank are modular.

1. Place the wave pumps below the water line as shown in Figure 1. Two pumps will be connected to one controller hub and must be placed on opposite sides of the tank. These will alternately push water, causing the wave effect. The other two pumps (connected to another controller hub) can be placed opposite of each other, beside the first set. In Figure 1, the two pumps shown at the front of the tank (bottom of the image) are connected to two different controller hubs.

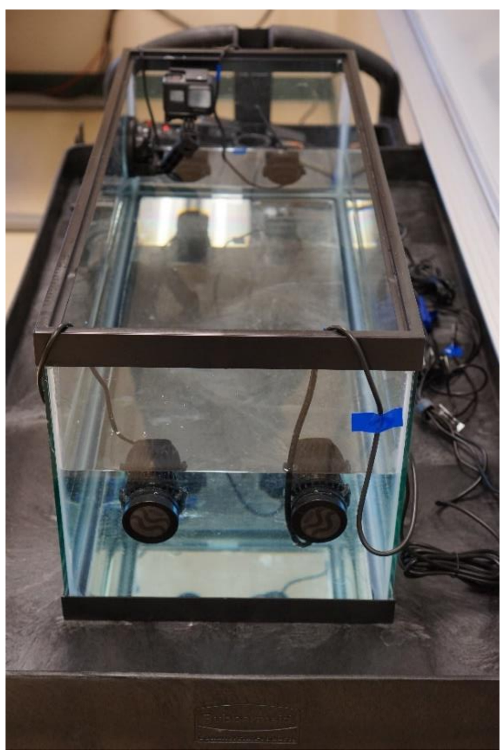

Figure 1. Wave pumps placed below water line.

2. Connect the power supply for the wave pumps and the wave pumps to the controller hub as shown in Figure 2. Tape the controller hub and LED displays down as shown in Figure 2.

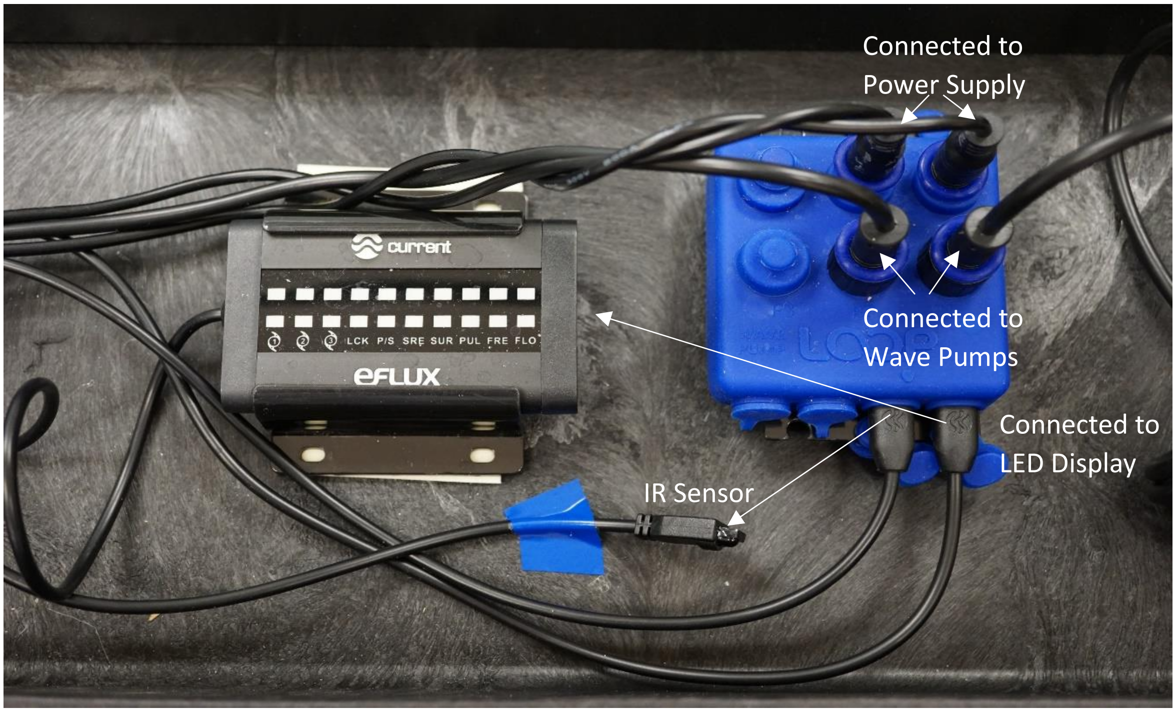

Figure 2. Controller hub and LED display setup showing proper connections.

3. Fill the tank with water to a level just above the pumps.
4. If the GoPro is being used, attach it to the tank with the suction cup as shown in Figure 3.

Figure 3. GoPro and mount.

5. Connect the power cables for the pumps to the surge protector. Remember to be cautious that water does not get into any of the outlets or connections.

6. Turn on the two sets of pumps at the same time with the provided remote controller. Adjust amplitude and frequency of the waves using the controller until wave motion is observed, as shown in Figure 4. For the tests conducted during Fall 2019 and Fall 2020, both the amplitude and frequency were set to half of the maximum setting. The settings may need to be configured to get the appropriate wave-like motion based on tank size, water level, etc.

Figure 4. Side view of wave motion after two sets of wave pumps are turned on.

Materials Provided

Option A – Wood Kit

For the Fall 2019 implementation of this project, a wood kit was used by students to construct boats. The materials that were provided to the students in the materials kit are given in

Table 2. Many of the smaller parts like wooden cylinders and sticks were locally sourced. The recommendations in Table 2 serve only as guides, as availability will be variable. From the kit, the most important components were the balsa wood sheets. An important observation with the wood kits was that glue used to keep components together dissolved in the water, making it murky over time. The components of the kit will be dependent on what is available and convenient for the instructor.

Table 2. Materials for the wood kit (Option A).

Part	Pieces per team	Price per team	Link
Consumable Parts			
Balsa wood sheets (150mmx100mmx2mm)	8	$7.00	https://www.amazon.com/15pcs-Sheets-Wooden-Airplane-150x100x2mm/ ($14.00 for 15 sheets)
Misc. wood sticks and pieces (optional)	20	$16.00	* Hobby Lobby (purchased locally)
Non-Consumable Parts			
Excel blade handle	1	$9.21	https://www.amazon.com/Excel-Blades-Safety-Hexagonal-Handle/
General purpose Shears	1	$5.95	https://www.amazon.com/VIVOSUN-Gardening-Pruning-Straight-Stainless/
Hot glue gun with glue sticks	1	$12.00	https://www.amazon.com/Projects-Sealing-Repairs-NEU-MASTER/
Cost estimate of a basic kit:		$ 50.16	

Option B – 3D Printing

For the Fall 2020 implementation of this project, 3D printing was used by students to construct boats. This alternative may be a better option if sourcing materials listed in Table 2 is not possible and if 3D printing is available. During the Fall 2020, students were asked to design boats in a CAD software program such as SolidWorks, which were then converted to .stl files for compatibility with the 3D printers used. The boats were printed using PLA material.

Instructions for the Preliminary Testing (Test 1)

These were the steps followed in both the Fall 2019 and Fall 2020 conduction of Test 1.

1. Weigh the boat.
2. Give the team an option of turning on the waves before putting the boat in the tank or after. Accordingly turn the waves on.
3. Place the boat into the tank.
4. Place marbles one by one into the boat until it sinks.
5. Weigh the ballast (marbles).
6. Divide ballast weight by boat weight to obtain the buoyancy score.

Instructions for the Final Official Test (Test 2)

These were the steps followed in both the Fall 2019 and Fall 2020 conduction of Test 2.

1. Weigh the boat.
2. Give the team an option of turning on the waves before putting the boat in the tank or after. Accordingly turn the waves on.
3. Instruct team member to place boat in the center of the tank.
4. (For Fall 2019) Have team member gently and gradually place 4 ¾" steel spheres one by one in the center of the boat. Next, have team member gently and gradually load the boat with ½" steel spheres one by one until the boat sinks.
   OR

4. (For Fall 2020) Have team member gently and gradually load the boat with either the 4 ¾” steel spheres or the ½” steel spheres (or a mix) one by one until the boat sinks. The distribution and use of different ballast sizes was left up to the team to decide.
5. Weigh the ballast (steel spheres).
6. Divide ballast weight by boat weight to obtain the final buoyancy score.

Post Experiment and Scoring

Scores for the teams were calculated at the conclusion of their second testing. The boats of each team were photographed and put together with the buoyancy scores in a PowerPoint Presentation. If a GoPro was used during testing, a short clip of each boat was presented to the class at the end of the experiment. Students were required to submit a short project report which explained the concepts generated, the building and testing process and the teaming lessons learned along the way. During the final week of class, each team made a short presentation describing their building process, experiences and lessons learned during the final project.

Suggestions for Carrying out the Experiment

A central idea for the learning objective of this project was for students to question the system context and understand the environment in which their boat would be required to perform. To achieve this goal, it was important to keep concealed the fact that wave pumps were going to be used in the wave tank to add turbulence. If a team asked, it was revealed to them separately, since it showed awareness of understanding the system context. However, revealing the wave pumps to the whole class would have taken away the advantage that the inquisitive team fairly gained. It was also beneficial to the concept generation and selection process if teams did not communicate with each other about their boat’s performance after the unofficial test. At the conclusion of second testing, all of the final designs were revealed.

Final Project Information

Note: This is the information document for the experiment that was conducted in the Fall 2019 and Fall 2020 semester using the wood materials kit. Specific dates have been replaced with week estimates based on a 14 week semester.

Project Introduction

Buoyancy is an important topic that many mechanical engineers must deal with. The principle of buoyancy states that the force acting on a submerged or partially submerged object equals the weight of the liquid that the object displaces. Because of buoyancy, ships stay afloat. This principle also gives us a means of calculating density of materials. For a ship to be seaworthy, it must maintain a balance between buoyancy and stability. A vessel that is too light, meaning too much volume and too little density, will be unstable. Therefore, it needs to carry a certain amount of weight for it to displace water. With added weight, its hull will sink further from the surface increasing stability.

For this project, each team will propose a concept for a "seaworthy" an exceptionally buoyant small-scale boat that can be made using only the materials and tools included in a kit provided by the course instructor. Each team will use the materials and tools in the kit to build the boat concept selected by the team members. At the end of the semester, we will have a competition to see which team has the lightest, most buoyant boat.

Project Description

Note: Project assigned approximately during week 7.

1. Students will work in their assigned teams for the project.
2. The project constraints are as follows:
   - The length of the boat cannot exceed 4.5 inches.
   - The width of the boat cannot exceed 3 inches.
   - The height of the boat cannot exceed 3.5 inches.
   - The boat must be made using only the materials and tools included in a kit provided by the course instructor.
   - Sharing ideas between teams and/or trying to find out information about the designs being considered by other teams is not allowed.
   - With the exception of the course instructor and the faculty and staff of the Mechanical Engineering Department Manufacturing Lab, you cannot request help from persons that are not members of your team.
3. After doing research about boats, the team will brainstorm possible boat ideas (concepts), select one, and build their boat.
4. During the approximately 9th workweek each team will schedule with the instructor a time to conduct an initial test of their boat. This activity will take place outside of the regular class time.
5. The teams will use the lessons learned from the initial test to change/improve/refine their boat design.

6. The final project presentations and the final project competition will take place approximately during the 13th workweek.
7. The details of the final project competition are as follows:
   - The competition will consist of adding ballast (weight) to each boat until sinking occurs. The type of ballast that will be used will be decided by the course instructor the day of the competition.
   - The ballast will be added by the course instructor, and the amount of weight required to sink the boat will be noted as the "final ballast weight".
   - Competition scoring will be based on 2 items:
     1. A buoyancy score that will be computed as follows:

        $$Buoyance\ score = \frac{Final\ ballast\ weight}{Weight\ of\ boat}$$

     2. The judges score of the overall design (aesthetics, function, feasibility, etc.).

   - Your grade for the project will consist of your competition score, your team's technical presentation, your team's final project memorandum, and an assessment of your performance by your teammates.

<u>Final Project Technical Presentation Requirements – Due: Approximately Week 13</u>

- 5-6 minute presentation summarizing the topics that need to be included in the final project memorandum.
- Everyone in the group must participate in the presentation and be professional.
- Show pictures of the boat that your team built that highlight key features of the design proposed by your team.
- Explain calculations used to design the boat and to predict how the boat will perform in the competition.
- Prepare the presentation using MS PowerPoint.

<u>Final Project Memorandum Requirements – Due: Approximately Week 14</u>

Each team will provide a brief memo describing their design and competition performance (at least a 4-page memo excluding pictures, using previously employed memo format). Topics the memo should touch on (this is not exhaustive, there are more):

- Description of your team's design process – ideas, preliminary designs, etc.
- Description of any calculations your team used in the design of your boat.
- Description of how your team built your boat.
- Pictures and description of your final boat.
- Assessment of how your boat performed in the competition.
- What your team learned about teaming while working together on the project.

Team Evaluation – Due: Approximately Week 14

Each individual will be allowed to evaluate the performance of their teammates (the average scores will be used to weight the students individual grade). A form for the team evaluation will be provided later in the semester.