Mechanical Design, Modeling and Testing of a Variable-Buoyancy Kinetic Sculpture

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Background

The objective of this project is to design, build and test a prototype of a variable-buoyancy kinetic sculpture. This project is born from the creative mind of Gordon Reeve. Gordon Reeve is a well-known sculpture artist from Winnipeg. Mr. Reeve has conceived a kinetic sculpture consisting of three large floating metal pieces. In his vision of the sculpture, each piece completes an independent floating-sinking cycle. The cycle begins with the piece floating calmly on the surface of the water. Then, with the up-wards water spray of a sinking ship, the piece plummets to the bottom of the body of water where it remains dormant for some time. Suddenly, without warning, the piece becomes buoyant again, and bursts from the surface of the water to repeat the cycle again. Each of the three pieces completes its cycle with a unique frequency and phase.

Objectives

The design, building and testing the prototype of a variable buoyancy kinetic sculpture was performed to:

- Help acquire funding for the full-sized sculpture by showcasing the sculpture's motion
- Identify the important parameters which control the dynamics of the sculpture
- Provide insight into the issue of roll stability
- Identify energy requirements in the buoyancy control of the piece

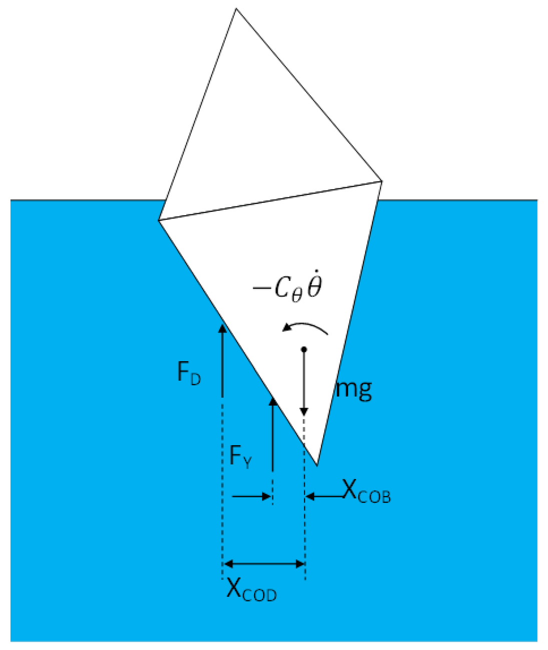
Testing of the piece attempted to

- Capture the 3D motion of the piece during floating and changes in buoyancy
- Quantify the limitations of the prototype's roll stability
- Characterize the motion of the prototype as "artistic" or "not artistic"

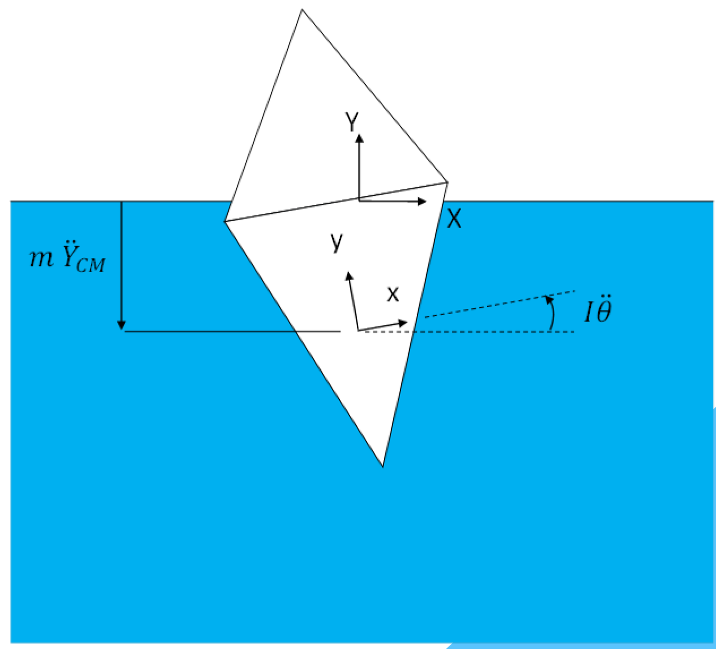
Modeling

$$m\ddot{Y}_{CM} = F_Y(Y_{CM},\theta) + F_D(Y_{CM},\dot{Y}_{CM},\theta) - mg$$

$$I\ddot{\theta} = F_Y(Y_{CM},\theta)\cdot X_{COB}(Y_{CM},\theta) + F_D(Y_{CM},\dot{Y}_{CM},\theta)X_{COD}(Y_{CM},\theta) - C_\theta\dot{\theta}$$



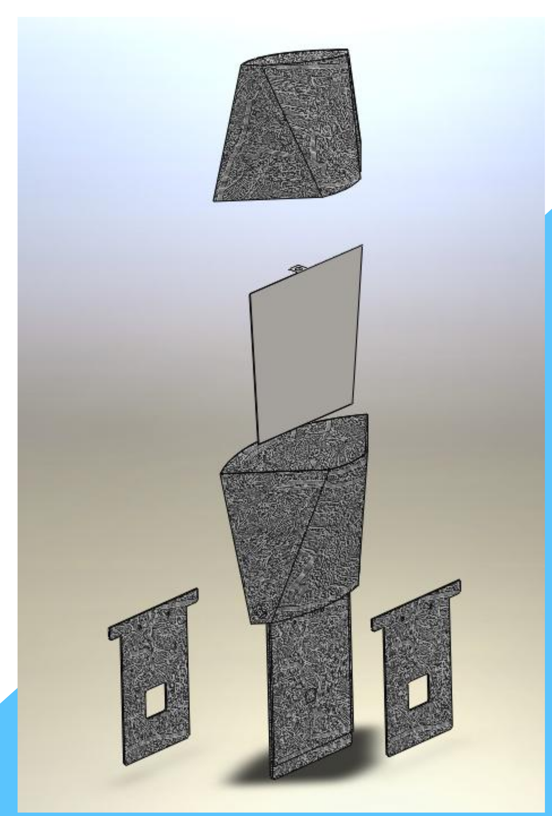
Free Body Diagram



Kinetics Diagram

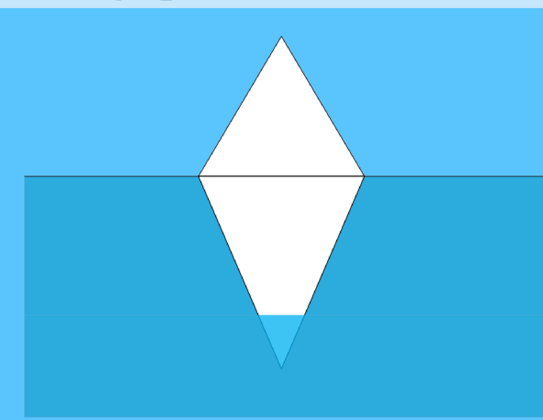
A two degree-of-freedom model was created in order to determine the critical parameters which controlled the motion of the piece. The two degrees-of-freedom examined in the model were the vertical and rotational components of motion. The relationship between the center of mass (X_{COM}) and the center of buoyancy (X_{COB}) was found to be the most crucial in determining the passive roll stability of the piece. The center of buoyancy is located at the centroid of the submerged area.

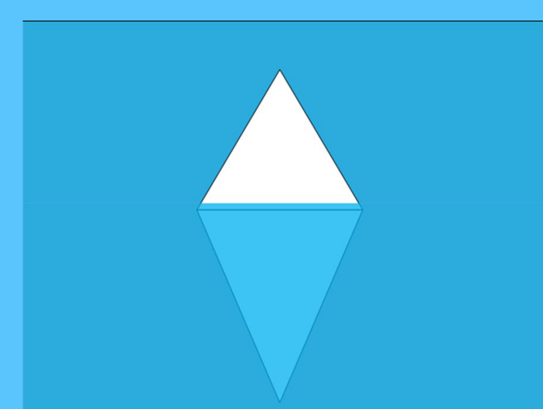
Mechanical Design and Building the Prototype

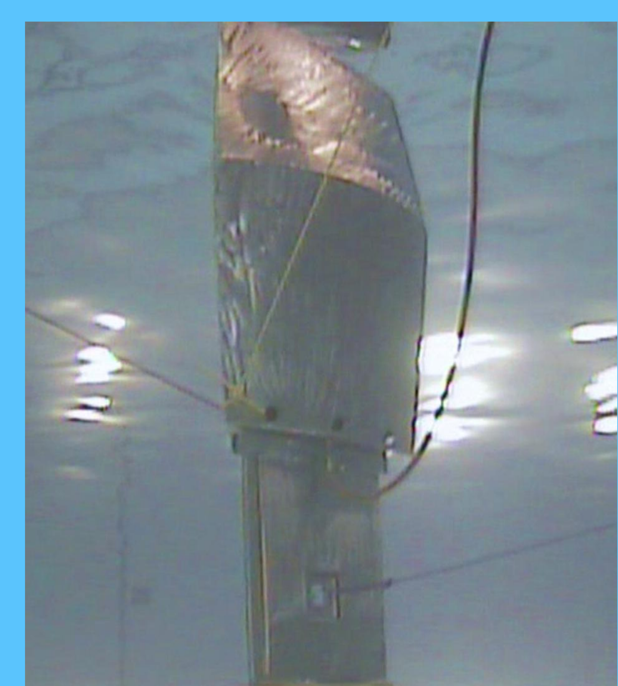


The prototype was made from 14 Gauge 316B Stainless Steel. The piece consisted of a hollow structure with a solid stainless steel keel attached at the bottom. The keel served to lower the center of mass without significantly changing the center of buoyancy.

The buoyancy of the piece was controlled using compressed air. To make the piece float, compressed air was forced into the piece, causing water to drain through holes in the bottom of the structure. To make the piece sink, air was released from the piece, causing it to fill with water.


Floating


Sinking



The above images show the completed prototype during testing. An air hose was attached to the bottom of the hollow body, which connected to a steel pipe inside the piece to enable air to enter and exit the body. Ropes were attached to enable adjustment of the piece's position. Ropes were left slack during changes in buoyancy and stability tests.

Testing

Preliminary testing was conducted in University of Manitoba swimming pool. The preliminary testing was primarily intended to judge the buoyancy control and passive roll stability of the prototype. The motion of the piece was captured using 2 above-water cameras and 1 underwater camera. No quantitative data was obtained, however, approximate pressures required by the air compressor were obtained and a strong qualitative sense of the piece's motion and stability were acquired.

Discussion

The first testing on the prototype was very encouraging. The buoyancy of the piece could be easily controlled and the piece exhibited excellent passive roll stability. The main short-coming of the prototype was its overly-rigid and mechanical motion. The sinking part of the piece's buoyancy cycle was also found to be unsatisfactorily slow.

Future Work

Although the first testing was successful, obtaining more quantitative data describing the motion will be valuable for future steps of the project. As such, further testing is planed to try and generate numerical information about the piece's motion and to parametrically study the impact of various parameters on the motion of the piece. A second generation prototype is also planned to create more energetic and exciting motion.

Acknowledgements

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