A Buoyancy Engine for the Seaperch Platform Built with Locally Acquired Materials

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The buoyancy engine is a common feature among underwater gliders used for oceanic research. This project outlines the design, calibration, and use of a buoyancy engine that can be used with the Seaperch made from easily accessible, inexpensive materials. The buoyancy engine is designed to utilize two working fluids, air and cooking oil. By adding either of these fluids to the Seaperch, the Seaperch will rise underwater, thus becoming a buoyancy engine. By using cooking oil as a working fluid, the system closely resembles a hydraulic system, while using air as the working fluid causes the system to behave similar to a pneumatic system. This project allows students to gain practical experience with buoyancy as well pneumatic and hydraulic systems which will hopefully supplement their education and help them in their future endeavors.

Definitions:

- Hydroglider: (Underwater Glider): an underwater vehicle which converts vertical motion due to small changes in its buoyancy to horizontal motion, propelling itself forward with very low power consumption.
- Buoyancy Engine: The device which causes changes in buoyancy in underwater gliders.
- Hydraulics: a system of actuated by the movement of oil by pistons through pressurized tubing.
- Pneumatics: systems which operate through moving air through pressurized lines with actuated pistons

Introduction

Since 1960, when Ewan S Fallon produced his "hydroglider" based on his new "buoyancy engine", data collection in the deep sea has never been the same. [1] Since then, gliders have been used extensively to collect data for scientific studies throughout the world. Some current models utilize a ballast system in which submerged volume is controlled by an oil bladder, which is either displaced outside the glider or pulled into the housing. By controlling the angle at which they ascend or descend, gliders can move enormous distances underwater, periodically surfacing to transmit data to be analyzed. Some of these gliders have ranges up to 35,000km [2] and are only constrained by the batteries used to transmit data to the receiver, making them a valuable research tool for scientists all over the world.

Though it is clear that buoyancy is a powerful force when properly utilized, it is an often misunderstood phenomenon. Even when students measure the forces of buoyancy on an object underwater, they can still find it difficult to understand the mechanism which causes it. [3] Some students often believe that the presence of air in an object causes it to float. Though air often makes things float by virtue of its very low density, it is not the air, but rather the volume displaced by the air which causes the buoyant force on the object. By using a medium other than air in a buoyancy engine, it would illustrate that it is indeed the water, not only air which causes things to rise and fall due to buoyant force. This would be a useful aid in physically demonstrating the proper source of buoyant force to students.

Goals

In this article, we will develop a method by which we can harness a buoyancy engine to control the small Seaperch ROV. The intent of this design is to provide a practical illustration of how buoyancy affects underwater vehicles, serving as a teaching aid to younger students. Since the idea of buoyancy can sometimes be a difficult concept for some to understand, it will be helpful to have a physical application in which students can see and feel the way that buoyancy works. This way, they can more fully understand and apply the phenomenon so they might use it in their future endeavors.

The other benefit of our discussion will be a practical illustration of pneumatics and hydraulics. These systems are extremely useful, and common in engineering, but younger students do not often get the opportunity to use these systems until they are much more experienced. [6] We will use both of these systems in this design in a way that students can learn a little more about their intricacies, and be less intimidated by the complexity of some of these systems in their futures.

Because this article is to appeal to younger students, the design presented will consist of parts which are inexpensive and easily acquired. It should be simple enough for a student to independently assemble, but still complex enough to provide an interesting and challenging project to supplement their learning.

Methods

The engine conceived for this project operates through driving fluid from reservoirs attached to the control box of the Seaperch to a cylinder attached to the ROV underwater. An appropriate fluid for this application is cooking fluid, since it is relatively inexpensive and easily acquired, yet it is less dense than water. As oil is pumped into the ballast attached to the Seaperch, the total displaced volume of the Seaperch will increase. This causes the buoyant force on the Seaperch to also increase according to the following relationship:

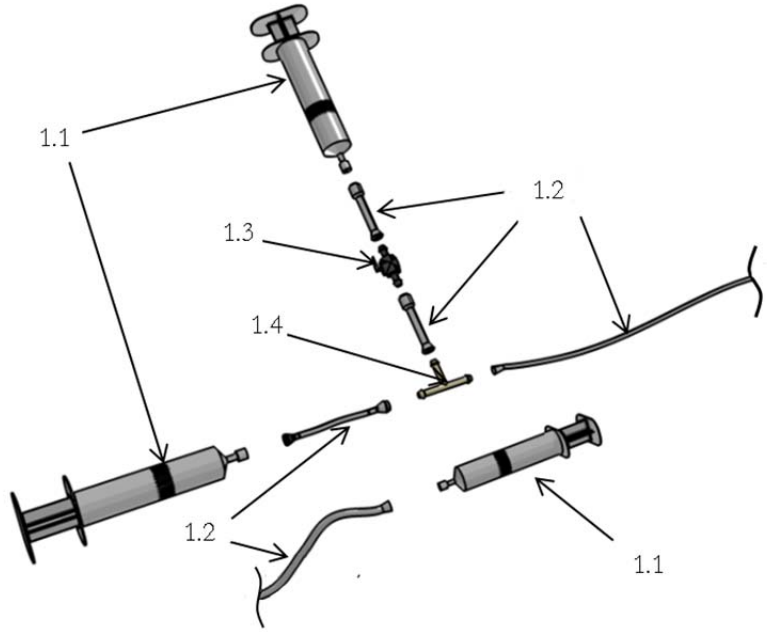
$$B = \rho V g. \qquad (1)$$

Where B is the buoyant force, ρ the density of the surrounding fluid (in this case, water), g the gravitational acceleration (9.81m/s^2), and V is the volume displaced by the object in the water. Because the object underwater will have its own mass, gravity will cause an additional force downward on the object. These two forces will directly oppose each other as explained by Eq 2.

$$F_{net} = B - mg \qquad (2)$$

These two equations together explain why some things float in water, while others sink. If the gravitational force on an object is greater than the weight of the water displaced by it, then it will sink. If not, then it will rise up out of the water until enough of the object is above the surface that the displaced volume decreases. Such that the buoyant and gravitational forces are exactly equal. Since fluids such as cooking oil are lighter than water per the same volume, i.e. less dense. Adding more fluid to the object actually causes the object to rise, even though the object weighs more with the additional mass. [4] The buoyant force caused by the additional displaced volume more than compensates for the additional weight, which causes it to rise against our intuition.

We will use both cooking oil and air in this design and compare the effectiveness of each. The air will provide a greater range of motion for the Seaperch, but using oil will allow us to make very minor, accurate adjustments to the buoyant force acting on the Seaperch.



Assembly Schematic *Fig 1*

Design

As mentioned before, this device operates using a system of large syringes to push fluid in and out of the main body of the Seaperch. The largest syringes normally available generally have a 60mL capacity; this is sufficiently large for our purposes, though larger syringes may also be used for even greater versatility. Below is a bill of materials and general schematic of the parts used in this design. All of these parts can be found at chemistry supply stores and should cost less than twenty dollars total for all the parts.

Bill of Materials *Table 1*

(note all prices are approximate, and may vary significantly)

#	Item	Qty.	Cost
1.1	60-mL Syringe	3	$7.00
1.2	¼" tubing	18ft	$5.00
1.4	¼" T-Junction	1	$0.30
1.3	¼" Ball Valve	1	$2.00
	Total		$14.30

As can be observed from the schematic, assembly is generally very straight-forward, with each part leading clearly to the next. All parts are fitted together using ¼" diameter tubing, with basic seals between fittings and syringes. Tubing between the T-junction and the syringe in the lower right corner of the schematic has been cut out of the picture for a more concise view. This portion of tubing should be at least 15 feet long – preferably as long as the tether from the control box to the main body of the seaperch.

This last syringe (lower right hand corner of schematic) or "main cylinder" is used as the main ballast container on the Seaperch. It is attached to the main cross member, in replacement of the vertical motor, which provides a sturdy support but does not interfere with the function of the other motors. Zip ties or duct tape would be excellent choices for attaching the syringe to the Seaperch, though other alternatives are definitely acceptable.

Once the Seaperch buoyancy engine has been assembled and installed, it must be calibrated to create a controlled system. To do this, the ball valve is left open while oil is added to the main cylinder on the seaperch until the seaperch neither rises nor falls in the water then the ball valve is closed. Foam is also added or removed from the upper cross members to cause this equilibrium to occur at an acceptable level, establishing a base equilibrium point. Then the Seaperch is actuated by the other syringe. Removing oil will cause the Seaperch to sink, while adding oil will cause it to rise.

To remove the oil and switch to air, one can simply remove all the stoppers from the syringes, allowing the oil to drain out the tubing and into some collector, and then replacing the stoppers on all the syringes. Since air is a compressible fluid, calibration is also quite different. Rather than using the second syringe to create a base equilibrium point under the water, it is instead used in tandem with the other syringe to fill and empty the main cylinder, the ball valve being left constantly open. The same process is utilized in actuating movement with air as with oil.

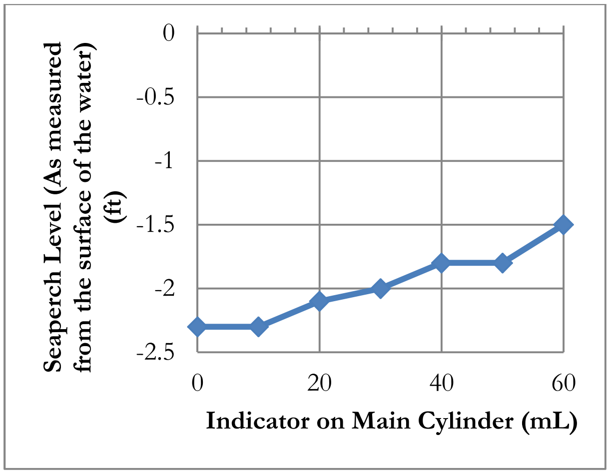
The testing of this system was performed with a Seaperch with the system installed, placed in a local pool. After an acceptable equilibrium was established, fluid was pushed in and out of the main cylinder, forcing the Seaperch to rise and fall under the water. The independent variable was established as the amount of volume displaced in the main cylinder, indicated by the tick marks on the side of the syringe. The distance from the top of the Seaperch to the surface of the water was measured with a measuring tape. This was performed in a pool which had a depth of five feet; chosen to facilitate the hand held operation of a measuring tape. However, it was quickly discovered that the air-based system had a range much greater than the 5 foot depth allowed. This unforeseen complication resulted in limited data about the full extent of the air based system's range, but it did indicate sufficient information for this study.

Results

With a 60mL syringe, the difference in buoyant force on the Seaperch that can be actuated by the engine can be calculated as follows:

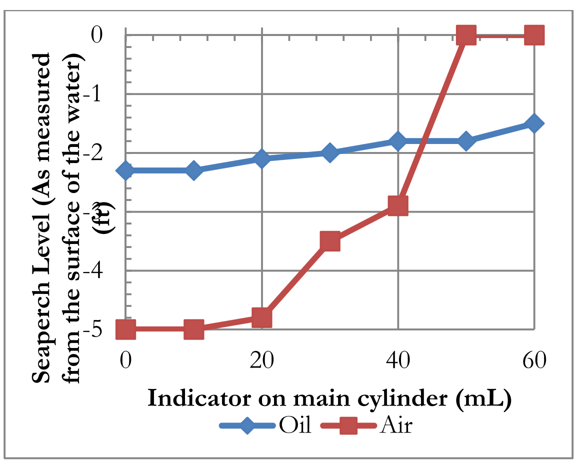
$$\Delta F = \Delta V g(\rho_{water} - \rho_{oil}) \qquad (3)$$

Where ΔF is the change in force on the Seaperch, and ΔV is the amount of volume that has been pushed into the main cylinder. (In the case of oil, this is equal to the amount of volume ejected from the syringe, which can be easily viewed from the indicators on the side.) Cooking oil has an average density of .86 g/mL, [4] so the full range of force available to the seaperch with this system is approximately .0823 Newtons, or .296 ounces. This is not an enormous difference, but it is enough to make the seaperch rise and fall in the water, though not very quickly. After the buoyancy engine has been calibrated, the Seaperch will be apparently weightless, so any change in buoyant force will be enough to cause movement, however slight. Fig 2 is a diagram which shows the vertical movement associated with the amount of oil pushed into the main cylinder.



Approximate Level reached with accompanying Amount of fluid added: oil *Fig.2*

Using Eq. 3 with air instead of cooking oil (using density of air .00118g/mL),[5] we can determine that the amount of force available to the Seaperch will be on the order of .587 Newtons, or 2.11 oz. This is almost ten times the amount of force available in the oil system, due to the difference in density between air and oil. Figure 3 compares the test results of these two systems.



Approximate Level reached with accompanying Amount of fluid added: oil *Fig.2*

Discussion

As can be seen from the diagrams above, the amount of movement available to the Seaperch is much greater when using air instead of oil, but both systems are effective in raising and lowering the Seaperch in the water. The oil has a greater "sensitivity" to changes in volume. To explain this, we can see that 1 mL of oil added to the Seaperch causes a difference of 0.001372 N in buoyant force on the Seaperch, meaning that we can be much more accurate in creating equilibrium on the seaperch under water. However, since we only have a 60mL capacity in our main cylinder, we are limited in the range of the instrument. Using air increases the range, but lowers the sensitivity. The air instrument has a sensitivity of 0.00979 N/mL, almost ten times as large, meaning it will be more difficult to make small adjustments underwater. On the other hand, the range is equally increased, allowing ten times the maximum force available.

Students can use this information to determine which solution they wish to apply to their Seaperches, or even switch between them and experiment with the different properties of oil and air based systems. Aside from the response of system which has already been discussed, the students will feel the difference in their actuation. Since air is a compressible fluid, the response will have a slightly delayed reaction, a common occurrence among pneumatic systems. Hydraulic systems do not have this delay because oil is non-compressible but it takes more force to move fluid through the lines. As students use these systems, they will gain an intuitive understanding of how these systems work and will hopefully feel more confident in using them in the future.

One notable advantage of using the buoyancy engine rather than a vertical motor is the ability to achieve equilibrium under water. The use of a vertical motor either provides a force up or down and causes us to constantly control the Seaperch's elevation under water. With this design, the Seaperch is able to maintain a constant level in the water, which is actuated by the amount of fluid in the main cylinder. This provides greater control of the movement of the Seaperch, and therefore reduces the amount of navigational error introduced by the use of the vertical motor.

If a student wanted to take this design further, they might wish to try a variation of working fluid. There are several fluids which are lighter than cooking oil, so they would create a larger buoyant force on the Seaperch, while maintaining the incompressibility advantage liquids have over gases. These fluids are going to be less accessible than oil and air, but would be very appropriate for this application. This design serves only as a basis for buoyancy engines and could be easily modified to satisfy a multitude of different needs.

Conclusion

As reinforced by this experiment, buoyancy engines can be very powerful if utilized correctly, as illustrated by the prolific use of hydrogliders throughout oceanic research. This system is designed to give students the opportunity to learn more about buoyancy by harnessing this engine on their own Seaperch. The phenomenon of buoyancy is illustrated by both adding oil and air to the seaperch to increase its volume and therefore increase the buoyant force on the seaperch under the water. By using oil, the principles behind buoyant force can be explained by relating changing volume to the buoyant force, rather than the presence of air, which is a common misconception among younger students. [3] However, by using both air and oil, students can attain a great deal of versatility in their buoyancy engine, and gain practical experience with both hydraulic and pneumatic systems, which are prolific in almost all modern engineering applications.[4]

This design, as mentioned before, serves only as a basis for buoyancy engines applied to the Seaperch. The basic design gives a concrete example of a fundamental principle of marine engineering, while the use of both liquids and gases allows for further experience in both hydraulic and pneumatic systems. This buoyancy engine would prove a valuable asset to any Seaperch program because with these additional tools, students will be better able to solve engineering problems creatively and effectively in their scholastic and other endeavors.■

ACKNOWLEDGEMENTS

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