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2.00AJ / 16.00AJ Exploring Sea, Space, & Earth: Fundamentals of Engineering Design  
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# The Task

Design and construct a remotely Operated Vehicle that can be used underwater for exploration with video capabilities and sensors for measuring environmental data.

# Constraints

- Maximum dimensions of 50cm x 50cm x 50cm
- Topside control via 15m tether with 12V DC power
- Maximum of three motors
- Submersible to a minimum of 20 ft.
- Must have light bank, camera, and sensor package

# The Initial Design

In order to maximize the chance of success, the decision was made to keep the design as simple as possible. We used a rectangular PVC frame with a 30 cm square base and 20 cm height. Extra beams were placed along the bottom and the top to serve as attachment holds for the motors and sensor package. Small holes were drilled in the PVC piping to increase the rate at which they flooded with water. Weights (objects with greater gravitational force than buoyant force) and floats (objects with greater buoyant force than gravitational force) were arranged to self-right the vehicle and counter any unwanted rolls or pitches.

The three motors were placed near the bottom of the frame, two at the rear for x-y direction motion, controlled by three-direction switches in the control box at the surface. The lift motor was placed in the middle of the bottom of the frame and controlled by button toggles at the surface. The camera and two light banks were placed at the front. The sensor package was attached to the top, with a float of similar size attached opposite for balance.

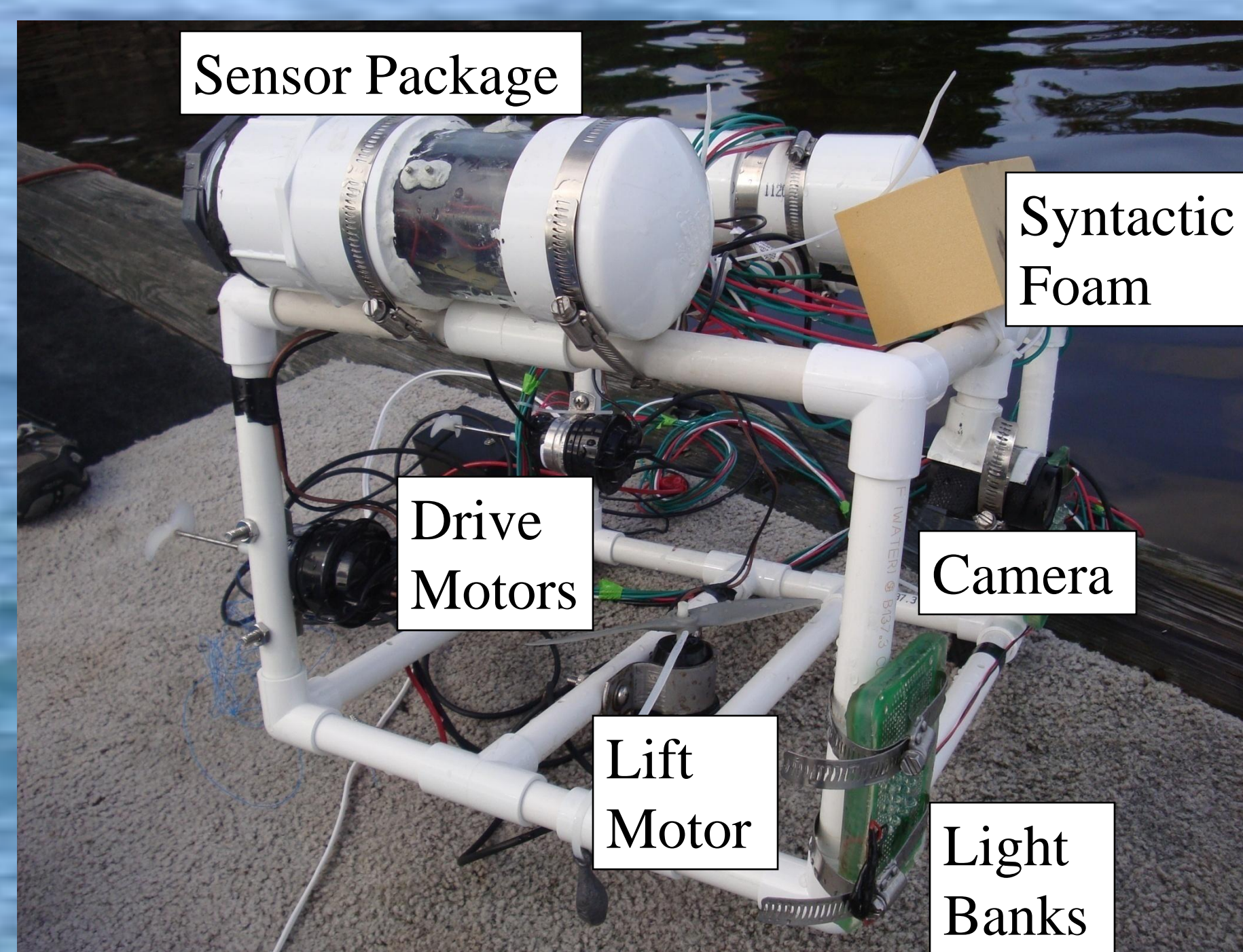
This basic design served decently. Small adjustments were made throughout the process.

Depth (m)	Temperature (C)	Conductivity (S/m)	Light (% intensity of sunlight)
2.17	21.5	1.7	0.4
1.32	20.8	1.8	0.5
0.52	10.8	1.6	0.4
0.21	20.0	1.8	9.0
0.06 (surface)	20.6	0	100

**Some Representative Data**

# To Sink and Swim

## Foundations of Engineering Design 2.00A/16.00A



# Testing and Variations from Initial Design

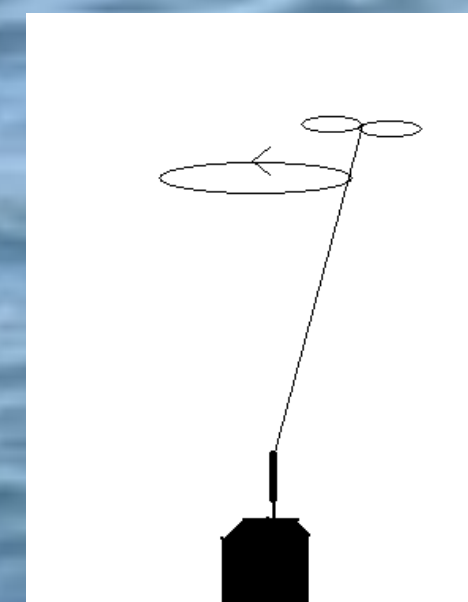
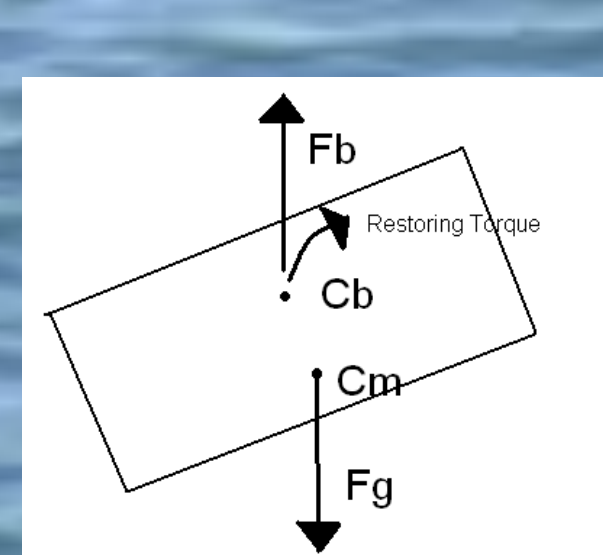
•In the first tests, **propeller precession** proved to be a significant issue. The phenomena reduced force output somewhat and caused damage to the plastic connectors affixing the shaft extensions to the motor shafts, including one catastrophic failure. Switching from hard plastic to nylon connectors, hammering the connectors further onto the motor shafts, and reducing shaft extension length from 10cm to 8cm reduced the prominence and negative effects of this behavior.

•The initial design **lacked sufficient flotation** and this was addressed in the short-term by adding two extra buoys which were later replaced with blocks of syntactic foam.

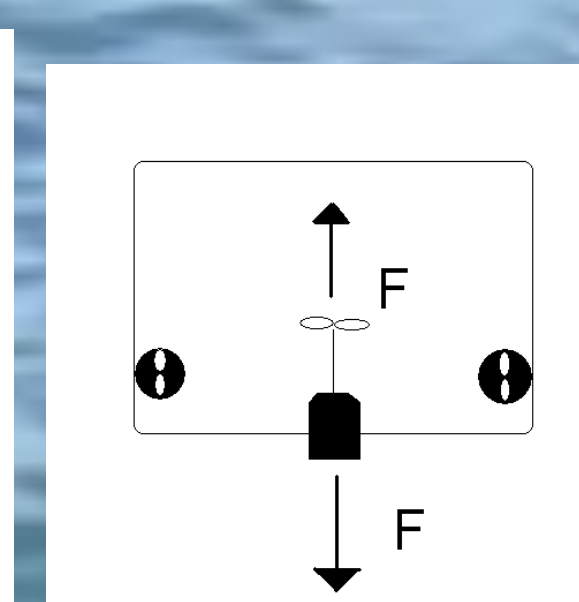
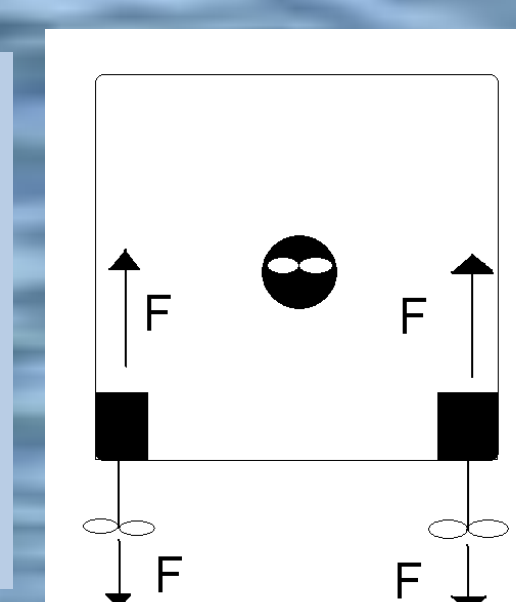
•The **weight of the tether** led to difficulty maneuvering in early tests. In order to address this, two buoys were attached to the tether. The first roughly 1.5 m from the vehicle and the second roughly 2m further up the cable. These provided a buoyant force that helped counter the weight from the tether.

•The initial **lift motor mount plan** was to use two long threaded rods in combination with a pair of brackets to suspend the motor between two of the cross beams on the bottom of the device. This was found to be both difficult and financially unfeasible so instead the decision was made to mount the motor directly to the rear cross beam then move the beam forward so the motor would sit at the center of mass.

•Perhaps the worst problem encountered in the final phases of testing was **imperfect waterproofing of the sensor pack**. In early tests it was shown to leak quite badly from the end cap press fit points. These were sealed with a marine sealant, but further leaking through the threads of the screw-on cap were only addressed successfully with a combination of Teflon tape (to allow the cap to be screwed on more soundly) and “monkey dung” (plumbers’ putty) sealant applied after shutting the cap, the latter of which had to be re-applied each time the cap was removed and replaced.



Diagrams, left to right:  
Self-righting Precession  
Motor Placement – Top View  
Motor Placement – Rear View



# Motors

In selecting motors and propellers the goal was to keep power consumption down while still generating sufficient force to keep the vehicle relatively quick and maneuverable. Two 500 gallon per hour (GPH) bilge pump motors were selected for the horizontal (forward/backward) drive. They were positioned on the vehicle so as to allow for a differential steering system. As the weakest motors available, they offered the lowest power consumption, but a pair of them provided plenty of force for forward drive.

A single 750 GPH bilge pump motor was used for vertical drive. With only one motor operating in this axis, the extra power consumption was necessary to generate sufficient force.

# Propellers

To aid in propeller selection a series of tests were done to determine which models gave the best performance for power usage (see table below).

Further tests showed that the use of a shaft extension paired with the white marine-style propeller gave force output superior to any listed in this table. However, limitations in the test apparatus prevented exact figures from being determined for comparison.

The initial decision was to use white-marine style propellers with shaft extensions on all three motors, however, after repeated tests it was determined that the force from the vertical drive motor with this arrangement was insufficient and was causing poor control, especially when large amounts of tether cable were in the water (for example, during deep dives). As a result, this propeller was changed to a very large, aircraft-type propeller which had been found in tests to give excellent force output but at a high power cost. This extra power expenditure was ultimately deemed acceptable due to the vastly improved performance with the new propeller.

Propeller	Force	Current
2 blade black midsize	1.3 lbs	>5 A
Small boat-style black	8.0 oz	2.3 A
Small/med boat-style white	11.0 oz	2.8 A
White boat-style reversed	7.0 oz	2.1 A

# Data Collection

The vehicle was equipped with the following sensors: pressure, light, conductivity, and temperature. A reading from each was recorded approximately every 30 seconds. The resulting data was calibrated and indexed by the depth of the reading (as obtained using the pressure range and the depth range) to provide our final table of data.

Our team had one successful day of data collection, May 6, 2009 during lab hours (2-5 PM) at the MIT Sailing Pavilion, during which we obtained a maximum depth of 2.7 meters. We had a few bad readings, but the vast majority of our data calibrated to at least somewhat logical results. Conductivity was consistently in the 1.75-1.85 S/m range whenever the sensor was in the water, and 0 or very, very close to it when it was not. At depths greater than half a meter, 0.2-0.5% of the intensity of sunlight was recorded by our light sensor, whereas at 0.23 meters, about 4% was recorded. The temperature variation was not generally more than one or two degrees from 20 C, and showed no discernable pattern.