

Senior Design Capstone Project

Human Powered Submarine: System Modeling

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Final Report

Background

The System Modeling Team was created to develop a computer modeling program to determine theoretical performance and effects of design changes for the Human Powered Submarine. Also, a scaled model of the HPS will be built and tested in a wind tunnel to calculate drag and lifting forces and to estimate performance, including speed and steering. The data collected in the wind tunnel, dynamometer data, and data from previous years will be incorporated into the system model to determine the overall performance. We hope to use this information to improve performance of the submarine, win the competition in San Diego, and break the HPS speed record.

Problem

The first problem is to develop motion equations for the HPS. Starting with a free body diagram of the submarine, a simple linear model can be derived. Through the use of Simulink and the incorporation of thrust and drag information; distance, velocity, and acceleration can be graphed with respect to time. The Simulink model gets more complicated when including a pitch angle.

The second problem is constructing a scaled down physical model of the submarine and a test rig to test the model in the wind tunnel.

Objective

Our main objective is two develop a dynamic model of the submarine to determine its performance. This will be accomplished through the following:

- Derive equations of motion
- Develop Simulink models to make performance calculations
- Construct a 1/3 scale model of the submarine
- Construct a wind tunnel duct and test rig to measure forces
- Test the model in the wind tunnel and incorporate results with Simulink model

Dynamic Analysis

Two free body diagrams must be used to determine the equations of motion. These diagrams can be seen below in Figures 1 and 2.

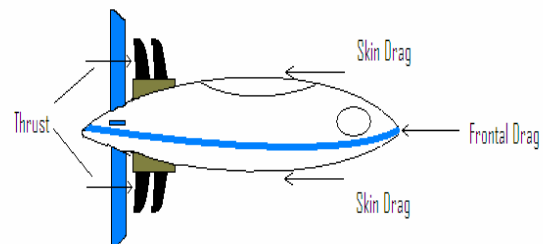


Figure 1: Linear Motion FBD

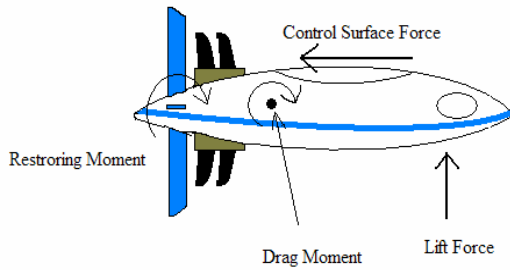


Figure 2: Angular motion FBD

The above free body diagrams are used to derive the equations below.

Linear motion equations:

$$T - D = ma$$

$$D = C_D \frac{1}{2} \rho_{water} A_{frontal} v^2$$

$$T - C_D \frac{1}{2} \rho A \left(\frac{dx}{dt} \right)^2 = m \left(\frac{d^2x}{dt^2} \right)$$

Angular motion equation:

$$(I_{yy} + I_{added}) \alpha = F_{cs} d_{cs-cg} + F_{bodylift} d_{cl-cg} - M_{restore}(\theta) - M_{drag}(\omega)$$

In order to solve these complex equations rapidly, Simulink is used. Figures 3 and 4 display the models for linear motion and angular motion, respectively.

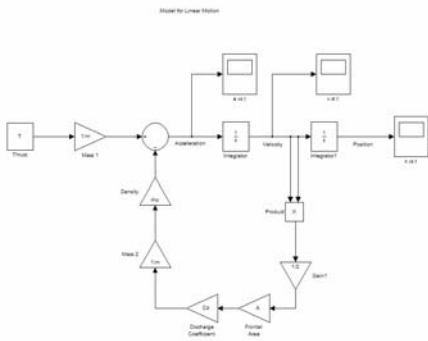


Figure 3: Linear motion Simulink model

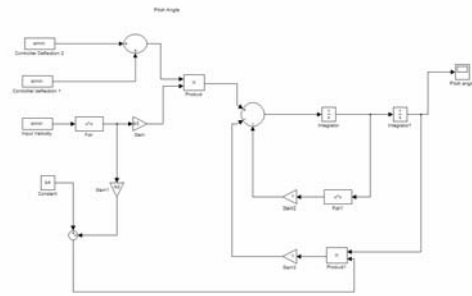


Figure 4: Angular motion Simulink model

Fabrication

The first thing to do in order to construct a scaled down model is to measure the dimensions on the real submarine. Once the measurements of the main hull were recorded and scaled down, the initial shape of the main hull was cut out of one inch thick foam and glued together. Figure 5 shows the process of measuring the main hull of the submarine.



Figure 5: Measuring the HPS

The foam shape was covered with light weight body filler and then was sanded down to the final shape of the hull. The fin housings were also created with foam and body filler in the same manner as the main hull. The rudder and planes were made from

body filler in a mold and shaped to the correct size. The fin housings and planes were then attached to the main hull. Figure 6 shows the mold used to manufacture the rudder and stern planes. Figure 7 shows the completed model of the submarine.



Figure 6: Plane and rudder mold

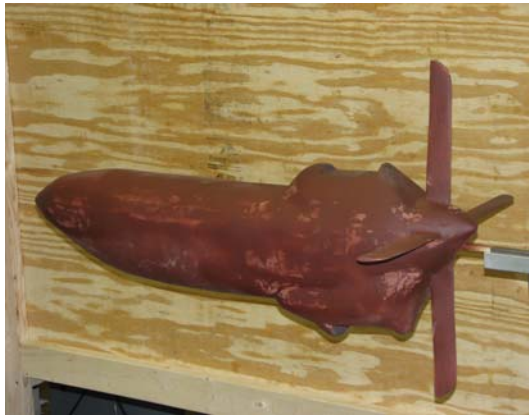


Figure 7: Submarine model

After completion of the physical model, a duct for the wind tunnel was constructed. The duct was fabricated from wood in a rectangular shape approximately 2 ft 10 in wide x 4 ft tall x 8 ft long. The open end of the tunnel allows the submarine to be placed inside while attached to the test rig. The test rig was constructed by a previous Design team. A pitot tube is used in conjunction with a water manometer to measure air speed. Figure 8 shows the completed wind tunnel with the model and test equipment attached.



Figure 8: Wind tunnel and test equipment

Mechanical Laboratory III Section

The wind tunnel testing of the model will give frontal drag and lifting force do to linear motion. By matching the Reynold's number of the model in an air stream and the Reynold's number of the submarine in water will allow us to determine the drag coefficients.

Object

The purpose of the wind tunnel test on the submarine model is to determine the frontal drag on the submarine as it goes through the water. Non-dimensional analysis will be used to determine the water speed that corresponds with the air speed in the wind tunnel.

Procedure

To find the air speed in the wind tunnel a Pitot tube is connected to a monometer to determine the difference in pressure between the static air and the moving air in the tunnel. Bernoulli's equation is used to determine the air speed in the tunnel.

To find the frontal drag on the submarine it is attached to a sting with a series of strain gages. Vertically mounted strain gages measure the drag and lift that is applied to the submarine. Horizontally mounted strain gages are used to determine any lift associated with the air flowing over the model. This strain is subtracted from the strain on the horizontally mounted gages to determine the actual frontal drag.

The strain gages on the sting are connected to a strain indicating unit that gives a reading of volts. The strain gages and strain indicating units are then calibrated to determine the strain caused by drag and lift.

To calibrate the horizontally mounted strain gages a 2 kg weight is placed on the sting. The voltage reading is recorded then the weight is doubled and another reading is taken. These two readings form a force vs. strain line that can be used to determine the strain caused by lift on the submarine. To calibrate the vertically mounted strain gages the same procedure is used, but the sting is mounted on its side so that the vertical strain gages are now horizontal. The weights are placed at the same point on the sting which the submarine will be mounted.

With the sting calibrated and the test equipment in place, the submarine and sting are placed in the wind tunnel as in Figure 8. Tests were done with two different wind speeds. Since the fan for the wind tunnel has a fixed speed motor, the blades on the fan had to be adjusted after the first test.

Results

For the first test the monometer reading was 2.4 inches of water, which converts to 74.22 ft/sec. This air speed correlates to .98 knots in water. The average frontal drag for this test is 3.17 lbf. Figure 9 shows the frontal drag measured during a 5 minute period.

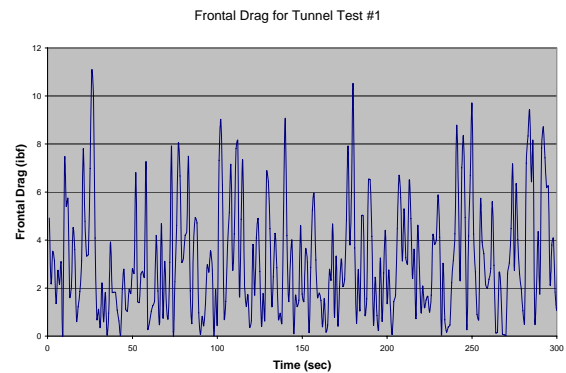


Figure 9: Frontal Drag for tunnel test #1

For the second test the monometer reading was .94 inches of water, which converts to 67.07 ft/sec. This air speed correlates to .89 knots in water. The average frontal drag for this test is 2.25 lbf. Figure 10 shows the frontal drag for the tunnel test #2.

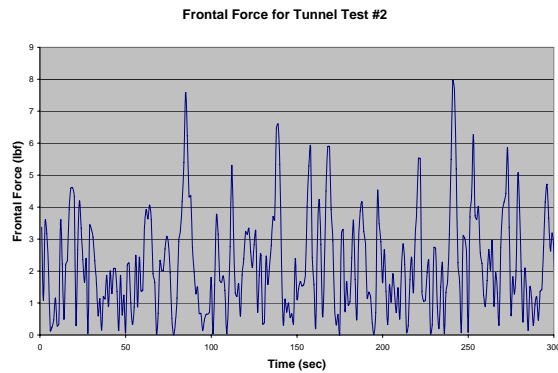


Figure 10: Frontal drag for tunnel test #2

The frontal drags measured in the two tunnel tests are used to determine the discharge coefficient at each air speed. For tunnel test #1 the discharge coefficient was calculated to be 1.73 and for test #2 it was 1.36.

Conclusion

As predicted, the frontal force was higher for the higher airspeed and the discharge coefficient was also higher. Since the maximum air speed of the wind tunnel correlates to a lower water speed than was desired, the calculated discharge coefficient will not be accurate to determine the performance of the submarine.

Data Analysis

Having determined the discharge coefficient of the submarine along with the thrust that was determined by the dynamometer team, the values can be put into the linear motion model to determine the maximum speed of the submarine. The maximum thrust reported was 28 lbf.

The linear model is set up to display the position, velocity and acceleration with respect to time. Figures 11-13 displays these graphs. It is shown on the velocity vs. time graph that the top speed is approximately 0.5 ft/sec. This is extremely slow for competition.

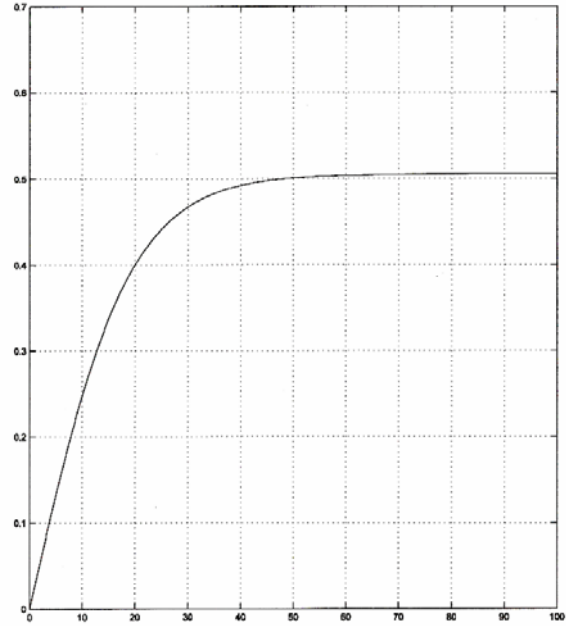


Figure 12: Velocity vs. Time

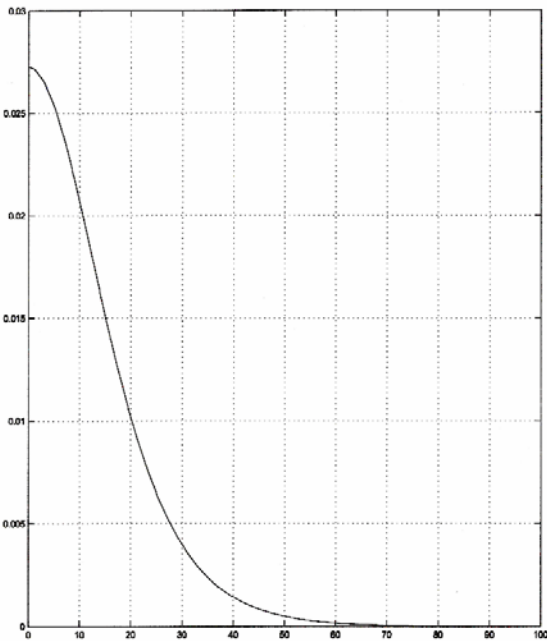


Figure 11: Acceleration vs. Time

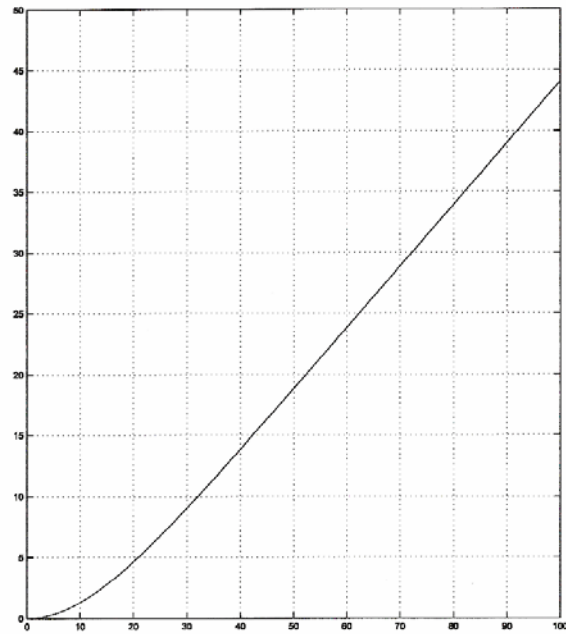


Figure 13: Position vs. Time

Future Work

Any types of design changes can be first made on the model and tested in the wind tunnel to determine the performance changes. For example, if bow planes were installed to eliminate the body lift, they can initially be made on the model and tested to determine their effectiveness.

Acknowledgements

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