EN400

LAB #7

HULL RESISTANCE and EFFECTIVE HORSEPOWER

Instructions

1. This lab is conducted in the Hydromechanics Lab on the ground floor of Rickover Hall.

2. Prior to arriving, read through the lab procedure so that you are familiar with the steps necessary to complete the lab.

3. Bring this handout and a calculator to the lab.

4. The lab is to be performed as a whole class. Your instructor will specify whether each small lab group or each individual must submit the completed lab.

5. Follow the stages of the lab in consecutive order. The lab follows a logical thought pattern and jumping ahead without completing the intervening theory questions will limit your understanding of the concepts covered.

6. For full credit, all work must be shown on the lab. Show generalized equations, substitution of numbers, units, and final answers.

Student Information:

Name(s): ______________________________________________________

Section: __________

Date: __________

Note: This lab does not have a pre-lab.
Apparatus

The following model and ship data for the USNA YP is provided:

<table>
<thead>
<tr>
<th>Model Data</th>
<th>Full-Scale Ship Data</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length between perpendiculars ($L_M$) = 5 ft</td>
<td>Length between perpendiculars ($L_S$) = 101.65 ft</td>
</tr>
<tr>
<td>Fresh water at 65°F</td>
<td>Salt water at 59°F</td>
</tr>
</tbody>
</table>

Table 1 YP Data

Background

Ship resistance is a function of many factors. Some factors include ship speed, hull form and size, displacement, hull fouling, water temperature, waves, current, and wind.

In the design of a ship, many towing tank tests of a model geometrically similar to the full-scale ship are performed to determine the ship’s horsepower requirements and performance characteristics. Tests are done on several hull designs in order to select the “best” hull to be constructed. A carefully planned and executed series of model tests, although somewhat expensive, is extremely beneficial and cost efficient in selecting the final design of a ship’s hull. Data collected on a model can be scaled up to predict the full-scale ship’s performance.

Instead of testing a potential design for a ship, this lab will use an established hull design, the USNA YP, and will concentrate on the effect of an increase in ship displacement on the power required to propel the ship through the water.

Throughout the life of a ship, its displacement will change, whether through fuel and water consumption or because of equipment additions. History has shown that a ship’s displacement (especially warships) will increase 10-15% over the life of a ship.

Components of Hull Resistance

In the laboratory, the two most important components of hull resistance are viscous and wave making resistance. Mathematically, this is written as:

\[ R_T = R_V + R_W \]

where:  
\[ R_T = \text{total hull resistance, lb} \]  
\[ R_V = \text{viscous resistance, lb} \]  
\[ R_W = \text{wave making resistance, lb} \]
1. Figure 1 is a graph showing the components of resistance for a YP hull. Note how the wave making component of resistance increases as speed increases. At speeds of 4, 8, and 14 knots, what percentage of the total resistance can be attributed to wave making?

   4 knots: _______  8 knots: _______  14 knots: _______

**Figure 1** Components of YP total hull resistance

The “Hull Speed” of a ship is the speed at which the wavelength is equal to the length of the ship. Just above this speed, displacement ships experience a large increase in resistance. The hull speed (in knots) is as follows:

\[
V_{\text{HULL}} = 1.34 \sqrt{\frac{LWL}{L}}
\]

\[
LWL = \text{Length of the waterline (ft)} (\approx L_{PP})
\]

1.34 is a constant in units of \(\frac{kt}{\sqrt{ft}}\) (typically referenced as “the speed-to-length ratio”)

2. Calculate the \(V_{\text{HULL}}\) of the YP and plot it on Figure 1.
Resistance for $\Delta S = 172$ LT

The model will now be towed in the tank at scaled speeds ($V_m$) corresponding to full-scale ship speeds ($V_S$) of 4, 7, 12, and 14 knots. Carefully observe the wave patterns created by the model.

3. In Figure 2, sketch the transverse and divergent wave patterns at speeds of 4 and 14 kts.

![Figure 2 Diagram of YP wake patterns at speeds of 4 and 14 knots.](image)

4. A very good approximation of the total hull resistance for a ship is to multiply the total hull resistance of the model by the cube of the scale factor. Using the experimental data and this relationship, complete the table:

\[
R_{TS} \cong R_{TM} \lambda^3
\]

Recall:
\[
\lambda = \frac{L_S}{L_M} \quad V_M = \frac{V_S}{\sqrt{\lambda}} \quad 1 \text{ knot} = 1.688 \text{ ft/s} \quad EHP = \frac{R_{TS}V_S}{550 \frac{\text{ft}-\text{lb}}{\text{s HP}}}
\]

where, $\lambda =$ scale ratio

$EHP =$ Effective Horsepower 

$R_{TS} =$ total resistance of the ship (lb) 

$R_{TM} =$ total resistance of the model (lb) 

$L_S =$ length of ship (ft) 

$V_S =$ speed of the ship (ft/s) 

$L_M =$ length of model (ft) 

$V_M =$ speed of the model (ft/s) 

<table>
<thead>
<tr>
<th>Vs (kt)</th>
<th>Vs (ft/s)</th>
<th>VM (ft/s)</th>
<th>RTM (lb)</th>
<th>RTS (lb)</th>
<th>EHP (HP)</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>7</td>
<td></td>
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<td></td>
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<tr>
<td>12</td>
<td></td>
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<tr>
<td>14</td>
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</tbody>
</table>

Table 2 Speed and resistance data
5. Show your understanding of these calculations by showing your work for a ship speed of 12 knots.

6. Why is the model being towed at speeds using the above equation (Froude’s Law of Corresponding Speeds)?

________________________________________________________________________
________________________________________________________________________

7. Why does the model have a row of studs running vertically near its bow?

________________________________________________________________________

8. What are the advantages and disadvantages to using a larger model? ________________

________________________________________________________________________

A smaller model? __________________________________________________________

________________________________________________________________________
Resistance for $\Delta s = 139$ LT

The following table contains bare hull EHP data for a YP at a displacement of 139 LT.

<table>
<thead>
<tr>
<th>Ship Speed, $V_s$ (kt)</th>
<th>Effective Horsepower, EHP (HP)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>4</td>
<td>8</td>
</tr>
<tr>
<td>6</td>
<td>28</td>
</tr>
<tr>
<td>8</td>
<td>62</td>
</tr>
<tr>
<td>10</td>
<td>142</td>
</tr>
<tr>
<td>12</td>
<td>272</td>
</tr>
<tr>
<td>14</td>
<td>512</td>
</tr>
</tbody>
</table>

Table 3 YP EHP Data

9. Plot your EHP results for 172LT and 139LT displacements using Excel. Submit Excel.

10. What happened to the effective horsepower of the YP after increasing its displacement to 172 LT? Why?

________________________________________________________________________
________________________________________________________________________

11. How does increasing speed affect the effective horsepower at a displacement of 172 LT? Specifically, what has happened to the horsepower requirement as speed increased from 4 to 7 knots, and from 12 to 14 knots?

________________________________________________________________________
________________________________________________________________________

12. The YPs were designed to have a maximum speed of 13.25 knots. Based on your data, explain why this value may have been chosen.

________________________________________________________________________
________________________________________________________________________

13. How would operating in shallow water affect the YP’s effective horsepower?
Added Resistance and Ship Hull Response in Regular Waves

To demonstrate how ocean waves affect resistance over and above calm water resistance, the model will now be towed at a constant speed corresponding to a full-scale speed of 12 knots in three different regular wave patterns. Full-scale wave height is approximately 4.2 ft (sea state 3). The three regular wave patterns will have the following characteristics:

- wave length five times the model’s length
- wave length equal to the model’s length
- wave length one-half the models length

14. During these runs, carefully observe the motion of the model, especially in pitch and heave. You will see a different response in each wave pattern. In the following table, record the dominant motion (pitch or heave) observed during each run.

<table>
<thead>
<tr>
<th>Wave Pattern</th>
<th>$V_S$ (kt)</th>
<th>Dominant Response Motion</th>
</tr>
</thead>
<tbody>
<tr>
<td>$L_{wave} = 5 \cdot L_M$</td>
<td>12</td>
<td></td>
</tr>
<tr>
<td>$L_{wave} = L_M$</td>
<td>12</td>
<td></td>
</tr>
<tr>
<td>$L_{wave} = \frac{1}{2} \cdot L_M$</td>
<td>12</td>
<td></td>
</tr>
</tbody>
</table>

**Table 4 YP Motions**

15. Which regular ocean wave pattern produced the largest amount of pitching motion?

_______________________________________________________________________

16. Which regular ocean wave pattern produced the largest amount of heave motion?

_______________________________________________________________________

17. Based on your observations of ship motion in the lab, list three factors, in addition to wavelength, that would affect the motion of a ship in waves.

   a. _____________________________________________________________________

   b. _____________________________________________________________________

   c. _____________________________________________________________________
Shaft Horsepower and Fuel Consumption

Once a ship’s effective horsepower has been determined through model testing, the shaft horsepower required to drive the ship must be determined. Shaft horsepower is the value used when purchasing a ship’s propulsion.

18. What element in the drive train causes the biggest propulsive losses? ________________

19. YP’s are equipped with two 437 HP diesel engines, each driving its own propeller shaft. Why would two engines be used instead of a single 875 HP engine driving a single propeller shaft?

________________________________________________________________________
________________________________________________________________________

Figure 3 is a plot representing the SHP and fuel consumption of a single propulsion engine. Use this plot to answer the remaining questions in this lab. To use the plot, use a desired SHP on the left axis, travel across to the curve labeled SHP, then down to the Engine RPM axis. At the discovered RPM, go up to the Fuel Consumption Rate curve, then travel right to find the Fuel Consumption Rate.

YP Propulsion Diesel Engine SHP and Fuel Consumption

Figure 3 Shaft horsepower and fuel consumption data for a single YP diesel engine
20. From the experimental EHP data and assuming a propulsive coefficient of 55%, determine the total SHP required to travel in calm water at 10 and 12 knots for both displacements. Then, use Figure 3 to complete the following table:

<table>
<thead>
<tr>
<th>Δ (LT)</th>
<th>Vs (kt)</th>
<th>Total EHP (from plot)</th>
<th>Total SHP</th>
<th>SHP per Engine</th>
<th>Fuel Consumption Rate per Engine (gal/hr)</th>
<th>Total Fuel Consumption Rate (gal/hr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>139</td>
<td>10</td>
<td></td>
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<td>12</td>
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<tr>
<td>172</td>
<td>10</td>
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</tbody>
</table>

Table 5  YP Fuel Consumption

21. How has the increase in displacement affected the amount of fuel burned by the YP?

_______________________________________________________________________
_______________________________________________________________________

22. A YP is ordered to travel a distance of 1,800 nautical miles and arrive with 50% of 6,800 gallons of fuel onboard. Using two engines, at what speed must the YP travel in order to meet this requirement? (Use Table 1 and Figure 3)

<table>
<thead>
<tr>
<th>YP Engine RPM (2 engines)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Engine (rpm)</td>
</tr>
<tr>
<td>----------------</td>
</tr>
<tr>
<td>500</td>
</tr>
<tr>
<td>825</td>
</tr>
<tr>
<td>970</td>
</tr>
<tr>
<td>1125</td>
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<tr>
<td>1290</td>
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<td>1460</td>
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<td>1650</td>
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<tr>
<td>1850</td>
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<tr>
<td>2060</td>
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<tr>
<td>2100</td>
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</tbody>
</table>

Table 6  YP Engine RPM