Chapter 14

Roll Motion in Beam Seas Experiment

14.1 Computer Programming Laboratory

1. **Purpose**: To investigate the effects of roll damping on the roll motion for a ship in beam seas. The simulation will investigate the relationship between the roll motion and wave frequencies for a ship experiencing regular waves coming from the starboard beam.

2. **Procedure**: We will be using Maxsurf Motions to simulate the transfer function for a ship experiencing pure beam seas. The first step is to have the software create the transfer function for the desired ship under one scenario. We will then create the transfer function for different amounts of added roll damping. Finally, we will perform the roll decay animation and see how the input Damping Factor relates to the rate of roll amplitude decay.

Before running the simulation, be sure to record the following information for the DDG-51: \( L_{PP}, B_{max}, D \), displacement, \( LCG \), and roll gyrdius \( k_d \).

Load the desired ship design (DDG-51 ver 1a.EMS5.msd) into Maxsurf Motions. Complete the required steps to run a simulation for a single speed (zero), single wave heading (starboard beam seas), and a single wave spectrum. *See previous directions on running Maxsurf Motions.* Once the program has done an analysis of the model, you can take the transfer function (RAO) results and save them in an Excel file. Using **Ctrl-Shift-C** for copying will copy the headings as well as the data.

**Roll Damping** Use the Roll decay simulation option from the **Calculate Wave Surface** menu (under the **Analysis** menu). Save the resulting data as a text file and open in Excel. Some guidelines from the Motions manual:

- Maxsurf Motions is able to display a rendered 3D view of the model. If an analysis has been run and the wave surface calculated (**Analysis** | **Calculate Wave Surface**), then the free surface will also be included in the render. In the **Perspective View**, choose **Display** | **Render**, or click on the **Render** button.

- After calculating the wave surface, Maxsurf Motions is able to animate the vessel for the specified initial roll angle or for the selected wave pattern. Choose **Display** | **Animate** to start the animation and use the ESC key to terminate the animation.

The specific steps you need to take are:

- Make sure you have specified all seakeeping input data correctly by working your way down the **Analysis** menu.
- Solve **Seakeeping Analysis** from the **Analysis** menu
- Calculate **Calculate Wave Surface** from the **Analysis** menu
• Select Roll decay simulation in the dialog that appears
• Specify the Initial heel angle
• Select Animate from the Display menu (make sure you are in the Perspective View of the model)
• Click OK

The output text file contains the roll natural period and the peak amplitudes (and the times they occur). You can use this data to find the damping ratio, which should match the value you input for roll damping. The damping ratio is related to the exponential decay coefficient by the natural frequency. So,

\[ \eta_4 = \frac{\text{Decay Coefficient}}{\omega_n 4} \]

3. Data Analysis - Roll Damping: Let’s explore how the input roll damping affects the resulting damping ratio.

   (a) Repeat the Maxsurf Motions seakeeping analysis transfer function (RAO) for various levels of added roll damping. Be sure to record the level of roll damping with each data set.

   (b) For each analysis, run the Roll decay simulation and solve for the damping factor for each condition.

   (c) Plot the relationship between the resulting damping ratio and the input added roll damping values for the ship you are using. Do they match?

   (d) Plot the peak magnitude from the roll transfer function against the damping ratio. If you want to halve the peak roll response magnitude, how much do you need to increase the roll damping input to Maxsurf? Does the roll response reduce by half for ALL encounter frequencies?

4. Questions!: Your report is tasked with answering questions! For this portion of the investigation, you should be considering the following questions:

   • Why would the predicted roll response of a ship require additional roll damping (but not additional heave or pitch damping)?
   • What is a reasonable range of inputted roll damping values?
   • Can you make recommendations for values of added damping values if you know the roll decay coefficient for the ship?
   • Do you have enough information to make generic recommendations for ship simulations? If not, what might be needed to do so?

We will be following the simulation investigation with an experimental investigation of a passive roll stabilization tank. For the experimental investigation we will be creating two transfer functions for a ship model - one that includes the roll mitigation device. The questions to consider for the next phase:

   • What happens to the magnitude and location of the peak roll response with the addition of the roll mitigation device?
   • Does the information learned from the simulation give insight into the effect of the damping ratio calculated from the experiment? If we consider the same damping factor for the ship considered during simulation, do we get the same types of changes in the roll transfer function?
14.2 Experimental Laboratory

14.2.1 Roll Motion in Beam Seas PreLab Assignment

1. Consider the roll response \( X_d \) of a typical combatant craft in beam seas.
   - Sketch the ‘transfer function’ for the response in roll \( \frac{X_d}{\alpha_0} \) versus \( \frac{\omega_c}{\omega_{n_k}} \).
   - Does the vessel experience resonant behavior? Why or why not?

2. For the Beam Seas lab we will be generating waves with wavelengths from 0.4 to 0.8 Hz. The slope of the waves should be 1/50 (wave slope is \( 2\pi \zeta_0/\lambda \)). **CHECK THE SLOPE RATIO!** Determine the values for the wave frequencies, wave lengths, and wave amplitudes assuming we will be testing 10 conditions.

3. What useful information is gained by doing a FFT on the heave, roll, and wave elevation time histories? What information do we need to create the transfer functions?

4. Is the wave probe on the carriage measuring the wave frequency or the encounter frequency?
14.2.2 Roll Motion in Beam Seas Experimental Assignment

1. **Purpose:** To investigate the effects of a passive roll stabilization tank on the roll response of a ship in beam seas.

2. **Procedure:** We will be using the same carriage and towing system from the DDG-51 Head Seas lab. In this lab, however, the model will be rotated 90° and the carriage will not be moving. The model will experience starboard beam seas at zero speed. The model will be free to heave and roll, but restrained in pitch, yaw, and sway motions. The roll motion and heave motion will be recorded using potentiometers located at the model center of gravity. The wave elevation will be recorded by a sonic probe located in line with the model’s centerline.

We will be using a 1/48th scale model of a proposed USCG icebreaker. Characteristics of the model are provided in the table below. The model is set up with a “Flume Tank” which was designed for this model to allow a demonstration of a passive roll stabilization system.

<table>
<thead>
<tr>
<th>Ship Characteristics:</th>
<th>USCG Icebreaker</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length</td>
<td>6.7 feet</td>
</tr>
<tr>
<td>Beam</td>
<td>1.51 feet</td>
</tr>
<tr>
<td>Draft</td>
<td>0.48 feet</td>
</tr>
<tr>
<td>Displacement</td>
<td>174 lbs</td>
</tr>
</tbody>
</table>

To determine the damping factor, \( \eta_4 \), we need the decay coefficient (found from the roll decay test) and the natural frequency (also found from the roll decay test). The equation for \( \eta_4 \) is

\[
\eta_4 = \frac{\text{Decay Coefficient}}{\omega_n}
\]

Be sure to calculate the damping factor both with and without the stabilization tank. **Is there a difference? If so, does this difference make sense?**

Before running the waves, be sure to record the following information about the experiment:

- Model geometry information \((LWL, B_{max}, \text{draft } (D), \text{displacement, } LCG, \text{roll gyradius } (k_4) - \text{if available, and scale ratio } (R))\).
- Record the roll natural period \((T_{n4}, \text{The roll natural period needs to be determined both with and without the stabilization tank!})\)
  
  (a) With the model at rest, displace the model in roll. As much as possible, only shift the model in roll (avoid any heaving motion).
  (b) Release the model and collect the resulting motion data.
  (c) Using Matlab or Excel, determine the natural period and the roll decay coefficient from the collected data. **We will need the decay coefficient to determine the roll damping factor with and without the stabilization tank.**
We will be testing the model in waves with frequencies from 0.4 Hz to about 0.8 Hz. The wave amplitudes will be kept small \((k\zeta_0 \approx 0.02)\) so that when we experience roll resonance the roll amplitudes do not become so large as to cause damage to the model or carriage. Two different model conditions will be tested. The first condition will be the “bare hull” condition. The model will have no appendages. The second condition will be the bare hull with the flume tank installed. **For each model condition enough different wave frequencies need to be run so that the location of the peak and the shape of the transfer function can be adequately defined.**

(a) Each run will consist of sending a regular wave train of a specified frequency and wave height down the tank. Once the waves reach the model we will record the data.

(b) The following measurements will be made for each run: time, roll response, heave response, encounter wave elevation using a sonic gage mounted on the carriage.

(c) **You are required to be on the carriage and observe at least two data runs (one with long wavelengths and one with short wavelengths).**

(d) Create a data summary spreadsheet. After each run, enter the following data (you will need to use the MATLAB code to determine the encounter frequency and motion amplitudes):

- data number
- intended wavelength and wave frequency
- wave slope (should be the same for all waves)
- wave amplitude
- encounter frequency
- heave amplitude
- roll amplitude

**Deliverables: Tables and Plots**

- Create a table with the tank information, including: tank dimensions, model geometry dimensions and ballasting, model natural frequencies

- Create a non-dimensional roll response plot (transfer function) \((X_d/\alpha_0 \text{ versus } \Lambda)\). Remember the wave slope is \(\alpha_0 = k\zeta\). Be sure to convert the roll angle to radians before non-dimensionalizing. *By Hand*, sketch a fair curve that best represents the trend of the data. Include the results for both conditions tested (with and without the stabilizing tank).

- Create a table with the wave conditions and measured data.

- Create a table with the natural periods and frequencies and the damping factors, \(\eta_4\) (one for the bare hull and one for the condition with the stabilizing tank).
• In your discussion of the wave analysis for the lab report, be sure to discuss each of the plots generated for the results. Topics of discussion could include:
  
  – the relationship between the natural frequencies shown in your table and what you see in your transfer function plots
  
  – the effect of wave frequency and magnitude of the ship’s response in roll
  
  – the effects of wave frequency and the roll stabilization tank on the apparent natural period
  
  – the way the roll natural frequency was determined
  
  – from your observations, what can you say about the phase relationship of the motions at different wavelengths?

Written Assignment

Details on the required written assignment will be provided in class.