Department of Mechanical Engineering

Massachusetts Institute of Technology

2.20 Marine Hydrodynamics, Sample Laboratory Assignment

Laboratory Assignment B

Surface Waves Kinematics and Added Resistance of Ship in Waves

To be performed at the Ocean Engineering Towing Tank Room.

Introduction This lab is in an investigation into some of the properties of surface gravity waves and their effects in ship resistance. The purpose is to gain an understanding of some of the fundamental concepts and relationships of surface wave kinematics by means of an experimental study. The wave-making and wave-detection capabilities of the MIT Towing Tank will be used in conjunction with empirical observations.

Pre-Lab Preparations You **must** submit a "pre-lab" report of the following pre-lab preparations at the beginning of the lab. Although you are encouraged to work the preparation as a lab group, your submitted "pre-lab" **must** be done individually.

In your final lab report you should include a copy of your "pre-lab" (in addition to the one turned in the day of the lab) along with a short paragraph that discusses the lab preparation.

(Time spent here will certainly save you many times the effort during and after the lab!)

1. Read through the entire lab *carefully* so that you have a clear idea of what has to be accomplished. Be familiar with the expected results and calculations so that you can repeat suspicious measurements (*during the lab*).

2. Understand the relevant theoretical topics. Review the relevant topics in the course (References: JNN pg. 237-266, Faltinsen pg.145-148) so that you understand the concepts, the methodologies, and what special care you have to take. Understand the derivation and physical meaning of basic wave properties such as wave length, wave number, period, frequency, phase velocity, dispersion relation, etc. Make plots/sketches of the: wave length as a function of frequency (dispersion relation); phase velocity as a function of frequency; and group velocity as a function of frequency. You should mark in each plot/sketch the areas (if those exist) where the previous functions have a linear behavior. Also, understand the significant dimensionless parameters in ship added resistance.

3. Think through and plan the lab with the other group members. Prepare an action plan for the lab including the number and range of measurements to be made and tables or graphs to roughly plot the data you anticipate. Plan and write a description of the method your group will use for determining the following wave characteristics using three wave probes and a controlled wavemaker.

(a) Amplitude

(b) Wavelength

(c) Frequency

(d) Phase speed

(e) Group speed

In addition plan and write a description of the measurements your group will need to determine the wave amplitude dependence of added resistance of a particular vessel in regular head sea waves.

4. As your pre-lab preparation submit to the lab staff copies of the plots asked in (2) along with the tables, graphs, action plan and short description asked in (3). Provide a checklist for experiments to be run and observations to be made.

   Be prepared to discuss with the lab staff your action plan when you enter the lab.

Laboratory Assignment

Equipment

The towing tank is a long rectangular basin of water with a wave-maker at one end and a "beach" at the other. The wave-maker is a hydraulically driven vertical paddle with controllable amplitude and frequency. The "beach" is a region of absorbing material intended to prevent the reflecting of waves from this end of the tank.

You will be using wave probes to measure the amplitude, or height, of the passing waves. The wave probes are a "resistance" type which produce a voltage proportional to the submerged length. This voltage can be logged by a computer at a prescribed sampling rate. As waves pass the probe, the computer can display the height of the free surface as a function of time. These data can then be stored electronically.

Visual measurements will also be taken for corroboration of the methods and equipment. A stop watch and tape measure will be provided for such measurements.

You will also be given measurements of the forces required to tow the ship at a given velocity with or without head waves.

Objectives

To measure the basic surface wave properties in terms of wave amplitude, period, wavelength, phase velocity, and group velocity. To measure the added resistance of a ship with no waves and in head waves.

Measurements

Towing Tank personnel will provide instructions for the operation of the wave-maker, towing and data collection system. Please follow their instructions.

1. Record the water depth h.

2. Calibrate the wave probes. The calibration of the probes consists of determining the relationship between the voltage read by the computer and the submerged length of the probe. With the assistance of the towing tank operator, you will make measurements of the voltage corresponding to different depths of submergence.

   The following steps (3) through (6) are to be completed for a range of frequencies between $1hz$ *and* $2hz$*, for at least one amplitude. Plan your runs so that you cover a large range of frequencies first, then fill in interim frequencies for better resolution, as time allows.*

3. Determine the amplitude, A, and the frequency, $\omega = 2\pi/T$ with T the period, of the wave using the wave probes. If $\eta(x,t)$ is the free surface elevation, a good definition of the wave amplitude here is $A = (\eta_{max} - \eta_{min})/2$ at some given x.

   For at least one run you should station someone at the tank window to confirm these measurements by a direct visual measurement of A and T (determine the time it takes for a fixed number of wave crests to pass a given point). Describe the procedure you followed to take the visual measurements. Comment on the difficulties in obtaining data from visual measurements.

4. Determine the wavelength, λ, which is the distance between two crests (or troughs or equal phase points). This value can be found by examining the simultaneous signals from two wave probes a known distance apart. (*Should they be close together or far apart? You will be asked by the towing tank personnel to explain.*)

   For at least one run you should estimate the wavelength by visual observation (this might be easiest with two people). Describe the procedure you followed to take the visual measurements. Comment on the difficulties in obtaining data from visual measurements.

5. Determine the wave phase velocity, V_p, which is the speed at which the wave crests (or constant phase points) move in the direction of propagation. This can also be determined from the signals of two wave probes a known distance apart.

6. Determine the wave group velocity, V_g, which is the speed at which a wave group travels, corresponding to the speed at which the wave energy travels. This can be found by measuring the arrival time of a point of constant position within a group at two probes a known distance apart, eg. the "front", "pick" or "back" of the group. (*Should they be close together or far apart?*).

7. An interesting experiment (do this for only one high wave frequency and one amplitude) is to start and stop the wavemaker after a fixed number, say N_1, of wave paddle oscillations to produce a wave group of finite length. Have someone count the number of waves N_2 in the wave group at *one instant*) (this will be difficult is the wave group is too long or too short, perhaps a photo picture would help). Count also the number of wave crests (or troughs) N_3 passing a given point x. You may do this visually or use the wave probe fixed in space. How are N_1, N_2 and N_3 related? Describe/explain what you think is going on.

8. For a single frequency and amplitude (this can be combined with an earlier run), spread grains of pepper on the free-surface and along the bulk of the water. Observe the motion of the pepper grains as waves are passing to get an indication of the particle motion.

9. Tow the vessel at a constant speed along the towing tank. Measure the drag on the vessel.

10. Tow the vessel at the same constant speed in waves of constant wave length with varying amplitudes. Measure the drag on the vessel.

Post-Lab Analysis (To Be Done Individually)

In your lab report, the final results you present must be in non-dimensional form. If the wavenumber is $k = 2\pi/\lambda$ and the gravitational acceleration is g (use $g = 9.80665 m/s^2 = 32.174 ft/s^2$), a good choice is to normalize length by $1/k$ and time by $(gk)^{-1/2}$. Tables and graphical plots should be used.

The lab report should include copies of your pre-lab preparation, the specific procedure of your group's experiment, data analysis, and a discussion of your results. A one-page report on the other experiment you observed should be attached at the end.

Besides the issues required to discuss/explain the above measurement steps, the following results are required to be analyzed and discussed in your lab report. In addition to these, you are encouraged to discuss other hydrodynamic issues you have learned from the experiments. You are also encouraged to design/perform new measurements in addition to those outlined above, with the permission of laboratory staff. Any novel ideas and insightful discussions will be given extra credit in the lab grade.

- Calibration of the wave probes.
- Relationship between wave length and frequency (from both the wave probe and visual measurements).
- Relationship between phase velocity and frequency.
- Relationship between group velocity and frequency.
- Relationship between phase velocity and group velocity.
- Also discussion of the observed particle orbits.
- Relationship between ship added resistance and wave amplitude.

The lab report should be written in a professional way. It should be type-written and should have been edited for grammatical and spelling errors. Although it needs to be complete, **conciseness** is also emphasized.