

Measuring procedures for seakeeping tests of large-scaled ship models at sea

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Abstract-This paper describes the procedures developed in the Laboratory for Ship and Marine Hydrodynamics (LSMH) of NTUA to test large models of ships at sea. It is common practice in experimental ship hydrodynamics to test scaled ship models in Towing Tank facilities, to investigate their performance in calm water and in waves. However, it is both time-consuming and very expensive to generate conditions, which simulate properly the actual sea environment. Parameters of the environment such as the incident wave angle, the short-crested nature of the waves encountered in real world, the effect of the wind and the scale of the experiment, which should be accommodated in the available facility, reduce, or even prohibit in some cases, the execution of such tests.

An alternative to laboratory measurements is to conduct tests with larger models at sea and to record both the sea conditions and the ship performance. This paper describes the design, specification, instrumentation and preparation of this kind of tests. Their advantages and shortcomings are also discussed.

I. Introduction

Since the problems involving the interaction of a moving body, of arbitrary geometry, with a fluid (water) in the presence of free surface are quite complicated and cannot be satisfactorily dealt with by analytical methods, tests constitute an invaluable tool to naval architects. However, most of testing is carried out in towing tanks using small-scaled ship models. The latter are towed in calm water and in uni-directional, artificially generated, pseudo-random waves. Only a few large research organisations built very expensive facilities capable of generating multidirectional, pseudo-random waves. However, even these facilities have length and breadth of the order of 100 m, thus, limiting the size of the models that can be accommodated for testing.

In order to overcome the limitations imposed by the testing facilities, large ship models are tested at sea in sheltered waters. The models are usually manned, although radio-controlled models could also be used. All kinds of standard hydrodynamic tests can be carried out using these models, calm water resistance, propulsion, seakeeping and manoeuvring tests. Critical for all of them is the knowledge of the kinematic position of the model during the tests. In addition, for the seakeeping tests the exact sea conditions should be monitored along with the dynamic responses of the model. In order to record the sea conditions a portable directional wave buoy is used. The model track is monitored via a Real Time Kinematics (RTK) System while the dynamic responses of the model are measured via an in house developed Six-Degree-of-Freedom (six D-O-F) system, consisting of seven accelerometers, is used. The development of all three of these systems is quite recent. Although portable, their accuracy is comparable with the respective equipment used in the Laboratory. Thus, they are the major contributors to the transfer of the laboratory in site.

This methodology, on the other hand, offers many advantages, such as the elimination of building large and very expensive facilities, the use of large models which reduces scale effects and the suppression of any speed or other limitation associated with the specifications of the towing carriage. However, there are still some problems and difficulties inherent to in-situ testing, which have to be overcome.

In the following sections both the advantages and the drawbacks of the methodology are discussed. Furthermore, the current practise of testing large models at sea, as it has been developed in the LSMH of NTUA is presented. It should be noted that the investigation of the model characteristics as a complementary process to model testing is used by some organizations, especially those involved in naval applications. Furthermore, Serter (1993), [3], reports tests of radio-controlled high-speed military models, carried out two decades ago, in a Swiss lake.

II. Test Methodology

A. Description of the model

The models under testing are scaled according to Froude's law of scaling, i.e. they are designed to be geometrically similar and are tested at speeds equal to ship speeds divided by the square root of the geometrical ratio. They have onboard machinery and propulsion equipment capable to achieve these speeds by their own means. A generator-set provides the necessary power to propel the model and to activate all system on board. Full controlled AC electric motors have been selected over internal combustion engines due to their excellent controllability in the entire range of their operation. The performance of the propulsion system is continuously monitored along with the performance of the vessel. State-of-the-art, satellite-based equipment is fitted to monitor the track of the model and its temporary speed. The model is manned; the operator drives it and supervises the proper functioning of the measuring instrumentation and the machinery. An auto pilot system, supported by a GPS-unit, takes care of the route of the model. Propellers and/or water-jets are used, depending on the actual propulsors.

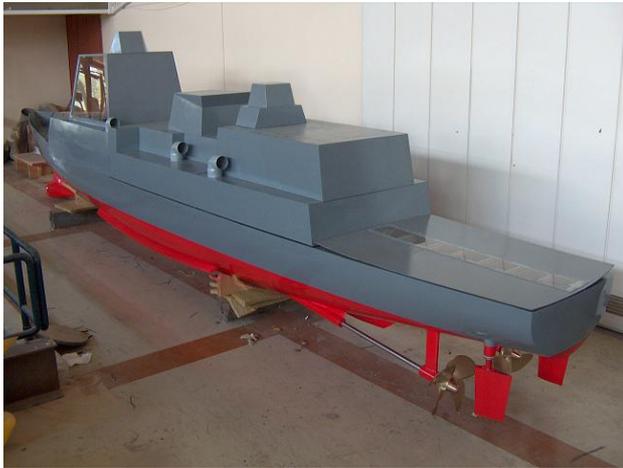


Figure 1. Large scaled manned model.

The sea (wave directional spectrum) and weather (wind force and direction) conditions prevailing in the area of tests are monitored via directional buoys and meteo stations in situ, respectively. Obviously, the aforementioned quantities refer to the model scale (usually around 1:10) and, thus, only very low sea states (significant wave height up to 0.5 m and modal periods in the region of 1.5 sec to 4 sec) should be considered. Nevertheless, it should be mentioned that, since the wave climate is not controlled, the seakeeping experiments are a tedious procedure.



Figure 2. Hull of the scaled model



Figure 3. Motors, torque flanges and control equipment

The models are fully autonomous with respect to power. A generator set (ROBIN SUBARU RL 12500E/3PH 12,5 kVA) supplies the required power to the electric motors of the propulsion system. The motors are driven by a control system, which maintains the desired revolutions at the shafts of the

propulsors. The control system measures at the same time the speed and the supplied voltage. Two motors (SIEMENS 1LA7134 950RPM) are usually chosen for twin-screw models, up to eight meters in length. The motors have independent speed control and power measuring system.

All the spaces of the model occupied by the electric generators, the motors and the control apparatuses are sufficiently ventilated by suitable, continuously operated, fans.

Steering of the vessel is achieved via a steering mechanism at the stern of the ship, driven by a programmable stepped motor, which is currently ready to accept auto pilot equipment.

The power supplied at the main shafts of the propulsors (either screw propellers or water jets) is of primary importance for the evaluation of the behaviour of the ship. The corresponding measurements are performed using special torque flanges (HBM T10F, see fig. 3), which record at the same time the rotational speed of the shafts.

B. Description of the equipment

As it was discussed in the Introduction, three measuring instruments enabled the transfer of the hydrodynamic tests from the closed hall of the laboratory, where plenty reference points to measure the body kinematics can be established, to the open sea, the directional wave buoy, the RTK system and the system to measure the six D-O-F motions of the freely oscillating and moving model.

The directional wave measurement system is based on a small-diameter disc buoy developed by Neptune Sciences Inc (Fig. 4). The so-called Wave Sentry Buoy provides users with real-time directional and non-directional wave data, wherever and whenever it may be needed. The electronics and battery housings are removable when the buoy is afloat at sea, without disturbing the mooring. If desired, the stored raw data can be downloaded to PC at the same time. Wave data are acquired automatically at preset intervals or on demand. After acquisition and onboard processing, wave data can be downloaded via a UHF radio modem or a hardwire connection upon retrieval.

The buoy records all components of motion needed to obtain directional wave data. Processed data include wave height, period wave direction, as well as non-directional and directional wave spectra. As it is light it is easily transported, deployed and retrieved from a small boat with two-person crew.



Figure 4. The Wave Sentry Buoy

The buoy weights 27 kg, the diameter of hull is 0.75 m and the height with antenna is 1.82 m. The life of its battery is about one month and the sampling rate 4 Hz. It communicates with shore receiver in UHF (458 MHz) band reaching a range (line of sight only) 8 km. In order to adapt its output to the sea conditions to be encountered by the models the recorded peak wave period has been reduced from 2 to 1 sec.

The RTK system (Fig. 5) uses the phase of the carrier wave for the differential positioning instead of the time to reach the signal the receiver. Thus the accuracy of the reading is highly increased. These systems take some time (up to a few minutes) to solve for the phase vagueness when it receives the satellite signal for the first time. This delay depends on the number of satellites received, multipath phenomena (reflection coefficient of the ground) and the number of frequencies of the receiver (one or two). In general, eight satellites are sufficient, while the number of effective satellites is increased by a factor of 1.5 if



Figure 5. ODYSSEY RTK System

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the receiver operates at two instead of one frequency. The precision of a typical RTK system is 0.5-2 cm on the horizontal plane, which is of prime importance for the model testing, and 1-5 cm vertically.

The system to measure the six D-O-F motions of a freely oscillating body is a very handy and reliable system of seven strap-down accelerometers (Fig. 6), which has been developed at the LSMH of NTUA to record the dynamic responses of ships and models. The full non-linear system of equations of motions is used to derive the six D-O-F motions. The system was used onboard of large ships and small models with very satisfactory results. An example of the system evaluation for a model attached on a five-component dynamometer in the towing tank is presented in Fig. 7. The pitch motion time history calculated from the data collected by the six D-O-F system compares very well with the one directly measured via the potentiometer sensor on the dynamometer.

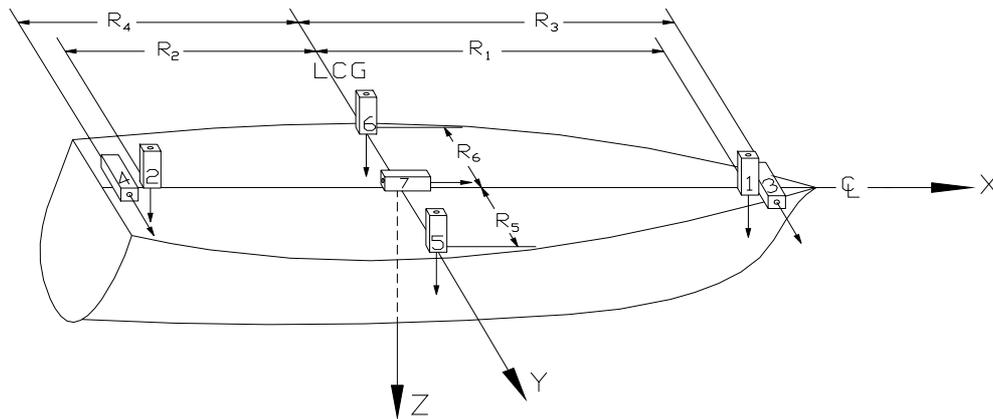


Figure 6. The layout of the seven accelerometers to derive the six D-O-F body motions

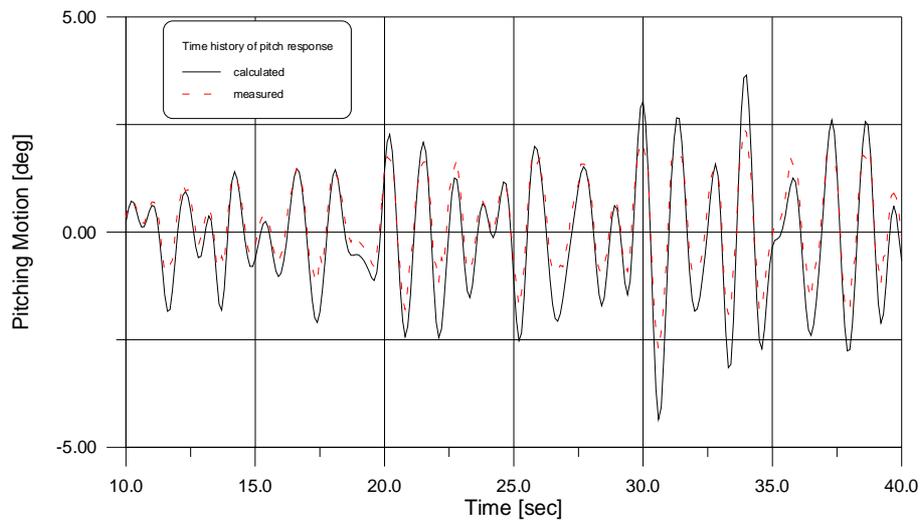


Figure 7. Comparison of the pitch response of a model as calculated via the six D-O-F system data and directly measured via the potentiometer of the dynamometer.

Furthermore, three powerful 8-channel battery-powered data acquisition systems feed laptop computers with the recorded data, for the system recording the six D-O-F responses, for the RTK system and for the directional wave buoy and the meteorological station. The latter is fitted on board the model to provide the direction and the intensity of the apparent wind on the sailing model.

C. Scope of measurements

The large scaled model is tested at sea for seakeeping, propulsion and manoeuvring. Using the information provided by marine forecasting services, in conjunction with the on-line wave measurements of the aforementioned directional wave buoy, an appropriate number at sea-states of pre-selected severity are used for the tests. Depending on the wind direction in the trial area and the site topography, fetch-dependent sea states with either short or long modal periods are encountered. Thus,

seakeeping data pertaining both to the Mediterranean Sea and (e.g.) the Atlantic Ocean can be obtained.

The kinematics of the model (speed, trajectories) is measured via an advanced Real Time Kinematics (RTK) system, which provides excellent accuracy. Furthermore, an in home developed inertial measuring system [1,2] keeps track of the model dynamic responses due to the incident waves for the seakeeping tests, conducted for a range of speeds and headings. Furthermore, course-changing manoeuvres in waves can be performed and the effect of the ride control system in e.g. a broaching situation can be investigated.

In the propulsion tests, the recordings of propeller shaft torquemeters, in conjunction with continuous, accurate measurement of the speed, makes straightforward the establishment of the speed-power relation. In addition, the propeller rpm and the rudder deflections are continuously monitored.

In the manoeuvring tests, all kinematics of the model are continuously monitored. Thus, heading, yaw rate, heel and speed vs. time and, in addition, propeller/rudder deflection are known. Normally, some standard manoeuvres following IMO recommendations are performed, to compare and judge course stability and manoeuvring characteristics of the actual ship. As this concept is aiming towards all sizes and types of ships, a full set of manoeuvres is carried out. They encompass turning circles (port and starboard), zigzag tests 10/10 deg. and 20/20 deg (port and starboard) and spiral tests.

Finally, measurements of hull pressures, elastic strains and high frequency vibration can be performed at areas of the model properly scaled, such as the midship section of an elastic scaled model or elastic panels subjected to slamming at the bow region.

Video recording of areas of specific interest (for example above propeller disks) can be performed using special miniature cameras.

III. Conclusions

The advantages of testing large models at sea are obvious. The tests are for short-crested, directional, wind-generated waves. The models are complete with their superstructures and thus, the wind effects are taken into account. However, the testing time can be much longer than in a seakeeping basin.

IV. Acknowledgements

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