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Measurement of speed loss due to waves

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ABSTRACT

Knowledge of the speed loss of ships due to waves is important in ship design and in planing ship operations. Added resistance due to waves is an important contribution, but only a part of the problem. The thrust and propulsive efficiency is also changing due to operation in waves, and the changes must be included in an accurate manner. The complexity of the problem means that CFD is at the moment not suited for practical predictions of speed loss due to waves. The conventional powering prediction approach also has severe shortcomings when it comes to prediction of speed loss due to waves. The use of non-linear time-domain simulations shows promising results. Model testing is still considered to be the most accurate method for prediction of speed loss. This paper demonstrates the importance of properly accounting for the friction correction in model tests. The importance of contributions from steering is shown, and a method to find the speed loss from short model test runs is given.

Keywords

Speed loss, added resistance, model testing, propulsion.

1 INTRODUCTION

On the background of increasing focus on reducing fuel consumption of ships, there is increasing awareness of the importance of the speed and power performance of ships travelling in realistic sea states, compared to the ideal calm water, no wind condition considered in standard speed-power predictions. A lot of attention is, quite rightfully, given to the prediction of added resistance due to waves, but this is only a part of the problem. What is really needed is knowledge of speed loss due to waves, or alternatively, required added power to maintain the speed in a seaway.

This paper initially discusses the factors contributing to speed loss. Then, alternative methods to predict the speed loss are discussed. Finally, how the speed loss in waves might be determined from model tests is discussed in detail. The importance of properly accounting for the larger frictional resistance in model scale is pointed out, and a method for correcting model test results is given. The effect of steering is discussed. A method to find the speed loss from tests where converged speed wasn't reached is demonstrated.

2 SPEED LOSS DUE TO WAVES

In this chapter we give an overview of the physical effects contributing to speed loss, before we discuss how speed loss can be predicted.

2.1 Factors contributing to speed loss

Added resistance

The added resistance is frequently the most important contribution to speed loss. The added resistance of a ship advancing at constant speed in a straight course in waves has been studied by many authors, for many years. Pérez Arribas (2007) gives an overview of the different methods. The overview given in the introduction to the recent paper by Liu et al. (2011) is also worth a read. The largest added resistance is experienced in head seas, when the length of the encountered waves is of the same order of magnitude as the ship length. Thus, most methods focus on this case. To deal with the special case of short waves, special methods have been derived, such as the one given in Faltinsen et al. (1980). Successful combinations of methods for short and long waves are reported by Guo and Steen (2010) and Prpić-Oršić and Faltinsen (2012). CFD methods based on RANS and Volume of Fluid (VoF) surface capturing is found to be capable of predicting added resistance with reasonable accuracy in both long and short waves Guo (2011), but computational cost of such methods is still prohibitive for practical use. Guo (2011) also confirmed that added frictional resistance has a negligible influence on the total resistance.

In other than head seas, ships will experience yawing motions of varying magnitude, depending on wave length and the course stability of the ship. The yawing motions influence the added resistance, but this is often not accounted for. Chuang and Steen (2012) showed results of experiments in small amplitude zig-zag tests, and showed how the added resistance was influenced by the zig-zagging.

Thrust loss

There are several factors contributing to loss (or change) of thrust when the ship travels in waves:

- Ventilation and out-of-water
- Wave-making by the propeller due to closeness to free surface
- Change of propulsive factors (mainly thrust deduction and wake fraction)

- Change of propulsion point

Ventilation and propeller out-of-water can lead to large thrust loss, but is only occurring in quite high sea states. Faltinsen et al. (1980) gives a good summary of how these effects can be estimated in a simple manner. Prpić-Oršić and Faltinsen (2012) show that a non-linear time-domain simulation is required to properly account for the effect of propeller ventilation on the speed loss. In the cases studied in this paper, the propellers are not ventilating or getting out of the water.

When the propeller is getting close to the free surface, but not sufficiently to cause ventilation, the pressure field surrounding the propeller will disturb the free surface. This will reduce the pressure differential over the propeller, since the free surface will partly allow the pressure differential to escape. Faltinsen et al. (1980) give a method to include this effect based on empirical data.

It is known that wake fraction and thrust deduction will change due to waves and ship motions, but there is surprisingly little knowledge in open literature about the magnitude of change and how to compute it. Usually, model tests are either performed with towed or with self-propelled model, while the determination of change of thrust deduction generally requires the model to be tested both towed and self-propeller in otherwise identical conditions. One of the few such published datasets are given in Naito and Nakamura (1977). This publication also includes one of the very few measurements of change of wake distribution, which shows that the wake is reduced in waves, especially close to the propeller hub. Guo et al. (2012) studied the change of nominal 3-D wake in waves in the propeller plane of the KVLCC2 using RANS and found that the change was largest where the calm water wake was largest, so that the wake field in waves appeared to be more uniform, with the characteristic "hook-shape" of the wake of this full-bodied tanker almost entirely vanished when travelling in a wave with a length similar to the ship length.

When the resistance changes, the propulsion point will change, since the thrust has to balance the resistance. Both the speed and the thrust will change. How much each of them will change depend on how the engine is responding. If a constant power control is applied, the speed will be more reduced than if for example a constant RPM control is used. Thus, the characteristics of the motor, including the effect of its control, must be taken into account in the speed loss calculation.

2.2 Methods for prediction of speed loss

Here we will discuss which methods which are available to predict the speed loss. Methods might be classified in different ways. Here we have chosen the following division of methods:

- The classical powering prediction approach
- Time-domain simulations
- Direct CFD approach
- Model testing of a self-propelled model
- Full scale testing

The classical powering prediction approach

In this approach, a modified resistance curve is created by adding resistance increase due to wind, waves, steering, yawing and other effects to the calm water resistance. Then, thrust deduction and wake fraction in waves are estimated, or taken to be equal to their calm water values, if other information is not available. Then, a powering prediction is performed in exactly the same way as for the calm water situation. In such a calculation, non-linear effect, like for instance propeller ventilation, can't be taken into account in a proper manner. Only the zeroth-order added resistance due to waves is included. Furthermore, effects of steering and yawing can hardly be included.

Time-domain simulations

In time-domain simulations, it is in principle straight forward to include non-linear effects. A ship simulation model that combines seakeeping and manoeuvring is required. Several such simulation models have been developed over the later years.

Direct CFD approach

In the direct CFD approach, the ship sailing in waves is simulated in a time-accurate CFD simulation. The propeller forces are simulated by including the rotating propeller in the simulation, for instance in a sliding mesh arrangement, or by using a simplified propeller model that takes the instantaneous inflow conditions to the propeller from the CFD simulation. A simplified propeller treatment will have difficulties in properly representing the unsteady working conditions of the propeller and the resulting dynamic propeller wake. By including the propeller, this problem is avoided, but resulting in a rather hefty increase in the computational cost. To properly represent the nonlinear effects included in the speed loss problem, the simulation should be performed in a realistic irregular wave train, resulting in a need for excessively long computational times. One of the few reports of such a calculation in the literature is Carrica et al. (2008). CFD in general holds great promise in marine hydrodynamics, but speed loss due to waves seems to be one of the most difficult problems to solve with this method, due to the huge computational effort required.

Model testing of a self-propelled model

When model testing a self-propelled model to determine the speed loss, the ship hull, propeller and rudder are all modeled, and all physical effects of importance should be included, except for cavitation. Thus, outside of the expense of such model tests, problems are related to scale effects, limited length of runs, and issues related to modeling of engine characteristics, auto-pilot and steering and so forth. These issues are discussed in detail in the remaining parts of this paper.

Full scale testing

Although one can say that full scale tests are not a prediction method, but a method to verify a prediction, we will still make a few notes on the quantification of speed loss from full scale measurements. There is currently rapid progress in technology for monitoring ship performance, and remote monitoring systems are rapidly implemented. Savio and Steen (2012) reports how the remote monitoring system Hemos can be used to identify propeller ventilation, while Hansen (2011) reports how another remote monitoring system is used to monitor the speed-power performance of a container vessel in service. This technical progress means that full scale measurements will play a more important role in hydrodynamics research in the future, but some major problems concerning the measurement of speed loss remain: The measurement of the wave condition, and the accurate measurement of speed through water. Together, this means that obtaining accurate speed loss results from full scale measurements is difficult.

3 MODEL TESTS TO MEASURE SPEED LOSS

Model testing is still considered the most accurate way of predicting the speed loss of a ship in waves. It enables inclusion of most important effects in a realistic way. Tests might be performed in a towing tank or seakeeping basin. Tests in long-crested head sea waves in a towing tank is most widespread, both because such facility is most common, and because speed loss is often largest in head seas. However, by limiting the testing to long-crested head seas, important effects due to steering and yawing are lost. This chapter discusses techniques for performing model tests of speed loss, and how such tests can be analysed and corrected. To exemplify, we use model test results of a recent series of tests with a 1:16:57 scale model of a 118 m long tanker, performed in the towing tank and ocean basin at the Marine Technology Centre in Trondheim, Norway. The main dimensions of the model are given in Table 1 below. The model was equipped with scale models of two Rolls-Royce Azipull azimuthing thrusters as main propulsors. The propellers had a diameter of 0.199 m and a pitch ratio $P/D_{0.7}$=1.2.

Table 1 Main dimensions of model

L_{OA}	[m]	7.142
Lpp	[m]	6.832
D	[m]	0.905
B	[m]	1.147
T	[m]	0.435

3.1 Model test set-up

For testing in a towing tank, different set-ups are possible:

1. Model connected to the carriage in the same way as for an ordinary propulsion test – fixed in sway and yaw.
2. Model connected to the carriage with wires and springs.
3. Free-running model.

The set-up 1 used for ordinary propulsion tests is limited with respect to the wave height and wave length, since only small motions are usually allowable in both surge and vertical plane motions. The set-up 2 is normally used for towing a model in waves. It is illustrated in Figure 1. In this set-up a beam is fixed transversely to the model at the longitudinal position of the centre of pitch. To each end of the beam, wires are connected in a crow-foot arrangement. Force transducers are mounted between the beam and the wires so that the longitudinal force from the wires on the model can be measured. The wires are pre-tensioned sufficiently to ensure that the wires won't get slack at any time during testing. In this way, the heading of the model is quite precisely maintained. The wires are connected to the carriage through springs. The springs have a stiffness which shall allow some freedom in surge. The spring stiffness must be such that resonant surge motions are avoided. The arrangement can be used for testing speed loss by adjusting the carriage speed so that the towing force measured at the points where the wire is connected to the beam on average equals the correct friction correction force. This might be a severe control problem, especially in irregular waves. Benefits of this type of set-up are that an actively controlled rudder is not required, and that the wires allow for a method of applying tow rope force.

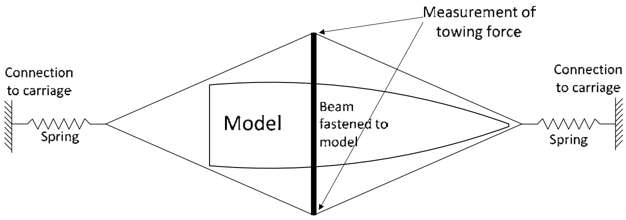

Figure 1 Towing arrangement for seakeeping tests (set-up type 2)

Model tests with a free-running, self-propelled model require use of a controlled rudder, with an auto-pilot to keep the model on course and on a track in the centre of the towing tank. Thus, not only vertical position needs to be measured, but also the horizontal position, effectively requiring the use of an optical position measurement system. Application of the tow rope force (see next section) is also challenging. The recommended way is to use an air fan which gives a thrust force in the direction of travel. By varying the fan speed, the thrust force can be controlled to give the specified tow rope force.

3.1 Friction correction force

In order to obtain correctly scaled propeller loading, a friction correction force has to be applied on the model. This force is often called tow rope force, named after the way this force was traditionally applied during a propulsion test. The tow rope force is given as:

$$F_D = \tfrac{1}{2}\rho V_M^2 S_M C_s \qquad (1)$$

Where subscript M means model scale and subscript S means full scale. V is velocity, S is wetted surface, ρ is water density and C_s is the tow rope force coefficient. C_s is in principle expressed as the difference in total resistance coefficient between model and full scale:

$$C_s = C_{TM} - C_{TS} \tag{2}$$

The main difference between model and full scale total resistance coefficient is the magnitude of the frictional coefficient, but also effect of roughness, transom stern drag, difference in air resistance and appendages, and the correlation allowance should be taken into account. Then, we arrive at the following expression for the tow rope force coefficient:

$$\begin{aligned} C_s &= [C_{FM} - (C_{FS} + \Delta C_F)](1+k) + (C_{BDM} - C_{BDS}) \\ &+ (C_{AppM} - C_{AppM}) - C_A \end{aligned} \tag{3}$$

Where ΔC_F is the roughness allowance, C_{BD} is the transom stern resistance and C_{App} is the appendage resistance coefficient. As an example, for a 1:16:57 scale model of a 118 m long tanker at F_N=0.212 the tow rope force amounts to 41.5% of the calm water resistance. Data for this model is found in Chuang and Steen (2011). If a speed loss test is performed without applying tow rope force, the added resistance due to waves becomes a smaller relative increase of the total resistance, so the predicted speed loss will be less. We will now look at how much less, and start with the condition of the model tests reported in Chuang and Steen (2011), where the power to the propeller was kept constant. Therefore, the following equality holds:

$$\frac{R_{TC} \cdot V_C}{\eta_{DC}} = \frac{R_{TW} \cdot V_W}{\eta_{DW}} \tag{4}$$

Where R_T is the total resistance, subscript C means calm water and subscript W means in the studied wave condition. η_D means quasi-propulsive efficiency, $\eta_D = \eta_H \cdot \eta_R \cdot \eta_0$. We assume here that hull efficiency η_H and relative rotative efficiency η_R are the same in calm water and in waves, so that we can replace η_D with the open water efficiency η_0 in equation (4). The total resistance in waves can be approximated by the following expression:

$$R_{TW} = R_{TC} + \Delta R_W - \left(\frac{dR_{TC}}{dV} + \frac{d\Delta R_W}{dV}\right) \cdot \Delta V \tag{5}$$

where the speed loss $\Delta V = V_C - V_W$ and ΔR_W is the added resistance due to waves, evaluated at the calm water speed V_C. If we insert (4) in (5) and neglect the term proportional to ΔV^2 we get:

$$\Delta V = V_C \frac{R_{TC} + \Delta R_W - R_{TC} \cdot \eta_{0W} / \eta_{0C}}{R_{TC} + \Delta R_W + \left(\frac{dR_{TC}}{dV} + \frac{d\Delta R_W}{dV}\right) V_C} \tag{6}$$

This is actually an expression for the speed loss due to waves when the power is kept constant. If R_{TC} is taken as the resistance corrected for tow rope force (which means the full scale resistance directly Froude-scaled to model scale), then the speed loss when tow rope force is not applied can be found by replacing R_{TC} in equations (5) and (6) by R_{TC}+F_D, equation (6) becomes:

$$\Delta V_{F_D} = V_C \frac{R_{TC} + F_D + \Delta R_W - \left(R_{TC} + F_D\right) \cdot \eta_{0W} / \eta_{0C}}{R_{TC} + F_D + \Delta R_W + \left(\frac{dR_{TC}}{dV} + \frac{dF_D}{dV} + \frac{d\Delta R_W}{dV}\right) V_C} \tag{7}$$

Usually η_{0W} / η_{0C} is not too far from one, and if we temporarily assume $\eta_{0W} / \eta_{0C} = 1$, just to see the effect of the tow rope more clearly, then (7) becomes:

$$\Delta V_{F_D} = V_C \frac{\Delta R_W}{R_{TC} + F_D + \Delta R_W + \left(\frac{dR_{TC}}{dV} + \frac{dF_D}{dV} + \frac{d\Delta R_W}{dV}\right) V_C} \tag{8}$$

So it is clear that neglecting tow rope means that ΔV becomes smaller.

The correction for lack of tow rope force in the experiment is $\Delta V - \Delta V_{F_D}$, so that corrected attainable speed is computed as:

$$V_{corrected} = V_{measured} - \left(\Delta V - \Delta V_{F_D}\right) \tag{9}$$

Later, Chuang and Steen (2012) updated the method to include higher order terms. In this method, R_{TC} and R_{TW} in equation (4) are represented by polynomials, and the equation solved by iteration for the attainable speed in waves V_W , both with and without towrope. Then the difference is used to correct the measured speed in waves according to equation (9). Results of a test in regular head waves of the previously mentioned tanker model are shown in Table 2. Unfortunately, the model tests were only performed without tow rope force, so a proof of the method is not available. In order to provide a partial validation, the table includes results of time-domain simulations with and without tow rope.

Table 2 Predicted full scale speed based on model tests of a tanker in calm water and regular head wave of height 2 m and period T=7.5 s (L_{PP}/λ=1.3)

Condition:	Speed [m/s]
Calm water	7.20
Without tow rope	6.80
Corrected (linear)	6.72
Corrected non-linear	6.71
Simulation, without tow rope	6.85
Simulation, with tow rope	6.70

Figure 2 shows the attainable speed of the same ship as Table 4 for a number of different wave lengths. Values corrected with the linear and the non-linear methods are shown, as well as the uncorrected measured value and the predicted speed using equation (7). It is seen that when the speed loss is large, it is important to correct for tow rope force, and that this should preferably be done with the fully non-linear method. However, that said, it is surprising that the speed loss predicted using the linear prediction method gives so good agreement with the measured value.

In the calculations, the calm water resistance is taken from model tests and the added resistance is computed using the method of Gerritsma and Beukelman (1972).

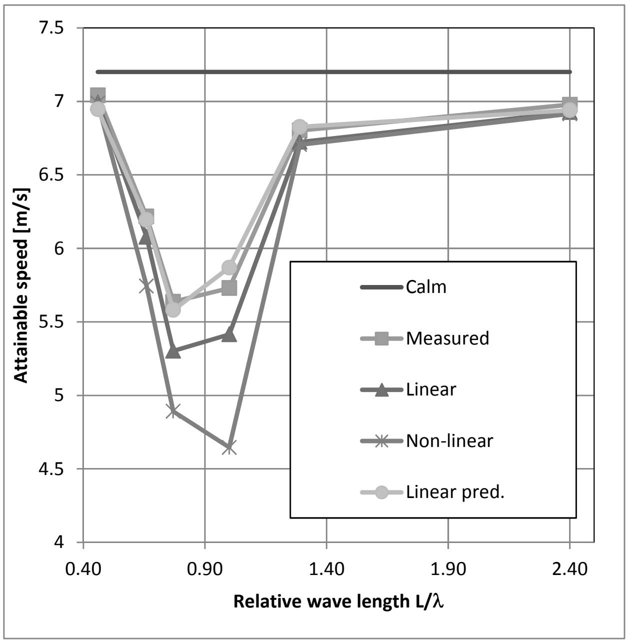

Figure 2 Attainable speed of tanker from model tests in regular head waves of height H=2 m.

3.2 Importance of steering

As indicated in the previous chapter, the speed loss can be predicted quite well in head seas if the added resistance due to waves is known, and as long as the waves don't cause the propeller to get out of the water or ventilate. However, in other than head seas, the waves will cause the vessel to yaw, and steering will often be applied to counteract the yawing and keeping the vessel on the wanted course. If yawing and steering are important for the speed loss, testing with a propelled, free model is required. Tests with the 1:16.57 scale model of the 118 m tanker, were performed in the ocean basin at the Marine Technology Centre at different headings relative to the waves. Since the model was free-running, self-propelled and controlled by an auto-pilot, we can use the results to exemplify the importance of steering on the speed loss. The speed loss is split into added resistance and steering using the following equations:

$$\Delta V_{added} = \frac{V_0 - V}{V_0} \frac{R_{aw}}{R_{aw} + (T - F_x) \bullet (1-t)} \bullet 100\% \qquad (10)$$

$$\Delta V_{steering} = \frac{V_0 - V}{V_0} \frac{(T - F_x) \bullet (1-t)}{R_{aw} + (T - F_x) \bullet (1-t)} \bullet 100\% \qquad (11)$$

where V_0 is calm water speed; t is calm water thrust deduction factor, V is attainable speed, T is thrust and F_x is longitudinal thrust force component. All these variables are measured in the experiment. However, the added wave resistance R_{aw} unfortunately has to be taken as the calculated value, which is a weakness of this method. To be able to separate speed loss due to steering from added resistance without depending on the computed added wave resistance, one would have to do extra tests with restrained heading, which would certainly be a challenge in our ocean basin. Results of using equations (10) and (11) to decompose the results of the tests with the tanker model in 30, 60 and 90 degrees heading are shown in Figure 3, Figure 4, and Figure 5. It is seen that in 30 and 60 degrees heading, speed loss due to added resistance and steering are of almost equal magnitude for this vessel, while in 90 degrees heading, speed loss due to steering dominates. Thus, it seems clear that to determine the speed loss in other than head seas, the steering should be properly included.

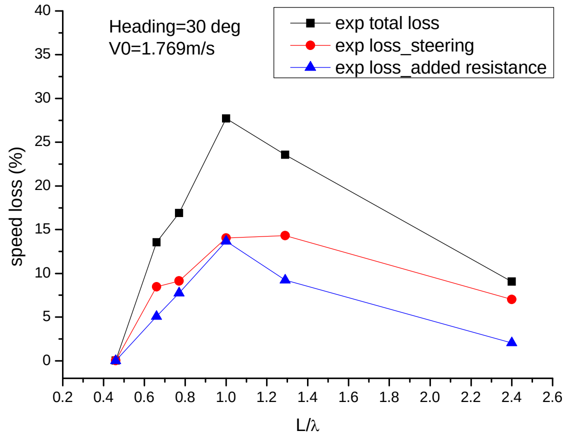

Figure 3 Speed loss due to steering and added resistance in regular waves at a heading of 30 degrees.

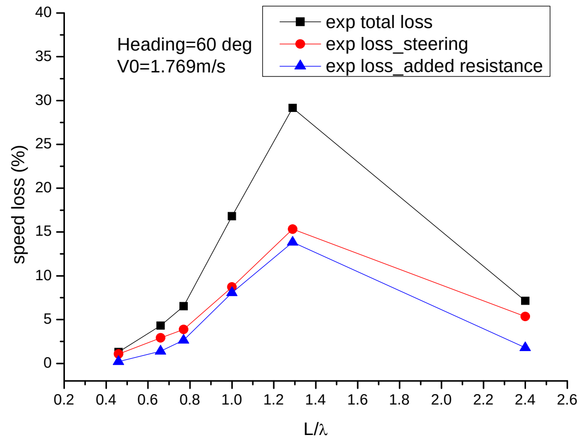

Figure 4 Speed loss due to steering and added resistance in regular waves at a heading of 60 degrees.

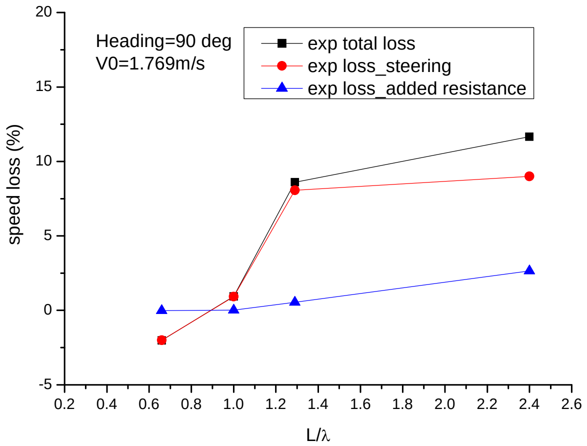

Figure 5 Speed loss due to steering and added resistance in regular waves at a heading of 90 degrees.

3.3 Correction of non-converged runs

Especially when large, heavy models are tested in model basins with limited length, it will often be difficult to get a converged speed in a speed loss test, since the acceleration resulting from an imbalance between thrust and resistance will be small, due to the large mass. The inertia force is expressed as:

$$m \cdot a = R_{TC} + \Delta R_W - T(1-t) - F_D \quad (12)$$

Here R_{TC} is the model resistance, T is the total thrust, t is thrust deduction fraction and F_D is the tow rope force, so here we assume that the tow rope is properly enforced on the model. An example of a non-converged run is shown in Figure 6.

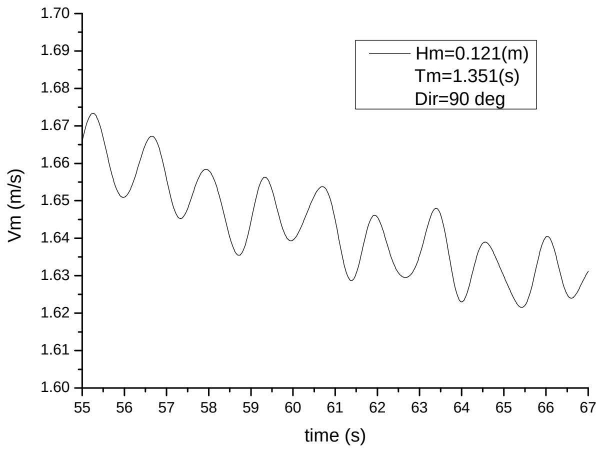

Figure 6 Example of non-converged speed loss run in beam seas.

Chuang and Steen (2012) applied the criterion $a \geq 0.001\ \text{m/s}^2$ to decide when the speed is treated as non-converged. To find the converged speed, we require that the acceleration shall be zero, so equation (12) becomes:

$$R_{TC} + \Delta R_W - T(1-t) - F_D = 0 \quad (13)$$

All terms in this equation is considered as speed-dependent, except for the thrust deduction fraction *t*. Polynomial approximations to R_{TC}, F_D and ΔR_W can be easily established. The thrust T is known from measurements at the non-converged speed V_{nc}. Then, by neglecting the change of efficiency and assuming that tests are performed at constant power we can find the thrust for a new speed V as:

$$T(V) = T(V_{nc})V_{nc}/V \quad (14)$$

Using (14), we can now solve equation (13) iteratively to find the converged speed. The method was applied to oblique wave tests with the same model as reported in section 3.1.

Table 3 Validation of method to correct runs with non-converged speed. Wave height H=0.121 m, calm water speed 1.769 m/s

L/λ	Heading (deg)	$V_{measured}$ (m/s)	$V_{corrected}$ (m/s)	Error (%)
0.77	30	1.470	1.471	0.079
0.46	30	1.768	1.766	-0.108
0.66	60	1.693	1.745	3.091
1.00	90	1.752	1.811	3.366

Further details of the method are shown in Chuang and Steen (2012).

3.4 Model tests to determine propulsive factors

The change of propulsive factors in waves is often overlooked. The classic study by Naito and Nakamura (1977) shows that for their single screw container vessel, the thrust deduction fraction at F_N=0.15 varies about ±0.04, while the wake fraction varies ±0.03, as can be seen from Table 4. It is worth noting that the propulsion tests in waves by Naito and Nakamura (1977) were performed at model propulsion point (that means without tow rope force).

Table 4 Values of thrust deduction and wake fraction in calm water and waves for a container ship. Values extracted from Fig. 18 of Naito and Nakamura (1977)

F_N=0.15	Calm	λ/L=1.2	λ/L=1.7
1-t	0.83	0.87	0.79
1-w	0.70	0.73	0.67

In order to properly measure the thrust deduction fraction in a model test, two different methods are suggested:

1. Perform both resistance and propulsion test at same speed in the same wave conditions
2. Perform the propulsion test at (at least) two different tow rope forces for the same speed and wave condition.

The first method is similar to the conventional ITTC'78 approach used in calm water. The problem with this approach is that it is time-consuming and that conditions might be different during resistance and propulsion tests if the propulsion test in waves is carried out with a free running model (method 3 of section 3.1). To do the propulsion test with a free model, the propulsion test must be performed first, and the resistance test performed afterwards at the same speed as was achieved in the propulsion test. The resistance test will necessarily have to be performed with a (partly) restrained model in a set-up somewhat similar to Figure 1. Then, differences between thrust and resistance might not only be the classical thrust deduction, but also be due to steering and yawing during propulsion.

In the second method, the thrust deduction is found from the results of tests 1 and 2 by solving the system of two ordinary equations:

$$\begin{aligned} T_1\left(1-t\right) &= R_T - F_{D1} \\ T_2\left(1-t\right) &= R_T - F_{D2} \end{aligned} \tag{15}$$

where R_T is the total resistance in the actual wave condition, including added wave resistance, T is the total thrust and F_D is the applied tow rope force. Both T and F_D are measured. For this approach to work, we have to assume that (1-*t*) is independent of propeller loading, and both tests must be performed at the same speed and wave condition, so that we can justify the assumption of R_T being the same in both measurements. The variation in propeller loading can be obtained by varying the air fan thrust in a free model set-up, but in that case it will be difficult to obtain the same speed. Dividing both equations in (15) with $\frac{1}{2}\rho V^2$ will reduce the sensitivity to small differences in velocity between the two runs. If the model is mounted in the spring and wire system shown in Figure 1, the test can performed at constant speed and the variation in tow rope force obtained simply by varying the propeller speed. However, this method is only recommended in head and following waves. Therefore, it can be concluded that determining thrust deduction in other than head and following waves is not straight forward and that it is difficult to give a general recommendation for method to be used.

To find the wake fraction in waves, we need data from a propeller open water test. According to Naito and Nakamura (1977) and McCarthy et al. (1961) the propeller open water characteristics don’t change in waves. That is a reasonable assumption according to our experience, as long as the propeller is well submerged, so ventilation and out-of-water effects can be excluded. Thus, to find the change of wake in moderate sea states, a calm water open water test can be applied. If the analysis is based on a load-varied propulsion test, according to method 2 above, we can separate the effect of propeller loading on the wake fraction.

4 CONCLUSIONS

Through analyses of a series of model tests with a 1:16.57 scale model of a 118 long tanker propelled by twin azimuthing thrusters, the importance of including tow rope force in model tests to determine speed loss is demonstrated. Furthermore, a method to correct results for the lack of tow rope force is demonstrated.

To find the speed loss in other than head seas, model tests should be performed with a free-running, auto-pilot controlled model, so that the effects of both added resistance and steering are included. For the model of the 118 m long tanker, it was demonstrated that steering and added resistance contributed equally much to the speed loss in 30 and 60 degrees heading in regular waves.

When performing speed loss model tests in an ocean basin, obtaining converged speed is a frequent problem, due to slow convergence and limited length of the basin. A correction method to obtain the value of converged speed from non-converged runs is demonstrated, and good results are found.

To determine the thrust deduction in waves, we need results from both resistance and propulsion test at the same speed in the same waves, or we can use two propulsion tests at different tow rope force. Both methods can be performed by testing at a pre-determined speed with a partially restrained model. However, in oblique waves, testing the model in free-running condition is recommended, so it is not clear what is the best method for obtaining the thrust deduction in oblique waves.

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