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AN OUTLINE OF A SHIPYARD'S NEED FOR MODEL TESTING

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Summary

In this paper it has been discussed which kind and to what extent the towing tank tests should be asked for by the shipyards or ship design offices in connection with design work. The discussion is based on the experience gained at the Instituttet for Skibs- og Havteknik (ISH), Denmark, over many years of design work and also on the experience of ISH of various ship hydrodynamical laboratories.

1. Introduction.

It was a common practice thirty or forty years ago for a shipyard to have the following towing tank tests carried out before the construction work started especially for a bigger ship, say, over 2000 tons deadweight.

a) One still water resistance test with a model of approx. 6 m length ballasted to the expected summer load line.

b) One open water test with a scale model of the propeller expected to be the correct one.

c) One self-propulsion test with the scale model of ship and propeller at the same condition as that of the resistance test.

The instruments used to measure force and moments were very simple and based on a mechanical balance system. The test procedure was according to Froude's law (see, for instance, Reference [7]) and the prediction for the full scale ship was carried out according to the Froude's method. The scale effect was taken into account using a formula for the friction coefficient where the ship length was incorporated. The ship propeller r.p.m. was determined from the model propeller r.p.m. by means of an empirical expression taking care of the different boundary layer thicknesses of ship and model.

All the tests used to be executed in 2 to 2½ days and the ship designer had the opportunity to visualize the form of the future ship in three dimensions. He would know that beautiful lines meant less resistance and he could see if the wave system which the model was generating during the tests, was not very unsatisfactory. The staff of the towing tank was able to tell the designer, if the engine already ordered was developing the necessary power to get the desired speed, and when the day of the trial trip arrived he would be sure that the ship during the speed trials would live up to the expectations.

There seems to be little doubt that the test procedures outlined here were adequate for the yard and designer at that time.

The ship technical laboratories of today offer the customer a much more sophisticated program of measurements, calculations and analysis ranging from the simple towing tests to very complicated seakeeping and manoeuvring experiments. The measurements are often carried out by means of highly sophisticated electronic equipment and the analysis of the data is performed on computers using specially developed programs having a complicated physical and mathematical background. The staff running the tests merely has the task of ensuring that wires are connected correctly and the data-carrying tapes or other mediums are produced and delivered to the computer in a correct way. They have very little knowledge of how good the measurements are and how the tests fared. The ship designer being present during these tests can only see the model running through the water and when the tests are over he would not know if everything went wrong or right. Some days later when the test results have been analysed by the computer he and the laboratory would know the results. If something went wrong they would have to wait for days before the towing tank is again available and the experiments can be repeated.

These procedures are complicated and often very laborious and time consuming. Furthermore the computers and other electronic equipment are very expensive in its initial cost as well as in maintenance. As a result, today's towing tank tests are rather expensive and therefore add considerably to the design cost.

The question one could ask is: Are these tests and complicated calculations really necessary for the ship designer and the shipyard? The following sections will discuss this point.

When hydrodynamical matters of theoretical or applied character are presented it is normally done by a member of the staff from a ship technical laboratory. As the ISH has no towing tank of its own it has to request for tests at various model basins on the same basis as any other customer. The experience narrated here can therefore be looked upon as a shipyard's or any other customer's view on model tests.

The investigation carried out at ISH has been limited to the problems connected with merchant ships of conventional design.

2. The shipyard's requirements.

The shipyard's requirements are connected to the yard's ability to fulfil the building specifications and contract. Only the hydrodynamical requirements will be discussed here.

For the sake of simplicity the design process can be divided into four steps as follows:

(1) The initial contact between the owner and the yard,

(2) the negotiations and the outline specifications,

(3) the building specifications and contracts and

(4) the detailed design.

It is of importance for the yard during the first negotiations with the owner (step 1) that is should have a reasonably good knowledge of the power needed to obtain the required speed of the ship. The yard has to know this power to a certain extent so it can be sure about the type and the range of size of the propulsion machinery. The prediction of this power can be made by means of very simple diagrams giving the power as a function of a couple of important parameters, as for example, ship type, speed and deadweight. Examples of diagrams of this nature can be found in "Power of Ships"[4].

When the yard and the owner have gone further into their negotiations (step 2) a more detailed design has to be made, say, for example, an outline specification and a general arrangement are worked out. Also during this stage the more detailed and accurate methods have to be used when calculating the hydrodynamical particulars.

The resistance of the ship can be evaluated from design diagrams, see, for instance, "Ship Resistance" [2]; the propeller characteristics can be obtained, for instance, from the Wageningen propeller series diagrams [9]. Also the wake and thrust deduction fractions can be estimated by means of available diagrams (see, for instance "Power of Ships" [4]). It will often be convenient to program this design steps if the shipyard has to do this kind of calculations often. A low cost desk calculator can quite easily store these design diagrams and calculation programs. The model tests can now enter into the picture, if the ship in question is of a very exceptional design (step 3), for instance, double hull, or unusual main dimensions or hull form of special nature. Often a series of tests will then have to be carried out and by this procedure the yard should have made an insurance against any unpleasant surprise.

The shipyard will have the responsibility that everything is as it should be, when the designer at last proceeds to make the final lines (step 4). This means in the first place that the shipyard can fulfil the requirements in the contract regarding speed. The ship technical laboratory will make the trial prediction and will also often take measurements and analyse the trial trip results. This will, in general, cover the needs of the shipyard concerning tank tests. Further tests will be performed only if there are problems in fulfilling the contract requirements or other difficulties, such as noise, vibrations or navigational hazards.

3. Model experiments.

This section will discuss some of of the experimental procedures which could be used at the various design stages. The discussion will however only cover the domains about which the ISH has experience. They are:

3.1 Model making
3.2 Resistance tests
3.3 Determination of open water propeller characteristics
3.4 Self-propulsion investigations
3.5 Streamline tests
3.6 Wake measurements with pitot tubes
3.7 Measurements in waves.

3.1 Model making.

Only a few people are in a position to visualize in detail the three-dimensional hull form on the basis of a two-dimensional representation. Nowadays it is a common practice for most big shipyards to do the plate expansion by electronic data processing and a half model of the ship is not made any longer. If the designer wants to check his design or present his product he will use the model tested in the tank.

A lot concerning the ship lines can be seen by looking at the model from various angles and by letting the hand run over the surface. Also a poor form of the stern and stem as well as an unsatisfactory rudder and propeller arrangement can often been seen clearly on a well made model. We will say again: "Normally beautiful lines mean a good ship with good propulsion properties".

All models in a test series should be of the same material even if it is normally regarded as of no importance for the test results.

3.2 Resistance tests.

It may seen attractive to use small models when the resistance properties of a series of ships are to be investigated. Small models are much cheaper than big ones; the tests can be performed in small low-cost tanks and the measurement equipment can be simpler, cheaper and easier to operate. The question is if one gets results of any significance.

Many tests with small models have been carried out under the supervision of the ISH, often in connection with the teaching of hydrodynamics. The tests were performed in a tank equipped with a towing system of the "Wellenkamp"-type and with the dimensions, $L \times B \times h = 18 \text{ m} \times 2 \text{ m} \times 0{,}9 \text{ m}$ [1]. The discussion in connection with small models will be limited to the tests conducted with a 1:125 scale model of the 6600 tons deadweight dry cargo liner M/S "Michigan". The resistance tests within a relatively big interval of velocities were performed with the parent model and two models equipped with a small bulb (I) and a bigger one (II). The data for the model are shown in table 1. and the lines drawing of the three models are shown in Fig. 1. Fig. 2 shows the results of a series of tests. The total resistance R_T is given as a function of speed V. The numbers in brackets on the diagrams indicate how many times the the tests have been repeated. It is seen that in some of the velocity intervals the scattering of the results is very extensive. The reason for this has not been investigated.

Looking on the averaging curve for the parent model and the two curves for the model with bulbs, one will notice that the differences are very small and of no significance. Also the values of R_T calculated according to the method in "Ship Resistance" [2] are shown in Fig. 2, and it will be seen that there is very good agreement with the measured values.

The residuary resistance coefficient C_R shown in Fig. 3 is calculated as:

$$C_R = C_T - C_F$$

where C_T and C_F are the total resistance coefficient and the friction resistance coefficient respectively. C_F is calculated by the ITTC-1957 method as:

$$C_F = \frac{0{,}075}{(\log_{10} R_n - 2)^2}$$

where R_n is the Reynolds number. Fig. 3 shows how the C_R varies with V for the three models and this variation looks different compared with the variations in R_T. The reason for this is that the friction represented by C_F calculated by the ITTC formula is much larger than the residuary resistance represented by C_R. For a Froude number of o,25, which for the real ship corresponds a velocity of approx. 9 m/s or

Model	M/S MICHIGAN		Units
$L = L_{WL}$	1,054	6,402	m
L_{pp}	1,020	6,195	m
B	0,150	0,911	m
T	0,0583	0,355	m
∇	0,00543	1,288	m^3
S	0,196	7,263	m^2
δ_{pp}	0,608	0,614	-
δ	0,589	0,594	-
β	0,983	0,982	-
φ	0,599	0,605	-
$L/\nabla^{1/3}$	5,999	5,978	-
L/B	7,027	7,027	-
B/T	2,573	2,566	-
LCB/L_{pp}	0,008	0,008	-

Table 1. Particulars of the models of M/S MICHIGAN.

Model	A	B	C	D	E	F	Units
$L = L_{WL}$	7,534	7,534	7,534	7,542	7,542	7.235	m
L_{pp}	7,360	7,360	7,360	7,368	7,368	7,069	m
B	1,115	1,115	1,115	1,115	1,115	1,052	m
T	0,432	0,432	0,432	0,432	0,432	0,399	m
∇	2,742	2,846	2,972	2,905	2,927	2,378	m^3
S	12,087	12,375	12,690	12,526	12,653	11,12	m^2
δ_{pp}	0,773	0,802	0,837	0,818	0,824	0,802	-
δ	0,755	0,783	0,818	0,799	0,805	0,784	-
β	0,996	0,996	0,996	0,996	0,996	0,997	-
φ	0,758	0,786	0,821	0,802	0,808	0,786	-
$L/\nabla^{1/3}$	5,382	5,316	5,240	5,285	5,272	5,42	-
L/B	6,755	6,755	6,755	6,762	6,762	6,88	-
B/T	2,579	2,579	2,579	2,579	2,579	2,64	-
LCB/L_{pp}	-0,0182	-0,0191	-0,0294	-0,0197	-0,0233	-0,0202	-

Table 2. Particulars of the models A - F.

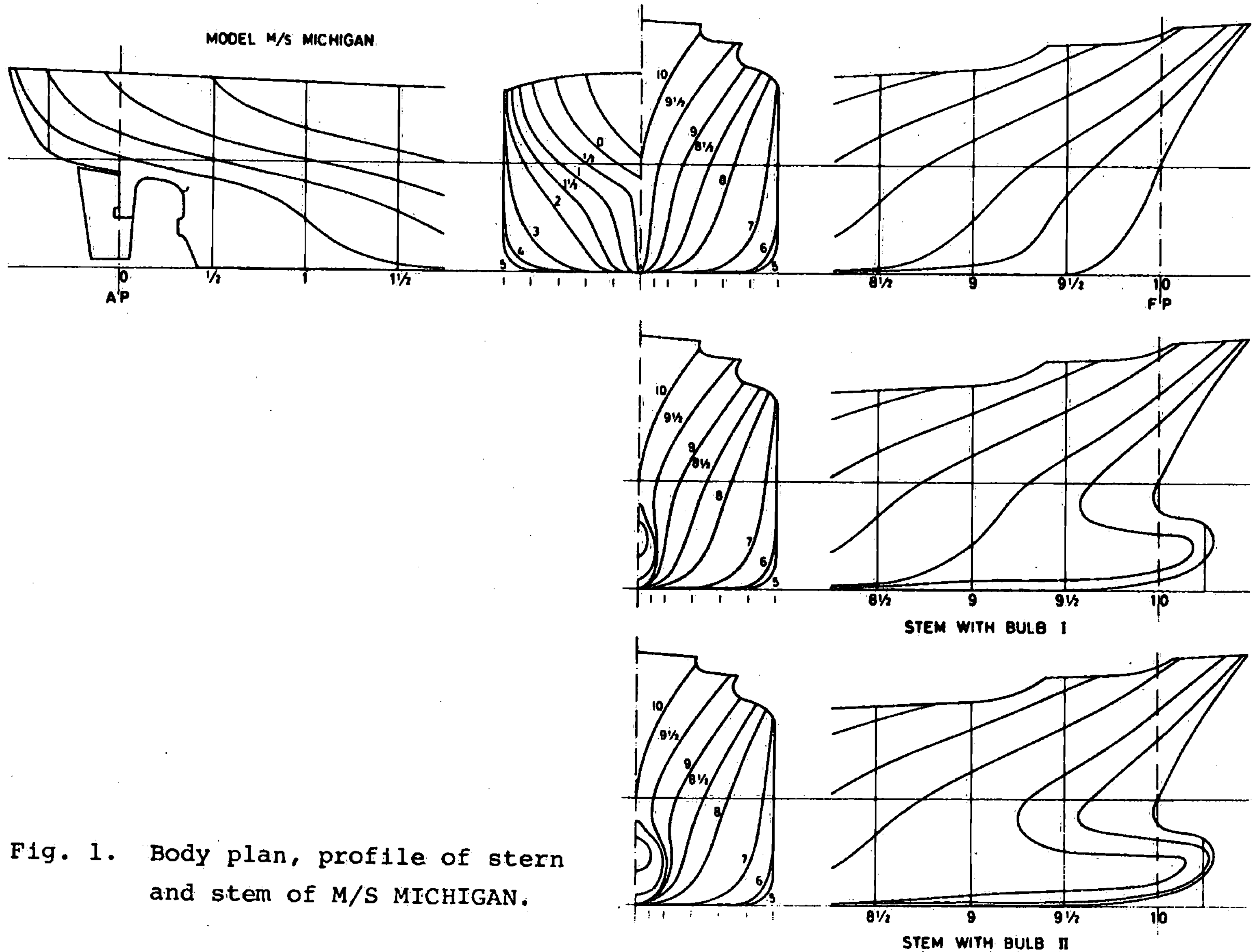


Fig. 1. Body plan, profile of stern and stem of M/S MICHIGAN.

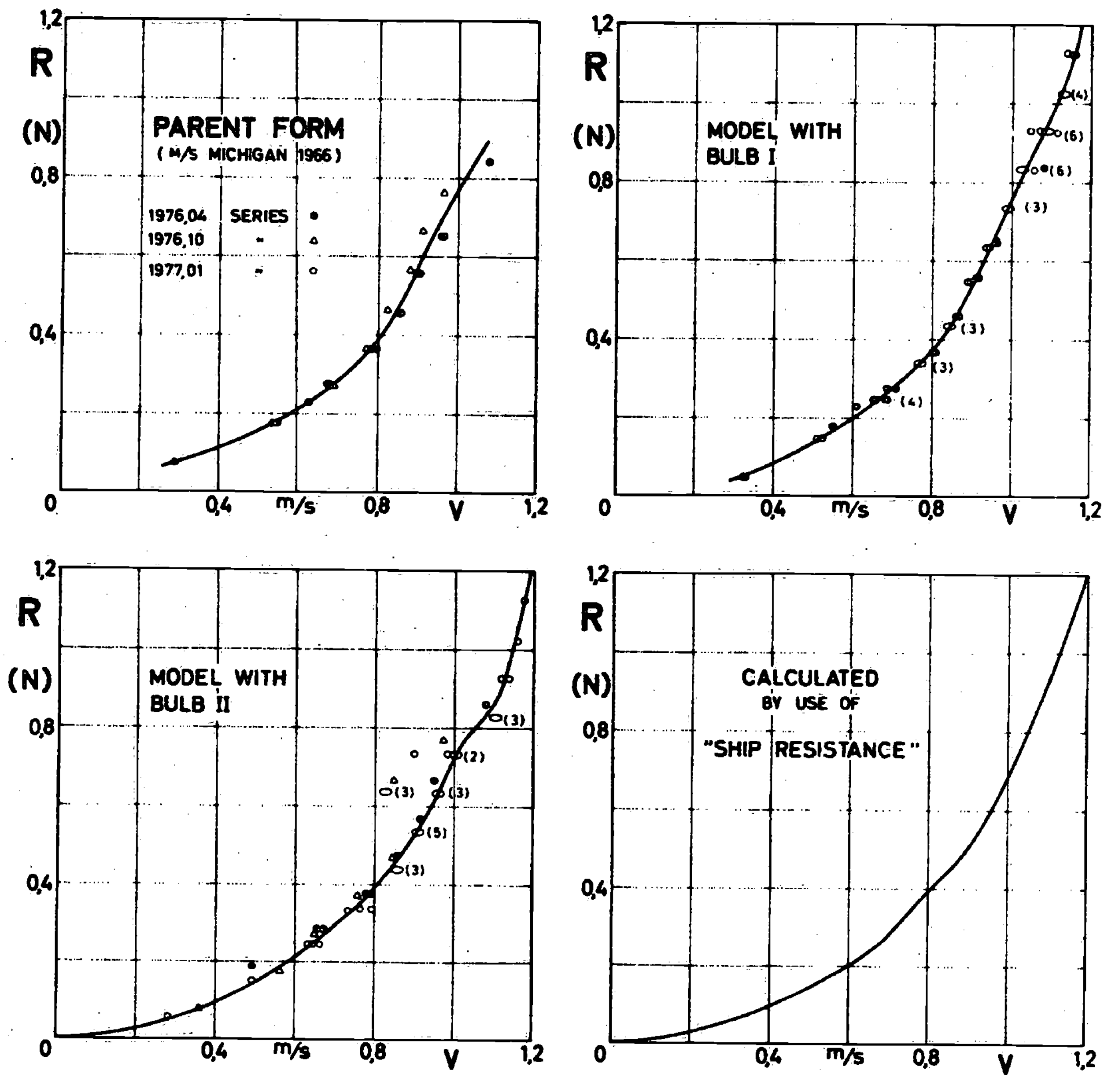
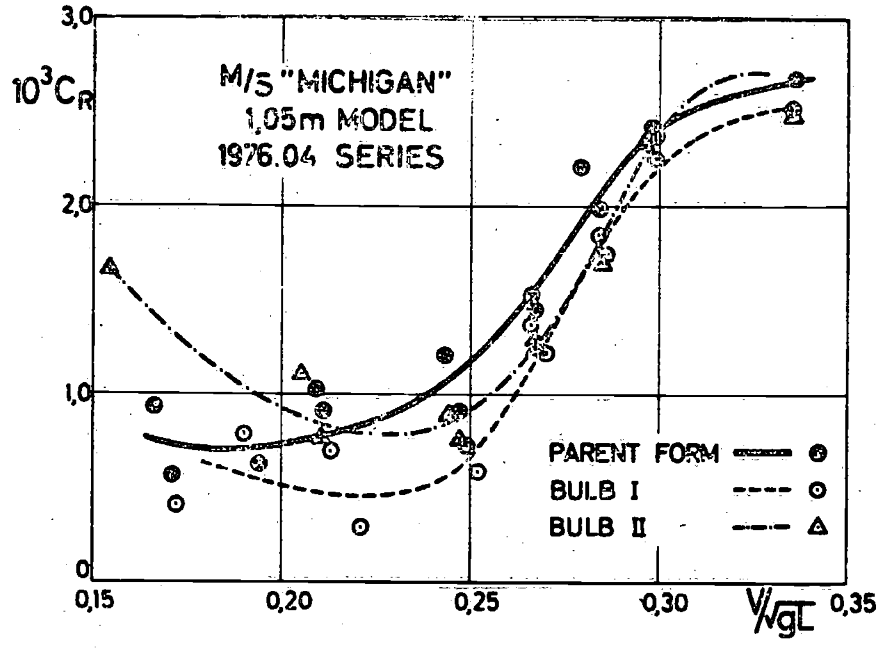


Fig. 2. Resistance curves for model M/S MICHIGAN.



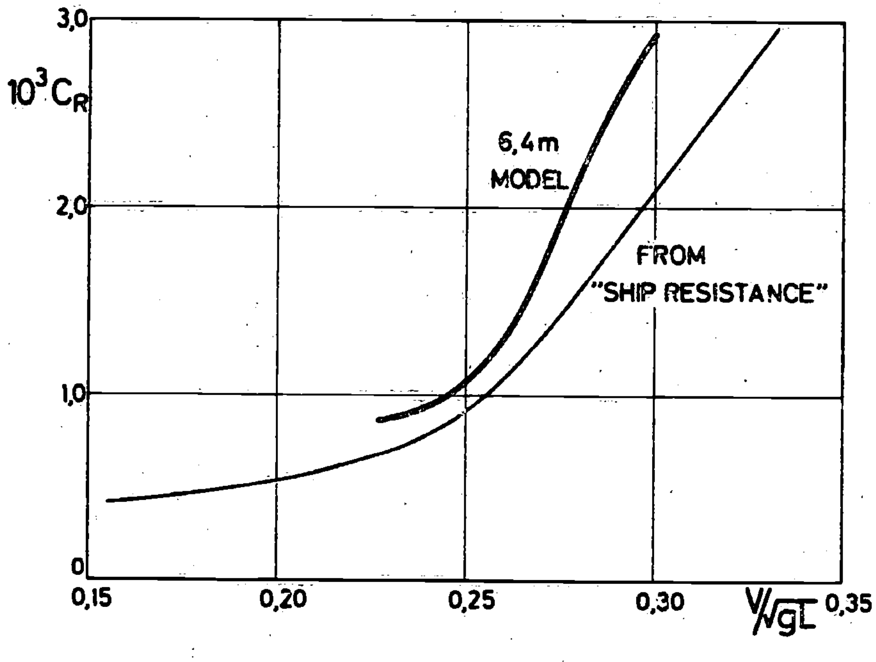


Fig. 3. Residual-resistance coefficient for model M/S MICHIGAN.

17,5 knots, C_R is approx. 0,9 and C_F in model scale approx. 4,9. C_F is more than 5 times as much as C_R and the object of our tests is to find C_R. The conclusion seems to be that even with these many tests it is not possible to determine if it is of any powering advantage to fit a bulb to the parent ship. One also has to conclude that small differences in the ship's form cannot be determined from towing tank tests in this small scale (1:125). For the comparison Fig. 3 also shows the result of test with an approx. 6,4 m model of M/S "Michigan" and the C_R values obtained from "Ship Resistance" [2]. It is seen that other than for a small velocity range there is a big difference between the results from the tests with the big and the small model.

Instead of spending time and money on small scale model tests one could as well use the results from the big series tests, for instance, the Taylor series, the Gothenburg series etc., or from speciel design diagrams, see, for example, "Ship Resistance" [2].

The proportion of C_F to C_R will be smaller if the model size is increased. With a 6 m model C_F is only about 3,3 times C_R and for a 12 m model C_F is about 2,8 times as big as C_R. If the Reynolds number for the 1 m model is $7{,}8 \cdot 10^5$, it will then be $1{,}15 \cdot 10^7$ for a 6 m model and $3{,}24 \cdot 10^7$ for a 12 m model. Therefore the best and most efficient way to establish a stable turbulent flow over the ship surface is to use the larger models.

The results from a series of model tests with bulk carrier forms have been compared in order to elucidate some of the problems concerning tests with big models. Fig. 4 shows the lines and stem and stern contours for one of the models, A, and the main particulars are given in table 2. This model represents in scale 1:26 a bulk carrier of a deadweight of approx. 50000 tons. The two other models incorporated in the test series had the same main dimension and form, but were fuller as stated in table 2 (model B and C).

Fig. 5 shows the residuary resistance coefficient C_R obtained from resistance tests using the ITTC-57 line for frictional resistance.

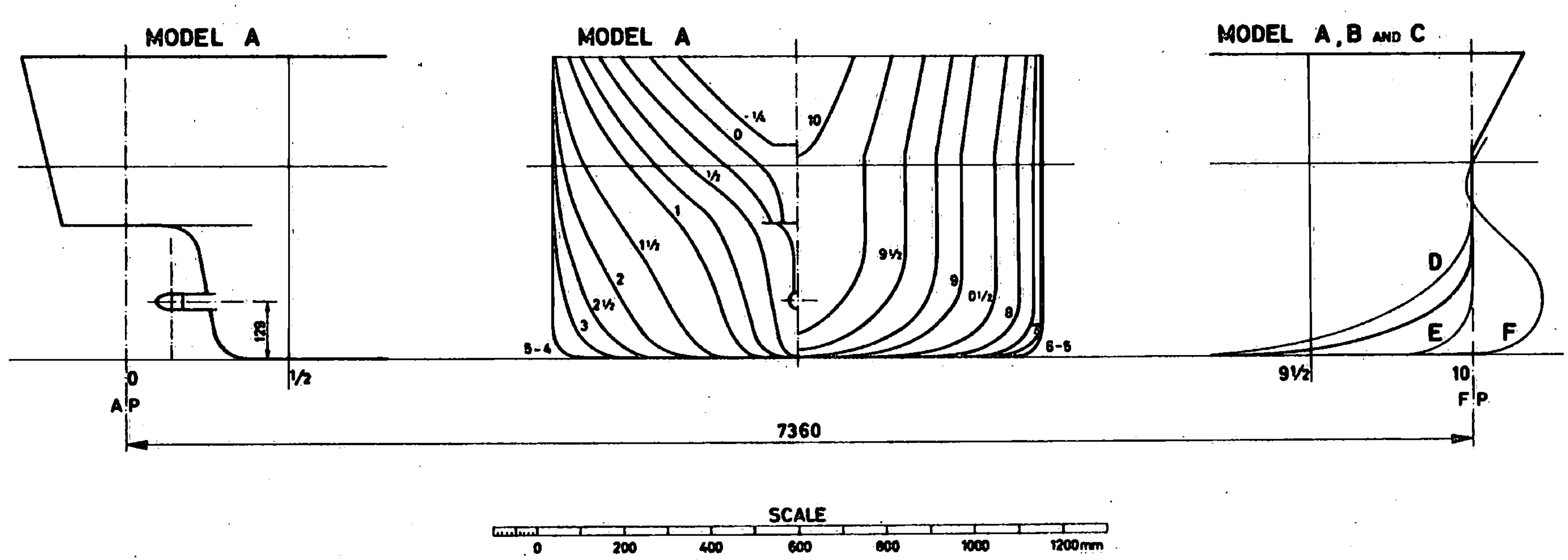


Fig. 4. Body plan, profile of stern and stem of Model A.
The stems for models B, C, D, E and F are indicated.

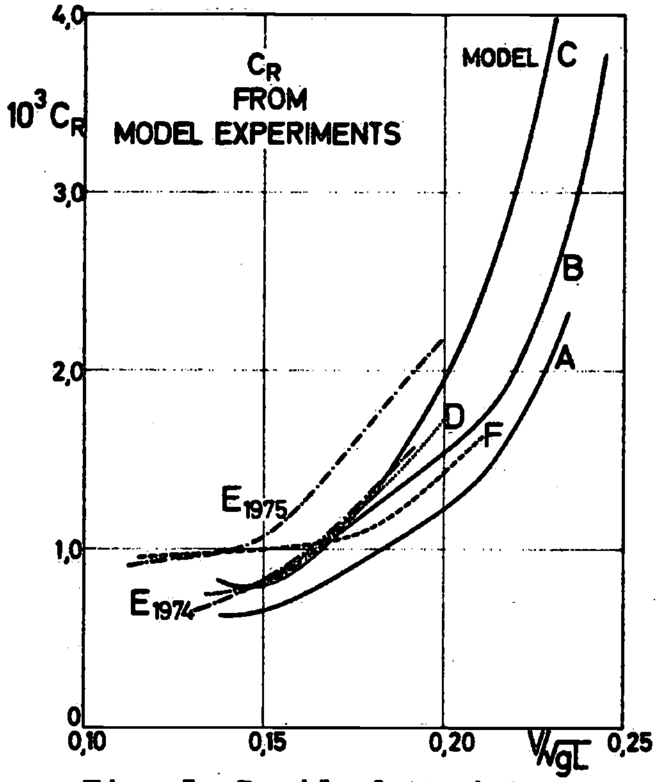


Fig. 5. Residual-resistance coefficient versus speed length ratio for models A-F.

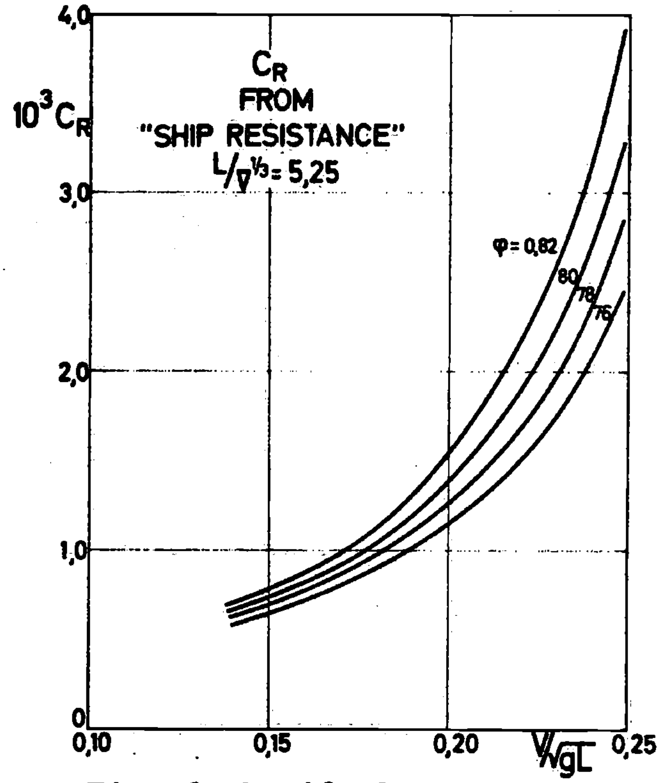


Fig. 6. Residual-resistance coefficient from "Ship Resistance" [2].

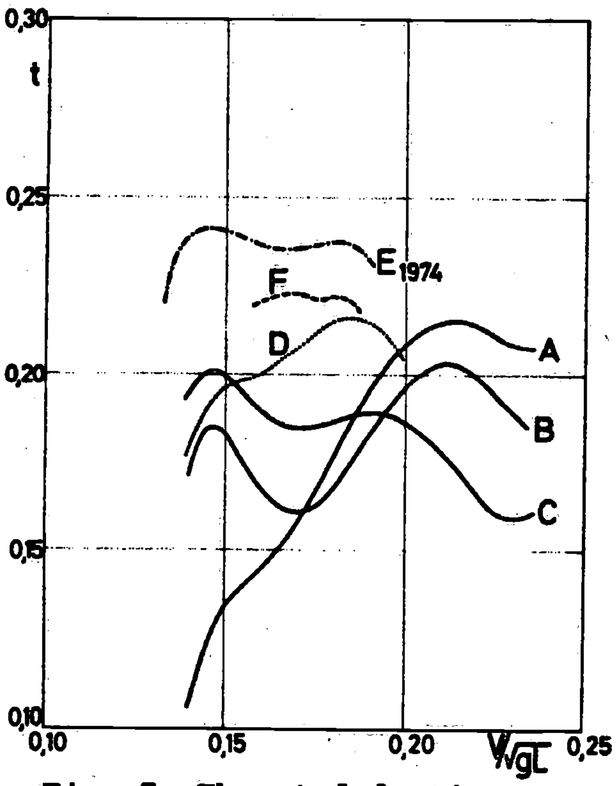


Fig. 7. Thrust deduction fraction for models A-F.

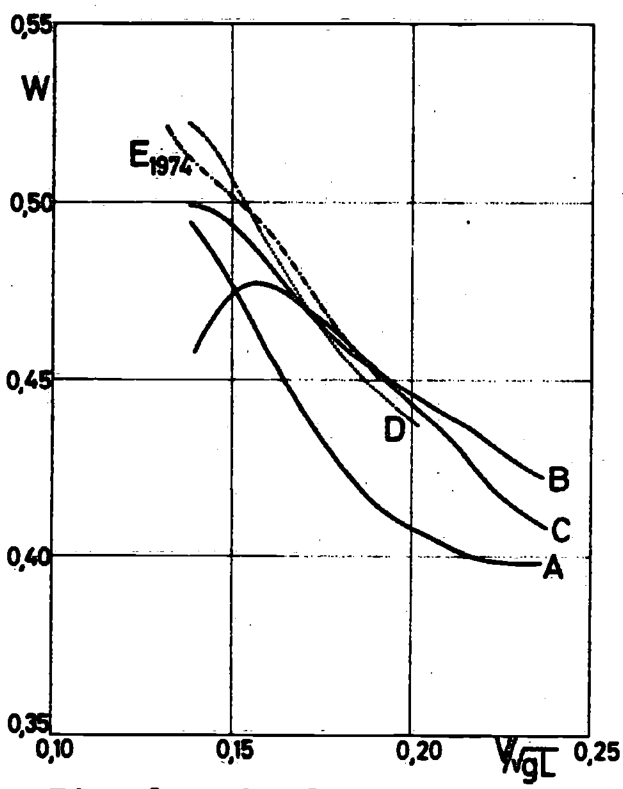


Fig. 8. Wake fraction for models A-E.

Even though the three models have the same form and main dimensions it is seen that C_R is not changing in a systematic way with the fullness. Using "Ship Resistance" [2] one should expect changes in C_R in the same way as those for the curves marked φ = 0,76, φ = 0,78 and φ = 0,82. The deviations of the run of the experimental curves from the expected run can be due to only the uncertainty of the tests.

In Fig. 5 C_R is also shown for the model D which has the same form as A, B and C except that is has some more cut-away at the stem (see Fig. 4). There is a little difference in the main dimensions (see teble 2), but it should be of no significance. It is seen that the C_R-curve of this model corresponds to the A, B and C curves. The figure indicates that one should not expect that a single set of tests always can help to decide if some form is better than another. It must be inferred that a systematic change in a model parameter will result in a systematic change in the C_R-curves. In Fig. 5 the uncertainty of the test results has concealed this fact.

Two other model test results are represented in Fig. 5. The model E has the same main dimensions and hull form as A, B and C, but the stem is of the cylindrical type (see Fig. 4 and table 2). The model E has been run twice, in 1974 and in 1975 . The 1974 test results fit quite well into the set of C_R-curves, but the 1975 test results lie much higher. Why this is the case cannot be explained on the basis of the standard material forwarded from the towing tank to the customer.

The residuary resistance coefficient of the last model, i.e. model F, as represented in Fig. 5, is tested in another laboratory. It is of the same form as the other models although it has been fitted with a small bulb (see Fig. 4 and table 2). One would have expected results closer to those of model B which has practically the same block coefficient. It is quite normal that tank test results in different laboratories are not fully compatible, although the powering prognosis can nevertheless be the same because of the empirical coefficients adopted by the different laboratories for the prediction technique.

Operating as a yard in ship design the ISH finds it impossible to investigate if the C_R values for these models can be made to match each other. This can only be done on the basis of the raw measured data which a yard normally never sees.

Many factors which are not evident and can seldom be recognized play an important role in obtaining the test results:

- Who has been responsible for the test, has he been careful or has he taken chances?
- On which day of the week have the tests been carried out? A longer period of inactivity (e.g. week-ends) may cause different turbulent conditions in the towing tank.
- Which type of tests has been carried out before this one? Has it been tests with a small model in still water, tests with a big model in waves, tests with a submarine or has it been an offshore test?
- How long has been the time between two tests and in what order have the tests been carried out?

If the yard is going to do further analyses of the tests, it would be an advantage if the raw test data are delivered together with the powering prognosis and the faired resistance and power curves.

The ship mentioned here is planned to operate at a Froude number of about 0,18. This means that C_R for most of the models will be approx. $1,3 \cdot 10^{-3}$ and C_F approx. $3,0 \cdot 10^{-3}$. For the real ship C_F will have a value of approx. $1,5 \cdot 10^{-3}$. With these figures in mind together with the inconsistent curves as shown in Fig. 5 one gets an impression of the effect of uncertainty on C_R when the necessary power for the ship has to be predicted.

In connection with the towing tests it is customary to note the wave system which is generated by the model. Normally this is done by taking photographs but a drawing should also be made because of the unsatisfactory photographical registration of the waves near the stern and stem. The wave profiles are anyway to be drawn if a comparison is to be made.

The conclusion in this section can be written as follows:

A. It is of importance for the shipyard to have towing tests performed and analysed.

B. It should not be expected that towing tests can give any significant indication of the effect of minor form changes.

C. The tests should be performed with the biggest possible models. Going from 1 m model to 7 m model is however, of much more importance than going from 7 m to 12 m model.

D. To draw conclusions on the basis of primary test data from one laboratory and comparable data from another one is very difficult.

3.3. Open water propeller tests.

In the past it was a normal procedure to have a model made of the propeller which was expected to be fitted on the ship. Open water tests were then conducted with this model propeller. The manufacture of a propeller model today is very time-consuming and costly and it is a normal practice to do at least the preliminary self-propulsion tests with a stock propeller and very often it is not necessary to make a special propeller model as discussed in the next section. The open water test data are then known for the stock propeller and no further tests are necessary. Open water tests are relatively simple to carry out, but a scattering in the results is, of course, also present here (see, for instance, [8]). It is important that the propeller model used has a diameter greater than 200 mm, otherwise most of the results will be severely affected due to scale effects.

Complete propeller diagrams for both ahead and astern operations, i.e. diagrams with all four combinations of revolution and velocity direction [3] are seldom necessary for the shipyard design offices.

3.4. Self-propulsion tests.

Self-propulsion tests are performed to make sure that the propeller, engine and hull are working together well. The tests are normally carried out in accordance with Froude's law, i.e.:

- speed of model equals speed of ship divided by $\sqrt{\lambda}$
- r.p.m. of model propeller equals r.p.m. of ship propeller times $\sqrt{\lambda}$

where λ is the linear scale ratio.

During the tests the model is relieved in some way by the friction correction in order to make the model propeller work at the same loading as the real propeller (ship propulsion point). The thrust and torque necessary for the propulsion of the real ship are proportional with λ^3 and λ^4 respectively. But making a powering prognosis for the ship on the basis of a self-propulsion test only would be close to gambling.

It is so that the propeller at these tests is working with a high number of revolution in a boundary layer much thicker than that of the real ship and the static pressure on the water surface will normally not have been reduced according to the model scale. The question is what these tests actually tell the yard? The answer is that the yard only gets information on these two items for the model:

The thrust deduction fraction, $t = \dfrac{T-R_T}{T}$

The wake fraction, $w = \dfrac{V-V_A}{V}$

where:

T is the propeller thrust

R_T is the towing resistance

V is the ship velocity

V_A is the velocity of advance of propeller

In order to calculate t one must have the results of the towing test and the data from the open water test for the propeller must be known in order to calculate w. The question of using thrust or torque identity or some mixed methods also obscures the problems of determining the wake.

The thrust deduction t and wake fraction w found by model test analyses have then to be corrected in some way for the real ship in order to compensate for all sorts of scale effects. Before reanalysing it is necessary to check t and w against the corresponding values obtained from diagrams or formulae as given in reference [5]. How good are now the values of the thrust deduction and the wake fraction? In order to get an idea the ISH has used the results from the tests made with the model A, B, C, D, E and F. These models are almost similar in size and form (see table 2), and they should be expected to give values of t and w which are not too different from model to model. The results are shown in Figs.7 and 8. As it is seen the curves are not consistent all over the velocity range. The laboratories have made some smoothing of the primary test results (R_T, T, Q, n and V) and these have been used to calculate t and w. This means that the t- and w-curves are very faired too. There is no reason to believe that it should be so if the uncertainty of the test procedure are taken into account. The fairness is no indication of their correctness. The yard will normally never be informed of the scattering of the results around these artificial curves, unless they ask for it. If the yard wants to do some analysing of their own they will have to ask for and get all the necessary raw test data.

The conclusion of the discussion on this matter could be that the yard should ask for a self-propulsion test when they have decided upon the hull form which under the present circumstances gives the least resistance. Because this test only gives the thrust deduction and wake fraction for the model, it can be performed with some stock propeller without losing its information value. Still it can be necessary to make the test with special manufactured model propeller(s), if the propeller arrangement is very extraordinary. It should also be mentioned here that tests with a propeller having a diameter less than 200 mm normally are without value because of the scale effects.

3.5. Streamline tests.

Streamline tests should be performed to obtain knowledge of where to place appendages, such as bilge-keels, bossings and struts in order to get as little extra resistance as possible.

Streamline tests have been ordered by the ISH on model A. One of the results is shown in Fig. 9. The streamline test was carried out by the wet paint method. The streamlines obtained by calculating the potential flow around the hull by a sink/source method (K. Rasmussen as part of his work for the master's degree at the ISH) is also shown in Fig. 9. As it will be seen there is a great difference in the two sets of streamlines. The lines actually cross each other with angles as

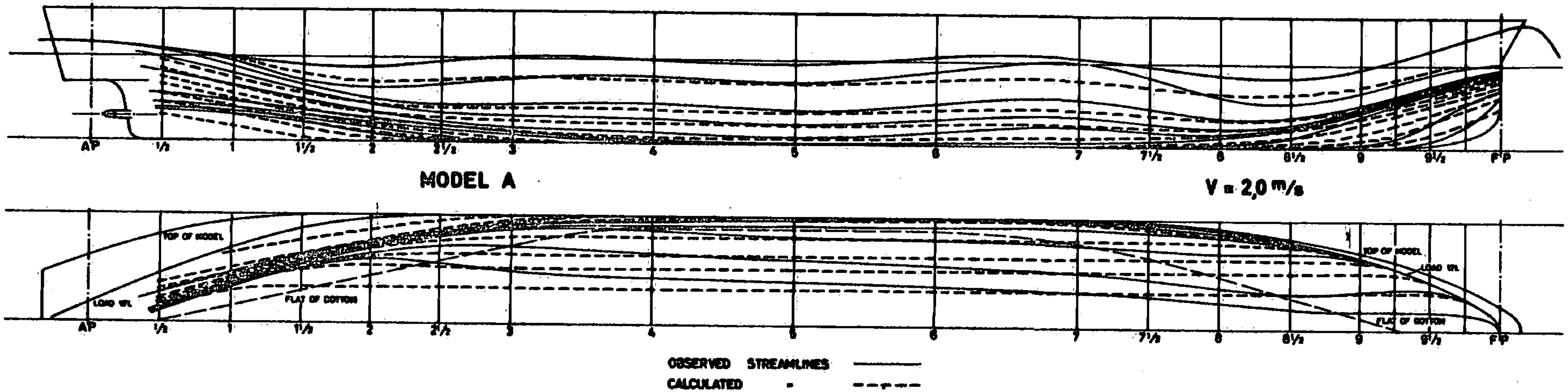


Fig. 9. Observed and calculated streamlines for model A.

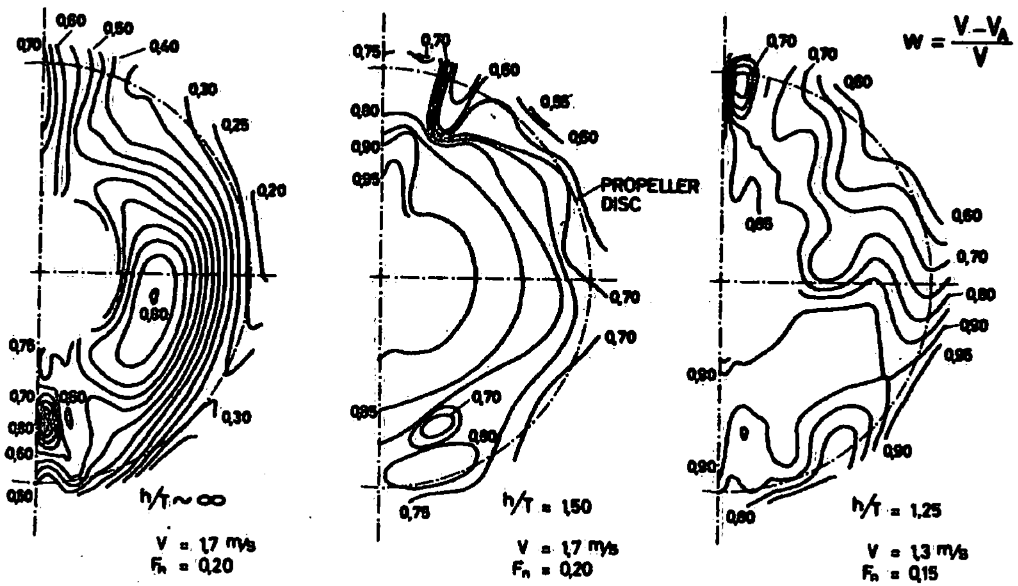


Fig. 10. Wake distribution for ship model E.

large as 8° under the midship part of the model and the observed streamlines diverge considerably from the calculated ones. These results are in good agreement with those found by Japanese researchers [10]. They have also stated that the streamlines for the real ship should lie between those observed from model test and the ones calculated from potential theory.

It is, therefore, concluded that a shipyard gets very little information of streamline tests for putting the above mentioned appendages. An experienced designer can decide where to place these appendages without model tests and may be as accurate as the laboratory can advise after performing a relatively costly and time consuming streamline test.

3.6. Wake measurements with pitot tubes.

The shipyard would like to know the wake field behind the ship partly for getting input data to design an optimum propeller and partly for getting information for calculation of pressure variations on the propeller blades and on the hull in order to be sure that noise and vibrations can be avoided as far as possible. It is normally sufficient to know the radial distribution of the wake for the purpose of propeller design. This information can be obtained relatively quickly and easily by resistance rings or blade wheels.

If one wants to know the complete wake distribution over the propeller disc, it is possible to get it by using a Prandtl pitot tube if the ship has a slender after body. If the after body is full it is often recommended by the ship technical laboratories to use a five-hole pitot tube because of the oblique flow to the propeller disc.

An extensive series of five-hole pitot tube measurements has been ordered by the ISH. Only some of the tests made with the model E wil be mentioned here. The experiments were performed with the model both running in deep water and over a false bottom. The ratio between the water depth h and the model draught T was 1,5 in one series of tests and 1,25 in another. The results are shown in Fig. 10. It is seen that the wake distribution is changing drastically with the water depth. It is not easy or possible for the yard to take this matter into account when the propeller is designed and the yard and the propeller factory will therefore normally work on the basis of the deep water wake distribution. The wake fraction of the real ship is in trial condition approx. 70% of the wake of the model when single-screw ships are in question. The curves for constant wake fraction must therefore also be changed in some way when going from model to the full size ship. Furthermore the unreliability of the measurements itself is to be taken into account. The experience which ISH has gained through the many experiments is that the uncertainty in the measurement of the wake fraction at a certain point can be as great as ±0,10 which is a considerable error considering the general level of about 0,40. By this kind of test the shipyard will get an impression of the distribution, i.e., how homogeneous or inhomogeneous it is; this is probably all the benefit it can get from these very costly experiments.

It must also be mentioned that there is a difference between the wake determined by the propeller acting as a wake measurer and a wake integrator and the wake fraction determined by use of pitot tube and a volume integration. For model A the volumetric mean wake fraction has been found equal to 0,472 and 0,455 at $F_n = 0,15$ and 0,23 respectively and they should be compared with the values in Fig. 8 (w = 0,475 and 0,398). There is normally for the yard no need to have pitot tube measurements carried out unless the design shows a very special form of the aft part of the hull. The subject has been more closely investigated by the authors in "Wake Distribution" ([6] to be published).

3.7. Measurements in waves.

ISH has had some tests carried out with models in waves. Most of the tests had been carried out with small models in head seas and added resistance and pitch were measured. The number of tests are however too small to make a basis for general evaluations. A few tests have been made with a big model and the results have been compared with strip theory calculations. A special interest has been taken in bending moments and shear forces in the hull girder. Unfortunately it has not been possible to get any reasonable agreement between tests and calculations. Discrepancies as great as the value itself are not unusual.

One objective for a shipyard to order model test in waves for a merchant ship should be to get information for designing an optimum hull and propeller arrangement in regard to motions, wave induced stresses and speed loss in rough weather. Another objective of the tests could also be to investigate whether a given design would fulfil certain requirements or not.

It would be impossible for a commercial institution like a shipyard to fulfil the first objective mentioned above because of the time and money involved. It is possible to fulfil the latter objective but no known requirements are defined today of any authorized body, shipowner or recognized expert whether a certain design is acceptable or not from the seakeeping point of view.

We will have to conclude that there is no need for the shipyard to do tests in waves when the question is about merchant ships.

Speaking of naval ships and offshore designs the problems are entirely different and measurements in waves are very relevant.

4. Statements and conclusions.

It is not the purpose of this work to devaluate model tests, on the contrary: It is the authors' opinion that model tests are very useful and necessary. Model tests do not give the final answer to any design questions but they can, used in a reasonable way, tell the experienced designer much about his design. This paper has shown some examples of how casual model tests results can be, and bearing this in mind the following can be stated about shipyard's use of model tests:

4.1. During design procedures step 1 and 2 it is normally not necessary to perform any model test.

4.2. It is useful to make model test at an early design stage when a new type of ship with special hull form is under development.

The following could be recommended:

A. A reasonably big model (6-7 m) should be made of a material which allows easy change in the hull form. One can get a three-dimensional visual impression of the design from the model. The stern and stem and arrangements of appendages can be controlled.

B. Only resistance tests should be carried out. Wave system is observed and resistance properties are judged.

C. Test at another draught than at design draught should only be performed if the ship has to operate often at this draught.

D. Prognosis for the real ship should be made.

4.3. When the lines of the ship finally have to be decided upon the following procedure is recommended:

A. A 6-7 m model is made.

B. Resistance tests are performed. Wave system and resistance properties are evaluated.

C. The model is changed if necessary.

D. A self-propulsion test with a stock propeller is performed when satisfactory resistance properties are obtained. Wake and thrust deduction fraction are appraised and a powering prognosis is made.

E. Further resistance tests and self-propulsion tests are carried out at one or two other conditions, for instance, ballast and trial conditions.

F. A pitot-tube measurement of wake is carried out, if a very inhomogenous wake field is expected. The results are for information and even if a reasonable evaluation of the test results is difficult they can give some indication concerning propulsion, noise and vibrations.

4.4. If the yard has the intention to use the results from the experiments in its design work in an efficient way, it should insist on getting a copy of the original test journal.

4.5. A yard representative should supervise all the tests, as it is of great importance to know how the experiments are performed. He should check that it is the correct model with which the tests are made, and that the model is made correctly. Also the displacement of the model should be correct and the model should be in good shape before and also after the experiments. The tests should also be carried out at reasonable time intervals (which should be noted), and the recording of the test results should be carried out properly. All these things do not seem to be necessary but it must be remembered that the towing tank work is a business and the model test of a particular shipyard is only one out of many.

4.6. The yard should make a logical registration and filing of the test data and prognosis. It is suggested that the results are plotted in diagrams, for instance, of the same type used in predicting the residuary resistance, the wake and the thrust deduction fraction and the power (see [2] and [4]). This will give the yard a possibility to correlate its own designs with the standard designs on which the diagrams are based.

4.7. The procedure outlined here is very much an ideal one but with the shipping market of today there is seldom time to go through a larger series of experiments to find the best hull and propeller arrangement for the design under consideration. Often the yard has to make the design and later on do some tests only to know how the design actually is and how the ship will perform during the trial trip. The yard will have to rely on the design diagrams and earlier experience and a good follow up on these matters is therefore essential for the flexible design work at the yard. More publications from the ship technical laboratories giving design data would be of great value and very much appreciated by yards and ship designers.

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