An approximation method for the wake wash of planning monohulls

J.A. Keuning
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Report 1241-P November 2000

Presented at the International Conference Hydrodynamics of High Speed Craft Wake Wash & Motions Control, November 2000, London, RINA, ISBN 0 90 30 55 62-7

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INTERNATIONAL CONFERENCE

HYDRODYNAMICS OF HIGH SPEED CRAFT

WAKE WASH & MOTIONS CONTROL

7 - 8 NOVEMBER 2000, LONDON

PAPERS

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ISBN No: 0 903055 62 7

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*Paper not available at the time of printing

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AN APPROXIMATION METHOD FOR THE WAKE WASH OF PLANING MONOHULLS

by J A Keuning and D B Visser, Delft Ship Hydrodynamics Department, Delft University of Technology

Paper presented at the International Conference

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AN APPROXIMATION METHOD FOR THE WAKE WASH OF PLANING MONOHULLS

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SUMMARY

In this paper an attempt to develop an approximation method for the wake wash of planing monohulls is presented. Since no mathematical tools were available for the calculation of the waves generated by monohulls travelling at such high forward speeds, this approximation method would consist of a set of empirical polynomial expressions. The coefficients of these expressions have been determined using the results of wake wash measurements carried out in Delft University of Technology's towing tank with a selection of models belonging to the Delft Systematic Deadrise Series (DSDS).

The intention of this research project was to establish whether such an approach could lead to reliable results by means of which a suitable general design tool for fast planing monohulls with respect to the wake wash could be obtained. The results of the model testing, the analysis and some rudimentary validations are discussed in this paper.

NOMENCLATURE

L	length over chine
B	beam over chine
T	draft at ord. 10 divided by the height of the chine at ord. 10, in %
β	deadrise angle midship
∇	the instantaneous volume of displacement, depending on θ and z
LCG	longitudinal position centre of gravity
A_P	projected chine area
LCA_P	longitudinal position centroid of chine area
A_T	submerged transom area
z	sinkage/rise of centre of gravity, relative to "zero-speed condition"
V_S	forward speed of the vessel
θ	running trim (relative to horizontal position)
H	typical wave "height": max. crest-to-trough value
τ	typical wave period: period of wave with "height" H

1. INTRODUCTION

Since some time now the wake wash of high speed craft has become a problem in particular on inland or confined waterways. Due to the general trend of an increasing design speed for all kinds of Patrol Vessels and more in particular of Fast Ferries the wake wash problem has drawn considerable attention over the last five years. With increasing frequency designers, builders and operators of these craft are confronted with questions about, complaints over and restrictions placed upon the wash generated by their vessels.

The Fast Ferry market consists to a large extent of Multihulls, but the Patrol Vessel market still consists to a large extent of various planing or semi-planing Monohulls. This is probably due to their relative "simplicity" and reliability, which is also reflected in their building- and operational costs. This meant that for all kinds of work boats, harbour launches, police patrol- and customs-boats, pilots-launches etc, which are all intensively operated on confined inland waters, a need was felt to have a design tool available to be able to optimise new designs for minimal wake wash.

For the fast planing monohulls no reliable mathematical tool was available for predicting the waves generated at these high Froude numbers. So the question was raised whether an empirical approach could yield a reliable and efficient alternative. At least for the time being. Such a new approximation method should be capable of predicting the trends in wake wash development with respect to hull parameters correctly and so be usable as a design tool.

Over the last decade in the design of fast planing hulls extensive use has been made of the approximation method for the resistance, the running trim and the sinkage of these hulls at speed as developed by the Delft Ship Hydromechanics Department. This approximation method is an empirical model based on the results of the Delft Systematic Deadrise Series (DSDS). This DSDS is a large systematic series of planing hull forms in which the Length-Beam ratio (L/B), the Length-Displacement ratio ($L/\nabla^{1/3}$), the Deadrise angle of the planing bottom (β) and the Longitudinal position of the Centre of Gravity (LCG) has been systematically varied and the resistance (R), the running trim (θ) and the sinkage (or rise) of the Centre of Gravity (z) has been measured over a large range of forward speeds covering the planing- and the semi-planing speed range and in particular the so-called "hump" region in the resistance curve of the various models. All data thus obtained was regressed to obtain a set of coefficients of three speed independent polynomial expressions yielding the resistance, the running trim and the sinkage of an arbitrary design.

An extension of the experiments carried out with the DSDS was set up with the intent to include now measurements of the wake wash generated by a small selection of the same models in the DSDS. This offered the opportunity to construct a consistent approach for both expressions, i.e. one set of expressions to approximate the resistance, sinkage and trim and a second set of expressions to approximate the wake wash using those data. Additional benefits were hoped to be gained because all expressions were derived from the data obtained from the same towingtank models.

So which models to choose? A dependency may be assumed to exist between the (wave making) resistance of the planing hulls and the actual waves they are generating: a hump in the resistance curve at a certain speed will probably also lead to a hump in the wake wash generated. The hullform parameters that have been varied within the DSDS were: L/B, $A_P/\nabla^{1/3}$, LCG and β and the measured quantities at speed were: Rt z and θ. So when selecting the models to be used in the wake wash experiment careful consideration went into determining which parameters appeared to influence the shape of the resistance curves most significantly.

At this moment there is no clear consensus or definition of how exactly the wake wash should be described and therefore measured. The wake wash of a planing hull is a complex system of waves varying in height and length as well as in direction of travel. Which quantities of this system precisely determine the hindrance inflicted on other moving or moored vessels or cause erosion of shore sides etc is still a subject of investigation. At the Delft Ship Hydromechanics Department a dedicated research project on this issue has just been started. For the present research however some manageable definition had to be used. So from literature and the experience obtained from full scale measurements of the wake wash generated by fast ships it was found that some maximum waveheight (H) in the wash should be determined and also the period (τ) of the associated wave.

The most important parameters influencing this maximum wave height (H) in the wake wash of planing ships, when considering one constant forward speed, were considered to be the actual volume of displacement of the hull (∇) at that speed, its L/B ratio, its deadrise angle β and the resulting sinkage z and trim θ at that speed. The associated wave period τ was considered to be primarily dependent on the forward speed of the vessel (V_S).

So this became the basis for the derivation of the empirical approximation method for the determination of the wake wash of planing hulls.

The idea behind the setup of the approximation method for the wash was as follows: based on the approximation method developed earlier for the resistance, the sinkage and the trim of a planing hull (as presented in the earlier publications Ref. [1] and Ref. [2]), for any design within the validity range of the DSDS, it is possible to determine the "attitude" which that particular boat will actually take on in the water at any given forward speed. Using that "attitude", the associated volume of its displacement and some of its hull shape parameters it should be possible to determine the wave height in the wake wash. This is calculated with a set of speed independent polynomial expressions of which the coefficients are obtained by performing regression on a data base giving for a large number of forward speeds the maximum wave height in the wake wash and the associated wave period determined using the same hull shape parameters (such as the L/B ratio and the deadrise angle β) and the same parameters describing the "attitude" of the model (i.e. the immersion at midship and its running trim).

To establish this necessary data base an experiment has been set up and carried out in the Delft towing tank with a number of models along the DSDS line of design.

2. THE EXPERIMENT

2.1 THE MODELS

Because the purpose of this research project was to establish whether the proposed approach to develop an empirical model would yield the desired results it was decided to use only a small selection of the models available in the DSDS for the wake wash measurements. When the approach followed in this study proved successful an extension could be planned.

The most relevant hull shape parameters were considered to be the L/B ratio and the deadrise angle β. Within the DSDS four parent models have been used with deadrise angles of 12.5, 19, 25 and 30° respectively. So to cover the range of the most frequently used deadrise angles for planing boats on the inland water ways (no severe wave climate) only the first three parents were chosen.

To investigate the influence of the L/B ratio on the wash for each parent model two additional L/B ratios were chosen, yielding L/B = 4 as for the parent and two extra to be the L/B = 3.0 and the L/B = 7.0. This resulted in 9 models in total to be constructed. Due to limited time available only 5 of these have actually been tested so far. A short summary of the main particulars of these models is presented in Table 1.

A small scale presentation of the hull shapes of these five models can be found in Fig. 1 on the next page.

From these sketches, as well as from Table 1, it can be seen that the model with length-beam ratio L/B = 3 has a smaller length over the chine than the other models: i.e. a chine length L = 0.78m against a L = 0.94m for the others. In the results and the analysis all data obtained from the model tests have been scaled to the same model length, i.e. a chine length of 0.94m, in order to make them immediately comparable to each other. All scaling has been done using the model law of Froude.

TABLE 1

Model	12.5 - 4	19 - 3	19 - 4	19 - 7	25 - 4
Deadrise angle midship (deg)	12.5	19	19	19	25
Length over chine (m)	0.94	0.78	0.94	0.94	0.94
Beam over chine (m)	0.234	0.260	0.234	0.134	0.234
Projected chine area A_p (m^2)	0.1463	0.1667	0.1463	0.0855	0.1463
Centroid of A_p aft ord. 10 (m)	0.0224	0.0338	0.0224	0.0225	0.0224

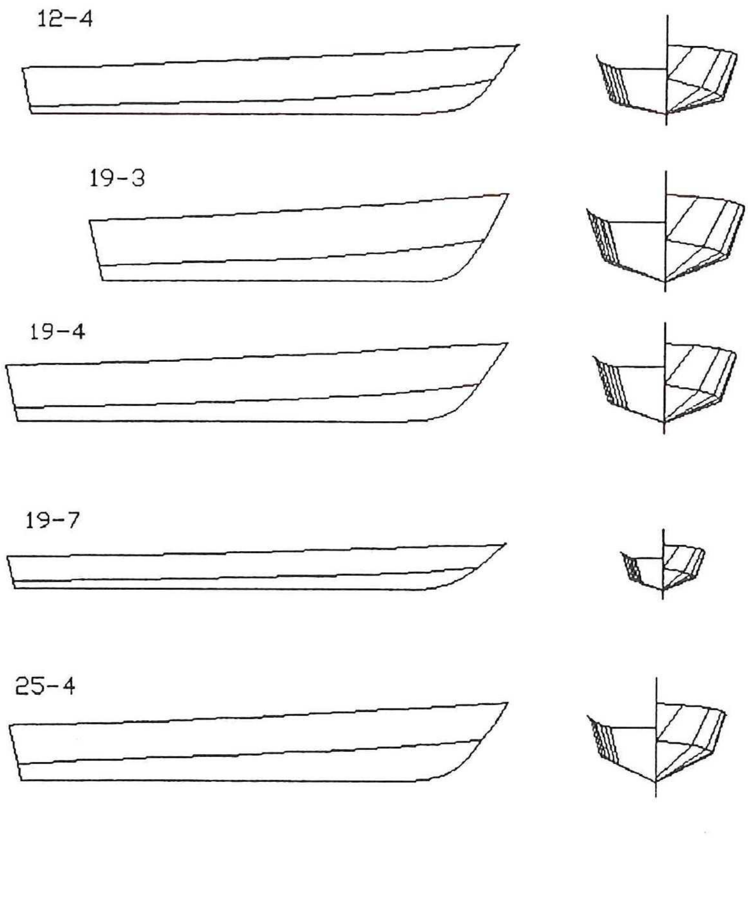

Fig. 1 Hull shapes of the five DSDS models used in the present study

2.2 THE EXPERIMENTAL SET UP AND MEASUREMENT SCHEME

The experiments have been carried out in the #1 towing tank of the Delft Ship Hydromechanics Laboratory. The dimensions of this tank are: length 145 meter, width 4.25 meter and water depth 2.5m. The maximum attainable speed of the towing carriage is 7.0 m/sec.

The physical dimensions of the towing tank used for the measurements, more in particular the width of this tank, and the intention to measure the wake wash at a customary distance from the centreline of the model (the track of the model), corresponding to the distance often stipulated in the requirements from the authorities, more or less determined the size of the models. This resulted in an overall length of about one meter. Although considered small for regular experiments the wake wash measurements were considered not to be very sensitive to scale effects, since the wake wash is considered to be primarily driven by gravity effects and viscous effects are not of prime importance.

Also a scale ratio is not of real practical importance in the present investigation, because all the results have to be non-dimensionalised to make them generally applicable. However considering for instance a scale of 1:16 would imply a full size ship with a length of 16m, a forward speed used during the experiments ranging from 4.0 m/sec (8 knots) to 20 m/sec (40 knots) and wash measuring at a distance from the centre line of the ship of about 30m. To increase the information about the way the wake wash wave height diminishes with the distance from the centreline it was also decided to tow the model "off-centre" in the towing tank allowing more distance between the track of the ship and the wave height measurement devices. So three waveheight measurement devices have been used during the experiments and the layout of their arrangement in the towing tank with respect to the model (and its track) is depicted in Fig. 2.

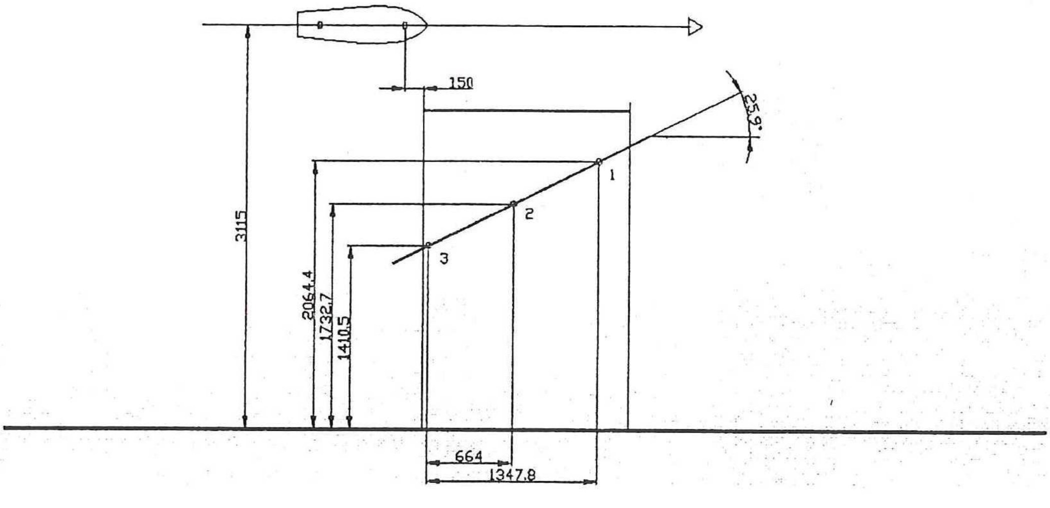

Fig. 2 Layout of the three wave height measurement devices with respect to the model and the tank wall

The models were rigidly attached to the towing carriage by means of two vertically adjustable rods connected to the models with hinges at their lower ends. One of the hinges was placed on a sliding track. Through careful adjustment of these rods both the immersion of the model at the midship section (at zero forward speed) and the trim angle could be applied and adjusted with a very high level of accuracy.

During all tests video recordings were taken from the model passing the array of the wave height measurement devices. These video recordings were, among other things, used to determine the exact moment (i.e. the time interval after the model passed the wave height measurement devices) at which the waves that were reflected from the tank side walls, interfered with the wake wash measurement itself. All wave height recordings were ended before this happened.

The wake wash measurements were carried out with each of the five models towed at 7 different forward speeds and at each of these speeds in a range of "attitudes" resulting from all possible combinations from four different immersions at the midship cross-section (draft relative to height of the chine at ordinate 10) and 5 different pitch angles θ.

Rise and sinkage were simulated by setting the draft at 60%, 90%, 120% and 150% of the chine height respectively and the running trim was varied by setting the pitch angle at -1, +2, +5, +7.5 and +10°, respectively, where a minus sign means "bow down" and a plus sign means "bow up". In order to minimise the number of runs highly unrealistic combinations of this "attitude" and the forward speed have been omitted (for instance bow down at high speed). Even so this yielded a total of about 350 runs.

The number of runs that could be carried out during a day in the towing tank was rather limited because the time interval needed between two measurements was quite long. This was caused by the fact that the water surface had to be absolutely flat again before beginning a new test run because the waveheight to be measured was sometimes small and the normal procedure to "sweep" the waves by the carriage on its way back could not be used due to the presence of the array of wave height measurement devices. In particular the longer components in the "left over" waves and the transverse waves in the tank took a long time to damp out. Standard procedure during the tests was to wait until less than one millimetre residue wave height was left and preferably with a period longer than two times the registration length of the measurement itself.

Before beginning the actual measurements it was decided first to determine the waves generated on the water surface of the tank by the passage of the towing carriage itself without a model attached.

Due to the physical construction of the (any) towing carriage some kind of pressure field over the water surface is inevitable when the carriage is travelling at speed. This will cause a surface elevation, i.e. a wave, travelling with the carriage speed. When this "carriage generated" wave was measured it appeared to be too big to be simply ignored. Therefore this wave has been measured for all speeds used during the experiments. Typical examples of registrations of this "carriage generated" wave are presented in the next two figures (Figs. 3a and b).

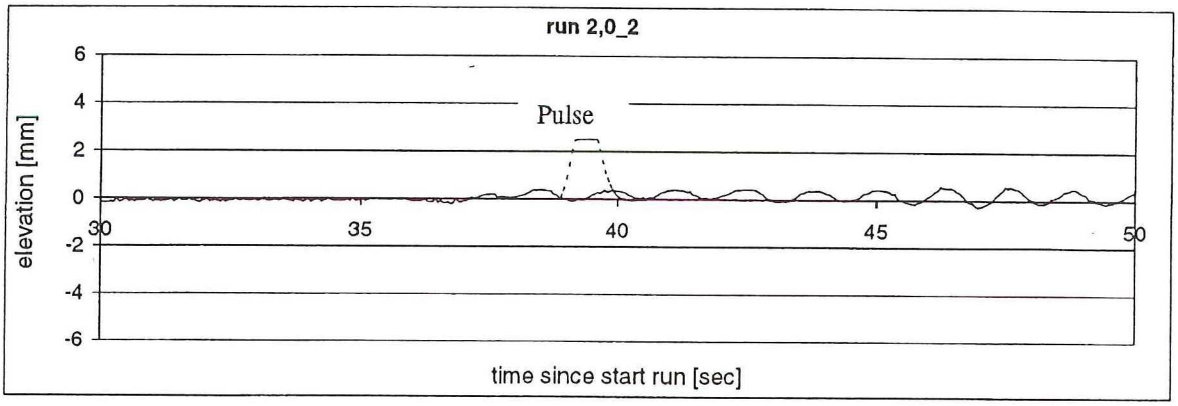

Fig. 3a Water surface elevation due to carriage (without model), 2.0 m/sec

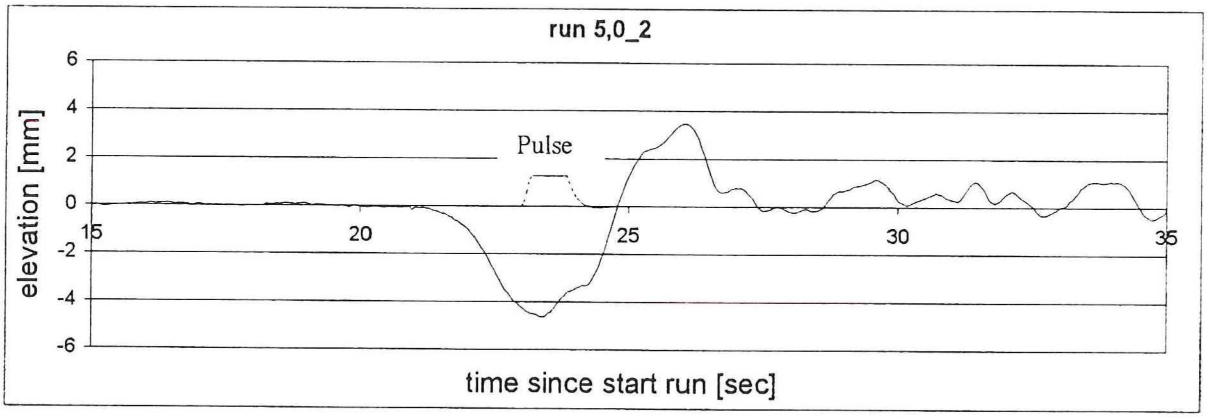

Fig. 3b Water surface elevation due to carriage (without model), 5.0 m/sec

The exact moment at which the midship cross-section of the model passed the wave height measurement devices was electronically marked on the time registrations of the wave height measurement devices by means of a pulse shaped signal. This was done both during the tests without the model, registering the "carriage generated" waves, as during the actual wake wash measurements, i.e. with the model attached. By doing so the later wave registration could be corrected for the disturbance waves to yield the actual wake wash. A sample of this procedure is shown in Fig. 4 for one of the highest speeds. All measurements have been corrected using this procedure.

The time histories of the wave height recordings from the three wave height measurement devices corrected using the procedure as described above have been "cut to length" (in time) eliminating any reflected wave disturbances using the video recordings.

Due to the large amount of data to be handled an automated procedure has been adopted to determine and register the maximum wave height in the wakewash and the associated wave period in these recordings. The way the automated process works is depicted in Fig. 5.

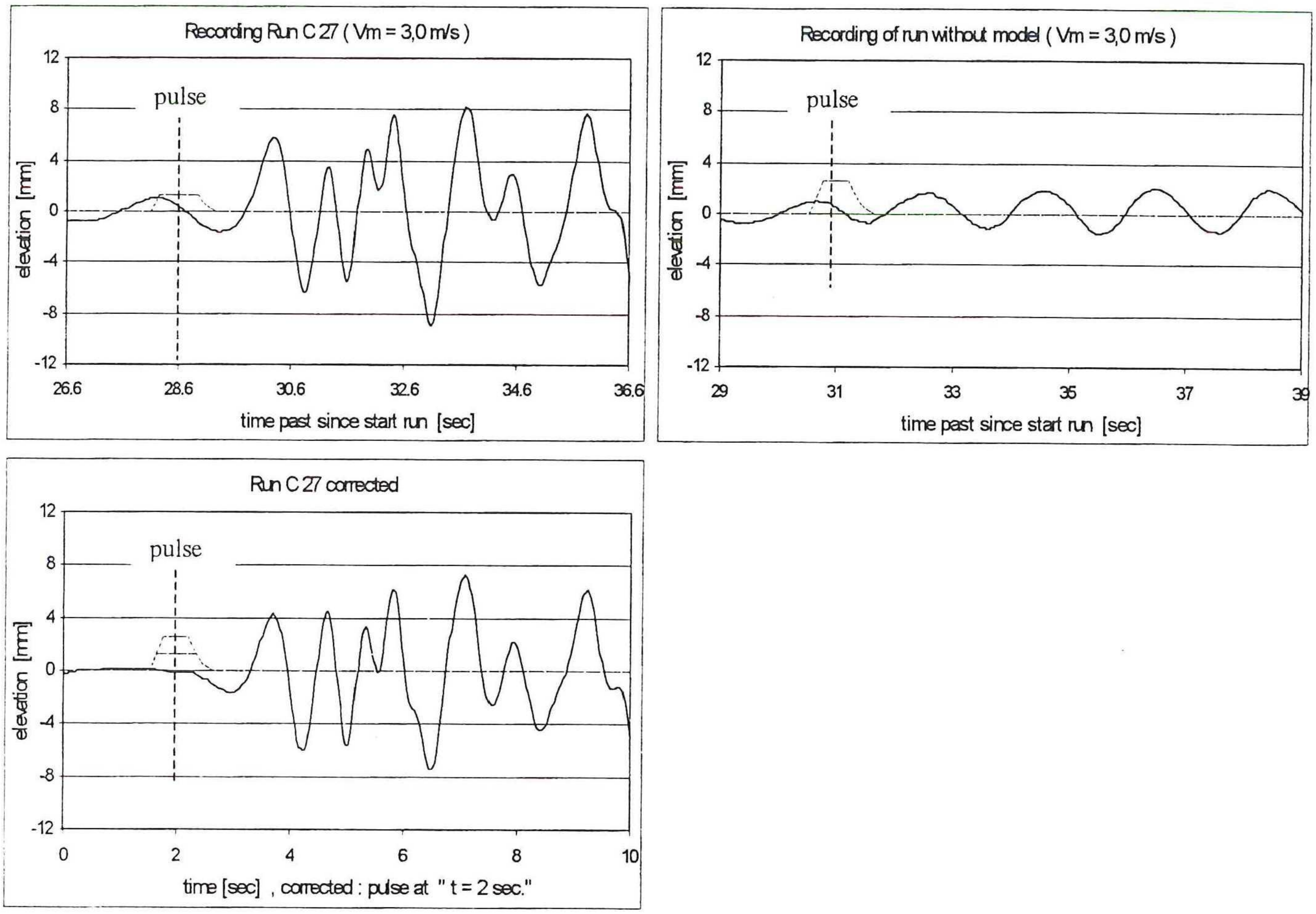

Fig. 4 Correction of the wake wash measurement for the "carriage-generated wave"

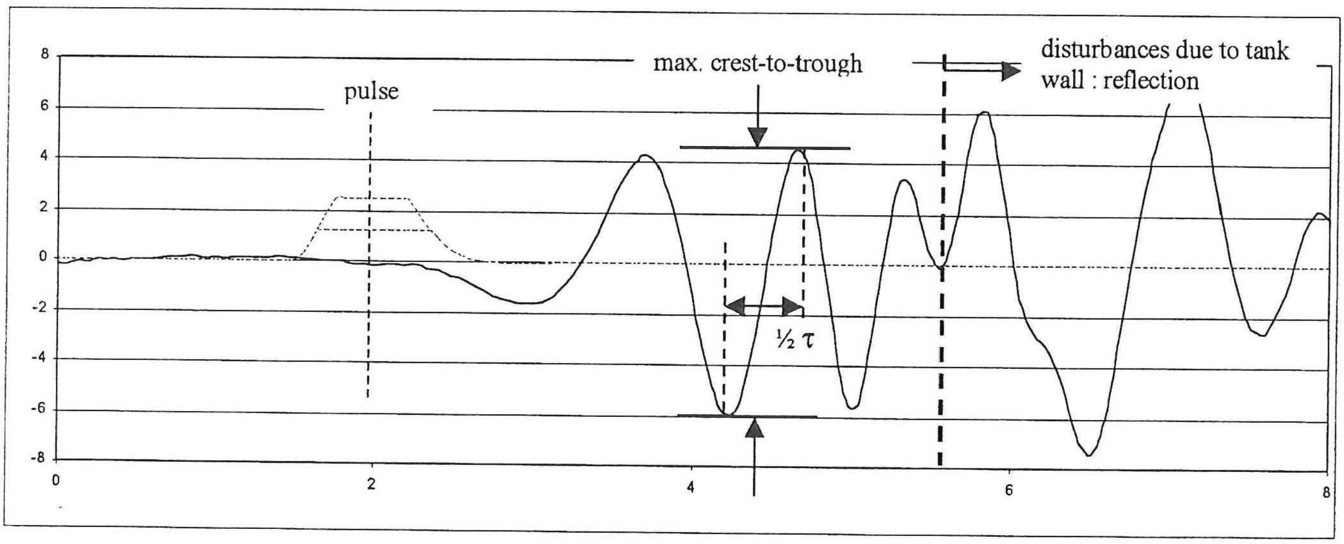

Fig. 5 Data acquisition from the wave height recordings

In contradiction to earlier measurements carried out measure has been taken of the maximum distance occurring between a successive crest and trough to yield a characteristic "wake wash wave height", instead of determining the maximum positive and negative wave amplitude (which are not necessarily successive!). This is done as shown in Fig. 5. The time passing by between the crest and (successive) trough (which together yielded this highest crest-to-trough value) has been doubled to yield the associated "characteristic wave period". In addition two other periods in the wake wash registration have been determined also. This was done from the registrations by hand, i.e. the period of the "first" and "second" wave occurring in each registration. Because all of these "hand-measured" periods were of the same order of magnitude as the "characteristic" period mentioned above, it was decided that they would not be further elaborated in the present analysis (for now).

Because the goal of the present study was to study the feasibility to develop an approximation method for the wash of "any" planing vessel, all quantities obtained from the measurements had to be non-dimensionalised to make them generally applicable.

So the forward speed of the model is expressed as a Froude number related expression. In planing boat hydrodynamics it is customary to use the cubic root of the volume of displacement ∇ at zero forward speed as the "characteristic length" in the Froude number instead of the waterline length because this waterline length shows large variation under speed. In the present analysis however the chine length L has been used because this "zero speed design displacement" of the models used is not known as a parameter. The Froude number therefore reads: $Fn = V_S / (\sqrt{g.L})$.

Whether the wave height H in the wake wash should be non-dimensionalised using the chine length L or the cubic root of the volume of displacement ∇ of the model (or possibly even the square root of the projected chine area A_P) has been (and still is) subject of discussions because there is rational for a supposed relation with all of them.

In the present study however first non-dimensionalising the wave height with the cubic root of the volume of displacement is chosen. The only volume known of the models in the experiments was the volume ∇ in the "trimmed θ " and "sinked z " condition at zero forward speed.

For each model in all conditions investigated this volume has been calculated using the known hull geometry and static waterline in those "attitudes". This yielded the non-dimensionalised "specific wake wash height": $H/\nabla^{1/3}$ ("wave height related to cubic root of displacement"). When discussing the format of the polynomial expressions also another non-dimensionalised wave height will be discussed using the chine length as parameter. Due to limited space available results of this will not be shown now.

The best approach to non-dimensionalise the wave period was considered to be multiplying it measured period by the forward speed of the ship and dividing it by the chine length L to yield the dimensionless "specific wake wash period" $\tau. V_S / L$.

3. RESULTS AND ANALYSIS

Most of the results of the measurements have been plotted based on the Froude number. Because the polynomial expressions, sought for in this study to establish the approximation method, will be derived as speed independent. This is not strictly logical but it gives a good impression of wash development and dependencies. The polynomial expression will be the same for all speeds but the coefficients will be derived for each individual speed and this approach yields a complete set of speed dependent coefficients.

To facilitate the determination of the relations to be derived the specific wake wash height has been plotted for each model (i.e. constant L/B ratio) with constant trim θ and variable immersion at the midship section. A selection of these results is presented in the Fig. 6 for L/B = 7 and in Fig. 7 for L/B = 4 respectively.

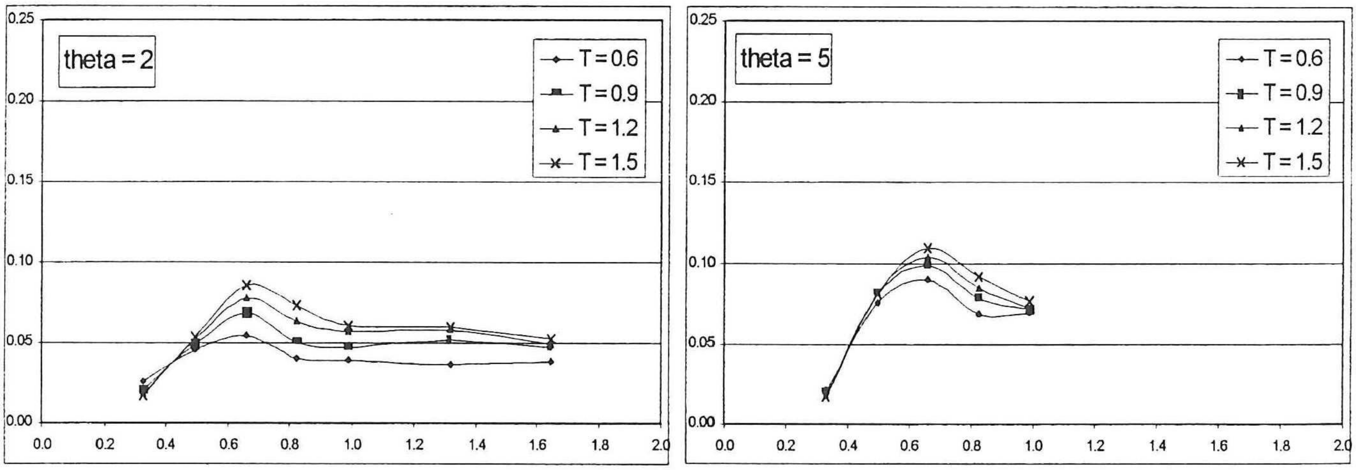

Fig. 6 "Specific Wave height" ($H / \nabla^{1/3}$) versus "forward speed" ($V_S / \sqrt{g.L}$) for L/B = 7.

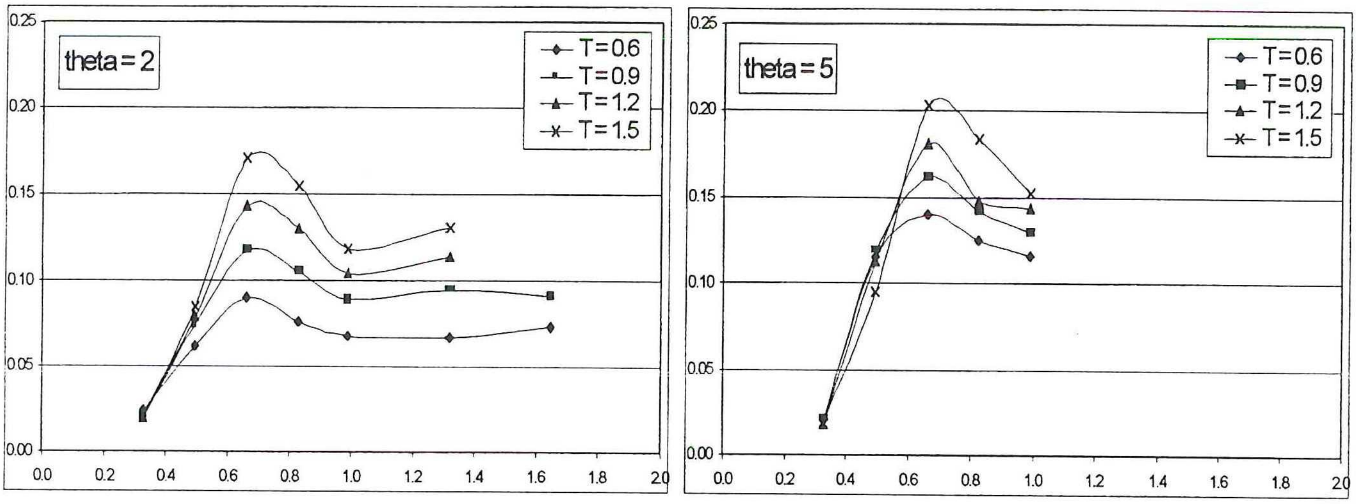

Fig. 7 "Specific Wave height" ($H / \nabla^{1/3}$) versus "forward speed" ($V_s / \sqrt{g.L}$) for L/B = 4

The same has been done for the associated wave period and a selection of these results is presented in the Fig. 8 for L/B = 7 and in Fig. 9 for L/B = 4 respectively.

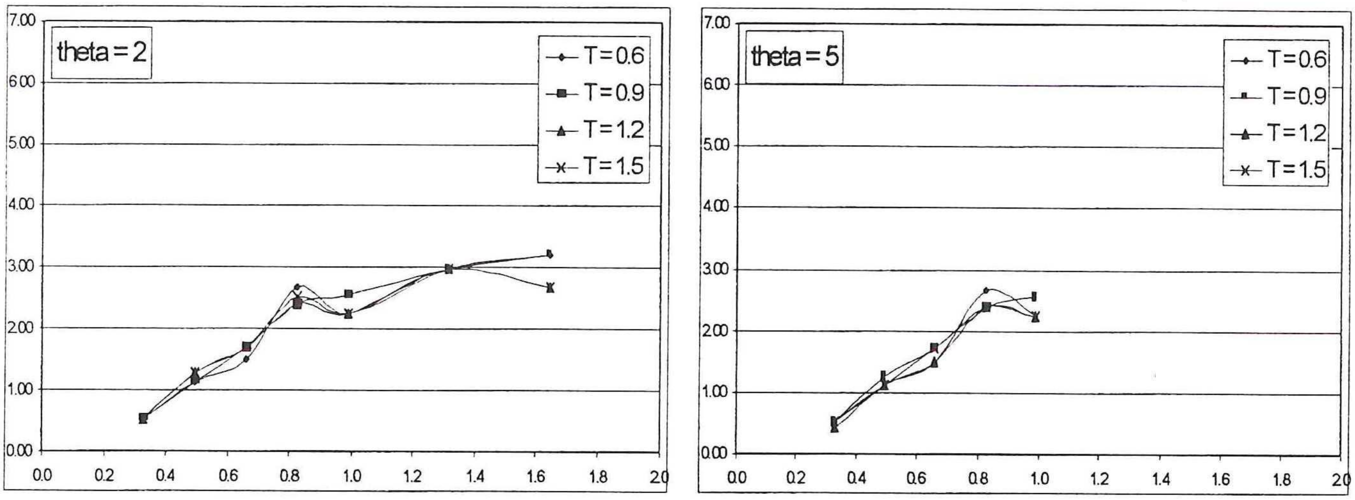

Fig. 8 "Specific Wave period" ($\tau.\ V_s / L$) versus "forward speed" ($V_s / \sqrt{g.L}$) for L/B = 7

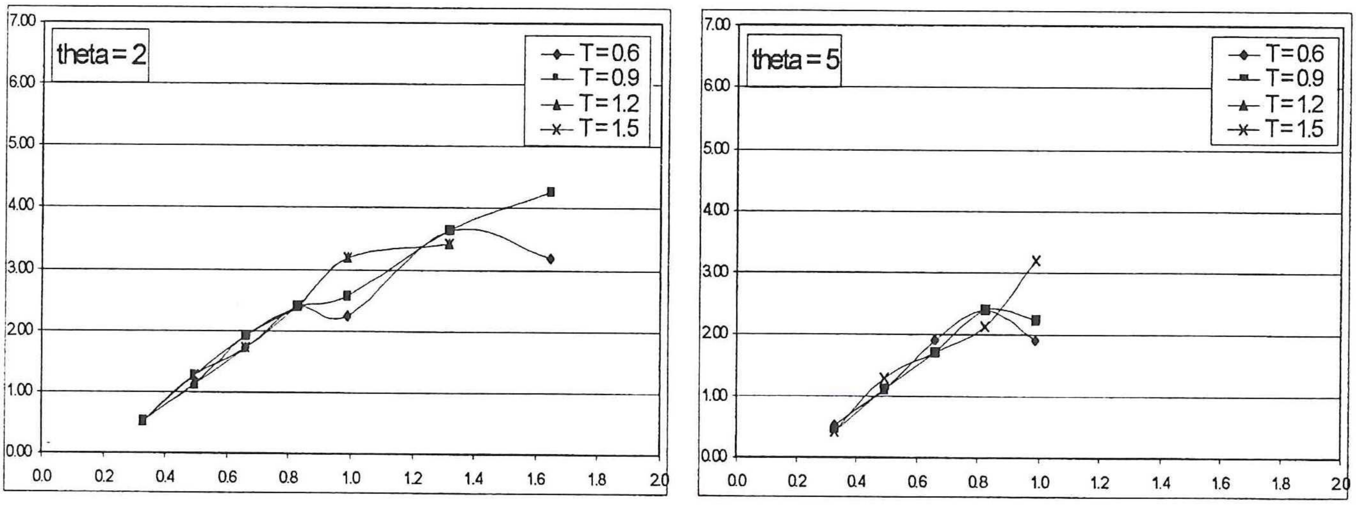

Fig. 9 "Specific Wave period" ($\tau.\ V_s / L$) versus "forward speed" ($V_s / \sqrt{g.L}$) for L/B = 4

In Figs. 6, 7, 8 and 9 the different immersions are represented by the differently marked lines in each plot. "T = 0.6" means that the draft at ordinate 10 is about 60% of the chine height at ordinate 10, "T = 0.9" about 90%, etc.

From these figures the strong dependency of the specific wash wave height on the L/B ratio is evident. A similar dependency is found in the resistance. Also the influence of the sinkage (increasing/decreasing immersion at the midship section) and thus of the volume of the displacement is obvious. The trim angle by itself, as it was applied during the tests, i.e. with constant sinkage, seems to have less influence on the specific wave height.

When dealing with the set up of the desired polynomial expressions for the specific wave height and specific wave period the various options available became evident. The decision on which parameters to use and how to implement them in the expression should be largely based on knowledge of the physics involved but inevitably some "trial and error" will be used also. The available time and the choices already made at the beginning of this project when deciding on the set up of the experiment for the generation of the database however play an important role also. The supposed relation between the resistance of the planing hull and its wave formation led to the selection of the parameters to be varied during the experiment. So those will also be used for the polynomial expression.

The choices finally made on the parameters used and the precise format will inevitably have an influence on the end result. Because the length-beam ratio L/B, the deadrise angle β, the trim θ and the sinkage/immersion are being varied during the model tests, it was decided that all these parameters should show up in the expressions.

From all the different plots of the results, however, it should be concluded that for instance the wave period looks almost linearly dependent on the forward speed of the vessel and shows little to none dependency on any of the other parameters involved. The first attempt to fit such a relationship for the specific wave period already gave sufficiently accurate results for a first approach.

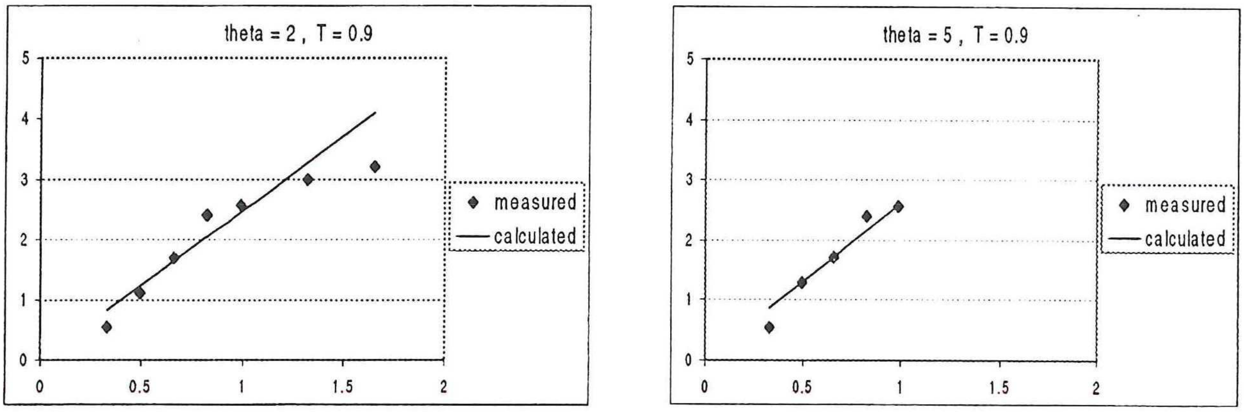

Fig. 10 "Specific Wave period" (τ. V_s / L) versus "forward speed" (V_s / $\sqrt{g.L}$) for L/B = 7

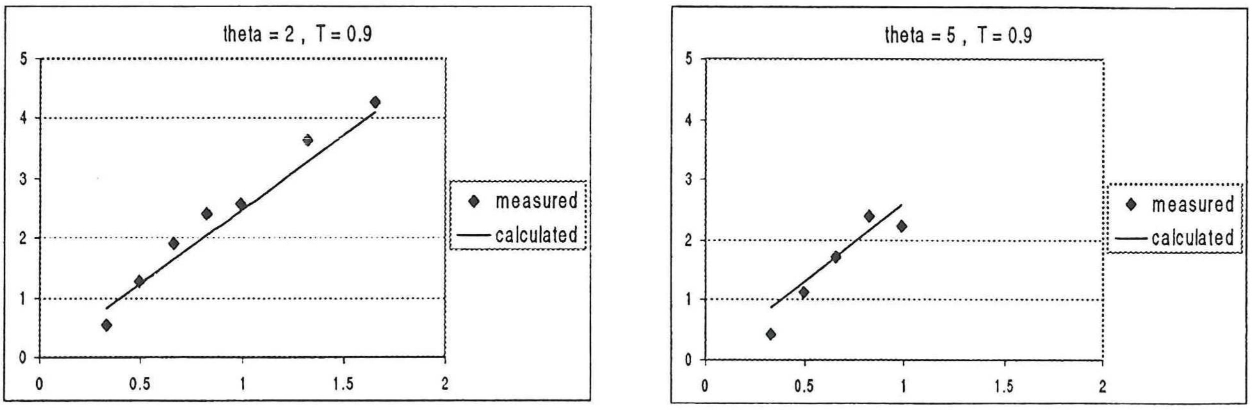

Fig. 11 "Specific Wave period" (τ. V_s / L) versus "forward speed" (V_s / $\sqrt{g.L}$) for L/B = 4

To examine the goodness of fit between the polynomial approximation of the specific wave period and the measurements in the data base some comparisons between the two (measured and calculated) are presented in Figs. 10 and 11. As can be seen from the figures the expression to approximate the wave period is actually a linear function of the form: $\tau .\ V_S / L \ = \ A_0 .\ Fn_L$

in which the coefficient A_0 has been determined at each (applied) trim angle θ, using statistics software. This was found convenient not because of any dependency on θ, but merely because the number of runs per trim angle was not by far the same for each θ.

Before a regression analysis could be made of the specific wave height it had to be decided what form the expression should have, which dimensionless parameter was to be set as dependent variable etc. As there is still no full understanding of the physics and parameters involved a few possible expressions have been studied. Two of these expressions will be discussed here.

The first expression is based on the relation between wave height and volume of displacement as prime driver and therefore yields the quantity $H/\nabla^{1/3}$ as a function of the length-beam ratio L/B, the deadrise angle β, the draft T at ord.10 relative to the chine length L, the trim angle θ and a quantity accounting for the submerged transom area: A_T / A_P, as follows:

$$H.\ 10^3 / \nabla^{1/3} \ = \ A_0 + A_1 .\ (L/B) + A_2 .\ \beta + A_3$$

$$(T_{ord.10} / L) + A_4 .\ \theta \ + A_5 .\ (A_T / A_P)$$

Again by means of statistics software the coefficients A_0, A_1, A_2, A_3, A_4 and A_5 have been determined, in this case per Froude number, so that an explicit expression is obtained at each (applied) forward speed.

The goodness of fit between the approximation by this expression and the data base it self can be made clear by comparing the measured values and the calculated values as has been done in Figs. 12 and 13.

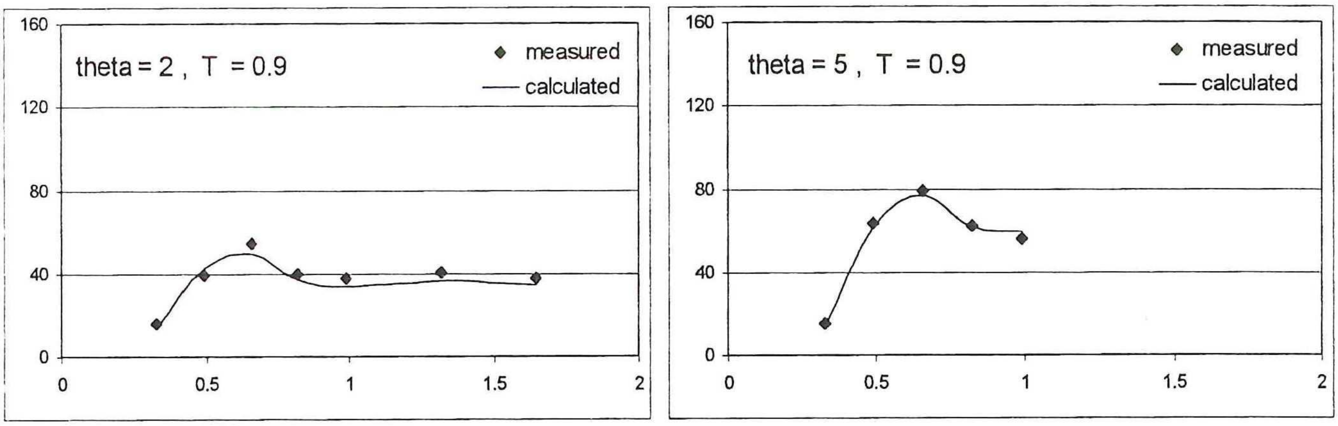

Fig. 12 "Wave height" ($1000 \times H/\nabla^{1/3}$) versus "forward speed" ($V_S / \sqrt{g.L}$) for L/B = 7

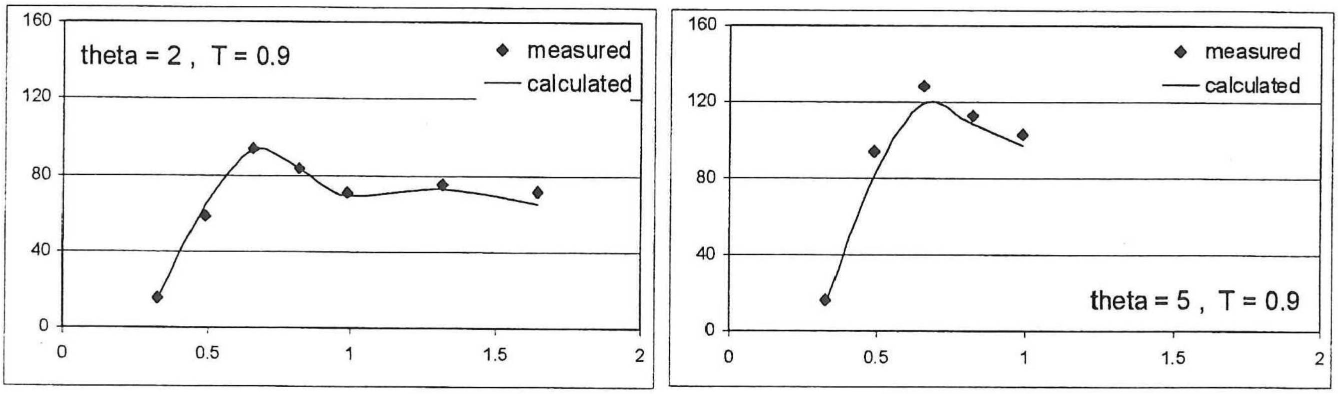

Fig. 13 "Wave height" ($1000 \times H / \nabla^{1/3}$) versus "forward speed" ($V_S / \sqrt{g.L}$) for L/B = 4

It appears from these results, which are typical for all other conditions tested also, that a reasonably reliable approximation should be possible with such an expression. The relation between specific wave height and volume of displacement however is rather "clouded" in this expression so it was decided to use another expression as well, in which the wake wash wave height is non-dimensionalised using the chine length.

So the second expression yields the quantity as representative for the "specific wake wash wave height" H / L and approximates this as a function of the squared length-beam ratio $(L/B)^2$, the deadrise angle β, the reciprocal of the ratio of draft T at ord.10 and chine length L: $(T_{ord.10} / L)^{-1}$, the loading factor: $A_P / \nabla^{2/3}$, the trim angle θ and again A_T/A_P. Again a speed independent expression is used and the regression is carried out at a number of Froude numbers, resulting in:

$$H.\ 10^3 / L = A_0 \cdot (L/B)^2 + A_1 \cdot \beta + A_2 \cdot (T_{ord.10} / L)^{-1} + A_3 \cdot A_P / \nabla^{2/3} + A_4 \cdot \theta + A_5 \cdot (100 \times A_T / A_P)$$

To visualize the goodness of fit of this expression for the wave height to the data base the "calculated" and the "measured" values of H/L are plotted together in figures like Figs. 14 and 15.

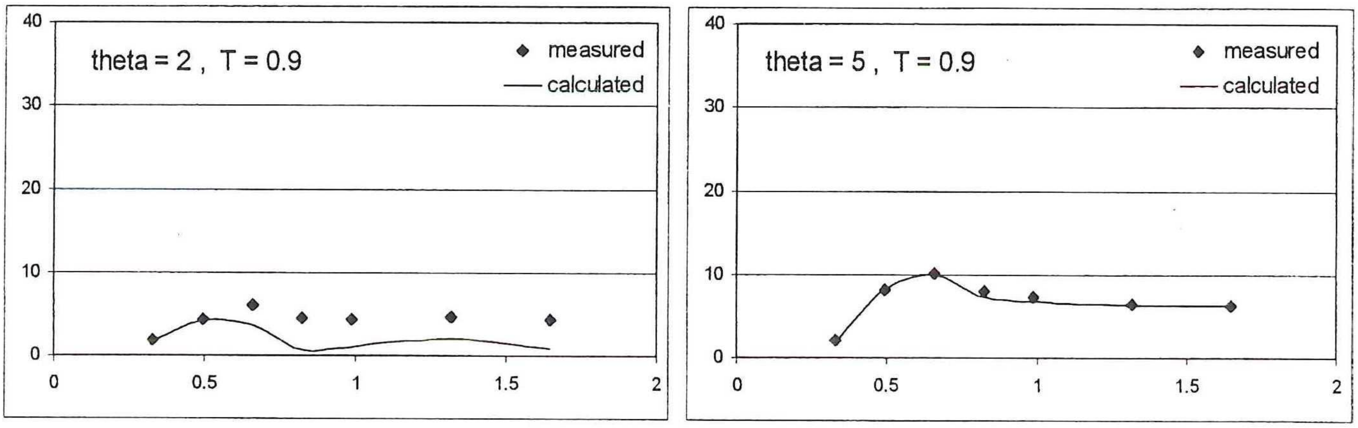

Fig. 14 "Wave height" ($1000 \times H / L$) versus "forward speed" ($V_s / \sqrt{g.L}$) for $L/B = 7$.

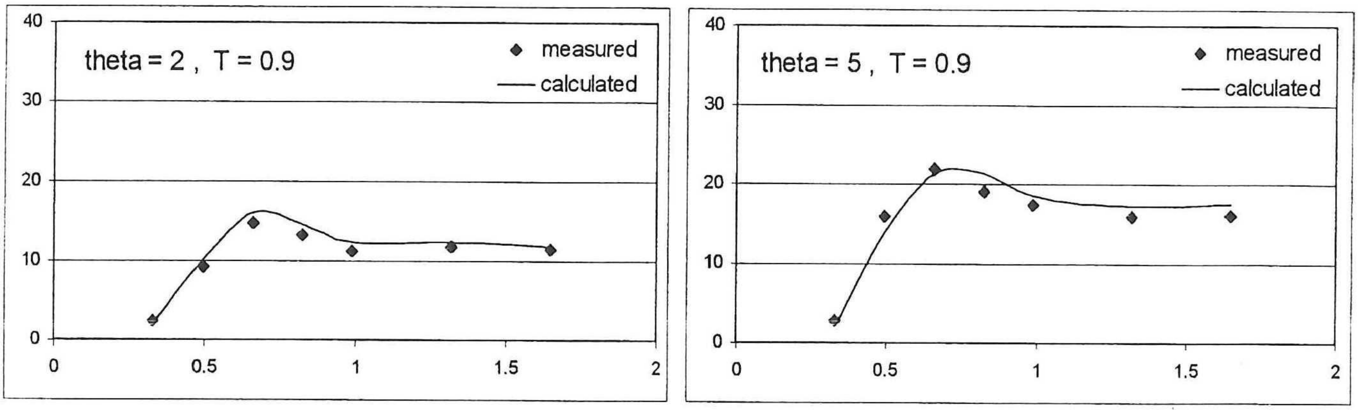

Fig. 15 "Wave height" ($1000 \times H / L$) versus "forward speed" ($V_s / \sqrt{g.L}$) for $L/B = 4$

As becomes clear from the figure associated with $L/B = 7$, $\theta = 2°$ and $T = 0.9$ the largest deviations exist where the (absolute) wave height is very small, probably due to the fact that inaccuracy has the largest influence in this part of the data base. Still there is reason to believe however that this approach, with the volume of displacement ∇ as one of the independent parameters, should give reasonably good results when used for the approximation of the wave height.

An experiment to validate the results obtained for the wake wash of a particular planing hull model has been started, but the measurement results will not be available at the moment of printing of this paper, so only the "calculated" results of the approach to approximate the sinkage, the trim and the resulting wake wash of a planing hull as described in this paper would be available at this stage.

Yet to be able to give some validation and to show that the proposed procedure actually gives reasonable results that are valid (at least with respect to the trends and dependencies) it was decided to produce some results of calculations on an existing planing hull.

Since drawings were available of a fast aluminum tender-like vessel of which the wash had been measured in the past during full scale measurements, it was decided to see what kind of results the procedure as it has been developed so far would give for this design. The boat has roughly the following particulars:

L	-	11.5m
B	-	4m
T	-	0.8m
∇	-	$15m^3$
β	-	16°
V_s max.		33kts

First some calculations were done with the DSDS based approximation method for the resistance, the running trim and the sinkage of this hull at speed, to get an idea of the "attitude" it would take on at different forward speeds and thus to get the input for the presently developed wash approximation method.

Results of this wash approximation together with some values obtained during full scale measurements are presented in Fig. 16, in which the maximum crest-to-trough values in [m] are plotted vertically and the Froude number based on the chine length L is plotted horizontally.

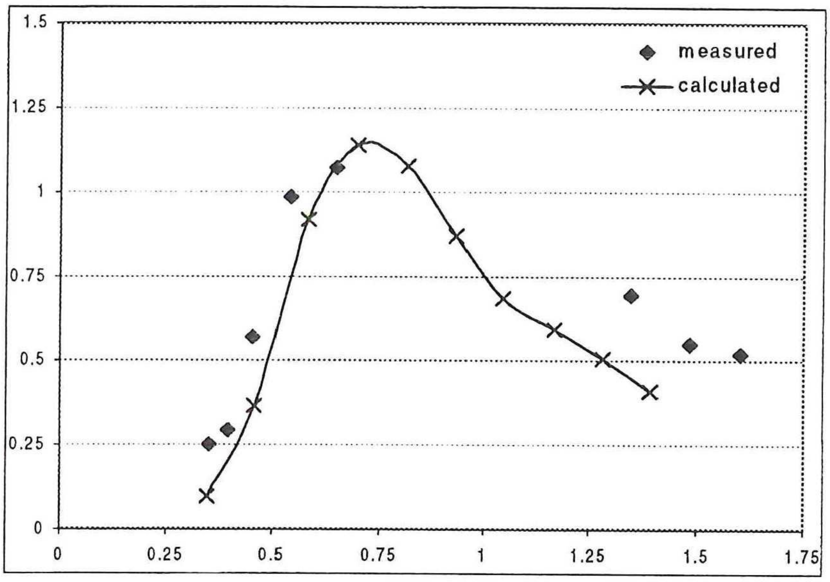

Fig. 16 "True wave height" H (crest-to-trough, [m]) versus "forward speed" ($V_s / \sqrt{g.L}$)

Clearly recognizable are the similar trends in the measurements and the calculated values. It must be taken into account though that the "attitudes" that were obtained from the DSDS based approximation method are not necessarily the same as those that were seen during the full scale measurements.

Since the precise circumstances and "attitudes" of those trials are not known, conclusions with respect to absolute values should not be drawn at this stage. Until a good validation is possible and an eventual extension of the data base will have taken place it is recommended to regard any obtained results merely qualitatively.

4. CONCLUSIONS

Although a good validation of the presented procedure for the wake wash approximation method is not yet available, it appears from the results presented so far that a usable method may be obtained extending the approach described. In any case a design tool for determining the dependency of the wake wash on the various design parameters seems to be feasible. An extension of the data base used and the coupling to the other approximation methods for resistance, sinkage and trim also based on the DSDS seems likely to yield a valuable design tool for planing monohulls.

ACKNOWLEDGEMENT

The authors specifically wish to acknowledge the support provided by DAMEN SHIPYARDS BV at Gorinchem, The Netherlands to the Delft Ship Hydromechanics Department for carrying out this research project.

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