Further design and seakeeping investigations into "Enlarged Ship Concept"

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CONTENTS

FURTHER DESIGN AND SEAKEEPING INVESTIGATIONS INTO THE "ENLARGED SHIP CONCEPT"

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ABSTRACT

The "Enlarged Ship" Concept, (ESC), as previously introduced by Keuning and Pinkster (1995) as a serious improved fast monohull concept, is now expanded upon with subsequent model testing, in irregular head waves, of a number of such design concepts. The effect of a modified bow shape, made possible by the ESC, is also investigated and evaluated with regard to its possible impact on operability in a seaway. Also the vessel resistance is measured and compared with the previously predicted improvements.

Parallel to the model testing, calculations are carried out with both linear (SEAWAY) and non linear codes (FASTSHIP) to predict heave and pitch motions and, in particular, the distribution of the peak vertical accelerations. Finally, an economic appraisal of the designs is also shown.

1 INTRODUCTION

A monohull sailing at high forward speed in head waves may incur unacceptably high levels of vertical accelerations. This may hamper the safe operability of the craft.

To optimise the seakeeping behaviour of one particular fast monohull design, the authors have explored the so-called "Enlarged Ship Concept", (ESC), Keuning and Pinkster (1995). In this concept the resistance and more in particular the seakeeping behaviour of a vessel is optimised by increasing the length and so increase the length to beam ratio, reducing the running trim under speed and improving the general layout of the ship. The work carried out then was based on a desk study, concerning three design concepts, namely a base boat with two Enlarged Ship configurations. Results from this study were very promising and favoured the Enlarged Ship Concept.

In the present paper, the same topic is now expanded upon further with subsequent model testing of four such design concepts, made possible by the fact that the ESC's are presently of interest to the shipbuilding community of such fast vessels in the Netherlands. Included within these tests, is the effect of a modified bow shape, made possible by applying the Enlarged Ship Concept.

The motions of the ESC in a seaway have already been improved by the introduction of the very specific features of the concept, i.e. increasing length, less trim, higher length-displacement ratio and shifting the wheelhouse relatively aft etc., but the workability is further increased by introducing bow modifications, i.e. reducing sectional flare and areas .

The philosophy behind these bow modifications is based on the real world observation that the operability of fast ships in a seaway is really limited by the (single) occurrence of very high peak values in the vertical accelerations, either at the bow, possible cause of structural damage or at the wheelhouse, possibly causing human injuries. The (single) occurrence of these very high peaks in the vertical accelerations provokes the crew to a "voluntary" speed reduction to prevent it "from happening again". This reduction action is undertaken irrespective of the momentary significant level of the vertical accelerations.

So, increasing the operability of a high speed vessel may be directly coupled to avoiding these very high peak values as much and as long as possible.

Many optimisation studies of high speed vessels however are based on comparison of significant acceleration levels only. This is initiated by the fact that the criteria used for the determination of the boundaries of safe operation of these fast vessels are generally based on the prevailing level of significant vertical accelerations in a seaway. The Dutch National Authority, for instance, still uses the threshold value of $av1/3 < 0.35$ g at the wheelhouse for her ships. The use of such threshold values based on the level of significant vertical accelerations, which for a signal with Rayleigh distributed peaks and troughs have a probability of exceedence of approximately 13.5%, would be quite acceptable if there is a well defined relation between these and the occurrence of the extremes in the vertical accelerations with for instance a probability of exceedance smaller than 0.1%. For a Rayleigh distribution this relation exists and since the surface waves are generally supposed to be Rayleigh distributed the same could hold true for the vertical accelerations if a fast moving monohull in waves is a linear system.

However it is well known that a fast moving monohull is a seaway is not a linear system. Therefore as shown by, amongst others, Keuning (1994), this distribution of peaks in the vertical acceleration is strongly dependent on hull geometry, general arrangement and forward speed and must therefore be determined for each individual design. On the other hand therefore, it may also be influenced through design optimisations.

A clear demonstrations of this is presented in Figure 1, from Ooms and Keuning (1997), in which the maximum measured values of the vertical acceleration in the wheelhouse of a fast Dutch pilot vessel, during a large number of full-scale test runs of 10 minutes duration in waves, is plotted on basis of the RMS of the same signal. The dotted line represents the approximation based on linear theory assuming the surface waves are Rayleigh distributed. The deviation of the linear theory is obvious. The maximum values of the peak accelerations (or their frequency of occurrence) is much higher than predicted by assuming that the system of a fast planing monohull in waves behaves linearly.

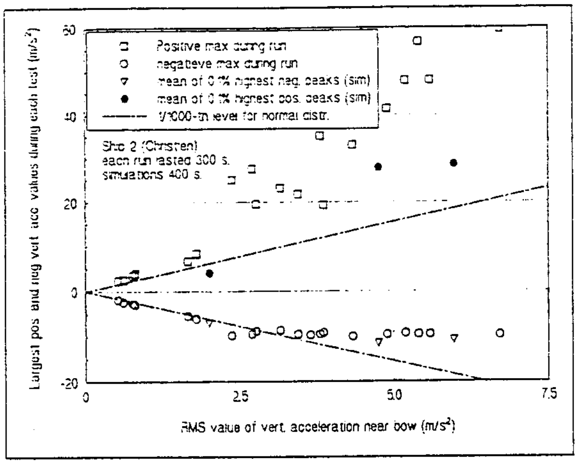

Figure 1: Relation between vertical acceleration peaks and RMS values

The deliberately created large area of "void space" in the forepart of the Enlarged Ship makes it possible to modify the bow sections in such a way that these high wave induced- and dynamic-lift forces are lowered in an effort to reduce the non-linear behaviour of the vessel and therewith these very high peak values. A similar improvement is at the same time achieved by moving the accommodation and more in particular the wheelhouse, which retain the same physical length on an otherwise lengthened ship in the ESC approach, relatively backwards along the length of the ship into the area of smaller overall motions and accelerations, see Figure 2.

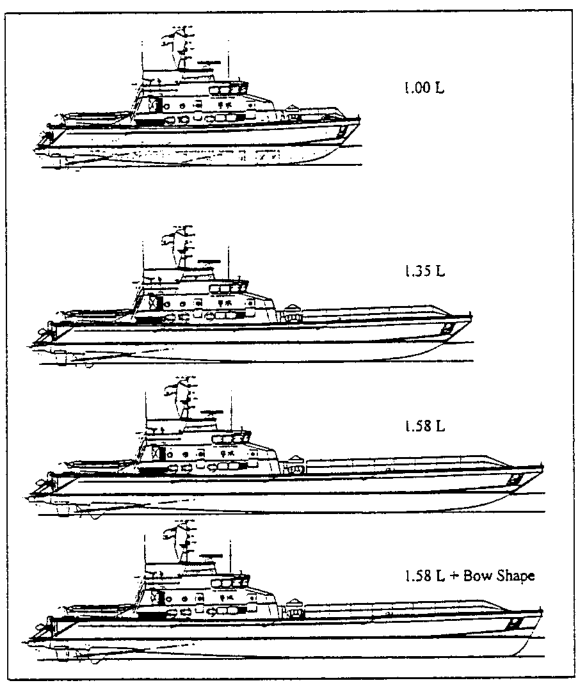

Figure 2: Base boat and alternative ESC designs

The best way of determining the above mentioned distributions of vertical accelerations at different locations on the ships is by way of model experiments. Therefore model tests are carried out to determine these vertical acceleration levels encountered due to ship motions. Different wave spectra are used during these experiments. All testing is done in irregular waves. Additional calm water tests have also been carried out to determine the resistance, sinkage and trim.

Motion calculations are further carried out with both linear (SEAWAY) and non linear codes (FASTSHIP) which have been developed at the Delft University of Technology, Ship Hydrodynamics Laboratory in order to asses the possibility to predict these distributions and the occurrence of high peak values.

The effect of the change in bow configuration on vertical acceleration levels in irregular head seas is quantified. The overall improvement in both resistance and operability, to be achieved by applying the Enlarged Ship Concept including bow modifications is evaluated using these results. Economic appraisals of the designs are also made for a given mission profile.

2 THE "BASE BOAT"

As basic monohull, as described by Keuning and Pinkster (1995), an existing semi-planning fast patrol boat (Royal Hong Kong Police 'King Class' 26 m., speed 25 knots) has again been chosen. This vessel is a well proven design from the Damen Shipyard Group of the Netherlands and has been described in more detail in the aforementioned reference. All design and functional requirements, such as speed, payload, accommodations etc., for the Enlarged Ship Concepts are based on and kept identical to those of this base boat.

Relevant design information regarding hull form, stability and trim, weights, building costs etc. of the basic monohull were kindly made especially available to the authors for the work carried out here. The main vessel design particulars are listed in Table 1.

3 THE "ENLARGED SHIP" DESIGNS

To yield the design of the Enlarged Ship Concepts for this study the basic Stan Patrol 2600 design, forthwith designated "2600", is enlarged in length only. Two such designs (alternatives "3500" and "4100") are made, each having a length of respectively 35 m., and 41 m. Each vessel has been increased in length by respectively 35% and 58% with respect to the basic design. A fourth design alternative, "TUD4100", has the same length as design alternative "4100" and is furthermore fitted with a highly different bow shape.

With regard to engineering of all these alternatives the starting point was relative data related to the base boat. The increase in length was created by stretching the original body plan using the respective length factors of 1.35 and 1.58. The body plan remains practically speaking the same for the first three designs with the exception however regarding the number of frames (frames pacing = 1 m. for all designs computed) and their longitudinal positions. Design "TUD4100" has, of course, different (sharper and longer) lines in the bow. Subsequently hydrostatic particulars were computed for the new body plans. The increase in structural weights of all alternatives was also computed via the original weight data which was augmented with extra frames and hull plating while, at the same time, taking into account the relevant positions of the centres of gravity of all components of the designs. The resistance and propulsion calculations were also made for each alternative and the position of the system centre of gravity of each design was such that a 0.5 degree trim-angle (down by the stern) at zero speed was obtained.

Since the idea behind the Enlarged Ship Concept is equal payload for all possible alternatives it stands to reason that the vessel configuration (ie. also position of accommodations, wheelhouse etc. with respect to the stern) remains largely

Table 1: Main Particulars of the different designs

		BASIC DESIGN ALTERNATIVES			
		2600	3500	4100	TUD4100
Length o.a.	[m]	26.70	35.70	41.70	41.70
Length waterline	[m]	23.40	31.60	36.90	38.20
Beam moulded	[m]	5.80	5.80	5.80	5.80
Depth moulded	[m]	3.35	3.35	3.35	3.35
Draught midships	[m]	1.62	1.46	1.38	1.43
Displacement	[kN]	970	1058	1115	1115
Deadweight	[kN]	170	170	170	170
Speed	[knots]	25	25	25	25
Total engine power	[kW]	2000	1446	1500	1536

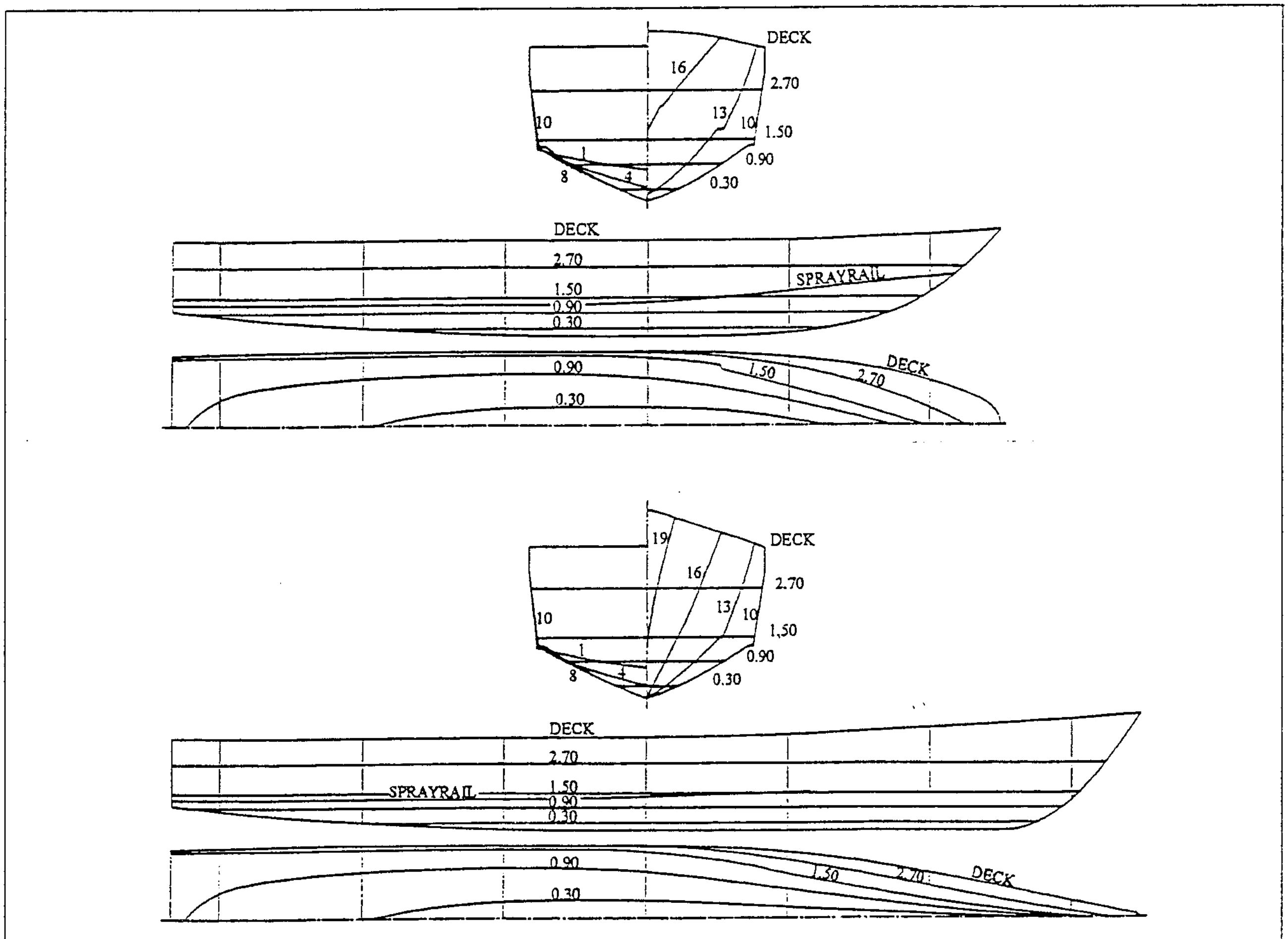

Figure 3: Lines plan for the "3500" and "TUD4100" design alternatives

unchanged to that of the basic design for each design alternative concerned.

All enlarged alternatives are shown in Figure 2 along with the base boat configuration. The main design particulars for the alternative designs are shown in Table 1. A simple lines plan is shown for the "3500" and "TUD4100" with highly different bow shape in Figure 3.

The reasoning behind the new bow-shape for the Enlarged Ship Concept is that the non-linear behaviour of the vessel to a large degree originates from dynamic lift forces and wave exciting forces. The magnitude of the dynamic lift forces is directly related to the change of momentum of the on-coming flow and therefore to the change in added mass of the sections while being sub- and emerged at high forward speed due to non-small relative motions. The mechanism is explained in detail by Keuning (1994).

The same holds true for the wave exciting forces which were by means of comparing measurement and calculations found to be highly dominated by the Froude-Kriloff component when calculated by integration of the undisturbed wave pressure over the actual momentary submerged volume of the ship sections whilst the ship is performing non small relative motions with respect to the waves.

The way sought to diminish these non-linear effects is by reducing both the change in added mass of the sections and the submerged volume of the sections whilst performing large relative motions with respect to the waves. Also deck submergence and bottom emergence should be avoided as much as possible, because they lead to abrupt changes in both. This obviously leads to reducing volume and flair in the sections as much as possible, both below and above the waterline, whilst increasing depth and freeboard as much

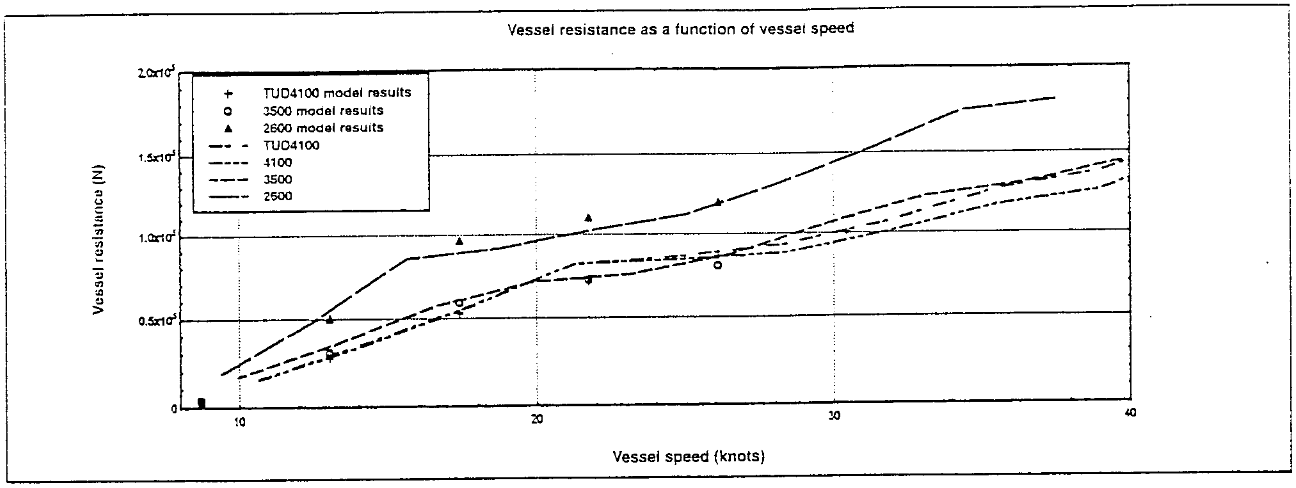

Figure 4: Resistance. Calculated and measured results.

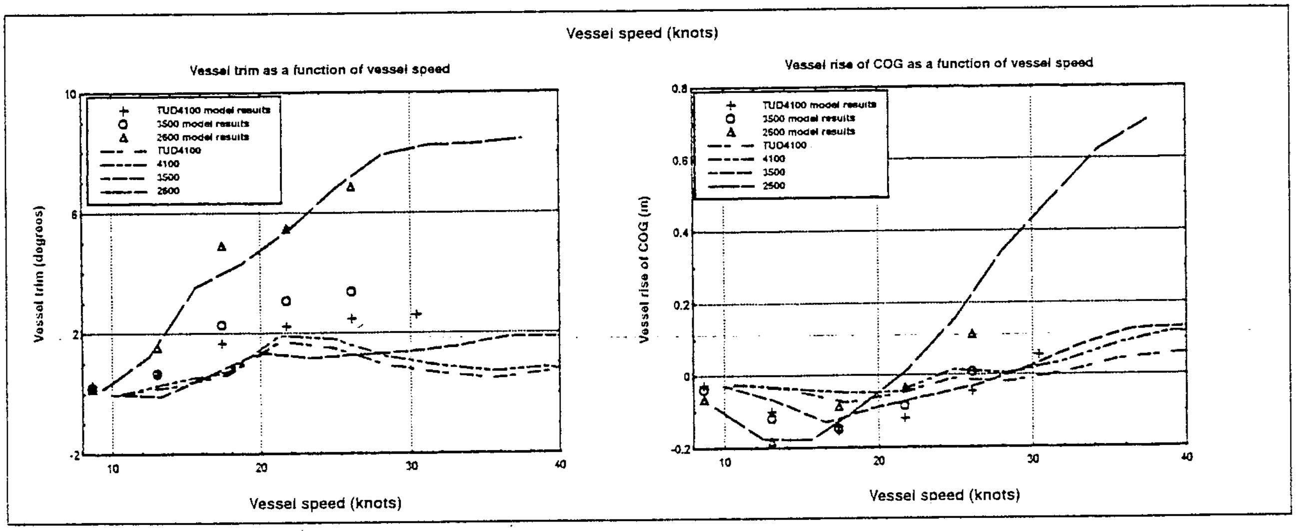

Figure 5: Sinkage and trim. Calculated and measured results

as "acceptable". An ultimate design exploitation of this concept could lead to a "wave piercing bow". However, this idea was not further evaluated because of lack of general acceptance by the foreseen ship-owners. Also an "axe-shaped bow" (ie. high positive deck sheer and downwards sloping bottom contour), was not further developed in this stage for the same reason.

As stated by Keuning and Pinkster (1995) and shown in Table 1, is that the larger the design the relatively lighter the ship becomes and to a lesser degree the lower the engine power becomes to propel the vessel at a constant speed of 25 knots. Again, it should be noted, however, that the "base design" is somewhat over-dimensioned with regard to scantlings in view of the working boat philosophy of the designing yard.

4 SHIP RESISTANCE

Vessel resistance, trim angle and rise of centre of gravity (cog), for all models are measured for different speeds in calm water in the range from 10 to 30 knots approximately. The same is calculated with the program FASTSHIP for planing hull forms. The results are shown in Figures 4 and 5 and confirm the tendencies as shown in Reference [1]. Model and calculation results show good agreement for the resistance and reasonable agreement for the sinkage and trim. Of particular interest of the ESC resistance curve when considering the design as a patrol boat is the diminishing existence of a "hump" in the resistance curve, which is quite favourable for a ship to be used at two rather separated speeds, ie. a cruising speed of about 12 knots and a design speed of 25 knots.

Therefore the advantage of the Enlarged Ship over the smaller ones with respect to resistance and trim remains.

5 SHIP MOTIONS

The experiments with the models of the designs in waves are carried out in the large towing tank of the Delft Ship Hydromechanics Laboratory. The dimensions of this tank are: length 145 metres, width 4.5 metre and water depth 2.5 metre. The tank is equipped with a hydraulically actuated wave generator of the hinged flap type. The towing carriage is capable of attaining speeds up to 8 m/sec.

Ship motions are measured for all models in irregular waves at a forward speed corresponding to the full scale design speed of 25 knots. Four wave climates have been selected, based on data derived from the Ocean Wave Statistics, Hogben and Lumb (1967), for carrying out the comparison. These are:

1) Tp = 5.3 s H1/3= 1.26 m : a condition most frequently encountered at the North Sea,
2) Tp = 8.4 s H1/3= 2.95 m : a condition exceeded only 5% of the time on the North Sea
3) Tp = 5.9 s H1/3= 1.29 m : a condition most frequently encountered in the Caribbean
4) Tp =10.4s H1/3= 5.5 m : a condition exceeded only 10% of the time in the Caribbean

The conditions 1 and 3 were considered to be so close together that they have been combined in order to reduce the number of tests to be carried out. The spectra used in the experiments are shown in Figure 6. These spectra are numbered condition 1, 2 and 4 respectively.

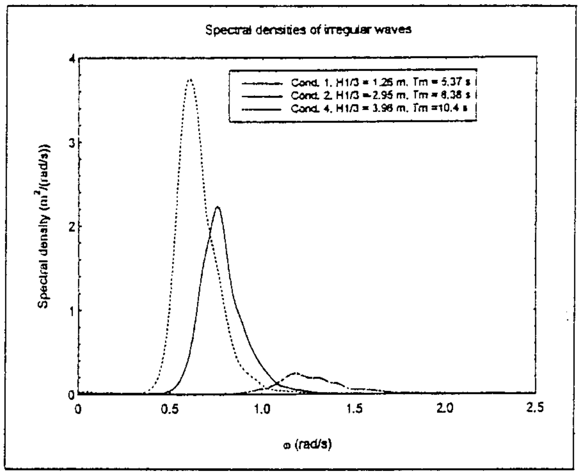

Figure 6: Spectra used in the experiments.

Ship motions heave and pitch and the vertical accelerations in three different locations along the length of each model, ie. the wheelhouse, the vessel Centre of Gravity in loaded condition (cog) and the forepeak are measured. Since the aim of the measurements is to differentiate between the different design concepts on a basis of occurrence of extremes in the vertical accelerations, the number of tests-runs in each spectrum has been increased to at least 12, meaning an average encounter between ship and waves of at least 500 waves. Each run has been executed in a different part of the spectrum realisation, but for each model the same parts of the realisations have been used to ensure a basis for comparison as similar as possible.

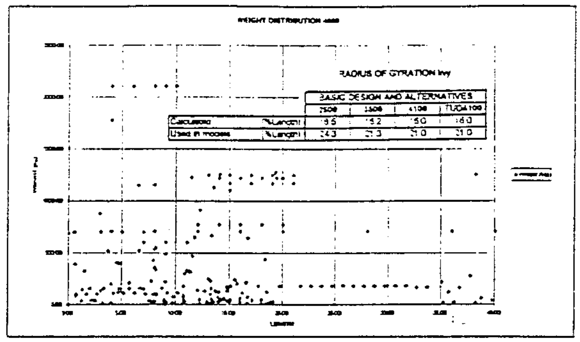

Figure 7: Weight distribution TUD4100 and values radii of gyration.

Before carrying out the experiments an analysis has been made of the weight distribution over the length of the various ESC designs in order to asses the differences in the longitudinal radii of gyration. From this analysis it was found that the radius of gyration of these patrol boat is generally lower than expected or used in the motion calculations. As expected in particular the largest ESC, ie. the TUD 4100, has a considerable lower radius of gyration than the generally assumed 25% of LOA. Obviously this lower radius has a significant impact on the natural periods of pitch of the various design variations. In Figure 7 the calculated weight distribution of this ship is presented and in the associated table the various radii for the other designs as used in the experiments and in the calculations are presented.

The results for the heave and pitch motions are presented in Figure 8 in the format of significant values on a basis of the three respective spectra, these being sorted on increasing

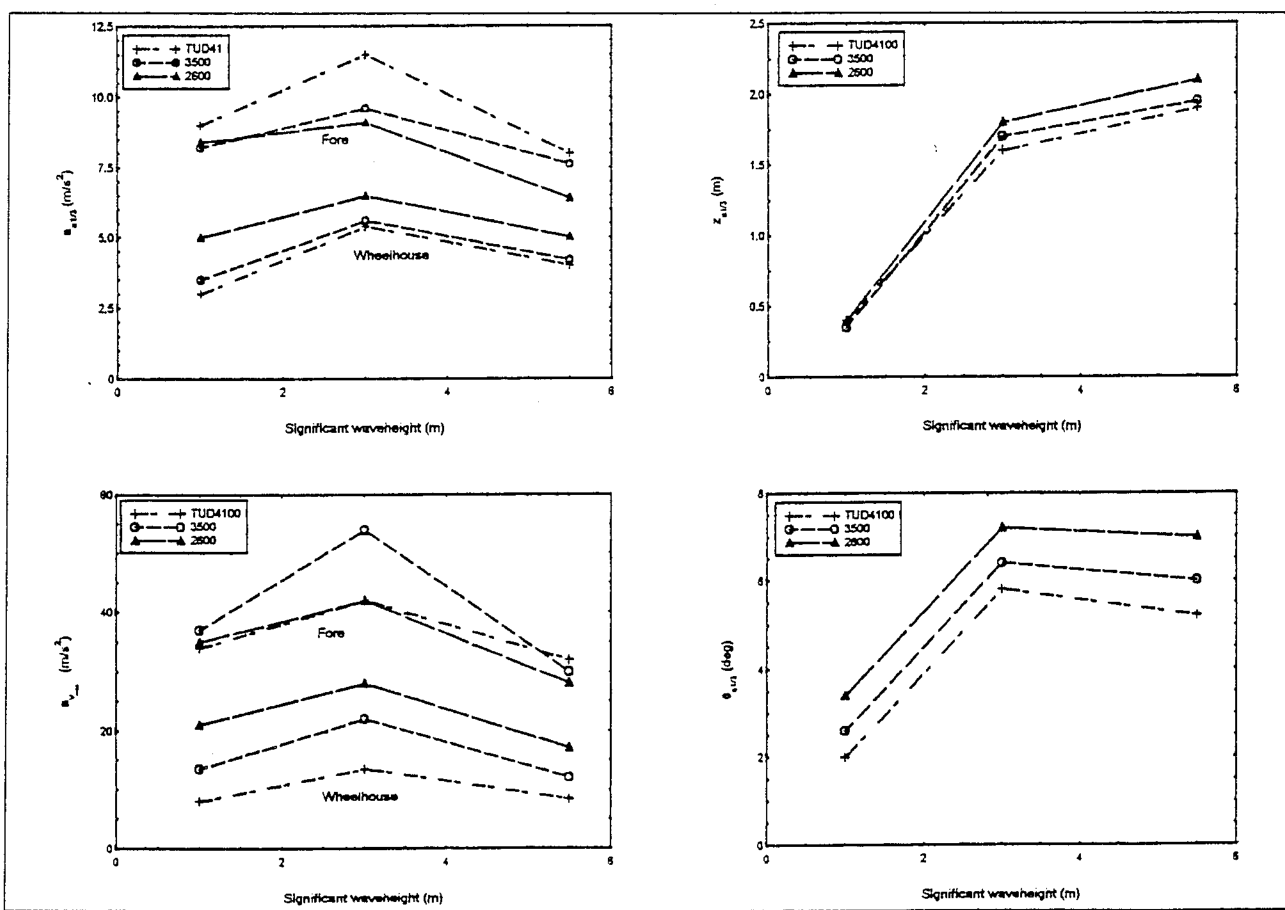

Figure 8: Ship motions and vertical accelerations.

significant wave height, in which the measurements have been carried out.

As may be observed from these results the differences in heave between the different models are small and for the pitch motion somewhat bigger both favouring the larger ships. The general trends of these results of the significant values of the motion amplitudes are quite well reproduced by the calculations, in particular by the linear ship motion code SEAWAY.

In Figure 8, also the significant vertical accelerations and the average of the highest three peaks measured during the total tests duration of all runs combined in the wheelhouse and in the bow, are presented for the three spectra.

It should be emphasised that all results are presented using a horizontal scale therefore this includes a change in significant wave height as well as peak period of the spectrum! From these plots it is obvious that the TUD 4100 ESC has significant lower values for the peaks at the wheelhouse in all conditions, even though the difference in significant values between the three designs is much more marginal.

As far as the vertical accelerations in the bow are concerned, it should be realised that these are also dependent on the distance between the point of observation and the centre of gravity of the ship, which is evidently larger for the ESC.

The acceleration levels are both calculated with the linear code (SEAWAY) and non linear codes (FASTSHIP), developed at the Delft University of Technology, Ship hydrodynamics Laboratory. Once again the significant values are quite adequately predicted by the linear code but the extremes are only properly predicted by the non-linear code. The results are shown in Figure 8 and confirm the tendencies as obtained from the measurements and also correspond with the results shown by Keuning and Pinkster (1995).

Considering the assumption that the workability of a fast vessel in waves is strongly dependent on the avoidance of unacceptable high peaks in the vertical accelerations, the improvement obtained by using the ESC with the modified bow is most clearly demonstrated by the results plotted in Figure 9.

In Figure 9, the magnitude of the peaks of the vertical accelerations in the wheelhouse for three of the design concepts, ie. the "2600", the "3500" and the "TUD4100", is plotted on a basis of percentage of exceedance. For each model, also the assumed Rayleigh distribution of these peaks is plotted for the sake of reference. The level of deviation between the measured distribution from the Rayleigh distribution originates from the non-linearity of the system.

From these plots, it is obvious that, considering a given "threshold" value of the allowable peak of the vertical acceleration, these are rather more frequently encountered in the case of the "3500" and even much more frequently so with the "2600" when compared with the "TUD4100". Also the non-linear behaviour of the "2600" and to a lesser extent of the "3500" is clearly demonstrated by these plots. The ratio between the significant value (approximately 13.5% probability of exceedance) and the maximum value (for instance 0.1% probability of exceedance) is shown to be strongly dependent on this non-linear behaviour and therefore, on the particular design under consideration.

Ship motion calculation codes based on linear theory are not capable of predicting such differences. From calculations carried out with the non-linear FASTSHIP code it turned out that the trends may be predicted although the absolute values may still differ.

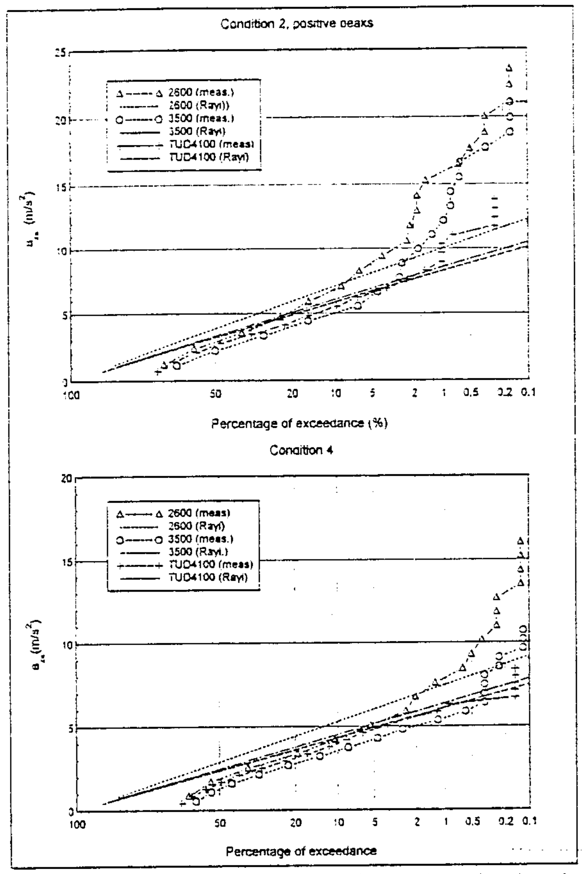

Figure 9: Percentage of exceedence of vertical accelerations in wheelhouse

The differences presented between the alternative designs in Figure 9 have an enormous impact on the workability of the vessels. However time did not permit calculations of these differences for a given mission profile in the scope of the present study.

6 ECONOMIC EVALUATION

In order to make an economical evaluation the building costs of the different design alternatives have been estimated. These were estimated using the original building costs of the "2600" (of which all costs components were known) and correcting this for changes in steel weight of the hull and extra painting costs (ie. cleaning, preparation and painting). The differences in building costs are indexed with regard to the "2600" in Table 2. Note the low increase in building costs of approximately 3% per 25% increase in vessel length.

The operational costs of all the design alternatives are considered for a scenario of a ten year economic life, sailing six hours per day at full speed, seven days a week for 48 weeks per year and crewed by five person (three shifts per 24 hours). The differences in operational costs are indexed with regard to the "2600" in Table 2. Note the relatively high decrease in operational costs of approximately 5% for design alternative "3500". This decrease is less dramatic in the case of the "4100" design alternatives (ie. 7%).

The transport efficiency (TE) - defined as (payload(kN)* service speed(m/s))/installed power (kW) - has been calculated for all four designs.

The differences in TE are indexed with regard to the "2600" in Table 2. Note the relatively high increase in TE of approximately 38% for "3500" design alternative.

Table 2: Main results of the economic calculations

		BASIC DESIGN ALTERNATIVES			
		2600	3500	4100	TUD4100
Length index	[m]	1.00	1.35	1.58	1.58
Building costs index	[m]	1.00	1.04	1.06	1.07
Operational costs.	[m]	1.00	0.95	0.93	0.93
Transport efficiency	[m]	1.00	1.38	1.33	1.30

CONCLUSION

Given the four designs presented in this paper, along with the wave scatter environment, seakeeping criteria and the patrol boat mission profile, the following conclusions are drawn with regard to the enlarged ship concept (see also Table 2):

- Conclusions given by Keuning and Pinkster (1995), are, on the whole, well supported by the results presented in this paper.
- In order to minimise the non-linear behaviour of a fast monohull in waves various design options are available, such as ESC, bow modifications etc.
- Optimisations with respect to workability, using limiting criteria based on significant values of vertical accelerations, may lead to erroneous results.

  Peak values of the vertical accelerations should be used rather than significant values.

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