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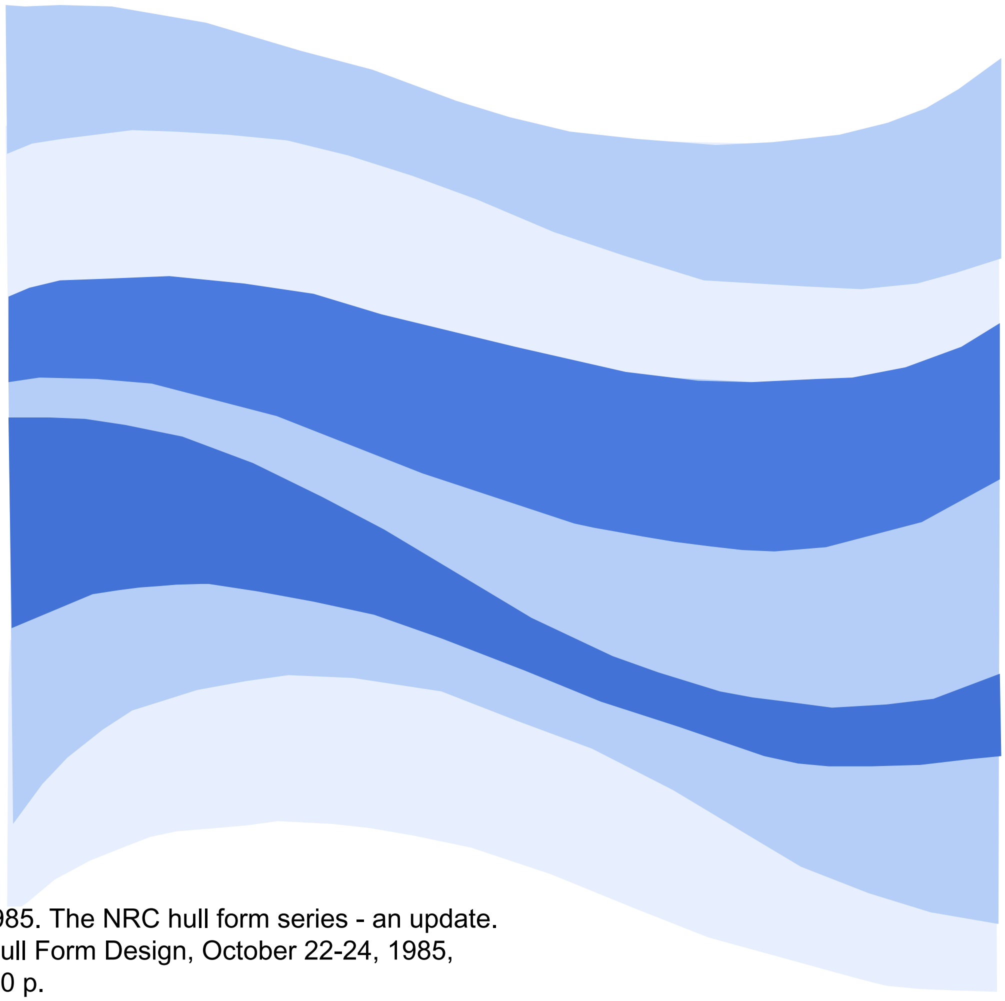
Research Report

RR-HYD-06

The NRC hull form series - an update

D.C. Murdey and A.J. Simões Ré

October 1986



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THE NRC HULL FORM SERIES - AN UPDATE

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SUMMARY

This paper describes a systematic series of model experiments that have been carried out on frigate hull forms. Data now available enable trends of performance to be established over a wide range of design parameters.

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THE NRC HULL FORM SERIES - AN UPDATE

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ABSTRACT

This paper describes a systematic series of model experiments that have been carried out on frigate hull forms. Data now available enable trends of performance to be established over a wide range of design parameters. After briefly describing the designs in the series, this paper presents some of the trends for resistance and selected seakeeping parameters.

LIST OF SYMBOLS

B	Moulded Waterline Beam at Midships, m
C_B	Block Coefficient
$C_{T\nabla}$	Resistance-Displacement Coefficient $R/0.5\rho\nabla^{2/3}V^2$
C_W	Waterplane Area Coefficient
Fn	Froude Number
g	Acceleration due to Gravity, m/s^2
L,LWL	Length on Waterline, m
Lpp	Length Between Perpendiculars, m
LCB	Longitudinal Position of Centre Buoyancy, % LWL from Midships
LCF	Longitudinal Position of Centre of Flotation, % LWL from Midships
R	Total Resistance, N
T	Moulded draught at Midships, m
V	Speed, m/s
V_s	Ship speed, Knots
Δ	Displacement, Tonnes
∇	Volume of Displacement, m^3
ρ	Density of Water, $N.s^2/m^4$

INTRODUCTION

Over the past ten years, the National Research Council of Canada Institute for Marine Dynamics (IMD), previously the Marine Dynamics and Ship Laboratory, has conducted resistance propulsion and seakeeping tests with models of a methodical series of frigate hull forms. The main objective of the series has been to provide data that can be used by designers in estimating the performance of future warships. New operational demands have resulted in design requirements for performance with special emphasis on seakeeping. The NRC series is intended to cover adequately the ranges of design and performance parameters for which little information is available from tests of earlier methodical series. The series also explores the effects of radical departures from normal ship proportions and hull form that may lead to important improvements in performance, particularly in waves. The development of the series is described in detail in Ref. 1.

In order to meet the immediate Canadian requirements for information on the performance of high speed displacement ships, the models were made and tested in phases. The first phase consisted of ten models and included a group of four for which different bows could be tested on the various sterns. The trends of performance identified from the first phase are given in Ref. 1.

Since the publication of Ref. 1 in 1980, testing of the basic series of 24 hull forms has been completed, and additional models made to extend the series to cover both extremely low and high length/displacement ratios. Two models with an intermediate length/displacement ratio have also been made. The test programmes have been expanded to include propulsion as well as resistance and seakeeping experiments.

This paper presents a summary of the extended series, briefly describes the models and tests, and highlights some of the results.

DESCRIPTION OF THE SERIES

The NRC series is based on the hull form of a Canadian frigate with proven satisfactory performance at sea. The parameters to be varied in the series were selected following a review of published work and a preliminary analytical parametric study, Ref. 1. It was a fundamental requirement of the series that the parameters to be varied would be restricted to those known or easily estimated at the earliest stages of design and which were expected to affect the seakeeping characteristics. These considerations lead to the following combinations of parameters: slenderness ratio (L^2/BT); beam-draught ratio (B/T); block coefficient (C_B); and waterplane area coefficient (C_W). The slenderness ratio was included instead of the more commonly used length/displacement ratio ($L/\nabla^{1/3}$) since the latter implies the inclusion of C_B which is already considered as a separate parameter in the series.

The models were made in two halves so that, for each group of four models with the same midship section, twelve additional designs could be modelled by interchanging bows and sterns. This enables variations in the longitudinal positions of the centre of buoyancy and flotation to be included in the series. In addition, the effects of changing section shape or transom width may be determined directly by comparing appropriate combinations of bow and stern.

The experiment design for the series as a whole is shown in Table 1 and the ranges of parameters covered by different combinations of bows and sterns in Table 2. Design 6 is the series parent model. Designs in each column of Table 1 differ in beam and draught while those in each row differ in section shape.

TABLE 1: HULL FORM DESIGNATIONS

	C_B	0.48		0.52	
	C_W	0.74	0.80	0.74	0.80
L^2/BT	B/T				
60	5.20		29		
	3.28		30		
105	3.28		31		
	5.20	1	7	13	19
150	4.20	2*	8*	14	20
	3.28	3	9	15	21
194	3.28		26		25
	5.20	4	10	16	22
238	4.20	5*	11*	17	23
	3.28	6	12	18	24
350	3.28		27		
480	3.28		28		

☐ - Models tested up to 1980   * - Models not made

TABLE 2: PARAMETERS OBTAINED BY INTERCHANGING FORE AND AFT AFTER BODIES

	C_B	0.48			0.50			0.52		
	C_W	0.74	0.77	0.80	0.74	0.77	0.80	0.74	0.77	0.80
LCF	LCB									
	-0.35					24/6				
-4.23	-1.53		12/6						24/18	
	-2.72					12/18				
	-0.35				18/6		24/12			
-5.63	-1.53	6		12				18		24
	-2.72				6/18		12/24			
	-0.35					18/12				
-7.04	-1.53		6/12						18/24	
	-2.72					6/24				

HULL FORM DESIGNATIONS ARE BOW/STERN

The series comprises four section shapes, two normal forms, an extreme 'V' form with a knuckle and an extreme 'U' form as shown in Fig. 1. The three new basic forms (Designs 12, 18 and 24) were developed from the parent design by a geometrical scheme described in Ref. 1. Forms with the same block coefficient have the same sectional area curve, and those with the same waterplane area have the same curve of fractional waterplane breadths. The C_W of 0.74 is associated with a transom width of 0.44 of the maximum beam, and a value of 0.74 of the maximum beam is associated with a C_W of 0.80. All four basic forms have the same midship section. The remaining designs were obtained by simple scaling of beam and draught of the appropriate basic design.

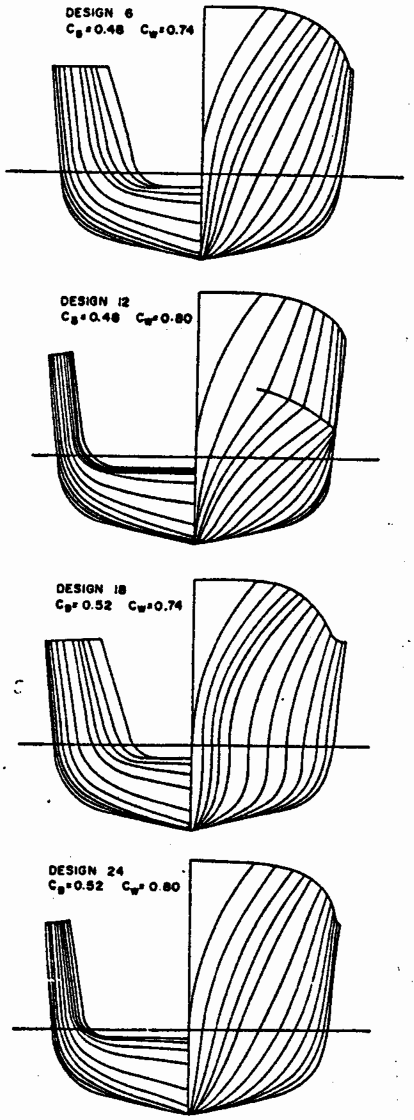

Fig. 1: Body Plans

The ranges of parameters were selected to give as large a variation as possible, so that trends in performance could be easily identified. In the original series, the limits of L^2/BT were 150 and 238. For the hulls based on Design 12, which had shown good seakeeping performance, Ref. 1, the series was extended to include extremely slender forms with L^2/BT values of 350 and 480. An interest in vessels that are relatively wide and deep for their length but still have the transom and twin screw stern arrangement of the frigate (such as some training or patrol vessel designs) prompted an extension of the series to include very low values of L^2/BT. Although some characteristics of such derivatives of the basic form are unlikely to be adopted in practice (for example, an extremely sharp cut-up aft), data from these models have already proved to be of value in actual design studies.

The expected large non-linear effect of L^2/BT on resistance required the manufacturing and testing of additional intermediate models for accurate interpolation of resistance estimates. Designs 25 and 26, which were only tested for resistance, serve this need.

The models tested up to 1980 are identified in Table 1. Four models, with the intermediate B/T, have not been manufactured since the near linear effects of changing B/T did not appear to justify them at this stage.

MODELS AND EXPERIMENTS

The models were made 3.396m on the waterline, which corresponds to a scale of 1/32 of the original parent form. All the models have the same length except models of Designs 27 and 28 for which the length on the waterline was increased to give them the same displacement as the model of the form from which they were derived, Design 12. These two exceptions were made since maintaining constant length would have given these extremely slender models an impractical low displacement and inconvenient narrow beam and draught. Turbulence stimulation was provided by studs at Station 19, 5% of L_{pp} aft the fore perpendicular.

Resistance experiments were carried out in calm water with each model, without appendages, ballasted to the design draught and without trim. The models were tested over a wide range of speed corresponding to a range of Froude number, Fn, 0.20 to 1.00, except for models of Designs 29 and 30, for which it was not practical to exceed a Fn of about 0.6. Resistance experiments were also carried out with the additional 12 possible combinations of the bows and sterns of Designs 6, 12, 18 and 24. Appended resistance and propulsion experiments have been carried out with the 20 models in the main series (models with L^2/BT values 150 and 238). However, the results have not been finally collated and analyzed, and are not considered further in this paper. With the exception of Designs 25 and 26, seakeeping tests have been carried out with all the models including the four combinations of the bows and sterns of Designs 6 and 12.

The seakeeping experiments were carried out in regular head waves, with the models self-propelled and without any external tow force. The only restraint on the models was provided by guiders, vertical poles fore and aft, sliding between rollers mounted on the tank carriage. This arrangement compelled the models to maintain a straight line down the centre of the tank, but gave the models freedom to pitch, heave and surge. For these tests the models were ballasted to give a radius of gyration about a transverse axis through the centre of gravity of 0.25 of the L_{pp}.

The wavemaker's settings were maintained constant during the tests so the ratio of wave amplitude to wavelength was nominally 1/100. The wavelength was varied in about twenty steps from one-half to three times the waterline length of the models. The experiments were repeated at each of four speeds corresponding to Fn 0.2, 0.3, 0.4 and 0.5, with the exception of Designs 29 and 30 for which the maximum Fn was limited to 0.3 and 0.4, respectively. This was due mainly to the very large power demands for self-propulsion of these models, which have very low L^2/BT.

Measurements were made of pitch and heave amplitudes and phases as well as the increases in propeller thrust, torque and rate of rotation required to maintain speed in waves. Only the motions data are considered in this paper.

TRENDS OF PERFORMANCE

Resistance Trends

The hull forms in the series can be considered representative of a wide range of ship size. For the purpose of presenting the resistance data in this paper, the resistance of ships 3500 tonnes displacement has been predicted. The extrapolations have been made using the ITTC 1957 ship model correlation line including a correlation allowance of 0.0004.

While comparisons of ship resistance for the various hull forms in the series could be made by a simple study of the resistance curves, the design of the series enables the trends to be demonstrated in an alternative way. In the main series, pairs of models differ only in one of the design parameters. For example, 12 pairs of designs differ only in C_B although, as shown in Table 1, the values of the three remaining parameters are different for each pair. The differences in resistance curves between the models in each pair thus give 12 measures of the effect of changing C_B. In particular, it is possible to judge if interaction effects are present, that is, if the effect of one parameter depends on the level at which the remaining three parameters are held. For example, a comparison of the differences between the results obtained for Designs 6 and 18, and 3 and 15 shows how L^2/BT affects the C_B trend. In this case, B/T is 3.28 and C_W is 0.74 for both pairs.

Figs. 2 and 3 show the difference between resistance-displacement coefficients ($C_{T\nabla}$) for models which differ only in C_W for L^2/BT 150 and 238, respectively. At the constant displacement being considered, differences in $C_{T\nabla}$ are proportional to differences in resistance at a particular speed. Increasing C_W is shown to be beneficial at higher speeds, with the benefit being greater at the lower value of L^2/BT. In contrast, as shown in Figs. 4 to 7, there is little evidence that the effects on resistance of increasing C_B and B/T depend on L^2/BT.

As to be expected, the effect of changing L^2/BT is itself relatively greater than the effect of changing any of the other parameters.

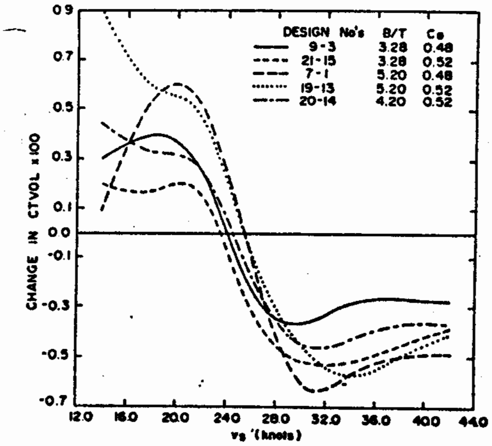

Fig. 2: Effect on Resistance of Increasing C_W with L^2/BT = 150

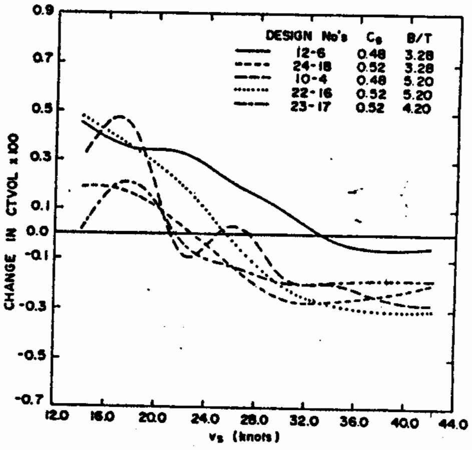

Fig. 3: Effect on Resistance of Increasing C_W with L^2/BT = 238

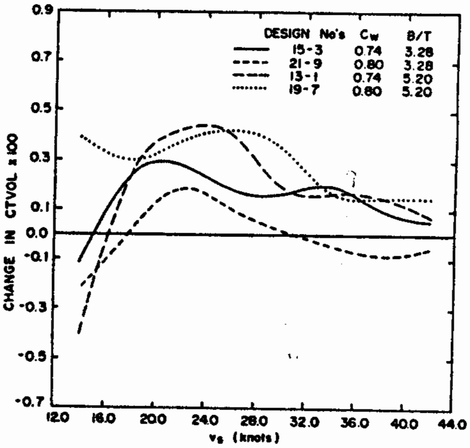

Fig. 4: Effect on Resistance of Increasing C_B with L^2/BT = 150

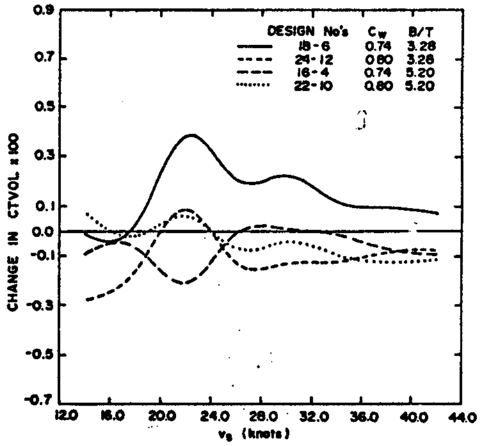

Fig. 5: Effect on Resistance of Increasing C_B with $L^2/BT = 238$

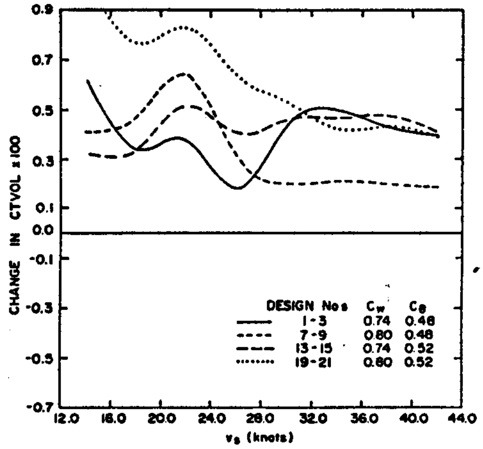

Fig. 6: Effect on Resistance of Increasing B/T with $L^2/BT = 150$

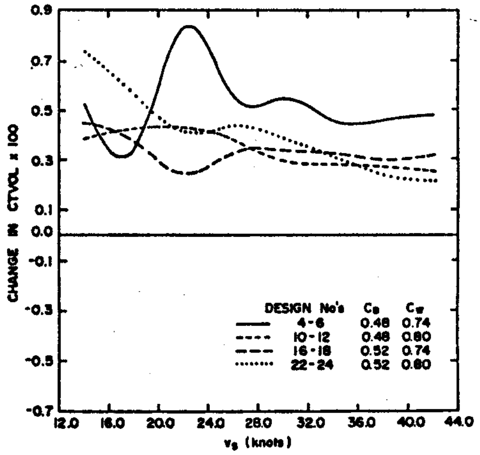

Fig. 7: Effect on Resistance of Increasing B/T with $L^2/BT = 238$

Fig. 8 illustrates the L^2/BT effect over the full range of the extended series, from a value of 60 to 480. In this figure the differences are made relative to Design 12, $L^2/BT = 238$.

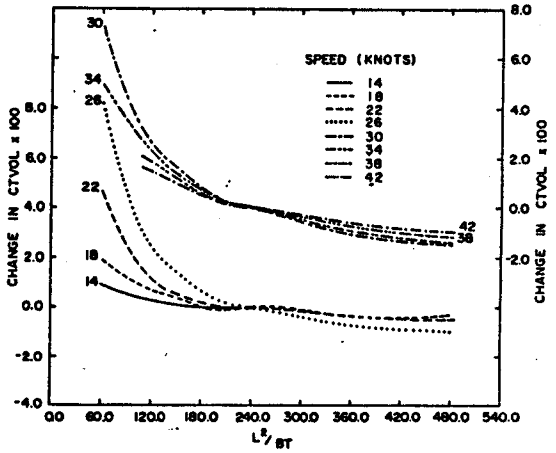

Fig. 8: Effect on Resistance of Changing L^2/BT at Various Speeds with $B/T = 3.28$, $C_B = 0.48$ and $C_W = 0.80$

The group of designs tested in which bows and sterns were interchanged shows very little effect of changing longitudinal position of the centre of buoyancy. However, an increase in resistance was observed when the longitudinal position of the centre of flotation was moved forward. The data from the tests of these same sixteen designs may also be interpreted directly in terms of the effect of changing the shape of the bow and stern. The effect of making the stern narrower on the fine sterns (changing from stern 12 to stern 6) and on the full sterns (changing from stern 24 to stern 18) for each of the four bows is shown in Fig. 9. The effect of making the bow more 'U' shaped on the fine bows (changing from bow 12 to bow 6) and on full bows (changing from bow 24 to bow 18) is shown in Fig. 10. These data, which show remarkable consistency, indicate the speed ranges over which particular hull shapes may be beneficial to resistance.

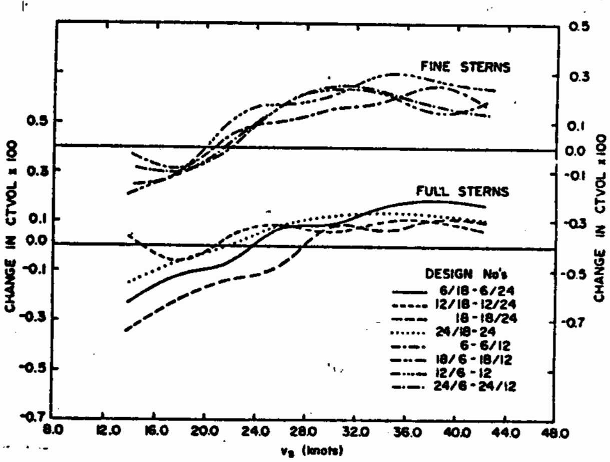

Fig. 9: Effect on Resistance of Reducing Transom Width

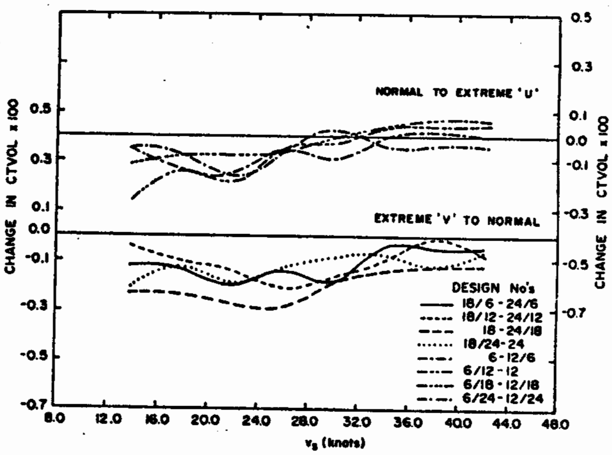

Fig. 10: Effect on Resistance of Increasing the 'U' ness of the Bow

Seakeeping Trends

The identification of trends for seakeeping is more complex than resistance due to the number of variables involved. In addition to ship speed, wave period and wave height are of importance, and seakeeping performance in itself is difficult to define by a single parameter. The response curves, which are the direct result of tests carried out in regular waves, are not considered suitable for comparing the seakeeping characteristics of the different hulls since they do not approximate sufficiently closely to realistic sea conditions. This problem can be overcome by using the responses as a basis for predicting the performance of ships in long-crested irregular waves. Such predictions have been made for ships with 3500 tonnes displacement using ITTC two parameter spectra. For this paper, predictions are presented for a significant waveheight of 4.0 meters and the data have been averaged over a range of zero crossing wave period from 6.1 to 9.1 seconds. Moreover, in order to further condense the results, predictions in the range of ship speed 13 to 33 knots have been averaged. In addition to pitch and heave, the acceleration and relative bow motion, which imply the effects of the phases between the pitch and heave motions and between these motions and the oncoming waves respectively, have been predicted.

As for resistance, the seakeeping trends are most clearly illustrated by considering the models in pairs, within which only one design parameter is varied. All the data have been made non-dimensional by dividing them by the corresponding value for Design 6, the parent design.

Figs. 11 to 13 show the effect on pitch, heave, bow acceleration and relative bow motion of changing C_W, C_B and B/T, while Fig. 14 shows the effect on these motions of varying L^2/BT for both constant displacement (3500 tonnes) and constant length (120 metres). In these figures each line corresponds to models in which one major hull form parameter is changed while the other three are held constant.

It is noteworthy that the results show major differences in performance from the parent. Thus important gains in seakeeping characteristics may be made by selection of appropriate hull form parameters.

The data show, in general, clear trends for pitch and heave and bow acceleration, with the latter following, broadly, the pitch. The trends for relative bow motion are not as well defined, and variations between designs are smaller. In general, pitch, heave and bow acceleration are reduced by increasing C_W, B/T and L^2/BT (at constant displacement) and are increased with an increase in C_B. The trends of relative motion with C_B and C_W while at first confusing, are indicative of interactions with L^2/BT and B/T. Interaction effects are more clearly seen in the trends of pitch with C_B and C_W, Figs. 11 and 12. The group of lines in Fig. 11 with the steeper trend of pitch with C_W are associated with the smaller value of C_B. Fig. 12 shows the expected interaction in the trend with C_B for the corresponding two values of C_W.

The comparisons just described are for ships of 3500 tonnes displacement. Since the effect of changing length is in itself of importance, it is interesting

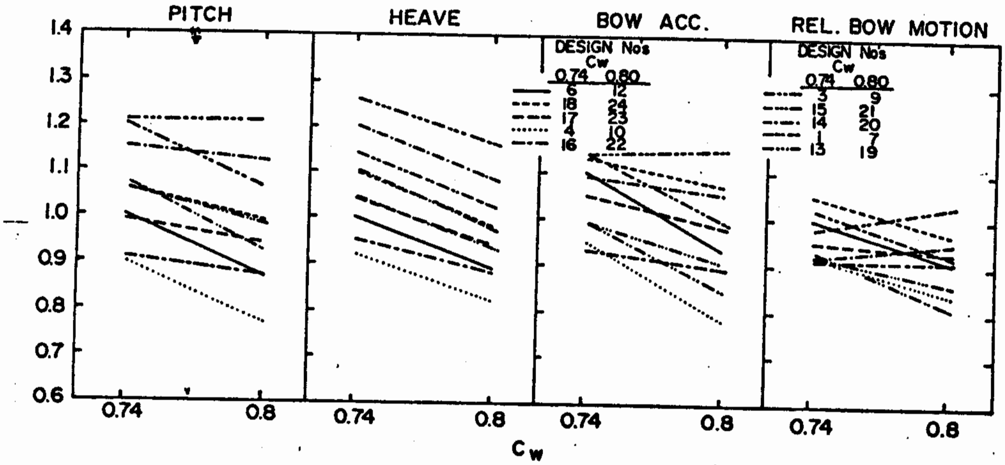

Fig. 11: Effect on Seakeeping of Increasing C_W

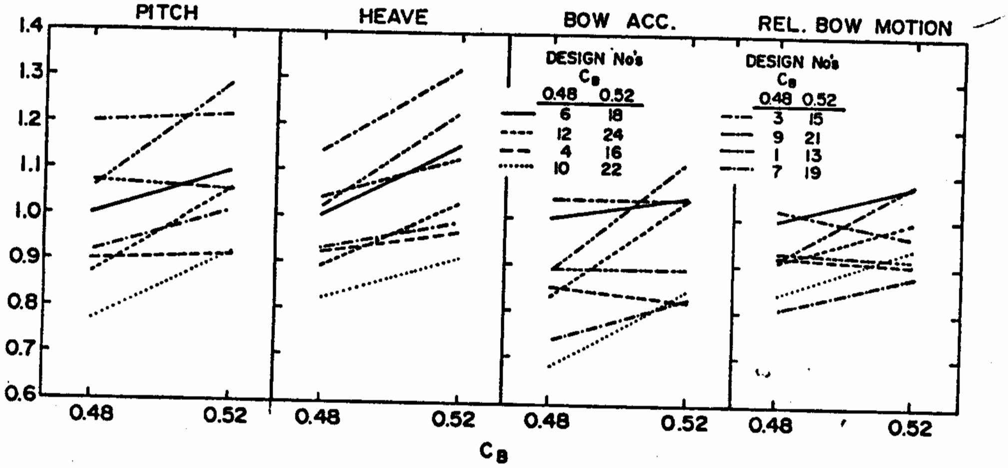

Fig. 12: Effect on Seakeeping of Increasing C_B

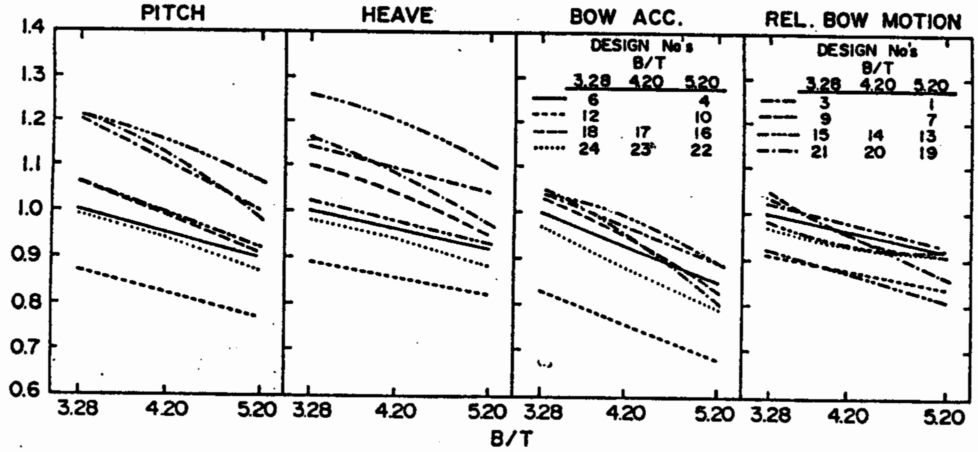

Fig. 13: Effect on Seakeeping of Increasing B/T

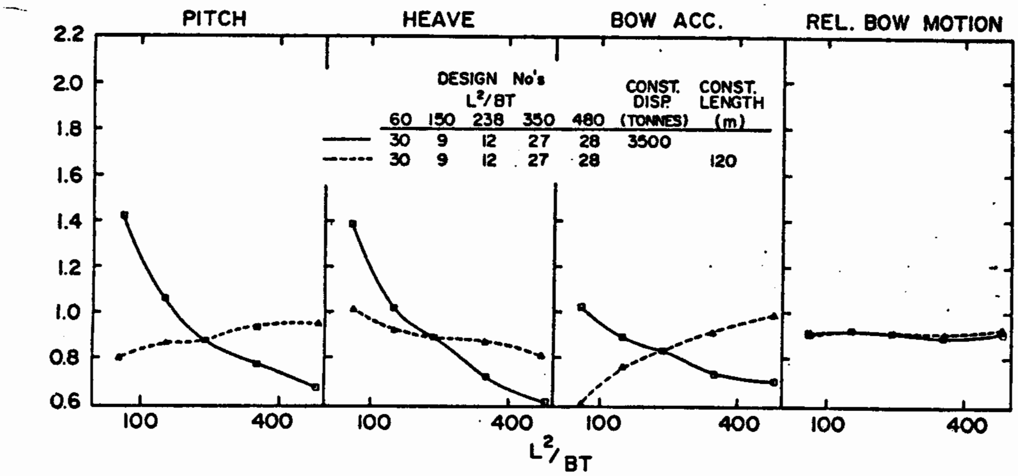

Fig. 14: Effect on Seakeeping of Increasing L^2/BT at Constant Displacement, 3500 Tonnes, and Constant Length, 120 metres.

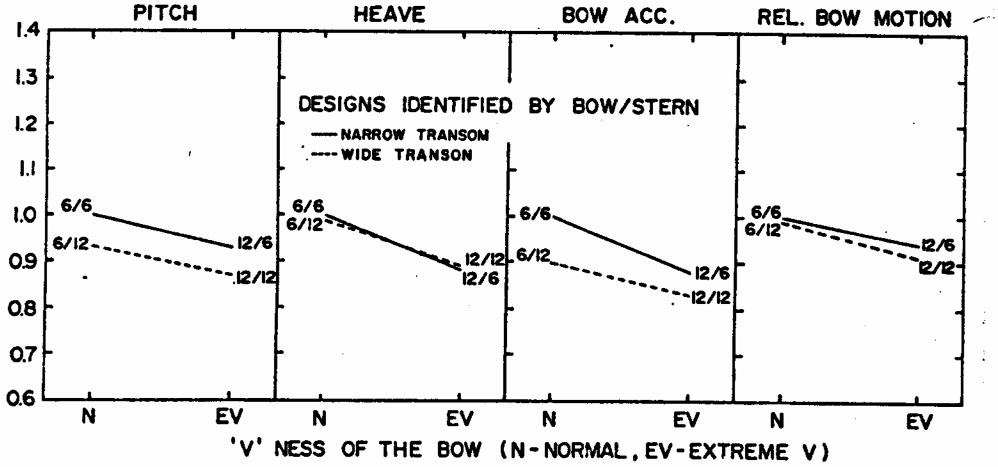

Fig. 15: Effect on Seakeeping of Increasing the 'V' ness of the Bow

to determine whether the trends attributed to L^2/BT may not be more closely associated with the corresponding changes in length. The predictions were repeated for ships of constant length, 120 metres, at the same speeds and sea conditions used for the comparisons between the 3500 tonne ships, and the two sets of data compared in Fig. 14. This shows that in contrast to the trends at constant displacement, increasing L^2/BT at constant length leads to an increase in pitch and bow acceleration, and to a much smaller decrease in heave.

The effects of changing from a normal (Design 6) to an extreme 'V' (Design 12) bow on the sterns of Designs 6 and 12 for pitch, heave, bow acceleration and relative bow motion are shown in Fig. 15. The decreasing trend is well defined as the bow changes from normal to extreme 'V' for all motions considered. The effect of changing the stern is shown by the vertical spacing between the lines in this Figure. The wider stern generally has smaller motions, but the effects are somewhat smaller than of changes to the bow.

CONCLUSIONS

The data from the series confirm important effects on seakeeping and on resistance of changes in basic form parameters. Thus trade-offs between seakeeping and resistance or overall performance optimization under particular design constraints, may be made in a quantitative manner.

The test data justify further detailed analysis, particularly for the statistical verification of trends and interaction effects and the development of prediction or interpolation schemes. They also serve as a basis for the evaluation of numerical methods, such as the strip theory prediction programmes in common use, as described, for example in Ref. 2.

While the overall consistency of the results, and in many cases the evident independence of the trends identified, gives confidence in applying the data to other similar ship forms, it must be remembered that, like any other systematic series, the results should be extrapolated with caution. Plans are in hand to extend the series, particularly at low L^2/BT, by the development of a hull form more similar to those used in practice for displacement ships with relatively large beam to draught ratios.

Further testing of the series will be directed to obtaining systematic data on slamming and shipping green water. New methods of experiment and analysis are being developed for these tests, which will be carried out with the benefit of the state-of-art wavemaker installed at IMD's new facilities in St. John's.

ACKNOWLEDGEMENTS

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