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Molyneux, W. D.

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SUMMARY

This paper presents the principal features of the models tested by IMD. Methods of storing and manipulating the data using modern computer techniques are discussed. The computer based methods are compared and contrasted with more traditional methods of using randomly acquired model data.

ADDRESS
National Research Council
Institute for Marine Dynamics
P.O. Box 12093, Stn. 'A'
St. John's, NF A1B 3T5 (709)772-2479

Canadian Shipbuilders and Ship Repairers Association

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Abstract

A Ship Model Data Base for Computer Application

by W.D. Molyneux

Group Leader, Ship Performance Group
Institute for Marine Dynamics
National Research Council of Canada
St. John's, Newfoundland

The Naval Architect needs to produce accurate estimates of ship performance once the basic proportions of the ship have been decided. The traditional source of ship performance predictions has been the towing tank, and the methods for preliminary design prediction have been based on systematic series or the analysis of randomly acquired model data. These data have been acquired over the years, but can still be used at the preliminary stages of performance estimating.

This paper presents the principal features of the models tested by the Institute for Marine Dynamics (formerly the Marine Dynamics and Ship Laboratory) of the National Research Council of Canada. Methods of storing and manipulating these data using modern computer methods and ways of expanding it from other consistent sources are discussed. The computer based methods are compared and contrasted with the more traditional methods based on the analysis of randomly acquired model data.

The methods of producing ship performance predictions in calm water by manipulation of the data for hull forms that do not fit exactly within the data base are discussed. Finally, suggestions are made for future expansion of the data base to maximize its potential as a design tool.

1.0 INTRODUCTION

Success or failure for a new ship design depends very much on its hydrodynamic performance. At a fundamental level this may be related to the economic evaluation of various hull form proportions. At a more detailed level it could be related to selecting the proper propeller design to maximize efficiency within the constraints of noise and vibration requirements. The problem facing the designer is to find sufficient reliable information concerning the relationship between hull form and performance to be convinced that the design being produced is the optimum for its operational envelope.

If a designer were to produce a separate physical model for each option worth considering the optimization process would become very expensive. There are two traditional sources a designer would use for low cost preliminary performance predictions. The results of various systematic series can be used for optimizing the basic proportions of a design, provided that the new design falls within the range of the parameters covered. This method has some disadvantages however, since most series only cover a very limited range of ship proportions and hull form coefficients. Extrapolation outside those ranges can often be unreliable. In addition, many of these series were developed from relatively old fashioned hull forms, which do not include modern benefits such as open water sterns for improved wake or bulbous bows for reduced resistance. Another solution is to use accumulated model data for various types of ship. This data often covers a much wider range of hull form proportions than a standard series, but since the hulls are not systematically varied, the interpretation of trends is more difficult. Individual designers will have their own stock of data but towing tanks usually have the best access to accumulated model data for a wide range of ship types. If the performance of all the models tested by a tank could be presented in a consistent fashion and in a way to establish trends, it would provide a useful service to ship designers.

It is also useful to consider some of the benefits of computer systems, other than their capacity for long and tedious calculation, which may be relevant to this problem. Modern computer systems are capable of storing and retrieving large quantities of data. This data may be manipulated very quickly with simple programs, and displayed graphically in an interactive format. This paper describes the development of a data base from all the models tested by the Institute for Marine Dynamics, (formerly the Marine Dynamics and Ship Laboratory) of the National Research Council of Canada.

2.0 OVERVIEW OF SHIP TYPES TESTED AT IMD

The National Research Council of Canada (NRC) opened its first facility capable of testing ship models in 1933. The basin was in Rockcliffe, just outside Ottawa. A total of seventy-eight models were tested in the basin, up to 1947, when a new basin was opened on the campus of NRC on Montreal Road. A manoeuvring basin was opened in 1955 and these two basins were the major Canadian test tanks, until the opening of the Institute for Marine Dynamics (IMD) in St. John's, Newfoundland in November 1985. A total of well over 400 models have been tested in the three basins, and although this sample is not large in statistical terms, it does contain many interesting and unusual designs. Some of these designs are particularly noteworthy since they are uniquely Canadian, with special features designed to enable navigation in ice-covered waters . For this reason IMD decided to collect together all the information on the models tested, and investigate methods of storage and presentation which would enable the data to be used for research and design purposes.

Most of the data was acquired on a project basis, and the types of vessels modelled reflect the major activities of the Canadian industry at the time the tests were carried out. For this reason, there is little systematic relationship between individual designs, although about ten percent of the total sample can be considered to have relations, for example, various bow or stern designs within a project. There is one notable exception to this randomly acquired data which is a systematic series of 47 hull forms, appropriate to fast surface ships. This series is described in reference 1. Since this systematically acquired data will be the subject of several different analyses, it was appropriate to separate it from the project data, which is the subject of this paper.

A total of 396 models (excluding the hull form series) were tested in the three Ottawa basins. A preliminary examination showed that it was possible to divide the models into thirteen separate categories, based on the description of the original project. Table 1 shows the classifications, together with the number of models in each category. A model was only placed in one category and in cases of ambiguity, the main dimensions, together with design speed and hull form coefficients, were used to select the most appropriate category. A summary of this data is shown in Figure 1. This figure shows that the data is not dominated by one particular type of ship. The largest group is large merchant ships, but this represents only about 20 percent of the total. The next largest group, with around 11 percent is the small ships (non-military) category. Several ship types make up between 10 and 7 percent of the total. These types are, in decreasing percentages, small warships, barges, fishing boats, large warships and icebreakers. Great Lakes vessels comprise about 6 percent of the total, and ferries, hydrofoils, sailboats, and twin hull ships each constitute less than 5 percent of the total. A surprising feature of the data was the relatively high proportion of "non-ship" models. This section was the eighth largest with just over 6 percent of the total.

Since the objective was to produce a ship model data base, some of the categories described above were clearly inappropriate, and were not considered further for this paper. The categories which were dropped were "non-ship", hydrofoils, twin hull ships and sail-boats. This does not mean that these categories have been forgotten, and hopefully, they will be the subject of further study in their own right.

Once the outline of the hull form data had been established, the next step was to determine what hydrodynamic data was available. The four types of test which are used to relate the hull form to basic performance are resistance, propulsion, seakeeping and manoeuvring. The model results were collected and the number of models tested for each of the four types of test were determined. This distribution is shown in Figure 2. The largest amount of data was available for resistance, followed by self-propulsion. The seakeeping and manoeuvring experiments were carried out using several different techniques. Seakeeping was used to describe any type of test in waves (for example head seas, following seas, and rolling), and manoeuvring for any type of test with a free running model (turning circles, zig-zags and iceberg avoidance). Since these types of test represent a very small portion of the total test data, no further subdivision was considered necessary at this stage.

Table 1 also shows the distribution of the test data over the ship types. The same data is shown plotted in Figure 3, for resistance and self-propulsion experiments. Since the number of models tested for seakeeping and manoeuvring were relatively small they were not plotted. It is worth noting the highlights of the data. In absolute terms the largest amount of data is for resistance experiments on large merchant ships. However, when looked at in percentage terms, seven of the ship groups have resistance data for more than fifty percent of the sample, and three groups have resistance data for over seventy percent. Overall, 59 percent of all the models made were tested for resistance. There is much less data for the other types of test. Only 34 percent of all models made were tested for self-propulsion, but the distribution over the types of ship is reasonably good, except for barges and small ships. Only about 10 percent of all models were tested for seakeeping or manoeuvring. Some of these smaller sets have interesting high spots in them. There are relatively high proportions of data on Great Lakes vessels entering locks, directional stability tests on barges, and seakeeping tests on fishing boats. In general, the most tested ship type are the icebreakers, which have high relative percentages in all types of test.

The division of the sample by ship type is clearly limited, since it is based simply on the original description of the ship. A better method of looking at this data, which may more easily allow the exploration of new concepts is a classification based on ship proportions. The basic parameters which are generally accepted to have the most effect on ship performance are speed, length, displacement, beam and draught. Since the models were constructed to many different sizes for many different scales, the hull form coefficients are best expressed in non-dimensional form. The four non-dimensional ratios which usefully express the above hull form parameters are:

$$L/\nabla^{1/3},\ L/B,\ L/T,\ C_B$$

Since the models were usually tested over a range of speed, which was often different from one condition to another for the same model, no attempt was made to incorporate ship speed into the classification process.

Figures 4 to 7 show histograms for the distribution of these ratios. These diagrams reveal some more interesting features of the

IMD data. In each case there is a reasonably broad distribution of the parameter. This is encouraging, since it means that the IMD data covers a very wide range of ship proportions even though the size of the sample is relatively small. It can be calculated from Figure 4 that 60 percent of the IMD data has a ratio of L/B less than 6, and 46 percent has a ratio of L/B less than 5. The IMD sample clearly contains a very high proportion of wide beam hull forms. The distribution of L/T, Figure 5, is similar to that of L/B. The histogram for $L/\nabla^{1/3}$, Figure 6, is more bell shaped than the other distributions. This distribution is difficult to interpret in terms of the ships, because one value of the ratio can be obtained from a wide range of coefficients. For example, a wide fine form can have the same ratio as a narrow full form. This may well account for the bell-shaped distribution observed. The ratio which relates the volume of the form to its principal dimensions is block coefficient. The distribution of block coefficients is shown in Figure 7. This is the only one of the distributions which shows two distinct peaks. The IMD sample may easily be split into high and low block coefficient forms. Reverting temporarily to our previous classification by ship type, the majority of the high block coefficient forms are made up of large merchant ships, Great Lakes vessels and barges. The low block coefficient forms are made up mostly from large warships, small warships and fishing boats.

The above figures do not show the distribution of data within a range of one parameter, for example, L/B. It would be possible to draw histograms of the variation of two parameters, but it was thought that the relatively small size of the reduced samples would make presentation confusing. One form of data presentation which does help to solve this problem is a scatter plot showing the distribution of one variable with respect to another. Figures 8 to 10 show the variation of $L/\nabla^{1/3}$, L/T and C_B plotted against L/B. The figures show there is a remarkably uniform distribution throughout the observed data. There is obviously some clustering around certain ship proportions, which have some correlations in this respect with our original ship classifications, which for convenience are also shown in the figures. Large merchant ships, large warships, and Great Lakes vessels are reasonably distinct sets when considered by ship proportion, but all other groups showed considerable overlap with other ship types.

3.0 DEVELOPMENT OF IMD DATA BASE

Once the IMD data had been collected together, it became clear that there was the potential to develop the information into a data base suitable for design purposes. However, to be most use to the designer, the same information must be available on each of the hulls tested, and presented in a consistent manner. In addition, the data must be of the highest quality, and the most accurate possible. Resistance experiments are the oldest form of ship model experiments. The test itself is relatively simple, and reasonably independent of extrapolation methods, and test techniques used. This is not the case for self-propulsion experiments where there are two widely used techniques, and for seakeeping and manoeuvring there are very many more.

The resistance is not always the subject for optimization in the development of a new design. However, it is always important, and it is unlikely that the calm water performance will be optimum, without at least a good resistance, within the restrictions of ship proportions. Bearing in mind the above considerations, together with the relative numbers of the different types of test, it was decided that the development of a ship model resistance data base was the most appropriate goal.

Even within this set of data there were several important things to consider before all the resistance data collected by IMD could be formed into a data base. Turbulence stimulators had been properly fitted to all the models but the data had been collected from two different tanks. Fortunately, there were enough repeat experiments carried out in both tanks to establish that the differences between them were insignificant, once tank blockage effects had been allowed for. A further complication arose around 1965, when the old mechanical resistance dynamometer was replaced by an electrical strain guage type. Again, ship model experimenters being cautious of new test equipment, made absolutely sure there was no significant difference between the methods. In 1972, a computerised data acquisition system was installed on the towing carriage, after which the system then remained reasonably stable until the present day.

The current method of analysis for resistance experiments at IMD relies heavily on computer based methods. A flow chart for the entire process from data acquisition to presentation of the ship prediction, suitable for including in a report, is given on the left hand side of Figure 11. Data is acquired directly on the towing tank carriage using a micro-computer sampling an analogue to digital converter at a set frequency. The mean values of the signals are stored, after visual inspection of speed and resistance as functions of time. This data is then transferred to the laboratory's main computer, for final analysis. The preliminary analysis program (RSP30), converts the measured resistance and speed data into non-dimensional coefficients, CTM(T) and Fn, after reading hull form information from the model description file. The coefficients are then output in a format compatible with IMD's interactive graphics package, which allows the operator to fit a faired spline through the data. The spline coefficients are stored in a second file, which is interpolated by the ship prediction program RSP32. The standard IMD package presents ship data based on the ITTC 1957 model-ship correlation line, although any of the major viscous correction methods may be used with existing subroutines.

This method is extremely flexible, since the user can select any combination of three-dimensional form factor, water type and temperature, correlation allowance and blockage correction. Model hull form data which remain constant from one option to another are read directly from the model description file. The tedious routine calculation of ship performance coefficients is done automatically, but the interactive curve fitting allows the operator some flexibility in interpreting the best line through the data.

Only the last 156 models of the IMD data base were tested using the fully computerised data acquisition system. It was decided that the modern analysis techniques offered many advantages and so every attempt was made to analyse the old data using the new methods. The original carriage data for each test was retrieved and a simple transformation program was written to convert this into non-dimensional form given the model resistance and speed, water density, model wetted area and length. Model description files were made up from the hydrostatics, given in the model reports and test records. The conversion of the old data to a computer based format is shown on the right hand side of Figure 11.

In order to test the above method, a small sample was chosen, based on the preliminary selection of ship types. This was done to ensure that the methods developed did actually work in practice, and any problems which might occur were worked out before the full analysis was started. It had the additional benefit of creating a complete set of data for which manipulation techniques could be developed. The fishing boats were selected as a starting point, and analysis of this data was completed in August 1984. This showed the method to be completely satisfactory from a technical point of view, and the rest of the data was analysed. This analysis was completed in 1986 for all the remaining models.

4.0 A REVIEW OF PUBLISHED DATA BASE ANALYSIS METHODS

Maximum benefit can only be derived from the accumulated data if it can be used to predict the performance of a new design. Unless the new design is very close to that of an existing form, some manipulation of the data is necessary. It is necessary, therefore to consider methods of interpolating trends from the data for it to be anything more than a filing system. It was decided to review the various published methods of presenting accumulated model data, before establishing what was most appropriate for IMD.

The earliest attempts at predicting trends from unrelated model data were based on graphical technqiues. Lap [2] published a series of design charts, derived from randomly acquired model data, for large single screw merchant ships, which could also be used for establishing trends in resistance with ship proportions. These were later expanded by Keller [3] to cover a wider range of prismatic coefficient. The ships were categorized, based on the position of the longitudinal centre of buoyancy. All the data were presented for a constant beam-draught ratio of 2.40. Since the models used in the derivation of these diagrams were not always to this ratio, a linear correction for the effects of beam-draught ratio was used. For an increase of B/T of 0.1 an increase in total resistance of 0.5 percent was proposed by Lap, and also used by Keller. However, Keller proposed a different version for ships with B/T greater than 3.0, where a decrease of 0.5 percent was thought to be more appropriate. The method allows no correction for length-beam ratio at all.

Another graphical technique, was presented by Moor et al [4, 5] for single and twin screw ships. This method was developed to establish standards of performance of large single screw merchant ships and large twin screw merchant ships. Again the dimensions were reducedto a standard ship dimension (400' x 55' x 24' for single screw, and 400' x 55' x 18' for twin screw ships). These dimensions being close to the average dimensions of the ships in the sample, when reduced to a length of 400'. This method differs from Lap's by using Mumford indices to give separate corrections for beam and draught. This is also a linear technique based on model experiments, and Moor recommends that it is not reliable for extrapolations of more than 10 percent of beam and draught from the standard dimensions.

Both these methods have been developed for a very narrow range of ship dimensions. The dimensions do correspond to the large merchant ship category, but this is a small part of the overall IMD sample. The extrapolation techniques used within the methods may be reasonable for small changes in L/B and B/T, but they would not be reliable for applicaton to the whole IMD data base. Lap's method was not appropriate at all since no variation of beam was allowed for in the presentation.

Statistical techniques are a potentially useful method of interpreting trends from large amounts of data. Multiple linear regression analysis is a technique which can be used for the development of empirical formulae from observed data. This technique has been widely adopted as a method of relating ship resistance to hull form particulars. It has been used for both systematic series data and randomly acquired model data with equal success. The earliest cited reference on the use of this technique was by Doust [6], analysing the resistance characteristics of trawlers. Another method developed from random data was prepared by van Oortmerssen [7], which was specifically for small ships. Holtrop and Mennen [8] have published a statistically based power prediction for large merchant ships, which has been updated on two occaisions [9, 10], which was also derived from unrelated model data, although the latest version included the model results from series 64.

Some other applications of this technique are not based on random model data, but collections of various systematic series data. This approach has been widely used for round bilge and transomed stern craft in pre-planing and planing speed ranges. Mercier et al [11], collected the results of seven hull form series for transom sterned craft, and used multiple linear regression analysis to predict trends of performance in the pre-planing speed range. A similar presentation was made by Jin Ping-zhong et al [12], for high speed round bilge forms, which included many of the series covered by Mercier, together with some Chinese data. Radojcic [13] prepared an analysis of stepless planing hulls based on the DTNSRDC series 62, the two hullforms within the series 65, and one other model. Although the ship proportions covered by these references are reasonable for many of the wide beam forms, the speed range is inappropriate for much of the IMD data.

A regression equation is developed by assuming a relationship between independent variables (usually hull form ratios or coefficients) and the dependent variable, in this case resistance. The difficulty in interpreting the results of a regression analysis is that there are virtually no limits to the forms that the independant variables may take. There is the possibility that an equation may be produced which is a good fit to the observed data, but when used as a predictor for a form which is not part of the original data set, its performance is poor. This will occur when the independent variables selected are not the ones having the most important effect on resistance. It is therefore essential to make sure that the variables in the final equation are both theoretically sound and statistically significant. No regression equation can be expected to give reliable predictions for a form which is outside the range of any of the variables used in the original analysis.

For a systematic series where there was a variation of hull form parameters, selecting the independent variables to be those parameters which were varied or their cross-products may be appropriate. When using statistical techniques for random model data however, it is difficult describing a hull form with a limited number of independent variables. For example, there must be hundreds of designs with identical principal particulars, but sufficient difference in resistance, caused by bow or stern design to make one superior to another. Only Holtrop and Mennen make some attempt to incorporate such small differences in hull form design into their prediction technique.

Since the IMD data considered as a whole covered a much broader range than any of the previous published data, it was thought that developing a regression equation for the whole sample was not feasible, without a better understanding of the mechanics of ship resistance. Also, when broken down into divisions more appropriate to the published methods, the number of models in each category became small, because of the diversity of the data.

A possible alternative to both graphical and statistical techniques was presented by Carlier and O'Dogherty [14]. This paper presented the implementation of a computerised data base for calm-water ship performance. Model data is stored in a computer format, and is retrieved by the use of utility programs. A selection of models can be retrieved, based on the limits of hull form proportions, considered by the designer to be appropriate for the new design. The data base has statistical routines incorporated for the carrying out of regression analysis, for two or more variables. This allows the designer to quickly review trends within a small set of data appropriate for the current area of interest. This method presents a very attractive option, which offers a combination of real model data, together with empirical analysis techniques. It was decided to investigate this type of approach to see if it would be appropriate for the IMD data.

5.0 IMPLEMENTATION OF IMD COMPUTERISED DATA BASE FOR SHIP RESISTANCE

It very quickly became clear that the analysis methods developed by IMD described above, could easily form the basis of a computerised resistance data base. The basic hull data stored in the model description file contained sufficient information for preliminary design purposes. Ship model resistance data was stored in coefficient form, using fairly small amounts of computer memory. The hull form data and the performance data were linked together through the naming system of the files. One major drawback however was the fact that the data was stored by model number. Therefore it was relatively easy to find a model once it had been identified, but identifying models by hull form proportions was very difficult.

The short term solution to this problem was the creation of a master index of all models, relating the model number to the hull form ratios L/B, B/T, L/T, $L/\nabla^{1/3}$ and C_B. This data can be sorted by any one of these values, and all the models within a certain range may be identified. Once the first choice is made, the variation of the other parameters within that range can be investigated, by plotting these values against one another. Since these coefficients do not fully describe the hull forms, a file of bodyplans, in model number order also helps the user to select an appropriate sample of hull forms. Unfortunately, not all the older models had complete hydrostatic calculations performed, but it is hoped to produce these eventually. Once this is done, it will allow a fuller description of the hull forms in classical terms, or in some new form which bears more relationship to the effects of hull form on resistance.

Another benefit of this method of presentation is that new data can easily be added to the data base. For example, several of the published hull form series give actual model experiment results, either faired or unfaired. These can easily be added to provide valuable extensions to cover areas where more data is required. Model data from any other source could also be added, for example, Canadian designs tested in other tanks.

Once a suitable group of designs have been selected it is necessary to establish trends from the data. The method of incorporating statistical algorithms as utility programs for the data base is good for large quantities of data, but if just a few models exist for one particular category it is difficult to implement accurately. IMD decided therefore to try a slightly different approach. If the difference in resistance between a hull form in the data base and a new design could be determined, by using an empirical correction based on trends derived from larger samples, a very useful prediction technique could be developed. A study of the published references, given above, indicated that no one method could reasonably cover the full range of hull form proportions. The two most flexible methods with the widest application within the IMD data base were van Oortmerssen [7] for the low L/B designs and Holtrop [10] for the higher L/B designs. Both references were widely cited, and considered reasonably reliable. An additional benefit of both methods was that they were easy to program within our existing data base format.

Two applications programs were written to predict the resistance of a ship, given a model description file, including a suitable scale. The technique developed was to use the most appropriate method to predict the performance for both the form within the data base, and the new design. The difference between the predicted resistance coefficients was added to that of the data base form to give a prediction for the new design. An example of this technique to predict resistance of a new design (A) is given in Figure 12, for the ship described in Table 2. For this particular case the new design (B) was also tested, and a comparison with the prediction method is given. This method has not been fully assessed, but it has been used for the resistance prediction of a new ferry design, a hull form suitable for small low speed patrol boats, such as fisheries protection craft, and some fishing boat designs. In all cases the results proved to be more than satisfactory.

There are two other possible uses for the data base. As well as predicting ship resistance, it is also useful for a towing tank to be able to predict the resistance of the model, prior to starting a test program. For this reason the prediction method also presents the results of a model to a scale given in the model description file. If no model prediction is required, the ship dimensions can be used, together with a scale of 1.0. Another use of the data base is to provide an indication of the relative performance of a new design. The first question asked by the designer on seeing the tank report is "How good is it?". The data in the data base can be used to provide information on similar designs already tested.

In addition to the programs used for resistance data base manipulation, several other small programs were written to enable delivered power predictions to be made. A program for predicting appended resistance was written, using published form factors for appendages given in [10], which may be added to the naked resistance data, derived from the data base. Hull factors can also be calculated from Holtrop [10], and open water data calculated using the well known polynomial equations for either the B-screw series or the Ka-470 series, in a duct. All this data is combined with the resistance data to produce a delivered power estimate for the ship.

6.0 FUTURE WORK

The development of the data base is a continuing process, and the work described here is only the beginning. It represents the first time all the IMD data has been collected together, and looked at as a possible design tool. The published methods of data base presentation using statistical or graphical methods are not appropriate for IMD's wide range of data. A computer based system with appropriate utility programs provides a very flexible method for providing resistance estimates for a new design prior to tank testing, or establishing standards of performance after the tests are completed. This system is directly compatible with IMD's analysis and reporting techniques for resistance experiments, and will be expanded to incorporate other experimental data.

There is clearly a lot more work to do in order to develop the method into one which is based on the soundest theoretical and empirical techniques. Other existing statistical methods for ship types not already covered, such as planing hulls, and high speed round bilge hulls could easily be incorporated to provide alternative empirical techniques for predicting the effect of hull form distortions. The possibility of developing statistical techniques for predicting trends from reasonably small samples, appropriate to the IMD data will be investigated. This would represent an extension of the simple, highly empirical method used today. In addition, a statistical analysis of the resistance of the NRC hull form series, currently being carried out, will be incorporated, to provide a predictor method for fast warship hull forms.

Some improvements can be made to the housekeeping aspects of the data base, such as a wider criteria for selecting suitable parent forms. This requires a better system of identifying the features of a hull form than the simple hydrostatic coefficients used today. The coefficients used to describe the hull shape should be based on a better understanding of the fundamentals of ship resistance. This would allow for a more effective method of predicting the effects of small changes in hull shape such as bow or stern design. In order to develop this experimental system of hull form coefficients in an efficient manner, all the bodyplan data would have to be coded and software developed for the determination of the coefficients. A new analysis of the resistance data will then be carried out to develop a prediction tool.

Finally, the resistance is only a small part of the hydrodynamic optimisation process. Once a successful data base has been established for resistance tests, it is hoped to apply the same techniques to all the other types of tests that have been carried out in a consistent fashion.

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Table 1

Distribution of Model Experiment Data

Ship Type	Number of Models				
	Total	Resistance Expts.	Self-Propulsion Expts.	Seakeeping Expts.	Manoeuvring Expts.
large merchant ships	79	72	52	2	6
small ships (LWL 50m) (non-military)	43	22	4	-	2
small warships (25m LWL 90m)	36	18	11	7	5
barges	33	10	2	3	8
fishing boats	32	17	12	9	-
large warships	30	18	6	4	4
icebreakers	29	24	20	9	6
non-ships	25	-	-	-	-
Gt. Lakes vessels	24	10	6	-	6
ferries	18	15	10	-	3
sailboats	17	17	17	-	-
hydrofoils	17	1	1	-	-
twin hull ships	13	10	10	4	5
TOTAL	396	234	133	38	45

Table 2

Comparison of Ship Designs

	Data Base Form Design A	New Design Design B
LWL, m	34.0	34.0
B, m	6.0	7.9
T, m	1.8	2.4
Δ, tonnes S.W.	185	320
Wetted Area, m^2	205.2	272.8
C_B	0.48	0.48
C_W	0.78	0.78
C_M	0.78	0.78
LCB % LWL FWD.MIDSHIPS	-2.7	-2.7
LCF % LWL FWD.MIDSHIPS	-5.1	-5.1

Figure 1

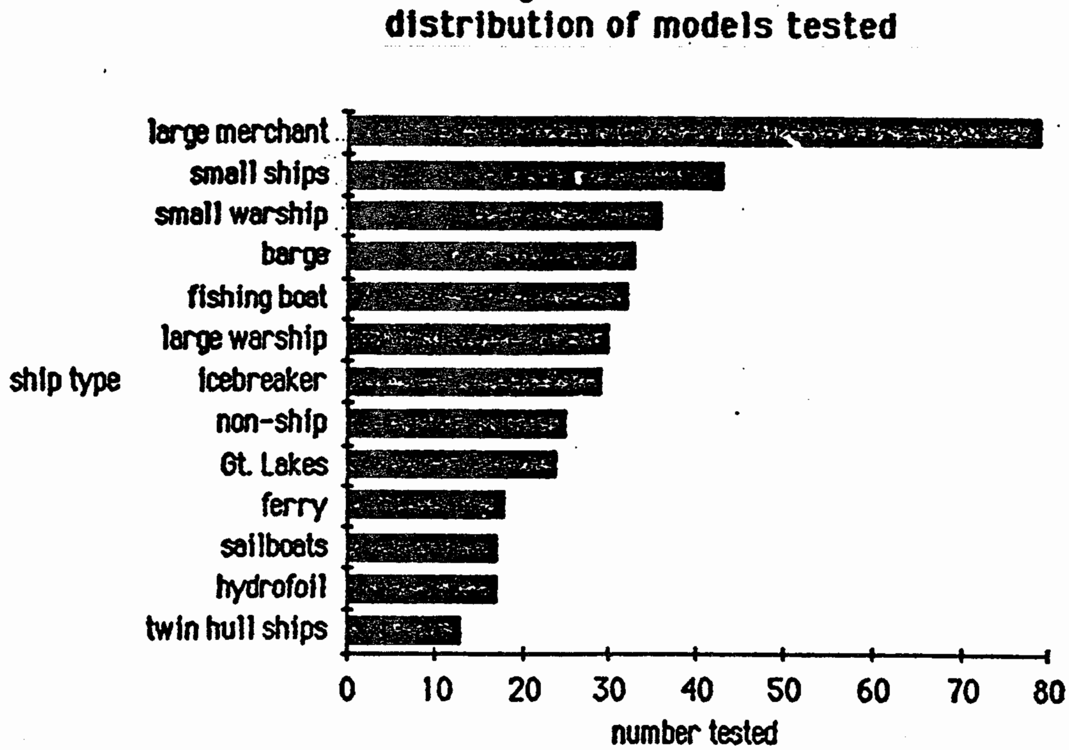


Figure 2

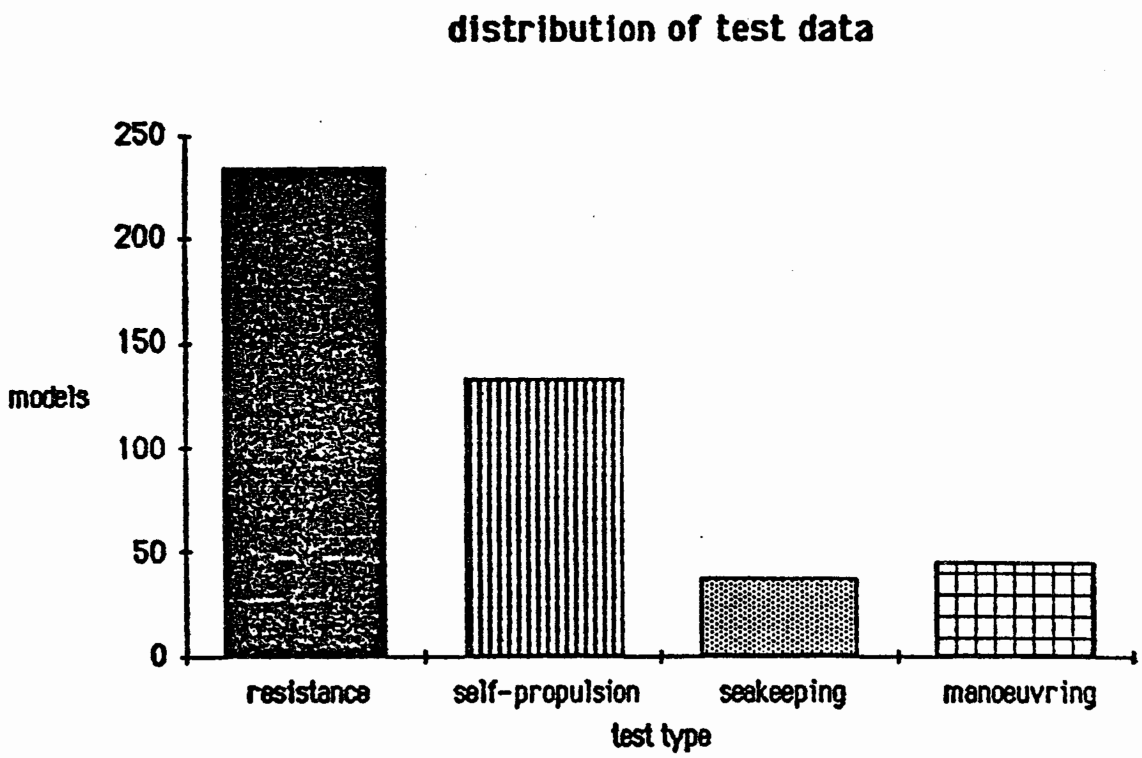
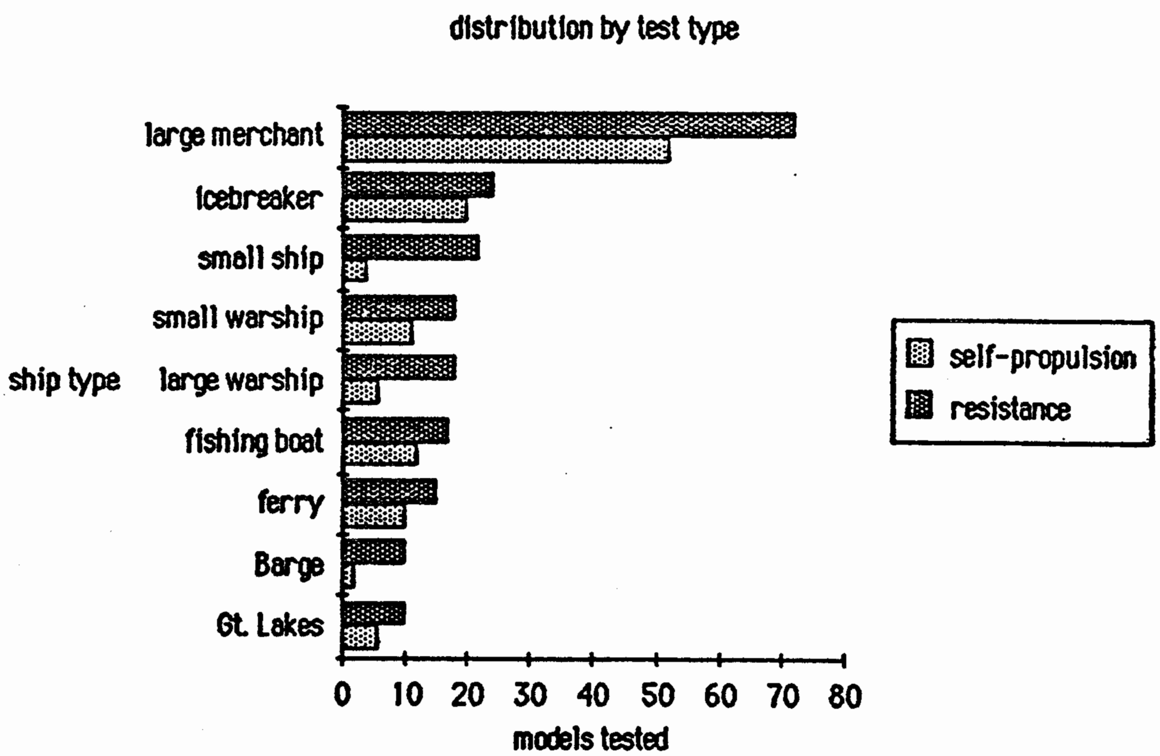


Figure 3



distribution by test type
ship type
large merchant
icebreaker
small ship
small warship
large warship
fishing boat
ferry
Barge
Gt. Lakes
0
10
20
30
40
50
60
70
80
models tested
self-propulsion
resistance

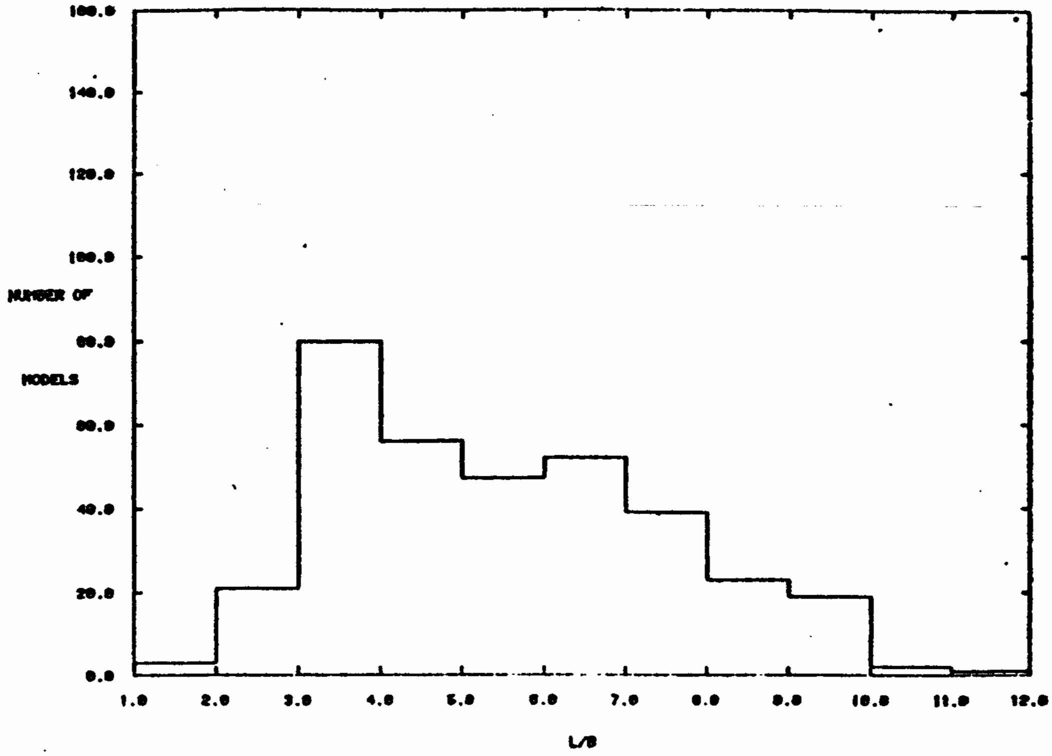


Figure 4 - Distribution of L/B Ratio

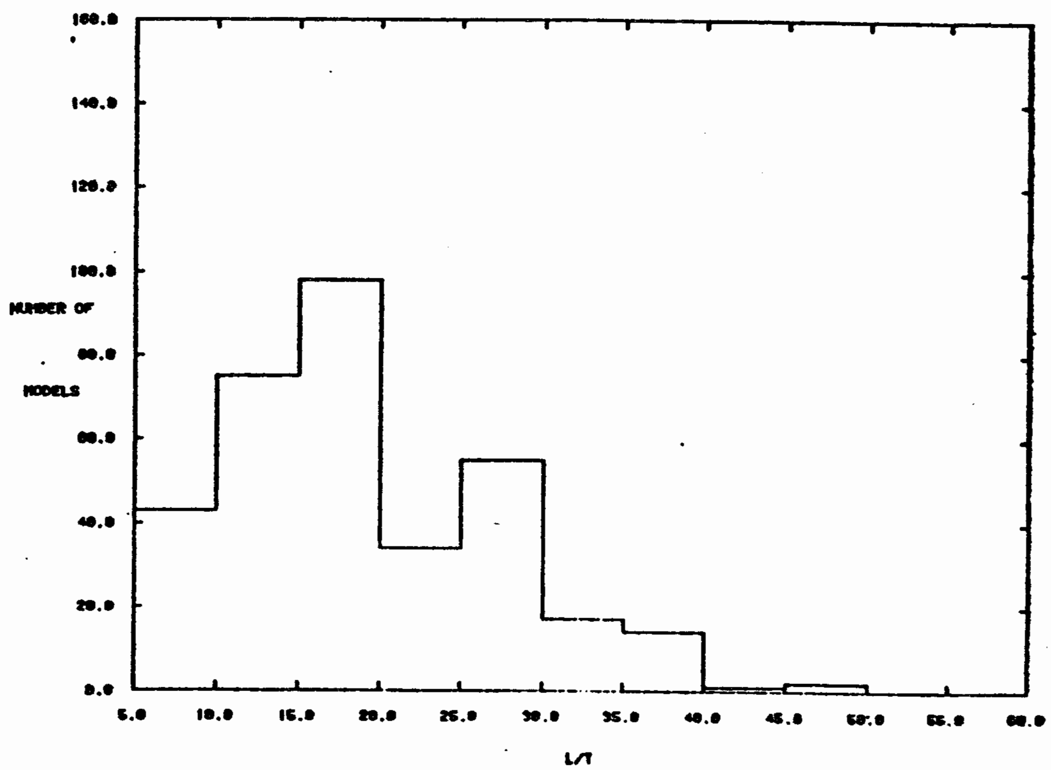


Figure 5 - Distribution of L/T Ratio

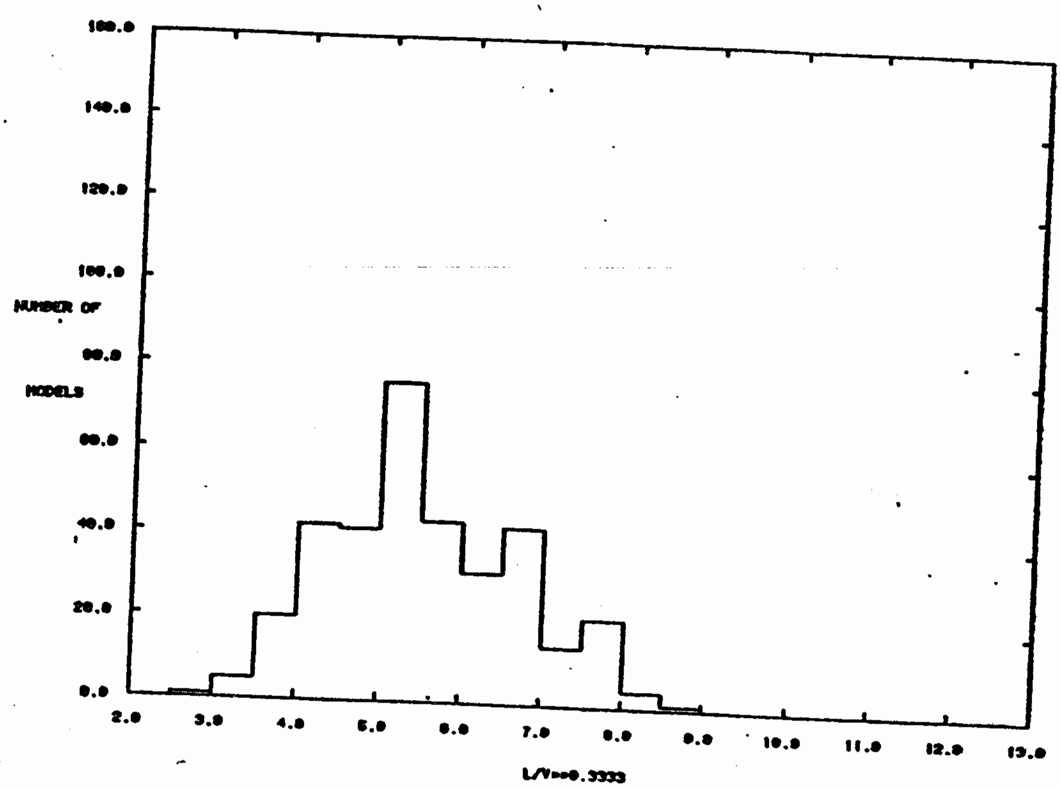


Figure 6 - Distribution of Length-Displacement Ratio

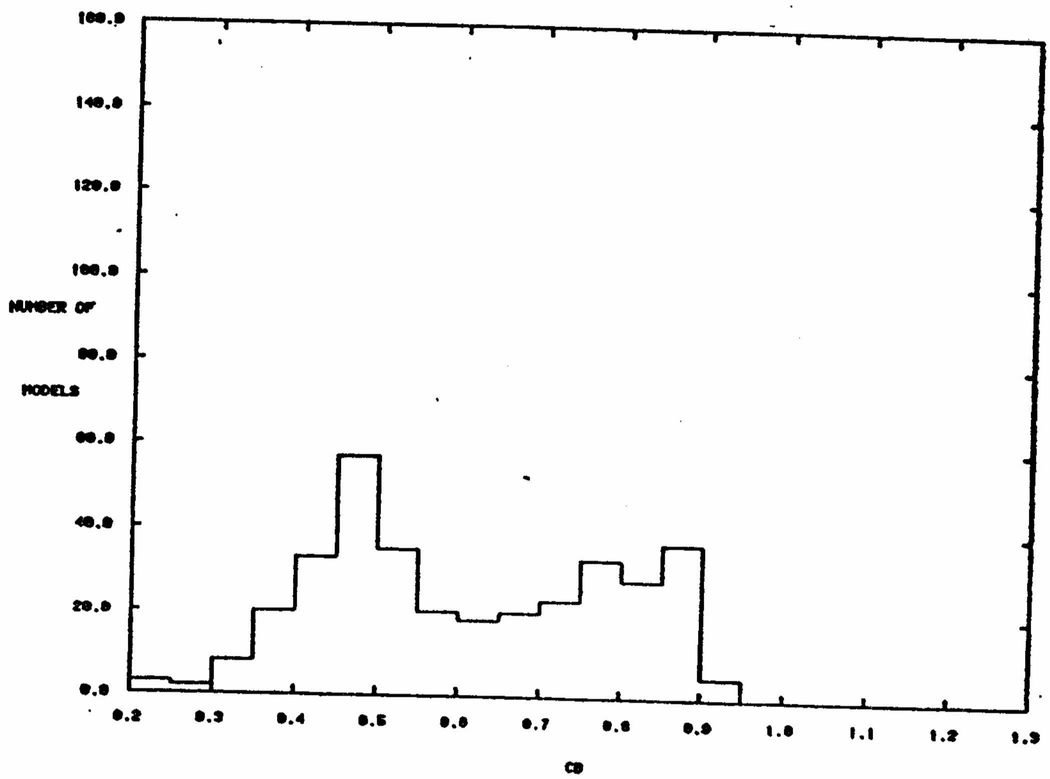


Figure 7 - Distribution of Block Coefficient

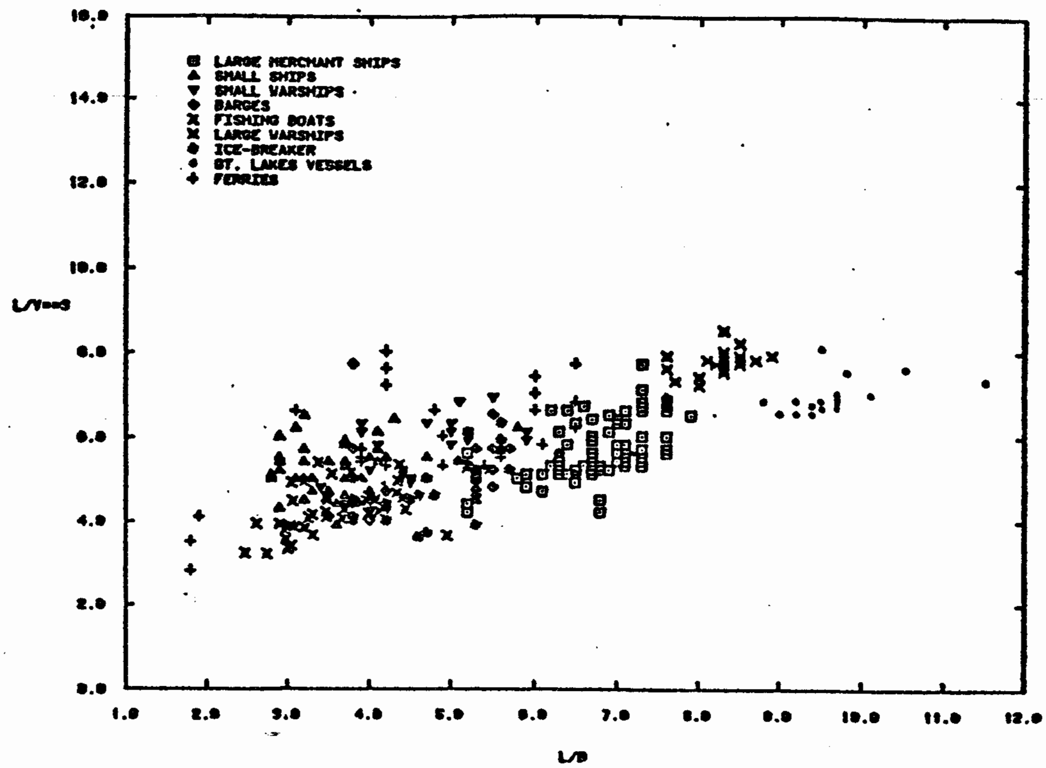


Figure 8 - Scatter Plot - L/∇**3 Against L/B

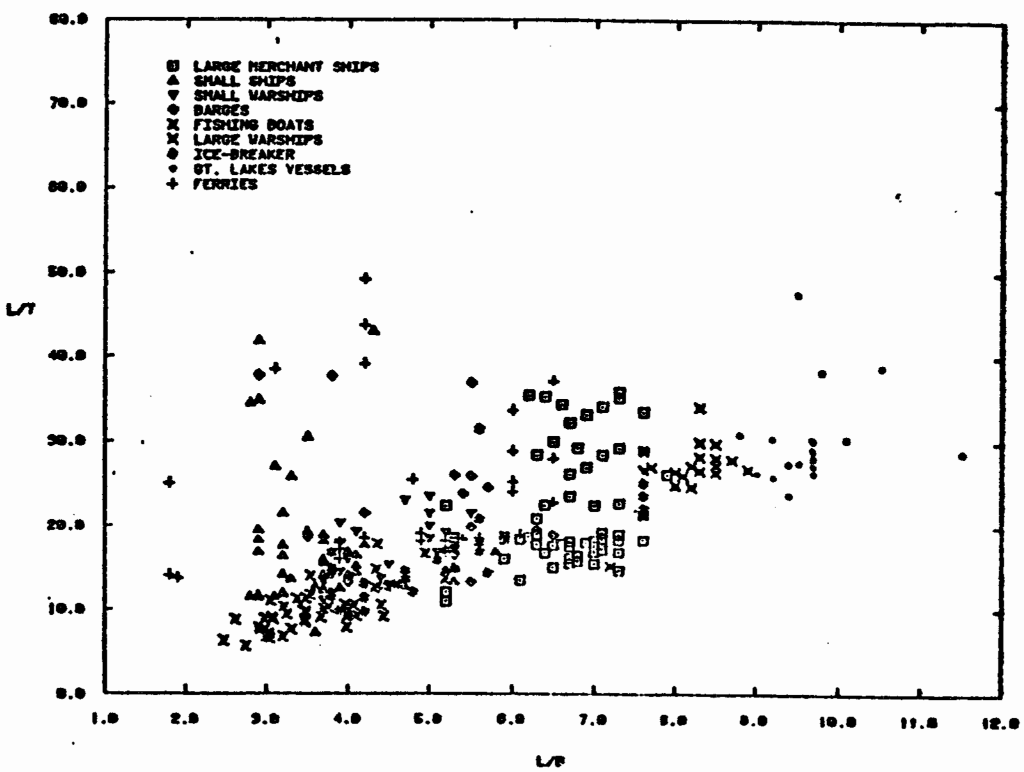


Figure 9 - Scatter Plot - L/T Against L/B

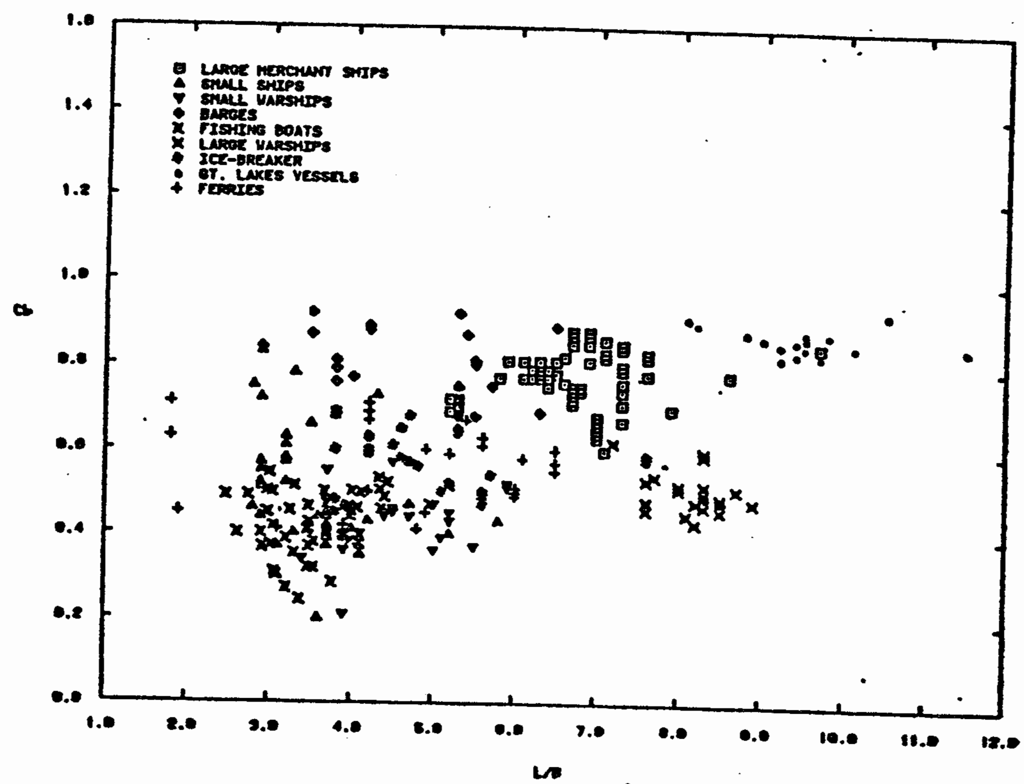


Figure 10 - Scatter Plot L/B Against C_B

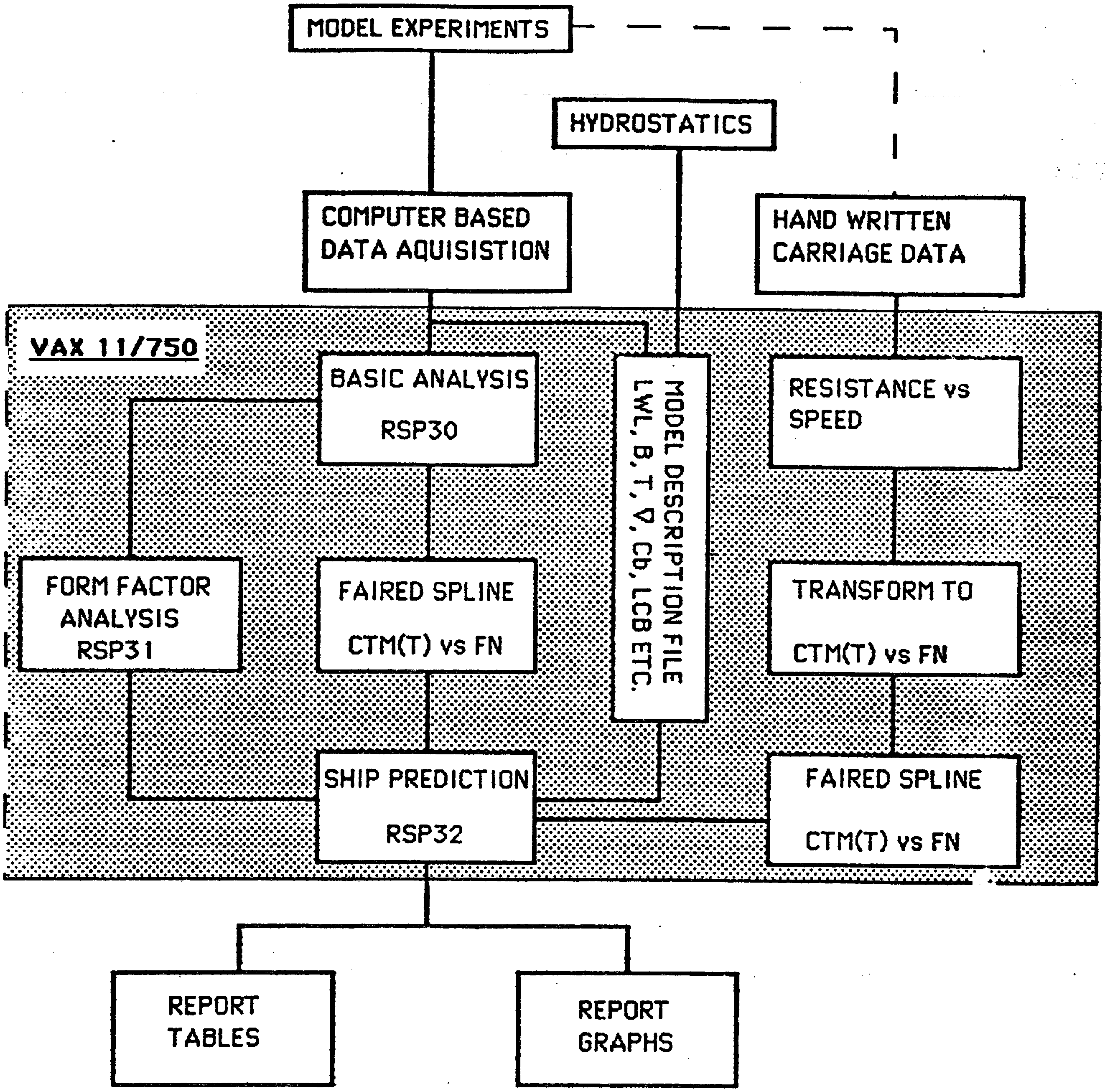


Figure 11 - Analysis of Resistance Experiments

FIGURE 12

MANIPULATION OF RESISTANCE DATA
USING REFERENCE [7]