Model Tests in Support of the Design of a 50 Meter Barque

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ABSTRACT

This paper describes a programme of model tests and computer predictions which was designed to assist in the selection of a hull design for a new ship, and ensure that it would meet the owner's requirements. Whilst that is a common requirement of model tests, this case was unusual because the subject was a 50 metre wooden sailing ship for disabled crews, and a choice had to be made with regard to a wide range of operational requirements.

The paper describes the background to the project, the scope of the testing, the presentation of the results, and their implications for the design. A general outline of the whole project is given, rather than details of specific tests or results, because of the dual limitations of space and confidentiality to the client, Tony Castro Ltd. It is hoped that the paper will provide an illustration of the range of investigations which are now available to assist in the design stages of any sailing vessel.

INTRODUCTION

The Jubilee Sailing Trust, having operated a 41 metre sailing ship for ten years, decided to build a larger wooden ship to increase the opportunities offered for handicapped and able bodied people to sail together. The specific requirements of the project included a comprehensive model test programme to evaluate two alternative designs and compare them with the existing ship. Having conducted model tests, trials and stability studies on their first ship, and having researched sailing vessel stability to develop new regulatory standards, the Wolfson Unit M.T.I.A. were uniquely qualified to conduct the work.

The Trust compiled a Design Basis which detailed their requirements, and the design was developed by Tony Castro Ltd., who commissioned the testing. Following some discussion between the three parties on the range of testing and the number of models to consider, it was decided to compare two designs with the existing ship. The test programme proposed by the Wolfson Unit was designed to address the demands of the Design Basis in all aspects related to the hull and rig performance. It included towing tank tests in calm water and waves, manoeuvring tests, wind tunnel tests of the rig, and computer predictions of stability, sailing performance and seakeeping.

BACKGROUND OF THE ORGANISATION

The Jubilee Sailing Trust is a UK charity which was set up in 1978 with a donation from the Queen's Silver Jubilee Fund. Their aim is to promote the integration of able bodied and disabled people through the medium of tall ship sailing. Their existing ship, Lord Nelson, was completed in 1986. In its first 10 years 11,600 people have sailed on Lord Nelson, and of these 4,670 were physically handicapped, including 1,899 wheelchair users.

PARTICULAR REQUIREMENTS OF THE SHIP FOR DISABLED CREW

The general arrangement must allow for features such as wide aisles and lifts between decks, as in any building ashore designed for disabled use. Additionally, there are problems to be overcome where disabled access conflicts with conventional ship arrangements. These include the desirability of flat decks, rather than decks with a large amount of sheer and camber, and the necessity for clear door openings without high sills.

Good seakeeping is a fundamental requirement of the Jubilee Sailing Trust, in particular they requested a ship with minimal acceleration in pitch and roll, and with a bow design to maintain dry decks.

A wealth of facilities have been developed and fitted on board Lord Nelson to facilitate operation by, and safety of handicapped crew members.

These aspects of the design were not the subject of the test programme but it is understood that they may be of interest to many people, and so they are elaborated on in the Appendix to this paper.

EXPERIENCE WITH LORD NELSON AND AREAS OF IMPROVEMENT SOUGHT

Lord Nelson has proved to be a very successful ship, and the new ship would need to match its performance in all respects. Furthermore, many lessons have been learned during ten years of operation, and in some aspects it was hoped that the new ship might offer some improvements.

The accommodation should be improved by increasing the overall size of the ship while maintaining the number of crew. The desire to build in wood required a further increase in size, the timber structure taking up significantly more space than steel.

The ship should have reduced roll and pitch, and the natural roll period should be longer with the aim that roll accelerations will be reduced.

The directional stability should be greater so that inexperienced crew members will be able to control the ship accurately.

In view of the interdependence of ship characteristics it was understood that some reduction in stability and manoeuvrability might accompany these changes but, provided the sailing performance remained good and an adequate bow thruster was installed, these could be accepted.

OUTLINE OF THE DESIGN OPTIONS

Lord Nelson has a hull which differs from many traditional sailing ships in that it does not have a full length keel. This fundamental feature of the design has been the subject of much discussion, and for the new ship it was a requirement that model tests should be conducted to investigate the relative merits of two alternative forms.

Two hull designs were prepared by Tony Castro Limited. These were designated Alpha, with a full length keel, and Beta, with a shorter keel and skeg hung rudder. Keeping the length, beam, draught and displacement constant, the forms differed principally in their profile shapes. Compared with Alpha, the Beta form had a larger midship section and hence a lower prismatic coefficient, the volume removed from the ends of the keel to reduce the profile area being re-distributed round the hull sections to maintain the same displacement at the design draught.

Above the waterline the hulls were similar, and shared the same superstructure and rig arrangements. The chosen rig was a three masted barque, similar to that on Lord Nelson.

	Lord Nelson	New Ship
Length Overall Including Bowsprit	55.0 metres	65.0 metres
Length Overall	41.2 metres	51.0 metres
Length Between Perpendiculars	37.0 metres	46.1 metres
Beam	8.5 metres	10.1 metres
Draught	4.1 metres	4.5 metres
Displacement Fully Laden	491 tonnes	682 tonnes
Displacement 50% Consumables	446 tonnes	642 tonnes
Maximum Speed Under Power	8 knots	12 knots
Sail Area	1000 metres^2	1200 metres^2

Table 1. Principal dimensions of the new ship compared with Lord Nelson.

TOWING TANK AND MODELS

The tests were conducted at Southampton Institute, where the tank is 3.7m wide, 1.8m deep and 60m long. Models of the new designs were constructed at a scale of 1:25 using wood strip planking sheathed in glass reinforced plastic. They were fitted with moveable rudders to enable representative rudder angles to be applied during sailing performance tests. A 1:25 scale model of Lord Nelson, which had undergone a more limited test programme for the design of that ship, was refurbished and used for comparative seakeeping tests.

The models were towed using a single post system which allows freedom to heave and pitch, but restrains the model in yaw, sway and roll.

RESISTANCE AND SIDEFORCE TESTS

These tests were conducted following the standard Wolfson Unit procedures which were described in a paper presented at the Eighth Chesapeake Symposium "The Interpretation of Results from Tank Tests on 12m Yachts" (Campbell & Claughton, 1987). Measurements were made of resistance, sideforce, yaw moment, roll moment, heave and trim.

The models were tested upright, at speeds of 4 to 16 knots, to obtain data relevant to sailing directly downwind or motoring upwind.

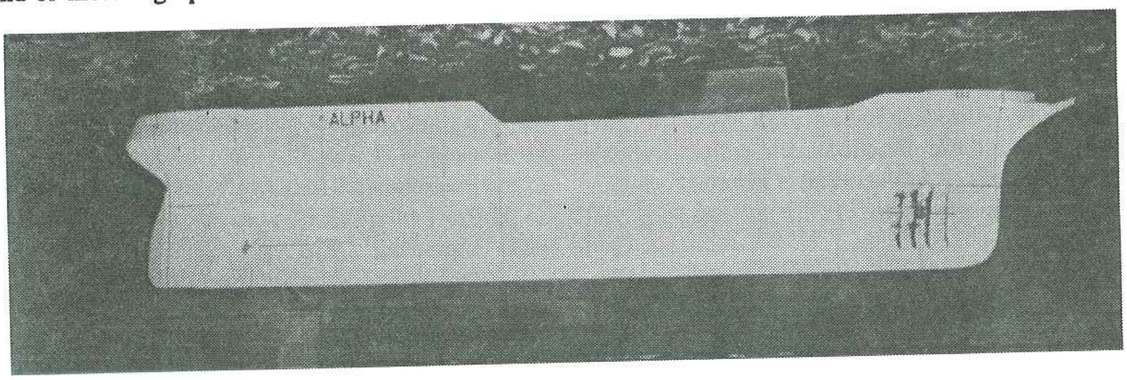
To obtain a force matrix for sailing performance predictions, the models were tested at heel angles of 10, 15 and 20 degrees, and speeds of 7, 10 and 12 knots. In each case a range of leeway angles was tested in order to determine the sailing sideforce, and a range of rudder angles to determine the effect of helm on the centre of lateral resistance (CLR).

The tests confirmed the expectation that the greater wetted surface area of Alpha would result in higher resistance at low speeds, and they proved their value in determining the less predictable residuary resistance, and the relative efficiencies of the two hulls at generating sideforce.

SEAKEEPING TESTS AND CALCULATIONS

As good seakeeping was one of the prime requirements of the new ship, this study was more detailed than would normally be the case for a vessel of this size. To address the Trust's concerns the Wolfson Unit proposed to study the motions and their affect on the crew's ability to work and move about the ship, the likely incidence of seasickness, and the probability of deck wetness in seastates which are likely to be encountered frequently in the proposed areas of operation. Predictions were required for a range of headings, with the ship motoring or sailing.

Ship motion measurements were conducted on all three



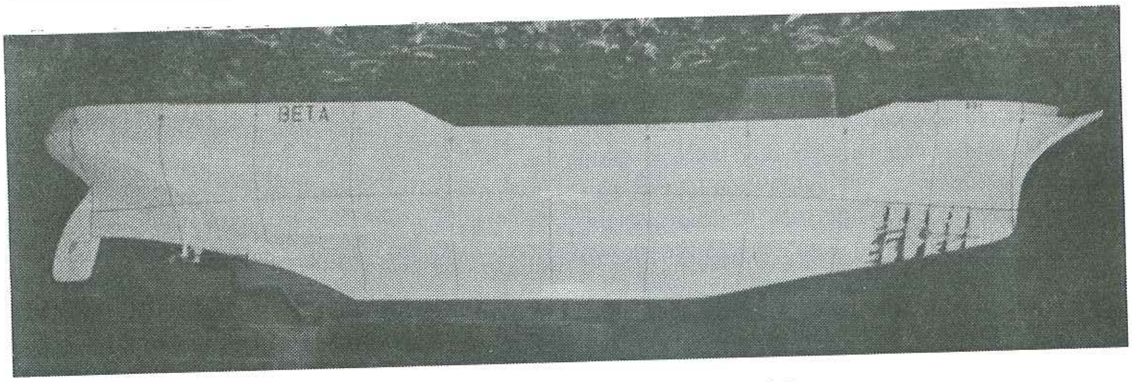


Figure 1. Photographs of the towing tank models

models. Because testing in the towing tank is restricted to head seas, the Wolfson Unit's seakeeping prediction programs were to be used to extend the seakeeping data to other headings. The testing and analysis techniques used at the Wolfson Unit were the subject of the paper "Motions of High Speed Vessels and their Affect on Passengers and Crew" (Campbell & Weynberg, 1993).

Head Sea Tests

The models were ballasted to match the estimated pitch inertia of the ship. They were towed in a number of representative seas states, upright to represent motoring into head seas, and heeled and yawed to represent sailing conditions. Measurements were made of resistance, heave, pitch, and vertical accelerations amidships and forward. A video recording was made to enable careful observation of the incidence of bow emergence and deck wetness.

To investigate typical sailing conditions, sea spectra typical of those found in coastal waters were chosen, with waves of 2 and 3 metres significant height, that is seastates 4 and 5, and with mean wave periods of 5.5 and 7 seconds respectively. To obtain comparable data, Lord Nelson was tested at the same Froude number as the new designs.

RAO Calibrations

In order to calculate ship motions in a particular seastate, the response of each parameter of interest is first calculated for a range of wave encounter frequencies. Non-dimensionalised with respect to wave height or slope, these functions are called response amplitude operators (RAO's). These may be combined with any wave spectrum to obtain the resulting ship motions.

To refine the accuracy of the computer predictions, a calibration of the calculated responses was carried out using equivalent measured data. Additional model tests were conducted upright in regular waves to enable a direct comparison of the measured heave and pitch RAO's with those derived from computer calculations. Figure 2 shows an example of the model data and calculated data, and it can be seen that there is good agreement between them. A calibration curve was applied to the calculated RAO data to improve the correlation, and the calibrated RAO curves are shown on the same figures. These calibrations were only measured in head seas, but it was assumed that they would also be representative at all other headings and speeds, provided they were applied on a wave frequency of encounter basis.

Measurement of roll period

The natural roll period of a ship is dependant upon the metacentric height and the roll radius of gyration. Since the roll inertia of a floating body includes added inertia of water entrained around the hull and appendages, the radius of gyration does not correspond exactly to the radius of gyration of the solid body, which may be calculated from weights and centres.

$$\text{Roll period} = 2\pi kc/(g\ GM)^{1/2}$$

where k is the radius of gyration in roll, and c is a constant which is dependant upon the hull form and appendage arrangement. GM is the transverse metacentric height, and g is acceleration due to gravity.

With such different keel arrangements, it was expected that the two designs would show substantial differences

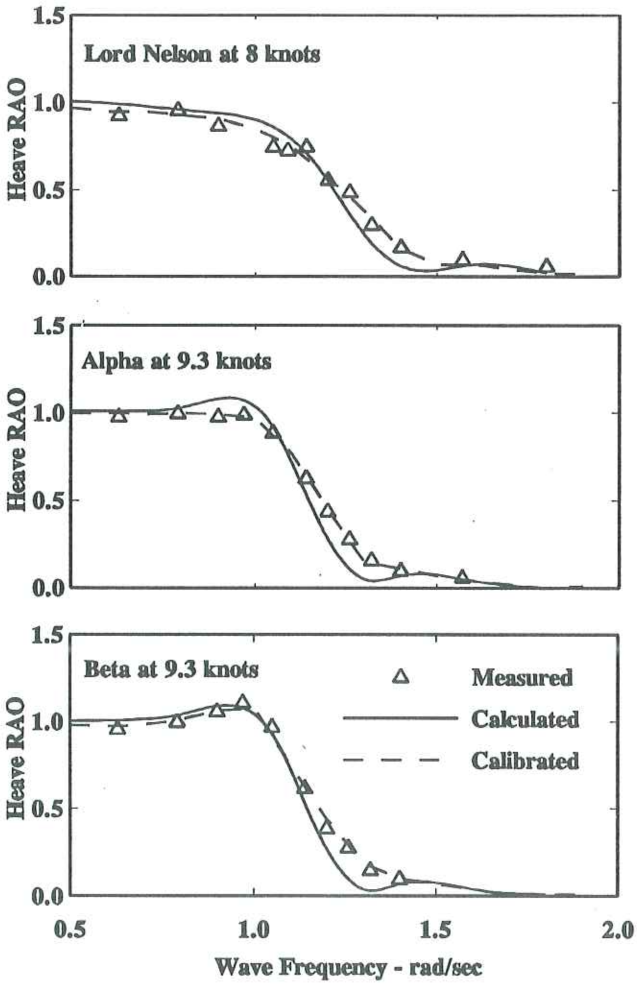


Figure 2. Comparison of measured and calculated vertical responses.

in their added inertias, and it was considered important that the values be measured for input to the computer model.

The towing tank models were used to measure the variation of roll period. Each model was ballasted to the appropriate displacement and centre of gravity, and its roll inertia, which was measured by swinging it out of the water as a compound pendulum, was adjusted to correspond to the calculated value. The models were then timed rolling freely in calm water in the towing tank.

An independent roll test was conducted on board Lord Nelson by the crew, albeit with some difficulty experienced in obtaining sufficient roll motion, and the roll period was found to be approximately 9 seconds. This compared well with the value derived from the model of 8.8 seconds, and the measured roll periods therefore were used with confidence as an input to the computer predictions.

Calculated Motions

The computer programs take no account of the roll damping that is provided by the sails, however, since the aim of the results was to compare vessels with the same rigs, this was not considered to be a problem.

The motions of the three vessels with respect to each other were compared on five bases: roll angle; transverse deck acceleration; motion sickness; vertical acceleration; and deck wetness. Since the motion parameters are influenced by the absolute motion of the vessel and the location on the vessel, it is possible to have a vessel with greater motions than another, but to have a lesser affect on the crew by siting the working or relaxing areas in different parts of the ship. The comparisons were therefore made for seven identifiable locations in the arrangement of each ship, for example the wheelhouse, the forward berths, the galley, and the fore topsail yard, as well as at three stations, 5, 1 and 0 (forward) to enable a comparison of the absolute motions. The comparisons were made at five headings in the two seastates, and an estimate was made of the likely speed of the vessel in each case.

A typical result is presented in Figure 3, for the deck acceleration in the wheelhouse of each ship. This is the lateral acceleration, resulting from a combination of roll, sway and yaw, plus the athwartships component of acceleration due to gravity at the associated roll angle. It is a measure of the propensity for objects or people to slide or tip. The results show considerable differences between the ships in some conditions, which in this case are predominantly due to differences in natural roll period and roll damping. The smaller Lord Nelson has a shorter natural roll period which is close to the predominant wave period in seastate 5, and its roll motion is therefore high in beam seas. The other designs will roll less in response to that wave frequency. In the shorter waves of seastate 4 the natural roll period of Lord Nelson is similar to the encounter period in quartering seas, and the deck accelerations are relatively high at that heading. Alpha and Beta will have higher natural roll periods because of their lower GM values and higher roll inertia, and will be excited less by the wave periods considered. The deck accelerations on Beta will be greatest in quartering seas in the long waves of seastate 5, but Alpha's long keel causes a substantial increase in the added roll inertia and damping, and moves its natural roll period further from the encounter period in the seastates examined.

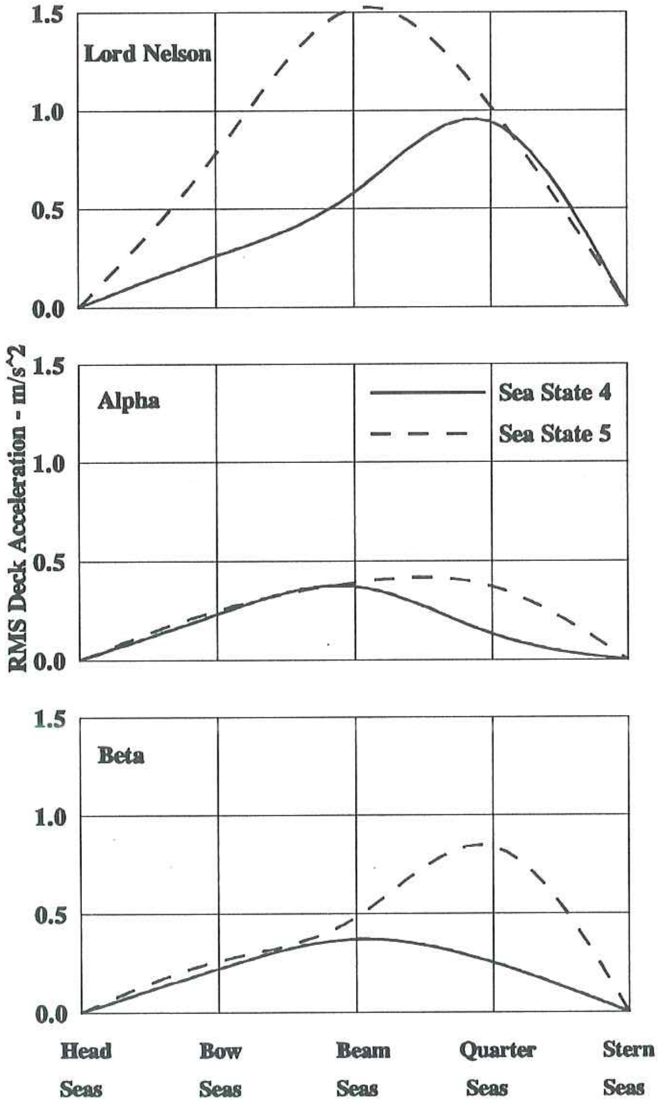


Figure 3. Deck acceleration in the wheelhouse.

Similar comparisons were made for the other aspects of seakeeping. The seasickness predictions were calculated according to a British Standard, for a mixed population of unadapted adults, research having shown that women are more prone than men, and that susceptibility reduces for experienced crew. No work has been done on whether handicapped people are more prone to seasickness than others and, since these predictions largely were for comparative purposes, any differences would be unlikely to alter the conclusions. It was interesting that the differences between the three ships were small in relation to the differences between various locations on the ship, thus highlighting the importance of the arrangement on the perceived comfort of the vessel.

The computer programs are a powerful tool in that they enable a large number of factors to be taken into account. They frequently produce some unexpected data which prompt careful consideration of the reasons behind them, and thus result in a better understanding of the relative merits of various features of the design.

WIND TUNNEL TESTS

The method of wind tunnel testing described in a paper presented at the Tenth Chesapeake Symposium "Model Test Techniques Developed to Investigate the Wind Heeling Characteristics of Sailing Vessels and their Response to Gusts" (Deakin, 1991) was developed further in subsequent years and is elaborated in the paper "Wind Tunnel Testing of Sailing Yacht Rigs" (Claughton & Campbell, 1994).

Tests were conducted in the low speed section of the University of Southampton no.1 wind tunnel which has dimensions 4.6m wide by 3.7m high.

Because the two designs were virtually the same above the waterline, a single hull and superstructure model was constructed and outfitted with the proposed rig at a scale of 1:30. The model rig included all of the spars and platforms, and the principal stays and shrouds. The correct yard pivot and shroud geometry are important for a square rig model to ensure that the correct yard bracing angles can be achieved. The sails were manufactured by a sailmaker, using normal sailmaking techniques, with a cloth which would maintain the required sail shape at the wind speed used. Because the model is tested on one tack only, the sail controls can be simplified, with only the windward braces to the yards, and the leeward sheets to the headsails and staysails required.

The braces and sheets were led to electric winches mounted on the deck, and were adjusted from the wind tunnel control room under the guidance of members of the crew of Lord Nelson. The model was mounted on a six component balance connected to a computer in the control room. Using a screen display of the forces it is possible to monitor, say, the driving and heeling forces while adjusting and observing the sails, and hence optimise or ease the sail settings as required.

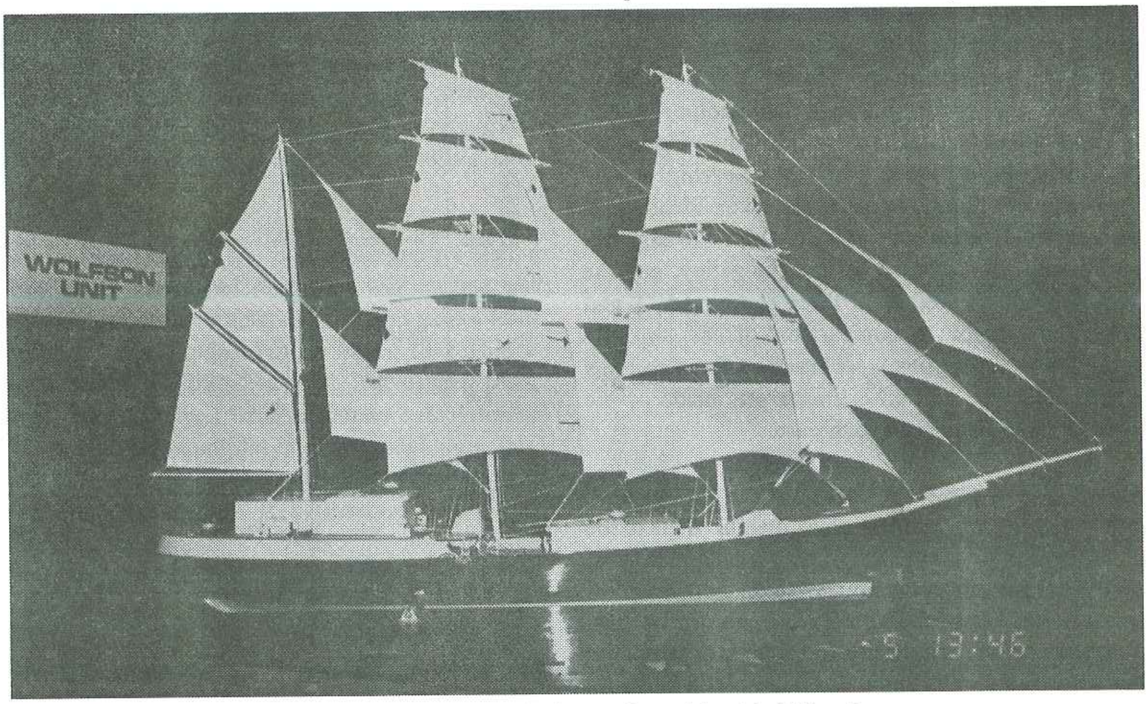


Figure 4. Photograph of the wind tunnel model with full sail set.

The objectives of the tests were:

1. To obtain sufficient data for input to the sailing performance prediction software with a number of sail configurations suitable for a range of different wind speeds and headings.

2. To determine the longitudinal centre of effort for the purpose of ensuring good helm balance, and to investigate the extent to which it might be controlled by the variation of sails set and their sheeting.

3. To measure the basic hull and rig windage, albeit without the inclusion of all the standing and running rigging, to assist predictions for powering to windward.

4. To highlight any problems of interference between sails and other rig components, and to examine alternative sheet leads.

5. To enable the designer and crew to investigate the relative merits of alternative sail sets, or sheeting variations.

Figure 5 shows two examples of lift and drag coefficient data, for the full sail plan, and for a sail plan suitable for use in gale force conditions. The full sail plan has about three times as much sail area as the storm sail plan, and the latter is dominated by the windage of the ship and its spars. As sail is reduced the area of the ship and its rigging constitutes a greater proportion of the total, and the lift/drag ratio, or efficiency of the rig, reduces.

In common with other clients who have witnessed wind tunnel tests on rigs, the crew were impressed by the value of the tests, in particular with respect to items 4 and 5 above, which are often perceived beforehand as a very minor aspect of the work.

The skipper of Lord Nelson noted a number of benefits which he found of particular interest:

1. The ability to determine the relative forces at different points of sailing, for example in this case the maximum driving force was obtained at apparent wind angles of 100 to 120 degrees, depending upon the sails set.

2. The ability to quantify instantly the effect of trimming the yards and sails on the driving force and balance of helm.

3. Observation of the probable leads of the main and fore course tacks and sheets when close hauled.

4. Investigation of the efficiency of the tween-mast staysails, their interference with the airflow over the square sails, and how their influence is affected by trimming of the yards at different headings. This is a regular point of discussion on board Lord Nelson, since the square sails provide the main driving force, and it is unclear whether setting the staysails is always a benefit. In fact the tests showed that the tween-mast staysails do provide additional drive, except on downwind headings when they become blanketed by the square sails.

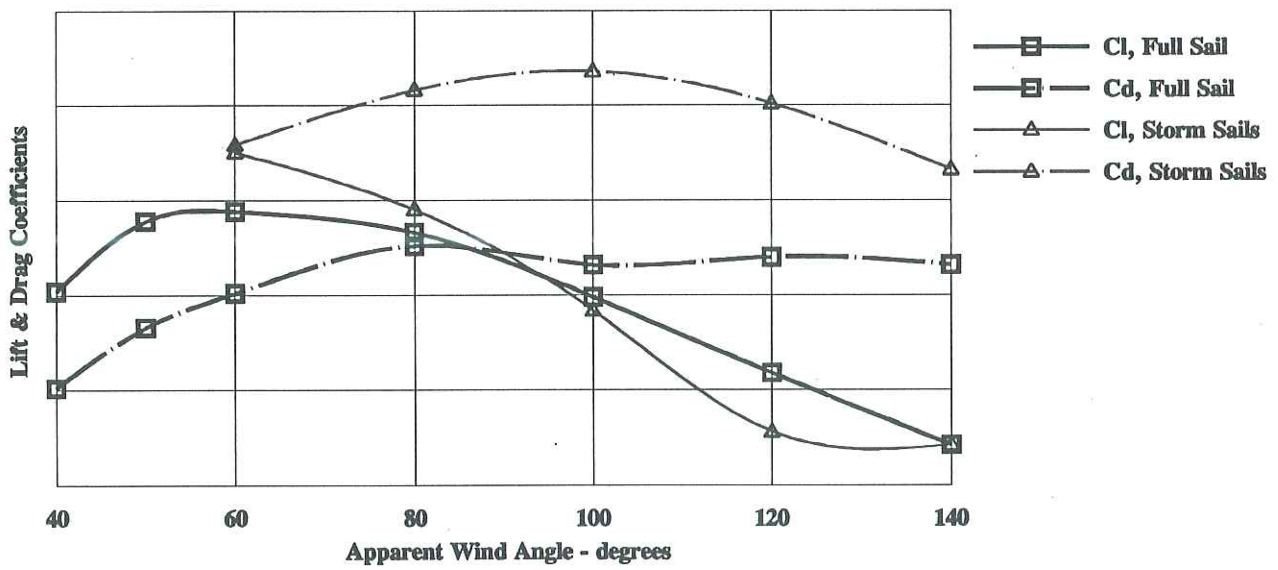


Figure 5. Examples of lift and drag coefficient data from the wind tunnel.

SAILING PERFORMANCE PREDICTION

The sailing performance was calculated using the Wolfson Unit's Velocity Prediction Program (VPP), WinDesign. Aerodynamic force data for various sail combinations were combined with stability data and hydrodynamic force data for the two hull designs. Additional considerations were the windage of the rigging components not modelled in the tests, the added resistance in waves, and the propeller resistance.

Since the rig tested was very similar to that on Lord Nelson, the same aerodynamic force coefficients were used, following adjustments for rig height and sail area. Resistance and sideforce data for Lord Nelson were on file from tests conducted during its design phase.

Polar plots were prepared for the three vessels, with equivalent sail sets, in a range of wind speeds. These data put into perspective the various differences which had been measured in the towing tank, enabling their effects on the ship operation to be quantified.

The long keel of Alpha proved valuable in reducing leeway and hence improving performance to windward, although its higher wetted area reduced its downwind performance in comparison with Beta.

The calculations also highlighted the dependence of sailing performance on good stability. If a ship of this type cannot carry a large sail area it will not have sufficient power to overcome the substantial windage.

MANOEUVRING TESTS

The directional stability of Lord Nelson under power had been measured during its commissioning period by the Wolfson Unit. Dieudonne Spiral manoeuvres were carried out under motor power alone, and in principle are very simple. Since it is necessary to measure the rates of turn with low rudder angles however, to conduct successful trials on a sailing ship requires very calm conditions in order that the high windage of the rig does not affect the results. They also require sufficient sea room to complete large diameter turns without fear of obstructing other vessels.

Greater directional stability was a requirement of the new design, and self propelled, radio controlled models were used to obtain comparative data. Because of the scale effect on the wind, very calm conditions are required for model tests, but since there is no need for the rig to be fitted, the models are less prone to disturbance in that respect. The measurements are made with the vessel performing a steady turn and so it is not necessary to scale the rudder rate, the yaw inertia, or to provide independent control of the propellers.

The towing tank models of the two new designs were outfitted with shafts, brackets and propellers. In each case a single electric motor was used to drive both the port and starboard propellers, via a toothed belt arrangement to ensure identical rotational speeds. The rudder was controlled by radio, and was carefully

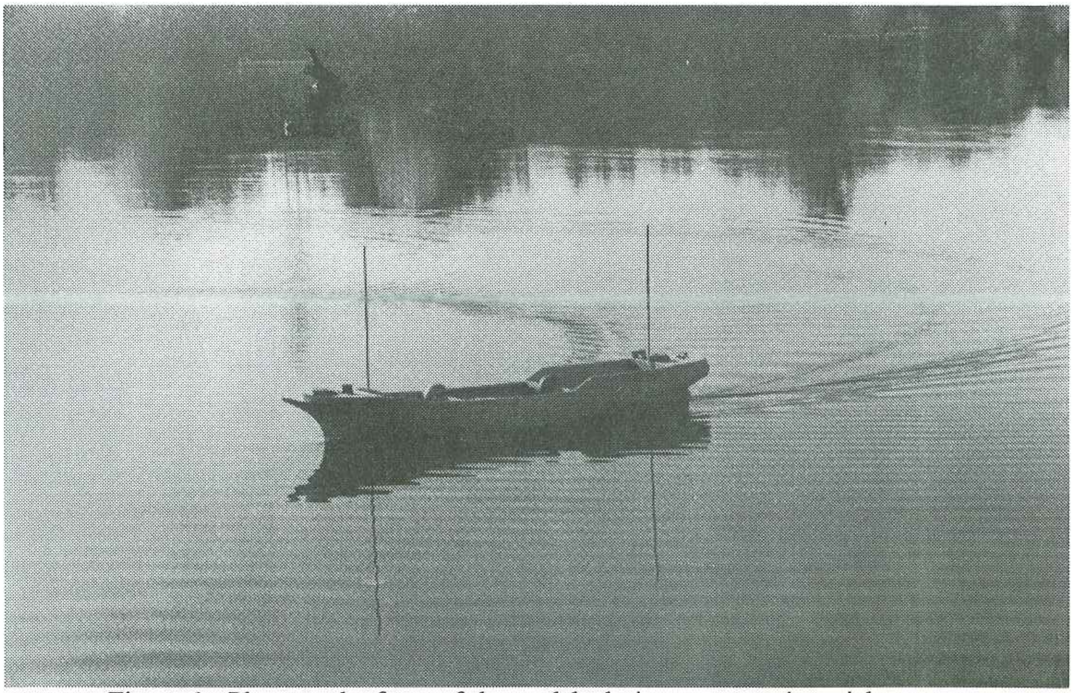


Figure 6. Photograph of one of the models during manoeuvring trials.

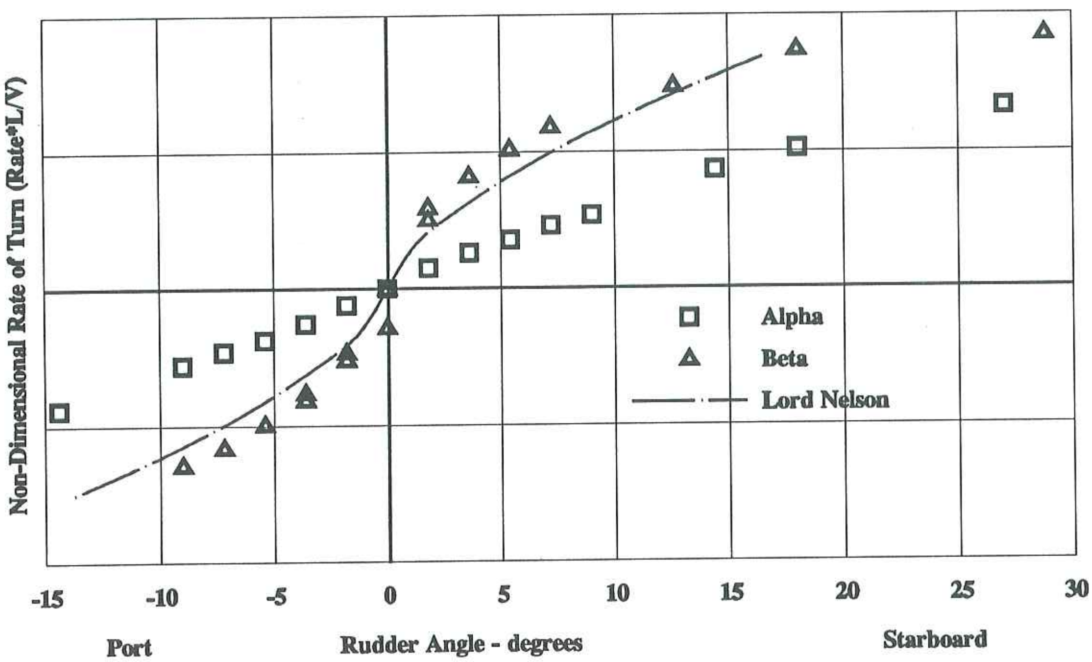


Figure 7. Comparative manoeuvring data for the three hulls, from model tests and trials.

calibrated to enable known rudder angles to be selected. The models were tested on a large outdoor manoeuvring pond where their rates of turn could be measured with a range of rudder angles set.

The tests at model scale are very straightforward, given calm conditions, and produce representative and reliable data. The results for Beta compared closely with those obtained at full scale on Lord Nelson, which has a similar underwater profile. As one might expect, it was in the results of these tests that the differences between the two designs were most distinct. The long keel of Alpha provides very high directional stability, and thus good control, but brings the penalty of a large turning diameter.

INTACT AND DAMAGE STABILITY

The stability was assessed by the Wolfson Unit at several stages of the design, as the hull form, deckhouse arrangement and weight estimates were developed.

The intact stability was calculated and assessed for compliance with the UK standards for commercial sailing vessels. The damage stability, assuming one compartment flooding, was calculated, using a definition to the inside of the 75mm thick wooden hull as the volume available for flooding. It was assessed for compliance with the UK passenger ship regulations.

INFLUENCE OF THE RESULTS ON THE DESIGN

The results enabled the Alpha design to be chosen with the confidence that it would enable the Design Basis requirements to be met, and would offer better performance than Beta in several aspects of the operation.

The importance of stability was highlighted during the seakeeping and sailing performance studies, and as this is an item affected by all elements of the design, it will be particularly important to monitor it throughout design and construction.

The damage investigation had a major influence on the location of bulkheads and the freeboard requirement, the main deck sheer being governed to a large extent by the damage floatation requirements. The stability calculations were necessary to show the maximum permissible centre of gravity height, from both the regulatory point of view, and for adequate sailing performance.

The design continued to develop after completion of this study, and the results had much influence, particularly on the rig design. Most importantly, the findings provide an insurance that, provided the design does not stray far from that tested, the ship will be a great asset to the Trust and fulfil their requirements admirably.

PROBLEMS OF INTERPRETATION

The three organisations involved in this programme had very different backgrounds and experience. The Jubilee Sailing Trust staff included a number of people with tall ship sailing experience, but none with experience of sailing ship design, while Tony Castro was very experienced in the design of smaller racing and cruising yachts. The Wolfson Unit staff combined limited experience in those areas with an understanding of the technical aspects of the test techniques and interpretation of the results. Much discussion was therefore required in order that all parties might appreciate the full implications and limitations of the test results.

The subject of helm balance was an example of an aspect which led to considerable debate, the wind tunnel results apparently suggesting rather different sheet settings to those commonly used on Lord Nelson in order to maintain good balance.

Rig windage was another area which caused some concern, with the wind resistance being very difficult to predict accurately, whilst contributing a major component of the total resistance in the important case of motoring into a head wind.

Attempts were made to quantify these effects with the aid of the test results and with trials data from Lord Nelson, and the sea trials of the new vessel are awaited with interest by all parties.

ACKNOWLEDGEMENTS

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APPENDIX
SPECIAL FACILITIES FOR DISABLED CREW

The new ship will have crewing arrangements similar to Lord Nelson, where a permanent able bodied crew of 11 operate the ship together with a voyage crew of 40, about 40% of whom are disabled. Up to 8 of the disabled crew can be wheelchair users. Severely disabled crew members are 'buddied' by an able bodied person.

Access is the predominant factor which influences the arrangement of the ship. Crew members who are blind, and those in wheelchairs, must have ease of access to as much of the ship as possible in order that the principle of equality for disabled and able bodied voyage crew can be maintained.

The sheer and camber must be limited, the former giving rise to a conflict with the damage floatation requirements and the latter with the provision of space below the deckhead for running services. The main accommodation deck needs to be continuous through the ship, and so watertight bulkheads are provided with sliding watertight doors which can be operated locally or from a central damage control position. Conventional high door sills would be an impossible obstruction, and a 'waterlock' system of two doors with a self draining lobby between them is used at all deckhouse access doors, which are located near the centreline to maximise their downflooding angles. When at sea only one door of each pair may be opened at any time, an alarm system being used to indicate any breach of this rule. The doors have no permanent sills, but portable sills are available for use in severe conditions, and access to the bridge is possible without going on deck.

The stairs between decks are inclined at a lower angle than is usual on a ship, and tactile surfaces at the tops alert blind crew to their presence. They are provided with seat lifts, operated by the user, for those with limited mobility. Blocks and tackles are also permanently rigged on the stairs to assist wheelchair users in the event of an emergency.

Vertical lifts between decks have no doors, and could give rise to problems of smoke invasion between decks. They are therefore arranged within a lobby with a fire door connected to the fire control system.

The need for wide alleyways below decks has some influence on the structure, where a deep web frame might be preferred but an alternative solution must be found. On deck the requirement for wide side decks forces shrouds as far outboard as possible, and careful consideration needs to be given to the siting of deckhouses, since large open deck spaces would be hazardous for people with various disabilities. The bow sprit incorporates a platform and railings so that wheelchair users can go forward to view the stem cutting the water. The side decks are fitted with raised guidance tracks to help the visually impaired remain central, and tactile pointers around the handrails indicate the direction of the bow and stern.

Throughout the ship there are fixing points to secure wheelchairs during rough weather.

The gangway is wide with battens only at the centre and, on the new ship, will incorporate a hinged upper portion so that the top does not terminate above the deck. Evacuation at sea would be via aircraft style chutes, directly into open reversible rafts.

The courses and lower topsails are rigged for conventional stowing on the yards, but the upper topsails, topgallants and royals are furled within hollow aluminium yards, to reduce the requirements for crew to go aloft to the upper yards. The running rigging is designed with reduced individual loads for ease of handling, and hydraulic steering makes it easy for those with little strength to take the helm.

Special features for the visually impaired include signs in braille, bright red and white colour schemes in the washrooms, a bright track radar screen, and a speaking audio compass with a digital display. For those with hearing impairment there is an induction loop in the lower mess deck to facilitate briefing sessions, and vibrator pads in the bunks alert them in the event of an emergency.

The washrooms incorporate basins which can be raised or lowered, lever taps, seats and plenty of hand holds in the showers, and close-o-mat lavatories.

Some of the ship's systems are specifically upgraded, such as the air conditioning system, which includes a substantial provision for heating the accommodation.