Model tests steer development of a new lifeboat hull

The RNLI's new hull development programme is set to pave the way for a new generation of safer and faster rescue boats. Barry Deakin, an engineer at the Wolfson Unit for Marine Technology at the University of Southampton, describes the model test contribution to the programme.

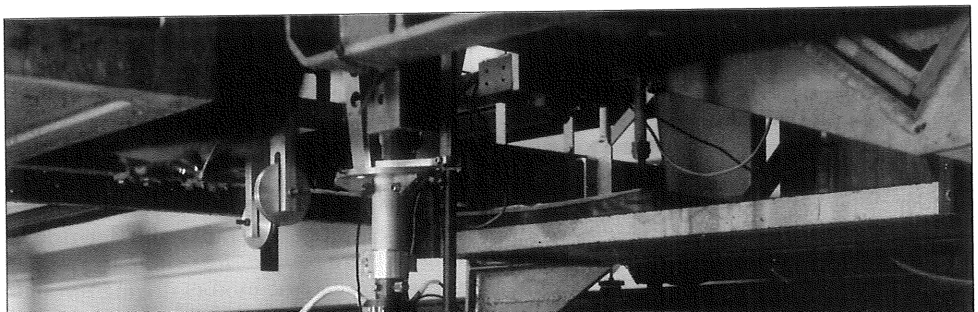
A new generation of fast rescue boats is being designed by the Royal National Lifeboat Institution (RNLI). They will be required to operate at up to 25 knots from the lifeboat stations with slipway launching facilities, where mooring in a sheltered harbour is not possible. The boats have to meet extremely high standards, being operated by volunteer crews in severe sea conditions, and the RNLI required reliable evidence that their design was not lacking in its operational characteristics. To achieve this, they commissioned an extensive programme of model tests, including detailed investigations of resistance, propulsion, seakeeping, rolling and manoeuvring, during their preliminary design phase.

Initially six hull designs, denoted H1 to H6, (see next page) were produced by the RNLI, with a length of 15m and a beam of 5.2m, to fit comfortably within the existing boat houses. The possibility of either water jet or propeller propulsion was under consideration. H1 served as a reference design, being based on an existing lifeboat, with deep, square propeller tunnels. H3 and H4 were variants of H1 which were not tested. H6 was a rigid inflatable form suitable for water jet propulsion. The other two were H5, with a constant deadrise, and H2, a warped bottom form, both without propeller tunnels.

The constant deadrise hull was modified, and extended in length by 10 per cent, to produce a fifth model, H5-2, and then H7 was produced following initial testing on the first models.

It was tested in two configurations, one suitable for water jets and the other for propellers in simple, semi-cylindrical tunnels.

A 1:10 scale model during resistance tests in the towing tank using the Wolfson Unit's comphrehensive system.



A further design, H8, was developed as a hybrid incorporating some successful features of the others, and again was tested in jet and propeller versions. The latest design, H9, was based on H8, extended in length, and tested with four subtly different propeller tunnel variations. The tunnels were shallower, and with a wider entry, than those of H7 and H8.

All designs were based on a nominal displacement of 28t. To ensure complete protection of the propellers and rudders during launch, recovery or on grounding, the tunnel hulls incorporated a deep centreline keel and bilge keels.

The 1:10 scale models were towed in the tank using the Wolfson Unit's standard system. This comprises a single free to heave tow post, and a fitting in the model which enables freedom in pitch, adjustment of yaw and roll angles, and measurement of resistance, sideforce, yaw moment, roll moment, pitch and heave. With the addition of two accelerometers, this comprehensive system incorporated all of the transducers necessary to enable all of the captive tests to be conducted using a common set up.

Differences in resistance

The resistance tests served as a good illustration of the value of investigating a comprehensive matrix of LCG values, trim tab angles and speeds to determine optimum configurations. Data presented in Figure 1 reveal that differences in resistance between the first models, H1 to H6, were in excess of 10%, and it was clear that a worthwhile improvement could be made over the base design, H1.

Models H2, H5 and H6 did not allow for the protection of propellers and, as jet propulsion became the less favoured option, propeller tunnels were introduced into the subsequent designs. The first tunnels on H7 and H8 were of simple semi-cylindrical form, which introduced resistance penalties of ten per cent or more compared with the versions configured for water jet propulsion, which had similar low resistance characteristics to those of H5. Following disappointing resistance results on H8, a paint flow visualisation test was conducted to investigate the tunnels. This revealed poor flow in the tunnel top in the vicinity of the propeller, and strong curvature of the flow at the elliptic tunnel entry. As a direct result of this simple test, the tunnel entry was altered, and the depth of the tunnels reduced.

The hulls were heavily loaded, with a displacement of 28t on a waterline length of less than 14m, and H5-2 demonstrated the desirability of an increase in length without an attendant increase in displacement. As a result of these data, H9 was designed with a length increase of seven per cent, the maximum possible within the constraints of the boat house envelope.

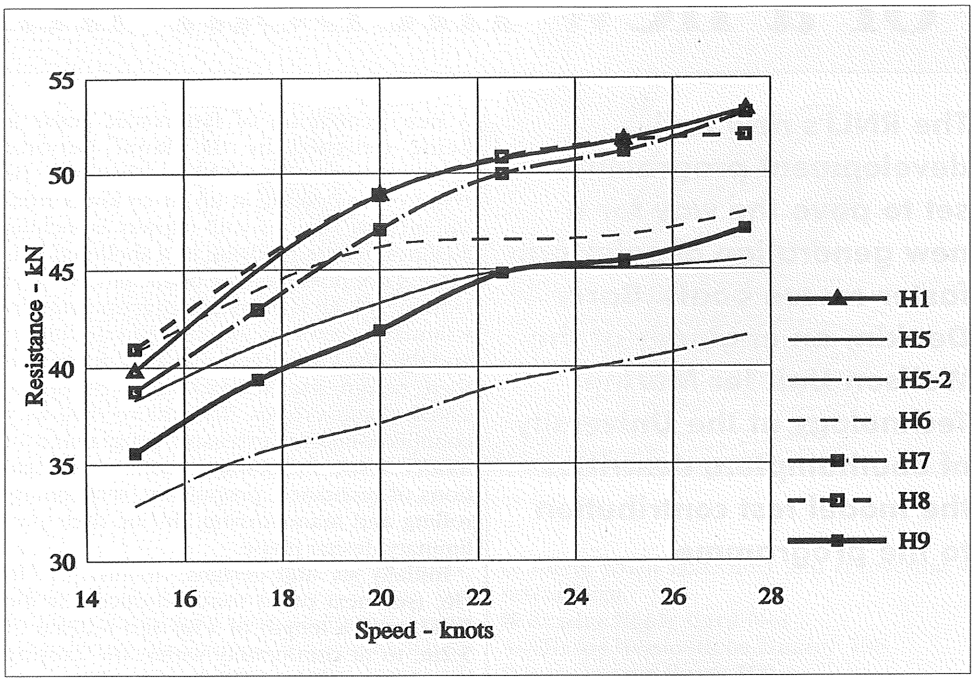


Figure 1: Variation of resistance with speed. Curves with symbols indicate models with propeller tunnels - differences in resistance between the first models, H1 to H6, were in excess of 10 per cent and an improvement could be made of the base design, H1.

The 1:10 scale models were too small to fit stock propellers and associated dynamometry for propulsion experiments, so a 1:6 scale model of H9 was built for this purpose.

This confirmed that the developed hull form would require substantially less installed power than the base boat to achieve the required speed. Further flow visualisation tests were conducted on four tunnel variants used on this model, and these assisted in the selection of the final tunnel configuration.

A requirement for oil lubricated shafts resulted in large diameter stern tubes, and these were to be supported by bossings within the tunnel. This arrangement gave further cause for concern regarding the probable non-uniformity of the wake, and wake survey tests were suggested as the preferred way to quantify any potential vibration problems.

Conventional tests with a stationary pitot rake, collecting data for, say, five locations in the propeller disc per run, would have involved considerable investment in towing tank time, which was difficult to justify. A prototype system was devised, incorporating five miniature pressure transducers fitted at the open ends of tubes and arranged along the propeller radius in a rotating rake. The frequency response of the transducers, and their location in the plane of the propeller, enabled the rake to be rotated slowly through a complete revolution during the course of a single run in the towing tank, and the complete wake survey could thus be derived from one run.

Sample data from one run are shown in Figure 2 on page 13. The transducer in way of the propeller tip produced a curve showing a considerable reduction in the dynamic pressure in the top of the tunnel, while the transducer near the hub revealed a generally smaller reduction in pressure except in the wake from the stern tube and its bossing. These curves can be integrated to derive the wake fraction, a value which has a major effect on propeller selection, and they reveal variations in the wake which may lead to propeller induced vibration.

Static margins

Oblique tow tests, towing each model at different yaw angles and measuring the side-force and yaw moment, were used to obtain the static margin between the longitudinal centre of gravity, LCG, and the centre of lateral resistance, CLR.

Previous work on RNLI lifeboats had shown that boats had directional stability despite the CLR being ahead of the LCG by some margin. This static margin was therefore used as one of several criteria to assess the potential directional stability of the different hull forms.

To assess seakeeping performance, each model was tested in the towing tank over a matrix of seastates, with waves up to 2.5m significant height, at speeds up to 25 knots. The model motions were compared, and the raw data from the two accelerometers and pitch angle transducer were analysed to yield the incidence of seasickness, the discomfort levels and hand control levels. These data were analysed as laid out in BS 6841:1987. A summary of the human factors data was shown, with negligible difference between the hulls, but does illustrate the strong relationship between seasickness incidence and wave height. These data were found to be virtually independent of speed.

During tests on the first four models it became apparent that two of the hulls were particularly prone to deck wetting, while H1 performed relatively well. In developing subsequent hull forms, the bow lines, particularly above the waterline, were given careful consideration, and slow motion viewing of the video recording was a guide to the progressive adjustments to the chine and upper spray rail. H9 was notably drier than the other models, with little or no solid water taken on deck, and this was regarded as a great success in the development process.

At the outset of the work it was anticipated that improvements could be made to the seakeeping performance, by way of reducing acceleration levels. In fact the most dramatic improvements in seakeeping were the reduction in deck wetness and pitch motion, whilst the accelerations remained stubbornly similar to the base boat. The only practical way to assess deck wetness is from model tests, and it was surprising how sensitive the wetness was to subtle changes in bow shape.

Beam sea rolling tests were conducted with the model positioned near the wavemaker at 90^{o} to the tank centre line, and measurements of the roll angle were made using a roll gyro.

The data were used to predict the roll motion, for a range of seastates, for the purpose of assessing the likely ease or difficulty with which the boat might be recovered onto a slipway, without damage due to beam seas.

It is important to have good directional control in any fast boat, but it is particularly important for lifeboats, which have to operate in difficult sea conditions from which most fast pleasure craft will have already sought shelter. Various numerical and experimental approaches have been applied by other investigators into the problem of measuring the control characteristics of a model, but the most complete simulation was considered to be the free running of a model under radio control. Instrumented model tests were beyond the scope of the programme, and manoeuvring tests, involving course keeping, spirals, turns and zig-zag manoeuvres were conducted using the 1:10 scale models, relying on video recordings for analysis.

Propeller and water jet tests

Models of propeller and water jet driven designs were tested for comparison, all powered by electric motors driving through toothed belts. Sealed lead acid batteries comprised the bulk of the ballast, and were positioned in the model to give the required centre of gravity and radius of gyration.

It was found that spiral manoeuvres could be conducted with the water jet drives although it took at least half a turn for the model to settle into a steady turn of constant diameter. As would be expected, the jet driven models exhibited good manoeuvring characteristics in the zig-zags, and were very manoeuvrable at slow speeds due to the vectored thrust.

However during the tests H7 by contrast, with propellers in tunnels protected by a skeg and bilge keels, and with a highly warped bottom, exhibited directional instability and was very difficult to control at 25 knots. The model would continue to turn to port with small degrees of starboard rudder applied, then would suddenly veer to starboard. These characteristics were demonstrated to all the parties involved in the hull development programme, who expressed general surprise that the problem was so manifest.

The initial application of rudders tended to heel all the propeller driven models into the turns. Some of the models heeled outwards in a steady turn, so in the initial phase of the turn the model could be observed to first roll inwards and then outwards. This behaviour was part of the instability characteristic of H7, with the model rolling as it veered from turning one way to the other.

The minimum turning circle diameters were also measured for comparison with a criterion based on the performance of existing RNLI lifeboats, for a diameter of less than five boat lengths.

Both H6 and H7 met this criterion but for different reasons, H6 because of the water jet characteristics and H7 because of the manoeuvrability associated with its directional instability.

A dynamic inclining test was performed, based on the IMO Draft Guidelines for the Code of Safety for High Speed Craft.

This involved heeling the models to an angle of approximately 3°, by moving ballast, then running the model on a straight course and measuring the change in heel angle, which should not increase by more than 5°.

H8 was run propelled alternatively by water jets and propellers in tunnels, and the final lengthened version H9 was propelled by propellers. These hulls were found to be directionally stable and were controllable without any problems.

A model outfitted with propellers and rudders for manoeuvring tests - both propeller and water jet driven designs were tested for comparison, all powered by electric motors driving through toothed belts. The jet-driven models produced good performances.

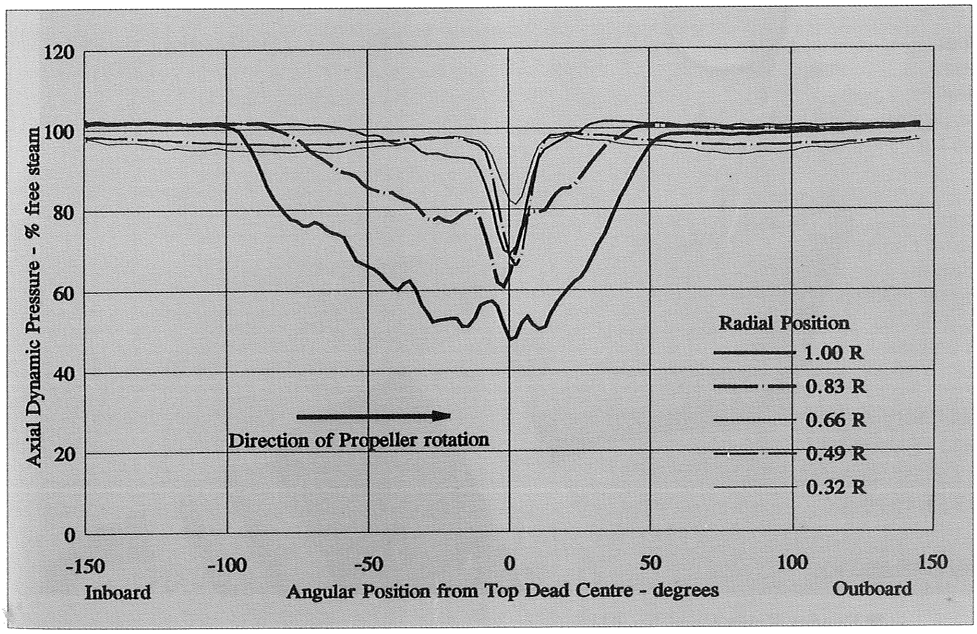
Final test sessions with H9 incorporated variations of the LCG and VCG, and a range of alternative rudder options.

The tests proved the value of such low cost methods in determining the handling characteristics, highlighting problems, and guiding the design development.

Design speed conditions

Frequently rescue craft are operated at their design speed in severe weather conditions, when any undesirable characteristics in their handling might prove hazardous. Tests were commissioned to observe the behaviour of the developing design in a range of conditions which, it was hoped, would provide the opportunity for the model to demonstrate any tendency for misbehaviour.

Figure 2: Wake survey data from one run - such tests were suggested as the preferred way to quantify any potential vibration problems



Following the calm water manoeuvring tests, the radio controlled model of H9 was taken to a large towing tank and run in a variety of regular and irregular following seas.

Wave heights of 2.5 to 3.5m were used, and regular wave periods were set to produce wave celerity speeds equivalent to 20, 25 and 30 knots full scale, so that the model would surge down the forward face of the waves. Tests were then conducted in two different irregular seastates, with significant wave heights of 2 and 2.5m.

It proved quite feasible to manoeuvre the model within the confines of the tank, the width of which represented 120m full scale, and the tests gave great confidence in the ability of the boat to turn on the face of steep following seas.

By filming from the moving carriage, the video record provided a better close up view of the motions of the boat than was possible from tests in the lake or the manoeuvring tank. The observations revealed the adverse influence on control of using excessively large rudder angles, due to the roll motions and bow down trim which they induced.

Manoeuvres under radio control

The model was tested in the manoeuvring tank in similar regular and irregular waves to those generated in the towing tank. The model was run freely, under radio control, at a variety of headings to the waves whilst maintaining a steady course and executing zig-zag manoeuvres and turns.

There was much more sea-room in the manoeuvring tank in which to execute manoeuvres and it was found that at the end of a run in following or quartering seas, the model could be turned back into the waves and then across the waves for a run in beam seas.

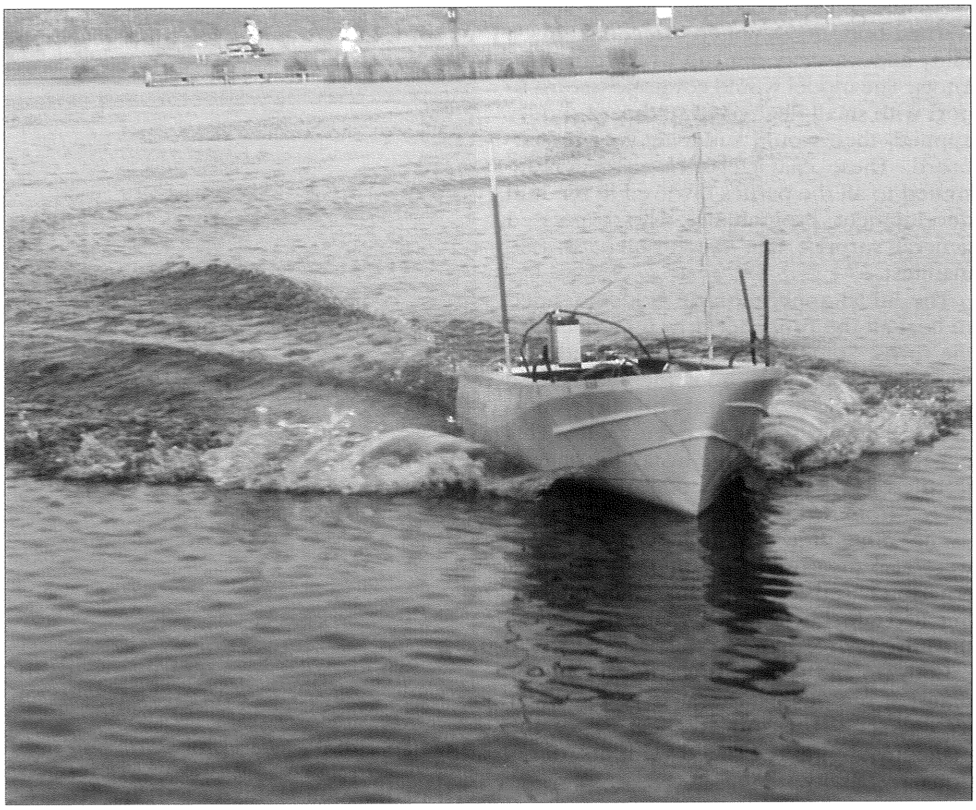
When running in head or oblique bow seas the model took no green water and very little spray on deck, despite on occasions leaping clear of the water through wave crests, and the model required nothing more than a foredeck with a small breakwater, to prevent water entering the hull.

Taking the controls

Previous experience in conducting model tests at sea showed that they can be fraught with practical difficulties, and ideal conditions rarely prevail. The small model size was suited to the manoeuvring basin and it provided the most enjoyable day's testing for the participants, enabling representatives of the RNLI to take the controls to gain confidence in the control characteristics of the hull form within an excellent working environment.

Hull design selected

The test programme was of great benefit in guiding the development, and a hull design has now been selected for tailed design and prototype evaluation, helping to steer the way for safer lifeboat procedures.■



Zig-zag manoeuvres by a model under radio control at 25 knots on the lake - RNLI representatives were able to take the controls to test various conditions.