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MARITIME & COASTGUARD AGENCY

Final Report

Research Project 524

The Parameters Affecting the Survivability of Small Passenger Vessels in Collisions

Executive Summary

This report describes the work conducted in, and findings of, Research project 503, to study the parameters affecting the survivability of small passenger vessels in collisions. The initiative for this project arose from the capsize of the Marchioness following its collision with the Bowbelle on 20th August 1989. In his report on the findings of the formal investigation into the incident Lord Justice Clark concluded that, although the stability of the Marchioness was relatively poor, this was not a factor in the catastrophic outcome. One of the objectives of the study was to provide a basis for a response to this conclusion.

The objectives included the assessment of the collision resistance of two types of vessel. Those resembling the Marchioness, typically older vessels that are partially decked and hence unable to comply with one compartment damage standards, and more modern fully decked vessels complying with one compartment standards. The former generally have comparatively low angles of downflooding, effectively restricting their stability to a smaller range than that of decked vessels. To address this objective two models were constructed, representing the Marchioness and a more modern, wider, vessel. As the project progressed it was agreed to extend the remit to test a third type of vessel that is in common operation, a catamaran. This was included within the original project budget.

The tests provided a good understanding of the behaviour of a vessel subject to a collision with a larger vessel, and the capsize mechanisms that might result. As a measure of collision resistance, a critical capsize speed was determined for each of the models, with a number of different configurations of deck, superstructure and stability. The critical speed is the minimum speed at which a colliding vessel may cause capsize.

Evidence was found that the critical speed is dependent on the stability and freeboard of the vessel. It was also determined that the critical speed for the Marchioness corresponded approximately to the relative speed at which the collision with the Bowbelle took place. The tests indicated that, if the vessel were fully decked, or retained an intact superstructure, the collision might not have resulted in capsize.

The third objective of the study was to contribute to the development of national safety levels for existing ships, equivalent to the enhanced levels being introduced in the EC Directive amending 82/714/EC. Whilst the study has provided a better understanding of capsize mechanisms, and has demonstrated a dependence of critical speed on the stability or freeboard for specific vessels, it has not enabled such dependence to be quantified for a range of vessel types. There were two reasons for this, the limited range of model configurations, whilst including a range of stability characteristics, did not form a parametric series, and the results did not indicate clear trends that were consistent across the range of model configurations. It has not been possible, therefore, to make general recommendations for the minimum levels of stability or freeboard required to ensure a particular level of safety from capsize in the event of a collision.

CONTENTS

1 INTRODUCTION

This report describes a programme of model tests to study the stability and safety of small passenger vessels when subjected to a side impact collision with a much larger vessel. The initiative for this project arose from the capsize of the Marchioness following its collision with the Bowbelle on 20th August 1989, and the findings of the formal investigation into the incident.

The MCA invitation to tender contained the following extract: *In the words of Lord Justice Clark – "It seems to us that in those circumstances, stability considerations were irrelevant to the casualty. Indeed there is considerable force in the point that no reasonably conceivable design could have enabled the MARCHIONESS to retain positive stability or buoyancy following a catastrophic collision of this nature".*

The Marchioness was certificated on the basis of a heel test for the purposes of stability approval, and had a limited range of stability. In comparison, vessels which are approved on the basis of a one compartment damage standard typically have a greater range of stability. Whilst the investigation concluded that stability was not a significant factor in the Marchioness incident, the MCA considered it worthwhile to study whether the greater stability offered by some vessels might result in increased levels of safety in the event of a similar collision.

The proposed programme was for tests on one model, which could be configured to represent the two types of vessel, and for a larger model to be used to represent the colliding vessel. This programme was altered as the work progressed, with the colliding vessel being represented by a fixed strut, and a total of three vessel types being modelled.

2 TEST FACILITY

The tests were conducted in the towing tank operated by Southampton Institute. The tank is 60 metres long by 3.7 metres wide by 1.8 metres deep. It is equipped with a manned towing carriage with a maximum speed of 4.5 m/s.

3 SIMULATION OF THE COLLIDING VESSEL

It had been intended that an existing large ship model with a suitable bow profile would be used to represent a colliding vessel. It became apparent however, that the relative size of potential colliding vessels compared with typical small passenger vessels precluded this option.

Small passenger vessels operate on the lower Thames, and other estuaries and "categorised waters", in close proximity with very large ships of various types, including container ships, bulk carriers and cruise ships. On the restricted waters of the Thames in central London it appears that one of the highest collision risks is posed by the waste barge and tug systems with limited manoeuvrability and a total displacement of over 2000 tonnes. The Bowbelle was a dredger of several thousand tonnes displacement compared with the Marchioness of 50 tonnes fully laden. This difference in the displacements would require modelling the passenger vessel at a very small scale, or conducting the tests in a very large facilty for which the budget was inadequate.

With such large potential differences in the displacements, in the early stages of the collision there would be little reduction in the speed of the larger colliding vessel. It was considered reasonable, therefore, to represent the larger vessel by a fixed strut attached to the towing tank carriage.

In a collision with the stem of a large vessel, the impact might occur with a vertical or raked stem, or with the upper part of a bulbous bow. The tugs operating on the Thames, and recognised as a potential hazard, have vertical stems. A vertical strut therefore represented the most general form of stem, and perhaps one of the most likely to occur in collision.

A vertical wooden strut was used, sleeved with a neoprene fender to avoid structural damage to the passenger vessel models. The strut extended below the water surface to a depth greater than the draught of the models.

4 PASSENGER VESSEL MODELS AND TEST CONFIGURATIONS

4.1 Marchioness

The Marchioness and the collision incident are described in the MAIB report published in 1991. A meeting with one of the MAIB surveyors involved enabled additional information to be obtained from their files.

The principal dimensions and some lines of the Marchioness had been lifted by the MAIB during their investigation. These were input to the Wolfson Unit's lines fairing software 'Shipshape' to produce a full lines plan suitable for model construction. Hydrostatic and stability data were derived from these lines using the Wolfson Unit's software. These correlated well with those supplied by MAIB and validated the process.

A model hull was constructed, at a scale of 1:16, of wood strip planks on frames, sheathed with GRP inside and out. It was configured with an arrangement based on drawings and photographs of the Marchioness. It included the skeg and rudder but no other appendages. One level of superstructure was constructed in two modules, fore and aft, with an open top allowing downflooding at any point along its perimeter. Marchioness was partially decked, with an undecked compartment extending through most of the aft part of the vessel with a very low coaming to the window height. This characteristic results in a low angle of downflooding, giving an effective range of stability of 22 degrees, and precludes compliance with the stability requirements for decked vessels. A plywood deck was constructed to enable this compartment to be made watertight, increasing the range to 55 degrees.

The model was ballasted to a displacement and centre of gravity corresponding to the incident condition as calculated by MAIB. The ballast was adjusted for each configuration tested to maintain constant displacement and centre of gravity.

Principal dimensions of the vessel are presented in Table 1, a drawing in Figure 4, and the stability characteristics for each configuration tested are presented in Figure 7.

4.2 Wider Vessel

A more modern type of vessel was selected by MCA staff. It was believed to be representative of many small passenger vessels in operation. Principle differences to the Marchioness are wider beam and a fully decked configuration enabling compliance with a single compartment damage standard, and giving a range of intact stability of 40 degrees.

The MCA stability file was supplied and included comprehensive drawings and stability information. The vessel had been extended but the original lines and drawings of the modifications were in the file. Hydrostatic and stability data were derived for the test configurations using the Wolfson Unit's software and these correlated well with those presented in the stability booklet.

The lines plan and modification drawings contained some inconsistencies requiring interpretation by the model builder, and for the hull definition compiled for stability analysis.

The vessel comprised two decks of accommodation above the main deck, giving a relatively high centre of gravity and a stability curve not unlike that of the Marchioness, despite the greater beam. It was decided, therefore, to conduct tests on the model in the loaded condition presented in the vessel's stability booklet, and in a second condition with the same displacement but a lower centre of gravity.

The model was constructed, at a scale of 1:16, of wood strip planks on frames, sheathed with GRP inside and out. It was fully decked and a simple open topped superstructure was constructed to represent the first level of accommodation on the full scale vessel.

Principal dimensions of the vessel are presented in Table 1, a drawing in Figure 5, and the stability characteristics for each configuration tested are presented in Figure 8.

4.3 Catamaran

Following tests on the models described above it was decided to conduct tests on a catamaran for comparison. An existing mould, manufactured for a model for another MCA research project, was used to construct the symmetric hulls of a conventional catamaran. The vessel is a 33 metre fast ferry operating in the UK on protected waters in close proximity to large ships, and therefore was considered a suitable example for this study.

The model was constructed, at a scale of 1:20, of GRP and Kevlar. It comprised the two symmetric, round bilge hulls, and a flat bridge deck. No appendages or superstructures were fitted.

The model was ballasted to represent a fully laden level trim condition, and a bow trim condition, using the stability information booklet for guidance on displacement and centre of gravity. Despite a difference in the GM values, the differences between the stability curves for these conditions was negligible, with less than 0.01 metre difference in the maximum GZ, and less than 1degree difference in the range. The displacement was 8% greater in the level trim condition, and hence the righting moment was also 8% higher.

Principal dimensions of the vessel are presented in Table 1, a drawing in Figure 6, and the stability characteristics are presented in Figure 9, together with those of the other models for comparison.

5 TEST TECHNIQUE

The collision strut was fixed to the forward end of the carriage at the centre of the towing tank. The passenger vessel model was placed at rest in the towing tank, ahead of the towing carriage, at the required orientation. Three orientations were studied: beam on, at 45 degrees with the stern towards the collision, and at 45 degrees with the bow towards the collision.

A low power laser was attached to the back of the carriage and aligned with the centre of the tank to enable the model to be placed accurately in line with the strut. Three locations were used for the impact point of the strut on the model: amidships and 25% of the length forward and aft of midships.

The carriage was run at the desired speed and stopped after the strut had pushed past the model and lost contact with it, or when it was apparent that the model was trapped on the strut in an unchanging situation.

The tests were recorded on digital video in DVCam format. Still images from the video record have been used to illustrate the tests in this report. A video presentation of selected runs accompanies this report.

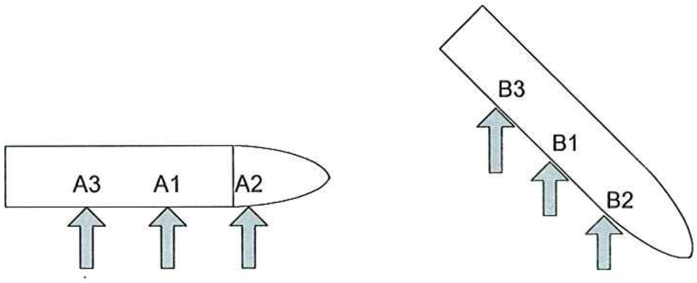
6 GENERAL OBSERVATIONS OF THE FORCES INVOLVED

6.1 Orientation and Point of Impact

The behaviour of the models was very dependent on the longitudinal location of the impact and the orientation of the model relative to the course of the colliding vessel, or strut. To simplify discussion of this aspect a notation will be adopted as defined in Figure 1.

It is understandable that the vessel is likely to be rotated and pushed aside by a collision of the type denoted C2, particularly if it has a raked keel or a substantial skeg that results in a centre of lateral resistance aft of midships. These features are common on passenger vessels and indeed are features of both the Marchioness and the wider monohull. Impacts C2 and A2 therefore were the least troublesome for these models and resulted in no significant heeling. The catamaran has no skeg and the keel line is rockered with the deepest point amidships, and its response in yaw was slightly different to the monohulls as a result, but impacts forward of midships did not result in capsize.

Figure 1 Definition of the notation used for the orientation and impact configurations



Similar results were obtained for impact B3, but the aft location of the centre of lateral resistance due to the keel and skeg arrangements of the monohulls reduced their rotational response, and one capsize occurred with the Marchioness model.

With the models oriented beam on to the collision the highest rate of capsize was for impacts A1, with the models at times being held on the strut, perhaps in the capsized state. For impacts A2 and A3 the model rotated and the number of capsizes was significantly less than for A1.

In impacts B2 and C3 the model moved sideways to some extent and the impact point moved towards the centre of the model. These impacts gave the highest rates of capsize for the models at these oblique headings, with the exception of the catamaran which, as mentioned above, did not capsize when stuck towards the bow in impact B2.

The collision between the Marchioness and Bowbelle was of type C3, one of the more severe combinations.

6.2 Transient Phase of the Impact

The behaviour following the collision may be divided into a transient phase in which the passive vessel is set in motion by an impulsive force, followed by a quasi-static phase in which the vessel responds to more steady forces.

In many cases the roll response was immediate on impact, and it appears that the transient phase has a major effect on the behaviour because the initial roll angle affects the subsequent development and balance of forces.

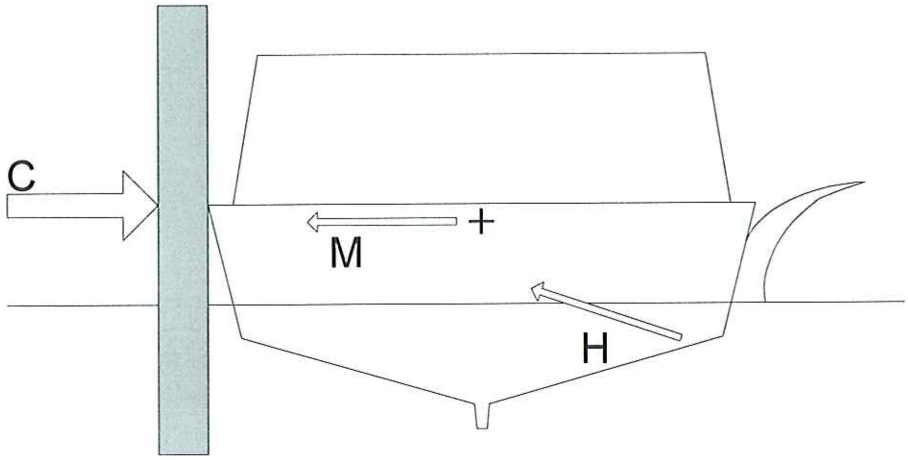
In the transient phase it appeared that the model responded to three principal moments that governed its initial roll response. These are illustrated in Figure 2.

1. The force of the strut applied to the side of the model and the height at which this force is applied. The height is at the point of impact and therefore is dependent on the section shape of the hull and superstructure, and the shape of the stem of the colliding vessel. This force is denoted C in Figure 2.

2. The reactive inertial force, due to the acceleration of the model in the direction of travel of the strut, acting at the centre of gravity. The height at which this force acts is dependent on the height of the centre of gravity. This force is denoted M in Figure 2.

3. The reactive force due to the water resisting movement of the model, acting through the centre of pressure. On impact, the water alongside the vessel, on the side away from the impact, is displaced under pressure resulting in generation of an instantaneous wave along the topsides. This may be likened to the response to a slam, and is similar in appearance to the spray sheet on the hull of a planing boat. It is illustrated by the second image of Figure 18. On the side adjacent to the impact there will be a negative pressure. The resultant is not a horizontal force acting at half the draught. Its magnitude and direction are difficult to predict, and are dependent on the shape of the hull. This force

Figure 2 The forces acting in the transient phase of the impact



is denoted H in Figure 2. It should not be confused with the resistance components normally associated with a hull moving steadily through water.

The relative magnitudes and lines of action of these forces govern the initial response of the vessel, in particular whether it rolls towards or away from the colliding vessel. If the colliding vessel has a raked stem, or the passive vessel a high superstructure, the force C is likely to be above the centre of gravity and will impart a roll moment away from the colliding vessel. Conversely, if the passive vessel has a high centre of gravity and is struck low on the hull, the moment is likely to result in a roll towards the colliding vessel. If there is no rotation or deformation the lateral acceleration of the passive vessel will be of extremely high magnitude, as it will adopt the speed of the colliding vessel immediately. Any rotation or deformation will increase the time taken to accelerate with a proportional reduction in the acceleration and hence the inertial force associated with it. If the colliding vessel is of a similar displacement to the passive vessel, the speed of the colliding vessel, and hence the acceleration of the passive vessel, will be reduced.

The hydrodynamic pressures complicate the issue so that such simplified predictions of the roll direction in any particular case would be unreliable. The forces are not in balance, so acceleration and rotation result.

Figure 16 and Figure 17 show the wider monohull exhibiting rapid rolls towards and away from the collision. The different behaviour is believed to result primarily from the presence of the superstructure

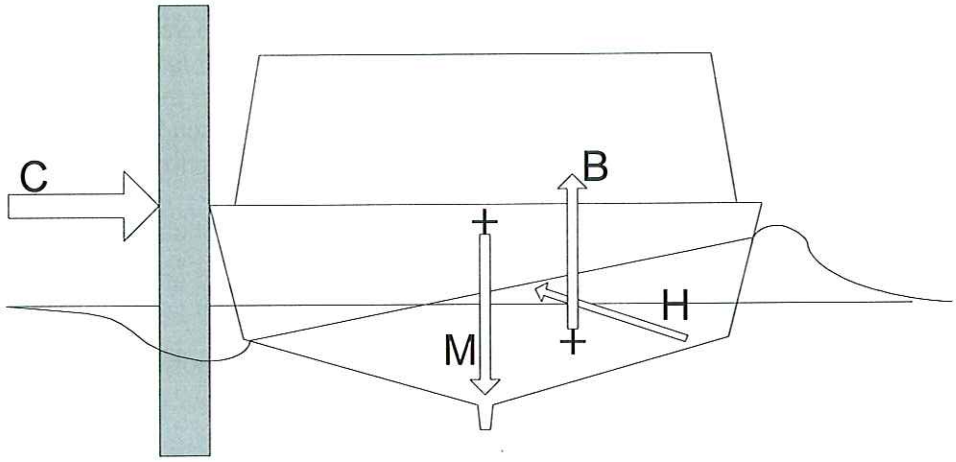
6.3 Quasi-Static Phase of the Impact

Once the passive vessel has been accelerated to the speed of the colliding vessel, the inertial force associated with the acceleration is reduced to zero, and the flow around the hull becomes steadier. A wave pattern is set up around the hull as illustrated in Figure 3.

On the pressure side a wave crest is formed and on the suction side a wave trough, so that the vessel floats on an inclined water surface. Its hydrostatic stability on this inclined surface generates a roll moment towards the colliding vessel because of the transverse displacement of the centre of buoyancy from the centreline.

On the pressure side the wave may rise above the deck edge at some point, and this appears to have a significant effect on the roll moment, resulting in a roll away from the colliding vessel. With an undecked configuration it may result in downflooding, as appears may have been the case in the Marchioness incident, and illustrated in Figure 10.

Figure 3 The forces acting during the quasi-static phase of the impact



As in the transient phase, the hydrodynamic forces resulting from the flow around and under the hull are difficult to predict and complicate the overall force balance. As for a vessel moving forward in normal operation, the hydrodynamic resistance will include viscous, form and wave making components.

The behaviour of the models indicated that the forces may be in balance, with the model held at a constant attitude against the strut, or nearly in balance, with the model rotating slowly around the strut, predominantly in yaw. Figure 12 shows this behaviour, where the relatively long interval between images 3 and 4 in the sequence indicates a relatively slow change of attitude. (It appears in image 3 that the ballast tower may have interfered with the collision strut and attenuated the roll, but careful examination of the video record reveals that no interference took place.)

An additional force in the system is the friction between the two vessels. This may apply a vertical force component at the point of contact, affecting the angle of inclination of the resultant force C. In the model tests the neoprene fender on the strut resulted in greater friction than would have been the case with a smooth strut, and undoubtedly affected the roll rotation in some tests. In a real collision the deformation of the vessels might result in considerable resistance to relative vertical movement at the point of contact, and so there was no justification for modifying the strut.

Tests on the catamaran further highlighted the difference between the transient and quasi-static phases. In some beam-on cases the model was capsized at 5.4 knots, with the capsize initiated during the transient phase of the collision. In other cases the model was held fast against the strut and pushed beam-on at speeds of up to 9 knots without excessive heeling. The latter cases arose following a stern-to presentation, where the impact did not cause capsize and the model subsequently yawed beam-on to the strut.

7 DETERMINATION OF CRITICAL SPEEDS

7.1 Selection of Test Speeds

The behaviour was highly dependent on the speed and so attempts were made to determine the critical speed of impact, that is the lowest speed at which capsize occurred, for each configuration tested. Initially, tests were conducted on both monohull models at all combinations of orientation and impact point, at 2, 4 and 6 knots. It was apparent from these tests that collisions at 2 knots posed no threat to the stability of the vessels. The differences between the behaviour at 4 and 6 knots was dramatic in some cases, and so subsequent tests were conducted at finer speed increments. Whilst repeat tests proved the method to give reliable and consistent results, the behaviour of the model at the critical speeds was dependent to some extent on the precise orientation and impact point, and subsequent response in yaw. In most cases therefore it was considered that the resolution of the test method did not justify tests at increments of less than 0.5 knots.

Collisions of type A2, B3 and C2 resulted in very few or no capsizes, and so the tests concentrated on the remaining six combinations of orientation and impact point.

A large number of test runs were required to address the matrix of 5 variables: model, configuration, orientation, impact point and speed. Over 200 runs were conducted, from which were derived the critical speeds for the worst combination of orientation and impact point for the 9 model configurations. These are presented in Table 2. Most of the photograph sequences correspond to the critical speeds, although some are for slightly higher speeds because of their better image quality.

The lowest critical speeds were found to be 4 knots for both the monohulls and 5.4 knots for the catamaran.

7.2 Scaling Method

For these tests Froude scaling results in all forces remaining in proportion, and therefore representative of the full scale situation, despite the small model size, with some minor exceptions.

Viscous resistance, or friction, does not scale in the same way as the other hydrodynamic components. In conventional ship model resistance tests this scale effect is corrected in the analysis procedure. The viscous effects are relatively higher for a model than at full scale. In these tests the viscous effects are believed to be small in comparison with the other components, and restricted to the quasi-static phase of the event. Scale effects therefore were neglected.

Surface tension does not scale, and so water droplets are relatively large at model scale. This may affect the appearance of any spray generated by the impact.

The speeds are presented as full scale values, as are the times of the images in the capsize sequences taken from the video. With Froude scaling, speed is scaled by the factor $\sqrt{scale}$. Because the model scale of the monohulls was 1:16, and that of the catamaran 1:20, the collision speeds and times were scaled differently.

Because the models were similar sizes, and the remit of this project is to address the safety of passenger vessels in general, rather than these specific examples, one might argue that the speeds could have been scaled by a constant factor. In this case the critical speeds for the catamaran would be reduced by 11%, for example the lower value of 5.4 knots for the 33 metre catamaran would be reduced to 4.8 knots for a 26 metre catamaran. Adoption of this alternative analysis would not have altered the conclusions of this study, and it was considered appropriate to relate the test data to the vessels modelled.

8 DIRECTION OF CAPSIZE

The capsizes of the wider monohull without the superstructure fitted were all towards the strut. With the superstructure fitted all capsizes were away from the strut. This indicates that the height of the point of contact of the colliding vessel is a dominant parameter.

For the Marchioness the results were less clearly defined. With the superstructure fitted all capsizes were away from the strut, although not necessarily because the strut impacted the superstructure. See Figure 14. Without superstructures there were capsizes in both directions. It appeared to be largely dependent on whether the pressure wave rose above the deck edge. This in turn was influenced by the orientation and point of impact. For example, in a collision of type B2, the model rotated rapidly in yaw, the bow being pushed ahead of the strut and generating a large wave that could overwhelm the deck forward and result in a capsize away from the strut. The lack of consistency in these events suggests that quite small differences in orientation or impact point can make dramatic differences to the balance of forces and hence the behaviour.

All collisions with the catamaran model resulted in heeling way from the strut, despite the fact that the model had no superstructure and the impact was at the deck at side, slightly below the vertical centre of gravity. With the catamaran trimmed by the bow the forward part of the deck was submerged at the higher speeds tested, and in some cases the model trimmed and rolled to a large angle but recovered.

9 EFFECTS OF IMPACT LOCATION AND YAW

Impacts at different points along the hull result in different yaw rates, and these can have a strong influence on the behaviour, particularly in the quasi-static phase. Comparison of Figure 11 and Figure 14 illustrates the effects of yaw on the Marchioness model. In Figure 11 the model was struck beam-on amidships and pushed sideways without yawing. It capsized very rapidly towards the strut. In Figure 14 the model was struck aft of midships from the stern quarter, as was the case in the Marchioness incident. It capsized away from the strut, after yawing to a beam-on attitude. The difference appears to be that, in the latter case the stern is pushed through the water much faster than the bow, and the pressure wave is concentrated well aft. The wave rises above the deck edge and the roll then increases rapidly. In the former, beam-on case, the pressure wave is distributed along the full length of the model, and this appears to generate sufficient buoyancy to roll the model towards the strut.

The hydrodynamic forces acting in these scenarios undoubtedly have an effect on the roll behaviour, but are more difficult to understand. When the deck edge immersed on the pressure side of the model it frequently resulted in capsize away from the strut. This may be due to an increase in the resistance to sway and a change in the direction of the resultant force.

10 EFFECTS OF THE SUPERSTRUCTURE

As described above, the presence of a superstructure may raise the effective height of application of the collision force, and affect the direction of capsize.

If the superstructure remains intact its buoyancy has a considerable effect on the trim and stability of the vessel. In these tests the superstructure was open topped in all cases, allowing flooding when the side panels became submerged. The structural integrity of the vessel, and any windows and doors, will govern the downflooding in real cases, and a particular vessel might fare better or worse than the models as tested. A large part of the Marchioness superstructure was completely destroyed during the incident, although it is not certain whether it was due to the collision, or the hydrostatic or hydrodynamic forces that followed.

Presence of an intact superstructure increases the range of stability and reduces, or eliminates, the dynamic effects of immersion of the deck edge. It increases the angle of maximum GZ so that the vessel retains greater righting moments at large angles of heel.

11 EFFECTS OF STABILITY CHARACTERISTICS

Comparison of the stability curves presented Figure 7 and Figure 9 show some common parameters and some highly variable ones. For example, Marchioness and the wider vessel with a high KG have similar maximum values of GZ, while the catamaran has a much larger value. The wider vessel with the low KG has a similar range of stability to the catamaran but still with a much lower maximum KG. It was hoped that these selective differences would assist in the identification of the most influential characteristics. A summary of the stability characteristics is presented in Table 2.

There is clear evidence from the tests that, for a given vessel configuration, increased stability provides increased resistance to capsize. Comparison of Figure 15 and Figure 16 reveals very little difference between the capsize sequences and so it can be concluded that their capsize mechanisms are the same. Figure 15 is for the lower stability condition, where the critical speed was 4.5 knots. Figure 16 is for the higher stability condition and the critical speed was 6 knots. The difference between the test configurations is merely that ballast weights were relocated to reduce the height of the centre of gravity. The GM increased by 51%, the maximum GZ by 83%, and the range of stability by 43%.

This finding is less clear however, when all of the test configurations are studied together. Figure 19 presents three plots of the critical capsize speeds for each configuration against the range of stability, the maximum GZ and the GZ curve area. Although there are some indications of trends, particularly with respect to range of stability, the data do not enable reliable trend lines to be defined.

The stability of the catamaran, with a righting energy (that is the product of the area under the GZ and the displacement) an order of magnitude higher than that of the Marchioness, gave only a modest increase in the critical speed. This indicates that righting energy is not an important parameter in this type of incident. This may be explained by the fact that, assuming the collision is with a much larger vessel, the available capsizing energy may be one or more orders of magnitude greater than the available righting energy. In the model tests the capsizing energy was effectively infinite because the carriage speed was not reduced on impact. Thus any increase in the righting energy, such as may be brought about by normal design changes, would be insignificant in comparison to the capsizing energy unless the collision is with a small vessel travelling at low speed.

Attempts were made to determine trends by comparing other parameters including GM, freeboard, displacement, length, beam, speed squared, and a number of non-dimensional variations and ratios of them. None of these attempts resulted in clear trends.

An example is presented in Figure 20 to show a possible trend between freeboard and critical speed. Speed squared has been used because it is believed to be more representative of the forces involved, and both have been divided by the cube root of displacement so that the data are independent of vessel size. An interesting aspect highlighted by these data is that all of the cases with relatively low freeboard capsized towards the strut.

The highest critical speed, by a significant margin, was with the wider vessel fitted with a superstructure. The stability characteristics of this configuration were not particularly high, being similar to those of the Marchioness with the full superstructure. This suggests that maintaining high freeboard and avoiding downflooding are worthwhile design aims.

12 IMPLICATIONS FOR THE MARCHIONESS INCIDENT

12.1 Validation of the Test Method

The sequence of images presented in Figure 10 show a re-enactment of the collision between the Bowbelle and the Marchioness, within the limitations of the experimental method. For convenience, the collision in this sequence was to the starboard side, but otherwise is representative of the attitude and impact point described in the MAIB report. The model behaviour appears to correlate well with that reported for the incident at full scale, and is consistent with the fact that impact damage was sustained from the deck to the keel.

At 4 knots the model did not capsize but was pushed sideways, approximately upright. At 4.5 knots the model capsized as illustrated in Figure 10. The MAIB report states that the Bowbelle was making good about 5.5 knots against a 3 knot tide, while Marchioness was making good 3 knots, perhaps less. The course of Marchioness was at about 45 degrees across the bow of Bowbelle. In this situation the relative speed between the vessels, and thus the collision speed, would be about 4.25 knots, although the actual speeds and courses of the vessels was not known accurately and this value probably has an uncertainty of at least 0.5 knot. This correlates very well with the test results.

The combination of this critical speed and the model behaviour provide evidence to support the validity of the test method.

12.2 Application of Results to the Marchioness

Lord Justice Clark believed that no conceivable design could have prevented the catastrophic result of the collision. The test results demonstrate, however, that some improvements could be made to the vessel to increase the level of safety. In the configuration of an open deck aft, the lowest speed at which capsize occurred was 4 knots, with the model beam on to the strut. It is believed that the incident occurred at a speed of about 4.25 knots, with the Bowbelle approaching from the stern quarter, and so the incident occurred approximately at the critical speed. The tests indicate that at a lower speed the vessel would not have capsized.

With the deck fully watertight the critical speed increased to 4.5 or 5 knots, and with both the forward and aft superstructures assumed watertight, the critical speed increased to 5.5 knots. In any of these configurations, it follows that the Marchioness might not have capsized.

13 APPLICATION OF RESULTS TO OTHER VESSELS

It was hoped that, if increased stability was shown to provide increased resistance to capsize, it would be possible to recommend some guidance on appropriate levels of the important stability characteristics for certain types of operation. Unfortunately, while the tests indicate that increased stability does indeed provide increased safety, the results are specific to each model. This makes general guidance impossible with the modest data set produced by this study.

It is notable that all models were capsized, and that substantial changes to the model configuration generally led to modest increases in the critical speed. This perhaps underlines the importance of collision avoidance, as it cannot be assumed that any vessel will withstand a collision with a larger vessel, regardless of the perceived adequacy of its structure and stability.

All small vessels therefore are vulnerable to collision and the findings of this study are relevant to all small commercial vessels and recreational craft. It provides further evidence that stability and freeboard are important factors for the safety of the vessel, but it is unfortunate that the scope of this study has not enabled firm guidance on the characteristics required.

The nature of this type of incident and the subsequent behaviour of the passive vessel is that there is no gradual scale of severity of response. The vessel either capsizes or it does not. In the former case the result will be instant and catastrophic, with loss of life almost inevitable. In this respect a collision induced capsize is similar to other stability casualties where incident databases consistently reveal that, although stability incidents do not represent a large proportion of the total number of marine accidents, they do result in a large proportion of the deaths. If the vessel does not quite capsize, there may be structural damage, perhaps affecting buoyancy and stability in the medium term, and personal injury, but the vessel may survive or there may be adequate time to evacuate. There is unlikely to be any indication to the crew that their margin of safety from capsizing was small.

14 CONCLUSIONS

1. A simple test method has been developed that appears to correlate well with full scale experience, albeit on the basis of only one casualty report.

2. This study has enabled a better understanding of the behaviour of small vessels in collisions. It has identified the forces involved and how they may be affected by various design parameters.

3. The critical speeds above which capsize may occur has been identified for a range of model configurations for 3 vessel types. For the Marchioness model the critical speed indicated by the tests corresponded approximately to the speed at which the Marchioness incident occurred.

4. It has been demonstrated that both stability and freeboard are parameters affecting the critical speed. This study therefore does not support the statement by Lord Justice Clark that "no reasonably conceivable design could have enabled the MARCHIONESS to retain positive stability or buoyancy following a catastrophic collision of this nature".

5. Notwithstanding the above conclusion, the study did not reveal clear relationships for stability parameters that applied to all configurations tested. It has not been possible, therefore, to derive guidance on the levels of stability required to provide a common level of safety from capsize for small vessels in general. It is not necessarily the case that such relationships do not exist, rather that, if they do exist, the limited scope of this study was insufficient to determine them. In order to develop guidance on stability and freeboard requirements to ensure safety from capsize in particular collision circumstances, a more systematic programme of tests on a parametric series of models would be required to determine any general relationships and the limitations of their application.

Table 1. Principal dimensions

		Marchioness	Wider Vessel	Catamaran	
				Bow trim	Level trim
Length Overall	metres	26.9	24.4	32.7	32.7
Length BP	metres	25.9	22.8	29.5	29.5
Moulded Beam	metres	4.35	5.94	8.32	8.32
Draught	metres	0.89	1.37	1.24	1.26
Freeboard to main deck	metres	0.65	1.10	1.79	1.77
Displacement	tonnes	50	108	90	98
LCG (fwd of midships)	metres	-1.16	-0.76	-1.13	-2.38
VCG (above USK amidships)	metres	1.54	2.84 & 2.22	3.27	3.28
Model scale		1:16	1:16	1:20	

Table 2. Critical capsize speed and stability summary for each configuration tested

Run No.	Critical Speed	Capsize Direction Relative to Strut	Impact Type	Deck	Superstructure		GM	Range of Stability	GZ Max	GZ Area	Righting Energy
					Aft	Fwd					
	knots						m	deg	m	m.rads	Tonne. m.rads
Marchioness											
146	4.0	towards	A1	Open Aft	Off	Off	0.72	22	0.280	0.046	2.3
138	5.0	towards	A1	On	Off	Off	0.72	56	0.300	0.166	8.3
134	4.5	away	C3	On	Off	On	0.72	47	0.308	0.191	9.6
128	5.5	away	B2	On	On	On	0.72	49	0.388	0.229	11.5
Wider Vessel											
88	4.0	towards	B2	On	Off		1.18	42	0.320	0.152	16.4
121	6.0	towards	B2	On	Off		1.79	60	0.585	0.378	40.8
110	8.0	away	B2	On	On		1.18	59	0.320	0.223	24.1
Catamaran											
Bow trim											
173	5.8	away	A1	On	Off		7.49	62	2.055	1.187	107
Level trim											
174	5.4	away	A1	On	Off		6.75	62	2.050	1.159	114

Figure 4 Marchioness model

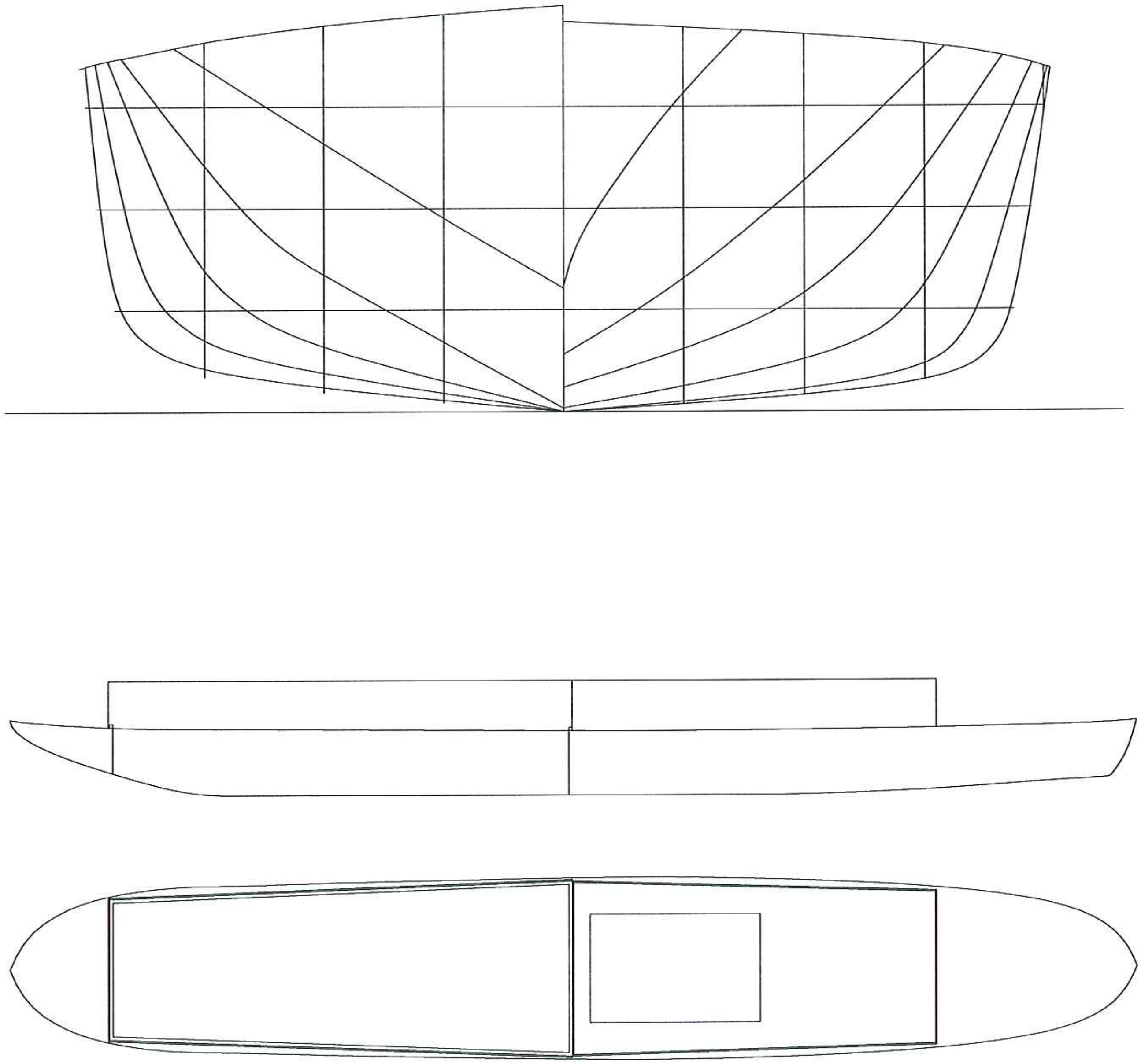


Figure 5 Wider vessel model

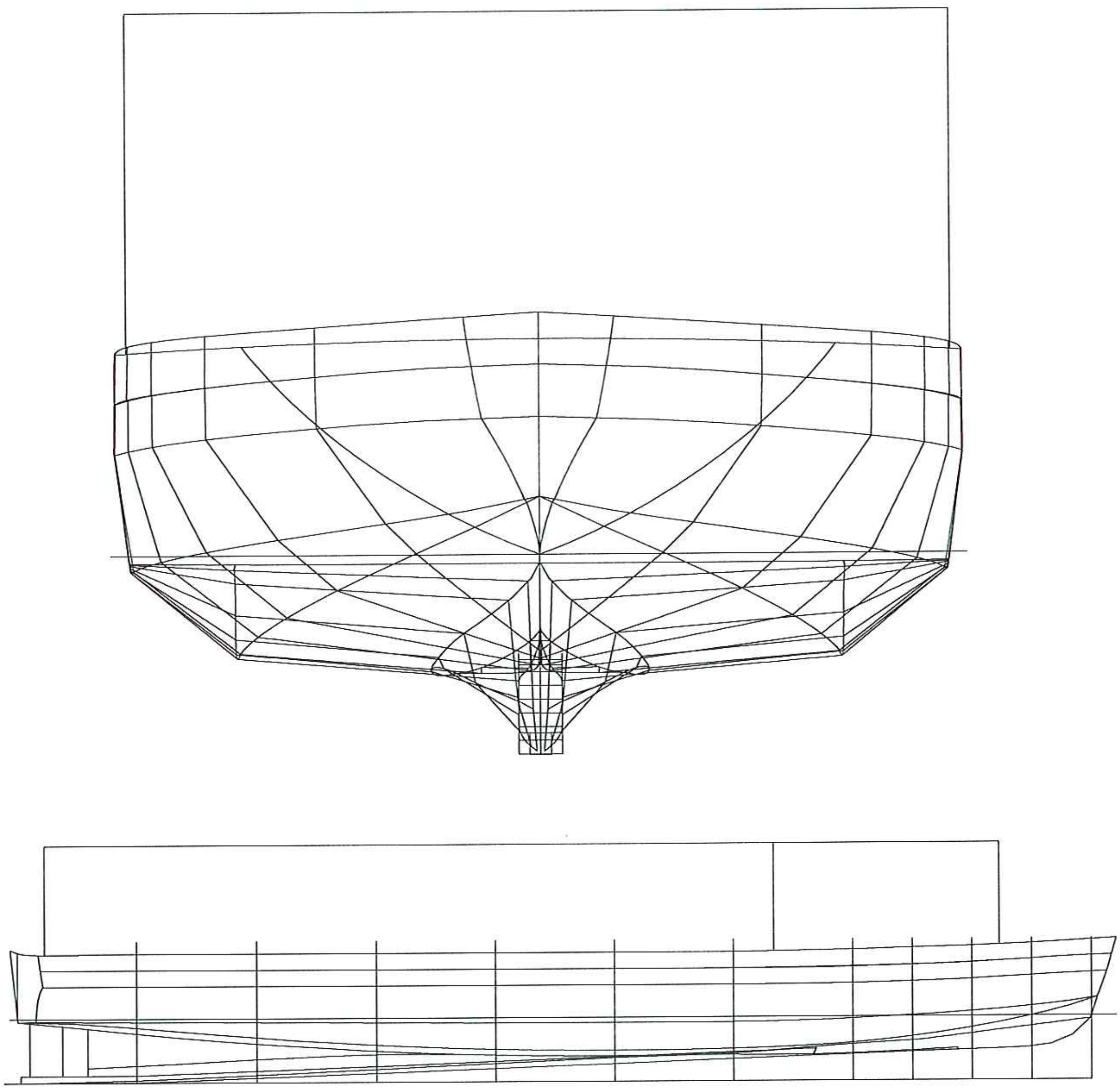


Figure 6 Catamaran model

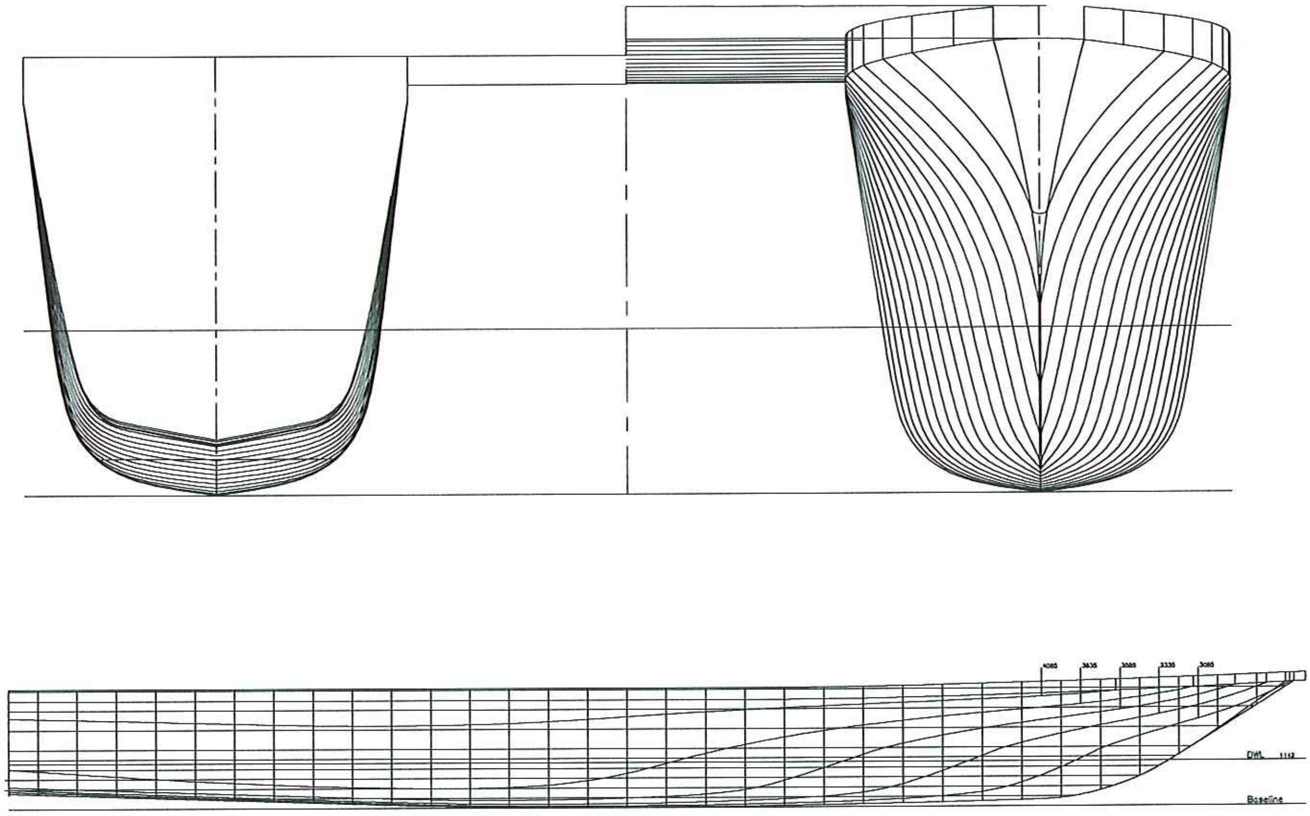


Figure 7 Stability curves for the Marchioness

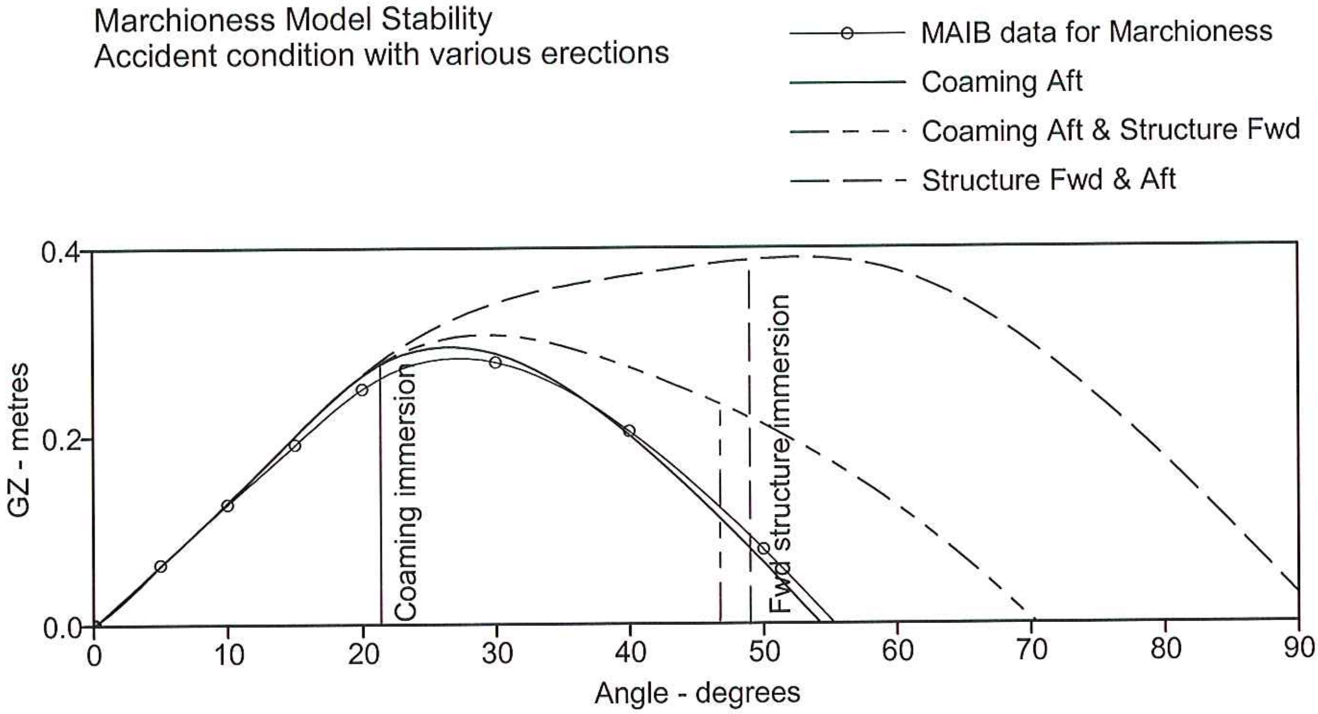


Figure 8 Stability curves for the wider vessel

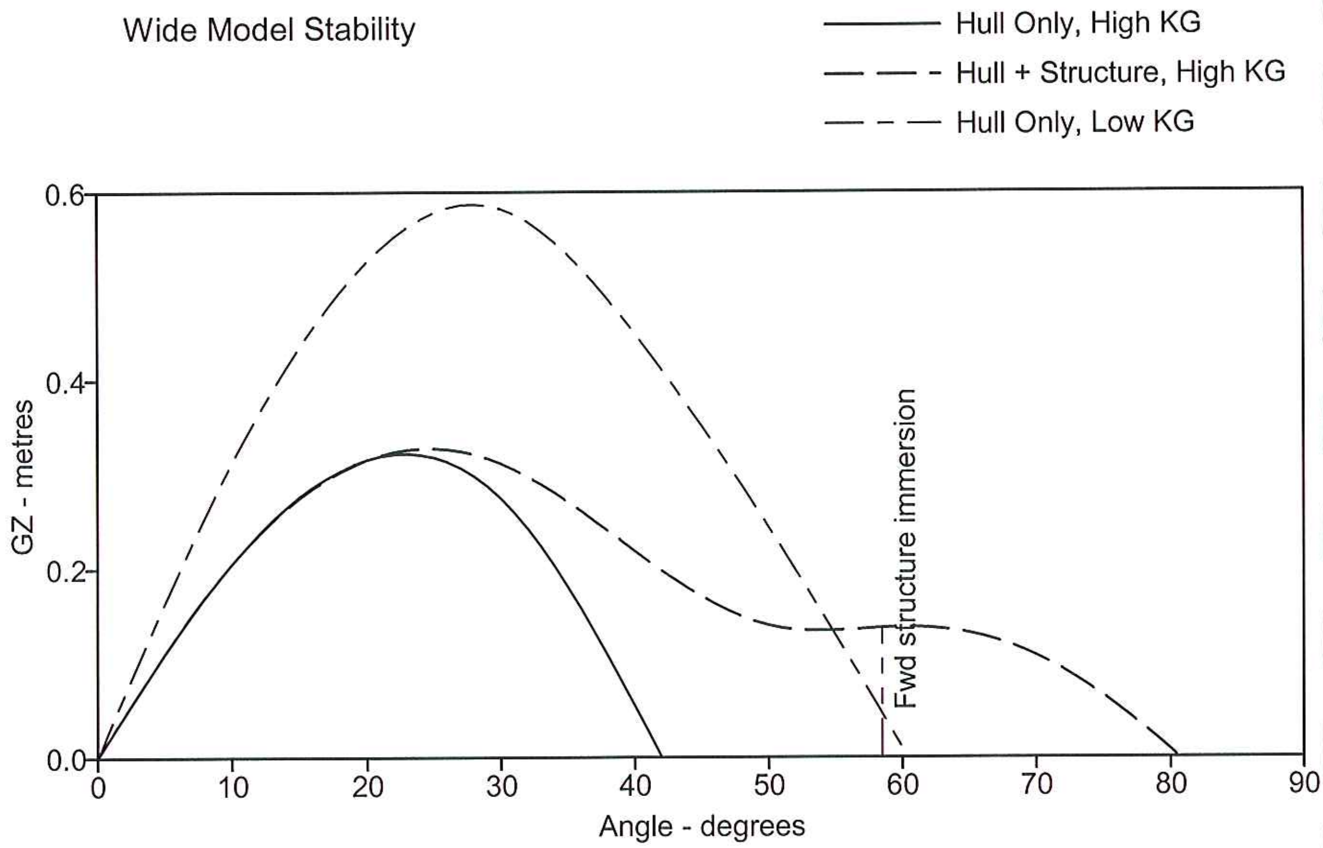


Figure 9 Comparison of the stability curves of the models

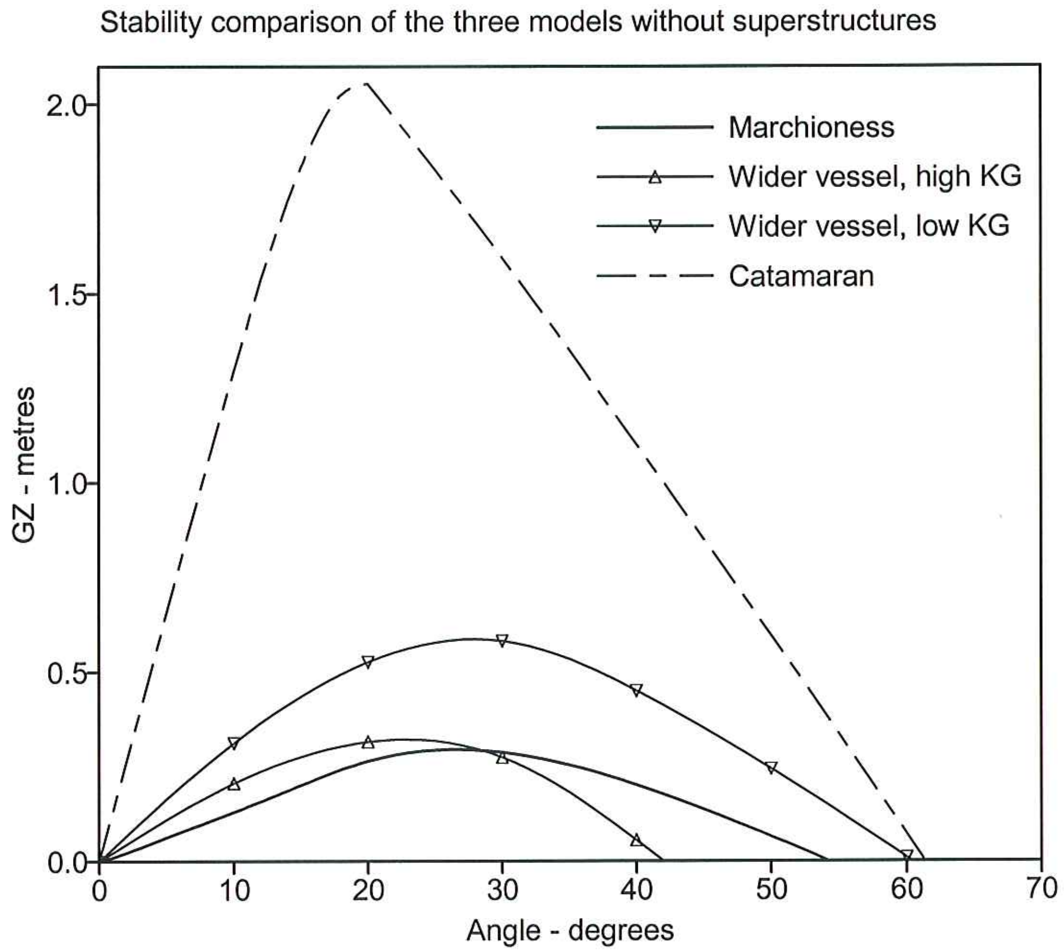
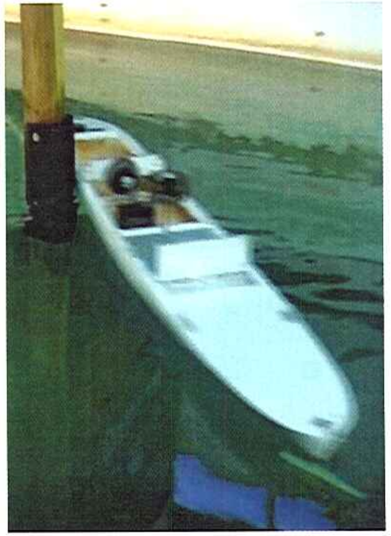


Figure 10 Marchioness (Incident Case) – Run No. 147, Collision speed – 4.5 knots

0 seconds

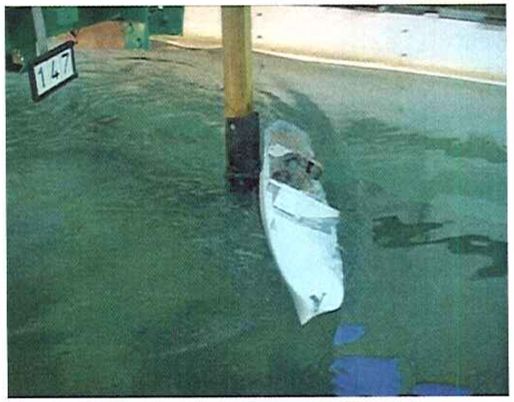


1.6 seconds

6.4 seconds

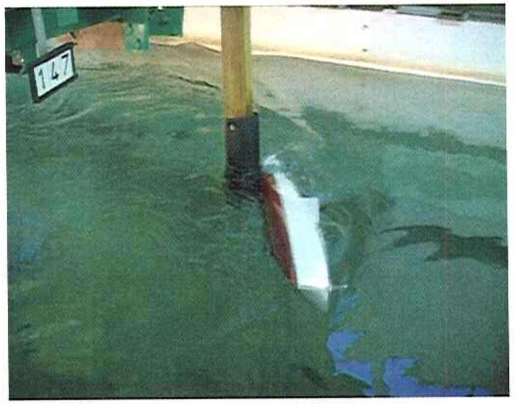
10.4 seconds

12 seconds



12.8 seconds

13.6 seconds



14.4 seconds

Figure 11 Marchioness – Run No. 31, Collision speed – 6 knots

0 seconds

0.8 seconds

1.6 seconds

2.4 seconds

3.2 seconds

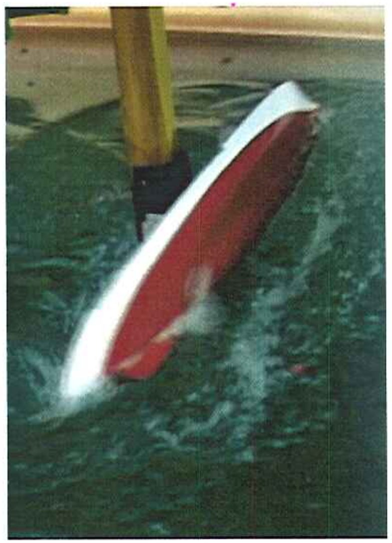
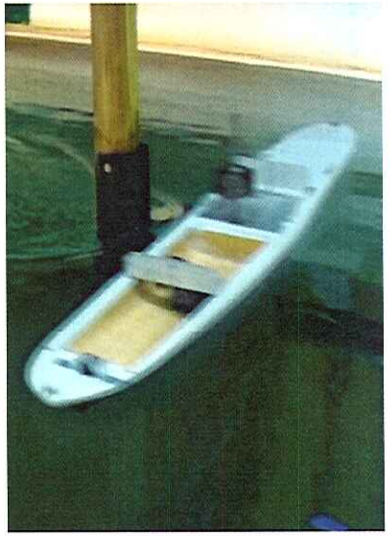
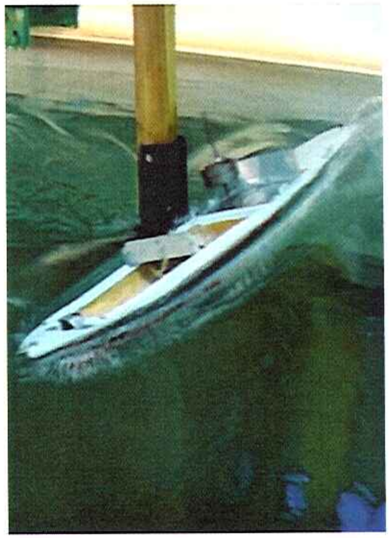


Figure 12 Marchioness – Run No. 145, Collision speed – 4.5 knots

0 seconds



1.6 seconds



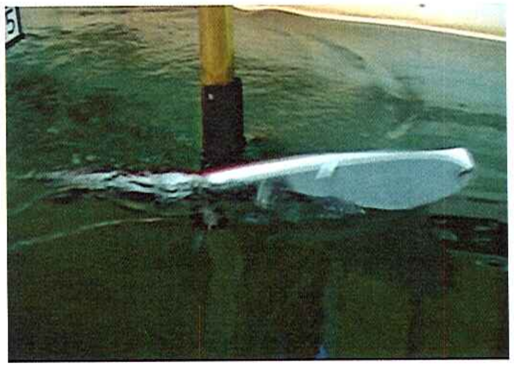
3.2 seconds

8.0 seconds

10.4 seconds

12.8 seconds

15.2 seconds



17.6 seconds

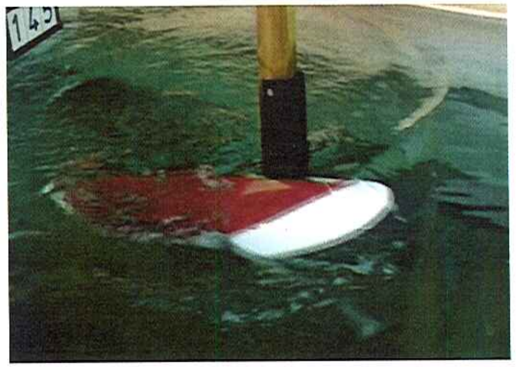
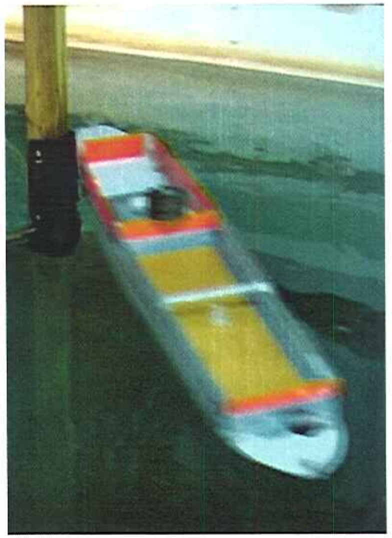


Figure 13 Marchioness – Run No. 128, Collision speed – 5.5 knots

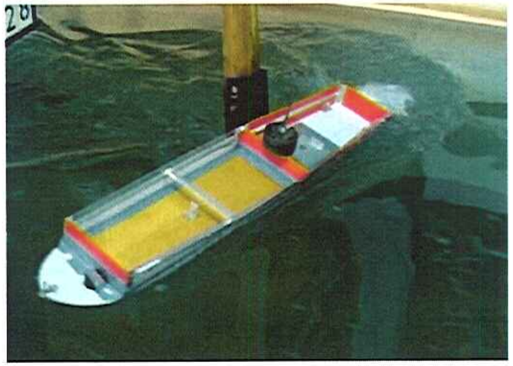
0 seconds



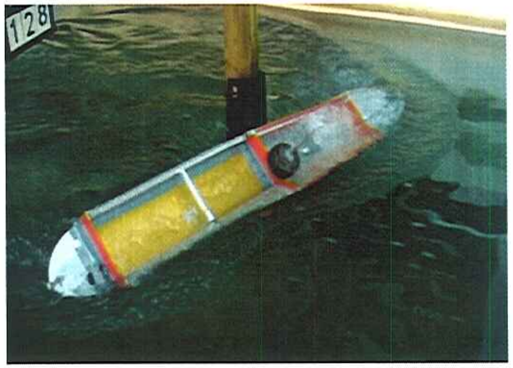
0.8 seconds

2.4 seconds

4.0 seconds



6.4 seconds



7.2 seconds

8.0 seconds

8.8 seconds

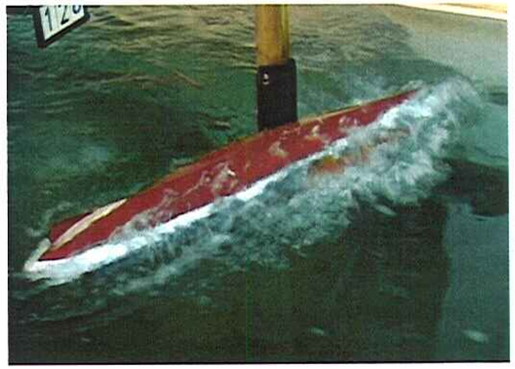
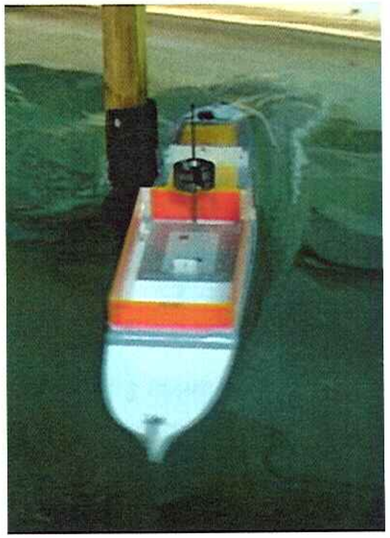


Figure 14 Marchioness – Run No. 134, Collision speed – 4.5 knots

0 seconds

1.6 seconds



3.2 seconds

6.4 seconds

8.0 seconds

8.8 seconds

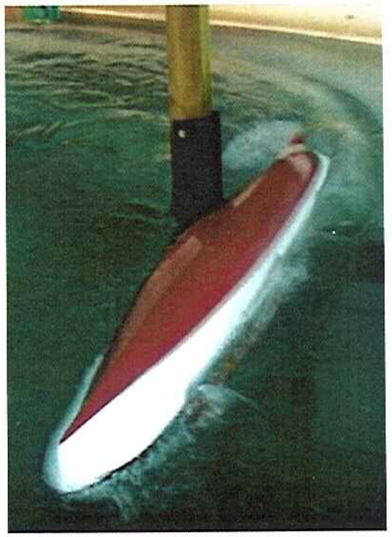


Figure 15 Wider Vessel, High Centre of Gravity - Run No. 88, Collision speed – 4 knots

0 seconds **0.8 seconds** **2.4 seconds** **4.0 seconds**

5.6 seconds

Figure 16 Wider Vessel, Low Centre of Gravity – Run No. 123, Collision speed – 6.5 knots

0 seconds

0.8 seconds

2.4 seconds

4.0 seconds

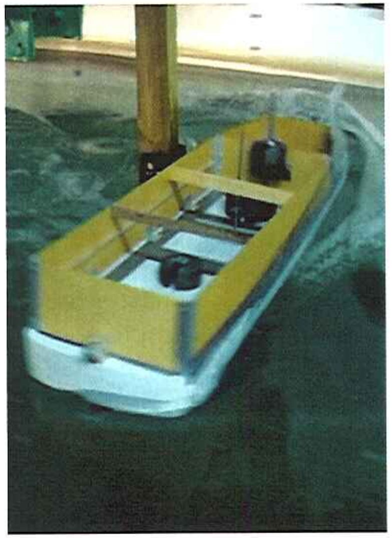
5.6 seconds

Figure 17 Wider Vessel, High Centre of Gravity – Run No. 110, Collision speed – 8 knots

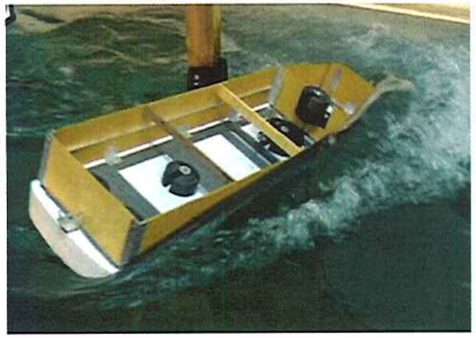
0 seconds

0.8 seconds

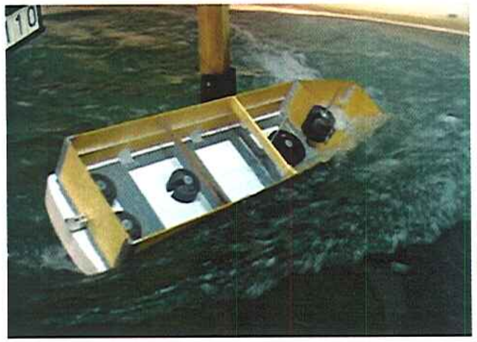
1.6 seconds



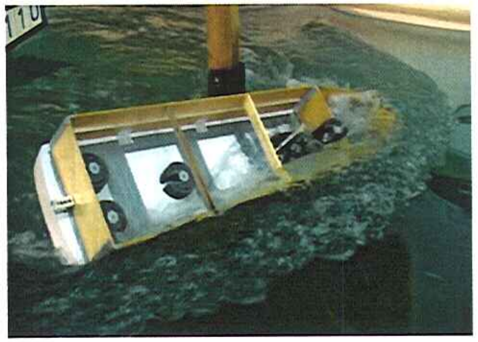
3.2 seconds



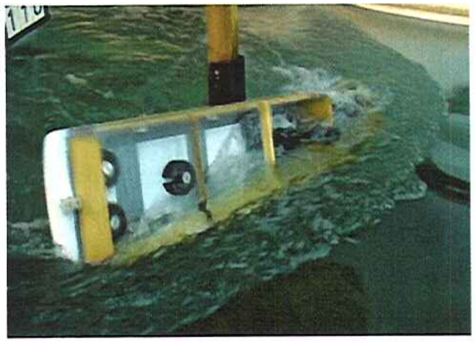
4.8 seconds



9.6 seconds



10.4 seconds



12.0 seconds

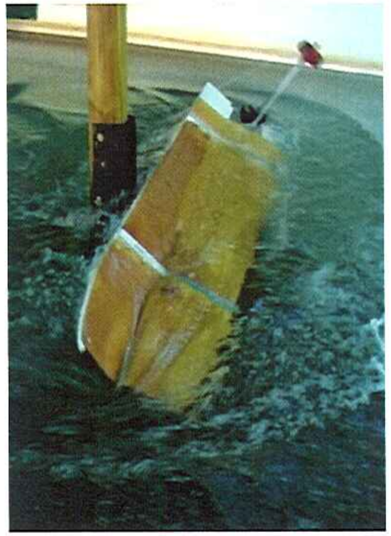
Figure 18 Catamaran – Run No. 174, Collision speed – 6 knots

0 seconds

0.9 seconds

2.7 seconds

3.6 seconds



4.5 seconds

5.4 seconds

6.3 seconds

Figure 19 Variation of critical capsize speed with various stability characteristics

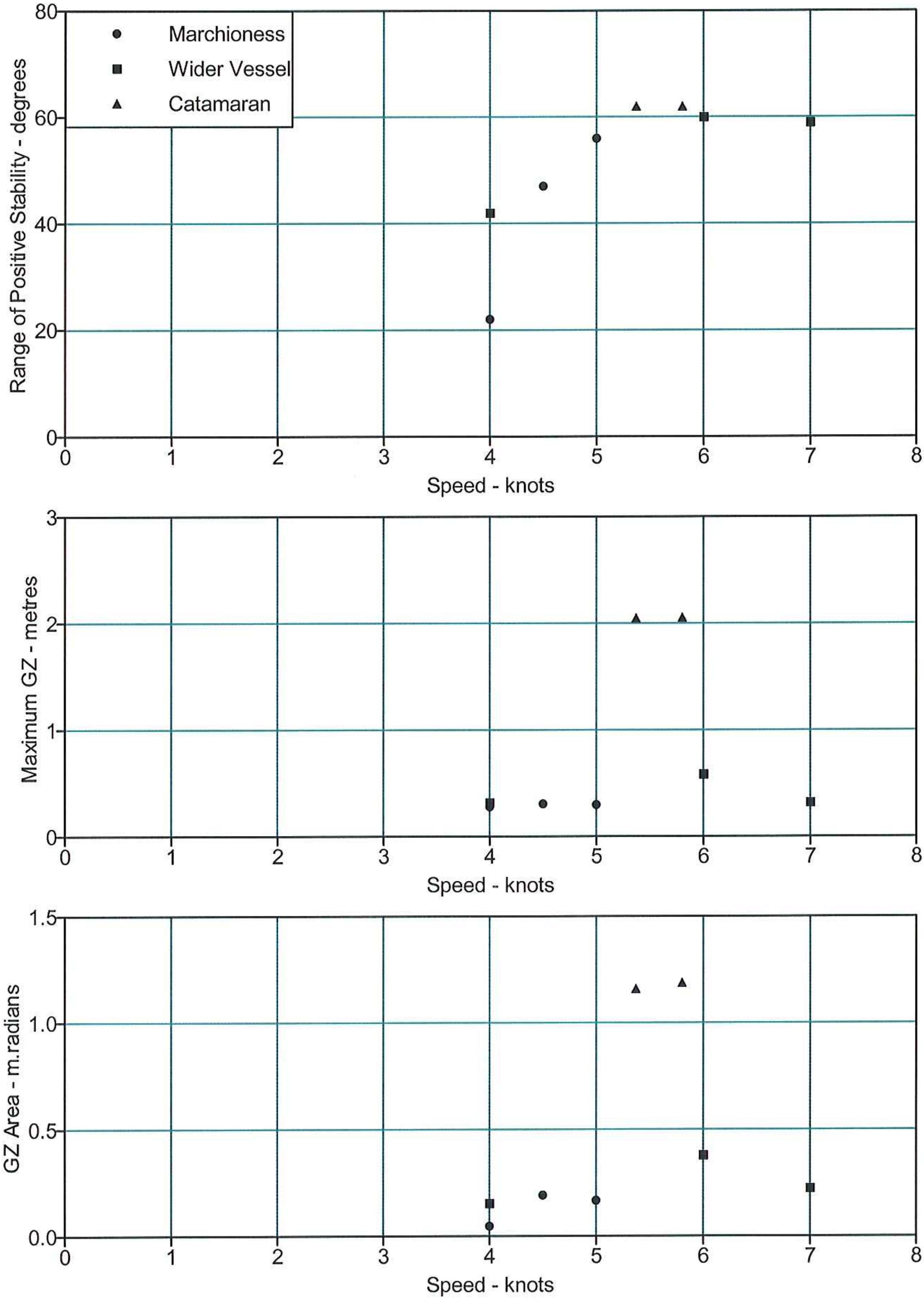


Figure 20 Variation of critical capsize speed with freeboard