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FOR MARINE TECHNOLOGY & INDUSTRIAL AERODYNAMICS

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The Seafarers' Charity & Research England

Evidencing a Seastate Allowance for Inshore Fishing Vessels, Phase 2

EXECUTIVE SUMMARY

This report describes a programme of model scale tests of a 9 metre fishing vessel catamaran design. The test vessel, a hard chine potter of typical proportions, was tested at two configurations – decked and open – over a range of loading conditions representing fishing operations. The tests were conducted in the 138 metre Boldrewood Towing Tank at the University of Southampton.

This work supports an ongoing project of the National Federation of Fishermen's Organisations (NFFO) and the objectives are twofold:

- establish whether the decked vessel configuration is sufficiently safe from capsizing in waves when operated within a seastate orientated allowance, as defined by the Wolfson Stability Method.
- determine the survivability in waves and, therefore, the relative safety from capsizing of the vessel at two configurations: decked and open.

The test vessel was selected in discussion with NFFO and a 2d definition of the hull was supplied to the Wolfson Unit to enable the model construction and the stability calculations.

A 1:9 scale physical model was built and load conditions were identified whereby the decked vessel would fail a statutory stability assessment but, according to the Wolfson Method, could still be operated safely in benign seastates, Physical testing at these conditions confirms the merit of a seastate-based allowance, since all capsize events occurred at combinations of stability and wave height deemed unsafe by the Wolfson Method.

The decked model was then re-configured as an open boat by blocking up its freeing ports, installing a deck drainage system designed to the current MCA Code of Practice and fitting a bilge pump of the appropriate capacity. The open model was then tested at selected combinations of loading condition and regular wave height to enable a direct comparison with the decked model.

Both the decked and the open model survived such direct comparison tests. However, whilst the open model exhibited adequate stability reserves in the conditions tested, the decked model appeared very vulnerable in the same test conditions, due to its low freeboard combined with the unprotected freeing ports.

Further tests were conducted to assess the impact of design features such as non-return flaps applied to the freeing ports (decked model), and the ability of the bilge pumps to clear large amounts of water trapped on deck (open model).

It is recommended to enhance the survivability characteristics of low-freeboard, small decked fishing vessels by protecting the freeing ports with suitable non-return flaps, and to explore options for regulating the minimum height of the fixed bulwark.

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1 INTRODUCTION

This report describes Phase II of a study into the survivability in waves of small fishing vessels at two configurations, decked and open, in relation to stability criteria and guidance presented in the current MCA Code of Practice for under 15m Fishing Vessels [1].

This study was conducted by the Wolfson Unit in partnership with The Seafarers' Charity (TSC) and has benefitted from the participation of several UK fishing industry stakeholders, including: G Smyth Boats, I K Macleod & Associates Ltd, the Marine Accident Investigation Branch (MAIB), the Maritime & Coastguard Agency (MCA), the National Federation of Fishermen's Organisations (NFFO), the Fishing Industry Safety and Health (FISH) platform and the Fishing Vessel committee of the Society of Consulting Marine Engineers and Ship Surveyors (SCMS).

The model tests were attended by 11 representatives of the above organisations, including regulators, naval architects, vessel surveyors, inspectors of marine accidents and boat builders, who co-designed selected elements of the test programme and contributed to the 'Recommendations' section of this report.

Phase I of the study focused on a typical 10 metre monohull design, and is described in Wolfson Unit report no.2900 [2].

2 REGULATORY LANDSCAPE

The new Code of Practice (CoP) for the Safety of Small Fishing Vessels of less than 15m Length Overall [1], that came into effect on 6/9/2021, is an unprecedented effort to improve safety within the small-scale fishing industry and aims at reducing the rate of fatal fishing incidents in the UK. Whilst the CoP applies to the entire under 15m fishing fleet, vessels that pre-date the new standard were not designed with it in mind and, therefore, may not fully align with the new requirements.

The model scale tests described in this report are intended to evidence the CoP provisions described in sections 2.1 to 2.5 below.

2.1 Freeboard

Ref. [2] presents the freeboard provisions introduced by the CoP and the alternative routes to compliance offered to low-freeboard vessels. A summary is provided below and in Figure 1:

- **CoP par. 2.20, 3.11, 3.12 & Annex 8:** vessels with a weatertight deck having a freeboard of 300mm or more may operate without geographical or weather-based restrictions and should fit freeing ports or equivalent water freeing arrangements.

- **CoP par. 3.12.4**: vessels with a weathertight deck having a freeboard between 300 and 200mm should either operate with restrictions or demonstrate equivalence with alternative safety provisions.

- **CoP par. 3.12.3:** vessels with less than 200mm freeboard that can neither demonstrate equivalence nor operate under conditional certification, must be converted to open vessels and comply with the open vessel standards.

2.2 Bilge pumping arrangement

The CoP bilge pumping requirements for existing open vessels are:

> ***4.10.4 (Existing Vessels) Where standards do not exist the bilge pumping arrangements must be fit for purpose.***

It is understood from the MCA that Ref. [3] Part 9 'Pumping and piping systems' is typically used for assessing the fitness for purpose of the bilge pumping arrangements of existing open vessels. In particular, paragraph 9.3.2 of Ref. [3] requires vessels of 7 to 10m to install two bilge pumps (one manual, one electrical) having a minimum combined capacity of 130 litres/minute. In addition, paragraph 9.3.3 states:

> ***9.3.3 The Table above [that is, 9.3.2] primarily relates to bilge pumping systems where the pumps are capable of drawing from any compartment. Where individual pumps are installed, such as submersible pumps, the requirements shall apply to each compartment.***

2.3 Bulwark height

- Decked vessels must meet the requirement stated in Section 4.16 'Bulwarks' of Ref. [3], in particular:

4.16.1 On decked or partially decked vessels, the perimeter of the exposed deck is to be fitted with fixed bulwarks, guard rails or wires, or a combination of these.

4.16.2 The height of the bulwark, guard rail, or wire is to be not less than 1m, where there is unreasonable interference with efficient operation of the vessel, this height for fixed bulwarks, rails, and wires, may be reduced, and the required height of 1m maintained by the use of portable wires and stanchions (…)

It is believed that the intent of 4.16.1-2 above is to prevent man overboard and ensure safe movement of the crew around the weather deck, not to keep green water off it. It is understood from the MCA that the minimum height of the solid bulwark, excluding wires and rails, is not currently regulated in the CoP.

- For open vessels (including decked vessel conversions), the minimum bulwark height is regulated indirectly through the clear height at side requirement, ie:

Annex 8 - The distance between the waterline (in an upright and fully loaded condition) and the lowest point on the gunwale is not less than 400mm for a Vessel of 7m (RL) or under and not less than 690mm for a Vessel of 14.99m in LOA. For a vessel of intermediate length, the clear height at side should be determined by linear interpolation.

At 9.106 metres overall length, the clear height at side of the test vessel in the fully laden condition should exceed 476mm. Assuming a fully laden displacement of 11.9 tonnes (LC 1.1), the clear height at side is 300mm (waterline to deck edge) + 698mm (bulwark height) = 998mm that is, twice the requirement. Had the open variant of the test vessel just met the requirement, its bulwark height would have been 476 (clear height at side required) – 300mm (waterline to deck edge) = 176mm, about 25% of the bulwark height fitted.

2.4 Aft freeing ports

The CoP recognises that standard water freeing arrangements may be unsuitable or impractical for some vessel designs, and permits alternative arrangements:

> ***2.20.1 For Vessels under 12 m (RL), where, due to the nature of the Vessel's design this requirement cannot be met or would prove impractical in operation, alternative arrangements based on MSN 1892 The Workboat Code section 6.3[1], or MCA Marine Survey Instructions to Surveyors 27 (MSIS 27) Fishing Vessel Instructions to Surveyors Chapter 2, 2.20 – 2.21, may be accepted on application to MCA (…)***

In particular, the UK Workboat Code [4] states that:

> ***7.1.3 A vessel (…) may be provided with a minimum of two ports fitted (one port and one starboard), which may be in the transom, each having a clear area of at least 225 cm2 (0.0225 m2). Ports may only be fitted in the transom of vessels which, with the vessel trimmed as necessary to represent a normal operating condition and regardless of loading condition, will ensure the deck can be effectively drained.***

It is understood from the MCA that the above water freeing arrangement is typically accepted for decked Cat C (and occasionally Cat B) fishing vessels under 12m (RL) fitted with a clear deck. Such vessels typically undertake hand lining, netting and potting which are deemed low risk in the CoP.

It should be noted that applications to the MCA under paragraph 2.20.1 must be supported 'by the designer of the Vessel or, where this is not possible, a suitable maritime professional' and must demonstrate equivalence with a recognised construction standard, see CoP par. 2.20.3.

This alternative arrangement is also available in overseas standards such as Transport Canada's 'TP 14619E - Simplified Assessment of Small Non-Pleasure Vessels' [5].

2.5 Fitting non-return flap closures to freeing ports

The CoP does not prevent the installation of non-return closures to the freeing ports, provided they may not be locked in the closed position:

> ***2.20.7 Water retained on board the Vessel will reduce stability and increase the risk of capsize. Lift-up closing appliances shall not be fitted to freeing ports, or locking devices fitted to freeing port flaps, if they reduce the total freeing port area along either side of the Vessel below the freeing port requirement. (…)***

and are fit for purpose:

> ***2.20.12 Where freeing ports are fitted with hinged flaps or shutters, sufficient clearance to prevent jamming is to be provided and hinges are to be fitted with pins of non-corrodible material. Greasing points or nipples are to be provided where practicable.***

The above provisions are reiterated in Section 3.10 'Water freeing arrangements' of Ref. [3].

Further design/maintenance guidance for non-return flaps is available in overseas marine safety notices [6], [7], whilst official safety guidelines provide photographic examples of acceptable freeing port covers [8].

[1] Section 6.3 of The Workboat Code Ed.2 Amt. 1 was superseded in 2023 by Section 7.1.3 of The Workboat Code Ed.3, quoted in this report

The international ISO standard 12217-1:2022 [9] is applicable to boats of 6-24m hull length and permits the fitting of non-return flap closures to freeing ports, as long as degree 3 'weathertight' protection from the exterior is achieved (see also ISO 12216 for the relevant definitions and a practical weathertightness test).

In accordance with ISO 12217-1:2022 [9], assessment of the stability and buoyancy properties of vessels of 6-24m hull length should take into account the following:

- **paragraph 6.1.1.6** - freeing ports equipped with weathertight, non-return flap closures must not be regarded as downflooding openings;

- **paragraph 6.1.2** – when performing a downflooding height test, downflooding heights must be measured as though freeing ports fitted with weathertight, non-return flap closures are closed;

- **paragraph E.3.2** – when determining righting moment (GZ) curves by calculation, flooding of recesses through freeing ports equipped with weathertight, non-return flap closures should be ignored.

3 PROGRAMME OF WORK

The project was split into four Work Packages (WP), as follows:

- WP1 Selection of a test vessel
- WP2 Digital stability modelling
- WP3 Physical testing of decked vessel variant
- WP4 Physical testing of open boat variant

The above WPs and associated deliverables are described in Sections 4 to 7, and a discussion is available in Section 8.

4 WP1 - SELECTION OF A TEST VESSEL

Very few catamarans in the under 12m fishing fleet have a CAD definition of their hull form. The drawings available (if any) are typically scantlings, which are unsuitable for model making and digital stability modelling. This restricted the Phase II test vessel shortlist to newer boats designed to current standards, whose freeboard and stability are typically well in excess of the requirement.

It was therefore agreed with NFFO to select a recent, 9 metre hard chine decked catamaran of typical proportions with a lines plan available, then alter its original loading to represent a low-freeboard vessel with marginal stability. In addition, the original lines were modified for maintaining anonymity.

The test vessel features and Wolfson stability guidance data are presented in the following tables:

Table 1	Principal Dimensions, Datums and Reference Frame
Table 2	Stability Notice and Freeboard Guidance Mark for Decked Vessel Variant
Table 3	Stability Notice and Freeboard Guidance Mark for Open Boat Variant

5 WP2 - DIGITAL STABILITY MODELLING

The WP1 data were processed to produce a digital stability model of the decked vessel variant in the Wolfson hydrostatics and stability suite (HST). The digital hull definition enabled a full stability analysis including assessment against the appropriate stability requirements, in accordance with [1] and [10].

Figure 2 and Figure 3 present the HST hull definition.

The loading conditions modelled and associated stability results are shown in the following tables:

Table 4 Loading Conditions
Table 5 Summary of Decked Vessel Stability and Max KG Criteria

6 WP3 – PHYSICAL TESTING OF DECKED VESSEL VARIANT

6.1 Model features

A 1:9 scale model of the vessel was constructed of carbon composite in accordance with the WP1 data and designated as M1204. The model had a flat main deck and a flat foredeck, both fitted with hatches for ballasting purposes, and a ballasting rig above deck to enable large changes in the vessel's displacement and centre of gravity position. The model had a fixed bulwark with four rectangular freeing ports on each side.

In addition, to enable testing the aft freeing port option discussed in Section 2.4 above, the transom bulwark had two rectangular ports, each having a model scale clear area of 5cm^2. Such an area was selected in accordance with Ref. [11], which recommends a minimum cross sectional area of 5cm^2 for minimising viscous scale effects through small openings.

At a scale of 1:9, a model scale clear area of 5cm^2 corresponds to a full scale area of 405cm^2 that is, 1.8x the minimum CoP requirement of 225cm^2.

Table 6 presents the water freeing arrangements of the decked variant. Figure 4 to Figure 6 show selected model features and Figure 7 to Figure 10 present various transom arrangements.

6.2 Test facility

The survivability tests in waves were conducted in the Boldrewood Towing Tank, University of Southampton. The tank is 145m long, by 6m wide, by 3.5m deep and is fitted with a wavemaker capable of producing full scale regular waves up to 6.3 metres high at a full scale period of 7.0 seconds.

6.3 Test technique

The model was ballasted to the LC1.1 condition, at 11.88t displacement, 4.140m LCG and an inclining in air was performed to adjust its VCG to 1.305m. The pitch gyradius was set to 25% overall length and the roll gyradius to 36% overall beam. Colour-coded vertical bands were painted on each side of the model at two locations (25% overall length and midships) to identify the Wolfson Guidance Mark and associated safety zones.

The model was tested over a range of loading conditions, wave heights and periods, broadly following the Phase I test protocol [2]. In preparation to each run, the onboard ballast was adjusted to achieve the desired loading condition and direct measurements were made of the static heel and trim angles using a digital inclinometer with 0.01 degree accuracy, to ensure consistency with the calculated heel and trim of Table 4. The model was then positioned on the towing tank centreline and approximately 20 metres from the wavemaker.

The model heading was controlled manually with light lines fore and aft. Most runs commenced with the model beam-on to the incoming waves, which proved the most onerous heading for most model configurations. At some runs the model underwent a rotation from 90° (beam-on) to 180° heading (stern-to). If the model had an initial list, it was presented with the low side (least residual freeboard) towards the incoming waves.

All runs but two were conducted in regular waves. This approach enables to correlate the minimum wave height to capsize the model (as measured in the towing tank with a wave probe) with the full scale sea state where it is probable to encounter such a 'critical' wave at least once during a typical inshore fishing trip. For example, formulae given in [12] indicate that approximately 1 in 2000 waves within a typical seastate (Rayleigh distributed spectrum) will be twice the significant height. The reader is referred to [13] for a full discussion on this subject.

Initially, a 'core' set of runs at 4 loading conditions and 6 regular wave heights was performed, to assess the motions, deck wetness and survivability characteristics. Subsequently, additional runs were performed at selected combinations of loading condition and wave height to assess the aft ports effectiveness and influence of the Longitudinal Centre of Gravity (LCG) position, the merit of fitting non-return closures to the side freeing ports and the influence of the shooting door on deck wetness. Tests representing the vessel in waves with its fishing gear snagged to the seabed ('snag tests') were also conducted.

6.4 Results

The resulting data are shown in the following figures:

Figure 13 Regular waves measured and capsize events observed
Figure 14 Variation of Minimum Wave Height to Capsize / LOA with Stability
Figure 15 Close-up of Figure 14 capsize data

The runs performed on the decked vessel variant, configurations tested and wave measurements made are presented in the following tables:

Table 8 Decked vessel variant, regular waves
Table 9 Decked vessel variant, irregular waves

7 WP4 – PHYSICAL TESTING OF OPEN BOAT VARIANT

7.1 Model features

The WP3 decked model was converted to an 'equivalent' open boat by blocking up the freeing ports and unblocking the two drainage openings on deck. Such openings were positioned amidships and 90 mm (full scale) inboard of the bulwarks. Each opening drained freely to a 900 litre compartment positioned in the demihull below, to which a remotely controlled bilge pump was connected. The port and starboard 900 litre compartments were not cross-connected.

Two bilge pumps were installed in the model, one per demihull, and were individually calibrated in-situ over a range of static heads and over the capacity range 64 to 194 litres per minute, The voltage supplied was then adjusted to obtain the CoP minimum required capacity of 130 litres/minute per pump (see Section 2.2 of this report), which was used throughout the tests.

Table 7 presents the water freeing arrangements of the open variant. Figure 11 and Figure 12 show selected model features.

7.2 Test technique

The technique described in Section 6 was also used for testing the open variant. All the tests were conducted at a constant bilge pump capacity of 130 litres per minute.

Having completed a 'core' set of runs to enable a direct comparison with the decked vessel variant, a small number of additional runs were conducted to assess the ability of the bilge pumps to clear up to 4 tonnes of water trapped on deck.

7.3 Results

The resulting data are shown in Figure 13 and Table 10.

8 DISCUSSION

8.1 Open vs decked vessel variant

The following runs enable a direct comparison between the decked and open boat variants over a range of load conditions and regular waves. Inspection of the videos, supplied as part of this report and slowed to represent full scale time, enable a qualitative assessment of motions, deck wetness and vulnerability to capsize:

- LC 1.1: runs 1-7 (open) and 27-33 (decked)
- LC 2.1: runs 9-14 (open) and 34-39 (decked)
- LC 3.1: runs 15-17 (open) and 40-42 (decked)
- LC 3.2: run 21 & 73 (open) and 43 (decked)

The two variants survived all the above runs, generally contouring the waves with both demihulls immersed and exhibiting no extreme motions. This supports the findings of previous multihull tests conducted by the Wolfson Unit [14], which concluded that 'in non-breaking waves multihulls have lower roll responses than monohulls, and no dynamic behaviour was found which might affect their safety'.

Ref. [14] also concluded that 'breaking waves with a height equivalent to the beam of a catamaran may be sufficient to cause capsize'. The waves generated were up to 4 metres in height, which is equivalent to the vessel's beam, but the typical wave steepness produced (~0.07) was half the breaking waves threshold. Therefore, no capsizes should be expected at the regular waves tested, unless the stability is compromised by large amounts of water on deck or bulwark submergence.

Inspection of the test videos shows how the freeboard reduction impacts freeing port effectiveness. For example, the beam-on encounters at 3.4m wave height, shown in run 31 @ LC 1.1, run 37 @ LC2.1 and run 40 @ LC 3.1 show a gradual increase in deck wetness from 300mm upright freeboard (dry freeing ports and dry deck) through to 200mm (freeing ports periodically immersed, wet deck) and 100mm (freeing ports submerged and bulwark occasionally overwhelmed, deck swamped).

At the most onerous load conditions 3.1 & 3.2 the open variant maintained a dry deck, except for small amounts of green water occasionally shipped over the gunwale and rapidly dispersed by the bilge pumps. Conversely, at LC 3.1 & 3.2 and beam-on to the waves, the decked variant had significant water on deck caused by the periodic immersion of the windward freeing ports and, occasionally, immersion of the windward bulwark.

So, whilst the large clear height at side and water freeing arrangements of the open variant appeared to provide adequate stability reserves in the conditions tested, the decked vessel appeared very vulnerable in the same test conditions, due to its low freeboard combined with the unprotected freeing ports.

For both variants, the bulwark height appeared to be the key safety provision against swamping and capsize. However, considering the CoP requirements of section 2.3 above:

- for the open boat variant and assuming LC 1.1 as its fully laden condition, the bulwark fitted was four times the requirement. Greater vulnerability to swamping is expected at the minimum bulwark height.
- for the decked vessel variant, the as-designed bulwark height was used. The CoP does not regulate the minimum height of the solid bulwark of a decked vessel.

8.2 Bilge pumping arrangement (open variant only)

- LC 3.1: run 24: bilge pump effectiveness with 3t water on deck ie 18% of displacement
- LC 3.1: runs 25 & 26: bilge pump effectiveness with 4t water on deck ie 25% of displacement

Despite the large free surface effects and the reduction of positive clear height at side due to the initial water content, the pumping capacity installed proved adequate to disperse the flood water and restore the initial stability characteristics whilst the bulwark prevented more flood water from landing on deck. The open variant operated with a virtually dry deck at all the other combinations of load condition and wave height tested.

8.3 Effectiveness of aft ports (decked variant only)

- LC 3.1: runs 45-47 (beam-on) and 70-72 (beam-on and following seas) at 3 regular wave heights.
- Runs 48 & 49 (beam-on and following seas): water freeing at the LC 3.1 displacement at 2 off-design LCG positions (0.18m aft and 0.22m fwd of design) and 1 wave height.
- LC 3.2: runs 68 & 69 (beam-on and following seas) at 2 regular wave heights.
- LC 3.1: runs 50 & 52: long snag line and short snag line respectively.

When tested beam-on to the waves, the model exhibited progressive accumulation of water on deck via the aft ports. As the mass of water on deck increased, the freeing port immersion increased resulting in more water admitted on deck per wave cycle. Near the end of the beam-on runs the model reached dynamic equilibrium with the ports submerged, water on deck, a deep draught and stern trim.

The above tests were repeated in following seas, when the mass flow rate of the water through the aft ports increased due to wave impact, and the stern trim resulted in the periodic immersion of the windward transom corner. When the waves had settled, the model had developed a heavy list with the windward bulwark submerged, but the residual stability was sufficient to prevent a capsize. A similar behaviour was observed at the off-design LCG positions.

At the heeled condition LC 3.2, deck swamping occurred through the low-side transom corner at both wave heights tested, runs 68 and 69. Within a few encounters, the bulwark became deeply submerged and the model capsized due to insufficient residual stability. Run 68 (aft ports open, side ports shut) may be compared directly to run 67 (aft ports shut, side ports fitted with flaps) where the model survived with a high freeboard and very little water on deck.

8.4 Snag tests and effect of non-return flaps (decked variant only)

The model was held hauler to windward by the tension in a thin line made fast to the tank bottom and connected to the boat at Stn 2.5 (hauler position) through a bridle, thus restraining the motions. Runs 50, 52, 74 & 75 were all conducted in regular waves at 100mm upright freeboard.

- LC 3.1: runs 50 & 52, snag tests with freeing ports open, long and short snag line respectively.
- LC 3.2: runs 74 & 75, snag tests with non-return flaps fitted, low and high snag line respectively

The model survived run 50, when the longer snag line fitted resulted in a shallow angle to the tank floor and, therefore, a small heeling arm. Whilst the deck constantly flooded through the freeing ports, the model never heeled beyond its residual range of stability and its gunwale generally remained above the water. At run 52, the snag line was shortened to about 4m and therefore had a steep angle to the tank floor. The windward bulwark was overwhelmed about 60s (full scale time) after the snag line came fast, and was fully underwater 120s later. At that point, the model capsized almost immediately.

The model was then ballasted to a less stable condition (LC 3.2), fitted with the short snag line used for run 52, when it capsized, and non-return flaps were applied to the freeing ports. Two runs were conducted: no.74 (snag line attached to a low point on the model, hence less heeling moment due to wave action) and no.75 (snag line attached to a high point, hence more heeling moment). Both configurations survived and exhibited little water on deck, despite the test conditions were more onerous than at run 52.

8.5 Effect of shooting door (decked variant only)

- LC 2.2: runs 53-58, open shooting door over a range of regular waves
- LC 2.2: runs 62 & 63, beam seakeeping at two irregular seastates
- LC 3.2: runs 64-67 direct comparison between shooting door open (nos. 64 & 65) and shut (nos. 66 & 67) in beam-on and following seas at 2 wave heights. Non-return flaps fitted at these four runs.

All the runs at LC 2.2 highlighted a common model behaviour, whereby the shooting door contributing to both the ingress and the egress of flood water, but no severe swamping occurred through the door itself. The most onerous encounters were observed when beam-on to the waves, where the bulwark was systematically overwhelmed at regular wave heights above 3m.

At the heavier displacement LC 3.2, run nos. 64 & 65, the model capsized. This was caused by significant flooding of the aft deck through the shooting door at every wave, which determined the progressive accumulation of water on deck and increased stern trim, followed by bulwark submersion until capsize.

8.6 Effect of non-return flaps (decked variant only)

- LC 3.2: runs 44 & 43 (no flaps fitted) and runs 66 & 67 (flaps fitted) enable a direct comparison at 2 wave heights that are, 2.4m and 3.4m.

In 2.4m waves, the no-flaps model configuration exhibited a very wet deck. The initial starboard (ie windward) heel resulted in the accumulation of the flood water by the starboard bulwark, which reduced the residual clear height at side which, in turn, caused the occasional immersion of the windward gunwale. In the same test conditions, the model fitted with flaps survived with a virtually dry deck and a positive clear height at side.

A similar behaviour was observed in 3.4m waves, where the flaps continued to protect the freeing ports from water ingress.

8.7 Wolfson stability method (decked variant only)

The type of plot given in Figure 14 was first presented in [13] and was used to summarise the outcome of the Phase I survivability tests [2]. The solid diagonal line represents the minimum wave height to capsize a vessel with known residual stability characteristics, according to the Wolfson stability method. Combinations of stability and seastate below the line represent operating conditions where the vessel is deemed safe from capsizing, whereas the zone above the line indicates danger of capsizing.

All the combinations of stability (calculated) and seastate (measured) resulting in a capsize lie above the line, which agrees with the Wolfson method.

Figure 14 presents five pairs of near-coincident points (run nos. 64 & 66, 65 & 67, 69 & 74, 69 & 75, 52 & 41), one representing a capsize and the other a no-capsize. This occurred when two different model configurations (one safer than the other) were tested at the same initial[2] load condition and measured wave height. In particular:

- Run nos. 64 (capsize) & 66 (no-capsize): fitting the shooting door resulted in a capsize, see section 8.5.
- Run nos. 65 (capsize) & 67 (no capsize): as above, at 40% higher waves.
- Runs 69 (capsize) & 74* (no capsize): fitting aft freeing ports resulted in a capsize; a snag scenario with flaps fitted and a low snag line proved a safer configuration.
- Runs 69 (capsize) & 75* (no capsize): as above, with a high snag line.
- Run 52* (capsize) & 41 (no capsize): the model with unprotected scuppers capsized when tethered by a short snag line, but survived when free to drift, see section 8.4

Within each pair of data points, the small vertical separation between them is due to small differences in the regular wave heights produced at each run. Such differences were 0.8% or less per pair. Figure 15 is a close-up of the capsize data of Figure 14.

The relatively large vertical separation between the capsize points and the safe/unsafe diagonal line may suggest that the minimum predicted wave height to capsize advised by the Wolfson method is extremely conservative for the catamaran hull form tested. However, further testing at lower and steeper non-breaking waves combined with lower bulwark heights may result in the model capsizing closer to the line due to its greater vulnerability to swamping.

[2] The model's displacement and centre of gravity prior to running. The mass and centre of gravity of any flood water on deck, the virtual rise of the vertical centre of gravity due to free surface effects and any external heeling moments applied (snag moment) are excluded.

9 RECOMMENDATIONS

The draft report ref. 2926_Rev3 and links to the test videos were circulated to all the project participants on 26/7/2024. The participants were invited to comment within the consultation window 26/7 to 16/9/2024.

After the consultation period, the Wolfson Unit collated and anonymised the participants' proposals, added Wolfson's own recommendations and produced this report, ref. 2926_Rev4. This was circulated to the project participants for information, ahead of its official release.

One participant responded in writing within the consultation window, as follows.

i. We[3] recommend that this research be actively integrated into UK policy regarding small fishing vessel survivability and considered during the scheduled 2025 review of the Code of Practice. The findings suggest a potential alternative compliance pathway for existing vessels with low freeboard, which currently face challenges under the existing provisions of MSN 1871 Amendment 2.

ii. The implementation of non-return flaps on freeing ports should be further promoted, particularly for vessels with low freeboard, as this measure could mitigate the risk of water ingress, a factor observed during model testing as contributing to capsize events.

iii. Additionally, the research highlights the opportunity to further regulate bulwark height on newly constructed fishing vessels, and potentially for existing ones. However, it is important to recognise that increasing bulwark height, depending on the fishing method, may negatively impact vessel stability, particularly if gear or catch needs to be lifted higher to clear the bulwark.

iv. We[3] recommend further comparative testing between decked vessels with low freeboard (200mm or less) equipped with non-return flaps, and open vessels with bulwarks close to the minimum height requirement (400mm). This category of vessel has been the focus of potential modifications under the current Code of Practice.

The Wolfson Unit notes that comments i. to iv. above are in keeping with the verbal feedback provided by other participants at the time of testing.

The Wolfson Unit recommends the following:

9.1 On low-freeboard decked vessels, protection of the freeing ports by suitable, well-maintained non-return flaps should be encouraged.

9.2 Official guidance regarding freeing port protection options permitted by the MCA Code of Practice should be provided to owners, boatbuilders and inspectors.

9.3 The minimum height of the fixed bulwark of a decked fishing vessel of less than 15m overall length, excluding wires and rails, should be regulated in future revisions of MSN 1871.

9.4 Future changes to the minimum permitted bulwark height should ensure adequate deck protection from green water without compromising the efficient operation of the vessel.

9.5 The effectiveness of new stability related measures introduced in future revisions of MSN 1871 should either be supported by recognised national or international standards, or evidenced by calculation or physical testing, as appropriate.

[3] The participant's organisation.

10 ACKNOWLEDGEMENTS

This work was supported by The Seafarers’ Charity [grant ref. 925 / 1491] and Research England [2023/24 Participatory Research Fund].

11 REFERENCES

[1] Maritime & Coastguard Agency, MSN 1871 Amendment No. 2 (F) The Code of Practice for the Safety of Small Fishing Vessels of less than 15m Length Overall, 2021.

[2] Wolfson Unit MTIA, “ Evidencing a Seastate Allowance for Inshore Fishing Vessels by Model Scale Testing (Phase I), Report no.2900.,” 2023.

[3] Maritime & Coastguard Agency, MGN 628 (M+F) Amendment 1: Construction and outfit standards for fishing vessels of less than 15m length overall, Revision 0720, 2024.

[4] Maritime & Coastguard Agency, The Workboat Code Edition 3 ‘The safety of Small Workboats and Pilot Boats - a Code of Practice, 2023.

[5] Transport Canada, TP 14619E (10/96) - Simplified Assessment of Intact Stability & Buoyancy of Small Non-Pleasure Vessels: Assessment Guide, 2006.

[6] South African Maritime Safety Authority, *Marine Notice No. 31 'Freeing Ports', Ref. SM6/5/2/1,* 2018.

[7] Maritime New Zealand, Maritime Rules Part 40D: Design, Construction and Equipment – Fishing Ships, 2019.

[8] Maritime New Zealand, *Safety update: Advice on acceptable freeing port covers,* 2017.

[9] ISO Technical Committee (TC) 188, ISO 12217-1:2022 Small craft - Stability and buoyancy assessment and categorization. Part 1: Non-sailing boats of hull length greater than or equal to 6 m, 2022.

[10] Maritime & Coastguard Agency, Marine Guidance Note 503 Amt. No.1 (F) Procedure for Carrying Out Small Fishing Vessel Stability Tests', 2022.

[11] International Towing Tank Conference, “Model Tests on Damage Stability in Waves: ITTC Recommended Procedures and Guidelines, 7.5-02-07-04.2 Rev.2,” 2014.

[12] W. G. Price and R. Bishop, Probabilistic Theory of Ship Dynamics, Chapman & Hall Ltd, 1974.

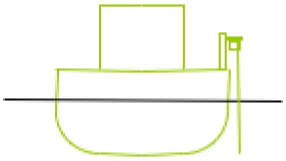
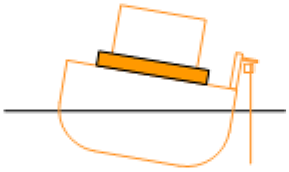
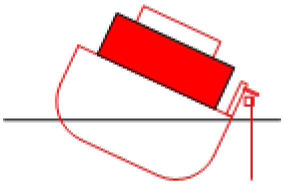
[13] Wolfson Unit MTIA, “MCA Research Project 509: High Speed Craft – Evaluation of Existing Criteria (Final Report)”.

[14] Wolfson Unit MTIA, “Capsize and Stability of Sailing Multihulls, Report No.1441/1, Research Project 427,” 1999.

Table 1 Principal Dimensions, Datums and Reference Frame

Length Overall	9.106 m
Length Between Perpendiculars	9.000 m
Beam Overall	4.005 m
Depth Amidships	1.006 m
Horizontal Datum	CAD Origin, 44mm aft of transom
Vertical Datum	Base line
Midships Position	4.825m aft of FP
X axis	+ve forward
Y axis	+ve starboard
Z axis	+ve upwards

Table 2 **Stability Notice and Freeboard Guidance Mark for Decked Vessel Variant**

STABILITY NOTICE				
Name **M1204** No. **0** Owner **0** Length **9.106 metres** Beam **4.005 metres**	**Loading & Lifting Guidance**	**Safety Zone**	**Minimum Freeboard**	**Maximum Recommended Seastate**
	Good margin of residual freeboard	**Good margin of safety**	At least 51 cm	
	Loading or lifting reduces minimum freeboard to less than 51 cm	**Low level of safety**	25 to 51 cm	1.2 metres
	Excessive loading or lifting reduces minimum freeboard to less than 25 cm	**Danger of capsize**	Less than 25 cm	0.6 metres

Freeboard Guidance Mark - size and location

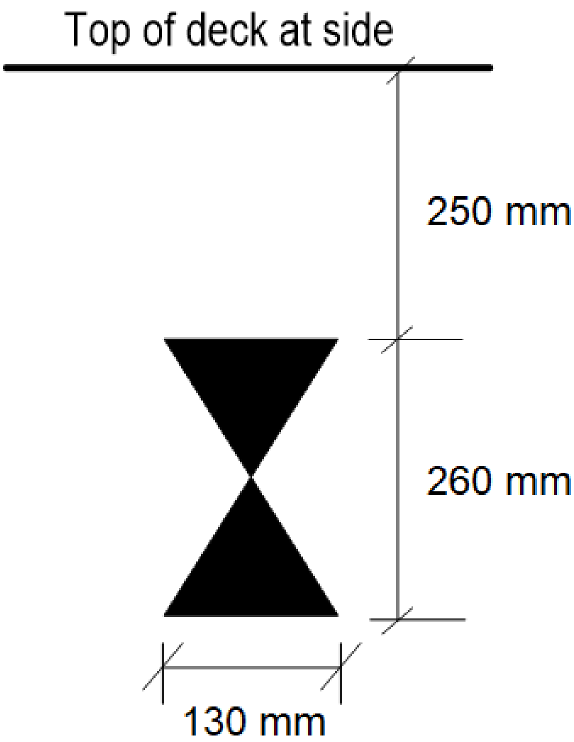
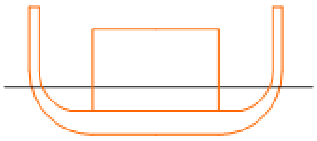
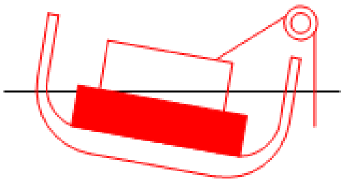


Table 3 **Stability Notice and Freeboard Guidance Mark for Open Boat Variant**

STABILITY NOTICE				
Name **M1204** No. **0** Owner **0** Length **9.106 metres** Beam **4.005 metres**	**Loading & Lifting Guidance**	**Safety Zone**	**Minimum Freeboard**	**Maximum Recommended Seastate**
	Even with a freeboard of at least 66 cm, swamping may be a hazard	**Low level of safety**	At least 66 cm	
	Excessive loading or lifting reduces minimum freeboard to less than 66 cm	**Danger of capsize**	Less than 66 cm	0.6 metres

Freeboard Guidance Mark - size and location

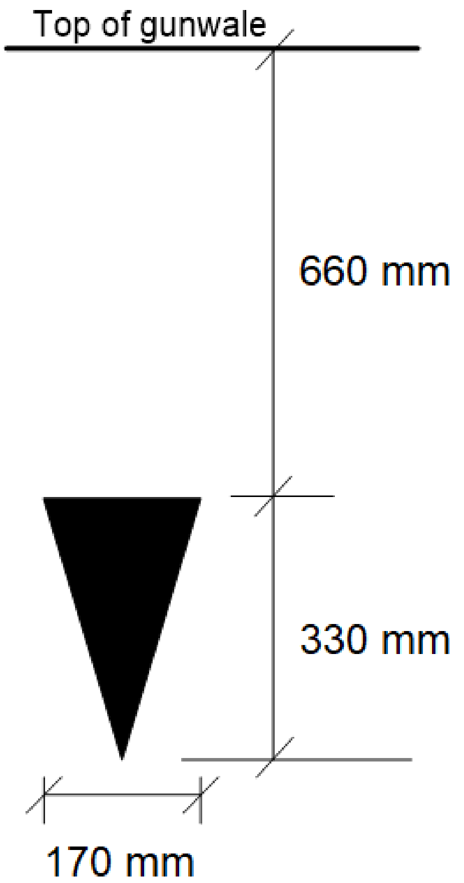


Table 4 Loading Conditions

ID	Upright / Heeled	Displ.	LCG	VCG fluid	Trim Angle	Heel Angle	Notes
		tonnes	metres	metres	degrees	degrees	
LC 1.1	Upright	11.88	4.140	1.305	0.00	0.00	**- Compliant condition** - VCGf @ ~309mm above deck - 300mm min upright freeboard, can operate as decked FV (unrestricted) - just passes the stability criteria[4] ie VCGf = Max KG - passes Move #3 of MGN 503F Offset Load Test
LC 1.2	Heeled	11.88	4.140	1.351	0.00	9.11	- this is LC 1.1 with 45mm VCG growth & ~4 t.m heeling moment applied - fails 4 out of 6 stability criteria[2]
LC 2.1	Upright	14.03	4.115	1.440	0.00	0.00	**- Top heavy & overloaded condition** - VCGf @ ~444mm above deck - 200mm min upright freeboard, can operate as decked FV (restricted) - fails 4 out of 6 stability criteria* - fails Move #2 of MGN 503F Offset Load Test
LC 2.2	Heeled	14.03	4.115	1.440	0.00	4.99	- this is LC 1.1 with ~a2 t.m heeling moment applied - fails all bar 1 stability criteria*
LC 3.1[5]	Upright	16.21	4.097	1.566	0.00	0.00	**- Potential loss condition in decked configuration** - VCGf @ ~570mm above deck - 100mm min upright freeboard, can operate as open FV
LC 3.2	Heeled	16.21	4.097	1.560	0.00	2.02	- this is LC 3.1 with ~0.75 t.m heeling moment applied

[4] CoP 3.5.1, for "all Vessels required to have approved stability information to the satisfaction of MCA, in accordance with MGN 281(F)"

[5] Conditions designated as 'LC 3.1a' in Table 8 and Figure 14 have LCG=3.917m (0.18m aft LCG shift applied). Those designated as 'LC3.1f' have LCG=4.314m (0.217m fwd LCG shift applied).

Table 5 Summary of Decked Vessel Stability and Max KG Criteria

				Filename: Z:\Projects\4234 Seastate allowance Phase 2 (Seafarers)\WP3 Tank\Test Vessel_Rev2.hst					
				LC1.1	LC1.2	LC2.1	LC2.2	LC3.1	LC3.2
Condition Data	Displacement	t		11.882	11.882	14.027	14.027	16.213	16.213
	LCG	m from Zero Pt		4.140	4.140	4.115	4.115	4.097	4.097
	VCGf	m abv base		1.305	1.351	1.440	1.440	1.566	1.560
	TCG	m		0.000	0.348	0.000	0.146	0.000	0.046
	Draught @ AP	m abv base		0.696		0.796		0.896	
	Draught @ FP	m abv base		0.696		0.796		0.896	
	Equilibrium Heel Angle	degrees (+ve stbd dowr		0.00	9.11	0.00	4.99	0.00	2.02
	Freeboard min.	m from deck edge		0.300	-0.012	0.200	0.03	0.104	0.036
	Freeboard min. location	% LOA		50%		50%		50%	
	Pos. Clear Height at Side	m from gunwale		0.998		0.898		0.798	
	Wolfson Safety Zone	as decked		Am	Rd	Rd	Rd	Rd	Rd
	Trim over LBP	m (-ve by bow)		0.000		0.000		0.000	
	Trim angle	deg (-ve by bow)		0.00		0.00		0.00	
GZ Data	Downflooding angle	deg to stbd		n/a	n/a	n/a	n/a	n/a	n/a
	Max GZ (stbd heel)	m		0.502	0.167	0.237	0.101	0.095	0.050
	Positive Range (ignore df)	deg		57.7	34.7	45.4	32.8	22.7	13.3
	GMs	m		2.154	2.218	1.639	1.744	1.251	1.329
Stability Criteria CoP 3.5.1	1: GZ area to 30°	m.rad	0.055	0.2	0.048	0.103	0.036	0.021	0.007
	2: GZ area to 40° or df	m.rad	0.09	0.274	0.067	0.128	0.041	0.021	0.007
	3: GZ area 30° to 40° or df	m.rad	0.03	0.074	0.02	0.025	0.005	0.000	0.000
	4: Max GZ Angle	deg	25	25	25.8	12.2	21.6	6.1	6.1
	5: GZmax abv 30°	m	0.2	0.2	0.152	0.187	0.061	0.000	0.000
	6: GMf	m	0.35	0.35	2.219	1.639	1.744	1.251	1.329
Wolfson	Hcrit, known stability	m full scale		3.519	1.220	2.067	0.975	0.703	0.299
	Hcrit, unknown stability	m full scale		2.309	1.155	1.155	1.155	1.155	1.155
MGN 503F OLT	Equilibrium heel (Move 2)	deg	15	7.9		5.1			
	Res. Freeboard (Move 2)	mm	75	177		70			
	Equilibrium heel (Move 3)	deg	15	7.5		4.6			
	Res. Freeboard (Move 3)	mm	75	134		6			

Table 6 Water Freeing Arrangements of Decked Vessel Configuration

CoP general requirement for existing vessels	para 2.20.5: 3% tot. bulwark area each side
Total bulwark area starboard side (m^2)	5.45
Required freeing port area, each side (m^2)	0.164
Actual freeing port area, each side (m^2)	0.164

All data at full scale unless otherwise noted

Table 7 Water Freeing Arrangements of Open Boat Configuration

CoP requirement	para 2.19.4.2: 2% tot. bulwark area each side
Total bulwark area starboard side (m^2)	5.45
Required drainage area, each side (m^2)	0.109
Actual drainage area, each side (m^2)	0.109
Capacity of each containment tank (litres)	900
Bilge pump capacity (litres / minute)	130, see MGN 628 (M+F) Amt.1, Part 9 ‘Pumping and Piping systems’, Para 9.3.2

All data at full scale unless otherwise noted

Table 8 Runs Performed, Decked Vessel Variant, Regular Waves

	Model Configuration						WAVES - measured Full Scale		Capsize?
			Water freeing arrangements						
Run	Variant	Load Condition	2x bilge pumps	8x side fr. ports	2x aft fr. ports	shooting door	T	H	
							secs	m	
27	Decked	1.1	off	open	shut	shut	4.58	1.74	N
28	"	"	"	"	"	"	4.73	2.45	N
29	"	"	"	"	"	"	5.10	2.75	N
30	"	"	"	"	"	"	5.34	3.15	N
31	"	"	"	"	"	"	5.67	3.44	N
32	"	"	"	"	"	"	5.86	3.76	N
33	"	"	"	"	"	"	6.20	4.00	N
34	Decked	2.1	off	open	shut	shut	4.71	2.43	N
35	"	"	"	"	"	"	5.00	2.82	N
36	"	"	"	"	"	"	5.33	3.17	N
37	"	"	"	"	"	"	5.64	3.46	N
38	"	"	"	"	"	"	5.94	3.82	N
39	"	"	"	"	"	"	6.26	3.96	N
40	Decked	3.1	off	open	shut	shut	5.58	3.38	N
41	"	"	"	"	"	"	6.02	3.76	N
42	"	"	"	"	"	"	6.33	4.00	N
43	Decked	3.2	off	open	shut	shut	5.75	3.44	N
44	"	"	"	"	"	"	4.75	2.43	N
45	Decked	3.1	off	shut	open	shut	5.70	3.42	N
46	"	"	"	"	"	"	6.01	3.79	N
47	"	"	"	"	"	"	6.36	3.98	N
48	Decked	3.1a	off	shut	open	shut	5.70	3.73	N
49	"	3.1f	"	"	"	"	5.82	3.80	N
50	Decked	3.1	off	open	shut	shut	5.71	3.83	N
52	"	"	"	"	"	"	5.75	3.76	Y
53	Decked	2.2	off	open	shut	open	4.75	2.41	N
54	"	"	"	"	"	"	4.91	2.72	N
55	"	"	"	"	"	"	5.28	3.11	N
56	"	"	"	"	"	"	5.54	3.48	N
57	"	"	"	"	"	"	5.83	3.76	N
58	"	"	"	"	"	"	6.19	4.04	N
64	Decked	3.2	off	flaps	shut	open	4.62	2.38	Y
65	"	"	"	"	"	"	5.54	3.33	Y
66	Decked	3.2	off	flaps	shut	shut	4.64	2.40	N
67	"	"	"	"	"	"	5.59	3.35	N
68	Decked	3.2	off	shut	open	shut	5.50	3.29	Y
69	"	"	"	"	"	"	5.92	3.67	Y
70	Decked	3.1	off	shut	open	shut	5.62	3.31	N
71	"	"	"	"	"	"	5.83	3.69	N
72	"	"	"	"	"	"	6.17	3.95	N
74	Decked	3.2	off	flaps	shut	shut	5.71	3.65	N
75	"	"	"	"	"	"	5.72	3.65	N

Table 9 **Runs Performed, Decked Vessel Variant, Irregular Waves**

	Model Configuration								WAVES - measured Full Scale		Capsize?
			Water freeing arrangements								
Run	Variant	Load Condition	2x bilge pumps	8x side fr. ports	2x aft fr. ports	shooting door	Spectrum		Hs	Tm	
62	Decked	2.2	off	open	shut	open	JONSWAP		0.97	4.28	N
63	"	"	"	"	"	"	JONSWAP		1.49	5.88	N

Table 10 **Runs Performed, Open Boat Variant**

	Model Configuration						WAVES - measured Full Scale		Capsize?
			Water freeing arrangements						
Run	Variant	Load Condition	2x bilge pumps	8x side fr. ports	2x aft fr. ports	shooting door	T	H	
							secs	m	
1	Open	1.1	on	shut	shut	shut	4.59	1.74	N
2	"	"	"	"	"	"	4.65	2.34	N
3	"	"	"	"	"	"	5.00	2.56	N
4	"	"	"	"	"	"	5.31	2.69	N
5	"	"	"	"	"	"	5.63	3.44	N
6	"	"	"	"	"	"	5.99	3.76	N
7	"	"	"	"	"	"	6.08	3.94	N
9	Open	2.1	on	shut	shut	shut	4.74	2.44	N
10	"	"	"	"	"	"	5.04	2.78	N
11	"	"	"	"	"	"	5.34	3.11	N
12	"	"	"	"	"	"	5.68	3.44	N
13	"	"	"	"	"	"	6.00	3.76	N
14	"	"	"	"	"	"	6.35	4.00	N
15	Open	3.1	on	shut	shut	shut	5.72	3.42	N
16	"	"	"	"	"	"	6.00	3.80	N
17	"	"	"	"	"	"	6.30	3.98	N
19	"	3.2	on	shut	shut	shut	5.04	2.79	N
20	"	"	"	"	"	"	5.36	3.15	N
21	"	"	"	"	"	"	5.69	3.44	N
22	"	"	"	"	"	"	6.03	3.78	N
23	"	"	"	"	"	"	6.15	3.92	N
24	Open	3.1 + 3t w.o.d.	on	shut	shut	shut	4.74	2.43	N
25	"	3.1 + 4t w.o.d.	"	"	"	"	4.77	2.45	N
26	"	3.1 + 4t w.o.d.	"	"	"	"	6.30	3.96	N
73	Open	3.2	on	shut	shut	shut	5.49	3.36	N

Figure 1 **Drainage of Decked and Open Vessels (source: ref. [1] Annex 8)**

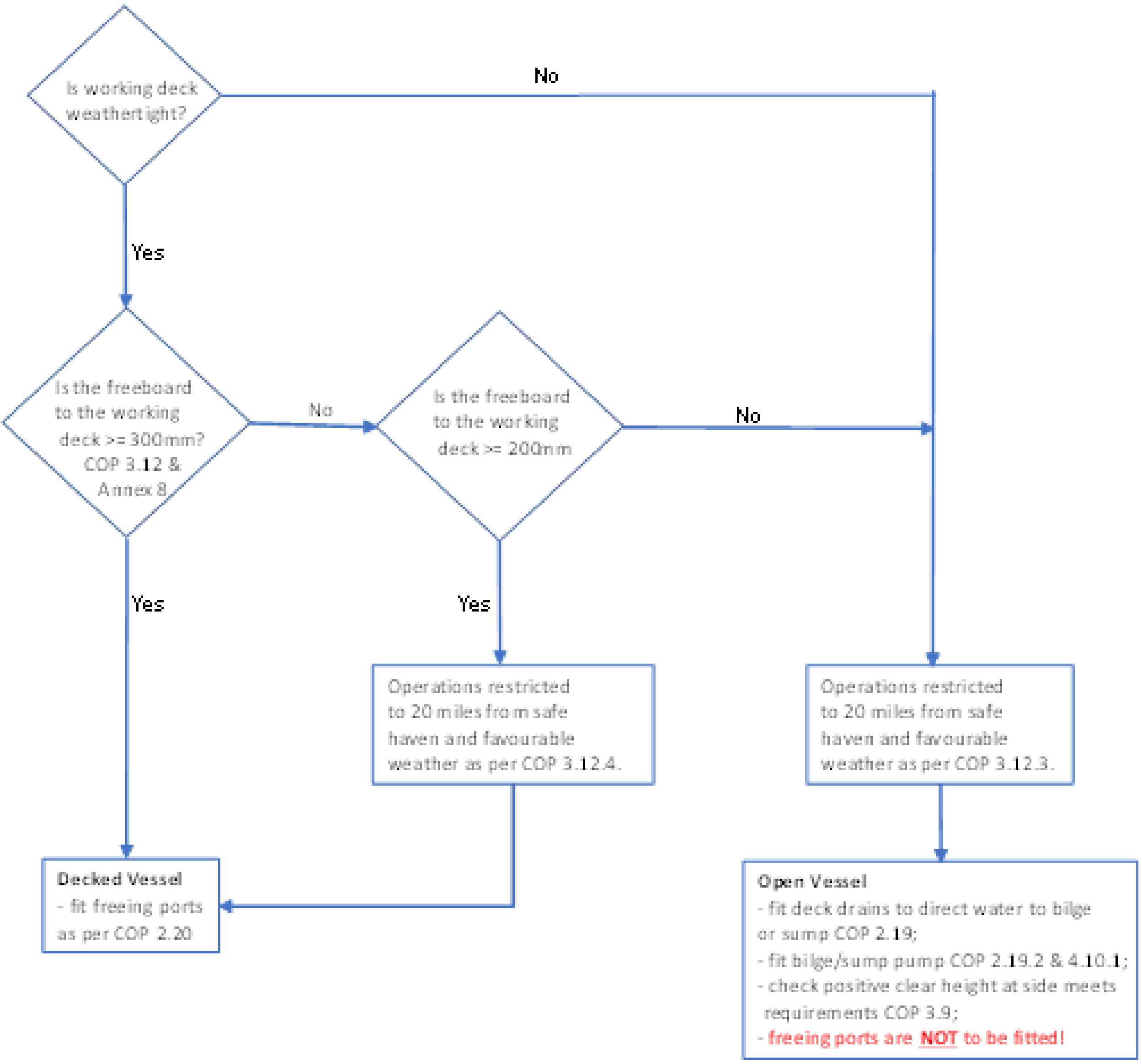


Figure 2 **Bow Quarter View of Hull Form, Stability Model of Decked Variant**

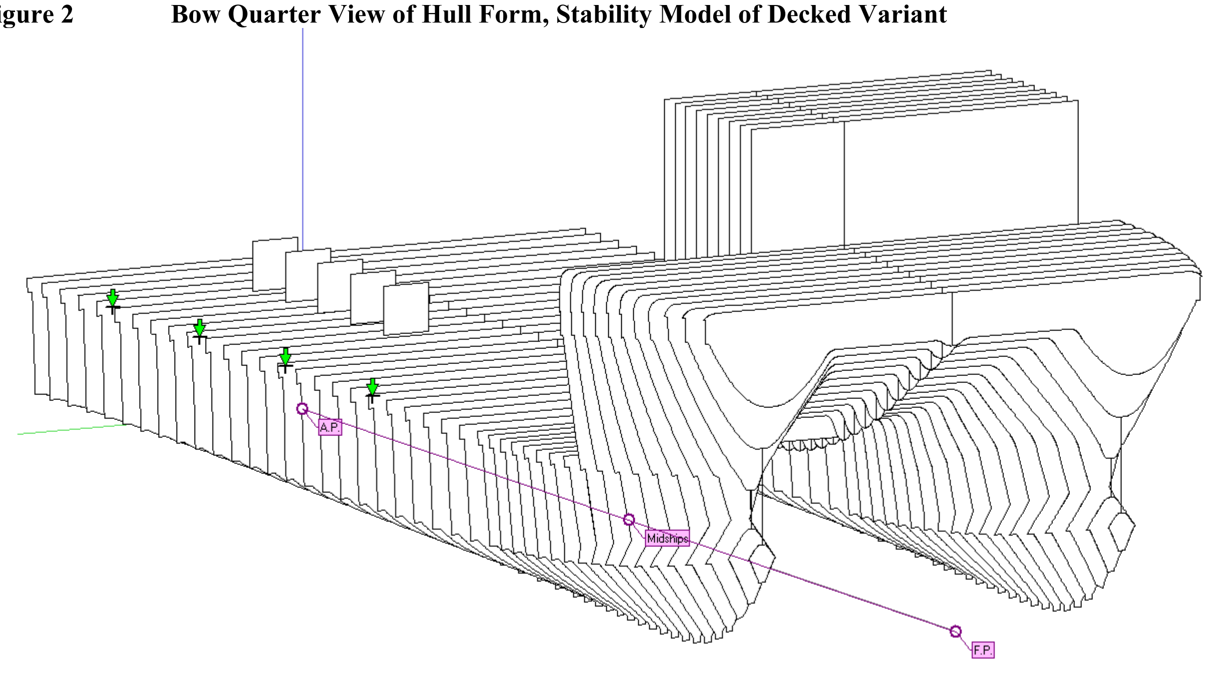


Figure 3 **Stern Quarter View of Hull Form, Stability Model of Decked Variant**

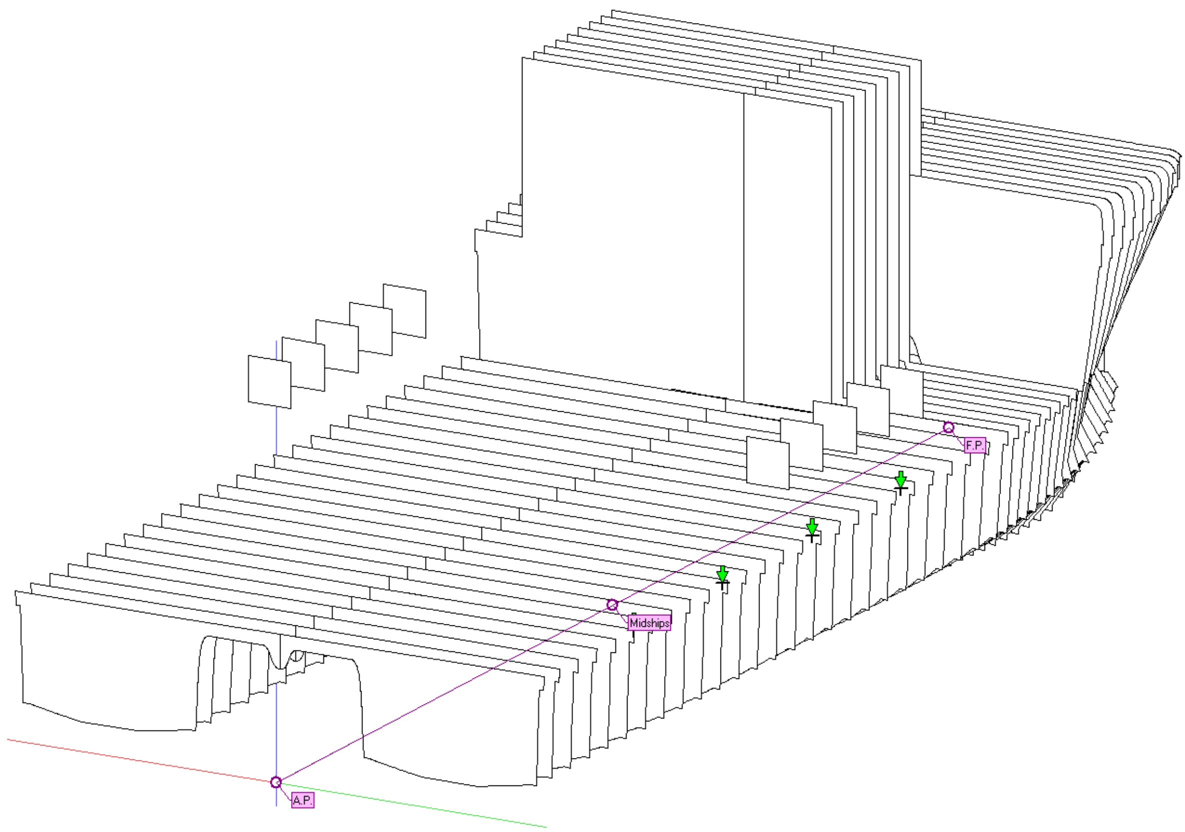


Figure 4 Bow view of M1204

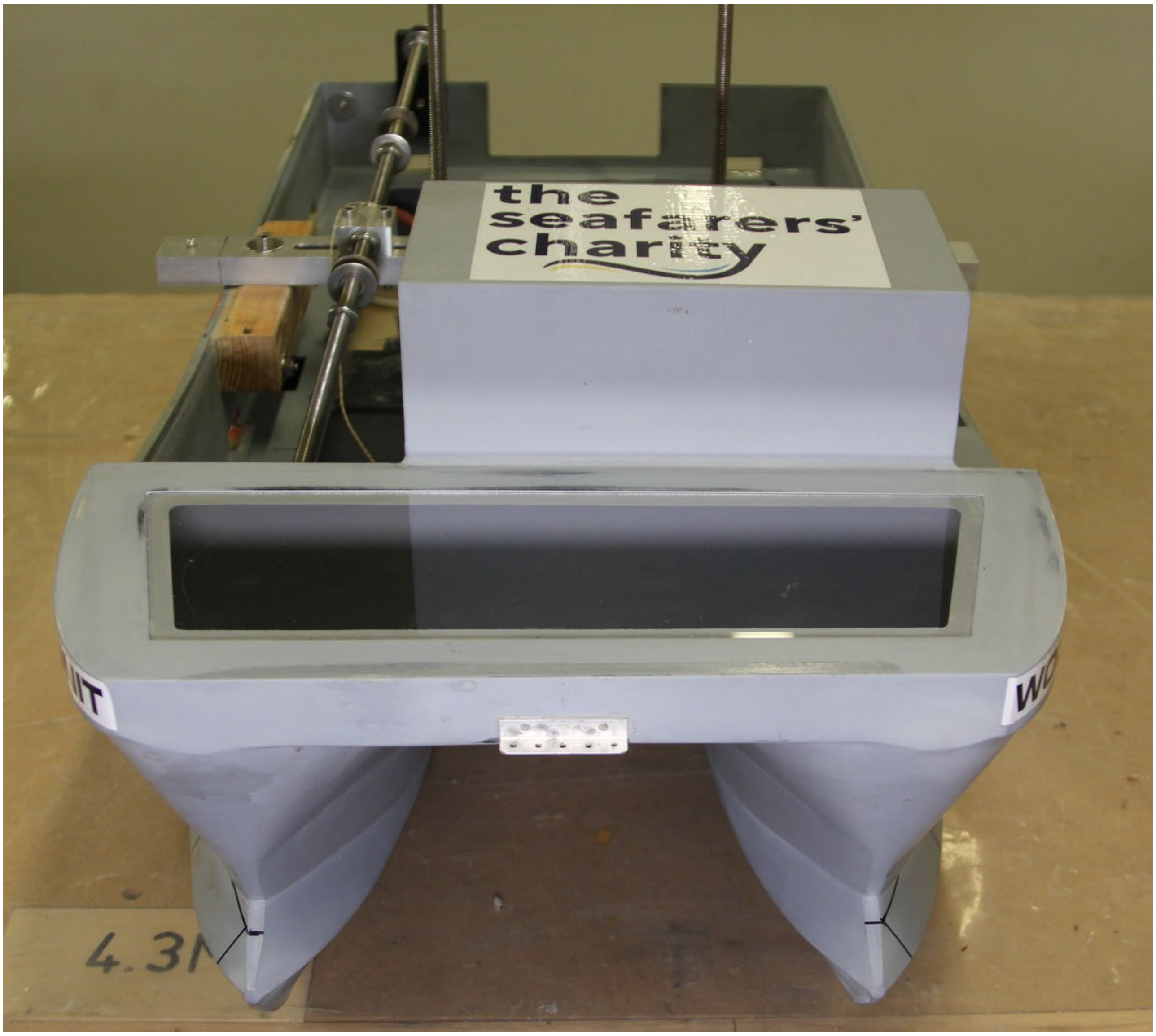


Figure 5 **Starboard view of M1204, decked vessel variant with non-return flaps fitted**

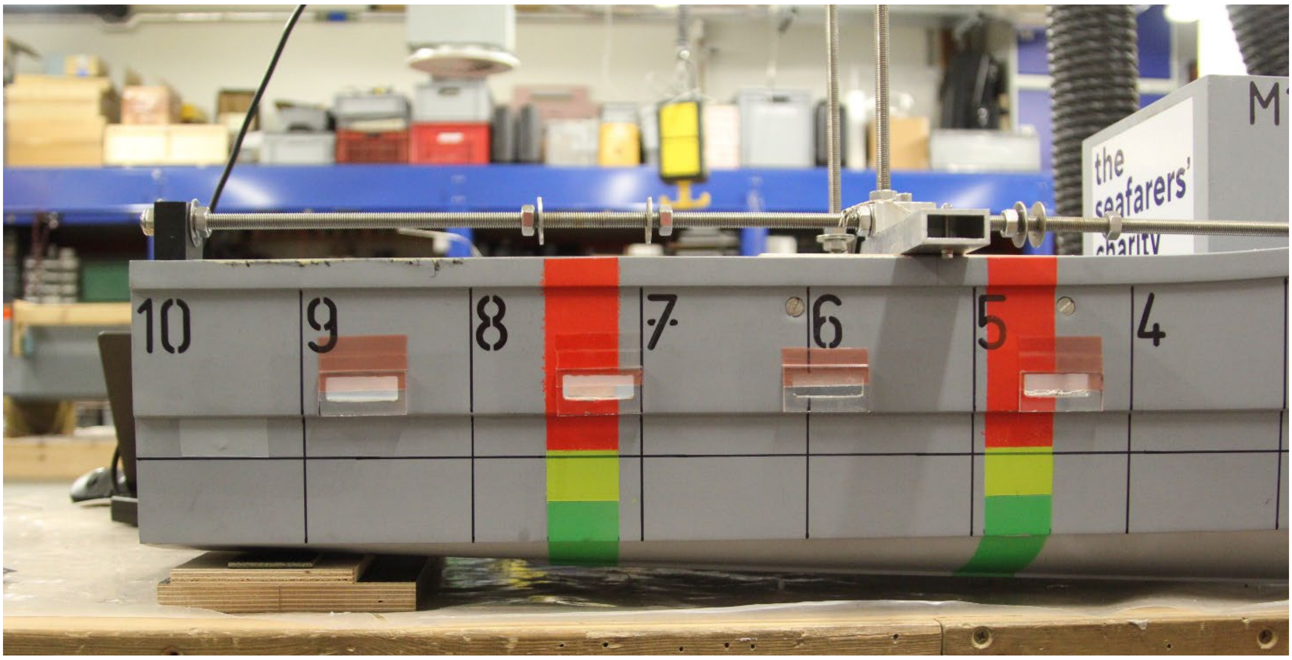


Figure 6 **Port side deck of M1204, decked vessel variant (deck drains blocked up)**

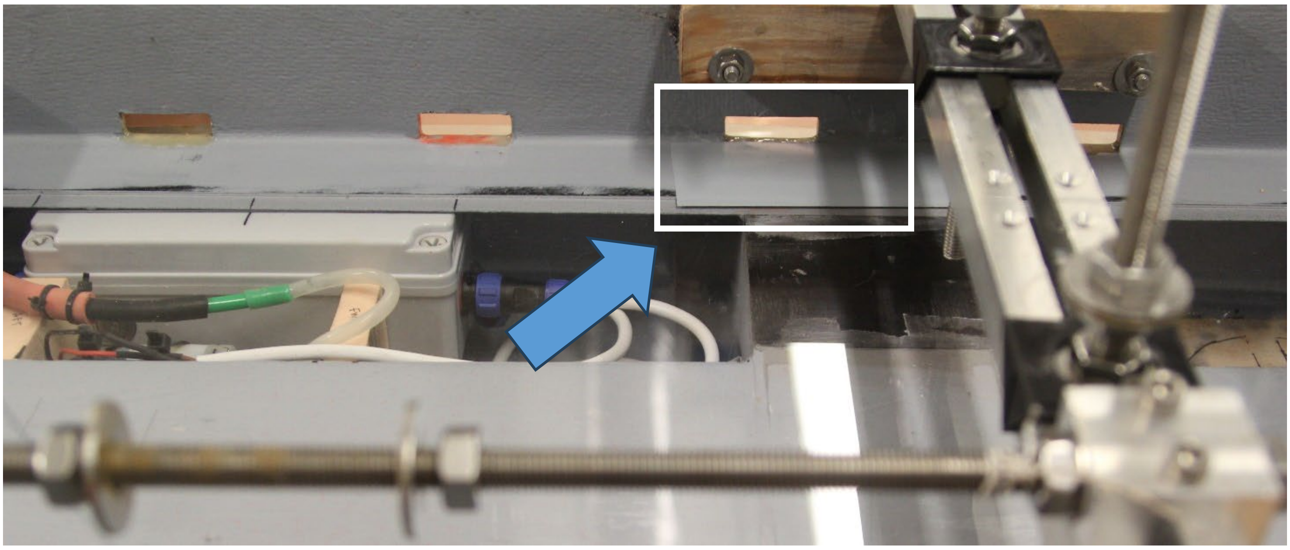


Figure 7 **Stern view of M1204, shooting door open, aft ports open**

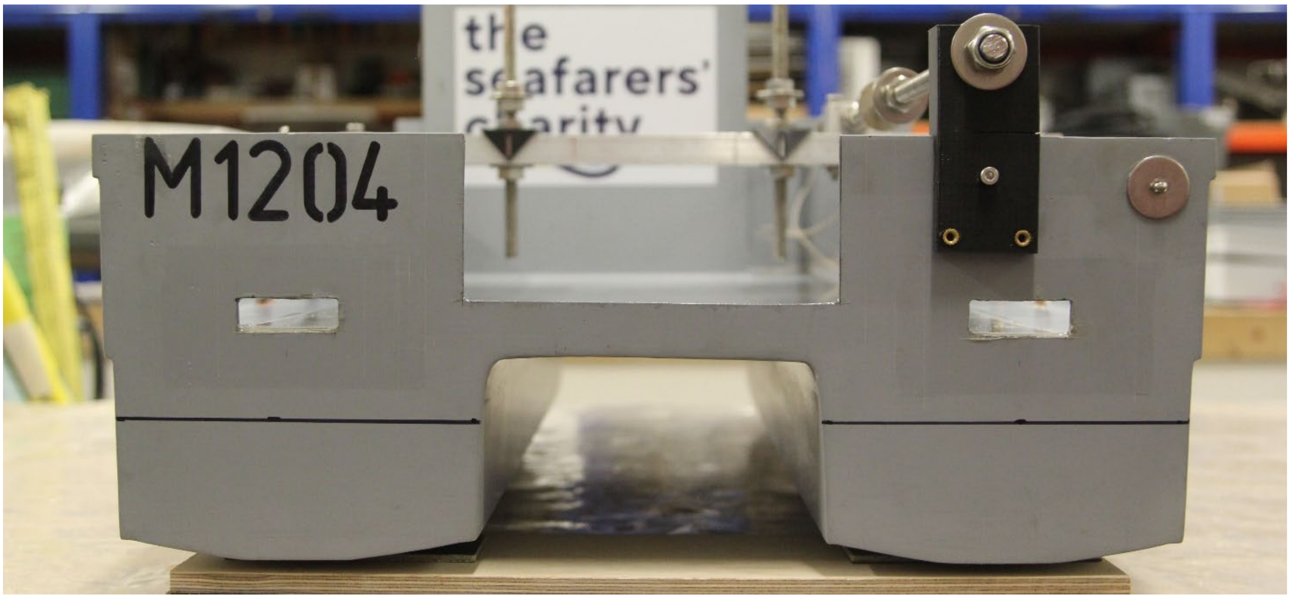


Figure 8 **Stern view of M1204, shooting door open, aft ports shut**

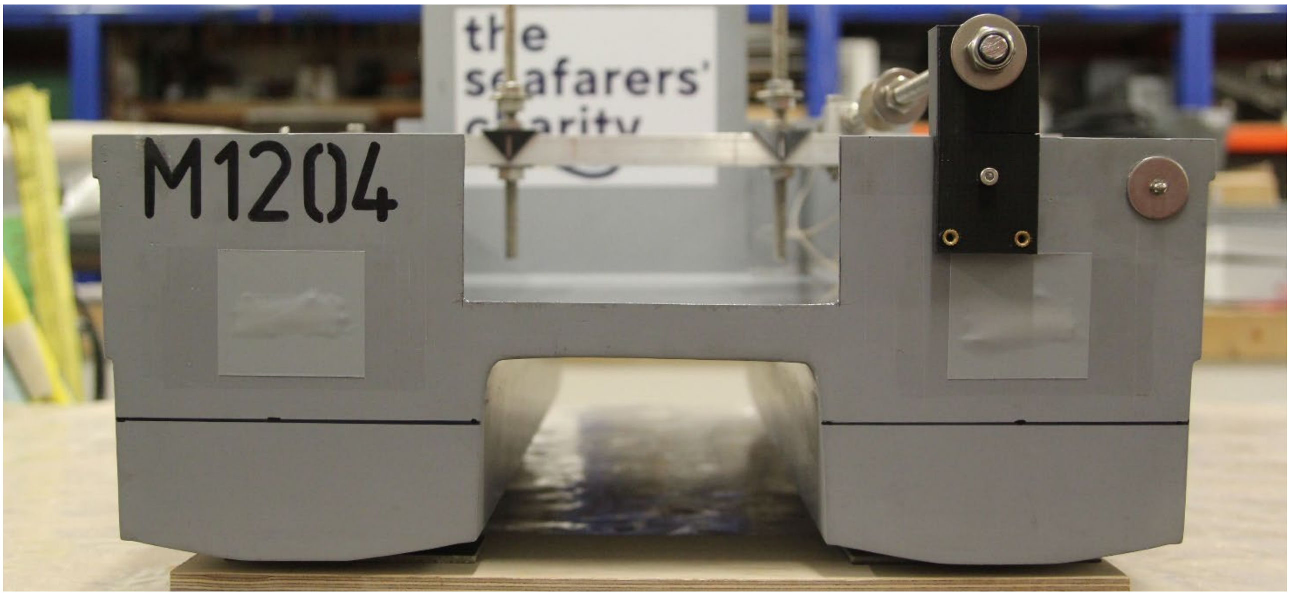


Figure 9 **Stern view of M1204, shooting door shut, aft ports open**

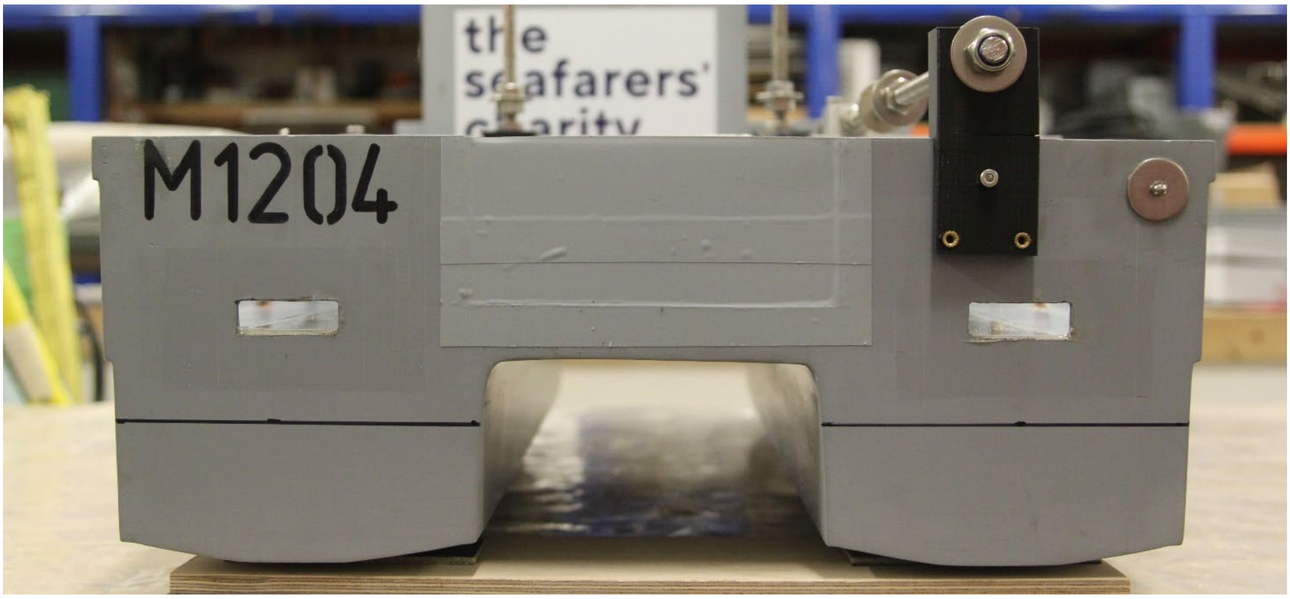


Figure 10 **Stern view of M1204, shooting door shut, aft ports shut**

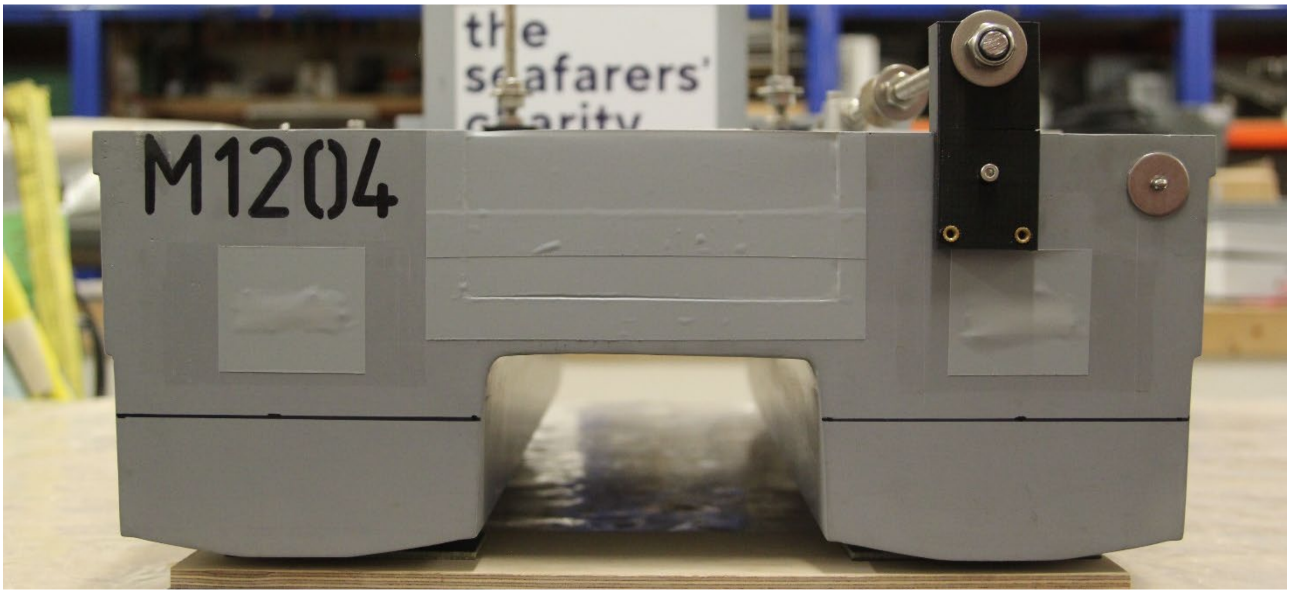


Figure 11 **Starboard view of M1204, open boat variant**

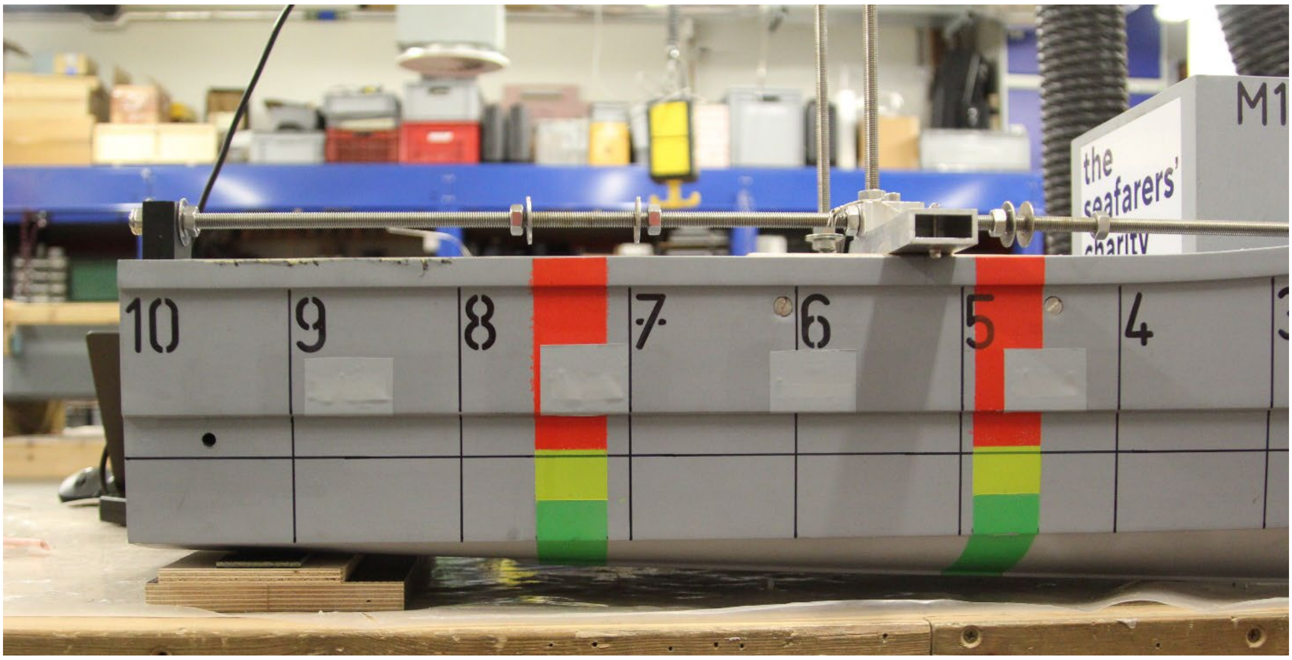


Figure 12 **Port side deck of M1204, open boat variant (deck drains open)**

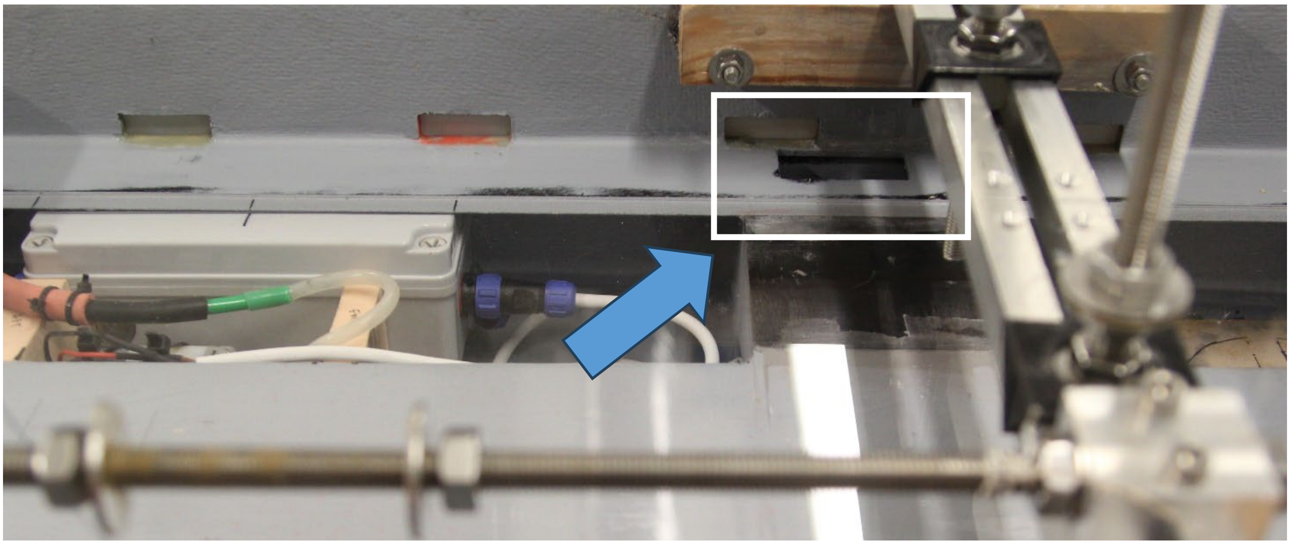


Figure 13 **Regular Waves Measured and Capsize Events Observed**

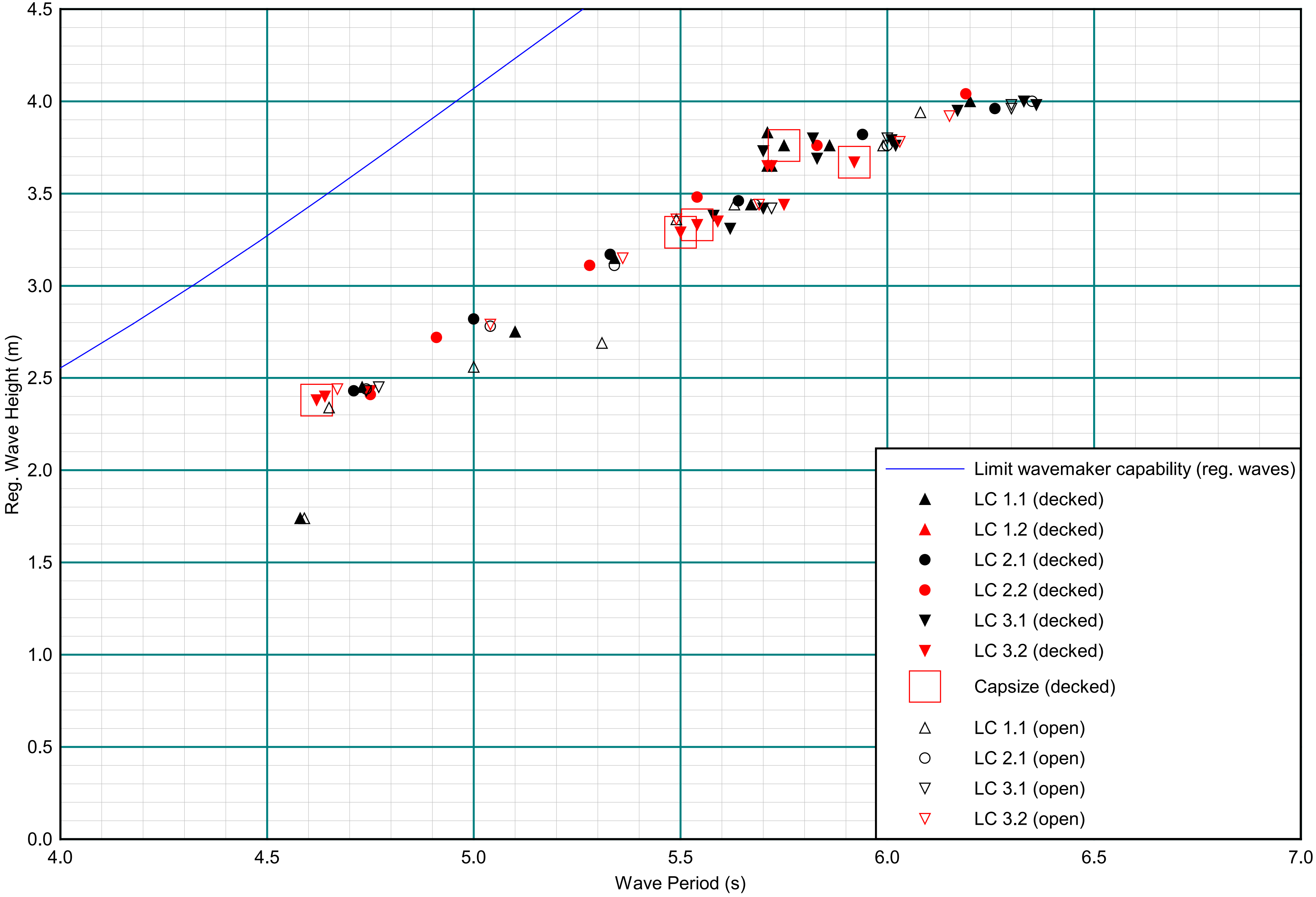


Figure 14 **Variation of Minimum Wave Height to Capsize / LOA with Stability**

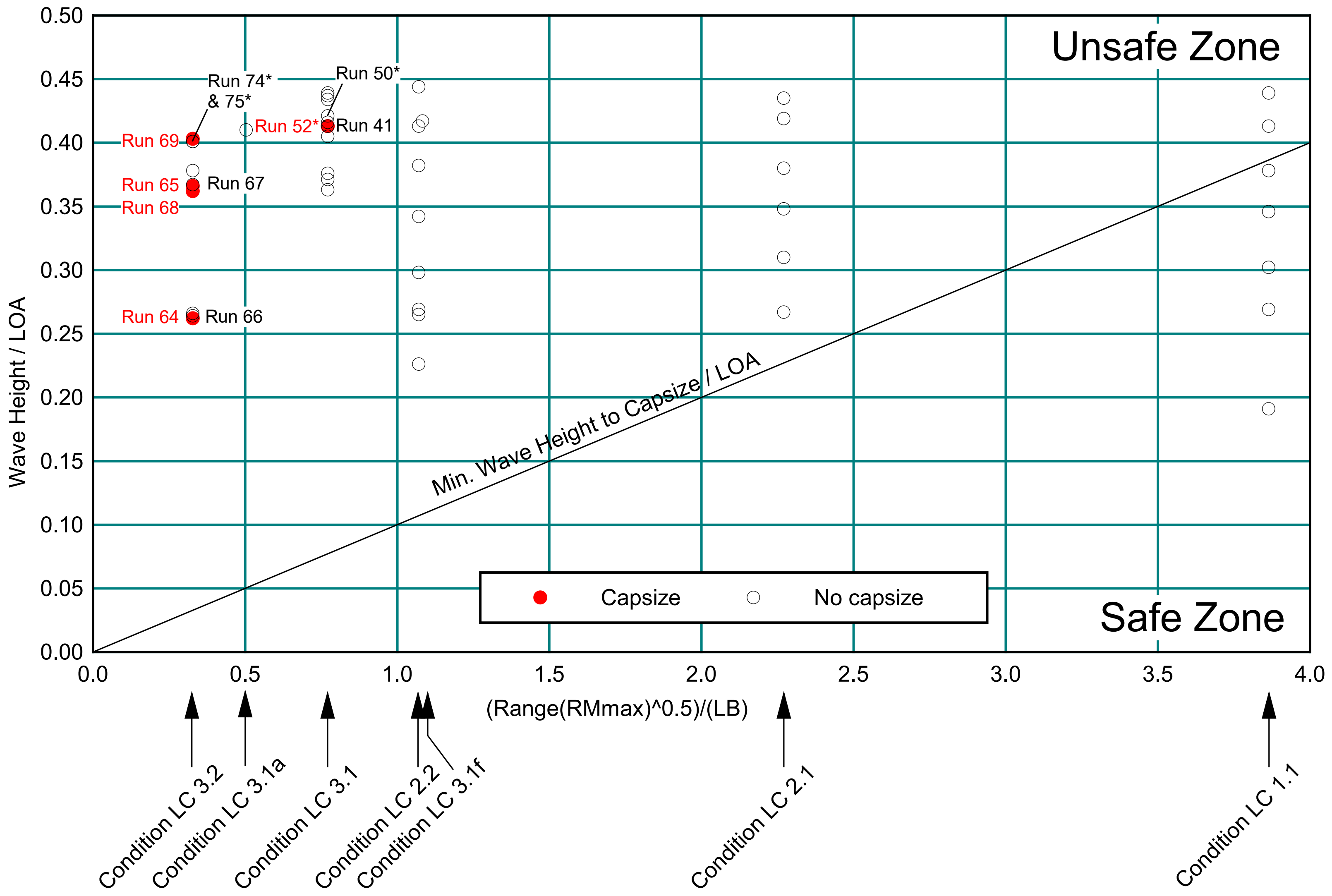
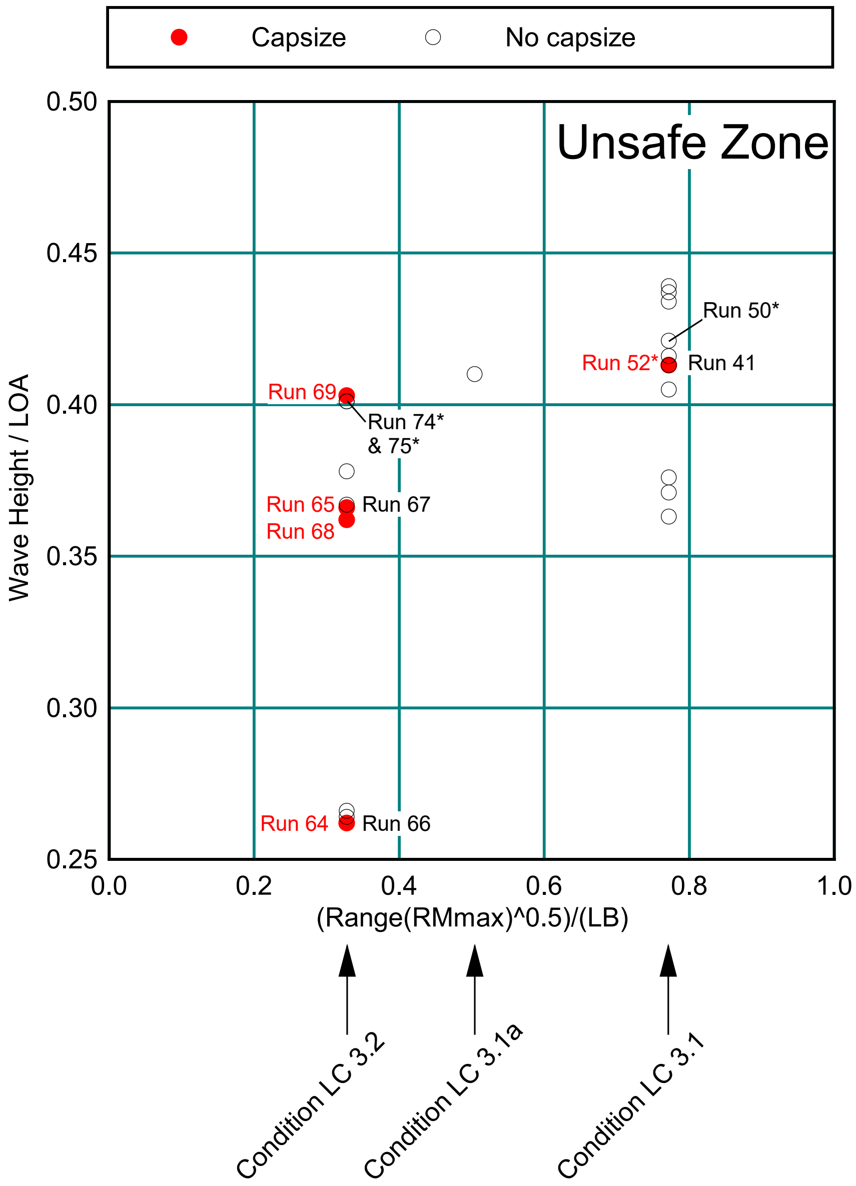


Figure 15 **Close-up of Figure 14 Capsize Data**



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