WOLFSON UNIT

FOR MARINE TECHNOLOGY & INDUSTRIAL AERODYNAMICS

UNIVERSITY OF Southampton

Date : February 2019
Report No. 2698 Compiled By : TP
Verified By : MP

FISA Para-Rowing

Review of Para-Rowing Equipment

1 INTRODUCTION

This report details a technical review of the static stability and hydrodynamic performance of the Para-Rowing equipment, as proposed to World Rowing.

The objective of the study is to quantify the stability of the current FISA one-design para design hulls and pontoons and their theoretical hydrodynamic performance. The second part of the study looks at how the hydrodynamic performance could be increased by use of an off the shelf solution, in the form of an existing Olympic style hull form, and what influence this has upon the overall stability.

2 BACKGROUND

Currently, FISA one-design para design hulls and pontoons, are adopted for the PR1 Single Scull and PR2 Double Scull (with or without pontoons) classes. Discussions are underway as to whether these are the most appropriate design options, for the longer course length of 2000 metres to be used for the Paralympic course length in the future. This programme of work is aimed at providing evidence with respect to predicted differences of level of safety and speed resulting from different configurations, i.e. FISA standard para hull designs versus Olympic style hull designs with/without pontoons.

The Wolfson Unit has been using theoretical and experimental hydrodynamic methods to assess stability (i.e. safety) and hydrodynamic performance of a range of vessels since 1967. These vessels include motor craft, ships, sailing yachts, dinghies, offshore structures and rowing and kayaking hulls.

The table below shows a comparison of the waterline beam (BWL) which is the width at the widest point of the immersed hull measured at the static waterline for an Olympic style hull and the FISA PR1 and PR2 designs.

Para Rowing	Typical Olympic Style (OS) Hull
PR1 – 450mm	280mm
PR2 – 490mm	320mm

It was decided to base the investigation against OS designs as these should be readily available for Para rowing to access.

The current rules allow for the PR1 and PR2 to have pontoons, which provide additional buoyancy outboard of the main scull, thus increasing the overall stability of the vessel. The current rules allow for a pontoon to be positioned either side of the main scull at a minimum distance of 600mm from the centreline of the pontoon to the centreline of the boat. The body plans in appendix illustrate the configurations invested in this report.

3 WOLFSON UNIT SOFTWARE

3.1 HST – Stability Software

HST is the Wolfson Unit's Hydrostatics, Stability and Tank Capacities Program allowing both the definition of hull geometry and also the calculation of the standard hydrostatic and stability parameters of a vessel as well as tank capacity data.

It is relevant for this investigation as it can be used to calculate the stability of the various hull and pontoon configurations with a variety of different athlete weights. The results of the stability calculations allow comparison of righting arm – GZ which is a key stability indicator. This is explained further in Chapter 4.

3.2 Hydrodynamics

The hydrodynamic aspect of the investigation has been conducted using Wolfson Unit in house hydrodynamic resistance modelling techniques based on published and experimentally derived data

The hydrodynamic study takes into account key vessel parameters such as length, breadth and displacement to predict the hydrodynamic and aerodynamic resistance elements. Using the resistance of all the relevant elements a resistance curve can be generated, from which a prediction of the expected vessel speed, using an assumed power input, is made.

For this investigation best recorded events times from 2017 have been used to estimate the power input by the rowers.

4 STABILITY OVERVIEW

It is acknowledged that rowing is a dynamically stable / unstable system but this simplification is to allow the reader and rule makers to get an understanding of the impact of stability and an inferred indication of safety.

In order to infer a level of safety, in this case the rowing scull's resistance to capsize (with the athlete(s) fixed to the boat) a stability assessment has to be conducted.

For hydrodynamic stability, a parameter "GZ" (in units of metres) representing the righting arm, is used. "GZ" is the distance between the lateral separation of the centres of buoyancy and gravity, as per Figure 1.

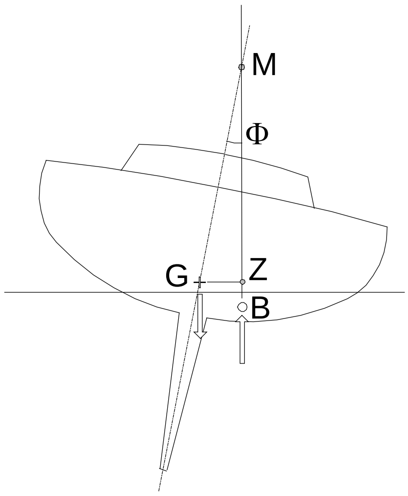


Figure 1: Hydrostatic Stability Parameters

The GZ arm is positive when the gravity force “G” provides a positive restoring force trying to rotate the craft back upright and counteract an externally applied heeling moment.

This can be plotted (as per Figure 2) against heel angle and the area under the graph up to the point of going unstable (below a GZ of zero) indicating the energy required to heel the craft to that angle. Figure 2 is for a sailing yacht with a significant amount of stability for illustrative purposes. So this area parameter will be used as an indication to a vessel’s stability and in our case, a rowing shell with or without pontoons and athletes arrangement level of safety to capsize and/or to downflooding of the cockpit.

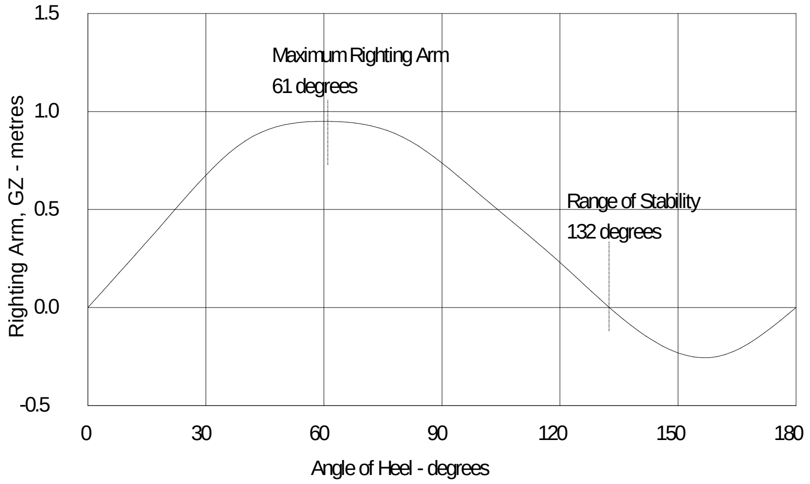


Figure 2: Righting Arm vs Heel Angle

With the stability of a vessel known it is possible to compare it against another configuration to understand the relative level of or inferred stability. The area under the two GZ curves is factored resulting in a non-dimensioning stability parameter (or implied level of safety factor).

$$GZ_1 / GZ_2 = \text{Implied level of safety factor}$$

Figure 3 shows an example of this implied level of safety. The red line illustrates the current minima safety of an existing design (Safety factor = 1) and then further configurations are then compared against this minimum inferred safety. Anything below the line indicates that the level of safety has reduced and likewise anything above the line, the level of safety has increased.

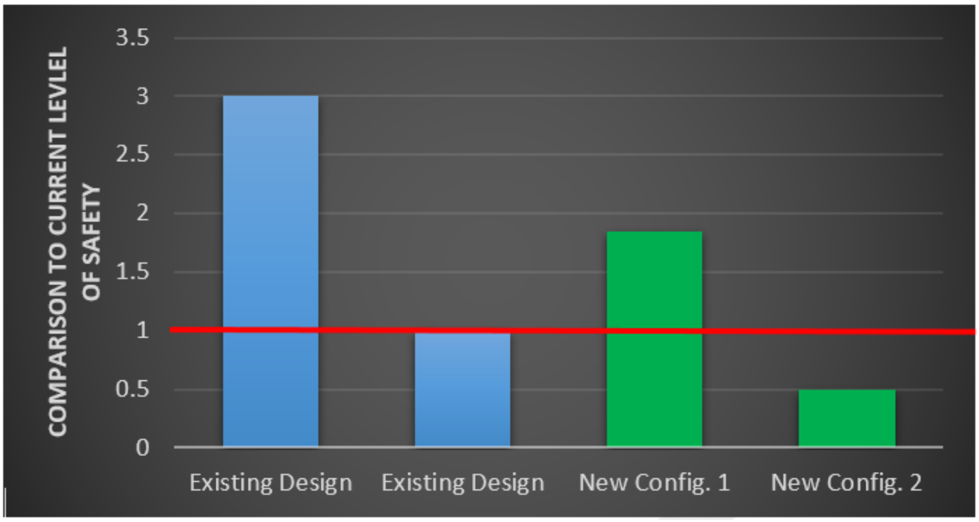


Figure 3: Example of implied safety factor

In order to assess the stability of this system the following assumptions have been made:

- The stability is assessed in a static state. I.e. the vessel is stationary with no dynamic stability
- The buoyancy and stability gained from the rowers oars has not been factored
- The balancing influence of the athletes body and arms has not been factored

5 EVENT ANALYSIS

5.1 PR1 Analysis

The PR1 scull is 6 meters long with a waterline beam of 450mm with a pontoon either side of the main scull. The technical documentation had been supplied by World Rowing.

The study carried out has investigated the following configurations:

- Static stability with pontoons
- Vertical centre of gravity influence upon stability
- Capsize and recovery stability
- Resistance and race performance prediction

For all PR1 investigations the following assumptions and criteria have been applied:

- The total athlete weight is 75kg
- The centre of gravity of the rowers is 0.45m above the waterline
- The pontoons are positioned so that in a static condition they are submerged so that each pontoon is providing 2kg of buoyancy (4kg in total).

5.1.1 Stability Results Summary for PR1

Figure 4 shows the GZ curve for 850mm and 600mm pontoon separations.

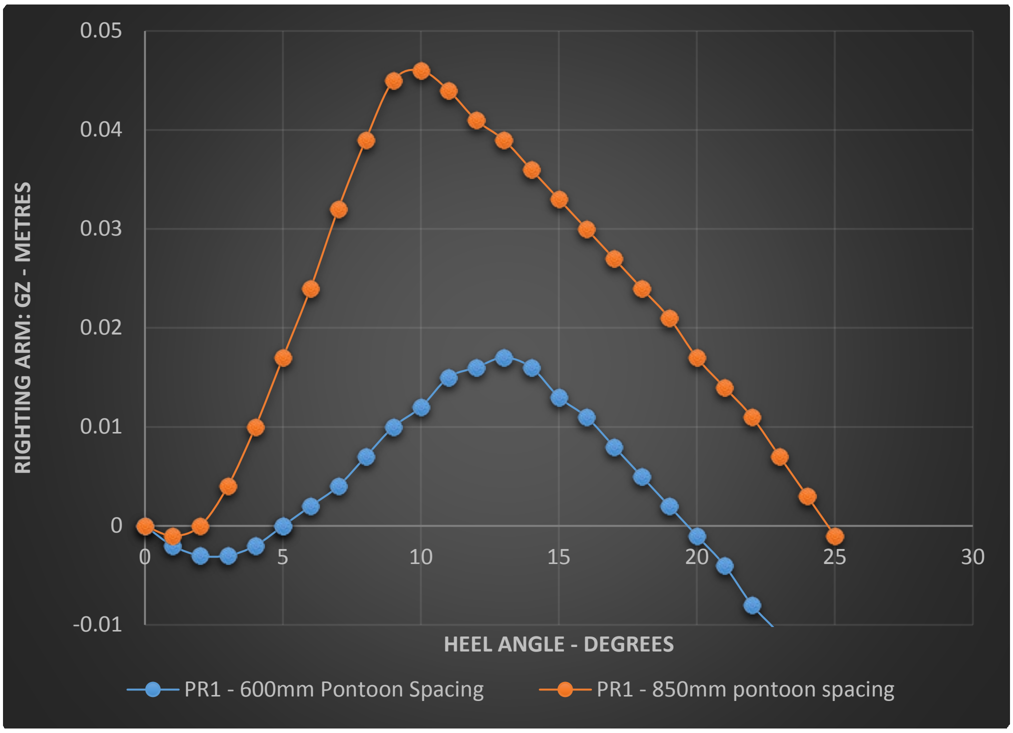


Figure 4: PR1 Stability for a 75kg Athlete

As stated earlier, the dynamic stability effects, athlete induced control and impact of the oars have been ignored.

This provides a range of 0.002409 to 0.009233 metres.radians as an area under the GZ curve up to a heel angle of 20 degrees, for 600 and 850mm pontoon spacing respectively. The following results presentation uses these values as a means to create a non-dimensioning stability parameter (or implied level of safety factor) to make changes in PR1 setup easier to understand.

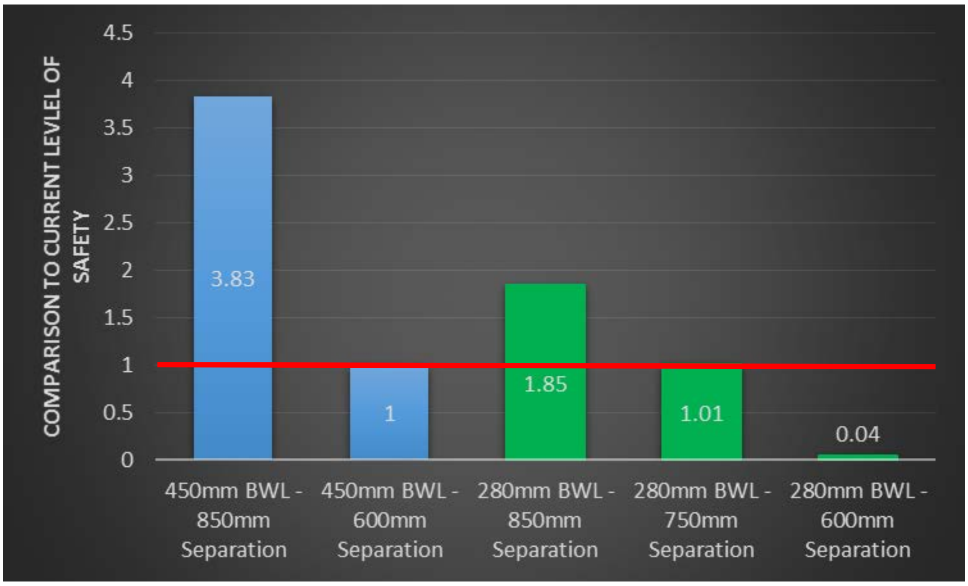


Figure 5: PR1 Stability Comparison

Using the existing waterline beam (BWL) of the PR1 scull and minimum pontoon separation of 600mm as the minimum standard, i.e. factor equal to 1.0. The area under the GZ curve for a summary of BWL and pontoon separation as represented in Figure 5.

Summary:

- The red line defines the existing Class minima limit in terms of ‘simplified’ level of safety.
- The first blue column is for the PR1 FISA (i.e. with 450mm BWL) one design with the pontoons at 850mm separation and shows the level of safety 3.8 units above the existing Class minima.
- The second blue column is for the PR1 FISA one design and represents the existing Class minima, hence lies upon the red limiting line.
- The first green column represents a BWL in keeping with a typical Olympic style single scull hull form (BWL = 280mm) and with pontoons at 850mm separation. This lies within the range of safety currently possible within the rules.
- The second green column represents a 280mm BWL scull with a pontoon separation of 750mm which achieves the existing inferred Class minima stability limit.
- The third green column represents a 280mm BWL scull with a pontoon separation of 600mm which has significantly less inherent stability and therefore results in a low comparative level of safety to the PR1 options.
- The modelling shows that to achieve the same level of stability as currently exists in the FISA PR1, an Olympic style single scull must have a minimum pontoon separation of 750mm.
- One consideration, not taken into account in this study, is that in most cases when installing a para seat on an Olympic style single the seat will be up to 75mm higher than in a PR1. This has the effect of raising the centre of gravity and reducing stability. To achieve equivalent stability as the PR1 the pontoons would have to be set at 820mm from centreline of the boat, which would also make the boat more difficult to right after a capsize.

Other pontoons variations have been investigated but these have been omitted in this presentation.

To conclude, from the analysis so far, it is possible to achieve a level of safety (in excess of the minimum that the Class rules currently allow) in terms of transverse static stability with a 280mm BWL scull with pontoons to that of the standard PR1 FISA design and pontoons. To achieve this, a larger minimum pontoon separation of 750mm would be required.

5.1.2 Capsize and recovery stability

Questions were raised as to the ability to re-right a PR1with pontoons and with the athlete still strapped in position. This led to carrying out a stability analysis on the inverted state.

Figure 6 shows that the PR1 FISA design with 850mm is the most difficult in terms of effort to right a scull after capsize and therefore all other configurations fall below the red line, which indicates they are easier to right after a capsize. This could be an important consideration in regards to safety.

The more slender beam results in a configuration that is easier to right, as does a narrower float separation, but this in turn has a lower upright stability which will make the vessel more susceptible to capsize.

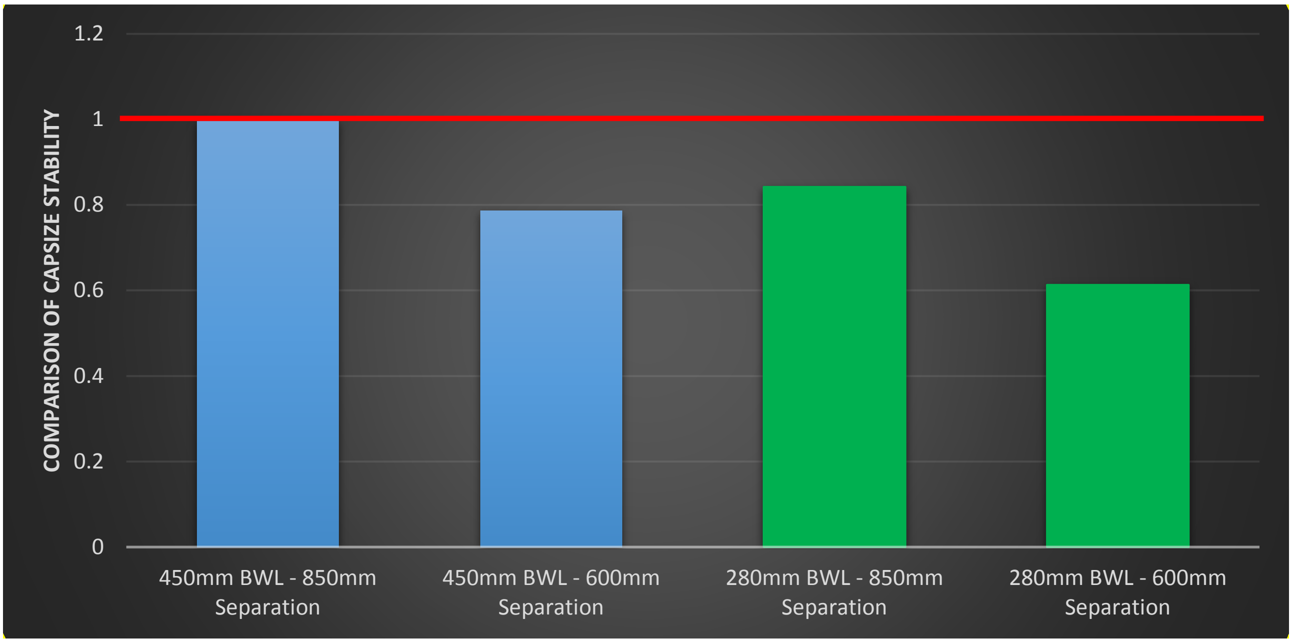


Figure 6: Inverted Stability

5.1.3 PR1 Resistance and Race Performance Prediction

Using our resistance model, the parameters for the PR1 scull, 280mm BWL scull and pontoons we used to generate a prediction of the resistance versus speed as shown in Figure 7. Solid lines represent configurations with the pontoons in the water and dashed lines with the pontoons clear.

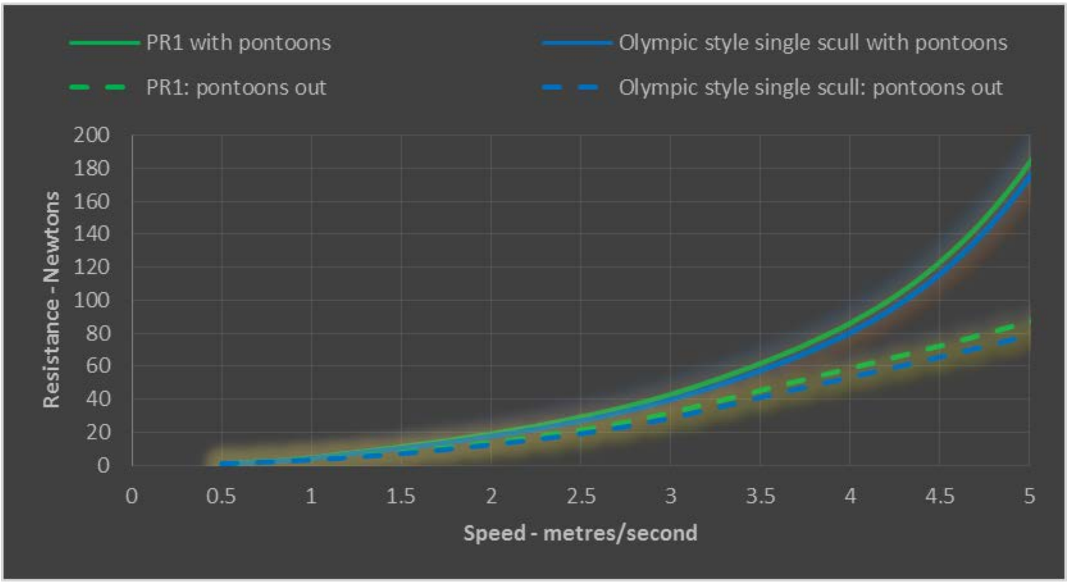


Figure 7: Resistance vs speed of PR1 and 280mm BWL configurations

	Both pontoons touching	Single pontoon touching	Pontoons out	Both pontoons deeply immersed
PR1	262.9	226.3	189.0	363.0
280mm BWL Scull	244.3	207.6	171.0	343.7

Table 1 Average power predictions in watts, to achieve 3.704 m/s

Table 1 summarises the predicted average power (in watts) required to achieve 3.704 m/s. Both pontoons touching assumes each pontoon carry 2 kg of displacement, single pontoon touching carry 2 kg of displacement, pontoons out with scull hull only and both pontoons deeply submerged each carrying 5 kg. For reference, 2 kg of flotation is approximately 50mm of immersion of the pontoons in the water.

This shows the required power reduction of the more slender scull hull over the PR1, which is primarily driven by its lower wetted surface area.

	Both pontoons touching	Single pontoon touching	Pontoons out	Both pontoons deeply immersed
PR1	3.359	3.503	***3.704***	3.036
280mm BWL Scull	3.436	3.598	3.833	3.094

Table 2 Predicted speeds (in m/s) for each configuration based on a set power

Table 2 presents the predicted speeds for the various configurations of scull and pontoon immersion for the same power input. The lower hydrodynamic resistance of the 280 BWL scull results in a notable increase in speed and there are significant reductions in speed due to pontoon resistance. These are also borne out in the predicted race speeds for a 2000m presented in Table 3.

	Both pontoons touching	Single pontoon touching	Pontoons out	Both pontoons deeply immersed
PR1	595.4	570.9	***540.0***	658.8
280mm BWL Scull	582.1	555.9	521.8	646.4

Table 3 Predicted 2000m course times in seconds

The baseline time used for the 2000m race was 540 seconds, which equates to an average speed of 3.7 meters per second with a constant power output of 189 Watts, based on the PR1 with the pontoons out of the water.

- Using the same power, the 280mm BWL scull and with the pontoons out of the water is predicted to complete the course at an average speed of 3.833 meters per second. This is approximately 3.5% faster than its PR1 equivalent which equates to a completing the course 18 seconds quicker.
- The athlete would have to produce 10% less power in the 280mm BWL scull option compared to the PR1 design to complete the course in the same time.
- The reduction in stability of the 280mm BWL scull is likely to result in more occasions when the pontoons will be immersed during a run, these increases in resistance can be inferred using Table 1. In such cases, it would be valid to compare the performance of the PR1 with pontoons out to the 280mm BWL scull with a single pontoon touching, for instance.

These highlight the potential performance advantage that could be expected by reducing the BWL of the main scull. If rule changes were to be passed, the waterline beam and wetted surface area are the biggest drivers in terms of power requirements and race time but these would require strict regulation to prevent exploitation at the expense of stability and safety.

5.1.4 Other areas

Although not within the scope of this study, if unrestricted, the ‘optimal’ hull shapes for PR1 athletes may not be a typical Olympic style hull form. These hull forms have been optimised for higher race speeds and to accommodate the dynamic effects of the athlete on a sliding seat which is different from a PR1 athlete input.

5.2 PR2 analysis

The PR2 stability and performance analysis is slightly more complicated that the PR1 scull due to the addition of an extra athlete and that it can be operated with and without pontoons.

The investigation carried out has been on the following configurations:

- Stability with pontoons
- Stability without pontoons
- Resistance and race performance prediction

- Pontoon design

For all PR2 investigations the following assumptions and criteria have been applied:

- The total athlete weight is 140kg (2 x 70kg rowers)
- The centre of gravity of the rowers is 0.45m above the waterline
- The pontoons are positioned so that in a static condition they are submerged so that each pontoon is providing 2kg of buoyancy (4kg in total).

5.2.1 Stability Results Summary for PR2 with Pontoons

A similar study to that carried out for the PR1 scull has been conducted for PR2 configurations.

Figure 8 shows the GZ curve for the PR2 with standard pontoon design.

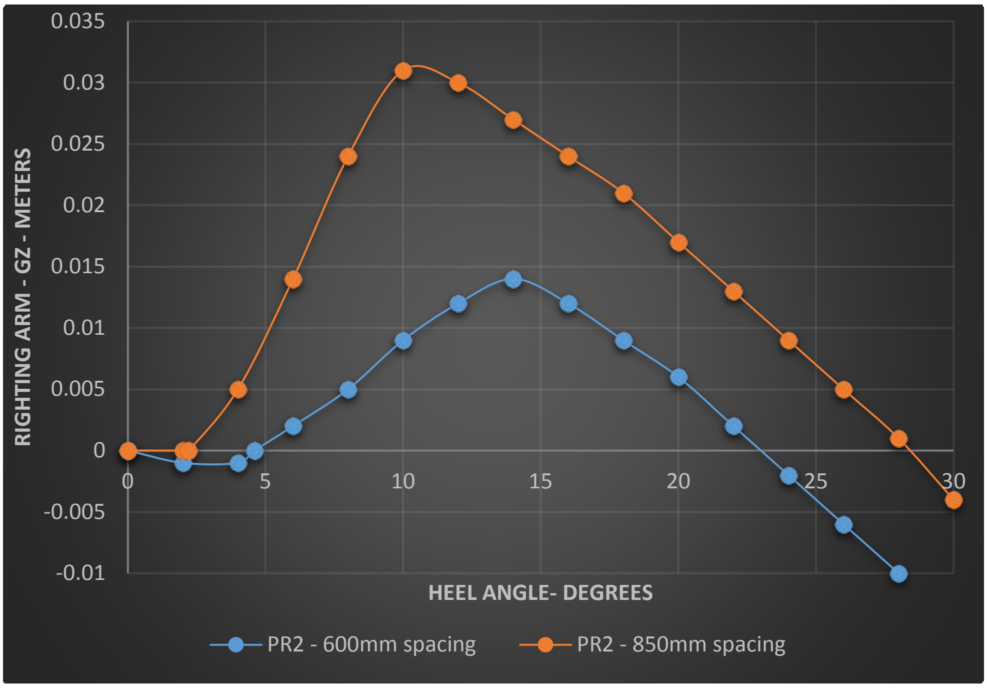


Figure 8: PR2 Stability with Pontoons for 140kg Total Athlete weight

This shows the results for the current rule range of pontoon spacing of 600 – 850mm.

This provides a range of 0.002 to 0.006 metres radians as an area under the GZ curve up to a heel angle of 20 degrees, for 600 and 850mm pontoon spacing respectively. Figure 9 uses these values as a means to create a non-dimensioning stability parameter (or implied level of safety factor) to make changes in PR2 setup easier to visualise. A number of additional configurations have been tested but not included in this report. The whole list of tested configurations can be found in the appendix.

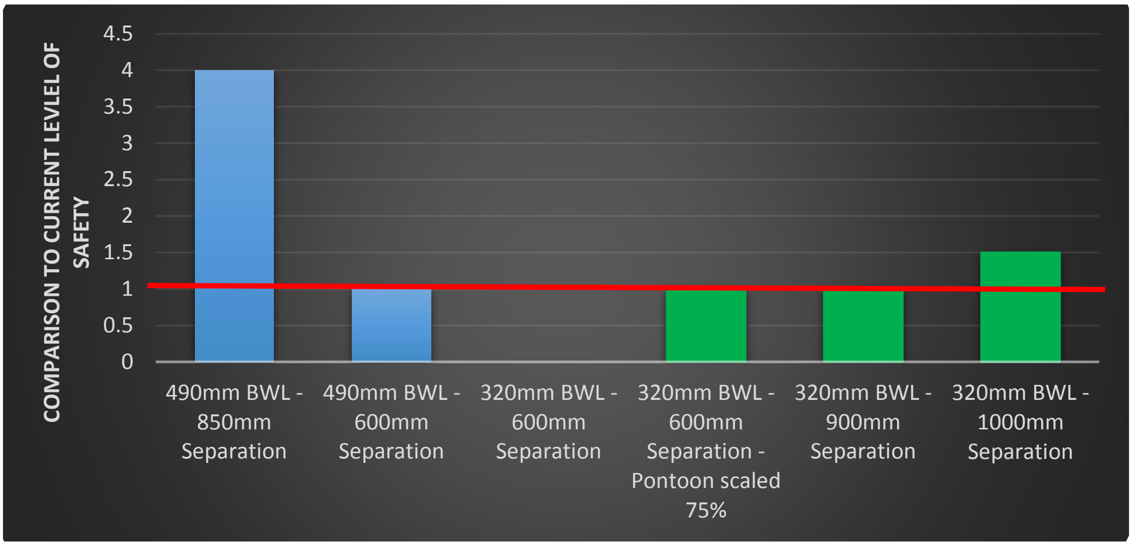


Figure 9: PR2 Stability Comparison

Using the existing waterline beam (490mm) of the PR2 scull and minimum pontoon separation of 600mm as the minimum standard, i.e. factor equal to 1.0. Figure 9 shows a summary of the area under the GZ curve for a selection of BWLs, pontoon sizes and pontoon separations.

Summary:

- The red line defines the existing Class minima limit in terms of 'simplified' level of safety.
- The first blue column is for the PR2 FISA (i.e. with 490mm BWL) one design with the pontoons at 850mm separation and shows the level of safety 3 units above the existing Class minima.
- The second blue column is for the PR2 FISA one design and represents the existing Class minima, hence lies upon the red limiting line.
- The 320mm BWL scull and with pontoons at 600mm separation is unstable in a static condition and hence has a score of zero. Due to our analysis not including dynamic stability effects it is possible to get a zero stability result.
- The first green column shows that in order for the 320mm BWL scull with 600mm spacing to have the same stability as the existing PR2 design the pontoon volume need to be increased by 75%.
- The third green column represents a 320mm BWL scull with pontoon separation of 900mm which achieves the existing Class minima stability limit.

To conclude, it is possible to achieve a level of safety (in excess of the minimum that the Class rules currently allow) in terms of transverse static stability with a 320mm BWL scull with standard PR2 FISA pontoons but they have to be positioned a minimum of 900mm for the centreline.

5.2.2 Stability Results Summary for PR2 without Pontoons

The PR2 scull without pontoons and with 140kg total athlete weight is inherently unstable whilst static. The rowers will use the oars and their balance to maintain stability before a race, but once moving the system gains dynamic stability, similar to the mechanism associated with riding a bicycle.

Looking at the GZ curve in Figure 10 it can be seen that the curve has a negative gradient from 0 degrees and the GZ value is always negative, if the vessel is inherently unstable, when modelled as a fixed system.

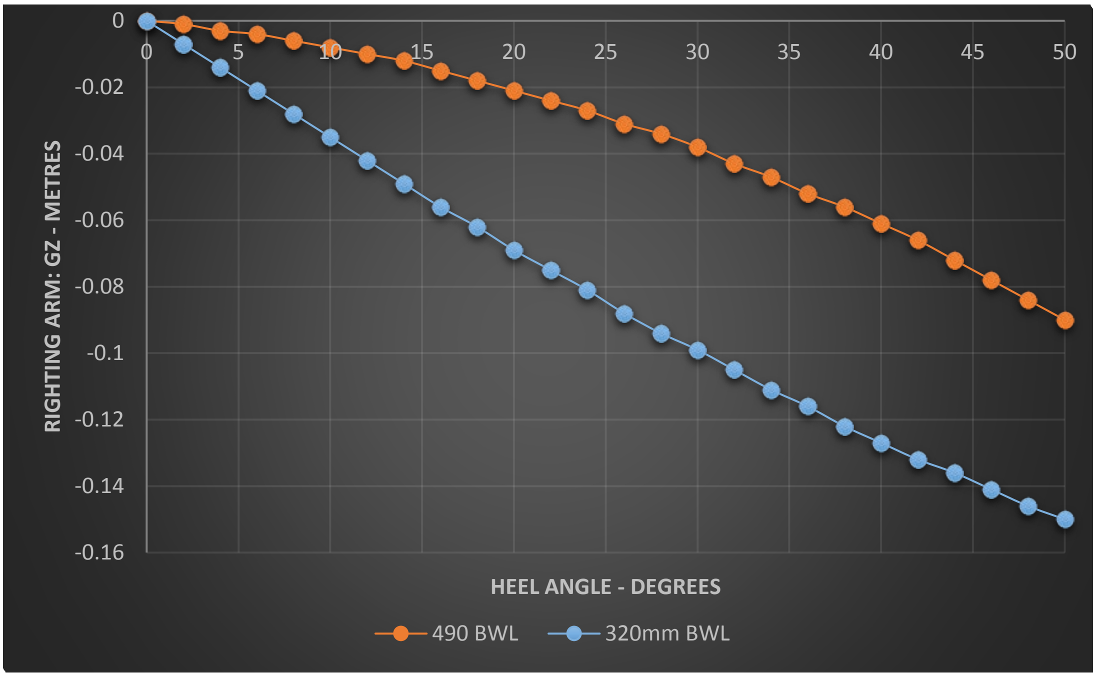


Figure 10: GZ Curve for 0 – 50 Degrees - Sculls only

5.2.3 PR2 capsize and recovery stability

The PR2 will follow a similar trend in terms of stability in the inverted state to that of the PR1, discussed in 5.1.2. Wider BWL and pontoon separation make the vessel more stable in the upright condition and less susceptible to capsize in the first place, but in the event of capsize is more stable in the inverted state requiring more effort to re-right.

5.2.4 PR2 Resistance and Race Performance Prediction

Using the resistance model, the parameters for the PR2 scull and 320mm BWL scull (both with and without pontoons) were used to generate predictions of the resistance versus speed as shown in Figure 11.

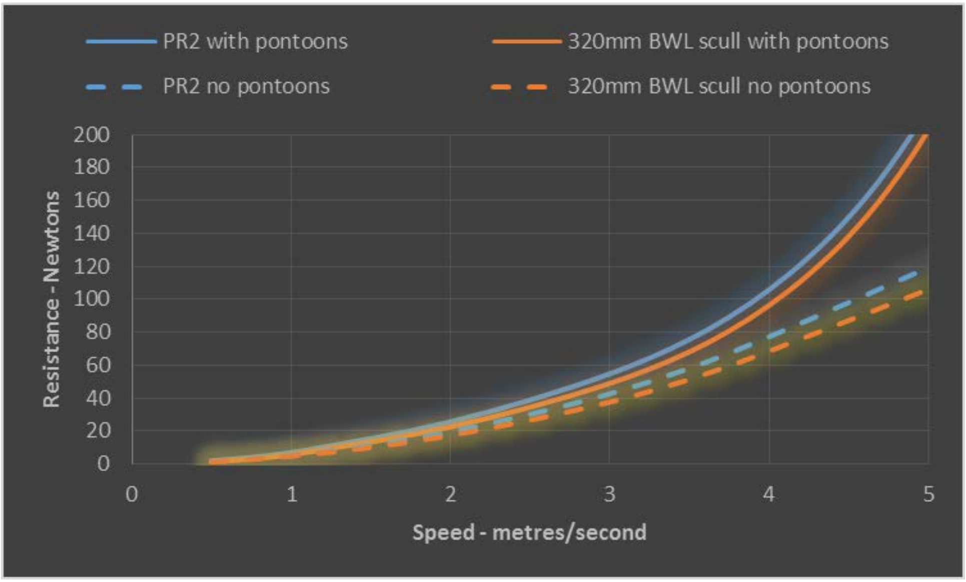


Figure 11: PR2 Resistance vs Canoe speed

There is a clear resistance benefit (when viewed in isolation from the stability characteristics) associated to the 320mm beam scull. The benefit is principally related to a reduction in wetted surface area that results in a lower viscous (frictional) drag component in comparison to the PR2 design.

The baseline time used for the 2000m PR2 race was 442 seconds for a 2000m course. This equated to an average speed of 4.53 m/s with a predicted average output power of 449 watts for the PR2 without pontoons, compared to 399 watts average power output for the 320mm BWL scull without pontoons completing the course in the same time. This has been extended to a comparison including pontoons immersed in Tables 4 and 5.

	No pontoons	Both pontoons touching
PR2	4.525	4.066
320mm BWL Scull	4.712	4.157

Table 4 Predicted speeds (in m/s) for each configuration based on a set power

	No pontoons	Both pontoons touching
PR2	442.0	491.9
320mm BWL Scull	424.4	481.1

Table 5 Predicted 2000m course times in seconds

When applying the results in Figure 11 and Tables 4 and 5 to a 2000m race:

- Using the same average power, the Olympic style hull without pontoons is predicted to complete the course at an average speed of 4.712 meters per second. This is approximately 4% faster in comparison to the current PR2 configuration without pontoons.
- With pontoons immersed the relative difference in race time between the PR2 and the Olympic style hull is less, 2%, due to the increasing drag of the pontoons at speed.
- The athletes would have to produce 12% less power in the Olympic style double scull without pontoons compared to the PR2 design to complete the course in the same time.
- The athletes would have to produce 9% less power in the Olympic style double scull with the pontoons immersed compared to the PR2 design with pontoons to complete the course in the same time.

To conclude, in the case of the PR2 and 320mm beam and pontoon arrangement, the more slender variant offers benefits in terms of reductions in race time.

6 CONCLUSIONS

The consistent story for both the PR1 and PR2 investigations is that the stability (or implied level of safety) is compromised in order to gain a hydrodynamic performance benefit through a reduction in scull resistance.

The following detailed conclusions can be made from this investigation into the FISA PR1 and PR2 rowing events:

6.1 PR1

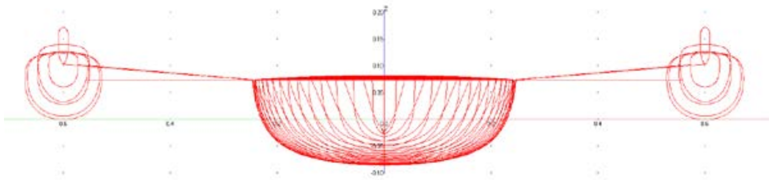
- There is a predicted performance increase of around 3.5% from using a 280mm BWL scull verses the current PR1 (450mm BWL) design with the pontoons not touching the water, .
- The 280mm BWL scull with 600mm spaced pontoons has significantly less stability then the equivalent PR1 with 600mm spaced pontoons design.
- The 280mm BWL scull with 750mm spaced pontoons has the same static stability as the current class minima, which is the PR1 with 600mm pontoon spacing.
- The investigation shows that the more upright stability a configuration has, the more difficult it is to right after a capsize. The configuration that requires the most "effort" to recover from capsize is the PR1 with 850mm pontoon spacing.
- If one were to infer the impact of reduced stability of the 280mm BWL scull option on race performance, a relevant comparison would be the PR1 with the pontoons out of the water and the 280mm BWL with one pontoon immersed to provide 2kg righting force which predicts the PR1 to be faster by up to 2.9%.

6.2 PR2

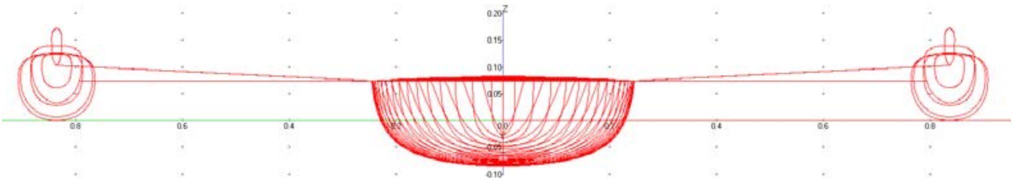
- There is a predicted performance increase of 4% from using a 320mm BWL scull versus the current PR2 (490mm BWL) design.
- The reduction of the scull waterline beam to 320mm reduces the stability to the extent that to meet the inferred class minima stability the pontoons have to be 900mm from the scull centreline. Although this could be classed as 'unstable' in comparison, the main hull is of similar proportions to that of an able bodied double Olympic scull.
- The PR2 and 320mm BWL scull are both inherently unstable in static stability analysis. This is to be expected with this type of hull form. The rowers will use there oars and balance to maintain stability before a race, but once moving the system becomes stable, similar to the mechanism associated with riding a bicycle.

7 APPENDIX

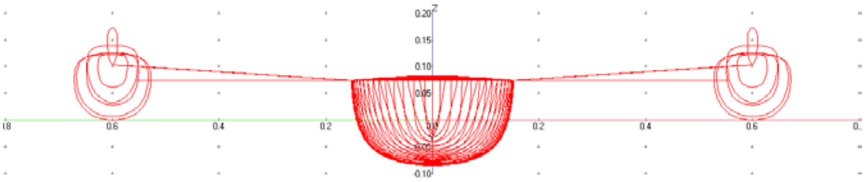
7.1 BODY PLANS OF ASSESED CONFIGURATIONS



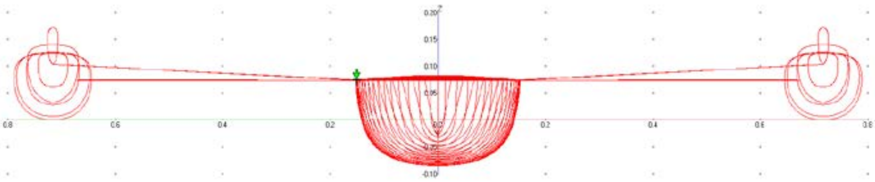
PR1 - 600mm Pontoons



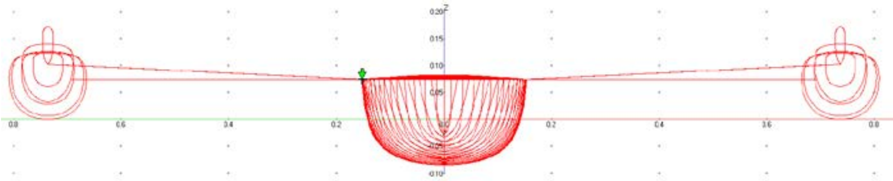
PR1 - 850mm Pontoons



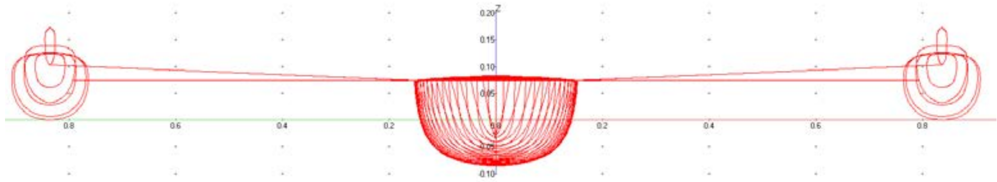
PR1 - Scaled 0.62 - 600mm_pontoons



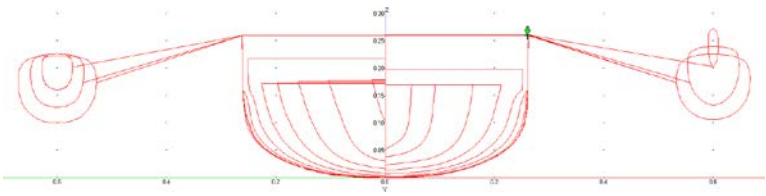
PR1 - Scaled 0.62 - 730mm_pontoons



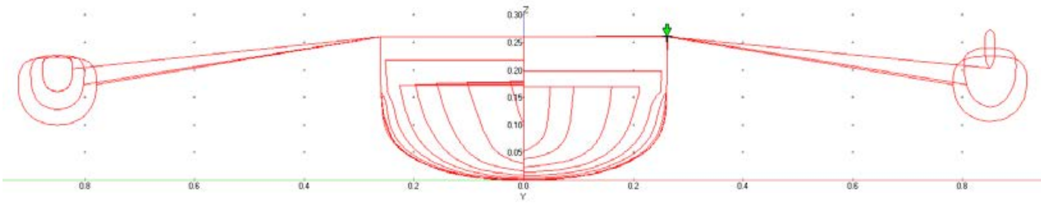
PR1 - Scaled 0.62 - 750mm_pontoons



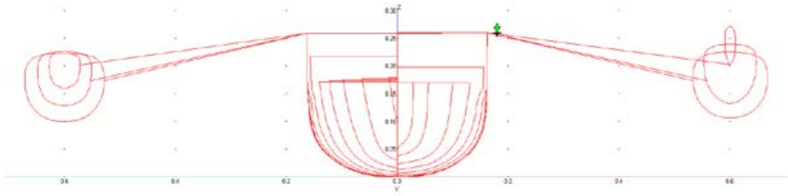
PR1 - Scaled 0.62 - 850mm_pontoons



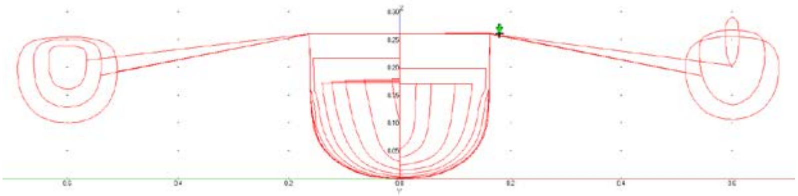
PR2 - 600mm Pontoons



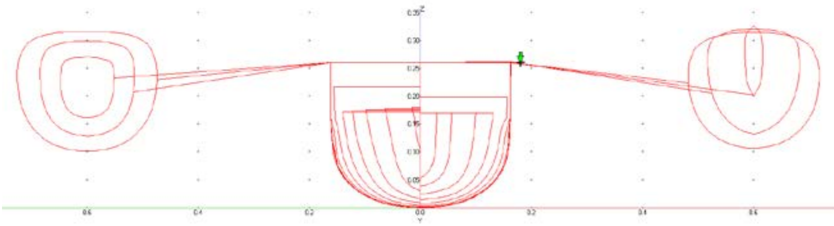
PR2 - 850mm Pontoons



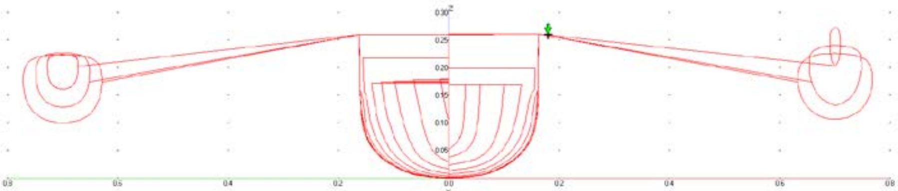
PR2 - Scaled 0.62 - 600mm Pontoons



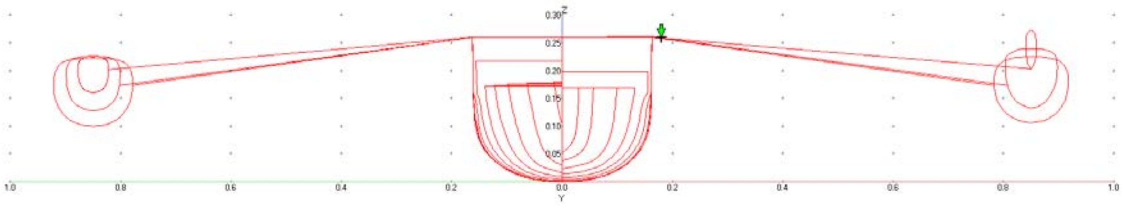
PR2 - Scaled 0.62 - 600mm_pontoons_1.25scaled



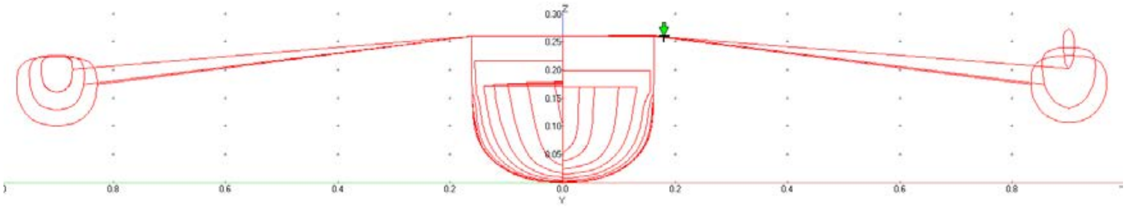
PR2 - Scaled 0.62 - 600mm_pontoons_1.75scaled



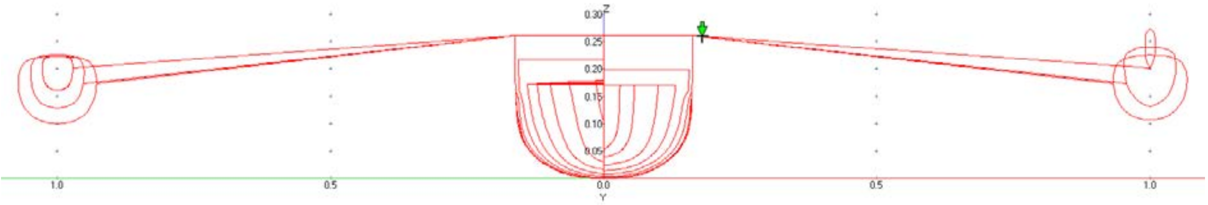
PR2 - Scaled 0.62 - 700mm Pontoons



PR2 - Scaled 0.62 - 850mm Pontoons



PR2 - Scaled 0.62 - 900mm_pontoons



PR2 - Scaled 0.62 - 1000mm_pontoons

WOLFSON UNIT FOR MARINE TECHNOLOGY AND INDUSTRIAL AERODYNAMICS
B185, BOLDREWOOD INNOVATION CAMPUS, SOUTHAMPTON, UK, SO16 7QF
TEL: +44 (0)23 8058 5044 EMAIL: WUMTIA@SOTON.AC.UK
WWW.WUMTIA.COM