A QUANTATIVE STUDY ON RELATIVE MOTIONS DURING TENDER BOARDING

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SUMMARY

Feadships are more often equipped with large beach lounges. While at anchor, owners and guests board and leave the yacht by tender at this beach lounge. Tender boarding is often already limited at a low swell. The ease of tender boarding is much dependant on the relative motions between tender and yacht. Especially the vertical relative motions hinder and impede a safe and comfortable transfer for the passengers. Studying the vertical relative motions can be used for evaluating tender boarding.

To research the relative motions the geometry and behavior of yachts are modeled and diffraction calculations are executed. Through these calculations the vertical relative motions of the tender are deduces. During this study, the surrounding conditions, the yacht's heading, and the boarding locations around the yacht are varied.

Studying the relative motions leads to an understanding of issues that occur during tender boarding. Through the execution of analysis, an optimal boarding location and yachts heading for tender boarding are deduced.

1. INTRODUCTION

Figure 1: Tender boarding from a platform

Feadships are more often equipped with large beach lounges. These lounge areas with large open platforms close to the waterline form the ideal location for tender boarding. While at anchor, owners and guests board and leave the yacht by tender at this beach lounge. An example of tender boarding via a beach club is illustrated by figure 1.

However, while passengers transfer between tender and yacht at sea, both tender and yacht are moving due to excitation forces. These excitation forces are caused by the surroundings, i.e. wind, waves and current. In practice, tender boarding is often already limited at low swell. This leads for instance to cases in which the surroundings can be seemingly calm but still tender boarding is unable. The ease of tender boarding is much dependent on the relative motions between tender and yacht. According to crew, horizontal relative motions can be controlled by crew by applying fenders and mooring lines, where vertical relative motions cannot that simply be controlled. In practice, especially the vertical relative motions hinder and impede a safe and comfortable transfer for the passengers. Practical cases occur in which the tender vertically moves over one meter, while no alternative means of boarding the yacht are available. As part of a larger study into the design of beach lounges and tender garages at Feadship, these relative vertical motions which trouble tender boarding have been studied. By quantifying the relative vertical motions, data could be attained which can be used to benefit tender boarding and the operational profile of the yacht overall.

2. AIM AND SETUP STUDY

The sub-study into relative vertical motions aims to evaluate the performances of the design concepts from the overall design study. These designs have a number of functionalities, of which one is to facilitate a transfer between tender and yacht. In order to evaluate the concepts' performances in meeting their required functionalities, the parameters influencing the performances and the comparison are to be known. From the overall design study, the sub-study into relative vertical motions and their influence on tender boarding will be discussed in this paper.

To study the relative vertical motions, the following framework is to be set up; first the dimension of the studied yacht and tender are determined. Secondly, the relevant surrounding conditions, in which tender boarding takes place, are considered. Thirdly, the yacht's orientation to these conditions, i.e. the yacht's heading, is considered. Lastly, relevant locations around the yacht where relative vertical motions are studied are determined. When these background questions are answered, the relevant cases for which the vertical relative motions are to be mapped are known. To later on evaluate the attained results, directives to tender boarding are considered on beforehand as well.

Next step is to determine the relative motions. Both the yacht and tender and their motions are to be modelled. Their motions combined lead to the relative motions. To correctly model the yacht and its motions, the tender motions and the surroundings (and their influence on each other), software to perform diffraction calculations at the Delft University of Technology is used.

By combining the input from the relevant cases and the results obtained by use of the diffraction program, the relative motions are computed. When the relative motions are determined for relevant cases, they can be evaluated and compared. From this data conclusions are drawn which specifically aim to evaluate and benefit tender boarding.

Following up the study mentioned above, the relative vertical motions have been studied during a recent series of model tests at Marin. The results attained during this second study will be used to verify the drawn conclusions from the original study.

3. STATING RELEVANT CASES

Several steps are taken in order to attain all input before the relative motions could be determined. These steps focus on setting up the framework for determining relative motions, which yields the input for the later calculations.

3.1 Choice of a benchmark yacht and tender

In the overall design study a benchmark yacht and tender are chosen for setting up design concepts. The choice for this yacht and tender is dependent on their dimensions. A benchmark yacht of minimum dimensions for applicability of design concepts is chosen. This same yacht has been chosen as benchmark yacht for the study into relative vertical motions. The yacht's main dimensions are listed in table 1.

Loa	62.00 m	7.50 m
Boa	11.10 m	2.50 m
Draft	3.25 m	0.60 m
Freeboard	2.30 m	0.60 m

Table 1: Dimensions benchmark yacht and tender

The dimensions of the benchmark tender follow from the choice for the benchmark yacht. Tender dimensions are chosen for a tender which yachts of about 60 meters are equipped. An analysis of dimensions of the 60 last built Feadships and their tenders results in the dimensions of the benchmark tender as listed in table 1.

The conclusions which result from this study will also be checked to hold true for a larger yacht. The performed calculations for the benchmark yacht will also be performed for a larger yacht, which is a scaled up model of the benchmark yacht.

3.2 Environmental conditions

The yacht is anchored at sea when tender boarding takes places. The most common locations for yachts to anchor are their most common sailing areas, generally the West Mediterranean Sea and the Caribbean Seas. An analysis of these areas will show which wave conditions (combinations of zero crossing periods and significant wave heights) are most common and thus relevant conditions to consider in this research. The scatter diagrams[1] showing which wave conditions occur and are most common in the West Mediterranean and Caribbean Seas are depicted in figure 2.

In practice, wind and wave conditions set limitations to the use of the tender and to the beach lounge. Generally when conditions are far too rough or unpleasant the tender and beach lounge will not be used. For instance, in seas with a significant wave height of 3 meters or higher the tender is no longer used. A similar criterion holds for wind (5 Bft. or higher). For this reason, as indicated with the fat lines and dots in figure 2, only wave conditions below these criteria are of interest. Per area the wave conditions with the highest occurrence are of most importance.

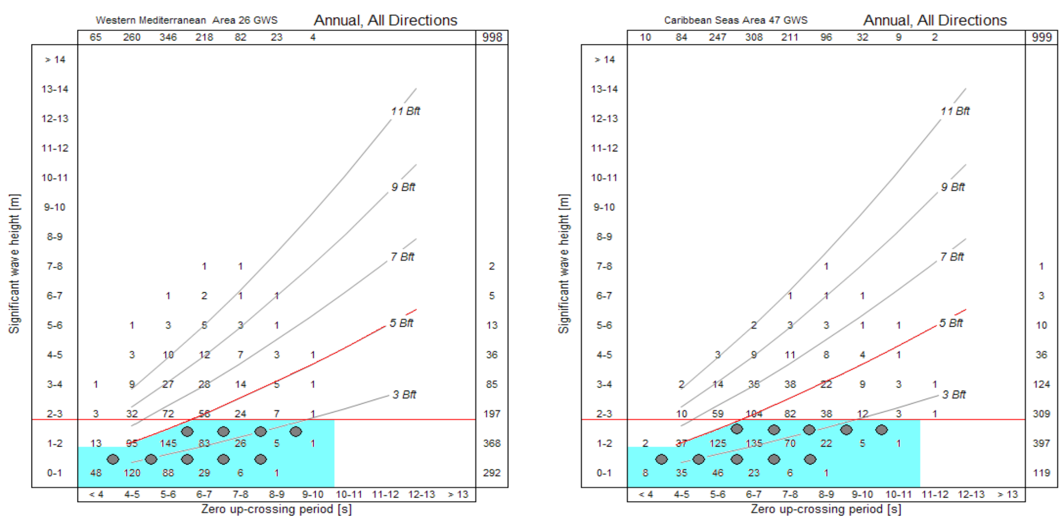

Figure 2: Selection of relevant conditions from wave scatter plots

With the wave periods known, a simplification can be made to the motions of the tender; the length of the tender is small relative to the occurring wave lengths, this means that the tender is expected to follow the wave profile and doesn't pitch or roll much. The following relation (which is derived from the 'Dispersion Relationship for deep water' [2]) is used;

$$\lambda = 1.56 \cdot {T_0}^2 \qquad (1)$$

With the shortest zero crossing period being 4 seconds, the shortest wave length is about 25 meters. This is 3.3 times the length of the tender. The vertical motions of the tender can thus sufficiently accurate be modelled by the vertical motions of the water surface, i.e. the wave elevation.

For the calculations wave spectra will be used to model irregular seas. Yachts anchor locations are not in open seas but in coastal waters. The JONSWAP Wave Spectrum is a spectral formulation for fetch-limited (or coastal) wind generated seas. For this reason JONSWAP Wave Spectra will be used to model the wave conditions.

Besides waves, also wind and current influence the motions of tender and yacht. However, these aren't expected to influence the vertical relative motions and are therefore not further considered in this study. The influence of incidental waves, for example from passing vessels, is also not considered in this study. For tender boarding these incidental waves aren't expected to play an important role, since these waves are easily detectable by crew members and in practice crew assists guests while boarding by alerting them which moment is suitable to board and which isn't. Hereby, a possibly negative impact of incidental waves on relative motions can simply be averted.

3.3 Yacht's heading

When the yacht is anchored, at zero speed, the surroundings determine the heading of the yacht to the direction of the incoming waves. The yacht's heading (relative to incoming waves) is of interest since it influences the height of relative waves next to the yacht. Wind, waves and current don't necessarily come from the same direction. For instance, currents tend to follow coastlines when a current nears them. Waves and wind however, can come from another direction as such currents. Generally the yacht weathervanes around its anchor between head waves (-180 degrees) and beam seas (-90 degrees).

Which heading occurs the most is not of interest since the heading can (and in practice will be) influenced by the yachts propulsion system. This way the heading which is most favourable for tender boarding can be kept for a while. In practice crew uses the propulsion system to create some leeway on the side of the yacht since they experience this to make tender boarding easier. The effect of leeway on the relative motions will be investigated. For this reason a heading of -150 degrees will be investigated. Generally the yacht shows the most roll response at a heading of -120 degrees. This heading is also investigated.

To make this study executable a number of headings will be chosen between head waves and beam seas which will be investigated. These headings are head seas (-180 degrees), -150 degrees, -120 degrees and beam seas (-90 degrees).

3.4 Measuring locations

The relative wave elevation will be determined at a set number of locations around the yacht. In the overall design study, for the considered designs not only tender boarding, but several functionalities were considered, which led to a total of thirteen set locations around the yacht for determining relative wave elevations, which are depicted by figure 3. Not all of those locations are of interest when tender boarding is considered on its own. For instance locations G and H were considered since the functionality of tender launching was also considered, which for certain yachts occurs at these locations. For tender boarding, the locations representing actual location where the tender will lie during tender boarding are relevant. The relevant locations from figure 3 are locations D, E, F, K and M. Locations D, E and F represent tender locations next to a side platform, location K represents a tender location next to an aft platform and location M represents a tender location in a stern dock.

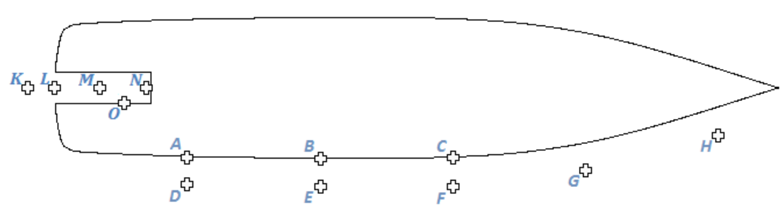

Figure 3: Modelled locations around the hull

3.5 Setting a directive

So far, the framework of relevant cases has been set up by determining relevant yacht and tender dimensions, surrounding conditions, yacht's heading and locations for modelling relative wave elevations. In the introduction of the paper it was stated that crew in practice can sufficiently control the tender's horizontal relative motions, and from analysing the relevant wave lengths and the length of the tender it is stated that pitch and roll of the tender are not relevant either. This leads to only the heave motion of the tender being of interest. To practically evaluate later on obtained vertical relative tender motions it is desired to set a directive to whether these motions are acceptable or not. This directive is as follows; for the amplitude of the vertical relative tender motions, an acceptable distance of over one staircase step is allowable. A maximum staircase step is 200 mm. However when boarding a tender, a passenger is assisted by supports and crew, which makes for a larger step being acceptable. In this case, it is considered that a maximum step of 250 mm up or down can be expected to be safely made.

4. DIFFRACTION CALCULATIONS

With the setup of the study considered, the necessary modelling and calculations can be performed to determine relative motions. By use of diffraction calculations performed with software Ansys AQWA the RMS-values of the vertical relative motions of the water surface will be determined. Figure 4 illustrates the different steps in the performed calculations.

The geometry and orientation of the benchmark yacht are modelled in AQWA Workbench and the yacht's behaviour in seaway can be modelled. An anchored yacht shows three relevant degrees of freedom in its motions; heave, pitch and roll. Especially the roll-response of the yacht needs attention in this modelling phase, due to the addition to the roll damping by zero-speed fin stabilizers.

In AQWA GS RAO's for the relative wave heights are determined at the relevant locations around the yacht's waterline. When all RAO's are collected, this data is combined with the wave data to compute the spectra of the relative vertical wave heights. From these spectra the RMS-values are determined, which are used to determine the significant wave height.

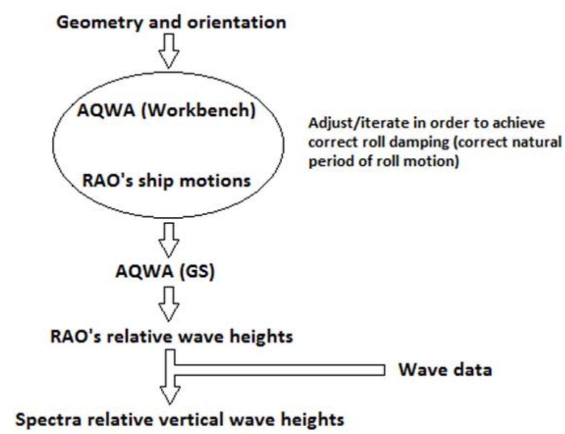

Figure 4: Steps taken in diffraction calculations

4.1 Modelling

The benchmark yacht is modelled with its hydrostatical properties, which are checked to reports from earlier performed model tests of the benchmark yacht. To correctly model the roll damping a check is performed to earlier performed model tests as well.

The separate additions to the total roll damping could not be modelled in the software. Ansys AQWA doesn't take viscous or Eddy damping into account. The passive stabilizers, and thus their addition to the roll damping, couldn't be modelled either. The final and most important addition, of the zero speed fin stabilizers, which give the roll damping a strong non-linear character (as depicted in figure 5), couldn't be modelled either. The total roll damping is modelled in the software by inputting a single value to represent the total equivalent linear damping. The non-linear character of the roll damping and the limited possibilities to correctly model this damping limits the cases which could be investigated; the planned complete operational analysis (all combinations of heading, surrounding conditions and measuring locations) could not be performed. The cases which could be investigated follow from the Marin report of the earlier performed model tests, by which the single value for the equivalent linear damping could be determined. The iteration process in figure 4 stands for the process to adjust the roll damping until the roll RAO of the model corresponded to the roll RAO of the model tested at Marin.

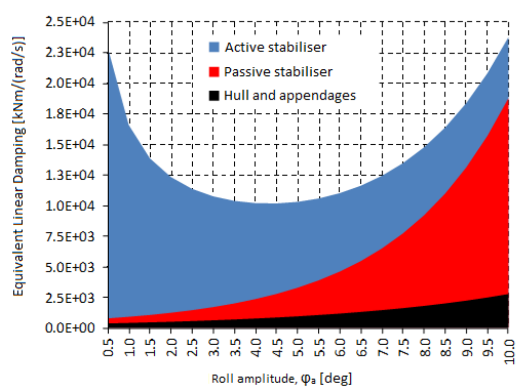

Figure 5: Characteristic of total roll damping

The wave spectra in the Marin tests in combination with the heading of the tests (-90 degrees) are cases for which the relative wave elevations can be modelled. Furthermore, all cases when the yacht's heading is in head seas (-180 degrees) are modelled as well, since the yacht does not roll at this heading. The headings -150 and -120 degrees are also of interest. These orientations could not be investigated if the roll damping is not correctly modelled. These orientations will be investigated, based on the following assumptions; the RAO's of the models roll motion are investigated for all four relevant headings, which is depicted in figure 6. It shows that for heading -150 degrees less roll response occurs than for heading -90 degrees at the same wave frequencies. Less roll response equals lower roll amplitude. Since the stabilizer fins deliver the same amount of work at lower roll amplitude (fin forces are independent of the roll response), in reality more equivalent linear damping is provided by the fins in heading -150 degrees than for -90 degrees (this can be seen in the characteristic of the roll damping illustrated in figure 5). However, in the model in AQWA the same amount of roll damping will be modelled for -150 degrees as for -90 degrees. Too few damping is thus modelled for -150 degrees in AQWA. The roll motion for -150 degrees is thus insufficiently damped, which results in too much roll response. The roll can be said to be damped 'too conservative' for -150 degrees. It is expected that the too high roll response results in higher relative motions. This 'conservative' modelling makes that the results for relative motions are too large for heading -150 degrees. On its turn, this makes that the results of calculations will be 'on the safe side'; heading -150 degrees is modelled with the same amount of damping as for -90 degrees.

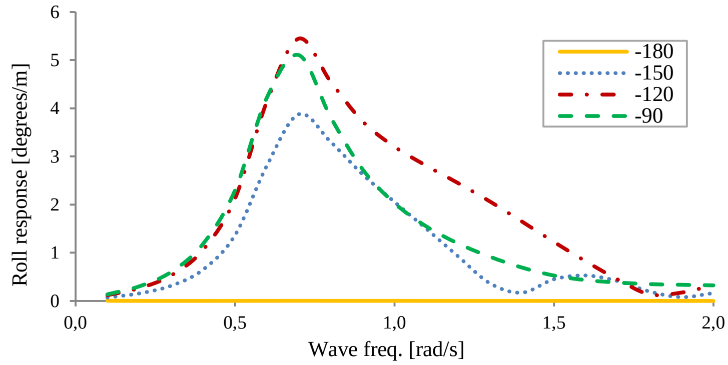

Figure 6: RAO's of the model's roll motion per heading

Comparing the RAO's of the models roll motion shows for heading -120 degrees more roll response than for heading -90 degrees at the same wave frequencies. Clearly, not all wave conditions can be investigated for heading -120 degrees. Only the same wave conditions as for -90 degrees will be investigated for heading -120 degrees, since these are conditions which lie around the peak of the roll spectrum and the peaks of the roll RAO's of -90 and -120 degrees lie fairly close to each other, but it is to be kept in mind that the roll is too much damped and the 'real' results are expected to be higher.

Overall, the complete operational analysis is not performed during this study, as it would only add value to the study if it could be performed correctly. The following analysis is performed; the conditions of the Marin tests for headings -90 and -120 degrees and all wave conditions for headings -150 and -180 degrees are modelled.

4.2 Data acquisition

When all modelling is performed, the RAO's for the three relevant ship motions of the yacht are calculated for the wave frequency range of 0 to 2 rad/s. These RAO's are added to the model, which is inputted inputted from Ansys Workbench into Ansys AQWA GS. This part of the software is used to calculate the RAO's of the relative wave elevations at the relevant locations.

Besides the incoming wave, also the diffracted and radiated wave from the yacht and the RAO motion of the yacht are taken into account. Figure 7 shows the separate components for a wave with a period of 1 rad/s and the yacht on heading -150 degrees. The top image shows the incident wave, which amplitude is everywhere around the yacht the same. The second image depicts the diffracted wave, which shows the wave coming from the top right in the figure and building up along the portside and reflecting of the yachts stern. The third image shows the radiated waves propagating in longitudinal and sideways direction from the bow and stern (combined pitch and roll motion). The bottom image depicts the RAO motion. It takes the heave, pitch and roll motions of the yacht into account. A plane is drawn at two meters above and parallel to the still waterline. When the yacht starts to heave, pitch and roll this plane stays fixed in its pivoting point. The wave heights are then denoted relative to this plane, and thus relative to the yacht.

When all four images are combined, at any given location the RAO-value of the relative vertical wave height is given for the selected combination of wave frequency and heading. The frequencies and heading are chosen and the relative

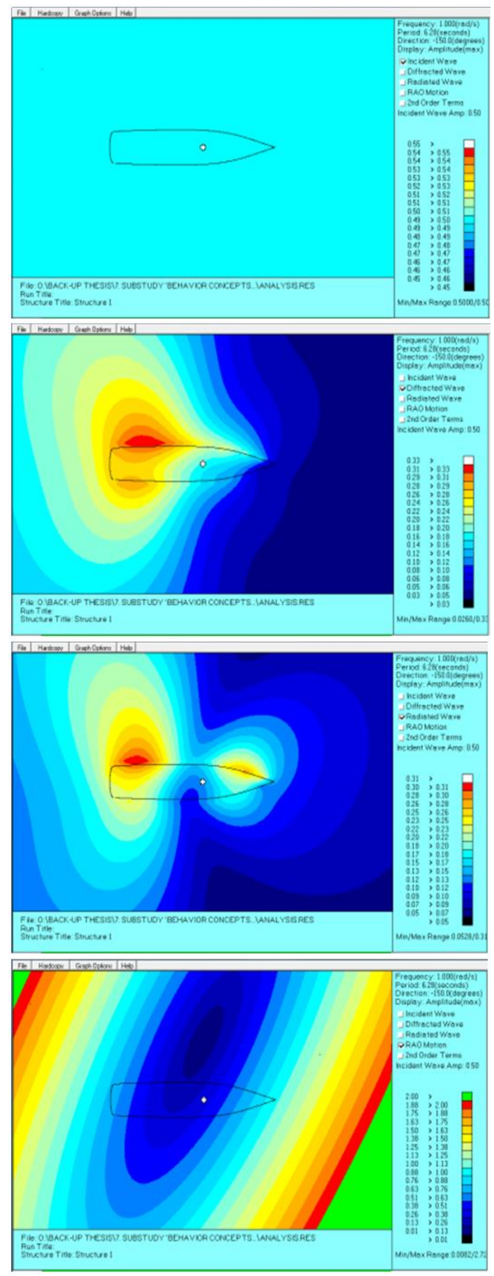
Figure 7: Components in relative wave height

wave elevation is determined. The output is a single value. This value is the relative wave amplitude. The incident wave is set to have a wave amplitude of 1 meter to obtain the preferred RAO-value (in meter relative wave height per meter incident wave height).

Ansys AQWA shows results one by one per frequency (from 0.1 to 2.0 rad/s in steps of 0.1 rad/s) for regular waves. These values are combined to complete a single RAO. In total 5 locations are considered with per location 4 headings and 20 frequencies. These 400 single RAO-values are combined into 20 RAO's.

4.3 Data processing

With the RAO's of the relative wave heights known, the following calculations are made: the motion spectrum of the relative wave heights is determined by combining a wave spectrum with the RAO of the relative wave. As illustrated in figure 8, the wave spectrum (input spectrum) is multiplied with the square of the RAO (response function^2). This results in the motion spectrum of the relative vertical motion (output spectrum). This spectrum is set up per location, per heading, per wave condition.
The area under the spectrum is denoted as m_0. The square root of m_0 is the Root Mean Square (RMS) or standard deviation (σ). This value can be used to determine the significant wave height of the relative waves. The standard deviation is the statistical average used to rate the wave heights. The relationship of the RMS to a normal (or Gaussian) distributed signal is illustrated in figure 9. The wave elevation and as a consequence the wave frequent ship motions follow typically such a Gaussian distribution. However roll motions with active roll stabilisation may not exactly follow a Gaussian distribution. The rather nonlinear and impulsive character of the dampening forces as excited by the 'kick' of the stabilisers are the cause of this different behaviour. In this case, the validity of this Gaussian distribution is considered to hold up.

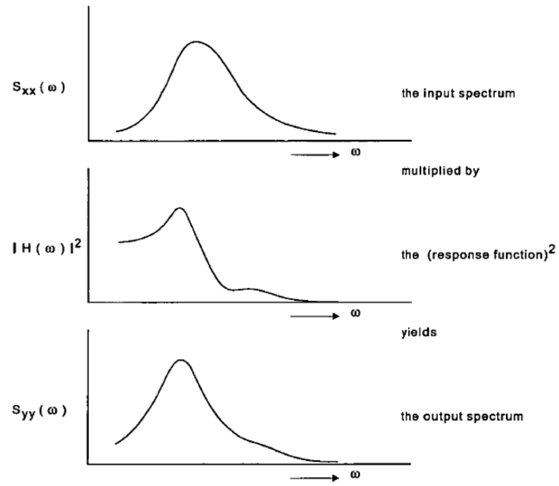

Figure 8: Spectra and RAO calculation

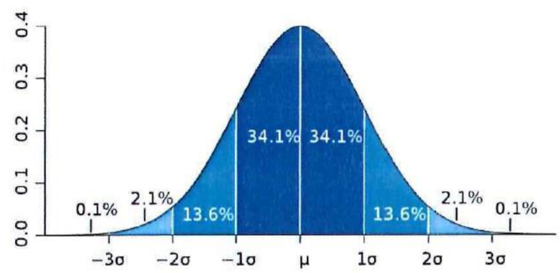

Figure 9: Relationship RMS to Gaussian signal

The significant wave height, $H_{1/3}$, of the relative wave are calculated by the following formulas [3];

$$RMS = \sqrt{m_0} = \sigma \qquad (2)$$
$$H_{1/3} = 4 \cdot \sigma \qquad (3)$$

The tender moves both up and down, thus the wave height is to be used. The directive that is set dictates that the step onto or from the tender is not to be higher than 250 mm thus the tender can move either 250 mm up or 250 mm down. The relative wave height, expressing the vertical motion of the tender, is not to exceed 500 mm. As it shows in figure 9, 4*m_0 (from -2*m_0 to +2*m_0) holds 95.4 % of all samples. This means that if the significant wave height doesn't exceed 500 mm, then it is known for a fact that 95,4 % of all occurring waves don't have a height over 500 mm. Statements involving the significant wave height thus have a 95,4 % certainty of holding up.

Performing all calculations results in a large number of RMS-values, which are to be used to calculate significant wave amplitudes, check directives to hold up, and to be drawn conclusions from.

5. CONCLUDING FROM THE DATA

With all data gathered, the vertical relative motions around the yacht are compared. At first, an optimal location for tender boarding is considered. Next, the set directive is evaluated. These evaluations are then checked to hold up for the scaled up model. Finally, the results from the recent series of model tests at Marin, as mentioned in the setup of this study, are consulted to verify the drawn conclusions from the original study.

5.1 Optimal location for tender boarding

The suitable locations for tender boarding, which were earlier stated as measuring locations for the relative wave heights, can be compared to draw qualitatively conclusions concerning tender boarding in relation to vertical relative motions. To do so, the

RMS values of the relative vertical motions spectrum are compared. Table 2 lists these RMS values for the relevant locations in the relevant conditions. Overall the following can be stated, the lower the RMS value, the more favourable a location is for tender boarding. When comparing the locations, the location with the lowest RMS values is favoured.

From the data in table 2, it can be seen that from the locations on the side of the yacht, locations D,E and F, the location closest to the stern of the yacht, location D, is in most combinations of heading and surrounding conditions favourable. Furthermore, the stern platform, which is according to crew on board most yachts currently used for tender boarding and illustrated by location K, is in most cases less favourable than location D. From all locations which lie around the yacht, Location D is expected to be the most favourable location for tender embarkation because the RMS of the relative vertical wave height is the smallest.

Location M represents a location in a bottomless stern dock, which was a concept in the overall design study. It can be seen that this location is favourable over all other locations for all heading other than 180 degrees.
At 180 degrees, location D remains favourable.

			RMS relative wave height				
Heading [deg.]	*Hs [m]*	*T0 [s]*	*D [m]*	*E [m]*	*F [m]*	*K [m]*	*M [m]*
180	*1,0*	*4,0*	0,12	0,19	0,21	0,22	0,11
	1,0	*5,0*	0,08	0,15	0,16	0,30	0,14
	1,0	*6,0*	0,06	0,12	0,12	0,26	0,12
	1,0	*7,0*	0,05	0,09	0,10	0,22	0,10
	1,0	*8,0*	0,04	0,07	0,08	0,18	0,08
	2,0	*6,0*	0,13	0,23	0,25	0,52	0,25
	2,0	*7,0*	0,10	0,18	0,19	0,43	0,20
	2,0	*8,0*	0,07	0,15	0,15	0,35	0,17
	2,0	*9,0*	0,06	0,12	0,13	0,29	0,14
	2,0	*10,0*	0,05	0,10	0,10	0,24	0,12
150	*1,0*	*4,0*	0,12	0,10	0,16	0,27	0,12
	1,0	*5,0*	0,15	0,13	0,15	0,28	0,13
	1,0	*6,0*	0,16	0,16	0,16	0,24	0,11
	1,0	*7,0*	0,16	0,17	0,18	0,19	0,09
	1,0	*8,0*	0,13	0,15	0,15	0,16	0,07
	2,0	*6,0*	0,32	0,31	0,32	0,48	0,21
	2,0	*7,0*	0,32	0,35	0,36	0,38	0,17
	2,0	*8,0*	0,25	0,29	0,31	0,31	0,14
	2,0	*9,0*	0,20	0,24	0,25	0,25	0,12
	2,0	*10,0*	0,17	0,20	0,21	0,21	0,10
120	*0,9*	*7,1*	0,19	0,20	0,21	0,10	0,05
	1,8	*7,1*	0,41	0,44	0,46	0,20	0,09
90	*0,9*	*7,1*	0,17	0,17	0,18	0,02	0,05
	1,8	*7,1*	0,21	0,21	0,21	0,02	0,05

Table 2: RMS values vertical relative motions

5.2 Evaluating the directive

As described in chapter 3, the following directive has been set to the relative motions of the tender during tender boarding; the significant wave height of the relative vertical motions is not to be higher than 500 mm. This directive can be checked for all modelled combinations of location, surrounding conditions and heading, to draw quantitative conclusions concerning tender boarding in relation to vertical relative motions. Table 3 shows the significant wave height for the relevant locations and surrounding conditions.

From table 3 it can be seen that the directive is not met (cell highlighted) for a most combinations of location and surrounding conditions. This confirms the problems which are experienced during tender boarding, which was to be expected as this underlies the aim of the overall design study. The headings cannot be compared to each other with certainty from these results, since the roll damping couldn't be sufficiently modelled. It is however clear that for location D in head seas the directive is always met.

5.3 Scaled up model

As earlier mentioned, the same modelling and calculations have been performed with a scaled up version of the model (to be approximately 90 meters in length) to evaluate if the results are valid for larger yachts as well.

Just as for the original model location D is the best location on the yacht's side for tender boarding. Just as for the original model, the roll damping of the scaled up model was problematic to model. For this reason, the results for headings 150, 120 and 90 for the scaled up model are overestimated.

The directive is just as for the original model in most cases not met. However, just as for the original model, it seems that location D in head seas is the preferred location for tender boarding, as the directive is there met in most surrounding conditions.

			Significant relative wave height				
Heading [deg.]	*Hs [m]*	*T0 [s]*	*D [m]*	*E [m]*	*F [m]*	*K [m]*	*M [m]*
180	*1,0*	*4,0*	0,49	0,74	0,85	0,89	0,43
	1,0	*5,0*	0,34	0,59	0,65	1,19	0,54
	1,0	*6,0*	0,25	0,47	0,50	1,05	0,49
	1,0	*7,0*	0,19	0,37	0,39	0,86	0,41
	1,0	*8,0*	0,15	0,29	0,31	0,70	0,33
	2,0	*6,0*	0,50	0,93	1,00	2,10	0,98
	2,0	*7,0*	0,38	0,73	0,78	1,72	0,82
	2,0	*8,0*	0,30	0,58	0,62	1,41	0,66
	2,0	*9,0*	0,24	0,48	0,50	1,16	0,55
	2,0	*10,0*	0,20	0,40	0,41	0,98	0,47
150	*1,0*	*4,0*	0,47	0,42	0,66	1,08	0,49
	1,0	*5,0*	0,58	0,53	0,59	1,14	0,50
	1,0	*6,0*	0,63	0,63	0,65	0,95	0,43
	1,0	*7,0*	0,63	0,69	0,72	0,77	0,35
	1,0	*8,0*	0,51	0,58	0,61	0,62	0,28
	2,0	*6,0*	1,26	1,26	1,30	1,91	0,86
	2,0	*7,0*	1,27	1,39	1,44	1,53	0,70
	2,0	*8,0*	1,02	1,17	1,23	1,24	0,57
	2,0	*9,0*	0,82	0,94	0,99	1,02	0,46
	2,0	*10,0*	0,69	0,80	0,84	0,86	0,40
120	*0,9*	*7,1*	0,75	0,80	0,85	0,40	0,19
	1,8	*7,1*	1,62	1,75	1,85	0,78	0,38
90	*0,9*	*7,1*	0,69	0,69	0,70	0,07	0,20
	1,8	*7,1*	0,83	0,84	0,84	0,08	0,22

Table 3: Significant wave heights around model

5.4 Validating results with Marin test results

As earlier mentioned, similar modelling and calculations as in this study have been performed more recent model testing at Marin. In this test program, vertical relative wave heights have been modelled and measured around a yacht of approximately 90 meters in length. The vertical relative wave heights were both measured during model tests and they were modelled in a diffraction program in which the roll damping was correctly modelled, after it had been determined by model testing. This enabled not only to validate the conclusions drawn from the earlier performed study in Ansys AQWA, but also to perform the complete operational analysis (for all relevant wave conditions and headings). The findings from this verification are listed below;

- When vertical relative motions are concerned, a location on the side of the yacht close to the yacht's stern is the optimal location for tender boarding.
- The set directive for the significant wave height is also in the Marin testing often not met. It is most of the times met at the location on the yacht's side close to the stern in a heading of -180 or -150 degrees. Also is it always met at a location aft of the yacht in a heading of -90 degrees.

A new conclusion that can be drawn from the Marin test results follows from the comparison of the headings. With the roll damping correctly modelled, the headings can be compared to each other as well (which was unable in the original study). Whereas crew experienced a bit of leeway being beneficial to tender boarding, the results from the Marin tests however show that creating leeway is not always beneficial. Only in surrounding conditions with relatively short waves (zero crossing period of 4 or 5 seconds, which do not most often occur according to the scatter plots in figure 2) the vertical relative wave heights at 150 degrees are (only slightly) lower than for 180 degrees. For most conditions, a heading of 180 degrees is preferred over 150 degrees.

6. CONCLUDING FROM THE STUDY

Practice shows that boarding a tender at sea from a yacht is troubled by relative motions. This study aimed to evaluate these relative motions and their influence on tender boarding. From a series of software modelling and model tests a number of conclusions from the viewpoint of relative motions are drawn concerning tender boarding at sea.

First of all this study clearly shows that in the multiple cases, while the surrounding conditions are perceived as seemingly calm by the owner, guests and crew on board of the yacht, tender boarding can very much be troubled by the relative vertical motions. In many cases the tender moves relative to the yacht over a height which is larger than can comfortably be overcome by owner and guests.

The optimal location for tender boarding at sea is, contradictory to a currently mostly used platform at the stern of the yacht, a platform on the side of the yacht close to the yachts stern. The platform on the yachts stern would be a suitable location for tender boarding, if the yacht is kept at a heading in beam seas. In practice crew uses the yachts propulsion installation to create some leeway on the yacht side, but it is unpractical to position the yacht in beam seas solely for the purpose of tender boarding, especially if tender boarding can also take place comfortably on the earlier optimal location with (or even without) far simpler heading control.

During this study, when considering the tenders relative motions, no evidence was found that supports the crews opinion that creating some leeway on the yacht's side is beneficiary to tender boarding. In fact, al software modelling and model tests show that a heading of -180 degrees (head seas) is preferred over a heading of -150 degrees (with some leeway). The fact that crew however do prefer leeway over head seas could be explained by a possibly higher probability of water overrunning a side platform or water coming into the beach club in head seas. Or by the fact that slamming of waves under a platform has a higher occurrence at one heading over the other. Or it could be explained by not the height of the relative motion but by the speed and/or acceleration of the relative motions. Finally, the simple fact that leeway might feel more comfortable as no wind might be felt could lead to the crew's opinion. These possible explanations are currently being studied in the continuation of the study into relative motions during tender boarding at Feadship.

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