“Recent Developments in the Design of Fast Ships”

by

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1. INTRODUCTION.

The combination of high forward speeds and waves of any significance has since considerable time been a serious challenge for designers and operators of fast ships. The possibility of a fast ship to maintain its intended high forward speed in those conditions is a serious measure for its operability. For decennia Damen Shipyards has put considerable effort in improving the operability of fast ships in a seaway. The last two decades this has resulted in a close cooperation with the Ship hydromechanics Department of the Delft University of Technology. As a result of this cooperation some successful new concepts have been developed and brought to the market. In the present paper an oversight of these developments will be presented and some results obtained with these new concepts when compared with existing contemporary designs will highlighted.

2. PROBLEM DEFINITION.

From full scale experience it is known for a long time that severe motions and in particular high vertical accelerations are the main reason for speed reduction of fast ships in a seaway. This speed reduction occurs primarily in head and bow quartering waves. Due to the large motions and the sometimes very high peaks in the vertical accelerations during impacts most crews apply voluntary speed reduction in order to maintain workable conditions on board of their ships, in order to prevent possible structural damage to the ship and in order to be able to guarantee the safety of the crew and the ship.

Principal reasons for these phenomena to occur in particular with fast ships originate from the fact that, both for practical and economical reasons, most fast ships are generally small, say smaller than 50 meters length over all, and therefore the waves they are sailing in are relatively large. Also due to the high forward speeds in head waves the frequency of encounter is high, which has a very negative effect on the acceleration levels on board of these ships.

For a long time the emphasis in the design of fast ships however has been put on the minimal obtainable resistance at the required maximum speed. This had to be obtained in calm conditions. Operation of the ships in a seaway was for a long time not considered as an important design issue. In some design areas, such as the fast ferries markets, the search for improved seakeeping behavior was found in the design
and application of ever larger vessels. By doing so the mentioned deviancies in the behavior in waves could be partly overcome, but this is not a solution applicable in most of the other areas of application of fast ships. The focus on calm water performance has lead to particular trends in the fast ship designs, such as low deadrise, low length to beam ratios and relatively short and heavy hulls, i.e. low length – displacement ratios. These trends however showed unfavorable for the behavior of these fast ships in a seaway. So when these ships moved their operational areas from the more sheltered inland waters to the more exposed sea areas a new design philosophy had to be developed.

3. THE DEVELOPMENT OF NEW DESIGN CONCEPTS

An important role in this new development, at least within the Damen and DUT cooperation, was played by the results obtained from a considerable amount of full scale measurements carried on board various fast Patrol Boats and SAR vessels of different sizes on the North Sea. As reported by Keuning in Ref [1] it became obvious that improving the operability in head waves meant reducing the peaks in the vertical accelerations on board as much as possible. Not the significant (or “average”) value of the vertical accelerations proved to be the prime factor for the crews to voluntary reducing the speed of the ship but the occurrence of the more scarcely high vertical peaks or slams. Avoiding these high peaks therefore became a primary driving factor in the designs.

To demonstrate this the next Figure is introduced. In this Figure 1 the distribution of the peaks in the irregular time signal of the vertical accelerations of a fast ship is presented. The horizontal scale represents the change of occurrence and is “transformed” according to the Rayleigh distribution, the vertical scale presents the magnitude of the vertical accelerations in meters per second squared.

Figure 1: Distribution of peaks and troughs of an acceleration signal
The wish to avoid the high peaks in the acceleration signal for improved operability in a seaway means that a distribution according to the black (straight) line is very much to be preferred above the distribution following the red line. This holds true even though the significant value corresponding with the black distribution line is higher then that of the red line.

These insights lead to the development and introduction of the Enlarged Ship Concept (ESC) in 1995, see Ref [1] and Ref [2]. First by the so called “simple ESC 4100” in which just the length was increased without changing the section and bow shape of the design and which proved already a considerable improvement over the conventional designs. This concept was subsequently followed by the development of the more improved concept called “TUD 4100” in which the improved bow geometry was introduced. These were subsequently followed by the more radical new design concept called the “AXE 4100” applying the philosophy in full of the AXE Bow Concept (ABC) in 2001, see Ref [3] and [4]. Based on an extensive research project FAST 1 carried out in 2003 by the Shiphydromechanics Department of the Delft University of Technology jointly sponsored by Damen, Royal Netherlands Navy, US Coast Guard and MARIN all relevant aspects of the behavior of the ABC in waves from any direction were analyzed and evaluated. This showed such promising results that Damen decided to introduce the ABC designs on the market in 2006 and these designs have been very successful indeed.

The philosophy behind these concepts is that first of all the length should be brought back into design. By increasing the length without changing the beam, the forward speed and the functionality of the design, the L/B ratio becomes larger, the L/DISP ratio also becomes larger and there a more suitable place available for positioning the important areas on board such as the wheelhouse or passenger areas can be found, i.e. the ESC 4100. By increasing the length without changing the functionality also more space (void space) becomes available enabling the design of the hull shape more from an optimal hydromechanics point of view.

To avoid severe impacts during sailing in waves the hydrodynamic lift generated at the fore sections of the hull have to be reduced. Also the dominant wave exciting forces for fast ships has been proven to be the so called non linear Froude Kriloff forces. These have to be reduced as far as possible, which is achieved by the introduction of changes in submerged volume below and above the waterline both in the horizontal and the vertical direction. This results, in particular at the bow, in taking care that only small changes in submerged geometry at the forward sections of the hull do occur when these sections are moving in and out of the water due to provoked motions in the incoming waves. This leads to very sharp bows with non flared sections and very deep fore foots with possibly a negative contour. The sheer line is significantly raised to generate more freeboard forward and so increase the reserve buoyancy. To illustrate this the lines of a Conventional, a ESC and a ABC design are depicted in the Figure 2. A more detailed description of these design concepts has been presented by Gelling at the 19th HISWA Symposium see Ref [5].
The improvements obtained with these designs in the vertical accelerations are clearly demonstrated by the results from a comparative study presented in Figure 3. Here the distributions of the peaks in the vertical accelerations at the bow of the three concepts sailing at high speed in head waves corresponding to a Seastate 5 on the North Sea are plotted on basis of a Rayleigh distribution scale. From these plots it is obvious that the application of the ESC and the ABC design philosophy leads to a significant reduction of the high peaks with limited occurrence, i.e. the right hand side of the figure is much lower. In particular the AXE 4100 is superior in this respect. This leads to a large improvement in the operability of these craft. These theoretical results are in the meantime fully confirmed by full scale experience with the actual ships. On the market both concepts are very successful. This is amongst others things demonstrated by the fact that from the ESC design more then 75 have been sold since 1997 and from the ABC design more then 30 since its introduction in 2007.
The ESC has been built primarily in the function of Patrol Boat in the range from 40 till 60 meters length over all with speeds ranging from 22 to 30 knots. The Axe bow designs range from 30 till 60 meters length over all and are primarily used as Fast Crew Suppliers, Fast Yacht Support Ships and more recently Patrol Boats. Some typical examples are depicted in the Figure 4.

Figure 3  The comparison of the distributions of the vertical accelerations at the bow for the new design concepts.

Figure 4  The AXE Bow Concept applied as Fast Yacht Support vessel (left) of 50 m length and the ESC as 42 m Patrol Boat (right)

One of the particular beneficial aspects of the application of the AXE Bow turned out to be the circa 20% lower fuel consumption in waves compared with conventional ships due to the considerable lower added resistance due to the waves.
These good results obtained with the designs with the AXE Bow lead to a new research project in 2009 into the possible application of this concept in catamarans. An important aspect was if and if so which modifications had to be introduced for application of the concept with catamarans.

In the last decade a considerable demand has come from the market for relatively small catamarans with improved seakeeping performance. These have to be operated from low up to moderate sea states in particular for application as service vessels for the offshore wind mill farms at the North Sea. Typical length of these vessels is in the 20 meter range and typical speeds are up to 25 knots in calm water. In addition to the usual requirements for low levels of vertical accelerations and small motions the improvement in the seakeeping behavior of the catamaran has also to be found in the avoidance of wetdeck slamming. This put special focus on the design of the hull shape.

The solution for the optimized catamaran hull design was found in applying the Enlarged Ship Concept first and so to extend the overall length from 20 to 25 meters. Then the AXE Bow concept was applied on both hulls. To avoid wet deck slamming the vertical motion of the fore ship had to be introduced in such a way that when sailing into the wave to deck was lifted but without violent accelerations. So a special geometry has been designed between the hulls to introduce the wave forces gently but not to eliminate them completely. Finally the avoidance of the wet deck slamming was found in cutting away the fore most part of the wet deck about 20% of the overall length. This was also made possible by the application of the enlarged ship concept.

The lines plan of the “TwinAxe” catamaran concept is depicted in the Figure 5.
The research project aimed at a comparison between the TwinAxe concept and a comparable conventional catamaran. It was decided that the comparison between the two designs would be focused on the resistance in calm water and the heave and pitch motions and vertical accelerations in head waves. In addition the possible tendency for bow diving in following seas was also investigated for both designs.

The calm water resistance of the two designs is compared in the Figure 5. From these results it is obvious that the resistance of the TwinAxe is lower than that of the conventional catamaran. This is in particular due to the higher L/B ratio of the hulls and their bigger separation. A typical cross over is found at 25 knots.

![Figure 5 Calm water resistance of the TwinAxe and the Conventional Catamaran.](image)

From the results in waves only the vertical accelerations at a location 10% of the Loa aft from the bow are shown. The tests have been carried out in a typical North Sea Seastate and at a forward speed of 25 knots. These results are depicted in Figure 6.

![Figure 6 The distribution of the vertical accelerations at the bow for the TwinAxe Catamaran (left) and the Conventional Catamaran (right) at 25 knots in irregular waves with significant wave height Hs of 1.5 meters.](image)
The enormous gains achieved in the vertical acceleration levels obtained with the application of the TwinAxe concept are rather obvious. It is also well worth to mention that in all the conditions tested, i.e. with significant wave heights ranging from 1.0 to 2.5 meters and forward speed of 25 knots any wet deck slamming with the TwinAxe did not occur. In the following sea conditions no bow diving occurred also. Although the development time of this new catamaran concept was rather short the obtained results were so promising that already a couple of these catamaran designs have been sold. A typical rendering of one of these designs is depicted in the Figure 7.

![Figure 7. Rendering of the TwinAxe Catamaran as windmill support ship](image)

Another application of the new concepts was found in the design of a possible new Search And Rescue (SAR) vessel for the Royal Dutch Lifeboat Institute (KNRM). At present they are looking for a possible replacement of their existing fleet of 18.5 meter long RIB vessels capable of a forward speed of maximum 35 knots and to be used on the North Sea in all weather conditions. Due to the special functionality of these SAR boats and their possible use in very extreme environmental conditions some modifications to the original AXE Bow design had to be made. The new SAR boats should have improved seakeeping performance when compared to the present ones when head and bow quartering seas are concerned. In all other conditions they should at least have similar performance and preferably better. Particular attention had to be paid to the possible occurrence of broaching in stern quartering seas. Also the tendency to bow diving in extreme following waves should be considered. Finally the maneuverability of these SAR ships in severe waves, both head and following, should be an issue. The boats should also be self righting. Based on these requirements a new design has been developed. Particular point in the design were the enlargement of the hull, the application of the AXE bow but without
the typical negative sloped contour (downwards) forwards because these SAR boats should be able to take the ground frequently and violently. For safety and maneuverability reasons the boats are equipped with waterjets of ample power. The tube along the entire length of the hull is there for fendering reasons mainly. The most striking difference with the existing boats is the very fine bow with increase sheer and freeboard. Compared with the existing boats the deadrise is increased and the L/B ratio of the hull also. A rendering of this design is depicted in Figure 8.

![Figure 8 Proposal for a new SAR vessel for the KNRM with Loa = 21 m and Vs = 35 knots](image.png)

From an extensive series of experiments carried out with a model of this new design and a model of the existing boat in the towing tank it has been demonstrated that a considerable improvement in the head seas conditions has been achieved with the new concept, without any loss of performance in following and stern quartering conditions.

4. DEVELOPMENT OF NEW ACTIVE CONTROLS

In addition to these new concept developments also research has been carried out in the area of active control for fast ships. This originates from the effect that both the size and the high forward speed of these craft make the use of actively controlled fins etcetera very attractive. Two typical examples with promising results will be mentioned here:

- an actively controlled trim flap or interceptor at the transom of the boat to control pitch, heave and vertical accelerations and
- a retractable vertical bow rotor below the bow of a fast ship to improve directional control and reduce the roll- and yaw motion in stern quartering and following waves.

The idea of controlling the ship motions with an active control on the trim flaps at the transom is not new. In 1984 Wang Ref [7], amongst others, published experimental and computational results of a hard chine planing hull equipped with actively controlled trim flaps. In his research he already showed that considerable gains could be obtained with this control.
Recently Rijkens has extended this research with model experiments to determine the forces and moments delivered by both active flaps and active interceptors at the transom. The results of these systematic series of experiments have been used to extend the calculation procedure used in the mathematical model for the motions of fast ships in waves. The type of flaps and interceptors investigated by Rijkens are depicted in the Figure 8.

And the results he obtained with the flaps on the vertical accelerations at the bow are depicted in Figure 9 for the tests with and without flaps.

Figure 9  Vertical accelerations at the bow with and without active control on the flaps
Finally a new device has been developed for controlling the roll and yaw motions of fast ships in stern quartering waves.

It is known from full scale experience and model experiments that quite a few fast ship concepts are sensitive for severe combined roll and yaw motions in stern quartering waves sometimes even leading to complete loss of control and a broach. This is aggravated once again by the fact that most fast ships are relatively small compared with the surrounding waves. The phenomenon of the broach will not be fully explained here but a extended description can be found in Ref [8].

The Vertical Bow Rotor (VBR) device is a vertical and retractable Magnus Rotor underneath the bow of a ship, preferably an AXE Bow because the very geometry of such a bow easily enables the housing of such a device. A additional benefit of the AXE Bow and VBR combination is that the VBR cylinder is and will remain deeply submerged when the ship is heaving, rolling and pitching in large waves. A Magnus Rotor has the property to generate very efficiently a very high lift force when the cylinder is put into rotation. The combination of the forward velocity of the ship and the rotation of the cylinder produces a lift force perpendicular to the forward velocity of the ship. By changing the rotations per minute (RPM) of the rotor and/or the direction of rotation the lift force can be fully controlled both in magnitude and direction. Almost like a rudder but than more efficient. The VBR in this application is made retractable because in those situations or conditions in which its application is not necessary she can be easily retracted and so effect of the rotor on the ship resistance remains. A typical configuration of such a rotor is depicted in the Figure below.

![Diagram of VBR at AXE Bow](image)

Figure 9: The configuration of the VBR at the AXE Bow of a 35 meter LOA Fast Patrol boat (dimensions rotor full scale)
To investigate the effect of the VBR on the dynamic behavior of a fast patrol boat in stern quartering waves extensive experiments have been carried out in the Ship Motion Basin of MARIN in Wageningen. The ship tested was a 35 meter Length over all Fast Patrol Boat from DAMEN and the VBR was dimensioned based on an extensive systematic test with various rotors in the towing tank of the Delft University of Technology. A few of the results are presented here. They show the effect of the VBR on the roll and the yaw motion in an irregular sea with a significant wave height of 2.5 meters and a peak period $T_p$ of 7.6 seconds, a typical North Sea spectrum energy distribution over the frequency range. The waves are coming from 315 degrees (stern quartering) and the ship travelled at a forward speed of 22 knots. From earlier tests it was found that this was the worst combination of waves, heading and forward speed. The distribution plots show the crests and troughs of roll and the yaw motion with and without the VBR.

![Graphs showing roll and yaw motions with and without VBR](image)

**Figure 10** Distribution of roll and yaw motions in stern quartering seas with $H_s = 2.5$ meter at 22 knots with and without VBR

These results show that a reduction of almost 40% on average in the roll motion and of almost 60% in the yaw motion can be achieved in those conditions.

To investigate the extended application of the VBR also measurements have been carried out in Seastate with 3.5 meters significant wave height, conditions in which the ship without the active VBR now and then broached. These results are presented on a different
way in the following figures, i.e. in the Figure 11 as Significant Double Amplitudes (SDA) of the motions and as Maximum Plus and Minus amplitudes in Figure 12.

![Figure 11](image1.jpg)

**Figure 11**: Significant Double Amplitude for Roll and Yaw with and without the Bow Rotor at 22 knots in a seaway from an angle of incidence of 315 degrees and with a significant wave height of 3.5 meters.

![Figure 12](image2.jpg)

**Figure 12**: Maximum Roll and Yaw angles with and without the Bow Rotor at 22 knots in a seaway from an angle of incidence of 315 degrees with a significant wave height of 3.5 meters.

From these results it can be concluded that the introduction of the VBR has very positive effects on the controllability and the reduction of the roll and yaw motions in stern quartering seas. The operability of fast vessels in those conditions can be very much improved by application of the VBR. In the conditions tested the vessel used for the experiments did not ever experience any broaching behavior with the VBR activated whilst without the VBR some broaches did occur. Although not specifically investigated yet it appears that the use of the VBR is especially suited in combination with the AXE Bow.
5. CONCLUSIONS

The High Speed Craft area lends itself very much for improvements in design. In particular improving the operability in general of fast ships in a seaway is a very interesting field of research and development. Some noticeable results have been achieved in this area over the last decade’s trough intensive cooperation between universities and research institutes with the industry. It is to be expected that if this cooperation is continued and intensified in the years to come new and very fruitful results will be achieved again.

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