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The Axe Bow: The Shape of Ships to Come

by

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Introduction

Damen Shipyards has been involved in the Fast Workboats market for over 30 years. In this period, a lot has changed. The ongoing demand for higher speed through the years has in many cases resulted in the replacement of steel as a hull construction material by aluminium and composites. Also, totally new markets have developed in the past decades. Initially, only law enforcing authorities required high speed workboats for their patrol tasks. Nowadays, all kind of commercial and non-profit organizations make use of high speed boats, e.g. Crew Boats, Fast Suppliers, Survey Boats and Life Boats.
In many cases Fast Workboats are used for 5000-6000 hours per year, whatever the sea conditions. Flat water performance therefore is not the yardstick. It is the speed that can be reached in adverse conditions that really counts in the design of Fast Workboats. The limiting factor in this respect is not determined by propulsion or resistance characteristics, but by the behaviour of the ship in waves. Too high vertical acceleration levels will impede work and life on board, cause sea sickness, wear out the crew and eventually will damage the ship's structure.

Realizing the importance of sea-keeping characteristics, the Product Group "High Speed & Naval Craft" of Damen Shipyards has for a long time co-operated closely with the Delft Shiphydromechanics Department (Delft University). As a result of extensive research projects, some significant successes were achieved in the past ten years. In the following chapters, the "Enlarged Ship Concept" and the "Axe Bow Concept" are described. Finally an analysis is made of possible application of the Axe Bow in yacht design.

The Enlarged Ship Concept

In 1995, Delft University and Damen Shipyards carried out a desk study on the influence of hull lengthening on the "practical characteristics" of a ship. In this study, a 26 m Damen Patrol Boat was taken as the "parent ship". In two steps the hull of this design was lengthened respectively by 25% and 50%, See Figure 1. Similar studies were carried out before, but in this case it was decided to keep the functionality of the two lengthened versions completely equal to the original design. In other words, only the hull length was varied, the accommodation, superstructure, speed and range were all untouched. For the three designs, the following "practical characteristics" were determined:

- Building cost
- Operational cost (i.e. mainly fuel)
- Transport efficiency
- Operability (i.e. sea-keeping characteristics)

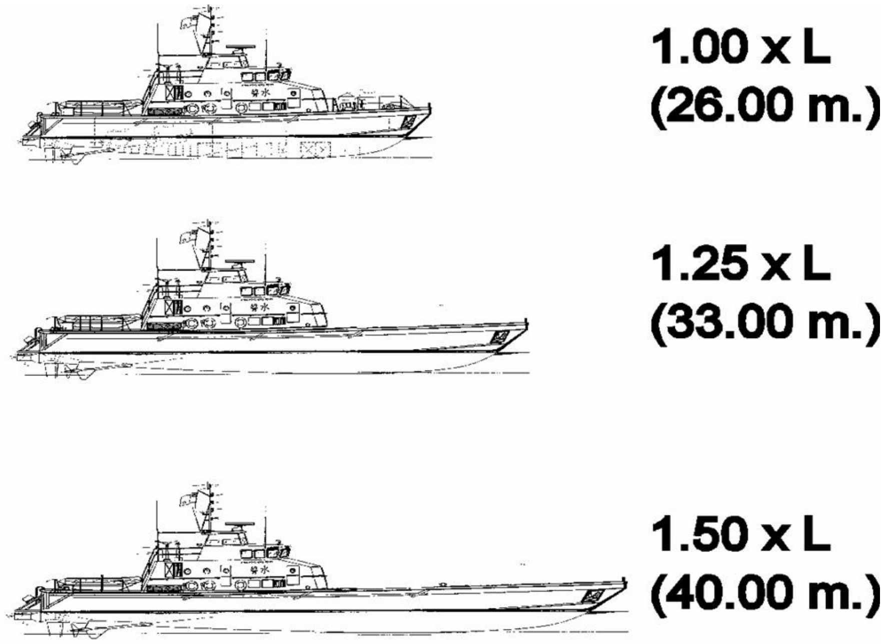

Figure 1: The Designs in the Enlarged Ship Concept (ESC) study

Comparing the results of the three variants, some very interesting conclusions were drawn for the lengthened designs:

- Building costs are only influenced marginally by the hull length, due to the fact that the extra length is "empty".
- Operational costs decrease, due to lower resistance
- Transport Efficiency increases significantly
- Operability increases significantly

In Table 1, the results of this analysis are summarized. For comparison reasons, the reference characteristics of the parent design are defined as 100% in Table 1.

	26 m parent design	25% enlarged hull	50% enlarged hull
Building costs	100%	103%	106%
Operational costs	100%	94%	93%
Transport Efficiency	100%	154%	167%
Operability	100%	135%	168%

Table 1: Comparison of "practical characteristics" of a 26m patrol boat with 2 enlarged variants

The final conclusion of the "Enlarged Ship" desk study was that – at equal functionality - a ship significantly profits from lengthening the hull.

In the study, the hulls were lengthened by simply increasing frame spacing. Realizing that the forward part of an enlarged ship is relatively empty, it was concluded that some of the volume and the deck area could be sacrificed in order to optimize the fore ship for sea-keeping characteristics. This was done in 1997, during the design of Patrol Boats for the Coastguard of the Netherlands Antilles and Aruba. A conventional 35 m design was enlarged to 42 m and the fore ship was designed to minimize vertical accelerations. IN Figure 2, the linesplans of the non-optimized and of the optimized Enlarged Ship design are shown.

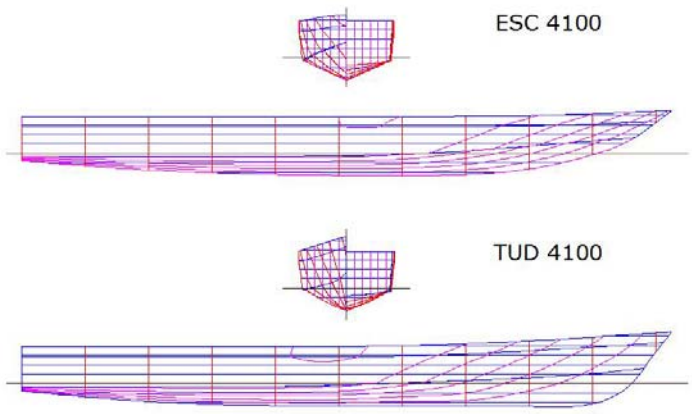

Figure 2: Line plans of the ESC 4100 and the TUD 4100 with improved bow shape

Extensive towing tank tests were carried out, which confirmed the forecast superior sea-keeping characteristics of the 42 m design. See Figure 3 for the comparison of the “vertical acceleration distribution” between the original 35 m design and the 42 m “Enlarged Ship”.

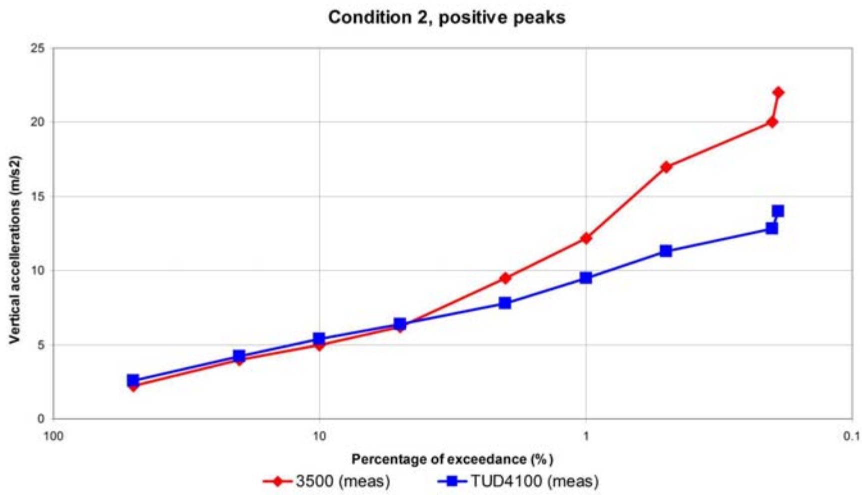

Figure 3: Distribution of peaks in the vertical accelerations in the wheelhouse for the ESC 4100 and the TUD 4100

In 1999 the first Patrol Boat (Stan Patrol 4207) of the enlarged design was delivered. The ship showed the expected excellent sea-keeping characteristics, both in the North Sea and the Caribbean. Figure 4 shows a picture of this first “Enlarged Ship”.
For a more elaborate explanation of the Enlarged Ship Concept, see Keuning e.a. Ref [1].

Figure 4 : The first Stan Patrol 4207

The Axe Bow Concept

Prediction of the operability of surface ships commonly is carried out with the use of linear theory based calculation methods. In the standard procedure, the seakeeping behaviour of a ship in a specific operating area is obtained by combining the Response Amplitude Operators (RAO's) of the motions with the wave spectra derived from scatter diagrams. The performance of a design is then determined on the basis of the "root-mean-square" (rms) or the "significant values" ($a_{1/3}$) of the calculated motions and accelerations.
This standard procedure however is not really applicable for fast craft, due to the strong non linearity's in the response of high speed ships to incoming waves.
According to Keuning e.a. (Ref [2]), the limiting criteria for safe operations of fast ships should be based on the actual distribution of the peaks and troughs of the responses (motions, accelerations) in irregular waves rather than on the average or significant values. In this procedure extensive time simulations have to be made in order to determine whether the limiting criteria for the safe operation of the ship under consideration are superseded or not. This is much more time consuming than the "linear" operability analyses carried out using the RAO's.

In order to determinate realistic limiting criteria for the operation of fast ships in irregular waves, the Delft Shiphydromechanics Department has carried out extensive series of full-scale experiments with fast patrol boats and SAR vessels on the North Sea. These were not limited purely to objective measurements, but also the opinion of the crews was taken into account.

Some very interesting conclusions were drawn from these studies:

- All crews decided for a voluntary speed reduction at roughly the same conditions on board the ship.
- The reason for voluntary speed reduction was not the magnitude of the significant amplitude of motions or vertical accelerations, but the occurrence of high vertical acceleration peaks.
- The voluntary speed reduction after a very big peak in vertical accelerations had just one reason: to prevent a repeat of such a high peak.

Clearly, most people react to “extremes” and not to “averages”. Therefore, it is apparent that research on optimization of sea-keeping behaviour should not be focussed on “significant values”, but on decreasing the high peaks in the response of a ship in irregular waves. For this goal, in 2003 a research project was started with the following participants:

- Delft Shiphydromechanics Department
- Royal Netherlands Navy
- US Coast Guard
- Maritime Research Institute Netherlands
- Royal Schelde (Damen Shipyards Group)
- High Speed & Naval Craft product group of Damen Shipyards Gorinchem

Based on an “Enlarged Ship” design, two hull forms were derived with significantly different fore body shapes.

The first variant is a Wave Piercer, designed to go through - instead of over – the waves, thereby limiting vertical accelerations.

The second variant was called the “Axe Bow Concept”, due to the peculiar Axe-shaped bow. As a first step in the design of what would become the “Axe Bow”, the pitching motion equation was analyzed. It was concluded that the level of vertical accelerations will decrease when the bow has a relatively low and non-progressive increase of buoyancy in pitching. This can be reached when the bow has a very fine entry, the sections are extremely narrow V-shaped and the flare above the waterline is limited as much as possible. In analogy with a mass-spring system, compared to a conventional bow the Axe Bow “softens” the spring and thereby decreases the vertical accelerations. The result however is that the pitching amplitude itself will increase somewhat due to the “softer spring” behaviour. For this reason the bow is very high (to forestall deck wetness) and extremely deep, in order to exclude the risk of slamming.

The same principles had been applied already (although to a lesser extent) in the optimization of the Enlarged Ship Concept in 1997. The Axe Bow design therefore could be regarded as an extreme version of the Enlarged Ship Concept.

Figures 5a, 5b and 5c, respectively show the models of the parent Enlarged Ship, the Wave Piercer and the Axe Bow Concept.

The following model test series were carried out with the three models:

- resistance tests (0 to 50 knots)
- head waves (25, 35 and 50 knots)
- following waves (25, 35 and 50 knots)
- free running with stern quartering waves (25, 35 and 50 knots)

Figure 5a: Model according to the Enlarged Ship Concept (ESC)

Figure 5b: Model according to the Wave Piercer Concept (WPC)

Figure 5c: Model according to the AXE Bow Concept (ABC)

All tests in waves were carried out in irregular waves, presenting a JONSWAP wave spectrum shape. The significant wave heights were 2, 2.5, 3, 3.5 and 4 m. The other integral wave parameters were constant: mean zero crossing period 6 s, peak period 7.8 s and gamma 3.3.

Compared to the performance of the “Enlarged Ship” parent model, the following conclusions were drawn for the Wave Piercer and the Axe Bow Concept:

Conclusions for the Wave Piercer:

- The flat water resistance of the Wave Piercer was the lowest of the three models. This probably is the result of the fact that the Wave Piercer had the longest underwater body (at the same waterline length) and the finest entry of the three models.
- In head seas the Wave Piercer performed quite well – as long as only focussing on the measurement results. Viewing the model test videos however, the picture changes dramatically. The model took so much water over the bow, even at lower speeds, that it

was decided not to test the Wave Piercer at the highest speed. The chance of loosing the model due to nose-diving was considered too high.

- Free running tests in quartering waves were not carried out with the Wave Piercer model, as the partners in the research project agreed that these expensive tests were of limited value, considering the disappointing performance of the Wave Piercer model in head waves.

Conclusions for the Axe Bow Concept:

- The highest measured vertical accelerations on the Axe Bow Concept proved to be 50% below those of the Enlarged Ship Concept. This notable improvement in sea-keeping performance becomes even more significant when realizing that the Enlarged Ship Concept already decreased peak vertical accelerations with 50% over conventional hull forms.
  In Figure 6 the sea-keeping performance of the Axe Bow is compared to the Enlarged Ship. This graph shows the probability of exceeding peak vertical accelerations in Sea State 5.
- Up to a speed of 35 knots, compared to the Enlarged Ship Concept, the flat water resistance of the Axe Bow is approximately 5% lower.
- During the free running tests in stern quartering waves, the necessary steering corrections for keeping track were very similar for the Axe Bow and the Enlarged Ship model. Both models did not broach, despite the very serious wave conditions.

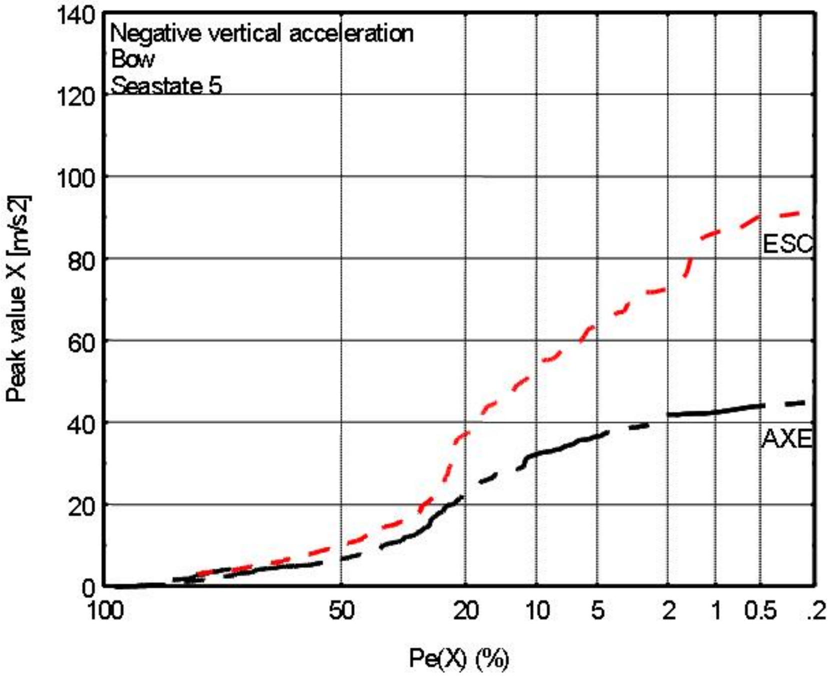

Figure 6: Distribution of peaks in the vertical accelerations at the bow Of the model according to the ESC and ABC

Based on the favourable characteristics of the Axe Bow Concept, Damen has designed a series of Fast Crew Suppliers and Patrol Boats. Figure 7 shows a 33 m Fast Crew Supplier in service in Mexico, appropriately named “Axebow 101” by the owner.

Figure 7: Fast Crew Supplier build according to the AXE Bow Concept

Axe Bows on Yachts?

In the design of Fast Workboats, optimization of functionality is the main objective. Only at a much lower priority, attention is given to styling. “Form follows function” clearly is the guiding principle for Fast Workboats. As a matter of fact this not only holds for the designers, but also for the users.

In general, the emphasis in yacht design is much more on styling than on pure functionality. This however does not obstruct application of the Axe Bow Concept in yacht design – but the owner clearly has to be interested in modern styling.

A yacht will particularly benefit from an Axe Bow, when it combines the following characteristics:

- Relatively high speed
  At relatively high speed, semi-displacement yachts with conventional hull forms will suffer from slamming at moderate to high sea states. This will be totally excluded with an Axe Bow hull shape.
- Long offshore cruising (or transits)
  In case a yacht is offshore for longer periods, it is impossible to shelter during adverse weather. Therefore, the hull design of these yachts should be focused on sea-keeping characteristics. The Axe Bow will significantly decrease the level of vertical accelerations and thereby will make life on board much more comfortable.

As mentioned earlier, the Axe Bow is an extreme version of the Enlarged Ship Concept. An Axe Bow yacht therefore should be relatively slender and light, in order not to spoil the hydrodynamic concept. This implies that an Axe Bow yacht has limited available volume for its length. As well as this, the volume should not be completely used in order to keep the ship light enough. Roughly, it can be concluded that a 50 m Axe Bow yacht should be compared with a 43-44 m conventional yacht. This however should not be regarded as a drawback, as the extra meters come at a low price and bring some very interesting features:

- Superior sea-keeping characteristics with total absence of slamming.
- Lower resistance at high speed due to longer waterline and slender lines plan. Apart from obvious merits as higher speed or less power, the low resistance hull shape yields the possibility of using steel as the hull construction material. This will have positive effects on stability and will decrease fatigue issues for larger sized yachts.
- Notably lower resistance at cruising/transit speed compared to more conventional semi-displacement and planing hull forms. This clearly has a very positive effect on the fuel consumption and thereby on the maximum range of a yacht.

In Figure 8 an artist's impression is given of a 50 m Axe Bow yacht.

Figure 8: AXE Bow Yacht artist impression.

Conclusions

In general, the following can be concluded for the Axe Bow Concept:

- The Axe Bow Concept decreases the level of peak vertical accelerations by 50% compared to the Enlarged Ship Concept (which already decreased peak vertical accelerations by 50% over conventional hull forms).
- Up to a speed of 35 knots, the flat water resistance of the Axe Bow is approximately 5% lower compared to the Enlarged Ship Concept (which already decreased flat water resistance significantly over conventional hull forms).
- Despite the deep fore foot, the Axe Bow Concept does not show a tendency to broach, when fitted with the right appendages.

Although developed for Fast Workboats like Fast Crew Suppliers and Patrol Boats, the Axe Bow Concept could be interesting for yachts. Particularly at relatively high speeds, and when used for serious offshore cruising, a yacht could clearly benefit from an Axe Bow. It must be realized however that an Axe Bow design should be relatively slender and light, in order not to spoil the hydrodynamic concept. Therefore, a 50 m Axe Bow yacht should be compared with a 43-44 m conventional yacht. This should not be regarded as a drawback, as these extra meters come at a low price, make life on board much more comfortable, and will reduce fuel consumption as a further bonus

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