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# The Development of the Next Generation Lifeboat for the KNRM

by

**J.A. Keuning**

**Report No. 1845-P** **2012**

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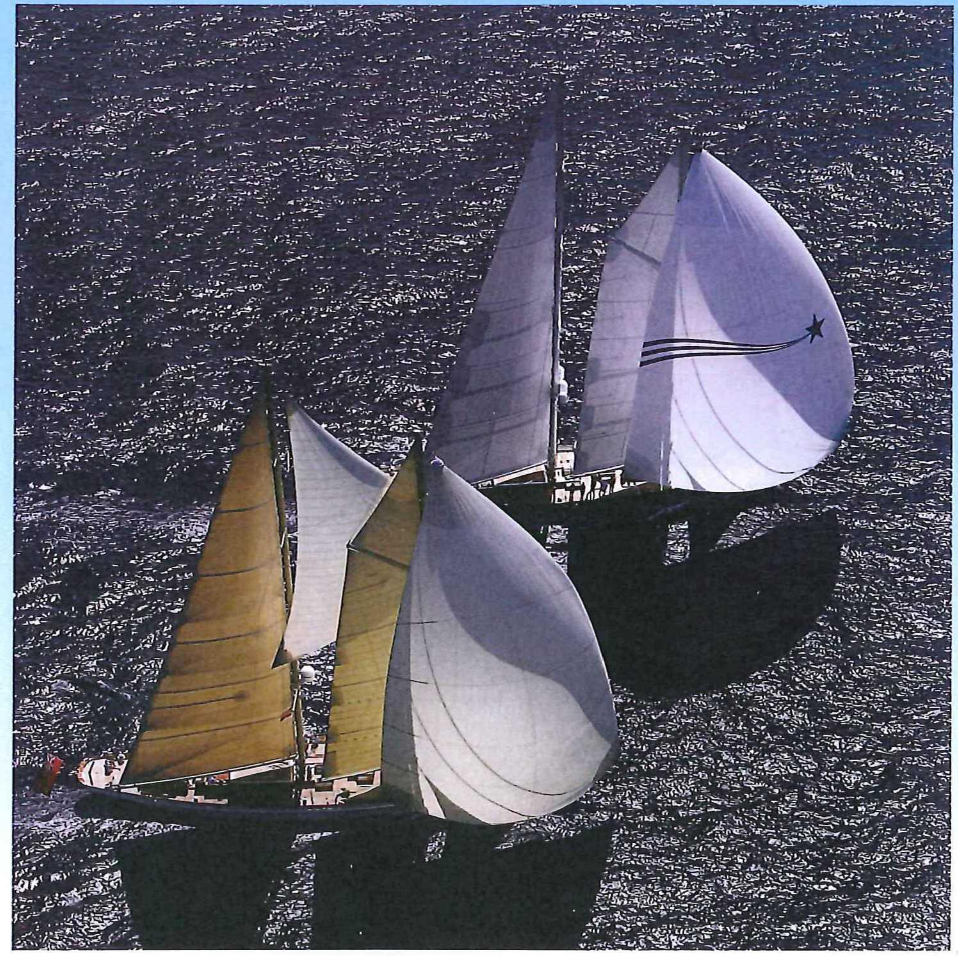
# 22nd International
# HISWA Symposium
# on Yacht Design and Yacht Construction

Amsterdam, 12 & 13 November 2012

# PROCEEDINGS



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# 22nd International HISWA Symposium on "Yacht Design and Yacht Construction"

**Amsterdam, 12 & 13 November 2012**

# PROCEEDINGS

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## on Yacht Design and Yacht Construction

**12 and 13 November 2012, Amsterdam, The Netherlands, Amsterdam RAI**

**Location:** Emerald Room, Amsterdam RAI

**Program Monday November 12, 2012**
**Moderator: Carl Cramer**

| | |
|---|---|
| 08.30 - 10.00 | **Registration** |
| 10.00 - 10.15 | **Opening** |
| 10.15 - 11.00 | **The development of the next generation lifeboats for the KNRM**<br>*Speaker: J.A. Keuning* |
| 11.00 - 11.15 | **Coffee Break** |
| 11.15 - 12.00 | **Use of glass in yachtbuilding and the regulations**<br>*Speaker: F. Verbaas* |
| 12.00 - 12.45 | **IMO regulations on NOx and SOx and its effects for yachtdesign**<br>*Speaker: U. Kleinitz* |
| 12.45 - 13.30 | **Lunch Break** |
| 13.45 - 14.30 | **Hull sailplan balance 'lead' for the 21th Century**<br>*Speaker: A. Claughton* |
| 14.30 - 15.15 | **Early design estimation of resistance and seakeeping properties based on systematic model experiments**<br>*Speaker: G.K. Kapsenberg* |
| 15.15 - 15.30 | **Coffee Break** |
| 15.30 - 16.15 | **Motions of a sailing yacht in large waves: an opening simple instationary modelling approach**<br>*Speaker: F. Fossati* |
| 16.15 - 17.00 | **Weather routing for motorsailors**<br>*Speakers: B. Pryszo, D. Sparreboom, M. Leslie-Miller* |
| 17.00 - 17.45 | **Delft Systematic Yacht Hull Series**<br>*Speaker: J.A. Keuning* |
| 17.45 - 18.45 | **Reception** |
| 19.00 | **Dinner** |

# 22nd International HISWA Symposium
## on Yacht Design and Yacht Construction

**12 and 13 November 2012, Amsterdam, The Netherlands, Amsterdam RAI**

**Location:** Emerald Room, Amsterdam RAI

**Program Tuesday November 13, 2012**
**Moderator: Carl Cramer**

| | |
|---|---|
| 09.00 - 09.45 | **The new generation off passenger superyachts- SOLAS or Passenger Yacht Code?**<br>*Speaker: A. Meredith-Hardy* |
| 09.45 - 10.30 | **Investigation of the effects of rig tension on sailing yacht performance using real time pressure and sail shape measurements at full scale**<br>*Speaker: D. Motta* |
| 10.30 - 10.45 | **Coffee Break** |
| 10.45 - 11.30 | **Carbon fiber rigging, yesterday, today and the lessons learned along the way**<br>*Speaker: A. Winistoerfer* |
| 11.30 - 12.15 | **Structural design of S/Y Dream Symphony: the largest wooden ship ever built**<br>*Speakers: A. Shimell and H. Ten Have* |
| 12.15 - 13.00 | **The robotic sailingboat, ASV Roboat as a maritime research platform**<br>*Speaker: R. Stelzer* |
| 13.00 | **Closing** |

# INTRODUCTION.

Once again you will find here the Proceedings of the International HISWA Symposium on Yacht Design and Construction.
As usual for a considerable time by now the Symposium is to be held in the RAI Congress Centre in Amsterdam on 12th and 13th of November 2012.
This year it is the 22nd time that the symposium is being organized and in that respect it is the oldest symposium in the area of yacht design and research!

The Organizing Committee again is very content with the work carried out by the Scientific Committee, which put together a very interesting program with a variety of topics. Between the more usual topics, such as issues involved with high performance yachts and new developments, a particular emphasis has been put this time on the construction: such as very large yachts entirely in build in wood and the application of glass as a more structural member. A few papers also deal with the aspects of the rules and regulations and their possible impacts on the design.

We are still successful in attracting a large group of students from all kind of educational programs to the symposium. This is an important aspect because the future of our yachting industry is with them and we hope to be able to stimulate their interest through this symposium. Also the symposium offers a nice opportunity for both the new and the elder generation to meet each other and exchange ideas and share common interest. I hope you will all make ample use of the opportunities we arrange in the time schedule to meet other people.
I would also like to place ample emphasis on the drinks organized at the end of today's papers and the dinner cruise through the Amsterdam canals later this evening.

Finally I would like to express my gratitude to our sponsors, DAMEN Shipyards, Maritime Research Institute the Netherlands, Royal Huisman Shipyards and Feadship, without whom the aims of the symposium, i.e. offering a worthwhile and motivating gathering of interested people from the various branches, research institutes and schools, would not be possible at an affordable price.

I am sure we will meet again in the future during next editions of this HISWA Symposium, although for me it will be the last time as member of the Scientific Committee, because after so many years of active participation I decided that the time has come to hand it over to a newer generation.

Jan Alexander Keuning
Chairman Organizing Committee
Scientific Committee

# *“ The Development of the Next Generation Lifeboat for the KNRM*

Jan Alexander (Lex) Keuning[1],

[1]Shiphydromechanics Department, Delft University of Technology, Delft, Netherlands

## ABSTRACT

The Royal Netherlands Sea Rescue Institution (KNRM) exploits a fleet of lifeboats around the North Sea coast of the Netherlands. The majority of this fleet consists nowadays of so called Rigid Inflatable Boats or “RIB’s”. The largest vessels in the fleet are from the so-called “Arie Visser” class with a length of around 18.5 meters and a maximum speed of 35 knots. These are all weather boats and are completely self-righting. Although they are quite satisfied with the existing boats the KNRM plans to replace these 10 boats in this class in the next 10 years. So an improved design (if possible) is sought for.

To work on the project of the next generation life boat a design group has been composed consisting of the Shiphydromechanics Department of the Delft University of Technology, Design office of W. de Vries Lentsch, being the designers of the existing boats and the High Speed Craft Department of Damen Shipyards at Gorinchem.

In the last decades the Shiphydromechanics Department of the Delft University of Technology has put much effort in research on improved seakeeping of fast ships leading amongst others to the development of the Axe Bow Concept (ABC). Damen Shipyards has put several designs from this ABC on the market with considerable success. So the design team took this concept as a possible concept for the improved design and made the required modifications to suit the KNRM needs.

First an extensive enquiry amongst the coxswains of the existing boat from the Arie Visser class was set up to gain insight in the new requirements for the improved boat. Based on these requirements the group developed two new designs: one a modest adaptation of the existing boats, subsequently named the “Evolutionary” design and one based on the successful AXE Bow Concept (ABC), subsequently named the “Revolutionary” design.

The first design phase was then to develop these designs using available software for computer simulations and calculations. The emphasis in the new designs was on improved operability and improved habitability (i.e. less noise and vibrations).

Extensive full scale measurements on the existing boats of the “Arie Visser” class were carried out, partly already in the past to find the limiting phenomena as far as “comfort” on board is concerned and these results were subsequently used for improving thee design. The now known behaviour of the existing boats could be used as a bench mark.

Subsequently the three designs, i.e. the Arie Visser, and the newly developed Concept 1 and the Concept 2, have been tested for their resistance, sinkage and running trim in calm water. Then extensive testing on their behaviour with high forward speeds in head irregular waves with various significant wave heights (Hs) and peak periods (Tp) of the spectral shapes have been tested with emphasis on measuring motions and vertical accelerations.

Next their behaviour in high stern quartering, following and beam seas has been investigated in the towing tank, because reliable calculation methods of such behaviour are not available (yet). These tests using free sailing radio controlled models in the Ship Model Basin (SMB) of MARIN were carried. With the emphasis on the possibility to compare the new designs with the existing one for possible differences in their tendency for bow diving and broaching behaviour in these high seas.

To convince the coxswains even further on the safety of the new boat in addition a new test set-up has been developed. many tests in very severe breaking waves have been carried out in the towing tank of the DUT in specially “conditioned” waves and the models run through these both in head as well as following waves conditions to compare their behaviour in extreme conditions for bow submergence and broaching.

Based on these results and the observations made by the various coxswains of the KNRM a final design has been chosen. The results of this research project will be summarized and presented in the present paper.

## 1.0 INTRODUCTION

In the design of high speed ships the hydrodynamics always play an important role, presumably more important than with the more conventional designs. A long lasting goal for high speed ships in a seaway is to be able to reach high speeds at reasonable cost while at the same time the capability to maintain this high speed and so the operability (and safety) in a severe seaway. This often calls for ingenious hydrodynamic approaches. In the present paper the emphasis will be on the hydrodynamics involved in the design of the new life boat. Life boats are even more special as a design case because they need to be safe and acceptably “comfortable” to more or less “modern day standards” in the “average” conditions in which most of their duties are carried out, yet they must still be operable and in particular safe in the more and even the most extreme conditions that can be met in their operational areas.

The operational area for the Royal Netherlands Sea Rescue Institution (KNRM) is the Dutch Coastal area and the southern part of the North Sea. This is a notorious dangerous area due to the presence of many estuaries, shoals, associated strong tidal currents and the fact that usually in the most severe conditions (i.e. gales and storms from the West through North West to the North) the Dutch coast is a lee shore. It is also one of the busiest shipping areas of the world with a high occupancy of recreational craft in particular in the summer. This calls for good operability in a wide range of operational conditions and a large fluctuation in ships sizes and types to be assisted or rescued.

Typical design characteristics of the "Arie Visser" class boats are: maximum speed up to 35 knots, overall length around 19 meters, occupancy of 6 crew, twin engines with water jets, full 180 degrees self-righting capability, good sea keeping capabilities among which high speed to be maintained in head seas and excellent manoeuvring behaviour in all conditions up to waves of 10 meters high. A photograph and the linesplan of one of these boats is presented in Figure 1 together with some main particulars in Table 1.e 1.

**Main particulars "Arie Visser" class design**

| Designation | Symbol | Unit | Arie Visser |
|---|---|---|---|
| Design | - | [-] | |
| Overall Length | Loa | [m] | 18.8 |
| Overall Breadth | Boa | [m] | 6.1 |
| Draft | T | [m] | 1.07 |
| Weight | W | [ton] | 28 |
| Longitudinal Center of gravity | LcG | [m] | 6.12 |
| Wetted Area with zero speed | S | [m^2] | 60.9 |
| Metacentre Height | GM | [m] | 1.77 |

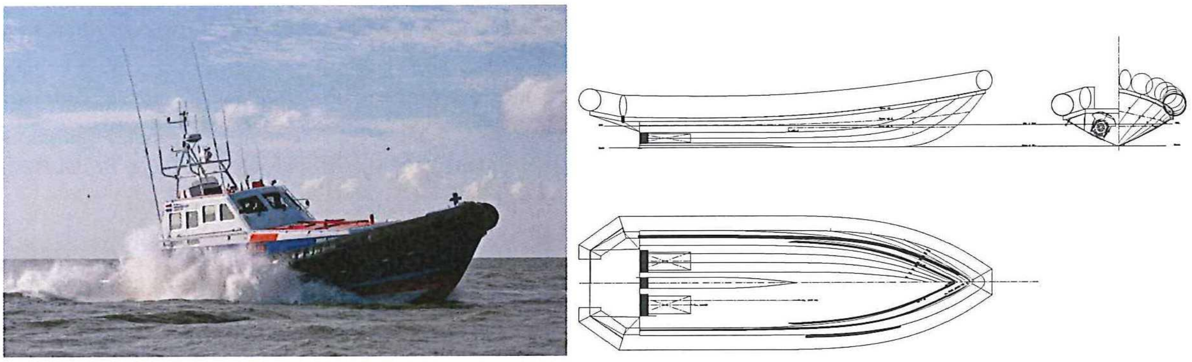


**Fig. 1.** Linesplan and photograph of the "Arie Visser" class design.

The operational achievements of these boats met the requirements of the KNRM to a certain level and the crews were generally satisfied with the performance of these boats and certainly fully confident in their safety. However from a series of full scale experiments conducted by the Shiphydromechanics Department over the years it became evident that higher achievements with respect to sea-keeping behaviour could be possible.

This led the Royal Netherlands Sea Rescue Institution (KNRM) in 2009 to initializing a large project for the conceptual development, the design, the engineering and finally the construction of a new SAR lifeboat for the North Sea capable of meeting these new requirements in the 10 – 20 years to come. In addition every way to improve on their operability in a seaway should have to be investigated.

To start the process an intensive questionnaire has been send around amongst the coxswains and crews of all SAR boats including the technical and supporting staff of the KNRM to acquire more knowledge about the possible short comings of the existing fleet and the wish list about the future design. In short the most important design objectives for the new designs became:

- Length around 20 meters over all
- No greater draft than 1.10 meter
- Maximum attainable speed of 35 knots
- Range at full speed of circa 600 miles
- Crew of 6 persons, seated in the wheelhouse (maximum suggested capacity of rescued persons on board circa 120!)
- Two engines with water jets in two separate engine rooms

- Noise levels in the wheelhouse not above 70 dBa
- Fully self-righting over 180 degrees of heel
- Improved sea keeping performance in head and bow quartering waves with higher sustainable speed
- At least a similar performance to the existing boats in large and steep stern quartering and following waves (i.e. broaching and bow diving), preferably with increased course keeping capabilities at high speed
- Good manoeuvrability at both low and high speeds also in large waves

With these design objectives now available a design team was composed, consisting of the Hydrodynamics Department of the Delft University of Technology (DUT), the High Speed Craft Department of Damen Shipyards and the designers of the existing boats De Vries Lentsch Design Office. This team, with the assistance of the staff and coxswains of the KNRM, took up the task to design the new boat. Recent developments in the hull form design of fast ships were introduced and considered in combination with fixed and moveable appendages. New calculation and experimental techniques were used to be able to predict, compare and verify the hydrodynamic behaviour of the various design variations.

## 2.0 THE DESIGNS

The principal decision about the design procedure was to make at least two full design alternatives to the existing boat the “Arie Visser” and to compare both these alternative designs in their behaviour in both calm water and waves with the “Arie Visser”. In this way the “Arie Visser”, of which design also very much full scale data, obtained during many tests at sea, were available, served in the process as the benchmark for the evaluation of the merits or short comings of the other designs.

A design objective was to investigate whether the application of the Axe Bow Concept (ABC) could be effective for these SAR boats.

The application of the ABC has been proven very successful for improving the operability in a seaway with fast Patrol Boats and Fast Crew Suppliers over the last decade. But these were generally bigger ships (35-55 meters Loa) and the SAR boats of the KNRM must be capable of dealing with very (more) rough conditions such as breaking waves.

The development of the Enlarged Ship Concept (ESC) and Axe Bow Concept has been adequately described in various earlier publications by the author, amongst others Ref [ ] and Ref [ ]. Therefore only a very short resume will be given here.

The development of the ESC and ABC was based on the observation, made during numerous full scale measurements onboard fast patrol boats, that the speed reduction sailing in waves was for 85% voluntary, i.e. applied by the crew. In addition it was shown from these results that this voluntary speed reduction was primarily provoked by the occurrence of rarely occurring events in the vertical accelerations (high slamming) irrespective of the significant or “average” value of the vertical accelerations. Yet in the design evaluations made for comparing fast ships designs these significant values were always used as the basis of the operability limiting criteria used

As an illustration of this the following figure is presented, giving the distribution of the peaks in a vertical accelerations signal measured onboard a fast ship. On the horizontal axis it presents the percentage of the total peaks in that given time trace of the elaborated signal a certain value of the vertical acceleration (on the vertical axis) is exceeded.

What really counts for the good operability is the right hand corner of this distribution, i.e. the (large) magnitude of the rarely happening events. These should be lowered as much as possible and in that respect the black boat is significantly better than the red boat, even though at the “significant” level (at roughly 13% probability of exceedance) the black boat is somewhat worse.

Along these lines the ESC and ABC have been developed and with the aid of the developed mathematical model a hull shape could be designed that meets these requirements. A typical lines plan of the ABC is presented in the Figure below.

Along these lines the ESC and ABC have been developed and with the aid of the developed mathematical model a hull shape could be designed that meets these requirements.

The ESC aims at lengthening the hull substantially (25% or 50%) without any change in the functionality, the speed and the beam of the craft. This turned out to have a significant effect on the operability in a seaway (35%-65% better) without a major effect on the building cost (+3% till +6%). As a bench mark the StanPatrol 2600 from DAMEN Shipyards was used and the plans of the Enlarged Concepts are shown in Figure .

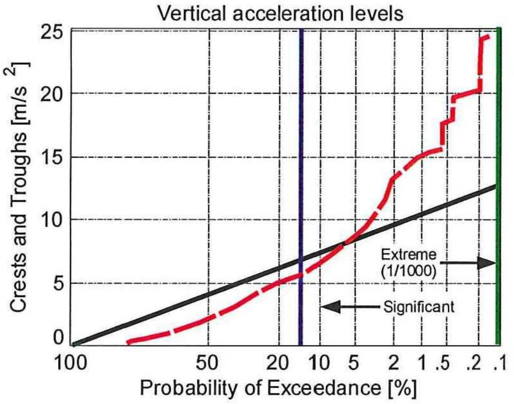


Figure 2 Distribution plot vertical accelerations

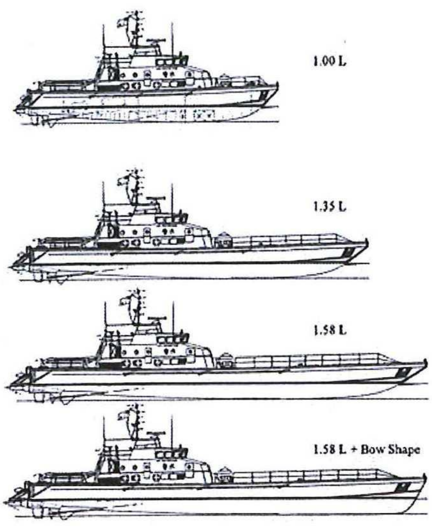


Figure 3 The Base Boat and the Enlarged Ships Ref [ ]

The results of this study are summarized in Figure 4 , in which the length, the building costs, the operational costs, the transport efficiency and the operability on the North Sea are compared with the base boat as bench mark.

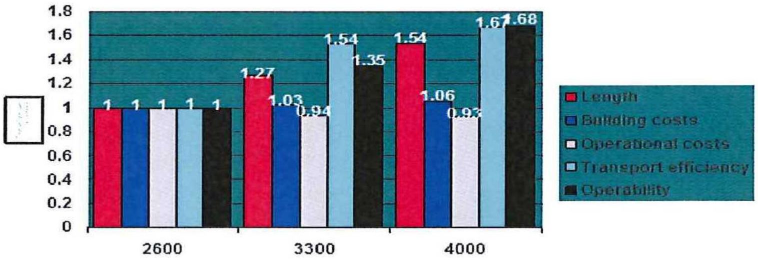


Figure 4 Results of the Enlarged Ship Concept study

From this the benefits of the ESC became obvious. Since in particular at the fore ship void space is being created, room became available to shape the bow sections in such a way that slamming was reduced to a minimum. This lead to the AXE Bow Concept, in which very deep fore sections, with no flare and a downwards sloping centreline are introduced.

A typical lines plan of the ABC is presented in the Figure below.

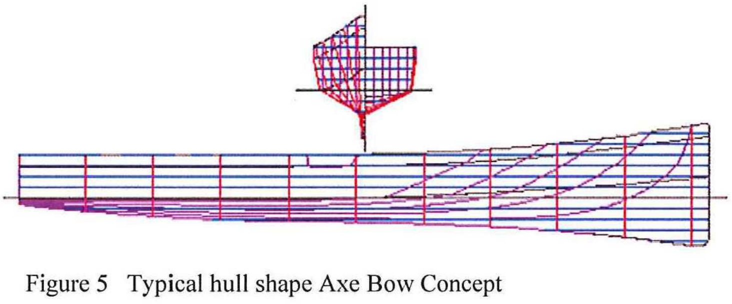


Figure 5 Typical hull shape Axe Bow Concept

From experience gained over the last decade with ships build according to the Enlarged Ship Concept (ESC) and the AXE Bow Concept (ABC) the positive effect on sea keeping performance of lengthening the ship, increasing the Length to Beam (L/B) ratio and the Length Displacement Ratio ($L/\Delta^{1/3}$) combined with significantly increasing the deadrise of the bow sections and reducing the bow flair is known. So it was decided to apply these new insights in two respective steps to the new SAR design and to investigate the effect on performance. The full shape of the AXE Bow, i.e. with the downward slope in the forward contour could not be applied for the SAR design, because these boats operate often at very shallow areas (and even go aground) and so the draft restriction was very stringent. The increase in the freeboard height forward and the reduction in bow flare however could be applied.

The main dimensions of the new KNRM design were more or less stipulated by the set .of design objectives so the most important considerations were on the hull shape and in particular on the bow shape of the new designs. From the existing design it was known that the relatively full bow sections introduced violent motions and high vertical accelerations in head and bow quartering waves, which usually led to a significant voluntary speed reduction by the crew in anything above 2.0 meters significant wave height. On the other hand this bow shape guaranteed in high and steep following waves sufficient reserve buoyancy to prevent bow diving.

So two alternatives to the base boat the "Arie Visser" (AV) were designed: i.e. the "Concept 1" (C-1), with a sharper bow and deeper fore foot but only modified modestly with respect to the Arie Visser (this design was therefore nicknamed "Evolution"), and "Concept 2" (C-2), with the Axe Bow philosophy applied but without the negative contour forward (nicknamed "Revolution"). Both the C-1 and C-2 design had an increased length (ESC) to improve their L/B and $L/\Delta^{1/3}$.

Another important consideration was the application of a tube, so typical for the RIB concept. A careful weighing of the pro's and con's was carried out. Every now and then structural problems with the tubes did arise in particular with respect to wear and tear but also the connection to the rigid structure gave problems. For a SAR boat coming alongside other vessels often the advantage of having an around fender is clear. However from a hydro dynamical point of view the benefit of a tube is not so obvious. The blunt intersection between the underside of the tube and the hull may generate high impulsive hydrodynamic forces when the ship is performing large relative motions at high speed in waves and from a point of view of wave excited forces the influence is actually disadvantageous in particular at the bow. The influence on the static stability of the tube at larger angles of heel (and pitch) is obvious but it is not necessary to derive the desired GZ curves through the use of the tube and the reserve buoyancy can be also be generated in other ways. Therefore it was decided to minimize the size and the volume of the tube as much as possible and to do so particularly in the forward third part of the hull. The reserve buoyancy was created (as is the design practice in the ABC) through significantly increasing the freeboard forward.

The weight distribution of the ship and the transverse moment of inertia of the water plane area and beam were chosen carefully to achieve a minimum value of the static GM value of at least 1.75 meters at zero speed. An important aspect for the safety of life boats is the Ultimate Stability, i.e. the stability at extreme values of heeling angle and their capability to recover from a full 180 degrees capsize. In first instance this is driven by the position of the centre of gravity of the boat and the shape and volume of the superstructure. Strict criteria are not available for the values for GZ at 180 degrees of heel but care should be taken to make these not too large because the self-righting motion, i.e. roll, can become very violent. The "Arie Visser" survived over the years various 180 degrees knock downs so here GZ values were considered to be appropriate and taken as the ones for the others to meet.

Various modifications to the designs were carried out during the process using hydrostatic calculations, resistance calculations and motions prediction analyses by using the non-linear time domain motion prediction program FASTSHIP as described in Reference [1] and [2]. This program has been validated extensively and was proven to be sufficiently accurate for the use in the design stage for comparing fast ships on their performance in calm water and waves and proved very use full for the purpose in particular through its short CPU time needed. All these considerations (and of course many more) led to the final development of the lines plans of the new designs C-1 and C-2 respectively. The lines plans and a rendering of the two designs are presented in the Figures 4 and 5.

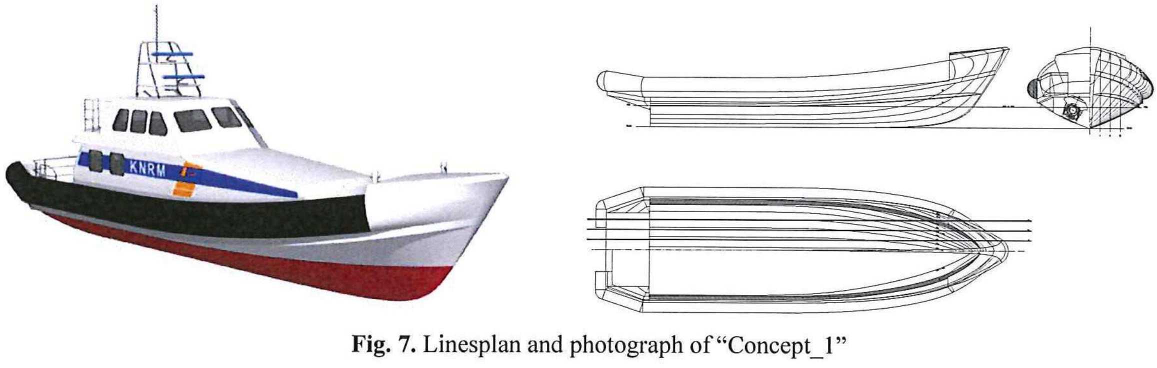


**Fig. 7.** Linesplan and photograph of "Concept_1"

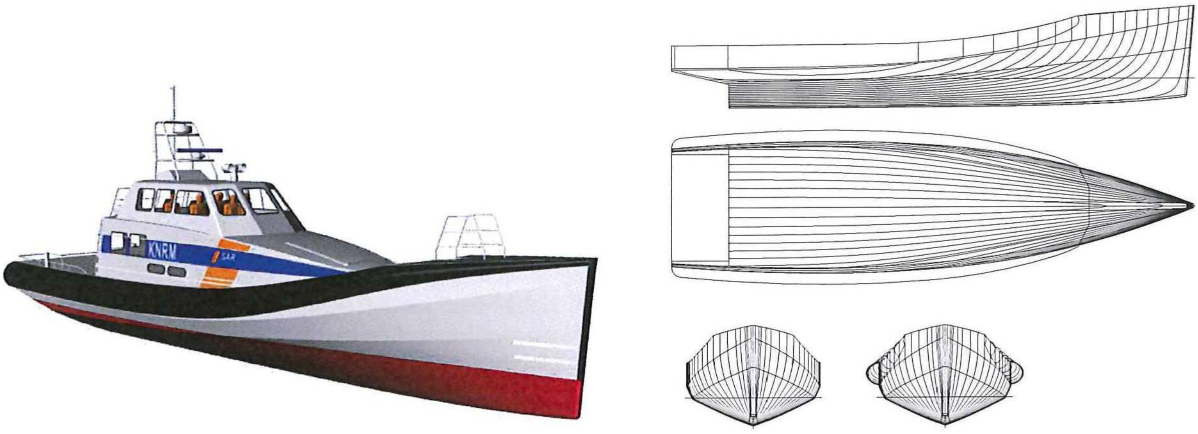


**Fig. 6.** Linesplan and photograph of "Concept_2"

The main dimensions are presented in Table 2.

**Table 2.** Main particulars "Concept_1" and "Concept_2

| Designation | Symbol | Unit | Concept_2 |
|---|---|---|---|
| Design | - | [-] | |
| Overall Length | Loa | [m] | 21 |
| Overall Breadth | Boa | [m] | 6.35 |
| Draft | T | [m] | 1.17 |
| Weight | W | [ton] | 39.9 |
| Longitudinal Center of gravity | LcG | [m] | 6.891 |
| Wetted Area with zero speed | S | [m^2] | 78.57 |
| Metacentre Height | GM | [m] | 1.46 |

The construction material of the boats is aluminium alloy for both the hulls and the superstructures just as with the Arie Visser (AV). The increase in the overall weight that becomes apparent from the comparison of the values in these tables with those of the Arie Visser, as presented in Table 1, can be largely attributed to the considerable amount of sound insulation that has to be applied in the new designs to reduce the noise levels to the desired rate, which in its turn led to heavier engines, bigger water jets and more fuel. This is the well-known downwards spiral!

## 3.0 THE EVALUATIONS OF THE DESIGNS

The evaluation of the designs has been carried out in first instance on a number of different aspects, i.e. the (ultimate) stability, the calm water performance, the behaviour in head waves under more or less "usual" working conditions and the behaviour in large following and stern quartering waves with an emphasis on a possible tendency towards broaching.

The principal aim of the evaluation was to discover if the new designs could yield a significant improvement in sea keeping performance under "usual" conditions without losing any performance in large following and stern quartering waves. Hereto the AV design is incorporated in all results to serve as the bench mark.

All experiments have been carried out with 1:10 scale models of the three designs. This scale has been chosen to suit the capabilities of the various experimental facilities used for the experiments. Part of the tests have been carried out in the large towing tank of the Delft University. This tank is 145 meters long, 4.25 meters wide and has a waterdepth of 2.5 meters. The maximum speed of the towing carriage is 8.0 m/s. There is a hydraulically activated wave generator at one end of the tank. The tests carried out in Delft were: the resistance tests and the sea keeping tests in head and following waves. The experiments in stern quartering waves have been carried out in the Ship motions and Manoeuvring Basin (SMB) of MARIN in Wageningen. This facility is 225 m long, 50 meters wide and 5 meters deep. Maximum speed of the towing carriage is 6.0 m/s. Waves can be generated from any direction.

During the Delft tests the models were connected to the towing carriage in such a way that they were free to heave and pitch but restrained in all other modes of motion. Therefore these tests were carried out with constant forward speed. A photograph of this setup is shown in Figure 6. During the tests in the SMB completely free sailing models have been used with an on board measurement system for all the motions. These models were equipped with engines and water jets and autopilots. The inputs for the auto pilots were the yaw, the yaw velocity and the cross track error (sway). A photograph of this setup is shown in Figure 7.

The maximum wave height attainable during the tests both in Delft and in Wageningen was about 4.0 meters at full scale. This was not high enough for testing the models in the most extreme conditions.

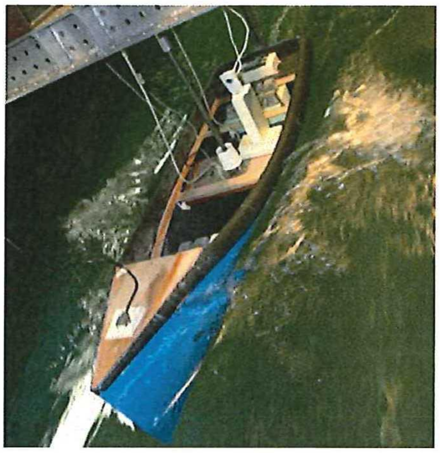


**Fig 7 Photograph of Delft test set-up**

**Fig. 8.** Photograph MARIN SMB test set-up

### 3.1 The Static Stability Curves

The static stability curves of the three designs are presented in Figure 8. These are the GZ curves for the design condition over the full range of 180 degrees.

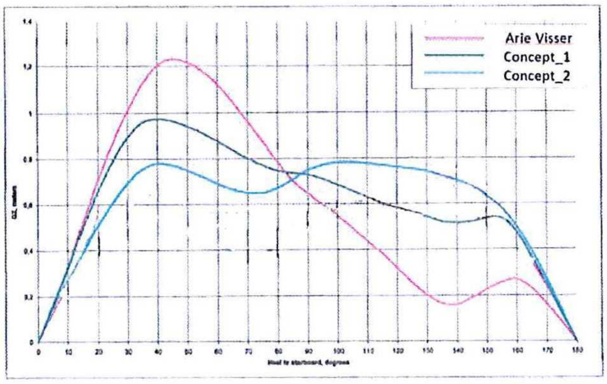


**Fig. 9.** Stability-curves, “Arie Visser”, “Concept_1” and “Concept_2”

From these results it is clear that all three designs are full self-righting and that C-2 has the best characteristics for the up side down condition. In the normal working range say up to 30 degrees of heel there are no significant differences between the designs.

### 3.2 The Calm Water Resistance, Sinkage and Trim

The results for the sinkage, trim and resistance of the three models are presented in the Figure 9, as function of the forward speed.

For the extrapolation to full scale the Froude’s method has been used, using the ITTC-57 friction line and the dynamic wetted area at each speed as measured during the runs.

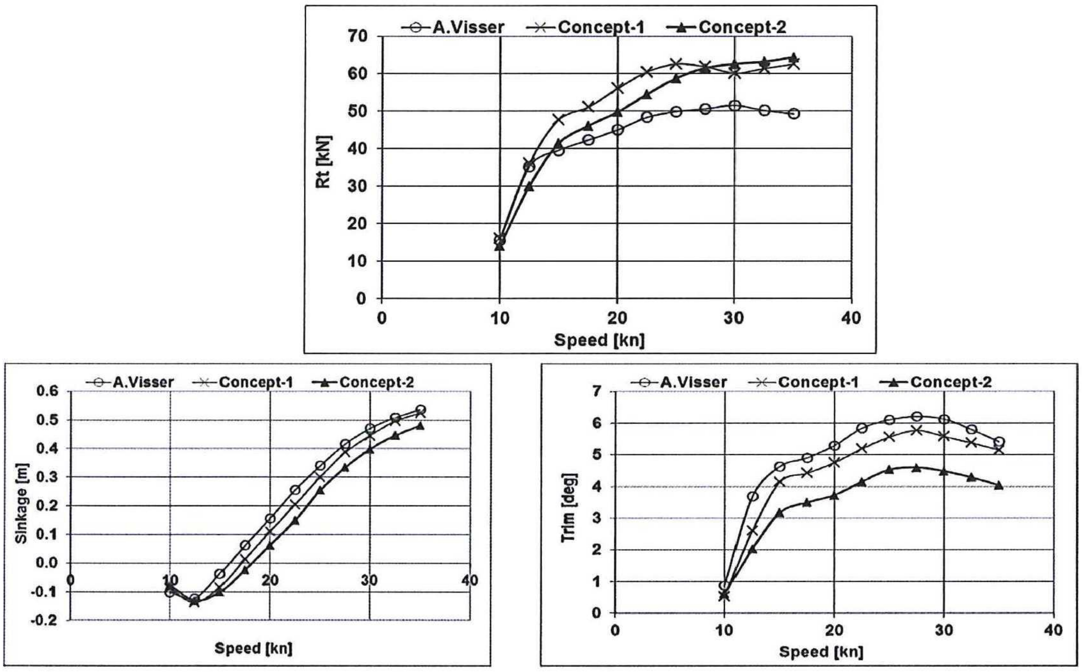


**Fig. 10.** Resistance, Trim and Sinkage results., "Arie Visser", "Concept_1" and "Concept_2"

From these results it can be seen that the AV rises out of the water more than C-1 and C-1 on its turn rises more out of the water than C-2. A similar trend can be observed with the running trim. This is in line with the expectations, because the hull of the AV is designed to generate more hydrodynamic lift than that of C-1 and the hull of C-2 is designed to yield the lowest lift in particular at the fore part of the ship. The maximum trimming angle of the AV and also the C-1 are above the optimum values generally accepted. The resistance of the AV is over the whole speed range considerably lower than of the other two. This can largely be attributed to the considerable difference in displacement and the more hydrodynamic lift generating hull.

From these results it can be concluded, as is generally known of course, that from a calm water resistance point of view reducing the weight remains important (considering the results for AV) and that over a large speed range the C-2 performs better than the C-1 except for the highest speed range. The running trim angle of the AV and the C-1 are uncomfortably high in the hump region. This may even be aggravated by the addition of the trimming effects caused by the water jets not present during these tests.

### 3.3 Comparison of the performance in head waves

During the design process various motion assessments have been performed using the FASTSHIP computer code. Based on these computational results it is to be expected that the C-2 outperforms the two other models significantly when the vertical accelerations at the bow and in the wheelhouse are concerned. Nevertheless it was decided still to carry out these tests with the three models in irregular head waves in order to be able to verify those findings.

For these tests, to limit the amount of experimental work, a selection of three environmental conditions with corresponding average forward speeds has been made. These combinations of wave climate and speed were known to be more or less realistic for the AV from full scale measurements and they are summarized in the Table 3 below:

**Table 3.** Test conditions DUT

| Condition [-] | Vs [kn] | Hs [m] | Tp [s] |
|---|---|---|---|
| 1 | 35 | 0.93 | 7.62 |
| 2 | 25 | 1.84 | 8.11 |
| 3 | 17.5 | 2.64 | 8.67 |

In particular Condition 2 is close to an environmental condition which is quite often met at the North Sea by the SAR boats in their operations.

In each generated wave spectrum at least 12 different test runs have been carried out with every model each test in a different part of the spectrum realization. Care has been taken that all three models met exactly the same parts of the realization so that an accurate comparison of their behaviour became possible.

To check on the validity of the FASTSHIP simulations, used in the design stage, as a typical results the outcome for the vertical accelerations at the bow in Condition 2 both measured and simulated are shown for the AV, C-1 and C-2 in Figures 10, 11 and 12. The results are plotted as distributions on an adjusted horizontal scale, which would yield a Rayleigh distributions for the crests and troughs as a straight line. The deviation of the actual plot from a straight line is therefore a measure of the non-linear behaviour of the output signal under consideration because the incoming surface waves (the input) are supposed to be Rayleigh distributed.

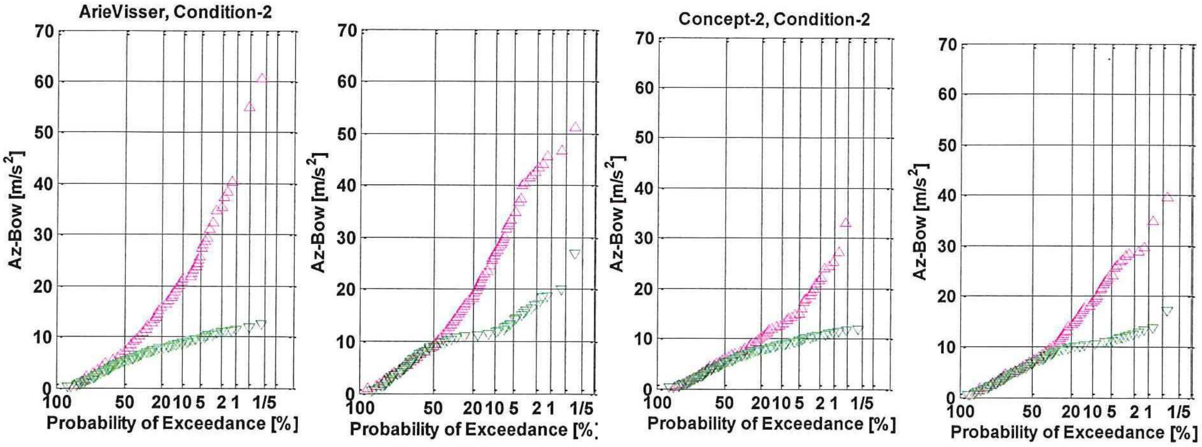
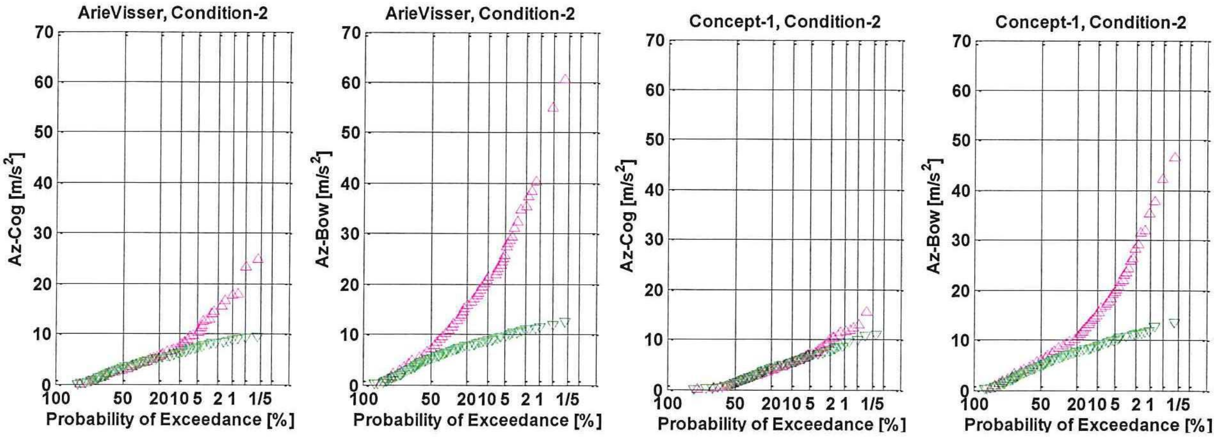


**Fig.11.** Az_Bow measured (left) and calculated (right) of Ärie Visser"and "Concept_2"

As can be seen from these distributions the similarity between the measurements and simulations is satisfactory although the absolute values may differ to some extent. In all cases however the trends in the differences in behaviour between the various designs are identical.

It is known from real life experience and full scale measurements that most speed reductions on board fast ships in head and bow quartering waves (and hence the loss of full operability) are voluntary and imposed by the crew. The driving factor in this speed reduction is the occurrence of high peaks in the vertical accelerations irrespective the average or significant magnitude of the accelerations at the time. Minimizing these high peaks with a low(er) chance of occurrence, i.e. in the right hand corner of the distribution plots, is of prime importance for optimizing operability. Therefore the emphasis in the comparison of the three designs is in that region of the distributions.

To show the differences in behaviour in that respect between the three designs in the Figures 13, 14 and 15 distributions of the vertical accelerations in the CoG (close to the wheelhouse) and at the bow (at 10% of Loa aft of the stem) are presented.



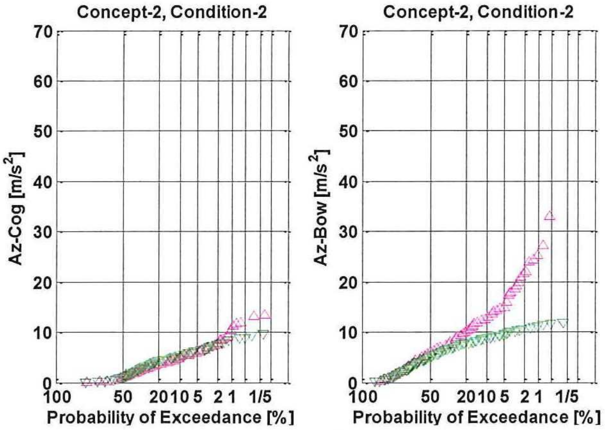


**Fig. 22.** Vertical accelerations at CoG and the Bow for "ÄV" , "Concept_1" and "Concept_2" respectively

The results for the other conditions showed a similar tendency. From all these results it became obvious that the C-2 outperforms the other two designs to a large degree.

### 3.4 Tests in following waves

To check on the possible tendency to bow diving and make a comparison in this aspect between the three designs, tests in high following waves have been carried out in the Delft tank. The conditions have been chosen in such a way that two situations did occur: one in which the ship was slowly **overtaken by** the wave and one in which the ship was slowly **overtaking** the wave. These tests have been carried out with a constant forward speed in the Delft tank. The speed during the tests was chosen at 18 and 25 knots respectively. The waves generated were a so called "bi-chromatic wave train". By generating two regular waves with a small difference in frequency the amplitude of the resulting wave is slowly varying in time. The capabilities of the wave generator to generate the maximum wave height possible determined the selected frequencies. The maximum wave height encountered was roughly 3.5 to 4.0 meters at full scale, this being the maximum capability of the wave generator at this scale and this wave length. The wave length was between 75 and 90 meters at full scale. In the actual realisation of the waves care has been taken that the highest wave would indeed be met during the runs. This procedure eliminated the otherwise inevitable necessity of carrying out an extreme large number of runs to gain sufficient statistical worthy information when carrying out the tests in a real spectrum due to the very low frequency of encounter between the ship and the waves. Care has been taken again that all models were tested in exactly the same wave realisations. So for the sake of comparison these test procedure proved very feasible and useful.

Presentation of the results of these tests is rather cumbersome, because sensible statistical elaboration of the signals is not possible due to the limited amount of fluctuations and tests carried out. The most important output is the video taken from all runs. On these videos it is evident that not one of the models had any tendency to bow diving. This was certainly also true for model C-2, which was prior to the tests suspected of this possible tendency due to the sharp bow sections.

### 3.5 Comparison with free Sailing Models in stern quartering Waves

Additional tests have been carried out with free sailing models in the SMB of MARIN at Wageningen. For these tests MARIN had developed a new measurement setup allowing the models to broach without being restrained by the measurement setup. This implied that there was no connection between the model and the towing carriage, which followed the model through the tank. The models were under control of an autopilot and the motions were measured using an inertia measurement system. During these tests also the worst possible environmental conditions, which could be realized in this specific facility, with respect to the possibility of broaching have been sought. This meant significant wave heights up to 3.5 meter, peak periods Tp of the Jonswap spectrum of 7.0 seconds and forward speed (average) around 20 knots. The wave incidence angles were 0 degrees (following) and 45 degrees (stern quartering) respectively. In each condition at least 15 different runs have been made, for all models in exactly the same part of the spectrum realisation. For these free sailing tests the models C-1 and C-2 were equipped with two skegs aft to increase their directional stability. For the AV design these were not applied because all except one of the existing AV boats sail without them and for the benchmark role it was considered sensible to keep as close to real life experience as possible.

A typical result is presented in the Figure 17 in which the distribution of the roll and yaw motion are presented for the tests with 045 degrees wave incidence. It should be noted that the number of variations in these combined runs is still rather limited due to the low frequency of encounter between model and waves.

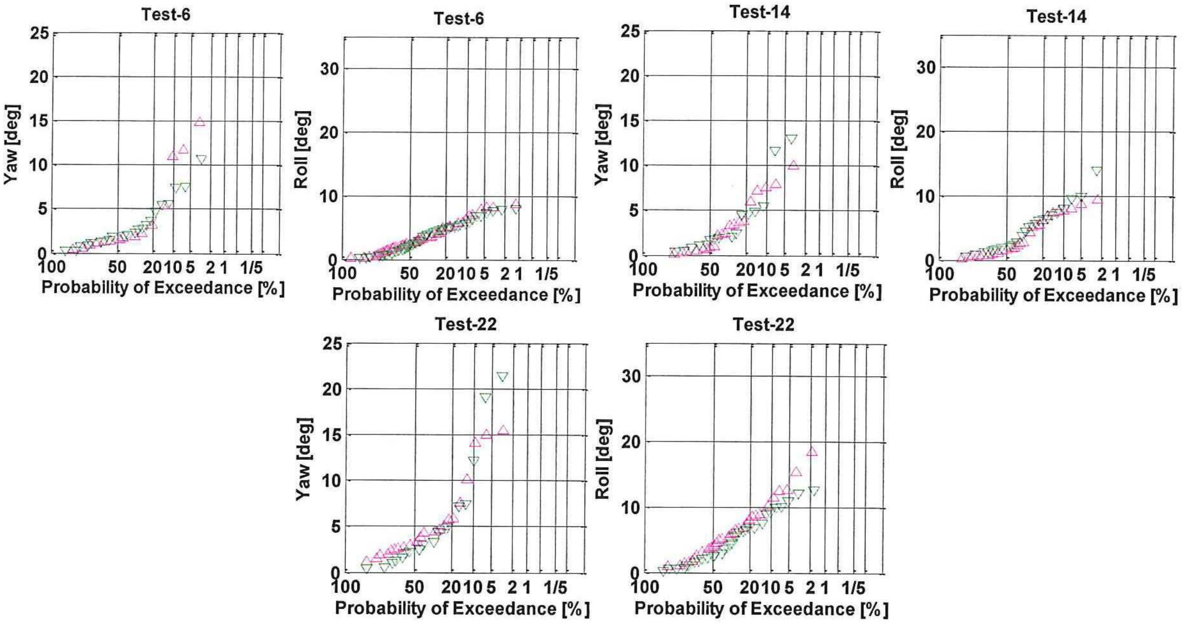


**Fig. 13.** Results stern quartering waves tests SMB; Test-6 Arie Visser, Test-14 Concept_1, Test-22 Concept_2

As can be seen from these results the AV rolls up to 10 degrees and C-1 slightly more. The C-2 model rolls considerably more, up to 18 degrees. A similar difference can be seen for yaw: the AV has maximum values of 15 degrees, C-1 has slightly lower yaw angles and C-2 exceeds them both will yaw angles up to 20 degrees. These differences can be attributed to a large extend to the difference in transverse stability: the GM values of the C-2 model was some 20% lower than those of the other models. This was actually below the design criteria set at the beginning of the project but proved difficult to achieve in the design process. The positive effect of the skegs explains the difference in yaw between AV and the C-1 model.

The maximum values of both roll and yaw are still relatively small considering the severe conditions the models were sailing in and it should be noted that from the visual observations and the video's no real broach has been observed during any of these tests. The only model that came actually close to a broach twice was the AV, but unfortunately this happened during a breakdown of the on board measurement system so these are not included in the results.

Based on these results and the requirements of the coxwains of the KNRM a slightly different design was developed along the lines of Concept 2. The new design was slightly smaller, i.e. 1.5 meters, was considerably lighter by the introduction of a GRP super structure and carried less fuel, all aiming at reduced weight. This resulted at 9 tons less displacement and a similar GM value compared to the Arie Visser class. This new design was called Concept 3 and most of the tests as carried out previously have been repeated with this design too. These results showed in all motions and behaviors improved valueas when compared to Concept 2. So for the final tests this became the desired model and all the further tests and the comparisons were made between the Arie Visser and Concept 3

### 3.6 Tests in extreme waves

**Finally** a series of tests have been carried out in the Delft towing tank in extreme waves. The aim of these tests was to compare the behavior of the Arie Visser and the Concept 3 in head waves for bow submergence and in following waves for broaching.

Hereto a special waves train has been generated in the towing tank with resulted in an very short series of extreme breaking waves at one particular place in the towing tank and a one particular instant. Using this method it was possible to generate extreme wave heights up to 8 meters at full scale. The models were remotely controlled and free sailing and the crux of the experiments was to be with the models at speed at the right time at the right place. When successful this resulted in an extreme situation for the designs. These tests were carried out a considerable number of times to account for errors in the timing. During the tests motions and accelerations were measured and video recordings made.

Of some of these tests videos "stills" are presented in the following figures, which show the Arie Visser and the C 3 in head waves and following waves respectively. The tests in head waves showed that nor the Arie Visser nor Concept 3 ever dug its bow into the waves. In addition the combined heave and pitch motion at the bow were considerably more modest with Concept 3 then for the Arie Visser. Also the surge motions was considerably less. This improved behavior of Concept 3 was certainly true for the vertical accelerations at the bow. It is also worth noting that in 80% of the tests in following waves the Arie Visser made a broach while Concept 3 never broached.

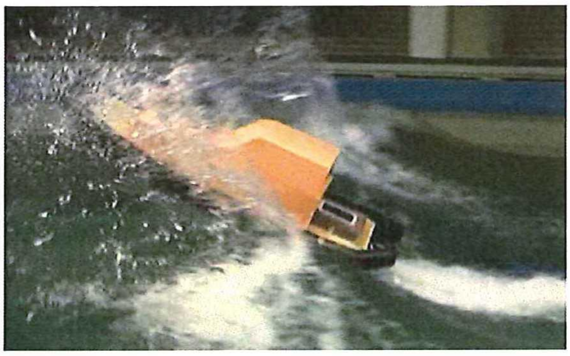


Fig. 14 Arie Visser in extreme waves

Figure 15. Concept 3 in extreme head wave

Figure 16 Arie Visser broaching in extreme following waves

Figure 17. Concept 3 in following breaking wave

## 4.0 CONCLUSIONS

The result of this project is that a rather sensible and feasible method has been found to analyse and compare the performance of relatively small and fast ships in average and more extreme conditions. This can be achieved within a limited amount of time and with a limited budget.

It is obvious from the results that the hull shape similar to the C-2 design is the best for application as SAR boat, because this hull shape has a much better performance in head and bow quartering seas without losing any performance in following and stern quartering seas. The addition of appropriate skegs to the new hull shape design is strongly recommended.

Another conclusion from this project was that the transverse stability is crucial for preventing extreme motions in following waves at high speeds, therefore the minimum GM value of 1.75 meters should and has been maintained.

Finally the weight of the ship should be brought down at least by 20% in order to allow an improved resistance characteristics whilst maintaining a low Centre of Gravity.

Therefore it was decided by the KNRM to design a new boat, i.e. the Concept 3, along the lines of C-2 hull, but slightly smaller (about 1.5 meter) and significantly lighter (about 20%). This became amongst other things possible through the application of a full GRP slightly smaller super structure also allowing lighter engines and smaller water jets. This also has the desired effect on the GM value which is increased to 1.80 meters.

A new design along these lines has been made and has been tested under similar conditions. It showed superior to the Arie Visser and Concept 1 and 2 in all aspects.

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