Enlarged Ship Concept applied to a Fully Planing SAR Rigid Inflatable Lifeboat

J. v.d Velde, J. Pinkster & J.A. Keuning

Report 1203-P **September 1999**

Presented on the Fifth International Conference on Fast Sea Transportation, FAST'99, Seattle, Washington, USA

TU Delft

Delft University of Technology

Faculty of Mechanical Engineering and Marine Technology

Ship Hydromechanics Laboratory

FIFTH INTERNATIONAL CONFERENCE ON FAST SEA TRANSPORTATION

FAST '99

Seattle, Washington USA

August 31 - September 2, 1999

CAVEAT

The papers bound in this volume are preprints prepared for presentation at the Fifth International Conference on FAST Sea Transportation (FAST '99), sponsored by The Society of Naval Architects and Marine Engineers (SNAME), held August 31-September 2, 1999, at the Bell Harbor International Conference Center in Seattle, Washington.

For information on obtaining a copy of the FAST '99 conference papers, contact the Service Center at SNAME Headquarters. By mail: 601 Pavonia Avenue, Jersey City, NJ 07036. By telephone, U.S. and Canada: 1-800-798-2188; international: 1-201-798-4800. All fax and e-mail inquiries, 1-201-798-4975, e-mail: eromanelli@sname.org.

FAST '99 Sponsors

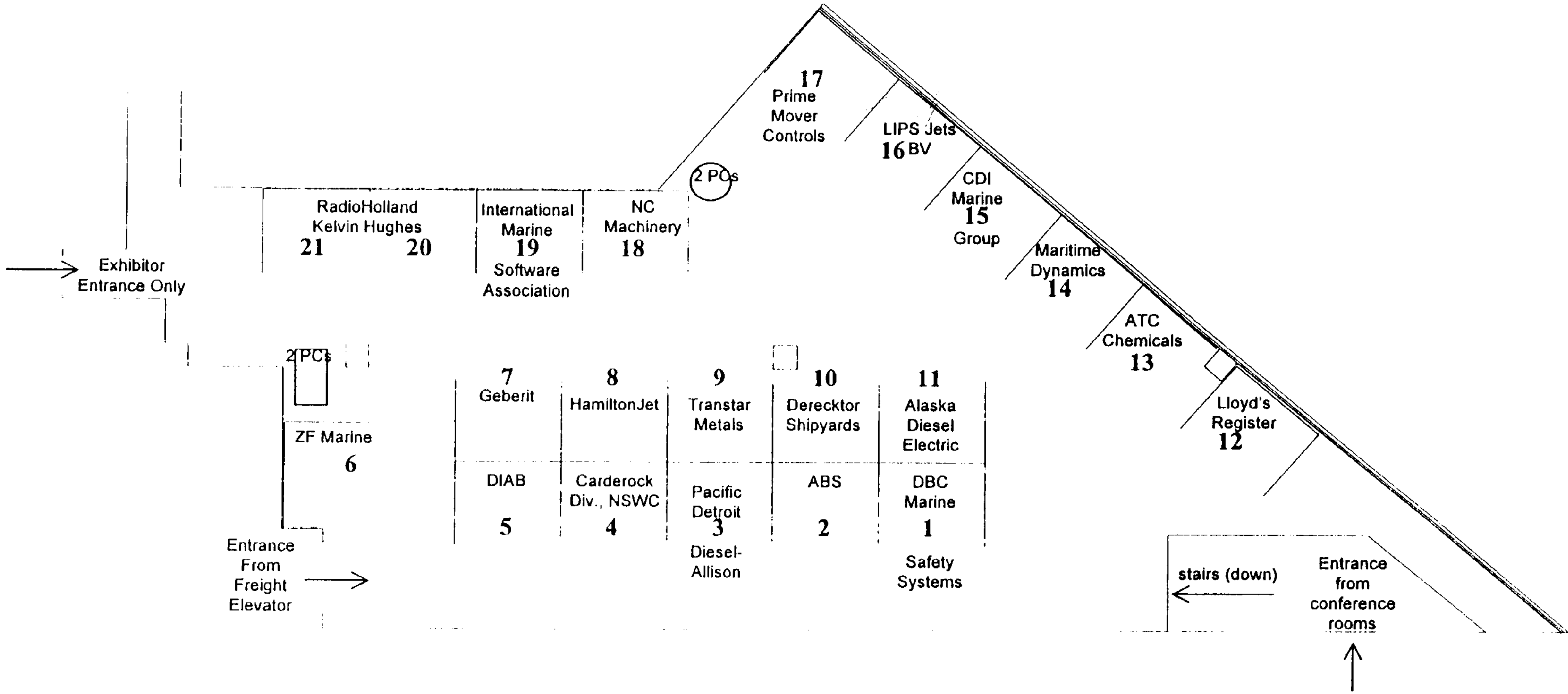
Organization	*Website*	*Phone*	*Fax*
American Bureau of Shipping	www.eagle.org	281-877-6000	281-877-6001
Art Anderson Associates	www.artanderson.com	206-622-6221	360-479-5605
Baird Publications	www.baird.com.au	613-9645-0411	613-9645-0475
Conmarke USA, Inc.	www.northwest-maritime.net	425-712-1948	425-712-7087
Det Norske Veritas	www.dnv.com	281-721-6600	281-721-6900
Detroit Diesel-Allison Corporation	www.detroitdiesel.com	313-592-5000	313-592-5137
Elliott Bay Design Group, Ltd.	www.ebdg.com	206-782-3082	206-782-3449
Germanischer Lloyd	www.germanlloyd.org	201-216-1725	914-366-0426
Glosten Associates, Inc.	www.glosten.com	206-624-7850	206-682-9117
Guido Perla and Associates, Inc.	www.gpai.com	206-382-3949	206-382-2090
Halter Marine Group, Inc.	www.haltermarine.com	228-896-0029	228-604-3518
HamiltonJet, Inc.	www.hamiltonjet.com	206-784-8400	206-783-7323
Hydromechanics Directorate, NSWC	www50.dt.navy.mil	301-227-1439	301-227-2138
International Coatings Ltd.	www.international-marine.com	206-763-8003	206-762-5239
John J. McMullen Associates, Inc.	www.jjma.com	360-613-2540	253-272-0796
Kvaerner Masa Marine	www.kvaerner.com	604-736-8711	604-738-4410
Lloyd's Register of Shipping	www.lr.org	281-599-8450	281-599-8455
Lockheed Martin Launching Sys	www.lmco.com/ls	408-743-1978	408-742-8325
M. Rosenblatt & Son, Inc.	www.mrosenblatt.com	360-479-9920	360-373-0632
Marine Technology	www.sname.org	201-798-4800	201-798-4975
Maritime Reporter	www.marinelink.com	212-477-6700	212-254-6271
Pacific Detroit Diesel-Allison	www.pacificdda.com	253-854-0505	253-850-2631
Pacific Maritime	pacmar@pacmar.com	206-284-8285	206-284-0391
Project Solutions	matt@projectsol.com	206-706-8075	206-727-6043
Robert McNeel & Associates	www.mcneel.com	206-545-7000	206-545-7321

Seanet Corporation	www.seanet.com	206-343-7828	206-628-0722
Ship & Boat International	www.rina.org	44-171-235-4622	44-171-245-6959
SNAME	www.sname.org	800-798-2188	201-798-4975
The Naval Architect	www.rina.org	44-171-235-4622	44-171-245-6959
The West Coast Mariner	www.west-coast.com	604-266-7433	604-263-8620

FAST '99 Exhibitors

Organization	*Website*	*Phone*	*Fax*
Alaska Diesel Electric	www.northern-lights.com	206-789-3880	206-783-7336
Albacore Research Ltd.	www.albacoreresearch.com	250-479-3638	250-479-0868
American Bureau of Shipping	www.eagle.org	281-877-6381	281-877-6031
ATC Chemicals	www.atc-chem.com	905-842-2338	905-842-1514
Carderock Div., NSWC	www50.dt.navy.mil	301-227-1439	301-227-2138
Caterpillar	www.CAT-Engines.com	425-865-0251	425-954-7385
CDI Marine Group	www.cdicorp.com	904-805-0700	904-805-0701
Clipper McMullen	www.victoriaclipper.com	206-443-2560	206-443-2583
Creative Systems, Inc.	www.ghsport.com	360-385-6212	360-385-6213
DBC Marine Safety Systems	www.dbcmarine.com	604-278-3221	604-278-7812
Derecktor Shipyards	www.derecktor.com	914-698-5020	914-698-6596
Detroit Diesel-Allison Corporation	www.detroitdiesel.com	313-592-5000	313-592-5137
DIAB Inc.	www.diabgroup.com	972-228-7600	972-228-2667
Geberit International AG	www.geberit.com	206-542-6372	206-542-6305
HamiltonJet, Inc.	www.hamiltonjet.com	206-784-8400	206-783-7323
HydroComp, Inc.	www.hydrocompinc.com	603-868-3344	603-868-3366
International Marine Software Assoc.	www.hydrocompinc.com/imsa.htm	603-868-3344	603-868-3366
John Crane – LIPS USA		228-872-5970	228-872-5974
John J. McMullen Associates, Inc	www.jjma.com	360-613-2540	253-272-0796
Kelvin Hughes, Ltd.	www.kelvinhughes.co.uk	44-181-500-1020	44-181-500-0837
LIPS Jets B.V.	www.lips-propulsion.nl	31-416-388483	31-416-370256
Lloyd's Register of Shipping	www.lr.org	281-599-8450	281-599-8455
Maritime Dynamics, Inc.	www.maritimedynamics.com	301-863-5499	301-863-0254
NC Machinery Co.	www.ncmachinery.com	425-251-5877	425-251-6423
Pacific Detroit Diesel-Allison	www.pacificdda.com	253-854-0505	253-850-2631

Prime Mover Controls	www.pmc-controls.com	604-433-4644	604-433-5570
Proteus Engineering	www.proteusengineering.com	410-643-7496	410-643-7535
RadioHolland	www.saitrh.com	206-768-1601	206-768-1603
Robert McNeel & Associates	www.mcneel.com	206-545-7000	206-545-7321
SNAME	www.sname.org	800-798-2188	201-798-4975
SPAR Associates, Inc.	www.sparusa.com	410-263-8593	410-267-0503
Thermal Ceramics	www.thermalceramics.com	800-245-8008	706-560-4056
Transtar Metals	www.transtarmetals.com	425-251-8550	425-251-4888
ZF Marine	www.boatdiesel.com	206-574-0375	206-574-0868



Exhibitor Entrance Only
RadioHolland Kelvin Hughes
21
20
International Marine
19
Software Association
NC Machinery
18
2 PCs
17
Prime Mover Controls
LIPS Jets
16 BV
CDI Marine
15
Group
Maritime Dynamics
14
ATC Chemicals
13
Lloyd's Register
12
2 PCs
ZF Marine
6
7
Geberit
8
HamiltonJet
9
Transtar Metals
10
Derecktor Shipyards
11
Alaska Diesel Electric
DIAB
5
Carderock Div., NSWC
4
Pacific Detroit
3
Diesel-Allison
ABS
2
DBC Marine
1
Safety Systems
Entrance From Freight Elevator
stairs (down)
Entrance from conference rooms

TABLE OF CONTENTS

Session 4A - Concepts

Session 5A - Rules

Session 6A - Structural Design

Session 4B - Hydrodynamics

Session 5B - Operations

Session 6B - Speed

Session 7A - Concepts

Session 8A - Structural Loads

Session 9A - Structural Design

Session 7B - Hydrodynamics

Session 8B - Propulsion

Session 9B - Novel Considerations

Enlarged Ship Concept applied to a fully planing SAR Rigid Inflatable Lifeboat

J. van der Velde[1], **Jakob Pinkster**[2], **J.A. Keuning**[3]

ABSTRACT

For a number of years now the Royal Dutch Lifeboat Institution (KNRM) satisfactorily utilise fast Rigid Inflatable Boats (RIB's) for Search and Rescue (SAR) purpose. These aluminium RIB's, fitted with a rubber tube, have a length of around 15m. and a displacement of about 14 tons. Two 500 kW main engines combined with a waterjet propulsion give these boats a calm water speed of 34 knots. These boats are "All Weather" and have an endurance of 200 nm. in calm water. However good these vessels may be, the KNRM still wishes to improve their SAR RIBs.

The actual speed that a rescue boat can maintain in seaway is dependent on the acceleration level felt by the crew on the bridge. The lower this acceleration level, the higher the operability of the boat. In order to decrease this level of acceleration, a new design for a SAR RIB for the KNRM was made using the Enlarged Ship Concept (ESC). This was accomplised in the following two steps: Firstly, computation's were made to assess the expected resistance and ship motions advantage's using the non-lineair program Fastship of the Delft Shiphydromechanics Laboratory. The results were very positive. Secondly, model tests were made for a base boat of 14.4 m length and an enlarged version of 19.2 m. The results showed that the larger vessel has a lower calm water resistance (up to a speed of 32 knots) than the base boat and, most important, the acceleration levels at the steering console in a seaway were significantly lower. The extra length of the boat results in an increase in building costs of only 10 % and, in comparison with other international SAR vessels, the price to performance ratio is very low.

Conclusions from this research were that a marked improvement in SAR RIB design was made and that ESC is also applicable to such fully planing crafts. The subsequent new SAR RIB design is discussed whereby from a design point of view, application of ESC to the SAR RIB's also has a number of other advantages such as: a larger deckhouse and larger deck-area, this can be used for a higher rescue capacity of up to 130 persons; the larger boat may be fitted out with more fuel bunkers and thereby the endurance will be increased to 540 nm.; the draft of the boat is decreased which increases the capabilities in shallow waters. Recommendations for further adjustments to the new design are also mentioned whereby the new craft is also suited for yet other purposes. Based on the results of the above study, the KNRM are now seriously contemplating the utilisation of such enlarged vessels in the future. Others yet to follow ?

[1] Previously M.Sc. student at Delft University of Technology, The Netherlands, presently project engineer, Damen Shipyards, The Netherlands.
[2] Assistant professor ship design, Delft University of Technology, The Netherlands.
[3] Associate professor ship hydromechanics, Delft University of Technology, The Netherlands.

1 INTRODUCTION

The KNRM (Koninklijke Nederlandse Reddingsmaatschappij, in English: The Royal Netherland Lifeboat Institute) uses rigid inflatable boats (RIB's) for more than 10 years now. These RIB's vary in length from 5 to 15 metres. The sailing area of these vessels is The North Sea and the Dutch coastal waters. Especially dangerous situations can occur for these vessel in the estuaries of the Dutch coast where seas can become very high and steep during Northerly storms.

For safe operation in high seas, it is important that a lifeboat is capable to wave ride. For this purpose, the maximum speed of the lifeboat must be higher than the maximum wave speed. The maximum wave speed is taken as being 25 knots. Obviously also essential for a lifeboat is fast and safe deployment to the place of action. From these two facts hails the KNRM's 33 knot speed requirement. However, not only is this high speed important. A lifeboat must be usable in all weather conditions, ranging from 0 to 12 Beaufort. In heavy storm conditions in the estuaries on the Dutch coast, seas may even reach a height of 12 metres and also be very steep at the same time. Aside from the fact that the vessel must be constructed strong enough to withstand the subsequent beating from such severe sea conditions, it is also important that the boat has good manoeuvrability characteristics along with high acceleration capabilities. This allows the lifeboat to flee away from the breakers and thereby prevent any unnecessary damage from occurring.

However speed and seaworthiness are two things which do not always go well together. A small deadrise leads to a lower resistance and therefore to a higher speed, but increases on the other hand, the chance of slamming which, in turn, leads to higher vertical acceleration levels.

If a SAR RIB sails in a seaway then her speed will be determined by the sheer level of vertical acceleration in the wheelhouse due to the seas encountered. This level of vertical acceleration in the wheelhouse is also a direct measure for the physical load on the crew. Furthermore, the lower the actual vertical acceleration, the higher the acceptable (i.e. attainable) average speed of the lifeboat will be.

A coxswain who sails in the estuaries in a seaway, will decrease trottle at the moment he sees a higher wave in order to lessen the load due to impact. As soon as he has passed the wave in question, he will increase trottle again. A better acceleration capability will result in a higher average speed of the lifeboat.

The Johannes Frederik Class (15 m) are RIB's with a fully enclosed wheelhouse that provides space for four crew and tens of rescued sailors. These large RIB's can be utilised in the heaviest seas and weather conditions and, in the past, have well proven their seakeeping capabilities.

However good this class of RIB is, KNRM are still trying to improve on their equipment and Table 1 shows a list of typical KNRM design demands on their next "All Weather" lifeboats. In this paper, an attempt is made to create a craft which meets the KNRM's newest design requirements for a fast "All Weather" lifeboat.

2 ESC AND A SHORT HISTORY THEREOF

In the Enlarged Ship Concept (ESC) [1], a given vessel, which fits all the required design specifications, is substantially lengthened (between 25 and 50%L) while at the same time deadweight and vessel speed remains constant. This results in a longer ship with a marked improvement with regard to ship resistance and motion in a seaway.

At the Delft University of Technology, the outset for the ESC lay in the fact that it was considered that most fast vessels are too heavy for their physical size. This was based on the sheer fact that a ship is generally designed in such a way that all objects, i.e. cargo, engines, accommodations and equipment etc., just about fit into the boat. This results in a vessel that is relatively heavy for her dimensions. This is bad for the sea friendliness and resistance of the boat. The solution to this problem is sought in a sizable lengthening of the vessel without changing either deadweight or speed and mainly results in (see also Table 2):

· A relatively lighter ship (ton per meter ship length),

· A slender ship, L/B increases,

· A relative decrease of the longitudinal radius of gyration (% ship length),

· A decrease in the Froude number, $Fn = v/\sqrt{GL}$

The above mentioned changes in the design parameters can lead to a reduction in ship motions and resistance.

Keuning and Pinkster applied the Enlarged Ship Concept to the Damen Stan Patrol 2600. In this study this base vessel (1.0L) was lengthened by 35% and 58 %L. The results of their research was positive. For a required vessel speed of 25 knots, the required engine power was reduced by 30 % and the vertical acceleration on the bridge in head seas was significantly reduced. When increased in length by 58%L the vessel became 15% heavier than the base boat. The sources for these results are to be found in [1] and [2].

Since then, the ESC has been partially applied to a series of three Coast Guard Cutters of the Royal Netherlands Navy [3]. This fast 25 knot vessel (see Fig. 1) is a Damen Stan Patrol 4100 designed and built by the Dutch shipbuilders Damen Shipyards and is basically enlarged from an existing base boat (a Stan Patrol 3500 from the same yard). These 41 m. cutters are presently satisfactorily carrying out patrolling duties in the Caribbean.

As clearly stated, in the past, research into this ESC topic was mainly focussed on fast semi-planing

Table 1. Typical KNRM design demands for a Dutch "All Weather" lifeboat.

	Demand	Lifeboat
1	Speed	>33 kn , by 1 Beaufort
2	Selfrighting	Absolutely
3	Seaworthiness	All weather
4	Manoeuvrability	Very good
5	Waterjets	Yes
6	Safety	High for the crew members
7	Towing capacity	Good
8	Engines/redundancy	> 1
9	Draft	< 1.0 m.
10	Saving capacity	Large as possible for given size
11	Endurance	6 hours at full speed
12	Sound level	< 80 dB in wheelhouse
13	Watertight subdivision	Yes
14	Crew comfort	As high as comfort/weight ratio allows
15	Classification society	ABS

Table 2. Consequences of application of Enlarged Ship Concept
(ESC = deadweight and speed remain constant)

Parameter	Symbol	Dimension	Consequence
Length	L	[m]	Increases
Breadth	B	[m]	Constant
Draft	T	[m]	Decreases
Speed	*v*	*[knots]*	*Constant*
Deadweight	*DWT*	*[ton]*	*Constant*
Relative weight	LSW/L	[ton/m]	Decreases
Slenderness	L/B	[-]	Increases
Relative longitudinal radius of gyration	k_{yy}/L	[-]	Decreases
Froude number	Fn	[-]	Decreases

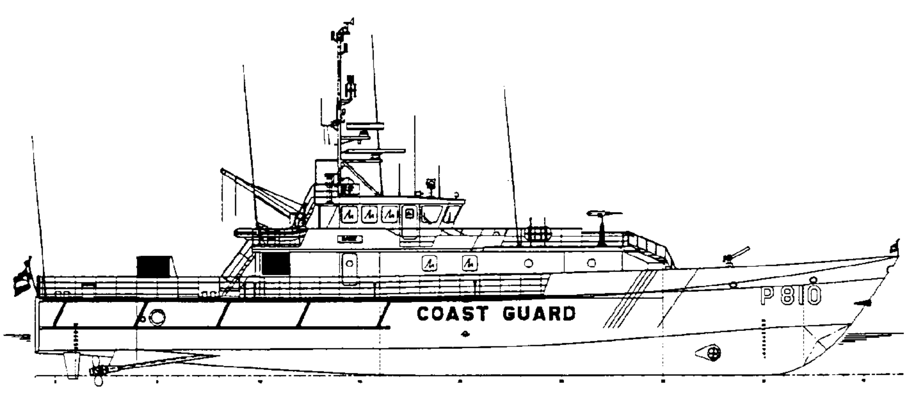


Figure 1. Applied ESC to a Damen Stan Patrol 4100/ 25 knot Coast Guard Cutter [3].
(Built for the Royal Netherlands Navy in 1999).

and deplacement vessels and it appears that both the actual level of vertical acceleration and vessel resistance are reduced by a lengthening of the vessel. If this could also be found to be true for a SAR RIB then the following double effect would indeed be gained here:

1. A lower vertical acceleration level would lead to a higher average attainable speed in a seaway or to a lower loading for the crew and those rescued.

2. A lower resistance would lead to an improved acceleration capability and thereby a higher average speed.

3. A higher average speed renders a faster deployment to the scene of rescue. This could save lives etc.

In summary, one may conclude that the advantages of applying ESC to a SAR RIB may result in an improvement in mission fulfillment and sustainability along with a greater seaworthiness. All these aspects are of supreme importance for a SAR craft.

In the aforementioned research [1] and [2], attention was focussed on semi-planing vessels (FnL = 0.4-0.8). In this paper, the fully planing regime (FnL = 1.36-1.62) is investigated. The question centered around this paper is therefore: Do the ESC advantages noted from previous research still hold true for the higher FnL numbers? In order to answer this, i.e. quantify the ESC effect, two studies are carried out. Primarily, a desk-study where quantitative results are forecasted using computer programs for both resistance and ship motions. Secondly, model tests are conducted in order to verify the desk-study results. In this paper, research [4] is centred on the actual design itself and the effects of ESC on a fully planing Search and Rescue (SAR) Rigid Inflatable Boat (RIB).

3 THE PRELIMINARY DESIGN INVESTIGATION

A desk study was carried out with the original KNRM "Christien" as a base boat to find out whether an improved design using ESC was feasible. The lengthened versions of the base boat were the ESC1680 and the ESC1920 respectively. The main dimensions of all three vessels are presented in Table 3. Figure 2 shows corresponding side elevations and Figure 3 shows body plans along with lines plans (side view only).

These two design variations of the base boat were designed in the framework of this research. For each variation, the lines plan, the hydrostatic curves, the weight and the weight distribution were determined in order to make a preliminary design evaluation possible.

The principal goal of the present desk study was to evaluate the hydrodynamic performance of the three designs with respect to their resistance and workability. This was primarily done by making use of the computer program FASTSHIP, developed by the Delft Shiphydromechanics Laboratory. This computer code calculates the calm water resistance, the sinkage and the running trim of an arbitrary planing boat at speed based on the results of the Delft Systematic Deadrise Series. It also calculates the heave and pitch motions as well as the vertical accelerations of these high speed planing craft in both regular and irregular head waves using a non linear mathematical model based on a time domain simulation as it was originally presented in [5].

First a short description of the three designs used in the evaluation will be presented.

3.1.1 The design variations.

The base boat was the "Christien" from the "Johannes Frederick" Class of RIB's in service with the KNRM. The principal dimensions of this design are presented in Table 3 and a body and lines plan of the boat is depicted in Figure 3. These RIB type craft are propelled by two Hamilton 362 waterjets and are capable of speeds up to 33 knots. A more detailed description of these craft may be obtained from [6] and [7].

For the lengthened versions of these craft it was important to determine if there were any possible restrictions on the allowable length of the new rescue craft considering their use or other restrictions imposed by the KNRM demands. From numerous discussions with the KNRM and various coxswains of the presently utilised KNRM lifeboats, it became obvious that they would like to see the maximum overall length restricted to 20 metres. This was based on their accumulated experience with handling these RIB's in their typical operating areas i.e. the southern North Sea and the Dutch coastal waters and, in particular, the shallow areas in the Dutch estuaries. Heavy northwesterly storms, in combination with strong tidal and shallow waters, will typically show very short, very high, extremely steep and so frequently (spilling) breaking waves. The capability to "flee" these kinds of extreme waves largely determined their formulated length restriction as well as the desirable "full power" operational speed of the crafts.

Derived from data from numerous years in the past, it was noted however, that 85% of all KNRM SAR operations occur in weather conditions below Beaufort 6. This generally results in a much more "moderate" wave climate, which would possibly allow larger ship lengths and higher speeds under such prevailing conditions.

To remain within this restricted overall length, as imposed by the KNRM, two new design alternatives were developed (ESC1680 and ESC1920) with an overall length of 16.80 m. and 19.20 m., corresponding to a relative extension, with respect to the base boat, of circa 17 % and 33 %. In the preliminary design evaluation, the increased lengths of these two design variations were obtained by simply extending the original frame spacing of the 14.4 m.

Table 3. Dimensions base boat "Christien" and ESC versions

Parameter	Dimension	BASEBOAT	ESC1680	ESC1920
Loa	[m]	14.40	16.80	19.20
Extra length	[%L]	0	17	33
Lwl	[m]	11.17	13.53	15.93
Boa	[m]	5.4	5.4	5.4
Bhull	[m]	4.2	4.2	4.2
Draft	[m]	0.81	0.75	0.68
LCG	[m]	4.9	5.4	6.3
Mass	[kg]	13.6	14.4	15.0
Speed	[knots]	34	34	34
Engine power	[kW]	2x500	2 x 500	2 x 500
Endurance full speed	[hours]	6	6	6

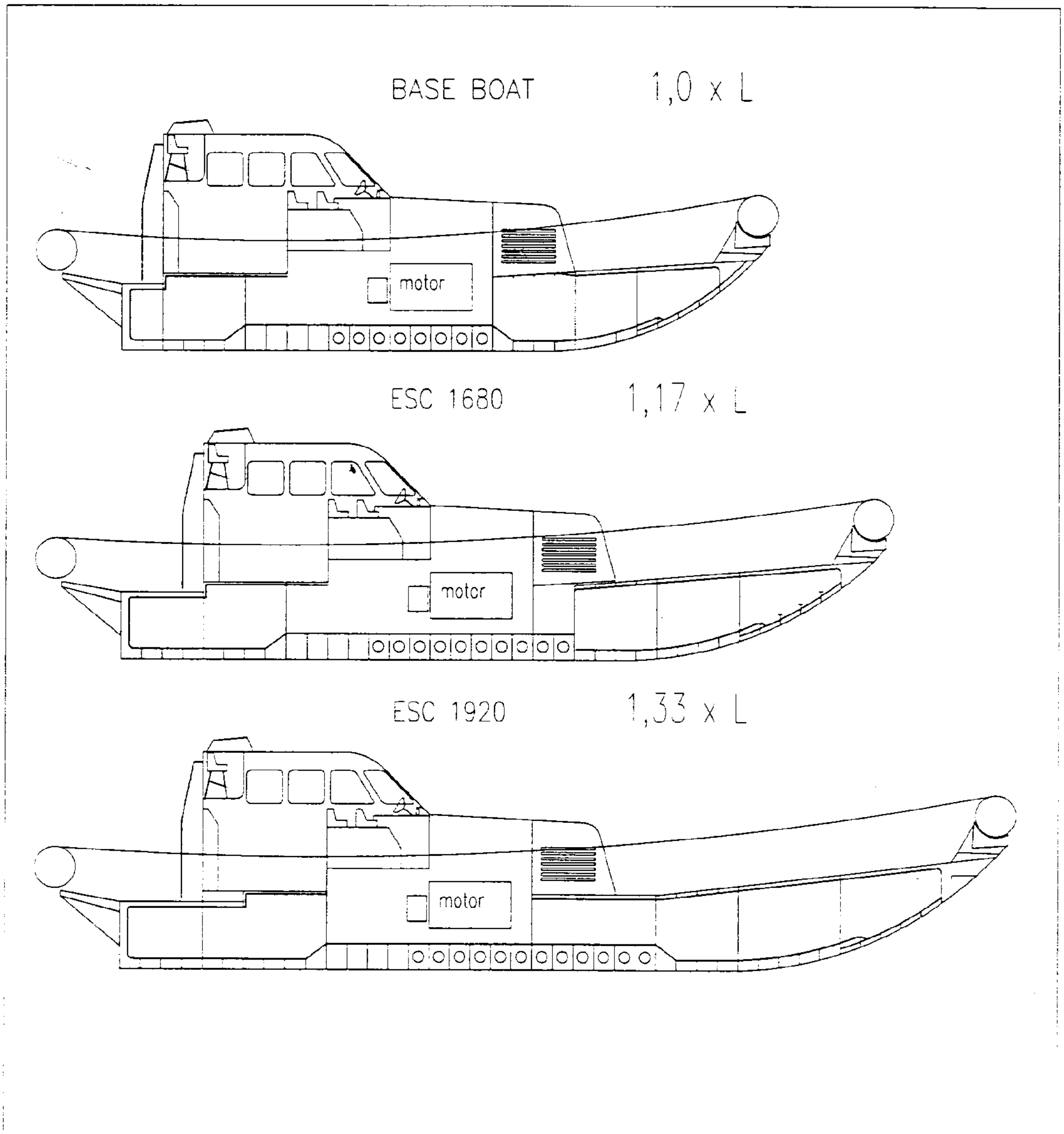
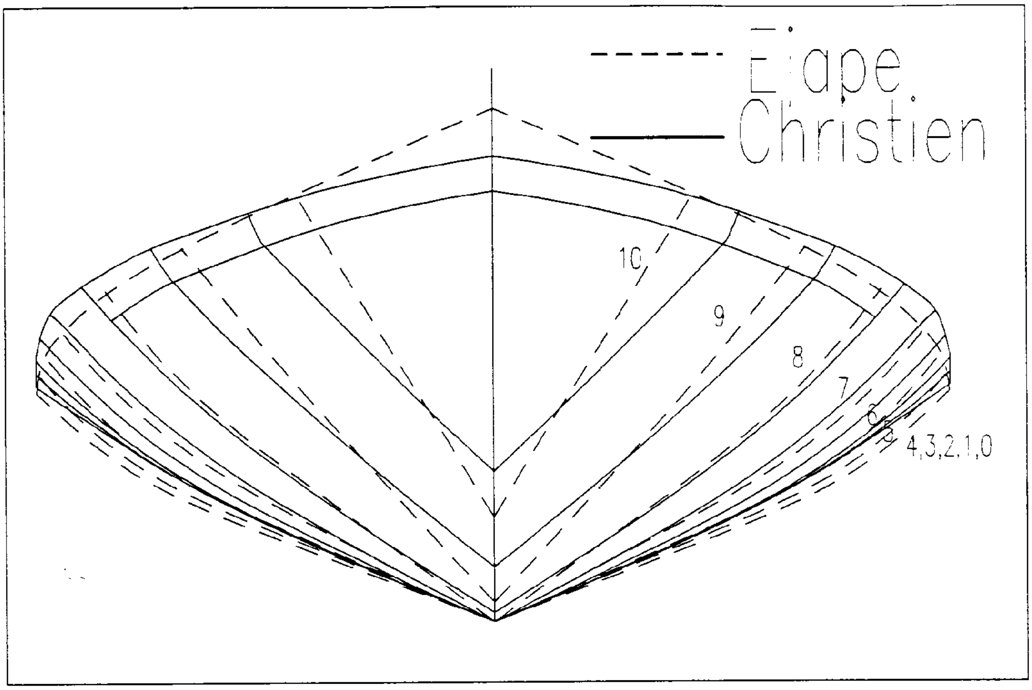
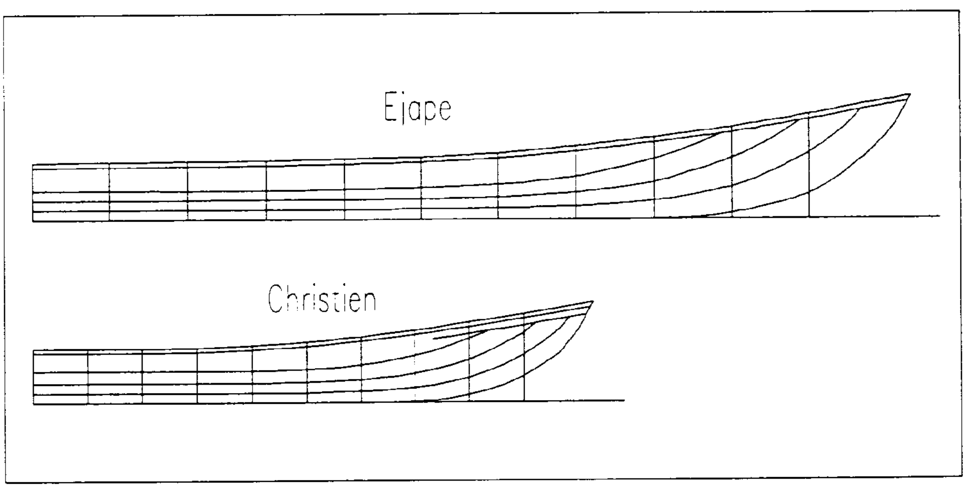


Figure 2. Side elevations of the base boat "Christien" and both ESC1680 and ESC1920.



Body plans



lines plan (side view only)

Figure 3. Body plan and lines plan of "Christien" and Ejape".

overall length base boat to yield the new desired value. For each of the two design variations a weight calculation has been carried out based on the design information available from the original vessel as well as a weight distribution and a corresponding center of gravity and longitudinal mass inertia. Within this exercise the ABS rules were utilised to determine the scantlings.

For the largest design also a bow shape alteration in conjunction with the elongation of the design has been established, albeit modest to suit the KNRM wishes. This change in bow shape is based on the assumptions that the ESC enables a less voluminous bow section due to the additional (void!) space created in this design concept. The bow section may so be redesigned with less flare compared to the base boat but with increased sheer. This is favourable for the minimisation of the vertical impact forces and the vertical accelerations, which are directly related to the changes in the non linear Froude-Kriloff forces depending on the instantaneous submerged volume of the hull whilst performing large relative motions. Also excessive hydrodynamic lift forces in the bow section may so be avoided. The favourable effects of these modifications on the workability of the boats have been shown earlier in [5]. The increased sheer however, still guarantees sufficient reserve buoyancy to prevent the ship from taking on too much green water in head waves or from "bow diving" in following seas.

3.2 Calm water behaviour

The calm water resistance of each of the three designs relative to forward speed is presented in Figure 4A in the speed range from 6 to 28 knots. From the results presented in this figure the beneficial effect of ESC on the resistance of the craft in the speed range from Fn = 1.0 to Fn = 3.0 is clearly demonstrated. This trend is similar to the ones found in earlier studies carried out on the application of the ESC on fast monohulls. In the present study however, the speed of the boats extends to much higher speeds than investigated in the previous projects. In these higher speed regions the smaller L/B ratio of the base boat will lead to a lower resistance than the ESC variations with their higher L/B ratio's. This is also illustrated by the fact that the longest boat, i.e. ESC1920, shows the smallest "hump" in the resistance curve at the lower speeds end . This is a particularly favourable effect for craft with a "patrol type" mission profile, which leaves them sailing at cruising speeds well below their design (top) speed during a considerable period of their operational time.

Although not shown here, similarly favourable results are found for the sinkage and trim of the ESC craft at speed: the base boat trims up to 6-7 degrees and the ESC versions only up to 3-4 degrees. As foreseeable side effect of this, the base boat is lifted considerably further out of the water when sailing at planing speed compared with the enlarged versions, which remain closer to their original trim position.

3.3 Motion analysis

3.3.1 Choice of conditions

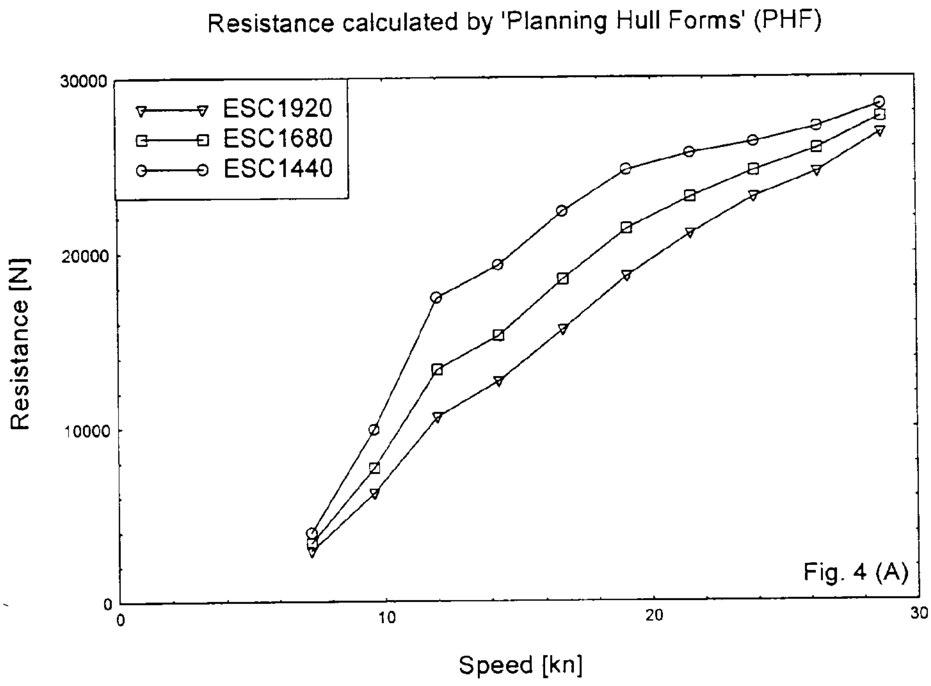
The motion analysis of these craft has been carried out with a reduced forward speed of circa 20 knots in a moderate seastate only. The seastate investigated is given by a wave spectrum with a Jonswap energy distribution over the frequency range corresponding with a significant wave height of 1.65 metres and an average peak period of $T_p = 7$ seconds. The choice for this moderate spectrum was based on the "real live" observations made during full scale test runs on board of several fast patrol boats. During these tests it became clear that for the safe operation of these craft in head sea conditions, proper use of the engine throttles is a dominant factor. When asked to leave the throttle "as it is", leading to a more or less "constant" forward speed of the boat (as situation similar to the towing tank tests and simulation runs), the crew found it unsafe to sail at a higher speed than 15 knots in the prevailing conditions. When "playing the throttle" was allowed to evade the severest of the encountered waves, the average speed was increased to circa 22 knots in exactly the same wave and heading conditions. This "throttle control" however, which is initiated by the visual observations of and the anticipation by the coxswain of the incoming waves, can not be simulated in the towing tank nor in the computer simulations (yet).

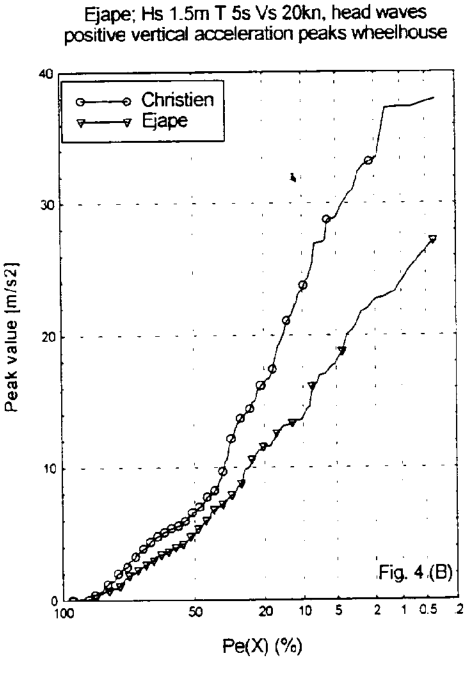
So it was decided to evaluate the mutual merits of the three design variations in a simulation carried out in a "moderate " seastate resulting in an "extreme" condition with respect to the accelerations levels on board. This turned out to be the aforementioned wave spectrum and a constant (!!) forward speed of 20 knots.

For the sake of compactness, only the results of the calculations of the vertical accelerations at the wheelhouse of both the base boat and the longest of the ESC variations, i.e. the ESC1920, will be presented here.

3.3.2 Limiting Criteria

From an earlier research project on the workability of planing craft in waves, it is known that the real limiting criteria for voluntary speed reduction on board planing craft are related to the occurrence of high peak values in the vertical accelerations in the working area. On the occurrence of one "big peak", the crew reduced speed to prevent it from happening again. This reaction turned out to be true irrespective of the actual prevailing "significant value" of the vertical accelerations at the time. So the frequency of occurrence of these high peaks in the vertical accelerations should be reduced as much as possible. To compare the designs with regard to workability, it suffices therefore to compare the respective frequency distributions of the vertical accelerations in the working area. In the case of the lifeboats this is





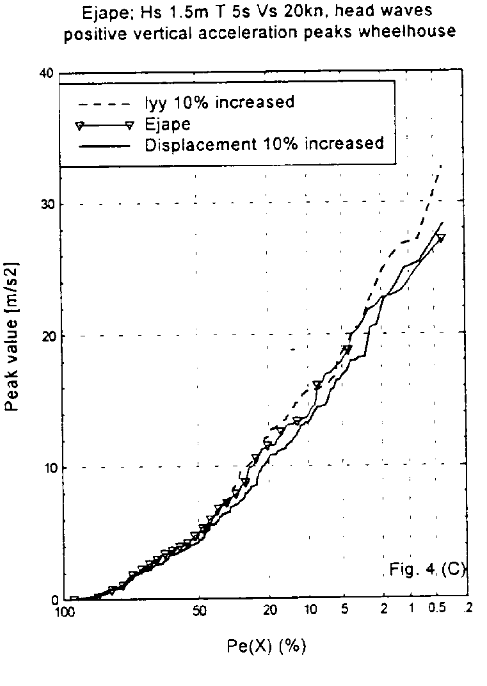


Figure 4. Calculations with FASTSHIP: (A) Resistance, (B) Frequency distribution of positive vertical acceleration amplitudes for "Christien" and "Ejape" and (C) idem also showing effect of change and pitch moment of inertia for "Ejape" in displacement

taken as the helmsman's position in the wheelhouse.

3.3.3 Results

In Figure 4B the frequency distribution of the positive vertical acceleration amplitudes is presented for the base boat "Christien" and the ESC1920 "Ejape" in the selected wave spectrum and at the selected speed of 20 knots. From these results it is immediately evident that the occurrence of the high peaks in the vertical accelerations at the wheelhouse is considerably less for the ESC1920 "Ejape" compared with the original design "Christien".

Because of the fact that the enlarged design can feasibly have a smaller longitudinal radius of gyration Iyy (related to it's overall length), the effect of such a reduction of Iyy on the motions has also been calculated. The results of these calculations together with the effect of a slightly increased displacement of the boat by 10% are presented in Figure 4C. The effect of the increased displacement is that the highest peaks in the vertical accelerations (with the lowest relative occurrence) are slightly increased. The decrement of the relative longitudinal radius of gyration however is rather beneficial: the final result thereof is a 20% reduction in the vertical acceleration level.

Based on the outcome of this analysis it was decided that the ESC1920 with the lowest possible displacement and pitch radius of gyration was the optimal design to strive for within the given constraints.

4 THE MODEL TESTS.

To verify and extend the outcome of the calm water behaviour and motion analysis obtained with FASTSHIP, it was decided to carry out a series of model tests in the Delft Shiphydromechanics Laboratory with the original design "Christien" and the optimised design ESC1920 "Ejape".

Model tests were carried out with the models in calm water to check on the resistance, sinkage and trim of the craft and in irregular head waves to verify the vertical accelerations levels obtained.

In addition, a series of tests were carried out with the model at a higher speed in a more severe following sea state to check on any differences in a possible tendency regarding bow diving behaviour between the two designs.

The measurements were carried out in the large towing tank of the Delft Laboratory. The model was connected to the towing carriage in such a way that it was free to pitch and heave but restrained in all other modes of motion. During the tests the model was towed at a constant forward speed. The irregular waves were generated using a hydraulically activated wave generator of the hinged flap type. For each head wave condition at least 15 different realisations of the same wave spectrum were used to yield statistically sufficient reliable data. In following waves, however, this was not feasible due to the low encounter frequencies of the waves. Some of the results of these measurements are presented in the following paragraphs.

4.1 Calm water results

Both the calculated and measured calm water results for the "Christien" and the "Ejape" are presented in Figures 5A, 5B and 5C. Although there is some difference between the calculated and measured values the trends of the earlier calculations are fully confirmed by the measurements.

4.2 Head wave tests

During the head waves tests it appeared not to be possible to use the same spectrum as was used in the calculations. The resulting motions became so large that physical constraints in the measurement set up hampered the motions of the craft. So a moderately reduced seastate had to be used in conjunction with a slightly lower forward speed.

The measured frequency distributions of the vertical accelerations of both designs are presented in Figure 5D. As may be seen from these results, the measurements show identical differences in behaviour between the two designs. The gains to be made by using the ESC concept in this design are rather obvious. Another interesting result was that the added resistance due to the motions in the waves was noticeably less for the ESC1920 design.

4.3 Following waves tests

From the tests in following waves, it became evident (mainly by visual observations) that there was no difference between the two designs with respect to bow diving behaviour. Both craft behaved very well in these conditions with respect to green water on deck and relative motions with respect to the waves. The "tube" definitely played an important role in this.

5 THE FINAL DESIGN

In the previous sections, much attention has been paid to the hull form of the enlarged ship and the advantages thereof. In this section the actual design itself will be elaborated upon. Figure 6 shows a general arrangement plan of the final design. Table 4 shows the main dimensions of the "Christien" and the enlarged ship with modified bow ("Ejape"), ESC1920.

The advantages of this new design are not only specific to the ESC, but this does help along a little. The following paragraphs highlight some parts of the new design in more detail.

5.1 Accommodation and interior

In the preliminary design the accommodation of the enlarged version is taken to be a pure copy of that of the base boat, see Figure 2. This is not the case in the final design and there are several reasons for this:

The large foredeck offers much space for the shipping of green water, this is dangerous for the sta

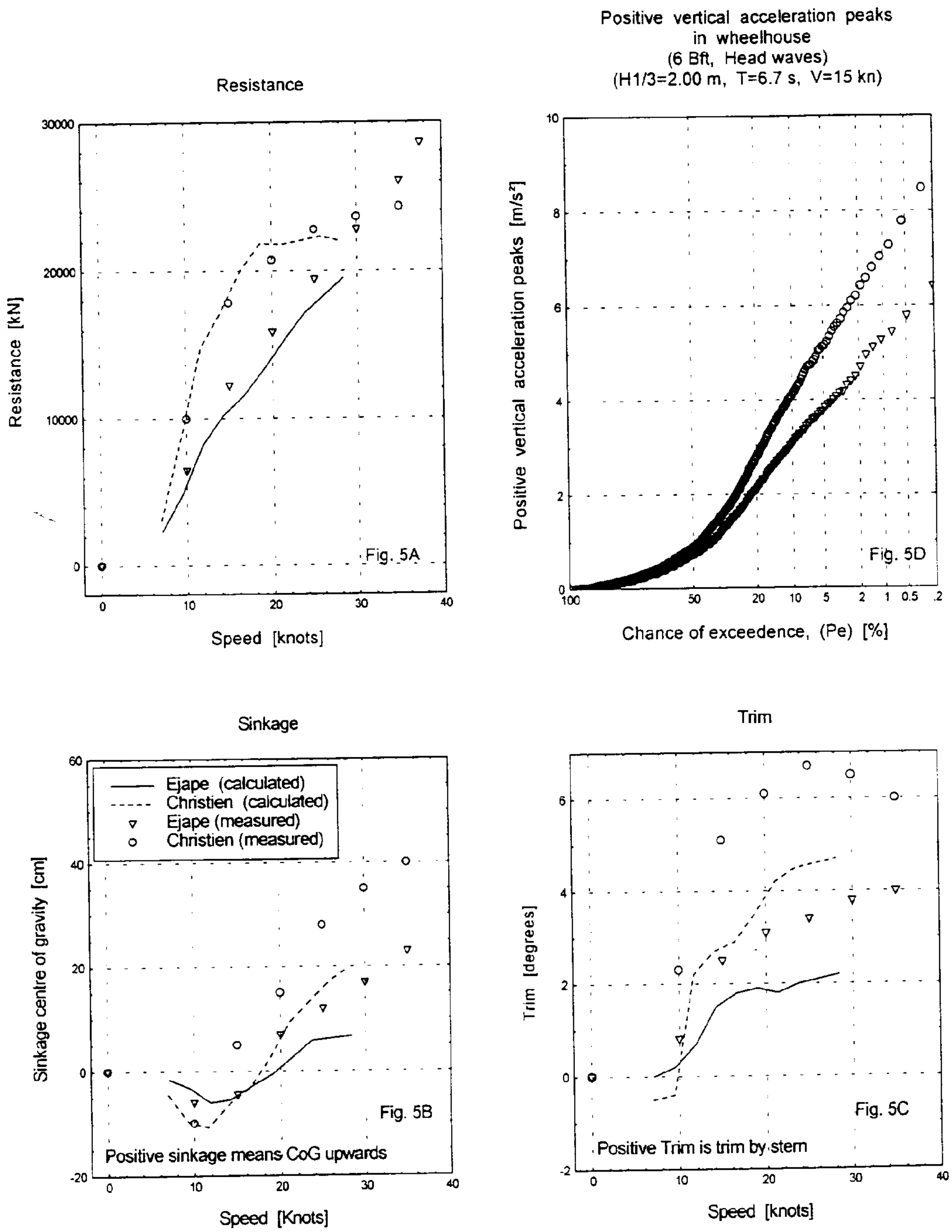


Figure 5. Results (calculated and measured) for "Christien" and "Ejape": (A) Resistance, (B) Sinkage, (C) Trim (all in calm water), (D) Measured frequency positive vertical acceleration peaks in the wheelhouse.

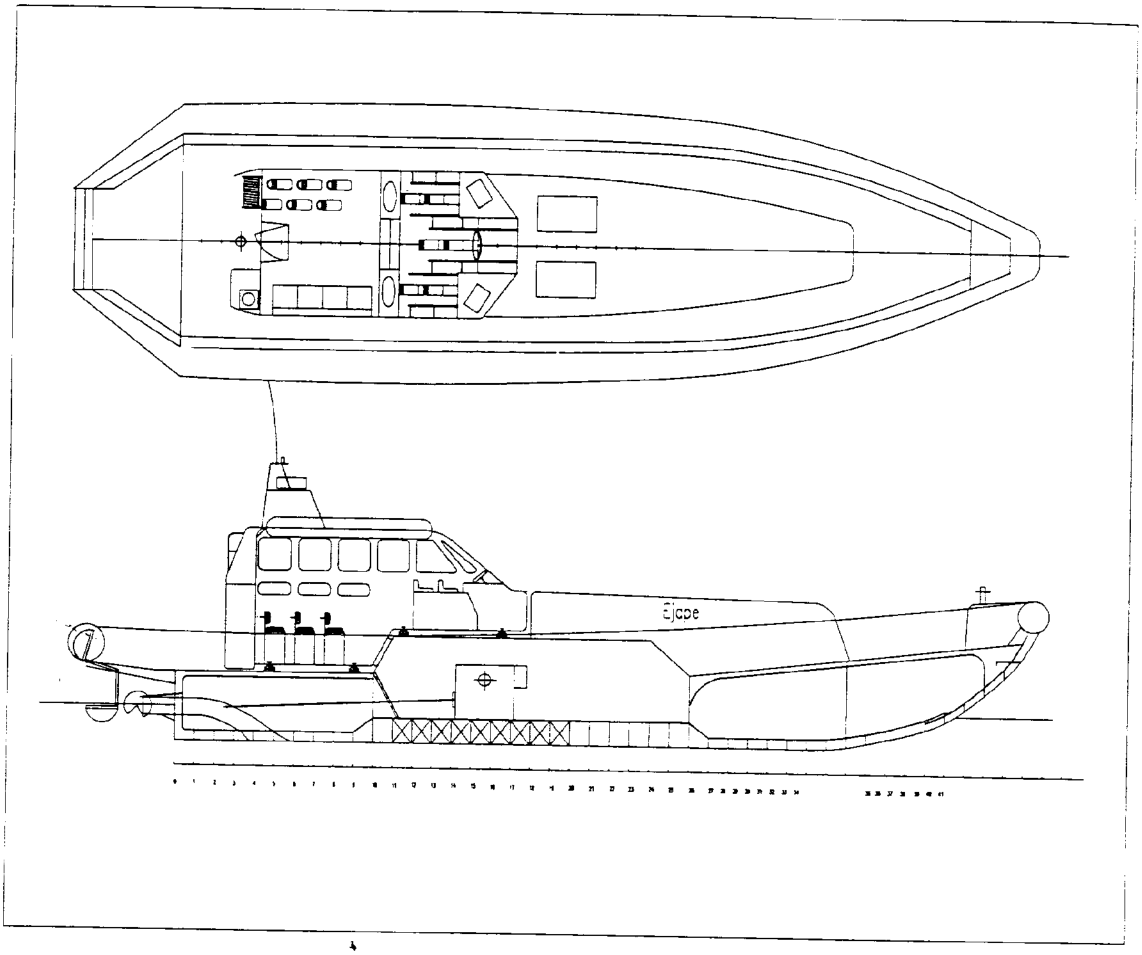


Figure 6. Final design of fast SAR RIB, "Ejape".

Tabel 4. Dimensions base boat and enlarged ship with modified bow

Parameter	**Dimension**	**"Christien"**	**"Ejape"**
Loa	[m]	14.39	19.20
Lhull	[m]	13.65	18.55
Lwl	[m]	11.17	15.85
Boa	[m]	5.39	5.39
Bhull	[m]	4.2	4.18
Bwl	[m]	3.4	3.33
T	[m]	0.81	0.68
Displacement	[m3]	13.57	15.0
LCG	[m]	4.9	6.3
Radius of gyr., iyy	[m]	3.5	3.4
Model scale	[-]	1:9	1:9

Table 5. Survivor capacity of "Christien" and "Ejape"

Parameter	**Dimension**	**"Christien"**	**"Ejape"**
Survivor capacity	[Persons]	90	130

bility of the craft.

A larger wheelhouse offers more space for crew and those rescued without a large weight penalty.

The accommodation consists of two parts, the wheelhouse and the engine cap. The wheelhouse is constructed from sandwich FRP and is flexibly mounted in order to reduce noise and vibration levels. The engine cap is also made from FRP. Besides the limited function of a storage space, the main function of the engine cap is to make sure that not too much green water is shipped on deck.

The present lifeboats are constructed of aluminium and do not have an elastically mounted wheelhouse. Weight and sound reduction are the main reasons for choosing the FRP construction material and elastic mounting.

This extra accommodation space is utilised for:

· Two extra crew saddles, more than the 4 that are now already present,

· Six saddles for the rescued,

· A toilet.

Despite this larger size, the total weight of the accommodation is the same as that of the base boat. This is due to the construction materials used.

5.2 Hull

The construction material of the hull is aluminium. The plate thickness is 7 mm with a 400 mm. framespacing. The hull is constructed according to ABS classification rules.

5.3 Displacement and draft

5.3.1 Weight

After the preliminary design was ready a new weight calculation was made. The resulted in a 5% increase in weight when compared to the calculations made for the model test weights. The reason for this difference lies mainly in the heavier engines and waterjets. However these engines and waterjets are so powerful that this propulsion system will have no problem to overcome the extra resistance; more about this in section 5.8 of this paper. The weight increase of 5% will have little or no influence on the vertical acceleration levels of the vessel (see Fig. 4C). The final displacement is 15.7 ton, for ESC1920 with modified bow, modified propulsion installation and extra accommodation space.

5.3.2 Draft

At a displacement of 15.7 tons, the draft is 0.68 m. This draft is 0.13 m. less than that of the base boat. This difference increases the mission capabilities of the vessel especially in the "strong tidal waters" of the Dutch Coastal Waters.

5.4 Tube

The tube is an essential part of a RIB. The advantages of the tube have been brought forward in many publications and is supported by the KNRM. The KNRM has as a design specification that the tube volume must at least be equal to the displacement of the vessel itself. The tube volume is largely determined by the diameter. However, the larger the tube diameter the greater the forces that the sea excerpts when the tube is immersed. In turn, these forces again lead to vertical accelerations.

The present vessels have a tube diameter of 80 cm. The "Ejape", due to its long length and relatively smaller weight, can accept a smaller tube diameter without departure from the tube volume design specification. The "Ejape" has a tube with a diameter of 75 cm. which is gradually tapered to 65 cm. in the bow (total tube volume 17 m3). In this manner, an attempt is made to minimise the tube forces on the vessel due to ship motions in a seaway and also the forthwith resulting vertical accelerations.

5.5 Towing bit

The towing bit has to be situated as far as possible forward in order to be able to manoeuvre the vessel well during towing operations. Due to the longer vessel design it is possible to place the towing bit 1.20 m. ahead of the transom. In the case of the base boat, this distance was 0.80 m.

5.6 Survivor rescue cradle

A rescue cradle to pick up survivors out of the water is situated behind the transom and the waterjets. The KNRM has had positive experience with this and therefore asks for such a cradle in their design specifications. By applying such a cradle the aft deck is lengthened by 80 cm. An added advantage thereby is the more spacious work deck aft.

5.7 Self-righting

Obviously an "All weather" lifeboat must be self-righting. Figure 7 shows the calculated stability curves for "Ejape". From these calculations it appears that the righting arm is positive for the complete heel angle range from 0 to 180 degrees.

5.8 The propulsion installation

The propulsion installation for the base boat consists of:

· 2 × Man Rollo D2848 LE401 engines of each 500 kW/2300 rpm,

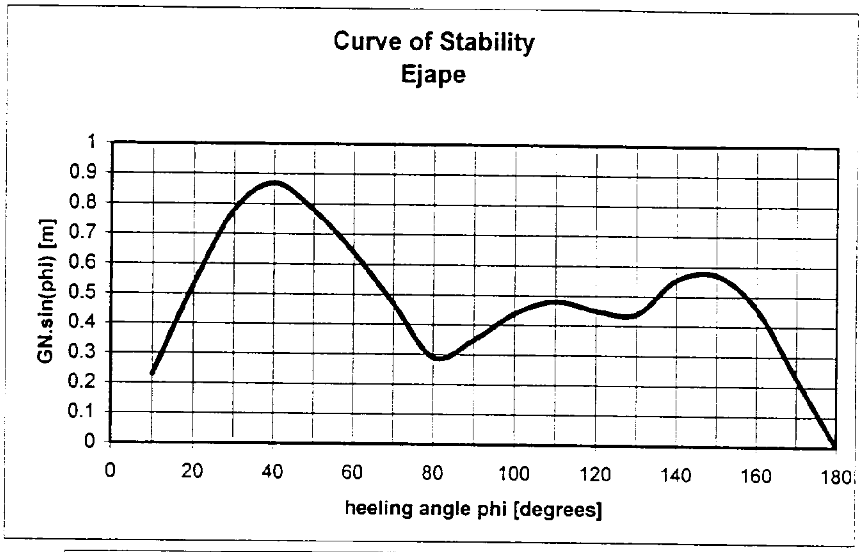
· 2 × Hamilton 362 waterjets.

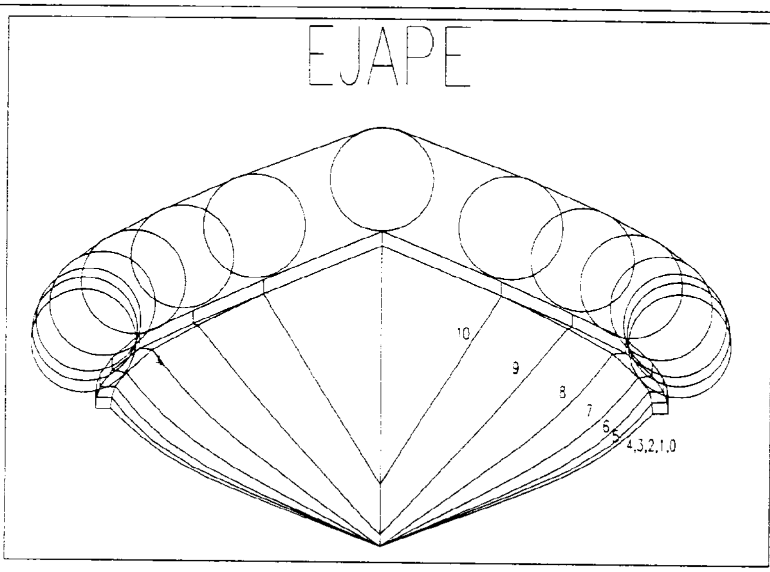
A disadvantage of this propulsion installation is that the waterjets are too light as far as performance is concerned. The waterjets are not capable of absorbing full power at low vessel speeds and start to cavitate. This may be noted especially when the vessel is accelerating or towing. The waterjets are able to absorb full engine power at a minimum speed of 22 knots. In order to improve the new design on this point the following different propulsion installation has been chosen:

· 2 × Man Rollo D2848 LE403 engines of each 500 kW/1900 rpm,

· 2 × Hamilton 391 waterjets.

This new propulsion installation has the follow





Figuur 7. Calculated stability curves for "Ejape" along with body plan with tube.

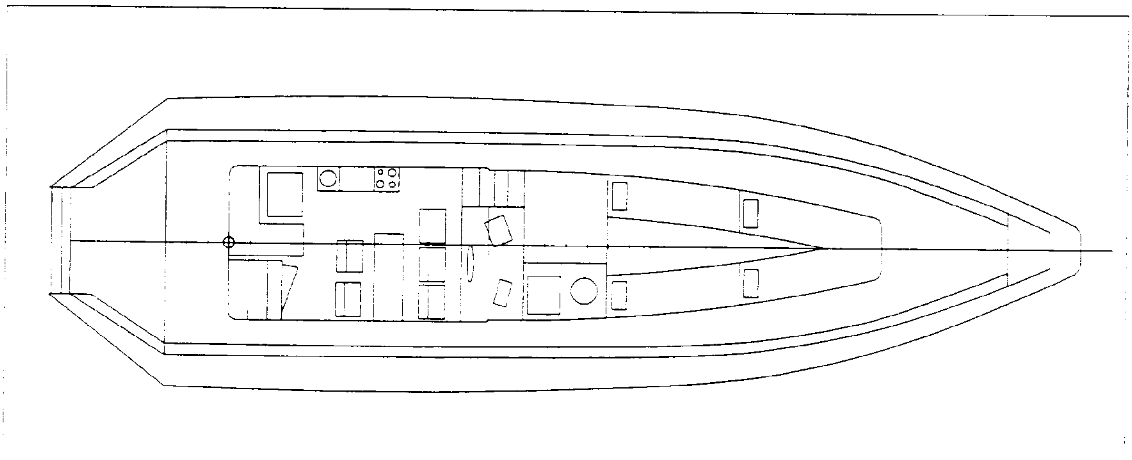


Figure 8. Modified design which incorporates extra living, eating, washing and sleeping spaces.

ing advantages and disadvantages with regard to that of the present base boat.

The advantages are:

· The waterjet can absorb full engine power at a speed of 15 knots without cavitating. This results in a vessel with improved acceleration characteristics.

· The system produces a higher thrust at 10 knots; this improves the towing performance.

· The waterjet has a higher degree of efficiency.

· The engine revolutions are less which leads to a decrease in engine noise level.

· The fuel consumption is lower.

· The propulsion installation has reserve thrust. Should there be an increase in resistance, eg. as a result of a larger displacement, then the boat is still capable of reaching high speeds.

The disadvantages are:

· The complete propulsion installation weight is increased by 530 kg.

· The price of the complete propulsion installation is increased by 20% of the original installation costs .

5.9 The survivor capacity

In order to determines the survivor capacity of a lifeboat, the KNRM looks at scenarios of mass evacuation. In such cases it is imperative that the vessel then carries as many survivors as possible and seating is thereby of less important. The lifeboat must be a stable and safe platform which provides a temporary transit haven from which the survivors may be transported ashore with the aid of other units. The demand of speed is dropped in such a case, but stability and safety requirements remain. The enlarged vessel has by virtue of both the longer length and deck area an increase in survivor capacity. The survivor capacity of "Christien" and "Ejape" are shown in Table 5.

Stability calculations in mass evacuation conditions shows that the vessel is still safe.

During the model tests, a condition was simulated with 75 survivors on board in following waves and sailing with a high speed. The vessel sailed well in this condition without any bow diving.

5.10 The range

The range of the base boat is 6 hours sailing at full speed. The distance traveled is dependent on the prevailing sea and weather conditions. In still water the range is 200 nautical miles.

During the model tests for the enlarged version, allowance was made for a higher range as the new generation of KNRM lifeboats will have a range of 16 hours.

A fuel capacity of 3.800 litre will enable the "Ejape" to sail for 16 hours at full power. The increase in resistance due to the extra displacement can be overcome by the new propulsion installation (this is not the case with "Christien").

If the "Ejape" is fitted out with extra fuel tanks then the subsequent range will be $16 \times 34 = 544$ nm.

It should be noted that with this increase in vessel weight, little or none of the advantages of the ESC will disappear, (see Fig. 4C).

5.11 Economics

The lengthening of the base boat and some extra building costs go hand in hand. Not only is this due to the extra length but also due to the modification of the propulsion installation. Lengthening the vessel by 33% alone leads to a first costs price increase of 10%. Extra modification of the propulsion installation and accommodation leads to a total price increment of 6%. The "Ejape" costs therefore in total around 16% more than "Christien". In comparison to other international rescue vessels, the price of this vessel is rather low and will cost around US$ 900,000.

6 CONCLUSIONS

An improved fast SAR RIB design has been made to meet the latest KNRM specifications whereby it has been shown that application of ESC on a such a craft leads to the following hydrodynamic characteristics and advantages:

· A lower resistance up to a speed of 32 knots. This leads to an improved acceleration capability.

· A significantly lower vertical acceleration level in the wheelhouse. This increases the mission operability.

· The smaller draft leads to an increase in mission capabilities in the "strong tidal waters and shallow waters" of the Dutch coast.

· The larger length improves the survivor capacity.

The new propulsion installation has the following advantageous:

· Improved acceleration capabilities.

· Improved towing capacity.

· Possibility of range extension.

The new wheelhouse size and construction has the following advantageous:

· Lower noise levels in the wheelhouse.

· Better and larger facilities for crew and survivors.

The total newbuilding price is increased only with 16% when compared to the base boat, 10% for extra vessel length and 6% for modification of the propulsion installation and accommodation.

7 RECOMMENDATIONS

The aforementioned new design is not only suitable as a lifeboat. With yet some more modifications it would be possible to create some extra accommodations under the motor cap, see Figure 6. Obviously, this extra accommodation will include some extra weight penalty which, in turn, may or may not partially diminish some of the ESC advantages. However, when well designed, such possible penalties could be reduced to a minimum. Figure 8 shows such a modified design which incorporates an extra shower/toilet space and 4 sleeping quarters. Finally, enough space is still available in the wheelhouse for cooking and a dinette table which can comfortably seat 5 people. .

ACKNOWLEDGEMENT

The authors wish to express their thanks to the KNRM, amongst others especially Mr. S.E. Wiebenga and Capt. N. de Jonge, for all the practical information and rounds of discussion and sailing demonstrations which was of great assistance in the production of the contents of this paper.

REFERENCES

[1] Keuning, J.A., Pinkster, Jakob, "Optimisation of the seakeeping behaviour of a fast monohull". Fast'95 conference, October 1995.

[2] Keuning, J.A., Pinkster, Jakob, "Further design and seakeeping investigations into the "Enlarged Ship Concept". Fast'97 conference, July 1997.

[3] Kok, F., "Kustwachtkotter Jaquar" (Dutch). Schip&Werf de Zee, Febuary 1999.

[4] Velde, J. van der, "Design of a Lifeboat for the KNRM". M.Sc. graduation thesis (Dutch), Delft University of Technology, The Netherlands, September 1998.

[5] Keuning, J.A., "The Non linear behaviour of fast monohulls in head waves". Doctor's thesis TU Delft, 1994.

[6] Stodgon, D, Wiebenga, S, Ruttenberg, M. Dutch R.H.I. "Lifeboats in operation". International Conference of surveillance, pilot & rescue craft for the 21st century-2, 9-10 March 1992.

[7] Zweep, Ch. van der, Stodgon, E.D., "A large RIB for Dutch lifeboat institution". Ship & Boat, June 1987.