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Enlarged Ship Concept, Applied to Ro-Ro Cargo/Passenger Vessels

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Abstract

Keuning and Pinkster (1995, 1997) successfully applied the "Enlarged Ship Concept", (ESC), to a fast semi-planing 26 m. patrol boat. Their results showed a significant performance improvement both in a technical and economical sense. In order to investigate if ESC may also render a similarly successful design strategy for a Ro-Ro/Passenger vessel, which is representative for present services in the UK-West Europe route, the underlying study was carried out. The outcome of this study is that some important results are quite the opposite to those of the patrol boat. This is mainly due to the large difference in vessel types and Froude numbers. Within a given payload weight, the larger Ro-Ro vessels have more cargo carrying capacity in terms of trailers. In other words, the enlarged vessels can carry more trailers, if the trailers are not fully laden. Furthermore, the larger vessels are less vulnerable in damaged condition since the lower hold is not used for cargo and can therefore freely be optimally subdivided. Also advantageous is the fact that the draft decreases as the length increases, which results in a higher freeboard for the larger vessels. Summarising, it appears that application of ESC to this type of vessel surprisingly creates more income possibilities for the ship owners and a much safer vessel, but it produces a more expensive ship to buy and exploit.

1 Introduction

Keuning and Pinkster (1995) explored the so-called "Enlarged Ship Concept", (ESC), by applying this to a fast 25 knot, semi-planing, 26 m. patrol boat. The Froude number was, based on vessel length, equal to 0.81. The main driver behind this application was the fact that a mono-hull sailing at high forward speed in head waves may incur unacceptably high levels of vertical accelerations, which may hamper the safe operability of the craft. In essence, they improved the seakeeping behaviour and decrease the resistance of the fast patrol vessel by increasing the length in steps of 25% and 50% and so increased also the length to beam ratio, reduced the running trim under speed and improved the general layout of the ship. Their work concerned three design concepts, namely a base boat with two enlarged ship configurations.

The most important results from this study showed, on the one hand, a 68% marked improvement regarding a decrease in vertical acceleration in the wheelhouse in head seas and a 40% decrease in required propulsion power in calm water at a speed of 25 knots). On the other hand, the maximum purchasing price of the largest design alternative was estimated to be only 6% higher than that of the basic 26 m. patrol boat.

Keuning and Pinkster (1997) presented further research on the ESC topic. Extensive model testing related to vessel resistance and motions were carried out and subsequent results were described in detail. This second study confirmed the results of the first study and favoured, once again, the Enlarged Ship Concept. In the meantime, the results from these studies have been applied to a number of new buildings of fast patrol boats in The Netherlands.

Now, the question arises: “Can the ESC also be successfully applied to the common work horse of the seas, the ordinary marine freighter?”.

In the present paper, an attempt was made to answer this question by applying the same ESC principle to a full time “freight carrying” vessel being a Ro-Ro/Passenger vessel representative for present services in the UK-West Europe route. The base vessel of 157 m length was lengthened by respectively 25 and 50 per cent, while deadweight and speed remain constant. The consequences with regard to vessel mass, stability and trim, cargo-hold configuration, propulsion power, freeboard, net tonnage and building costs were evaluated. On the operability side, seakeeping performance as well as operability are also assessed. Finally, costs were determined for the base ship as well as for the two ESC alternatives.

2 Base Ship

The base vessel used for the study was MV NORBANK, owned by North Sea Ferries and built in 1993 by the Dutch shipyard Van der Giessen - de Noord. This vessel is a well-proven design and has been described in more detail in S&WdZ (1993). The vessel's main particulars are given in Table 1 (ESC-0).

Parameter	ESC-0	ESC-1	ESC-2
Increase in Length (%L)	0	25	50
Loa (m)	166.77	206.18	244.97
Lpp (m)	157.65	197.06	235.85
Bmld (m)	23.40	23.40	23.40
T (m)	5.80	4.97	4.50
KB (m)	3.26	2.69	2.36
BM (m)	9.01	10.25	11.35
KG (m)	10.42	10.83	10.87
MG (m)	1.85	2.11	2.84
Cb (-)	0.61	0.64	0.66
Depth to main deck (m)	8.60	8.60	8.60
Depth to upperdeck (m)	14.40	14.40	14.40
Lightshipweight (t)	7417	9126	11176
Deadweight (t)	6020	6020	6020
Displacement (t)	13437	15146	17196
Speed (kn)	22	22	22
Propulsion power (kW)	24480	25700	33500
Passengers (-)	120	120	120
Lane length upperdeck (m)	930	1190	1450
Lane length maindeck (m)	910	1170	1430
Lane length hold (m)	200	0	0
Trailer capacity 40 t (-)	156	165	165
Water ballast (t)	234	0	0
Gross tonnage (GT)	17464	21452	25396
Net tonnage (NT)	5239	6436	7619
k_{xx}/B (-)	0.43	0.43	0.43
k_{yy}/Lpp (-)	0.29	0.29	0.29
k_{zz}/Lpp	0.29	0.29	0.29

Table 1 Main Particulars of Base Ship and Alternative ESC Designs

All design and functional requirements, such as speed, payload, accommodations etc., for the Enlarged Ship Concepts were based on and kept identical to those of this base ship. Relevant design information regarding hull form, stability and trim, masses, building costs etc. of the basic mono-hull were kindly made especially available to the authors for the work carried out here.

3 Elarged Ship Designs

To yield the Enlarged Ship Concepts, the basic 157.65 m design, forthwith designated ESC-0, was enlarged in length only. Two of such design alternatives, ESC-1 and ESC-2, ere made, having a length of respectively 197.06 m (+25%) and 235.85 m (+50%). The enlarged alternatives are shown in Figure 1 along with the base ship, whereas the main design particulars for all designs are given in Table 1.

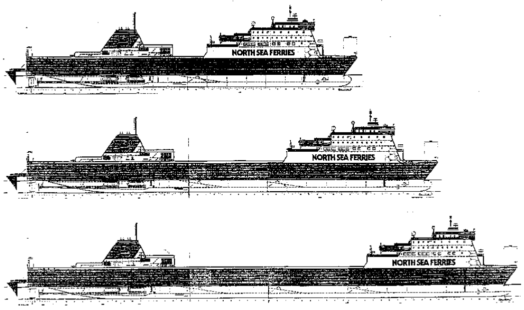

Figure 1 Base Vessel and Lengthened Ships

With regard to engineering these alternatives, the starting point was relative data related to the base ship. The increase in length was, in both cases, created by inserting a parallel amidships section with respective lengths of 25% of L_{pp} and 50% of L_{pp}. In this way the original body plan has remained unchanged in both the forward and aft part of all design alternatives; thus keeping the good lines of flow to the propellers and along the bow. Subsequently hydrostatic particulars were computed for the new body plans.

The increase in structural masses of all alternatives was also computed via the original mass data, which was augmented with extra frames and hull plating while, at the same time, taking into account the relevant positions of the centres of gravity of all components of the designs. An increase in longitudinal bending moments - approximately proportional to the square of the length ratio for the enlarged vessels (1.55 and 2.25) - may be expected. For this, an extra allowance has been made for an increase in steel mass of the parallel amidships sections of respectively 20% and 45% for the ESC-1 and ESC-2 alternatives. This extra steel, in the form of deck-plating, is thought to be placed in the upper deck of the amidships section, as it is then effectively positioned furthermost from the neutral line and thereby reduce the bending stresses to an equal level of the base ship. The deadweight of the enlarged vessels was placed in such a manner that no trim angles occurred.

The resistance and propulsion calculations were also made for each alternative.

Since the idea behind the Enlarged Ship Concept is an equal payload for all possible alternatives, similar main dimensions - such as breadth, draft, vessel configuration (accommodations and wheelhouse with respect to the bow) - remains unchanged to that of the basic design for each design alternative concerned. Consequently, the forward position of the wheelhouse has a distinctive disadvantage with regard to ship motions.

4 Ship Resistance

The still water resistance for all three designs has been calculated using the method of Holtrop and Mennen (1978) for a range of speeds up to the design speed of 22 knots. This speed corresponds to a Froude number of 0.29 for the base ship.

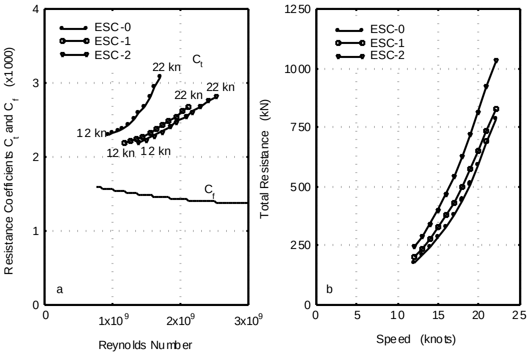

Figure 2 Results of Resistance Calculations

Figure 2-a shows the still water resistance coefficients (C_t) of the three ships, subdivided into frictional (C_f) and residual (C_r) parts. From this figure it appears that - when comparing with the base ship ESC-0 at a speed of 22 knots - ESC-1 has a decrease in resistance coefficient of about 15% while ESC-2 shows 10% decrease only. However, this favourable effect becomes completely lost due to an increase of the wetted surface of the hull with 20% and 45% respectively. As a result of this, the total still water resistance will increase with 5% for ESC-1 and 30%; see Figure 2-b.

As an important conclusion regarding still water resistance is that, when the Enlarged Ship Concept is applied to these ships, there is not a similar profit to be gained as for the fast semi-planing patrol boats from Keuning and Pinkster (1995) with up to 40% reduction in still water resistance. This finding may be attributed to the relative low Froude numbers of the base ships, 0.29 compared to 0.81 of the patrol boat.

Since the vessel resistance is known for MV NORBANK (ESC-0), a ratio between actual and computed resistance was determined. This correction coefficient was then applied to the computed resistance of the larger vessels for establishing the required propulsive power.

Since the topic investigated in this paper deals with large seagoing vessels, ship motions are calculated at 20 and 15 knots. When assuming that the still water resistance is proportional to at least the square of the ship speed and using calculated data on added resistance in a seaway, a sustained sea speed in rough weather dropping from 22 to 15 knots would expect to be an acceptable average.

5 Ship Motions

The vessel's motions have been calculated by using the linear strip theory program SEAWAY of the Delft Shiphydromechanics Laboratory by Journée (1992). These calculations have been carried out in Beaufort 7 to 12, at wave directions ranging from head to following seas. The energy distribution of the irregular waves in the considered coastal areas has been described by uni-directional JONSWAP wave spectra. According to Hasselmann et. al. (1973), this wave energy distribution is a favourable choice for a fetch limited seaway. A commonly used relationship between wave period, wave height and Beaufort number has been utilised. The long-term probability on exceeding a certain sea state has been obtained from Global Wave Statistics and the limiting criteria of the ship motions from Karppinen (1987).

In order to assess the ship's radii of gyration, an analysis has been made of the mass distribution over the length of the various designs.

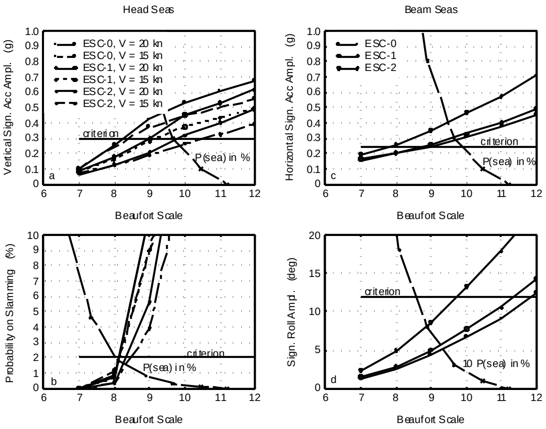

Figure 3 Motional Behaviour of ESC's in Seaway

Figure 3-a shows the vertical significant acceleration amplitude at the bridge in head sea conditions as a function of the Beaufort scale, with an acceleration criterion of $0.3 \cdot g$. At both speeds course can be maintained by ESC-0 in sea states up to Beaufort 8, which will be exceeded during about 2% of the year. However not unexpected, the two enlarged ships ESC-1

and ESC-2 can maintain their course up to Beaufort 9 and 10 respectively.

Figure 3-b shows the probability on slamming in head waves, defined by a relative vertical velocity criterion at the bow. Using a mean slamming criterion of 2%, all ships can maintain their course up to Beaufort 8. The effect of ship size and forward speed on slamming appears to be small.

Figure 3-c shows the horizontal significant acceleration amplitude at the bridge in beam seas as a function of the Beaufort scale with an acceleration criterion of $0.24 \cdot g$. The effect of forward ship speed is negligible. ESC-0 and ESC-1 can maintain course in sea states up to Beaufort 9, which will be exceeded during less than 1% of the year. However, the operability of ESC-2 is limited to Beaufort 8, which sea state will be exceeded during about 2% of the year.

Figure 3-d shows the significant roll amplitude in beam seas as a function of the Beaufort scale with a roll criterion of 12 degrees. The effect of forward ship speed is negligible. ESC-0 and ESC-1 can maintain the ships heading in sea states up to above Beaufort 11, but the operability of ESC-2 is limited to Beaufort 10. However, the probability of occurrence of this sea state is 0.2% only.

From these calculations it was concluded that the overall motional behaviour of ESC-1 is comparable with that of ESC-0. The behaviour of ESC-2 is somewhat better in head seas and somewhat poorer in beam seas when compared to the base ship.

The largest impact of all may be found when evaluating bending moments.

Figure 4-a shows the distribution of the vertical bending moment (M_y) in still water over the ship length. Compared to ESC-0, for the enlarged vessels these moments have been increased by approximately 40 and 60 per cent.

According to the classical theory of a uniformly loaded elastic beam, simply supported at both ends, the bending moment increases with the square of the length of the beam. When considering a vessel positioned in a longitudinal (quasi static) wave with a length equal to that of the ship and the wave crests at both ends, one can expect a similar increase in bending moments for the enlarged ships (55% and 125% respectively). This simple approach to the problem is confirmed by dynamic calculations in head seas (rendering increases about 50% and 150% respectively); see Figure 4-c.

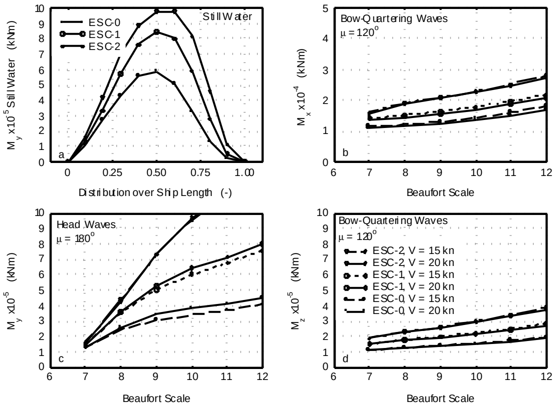

Figure 4 Torsional, Vertical and Horizontal Moments

The largest horizontal bending moments (M_z) have been found in bow-quartering waves ($m = 120^0$); see Figure 4-b and Figure 4-d for the corresponding significant amplitudes. The stresses caused by the torsional moments (M_x) do not play an important role because of the closed character of the amidships section. As the lateral bending moments (M_z) are much smaller than the vertical bending moments (M_y), the latter is dominant for this ship type. Considering similar main frame scantlings for all three designs, the result would be an increase in bending stresses in the outer fibres of the larger vessels in the order of 55% and 125% respectively. To deal with this increase, an increase in scantling mass for the enlarged part of the vessels has been allowed for about 25% and 45% respectively. Since this extra mass is mainly required in the amidships section, the mass distribution is assumed to have the form of a triangle with its base length equal to the length of the enlarged part and its top in the middle of it. This extra mass is distributed as such, mainly in the upper deck of the vessels, having thereby the most optimum effect in reducing bending stresses. As the ends of the enlarged part are the original amidships section, here lower scantling dimensions can be expected due to a distance from amidships. However, this will be, more or less completely, overruled by the effect of an increase of the ship length.

6 Economic Evaluation

In order to make an economical evaluation, the building costs of the different design alternatives have been estimated. These were estimated using the original building costs of the base ship (of which all costs components were known) and correcting this for changes in steel mass of the hull, extra painting costs (cleaning, preparation and painting) and extra machinery costs. The differences in building costs are indexed with regard to the ESC-0 in Table 2. Note the increase in building costs of about 10% for ESC-1 and 28% for ESC-2.

The operational costs of the design alternatives are considered for a scenario of a twenty year economic life of the ship, sailing 18 hours per day at 22 knots, 7 days a week for 48 weeks per year and crewed by 30 persons (3 shifts per 24 hours). The differences in operational costs are indexed with regard to the ESC-0 in Table 2. Note the relatively high increase in operational costs of about 8% for design alternative ESC-1. This increase is even more dramatic in the case of the ESC-2 design alternatives (18%).

The transport efficiency (*TE*) - defined in this particular case as: number of trailers times service speed in m/s over installed power in kW - has been calculated for the three designs. The differences in *TE* are indexed with regard to ESC-0 in Table 2. When dealing with trailers of 40 ton, an increase in *TE* of only 1% for ESC-1 is gained while a decrease of about 20% is calculated for ESC-2. However, when allowing less than 40 ton per trailer and utilising the available trailer space on both D and E decks, the increase of *TE* becomes 17% and 13% respectively.

Index	ESC-0	ESC-1	ESC-2
Increase in length (%L)	0	25	50
Building costs	1.00	1.10	1.28
Power at 22 knots	1.00	1.05	1.32
Operational costs	1.00	1.08	1.18
Transport efficiency 1)	1.00	1.01	0.80
Transport efficiency 2)	1.00	1.17	1.13
Trailer capacity 1)	1.00	1.06	1.06
Trailer capacity 2)	1.00	1.22	1.49

1) 12.2 m. trailers total all in load of 40 tons each (6020 dwt)
2) idem, with all in load of less than 40 tons each (6020 dwt)

Table 2 Results of Economical Calculations for Ro-Ro/Passenger Vessel

Applying the enlarged ship concept to such a Ro-Ro vessel as presented in this paper, renders an improvement in concept design with regard to the increase in the transport capacity of non-fully laden trailers. The stipulated condition that payload remains constant must still be applied. When allowing fully laden 40 tons trailers of 12.2 m length, the number of trailers transported by the design alternatives are approximately 6% higher than that of the base ship. This is due to the fact that the larger vessels do not require 234 ton of ballast in the fully loaded condition.

Furthermore, when keeping payload constant, the larger design alternatives have relatively enough space available on both D and E decks for the carriage of homogeneous cargo of respectively 191 trailers of 34.6 ton and 233 trailers of 28.3 ton. This is an increase by respectively 22% and 49% compared to the base ship. Based on a single price per trailer, the earning capacity of the larger alternatives will therefore increase with a similar percentage if, and when, the market has lighter trailers on offer.

If only the D and E decks are utilised for the carriage of trailers, loading and discharging times per trailer will be relatively reduced due to the fact these decks are more easily accessible than the lower F hold.

Although not advocated by the authors, if (the lowest) F deck were included within the cargo carrying capacity, space would be available for yet another 28 and 40 trailers for the alternatives. This would result in the carriage of homogeneous cargo of respectively 219 trailers of 30.1 ton and 273 trailers of 24.2 ton. This is an increase of 40% and 75% respectively, compared to the base ship. The earning capacity of the alternatives will therefore increase with a similar percentage if, and when, the market has lighter trailers on offer.

7 Conclusions

The following conclusions are drawn with regard to the feasibility of the Enlarged Ship Concept applied to a freight-carrying vessel (see also Table 2):

- The ESC when applied to such large and relatively moderate Froude number vessels appears, at first glance, to be far less viable than for the fast patrol boat. This is mainly due to the relatively larger increase in building and exploitation costs.

- Heave and pitch related phenomena on the bridge of such a RoRo vessel in waves, although not excessive, are sufficiently reduced by the application of ESC.

- Transverse motions on the bridge of such a Ro-Ro vessel in waves are increased by the application of ESC. However, this increase is still acceptable with the criteria applied.

- The vertical amidships bending moment in rough weather increases largely for the larger design alternatives. In Beaufort 10, the increase is of the same order as the expected increase of the calm water bending moment, which is proportional to the square of the ratio between vessel length and base ship length.

- In the case of the Ro-Ro Freighter/Passenger cargo vessels, a definitively advantage of the ESC is the provision of space for the accommodation of lighter cargoes if available. This, consequently, increases the earning capacity and transport efficiency.

- Applying ESC to a Ro-Ro vessel renders an improvement in concept design with regard to a significant increase in survival capability after having suffered the ingress of water into the hull The condition that the lowest hold remains empty and optimally subdivided for this purpose must be respected.

8 Recommendations

Further optimisation of the enlarged designs of the Ro-Ro Freighter/Passenger ferry may well lead to more promising results and is recommended as follows:

- Optimise the vertical position of the upper deck of the enlarged vessels in order to reduce the vessel mass, while, at the same time, satisfying the requirements regarding allowable stress values in the construction due to longitudinal bending moments.

- Optimise the mass of the enlarged vessels by the utilisation of high tensile steel. This will surely reduce the vessel mass while at the same time being able to withstand the higher longitudinal bending stresses.

- Optimise the vessel form with regard to vessel resistance and propulsion. This can be done by optimisation of the longitudinal centre of buoyancy, ships lines, etc.

- Optimise the vessels turn around time by not utilising the F deck for the carriage of trailers.

9 Acknowledgement

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10 References

Hasselman et. al. (1973)
K. Hasselmann, et al., *Measurements of Wind-Wave Growth and Swell Decay during the Joint North Sea Wave Project (JONSWAP),* Deutches Hydrographisches Institüt, Hamburg, 1973.

Holtrop and Mennen (1978)
J. Holtrop and G.G.J. Mennen, *A Statistical Power Prediction Method*, International Shipbuilding Progress, Vol. 25, No. 290, October 1978.

Journée (1992)
J.M.J. Journée, *"SEAWAY-Delft", User Manual and Technical Background of Release 4.00,* Delft University of Technology, Ship Hydromechanics Laboratory, Report 910, 1992.

Karppinen (1987)
T. Karppinen, *Criteria for Seakeeping Performance Predictions*, Technical Research Centre of Finland, Ship Laboratory, Espoo, 1987.

Keuning and Pinkster (1995)
J.A. Keuning and Jakob Pinkster, *Optimisation of the Seakeeping Behaviour of a Fast Monohull,* Fast'95 Conference, October 1995.

Keuning and Pinkster (1997)
J.A. Keuning and Jakob Pinkster, *Further Design and Seakeeping Investigations into the "Enlarged Ship Concept",* Fast'97 Conference, July 1997.

S&WdZ (1993)
S&WdZ, *NORBANK, a New Super Freighter for North Sea Ferries,* Schip en Werf de Zee, November 1993.