Contemporary Bulk Carrier Design to Meet IMO EEDI Requirements

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ABSTRACT

In 2008 Danish design company Grontmij A/S (formerly known as Carl Bro/Dwinger Marine Consultant) introduced a new generation of 35000 DWT handy-size bulk carrier design, named Seahorse 35 (SH35). The SH35 was developed in close cooperation with bulk carrier charterers and operators, with focus on economical and efficient cargo handling, loading flexibility, safety, environmental and maintenance friendliness and low operational cost. Since the SH35 was developed the market situation has changed dramatically, calling for re-visiting of the design with main focus on fuel oil efficiency and energy saving, and not least fulfillment of latest IMO EEDI requirements. Thus the designer Grontmij/Schmidt Maritime in close cooperation with Force Technology has introduced and successfully completed a series of optimizations, effectively leading to remarkable reduction of fuel oil consumption and compliance with EEDI standards.

The objectives of the proposed paper are to present the specific design changes and improvements, including topics like:

- Hull lines evaluation by application of CFD codes.
- Alternatives of main engine/propeller RPM selection.
- Propellers re-design to suit variable main engines data.
- Application of energy saving devices (Mewis Duct by Becker Marine Systems).
- Experimental (model testing) verification of the above applications.
- EEDI comparative calculations and comparison with base line.
- Conduct of speed/power sea trials for verification of the propulsive performance.

The conclusions summarize the major findings of the above presentation. Finally some plans for future work on the propulsive efficiency further improvement are noted.

Keywords

Bulk carriers, hull lines, propulsion systems, propeller optimization, model testing, energy saving devices, emissions reduction and energy saving.

1 INTRODUCTION

Bulk carriers constitute a significant share of the world trade fleet and are generally considered as "low-tech" ships, characterized with relative high block coefficient (maximizing the payload), low to moderate service speed, single screw propulsion arrangement and high stroke/low revs main engines. In recent years the demand for improved fuel efficiency, low emissions and optimized operation, focused in the IMO introduced Energy Efficiency Design Index (EEDI). The latter considerably influenced the design of bulk carriers and the selection of their operational profile with emphasis on low speed (slow-steaming) service. The service (design) speed reduction is a very effective way to reduce fuel consumption and emission. The rule assumes that the power scales with third power of speed. Thus, a 10% speed reduction leads to about 27% (0.9^3=0.73) power saving. Several factors, however, introduce penalties for the slow-steaming approach:

- Slower speed means reduced transport capacity. Reducing speed with 10% would require 10% more ship capacity to keep transport capacity constant. However, revenues and required ship capacity scale with speed, while fuel saving scales with speed to the third power.
- Safety aspects pose lower limits for very low speeds. A ship should be able to maneuver safely against strong winds and seaways at some threshold low speed.
- Crew costs are independent of speed. However, slow ships transport less. For the same transport capacity, more ships are needed, hence crew cost increases.
- Capital cost of cargo depends on transport time and cargo value. Slower transport then increases the capital cost on the cargo.

Furthermore a greater attention is paid to the hull lines optimization (minimizing resistance) and adequate (to the operational low speed profile) selection of main engine and propeller.

In view of the above contemporary trends, the hydrodynamic optimization of the hull lines and propulsion system faces certain challenges, the successful solution of which needs both CFD studies and model testing verification. Among those, typical design approaches include: optimum hull lines definition for the specific ship service speed (Froude number); appropriate selection/design of the propulsion system – main engine and propeller; adequate design and arrangement of the rudder to ensure best interaction with the hull/propeller; verification and implementation of proven Energy Saving Devices (ESD).

In the following sections, a brief review of these approaches is presented with illustrations from model test results obtained at Force Technology. Furthermore the tank tests based predictions are compared and verified by a number of speed-power sea trials. Some typical trends and recommendations are outlined.

2 HULL LINES DEVELOPMENT AND MODEL TESTING VERIFICATION

SH35 is a 180m double hull Bulk Carrier with deadweight of approximately 35000 DWT – see Figure 1. She is propelled by a single four bladed FP propeller. The rudder is a standard semi-balanced (Horn) rudder, as shown in Figure 7.

Figure 1. SH35 General view

The main characteristics of the vessel are summarized in Table 1.

Table 1. SH35 Main particulars

Particular	Design	Ballast
Length, L_{PP}	176.75	176.75
Breadth, B	30.00	30.0
Design draught, T_A/T_F	9.0/9.0	6.5/4.5
Displacement volume	38402.2	21890.4
Block coeff. C_B	0.790	0.740
Prismatic coeff. C_P	0.794	0.750
L/B ratio	5.998	5.677
B/T ratio	3.333	5.183
$L/D^{1/3}$ ratio	5.334	6.089

The hull lines were developed in Force Technology, based on initial lines delivered by Grontmij A/S. Multiple hull from variations were investigated by means of CFD calculations with illustration of the flow characteristics, such as wave profiles, velocity and pressure distributions, flow streamlines traces. Initial and final (optimized) hull lines are presented in the following figure, together with a wave plot comparison between the initial and final lines.

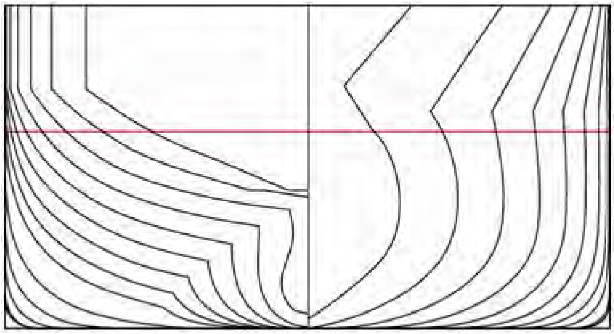


Figure 2. Initial lines (sections)

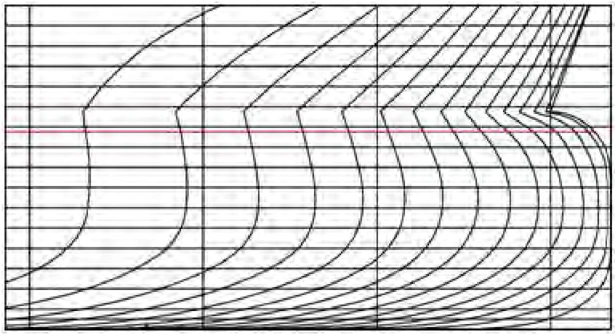


Figure 3. Initial lines (profile view)

The results of the CFD calculations for the initial hull form indicated a significant bow wave. Because of the rather short bulbous bow and the limitations on the length of the vessel, a traditional bulbous bow would not be effective in cancelling the bow wave. Therefore it was proposed to increase the length of the waterlines by a vertical stem contour. This was combined with increased transom height to reduce submergence, hence base drag. The central skeg was made thinner aiming more free flow into the propeller disk. Finally a smoother fore-shoulder was accomplished resulting in more even pressure distribution; with strongly improved bow wave system – see the wave pattern comparison in Figure 4.

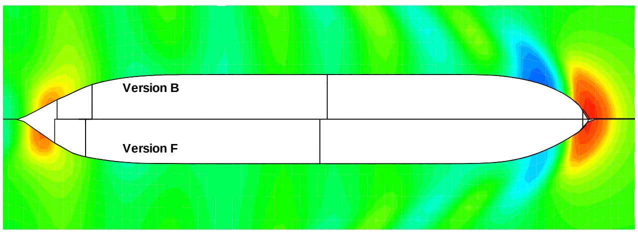


Figure 4. Wave pattern comparison, Version B – initial lines, Version F – final lines

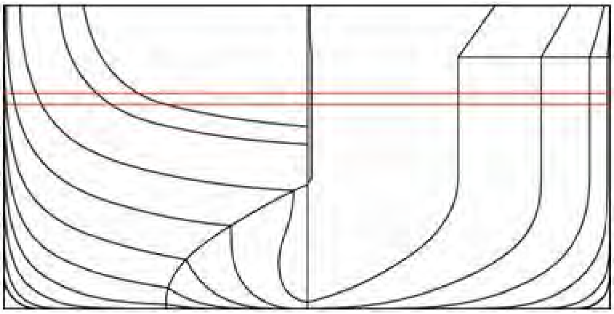


Figure 5. Final lines (sections)

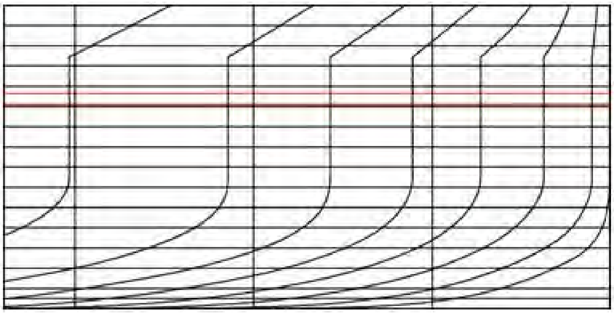


Figure 6. Final lines (profile view)

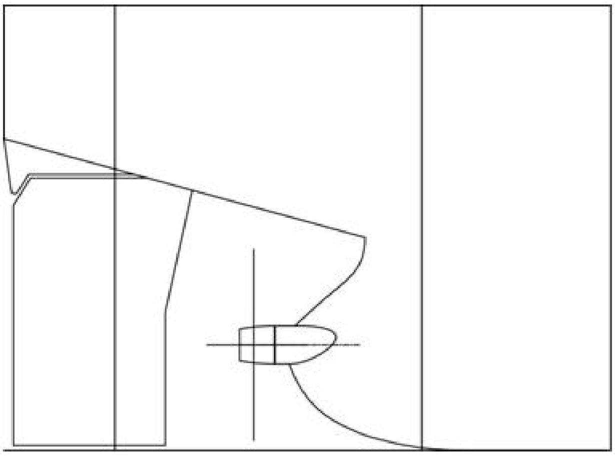


Figure 7. Propeller/rudder arrangement

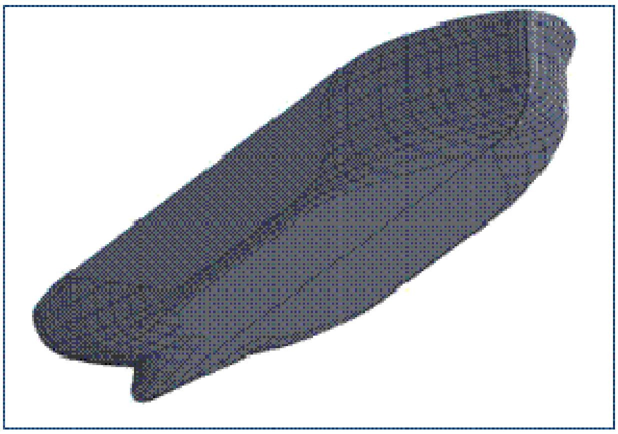


Figure 8. Final hull form (isometric view)

Following the CFD aided lines optimization process, a series of model tests with the SH35 project were conducted over the last few years at Force Technology and other testing facilities. The primary objective was a continuous pursuit of improving the propulsive efficiency through verification of the still water resistance and propulsive performance of the vessel at various loading conditions (draughts); evaluation of different propeller designs and main engine arrangements; investigation of the rudder type and arrangement (location); application of energy saving devices.

The picture in Figure 9 illustrates the model under resistance testing at the design speed of 14 knots and design loading condition. A moderate bow wave followed by a weak wave trough indicate comparatively low wave making resistance and verifies the CFD derived wave pattern in Figure 4. In addition to the design and ballast loading, the model was tested at two more scantling draughts, at 10.10 and 10.65 m even keel correspondingly. Figure 10 presents the residual resistance coefficient C_R for the four loading conditions. It is interesting to note that C_R is almost independent of draught variations around the design loading, which is one of the clear advantages of the adopted vertical stem configuration. At ballast draught the C_R coefficient is significantly higher due to the extreme B/T ratio – see Table 1.

Figure 9. Wave profile at design speed (Vs = 14.0 knots)

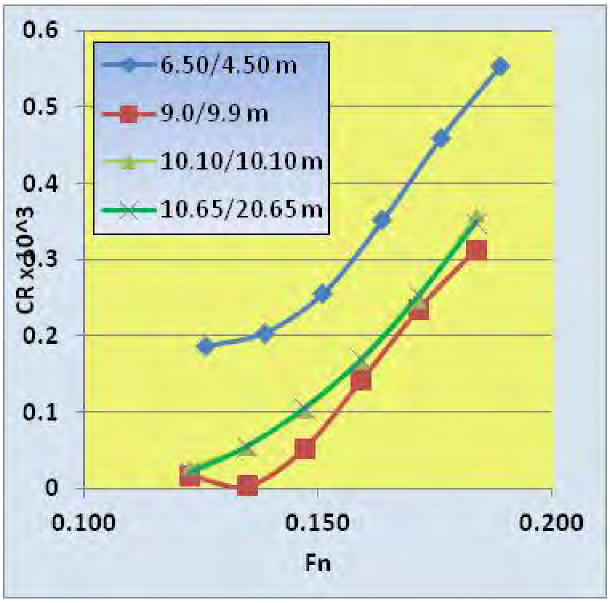


Figure 10. CR coefficient at variable loading conditions

3 MAIN ENGINE AND PROPELLER ALTERNATIVES STUDY

3.1 Main Engine Alternatives

A significant development on 2-stroke diesel main engines has taken place within the past 5 years. The efficiency of a 2-stroke diesel engine to be installed in a direct coupled propulsion system with a fixed pith propeller can be characterized by the engines power/revolution relationship and the thermal efficiency. For propulsion systems with direct coupled (no gear) and fixed pitch propeller, the propeller designer has to design the propeller according to the main engine power/revolution relationship. The main engine designers have improved the power/revolution relationship, by designing engines that can develop higher power at lower revolutions. The lower main engine revolutions enable the propeller designer to increase the propeller diameter, which results in lower propeller loading and higher propeller efficiency.

The thermal efficiency of a main engine can be defined as the amount of fuel required to generate 1 kWh. For 2-stroke diesel engines the thermal efficiency is normally defined as the Specific Fuel Oil Consumption (SFOC) [g/kWh]. Furthermore the newer electronic or semi-electronic engine control systems enable a detailed tuning, whereby minimum SFOC can be obtained at the normal operating point for the engine.

The first SH35 was ordered with a full mechanical MAN B&W 5S50MC-C7.1 TI (NO_X Tier I compliant) engine. The later SH35 vessels have been ordered with several different versions of the MAN B&W 5S50 and Wärtsilä 5RT50-flex-D.

For the purpose of this overview, 5 MAN B&W main engines are presented, as shown in Table 2.

Table 2. Main engine alternatives for SH35

Version	Main Engine Type	M/E Layout Point
1	5S50MC-C7.1 TI	SMCR 7.500 kW @ 121 RPM
2	5S50ME-B8.1 TII	SMCR 6.900 kW @ 110 RPM
3	5S50ME-B9.2 TII	SMCR 6.350 kW @ 99 RPM
4	5S50ME-B9.2 TII	SMCR 6.050 kW @ 99 RPM
5	5S50ME-B9.2 TII	SMCR 6.050 kW @ 99 RPM

The main engine propeller curves for the 5 versions are shown in Figure 11 together with the main engine layout limits given by the main engine designer. For each main engine propeller curve the Specified Maximum Continuous Rating (SMCR) and the Normal Continuous Rating (NCR) is plotted for each version. The SMCR is being the upper point and the NCR being the lower point shown. For each of the main engine layouts and propeller designs, the NCR is defined as the main engine power required to enable the vessel to reach a speed of 14.0 knots at scantling draft of 10.1m, including 15% sea margin and 1% shaft loss, except for version 5 where the speed is reduced to 13.0 knots.

The thermal efficiency improvements for the 5 versions are shown in Figure 12. The SFOC curves for each main engine type and setup are plotted together with the normal continuous rating (NCR).

From Figure 12 it is clear that the semi-electronically controlled ME-B9.2 TII engine used for versions 3, 4 and 5, is significantly more efficient than the ME-B8.1 TII (version 2) and MC-C7.1 TI engines (version 1).

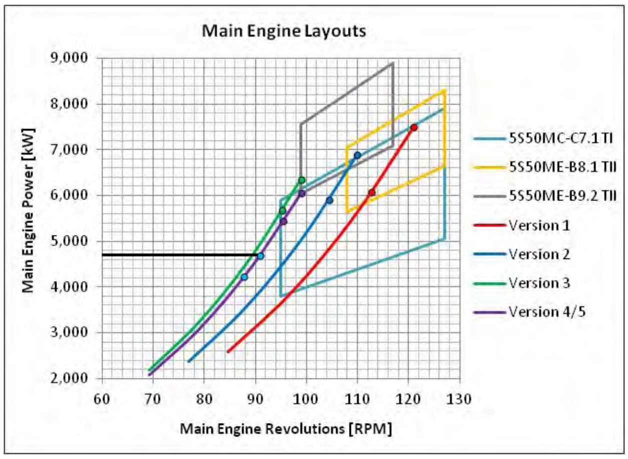


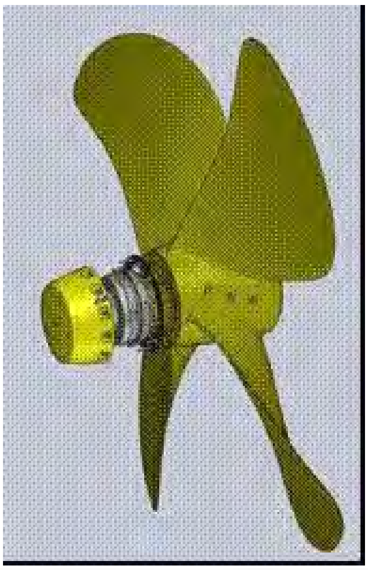
Figure 11. Engine/Propeller characteristics (Source: MAN B&W)

Figure 12. Main Engines SFOC and NCR (Source: MAN B&W)

From Figure 11, it is clear that the semi-electronically controlled ME-B9.2 TII engine used for versions 3, 4 and 5, is significantly more efficient than the ME-B8.1 TII (version 2) and MC-C7.1 TI engines (version 1).

3.2 Propeller Design

In order to select the most efficient propeller design for the SH35, a number of comparative tank tests have been carried out with different propeller designs. The tank test results concluded that the New Profile Type (NPT) propeller designed by Stone Marine, UK to be the most efficient. According to Stone Marine, the NPT principal is a new developed blade section, which reduces the pressure peak on the suction side of the propeller blade, as illustrated in Figure 13. The NPT principal enables the propeller designer to reduce the blade surface area of the propeller. The reduced blade surface area results in reduced viscous drag and thereby improved propeller efficiency. Furthermore, the NPT propeller is claimed to have a smaller optimum diameter compared to conventional propellers designed for same thrust and RPM.



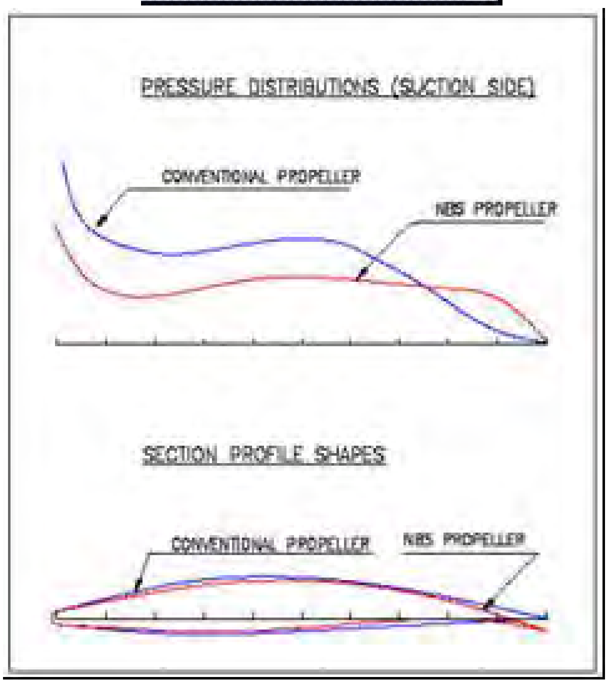


Figure 13. NPT propeller blade pressure distribution

The comparative tank tests concluded that for the same diameter, thrust and revolutions, the NPT propeller was found superior compared to a conventional design propeller, gaining approximately 2% higher efficiency.

The following 4 bladed NPT propeller designs are presented in this study:

Table 3. Propeller designs for SH35

Version	SMCR	NCR	Propeller diameter
1	7.500 kW @ 121 RPM	6.082 kW @ 113 RPM	5,54 m
2	6.900 kW @ 110 RPM	5.914 kW @ 105 RPM	5,60 m
3	6.350 kW @ 99 RPM	5.670 kW @ 95 RPM	5,90 m
4	6.050 kW @ 99 RPM	5.440 kW @ 96 RPM	5,90 m
5	6.050 kW @ 99 RPM	4.230 kW @ 88 RPM	5,90 m

Interesting parameters were the propeller diameter and revolutions variation, adjusted to match the corresponding main engine characteristics, as per Table 3 above. Based on the comparative propulsion tests, conducted at Force Technology, the total propulsive efficiency was found to increase significantly with increased propeller diameter/lower RPM values, as illustrated in Figure 14. In full compliance with general knowledge, the effective wake fraction and propeller revolutions decrease when the propeller diameter increases, while propeller open water efficiency and the total propulsive efficiency increase with D. This is mainly associated with reduced propeller loading.

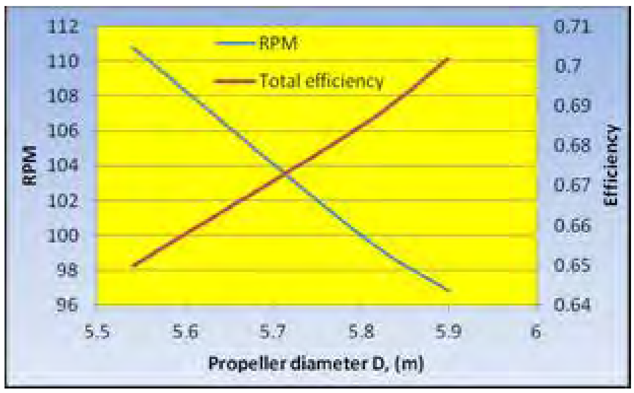


Figure 14. NPT propeller RPM and total efficiency versus D

4 ENERGY SAVING DEVICES

After the main engine and propeller layout have been finalized, various fuel saving devices were evaluated. The Becker Mewis Duct® (MD) marketed by Becker Marine Systems (BMS), Germany was found most suitable for the SH35. The Becker Mewis Duct ® consists of a duct and radial fins installed in front of the propeller as shown in Figure 12. The duct is equalizing the wake field in way of the propeller, which leads to improved propeller efficiency. The fins in the duct generate a pre-swirl, which results in reduced rotational losses for the propeller. Furthermore the pre-swirl reduces the hub vortex losses as well.

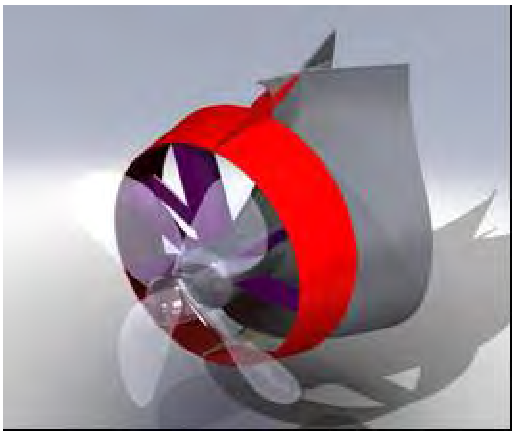


Figure 15. Becker Mewis Duct® (Source: Becker Marine Systems)

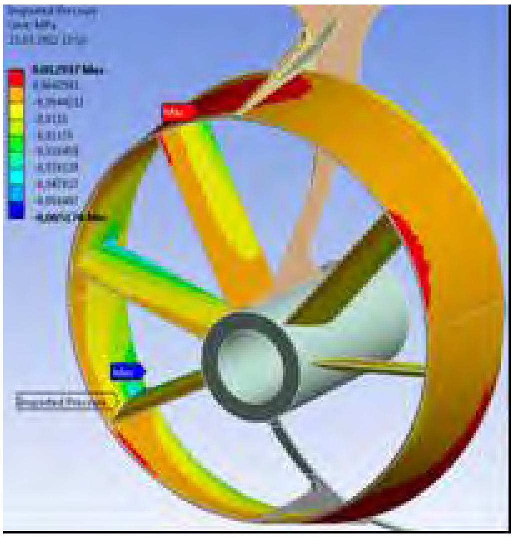


Figure 16. Becker Mewis Duct® (Source: Becker Marine Systems)

Tank tests with the Becker Mewis Duct® have been conducted at SVA, Potsdam, Germany. Power savings in the order of 4.0% were predicted. This power gains need yet to be verified by full scale trial results with MD.

5 RUDDER ARRANGEMENT STUDY

A series of additional resistance and self-propulsion model tests in still water were performed at Force Technology with the SH35 ship model. This test series has the following two main objectives:

a) To investigate the performance of two types of rudders, namely the standard Horn rudder and a spade rudder.

b) To investigate the effect of the longitudinal rudder position (leading edge to propeller disk clearance) on the ships propulsive performance. These tests were accomplished with both types of rudders by placing them at nominal (base) position and then 20 and 40 mm (model) closer to propeller disk.

The ship model was ballasted to one draught, corresponding to 9.75 m even keel. All resistance and propulsion tests were done at three speeds, corresponding to 13, 14 and 15 knots. The propeller model corresponded to 5.6 m full scale propeller diameter. Rudder configurations and geometrical particulars are illustrated in Figures 17 and 18 and in Table 4.

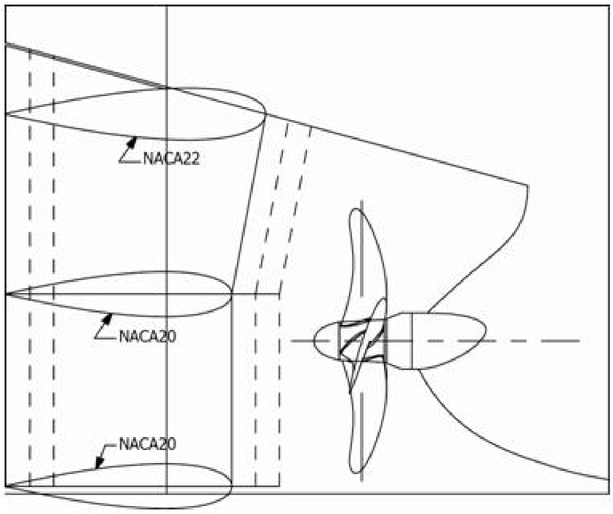


Figure 17. Horn (standard) rudder configuration

Table 4. Rudder Particulars

Rudder type	Lateral area	Aspect ratio	Thickness (top/bottom)	Distance to propeller plane
	[m^2]	[-]	[% chord]	[m]
HORN	34.44	1.70	22/20	45.5%D 37.1%D 28.6%D
Spade	29.15	1.58	13/13	44.1%D 35.7%D 27.2%D

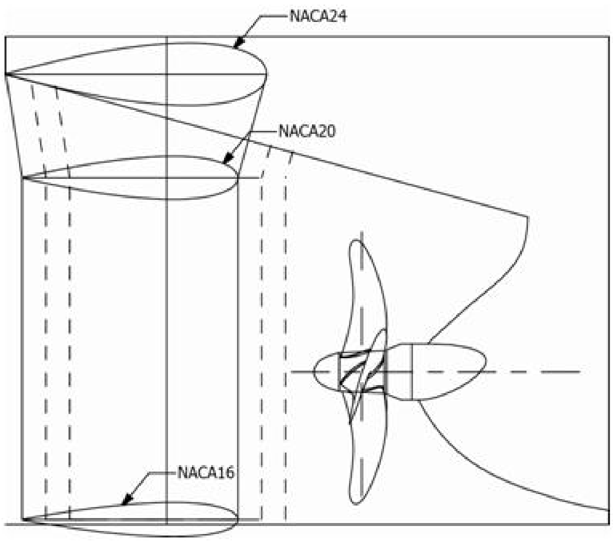


Figure 18. Spade rudder configuration

In the table above, equivalent aspect ratio is defined as lateral area, divided by mean chord square (A_{TOT}/c_{MEAN}^2). Distance to propeller plane is distance from rudder leading edge at propeller shaft level.

The test results are summarized in Figure 19 with the following conclusions:

- Both Horn and spade rudders exhibit optimum longitudinal position at about 30%-35% c/D.
- At base position, the spade rudder shows about 1.1% power gain against the Horn rudder, while at the optimum position the power gain increases to approximately 1.5% power saving.

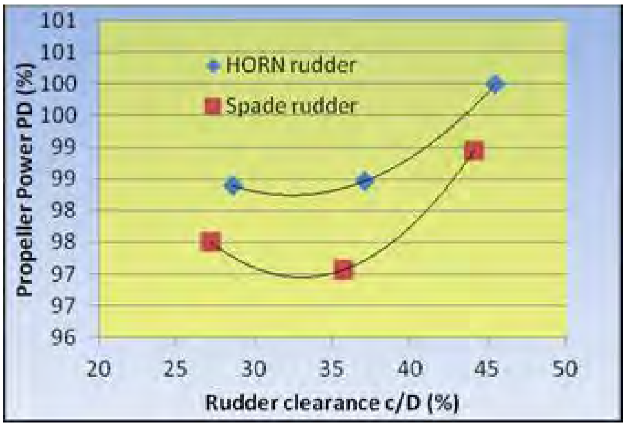


Figure 19. Propeller power comparison at 14.0 knots

In the above figure 100% power corresponds to the power associated to the base case (Horn rudder at nominal position of c/D = 45.5%). These results were found in very good qualitative agreement with the conclusions from a simiral study, reported in reference [1].

6 EEDI CALCULATIONS AND COMPARISON WITH BASE LINE

The Marine Environmental Protection Committee (MEPC) to the International Maritime Organization (IMO), at its fifty-ninth session (July 2009), recognized the need to develop an Energy Efficiency Design Index (EEDI) for new ships in order to stimulate innovation and technical development of al elements influencing the energy efficiency of a ship from its design phase. The MEPC circulated Interim Guidelines on the method of calculation of the EEDI, as presented in reference [2].

In its simplified form, as proposed in reference [3], the EEDI is calculated by the following formula:

$$EEDI = CF \frac{SFC_{ME} \sum P_{ME} + SFC_{AE} P_{AE}}{Capacity * V_{REF}}$$

Where: *CF*- Carbon emission factor; (g-CO2/g-fuel)

SFC_{ME} - Specific fuel consumption of main engine, (g/kWh)

SFC_{AE} - Specific fuel consumption of auxiliary engines, (g/kWh)

P_{ME} - 75% of the rated installed power (MCR) for each main engine without any deduction for shaft generators, (kW)

P_{AE} - Installed auxiliary power (kW),

Capacity – For dry cargo carriers, tankers, gas tankers, containerships, RO-RO cargo and general cargo ships, deadweight should be used as *Capacity*.

Vref – Is the ship speed, measured in knots, on deep water in the maximum design load condition (*capacity*) as defined above, at the main engine shaft power as defined above and assuming the weather is calm with no wind and no waves.

The base line EEDI for bulk carriers > 400 GT build in the period 1995 – 2004 is presented in the next Figure 20.

The SH35 EEDI has been calculated for the 5 versions of main engine/propeller designs (according Table 3 above) and the results are summarized in Table 5.

The present IMO regulations dictate a scheme for reduction of EEDI for new vessel built after a certain date to demonstrate an EEDI at certain percentage below the base line for bulk carriers, as illustrated in Table 6.

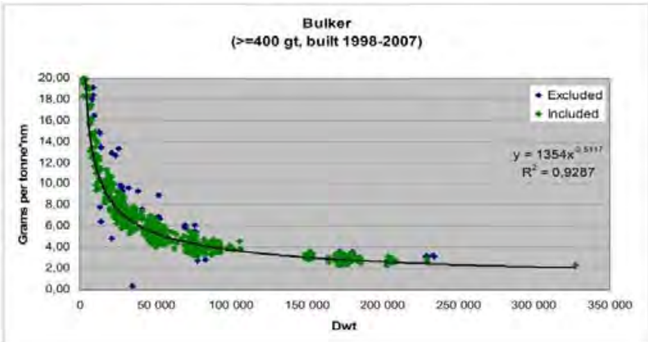


Figure 20. EEDI Base line for dry bulk-carriers (source ref. [3])

Table 5. Results of EEDI Calculations for SH35

SH35 Case #	1	2	3	4	5
EEDI	6.53	6.23	5.60	5.32	4.50
EEDI [%]	100%	95%	86%	81%	59%
BL EEDI	6.54	6.54	6.54	6.54	6.54
EEDI [%toBL)	0%	5%	14%	19%	31%

Table 6. IMO Stipulated EEDI Reduction Rate

Phase #	Vessel built	EEDI below base
Phase 0	Jan 2013 – Dec 2014	0%
Phase 1	Jan 2015 – Dec 2019	10%
Phase 2	Jan 2020 – Dec 2024	20%
Phase 3	Jan 2025 –>	30%

From the summary presented in Table 5 and with reference to the requirements in Table 6, it is demonstrated that the latest SH35 design complies with IMO 2025 EEDI requirement with the following major conclusions:

- With the most efficient main engine and propeller option (Version 3) the EEDI has been reduced by 14% below the EEDI base line.
- With the most efficient main engine and propeller and the Becker Mewis Duct® option (Version 4) the EEDI has been reduced by 19% below the EEDI base line (close to 2020EEDI compliance). Considering that the EEDI calculation includes a SFOC margin of 5%, it is likely that the fully optimized SH35 will actually meet the 2020 EEDI requirement.
- With the most efficient main engine and propeller, Becker Mewis Duct® and the design speed reduced to 13 knots (Version 5) the EEDI has been reduced by 31% below the EEDI base line (full 2025EEDI compliance).

7 FULL SCALE PROPULSIVE PERFROMANCE VERIFICATION

At present (i.e. September 2012) 14 or 15 Seahorses have been delivered; but sea trial reports have not yet been available for all these vessels. In the tables below, the sea trial results of some of the first vessels have been compared to the tank predictions.

When analysing sea trial reports, it must be kept in mind that the sea trial conditions differ from those of a model test. The weather conditions some time are exceeding the tolerable limits and hence proper sea trials cannot be made. Also other variables, as for instance the vessels draught, may be surprisingly difficult to determine with a reasonable degree of accuracy. Draught marks cannot be accurately read at sea, particularly not during night time, draught measurement systems may not be calibrated and the loading computer may not be updated with information about lightweight and tank capacities. As the costs per day of a sea trial are quite substantial, it is often not possible to wait for better weather conditions, or to repeat test runs.

In order to utilise the sea trial measurements these must be corrected for weather conditions different from the specified ones. In China, where all the Seahorses have been built, the trial analysis with all the necessary corrections involved is normally done by a consultant company, which runs the speed trials on behalf of the yard. The wave conditions are normally based on visual judgment of wave height, and this is of course another source of error. For some of the first vessels in the Seahorse class, a model tank has been asked to provide corrected data based on the sea trial report.

In Table 7 the following entities have been listed for four vessels: Tank predicted sea trial shaft power; measured sea trial shaft power and corrected sea trial shaft power. The corrections have been made by the yards consultant or by a reputable European model tank. With a deviation of -0.5% the corrected shaft power for the first Seahorse is almost spot-on the model tank prediction (the model test and the prediction were made by different model tanks). Thereby a comfortable margin to the contract value was documented and verified. For the second ship the correction is quite large, and the corrected power is almost 6% below the contract value. This, however, is not typical, and generally the prognosis and the measured/corrected shaft power are within 1-2% on average. In Table 8 the variation in propeller revolutions seems to be a little larger; but this must be expected, as the RPM value is a function of both engine power and propeller particulars (mostly P/D ratio). If the RPM was related to a constant power, rather than a constant speed, the variations would be significantly reduced.

Table 7. Propeller Power Correlation with Tank Predictions @ 14 knots

Yard	A	B	C	D
T_A/T_F (m)	6.5/4.5			
D (m)	5.54	5.54	5.80	5.60
Prop. type	NPT			
Tank P_D (kW)	4150	4150	4081	3863
Trial $P_{D,}$ Yard corrected (kW)		3900	3900	
P_D deviation (%)		-6.0%	1.0%	
Trial $P_{D,}$ Tank corrected (kW)	4130		4171	3910
P_D deviation (%)	-0.5%		2.2%	1.2%

Table 8. Propeller Revolutions Correlation with Tank Predictions @ 14 knots

Yard	A	B	C	D
T_A/T_F (m)	6.5/4.5			
D (m)	5.54	5.54	5.80	5.60
Prop. type	NPT			
Tank RPM	104.5	104.5	96.4	94.3
Trial RPM, Yard corrected		99.6	96.2	
RPM deviation (%)		-4.7%	-0.2%	
Trial RPM, Tank corrected	101.9		98.4	91.6
RPM deviation (%)	-2.5%		2.1%	-2.9%

8 PLANS FOR FUTURE WORK

The work for further propulsive performance improvement of the SH35 design continues with towing tank trim optimization tests, new rudder design and course keeping enhancement studies.

The effect of the static trim (both forward and aft) will be systematically varied in a wider range of mean draught variations, aiming definition of conditions providing significant power savings.

The idea of the rudder re-design was encouraged by the results of the carried out rudder variation studies, where a promising power saving potential was indicated by re-arranging the rudder.

9 CONCLUSIONS

- Initial hull lines optimization by CFD multi-variant studies proved to be a cost effective way of defining the final hull lines for the vessel. The adopted vertical stem with close to constant shape of the waterlines contributed to stable and relatively low level of the wave-making and pressure induced resistance of the hull.
- New generation of two-stroke diesel engines allowed achieving a combination of low rotation rate with minimum specific fuel consumption (higher thermal efficiency). Furthermore the contemporary electronic or semi-electronic engine control systems enable a detailed engine tuning, where minimum specific fuel consumption can be obtained at the normal operating point for the engine. The latest versions of SH35 were equipped with such a power plant.
- Application of the NPT propeller, contributed to further improvement of the overall propulsive efficiency. This was further elaborated by studying variable NPT propeller design alternatives, to match variable main engine installation. The general trend of low revs/high propeller diameter concept was well documented and proven by comparative model tests, where power savings of up to 3.5% were verified.
- Aiming further propulsive efficiency improvement, the Becker Mewis Duct® concept was explored and verified by model tests. Based on the subsequent predictions approximately 4% power saving was reported.
- Propeller-rudder interaction plays an important part in the overall propulsive efficiency. One of the major parameters influences this interaction is the horizontal clearance between the rudder leading edge and the propeller disk plane. The experimental study indicated that for the specific case of SH35 arrangement 30%-35% c/D value appeared to be most effective, leading to about 1.5% power saving compared to the nominal rudder position (at 45% c/D). Replacing the existing semi-balanced (Horn) rudder with a balanced (Spade) rudder may lead to additional 1% power gain.
- It has been demonstrated that a modern handy-size bulk carrier can be optimized to meet the 2020 EEDI requirements of 20% EEDI lower than the base line and to maintain the design speed (14.0 knots).EEDI calculations and comparison with base line.
- To meet the 2025 requirement of an EEDI 30% below base line, the maximum installed main engine power has to be reduced by approximately 25% resulting to a reduction of design speed from 14 to 13 knots.
- Considering the significant reduction in fuel oil consumption and following EEDI gain, owners and charteres might find a 1 knot or even higher speed reduction acceptable, but how low can we go in max installed main engine power and still have a safe ship with sufficient maneuvering speed in a heavy sea-state? This issue needs further careful investigations, which is currently in the focus of the IMO/IACS/ITTC cooperative work.
- Speed and power sea trial results with a number of SH35 projects revealed comparatively consistent and good correlation with model test predictions, especially for the propeller shaft power. The latter deviated (on average) from the tank prediction with about 2.0%.

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