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Container Vessels – Potential for Improvements in Hydrodynamic Performance

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Abstract

Under the pressure of rising fuel costs an old virtue came back to the focus of ship designers, owners and operators: optimization of the whole system with the target to minimize the fuel consumption under actual environmental conditions. While today's optimization strategies mainly improve the resistance of a vessel for design draft and speed for calm water conditions, future strategies will achieve additional gains taking into account the expected operational profile and actual service environment of a project vessel. Energy saving devices target improvements in propulsion efficiency by recovering losses from the propeller slip stream or improvements in the water flow to the propeller, allowing a propeller design with higher efficiency. Optimization for "off-design" conditions, application of energy saving devices and benefits of operational guidelines will contribute to performance improvements for future container vessel designs.

Keywords

Container vessel; Hull lines; Energy saving device; Optimization; Ship operation.

Introduction

During the last four decades the loading capacity of container ships has increased from a few hundred TEU for the first full container ship to more than 11,000 TEU for the most modern vessels now in operation. Over this period of development numerous design and construction problems associated with the increasing size of the vessels and their propellers were overcome. The demand for sufficient stability, higher speeds and low vibration levels has led to new hull forms specific to this type of vessel.

Under the pressure of rising fuel costs – the price for the OPEC Reference Basket (ORB) increased by a factor of about 3 in the last five years (see Fig. 1) – an old virtue came back to the focus of ship designers, owners and operators: optimization of the whole system with the target to minimize the fuel consumption under actual environmental conditions. One approach is the application of energy saving devices; another, the optimization of the way the vessel is operated.

Very large container ships suffer from several specific hydrodynamic problems due to their pure size and the special transport profile. These include propeller cavitation and erosion, rudder cavitation and erosion, and parametric rolling. They are discussed in detail in the HSVA-paper "The Challenge of Very Large Container Ships – A Hydrodynamic View" presented at PRADS 2004.

While today's optimization strategies mainly improve the resistance of a vessel at design draft and speed for calm water conditions, future optimization strategies will achieve additional gains taking into account all aspects of hydrodynamics (e.g. potential for higher propeller efficiency and lower risk for erosive cavitation when the propeller load is reduced).

Furthermore, the operational profile and the service environment of a vessel will be taken into account for the ship design. It is still common practice that one draught is defined as design draught and all requirements for minimum speed or maximum fuel consumption etc. are defined for this single draught ignoring that, in the majority of cases, the ship will operate at other draughts and speeds. This means that the ship is optimized for conditions at which it seldom sails. A hull design optimized for a range of draughts and speeds will be first choice for container vessels.

Energy saving devices target improvements in propulsion efficiency by recovering losses from the propeller slip stream or improvements in the water flow to the propeller, allowing a propeller design with higher efficiency. Well known energy saving devices are wake equalizing ducts (Schneekluth-ducts), wake equalizing fins, vortex generator fins, pre-swirl and rudder fins, rudder-bulbs (Costa-bulbs), boss cap fins and divergent propeller caps. In combination they can reduce the power consumption without any changes to the hull by more than 5%.

Container vessels have a high ballast water capacity in order to ensure sufficient stability for all loading conditions. The ballast water also can be used to influence the trim of the vessel. Since modern hull lines often feature a very wide transom which is quite deeply submerged especially at scantling draught small changes to the trim can result in a significant change in power consumption / achievable speed.

Optimization for "off-design" conditions, application of energy saving devices and the effect of operational guidelines for container vessels and their benefit for ship owners and operators are discussed in the following paragraphs.

Fuel Oil Costs – The Driving Force

More or less all container vessels nowadays are powered by combustion engines burning fuel oil distilled from crude oil. Figure 1 shows the recent history of the price for the OPEC reference basket. After a period of stable prices the costs went up by about 165% within the last 5½ years.

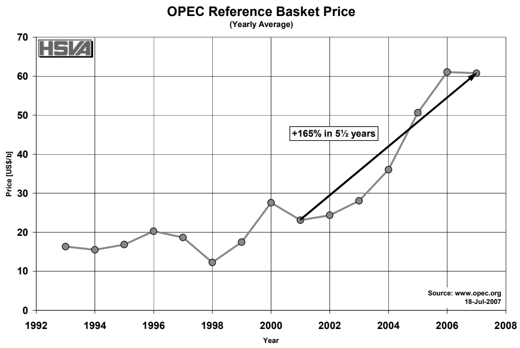

Fig. 1: OPEC Reference Basket Price History

Figure 2 and figure 3 give a broader view to the history of oil prices back to year 1861. In this diagram the oil price is recalculated to the USD-value in year 2004. Since 1880 the oil price was more or less constant for roughly 90 years. In the first oil crisis 1974 the oil price almost quadrupled in just one year. The second oil crisis 5 years later was not so drastic: compared to the previous year the oil price doubled only (compared to the year before the first oil crisis the price was almost nine times higher!). But the impact on the shipping market was still tremendous.

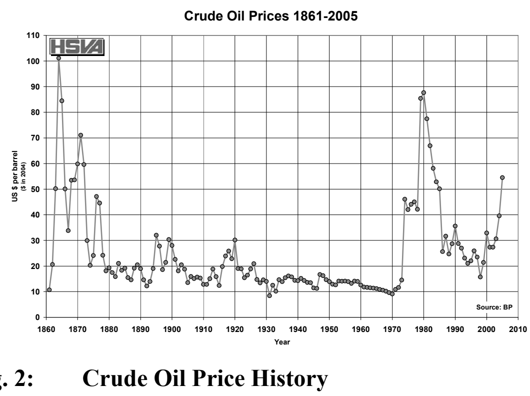

Fig. 2: Crude Oil Price History

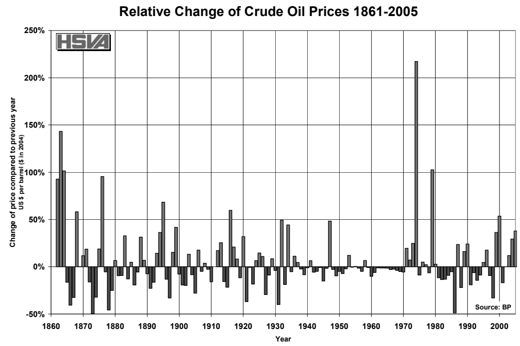

Fig. 3: Crude Oil Price History – Change of price relative to previous year

In this light the increase of the oil price in the last few years was not fast and drastic enough – just +165% in 5 years – to influence the shipping business significantly. The world economy booms and most of all cargoes traded world-wide are transported on ships from the maker to the consumer. Currently the ship owners are satisfied by their earnings and can afford to pay relative high prices for fuel oil. Most probably it will take a more dramatic (faster) change of the oil price and/or the world trade to increase the pressure on the ship owners to have a closer look at the economy of their vessels. But nonetheless some ship owners have already started this wise process and are eager to gain a competitive advantage from more efficient vessels.

Optimization for Calm Water Conditions

Actual hull designs of modern container vessels have a similar performance and are all thoroughly optimized for calm water and cavitation performance. Shipyards, ship owners and operators know about the performance of their own vessels and of their competitor vessels very well and the efforts undertaken to optimize the hull form of new designs are remarkable. Starting with numerical investigations of numerous hull form variants, the most promising hull form variants are investigated in model test campaigns. During concept stage the large shipyards often test at least two promising hull form variants to find out the real performance of the actual design, sometimes even different main dimension variants are tested in model scale.

Optimizing the hull form

If the projected vessel does not achieve the target speed or a further optimization of the vessel is wanted the first step should be a comparison of the vessel's performance with the characteristics of comparable ships previously investigated at the model basin. The experienced engineers and experts for hydrodynamics will investigate the potential for improvement and possible measures to improve the vessel. In case the hull lines are already well optimized, only small gains can be expected by reshaping the hull. But small gains here and there may sum up to significant improvements. This requires time, endurance, experience and last but not least a budget allowing the thorough optimization and extensive model testing.

If the main dimensions and the propeller diameter are already fixed and the hull form is almost optimal the following potentials for improvement of the ship's resistance remain:

Table 1: Maximum possible improvements by modifications of the hull form

	Possible gain
Fore body hull form	
Small modification at the bulbous bow	2 %
Small modifications in bilge area and forward shoulder	2 %
Form variations using automatic optimization strategies	2-5 %
Mid ship hull form	
Variation of mid ship section coefficient	1 %
Aft body hull form	
Small modifications in bilge area and waterline angles	2 %
Small modifications in the area of stern boss	1 %
Small modifications in the area of stern bulb	1 %
Arrangement of a ducktail to increase the effective length	2 %
Note: Possible gains are not cumulative! Model tests are recommended for verification.	

Optimizing the arrangement of hull, propeller and rudder

By optimization of arrangement and shape of rudder and propeller further savings are possible:

Table 2: Maximum possible improvements by optimizing the arrangement of propeller and rudder

	Possible gain
Increasing propeller efficiency (risk of cavitation)	3 %
Arrangement of rudder and propeller in aft ship	2 %
High lift profiles (e.g. MP 73) to reduce rudder area	1 %
Note: Possible gains are not cumulative! Model tests are recommended for verification.	

Arrangement of devices improving propulsive efficiency

By application of propulsion improving devices the additional gains are possible (see Table 3). These devices have different working principles. The first reduce flow separations and improve the inflow to the propeller. The second recover energy contained in the rotation of the propeller slip stream. The third reduce the losses in the propeller hub vortex by reducing or eliminating it completely.

Table 3: Maximum possible gains by measures improving propulsive efficiency

	Possible gain
Avoid separations, improving wake field	
Grothues wake equalizing spoiler	3 %
Schneekluth wake equalizing duct (WED)	4 %
Sumitomo integrated Lammeren Duct (SILD)	6 %
Recovering rotational losses	
Twist rudder without rudder bulb (BMS / HSVA)	2 %
Single Pre-Swirl Fin (Peters / Mewis)	3 %
Pre-Swirl Fin Systems (DSME, Korea)	4 %
Rudder Fins (HHI, Korea)	4 %
Reducing hub vortex losses	
Divergent boss cap	2 %
Rudder with rudder bulb	2 %
Propeller boss cap fins (PBCF)	3 %
Reducing rotational and hub vortex losses	
Twist rudder with rudder bulb (BMS / HSVA)	4 %
High efficiency rudders of Rolls Royce or Wärtsilä	6 %
Note: Possible gains are not cumulative! Model tests are recommended for verification.	

Optimizing the hull surface

Lately new anti-fouling paints based on silicone have been developed. These special paintings offer a very low average hull roughness (ARH) down to about 80 microns and less. As a standard value model basins consider an ARH of 150 microns. Vessels delivered with sub-optimal surface finish (ARH-values exceeding 200 microns) have been reported. Figure 4 shows the influence of the hull roughness on the power consumption and the achievable speed for a 4200 TEU container vessel. The difference between a good, smooth hull surface and a poor hull surface equals to about 4% in total resistance or 0.2 kts in speed. In consequence every ship owner is well advised to maintain as clean, and smooth a hull as possible. Spending more money for a good and very smooth hull surface is a good investment.

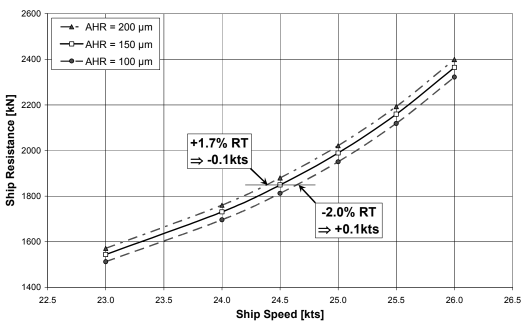

Fig. 4: Influence of Average Hull Roughness

Some ship owners hire divers polishing the propeller blades in a regular interval (e.g. twice a year) reducing the frictional resistance of the propellers which results in a lower torque, a higher efficiency and less fuel consumption. Special propeller blade coatings that reduce fouling and maintain smooth surfaces are also available. These coatings increase the periods between propeller polishing and help to save money.

Propeller Diameter versus Pressure Pulses

Expecting rising fuel oil costs it is the aim of all shipyards, to design vessels with the lowest power demand possible for the contract conditions. To achieve this, the designer has to find the best compromise between propeller efficiency and pressure pulses to suit ship owners needs. On one hand the larger propeller diameter leads to higher propeller efficiency, on the other hand the larger propeller diameter may cause a slight decrease in hull efficiency and most probably will cause higher pressure pulses due to reduced propeller tip clearance.

HSVA investigated a large number of container vessels which have been investigated in resistance and propulsion tests in the large towing tank and in cavitation tests for pressure pulse measurements in the HYKAT. From these test results empirical formulas have been derived to assess hull efficiency and pressure pulses for such variations.

For a 4200 TEU container vessel the following variations in propeller diameter have been assessed. The original propeller diameter is 7.75 m When increasing the propeller diameter in two steps up to 8.0 m and 8.2 m thus reducing the propeller tip clearance from 2.65 m down to 2.40 m and 2.20 m one can expect the following gains in speed at constant propulsion power and an increase in pressure pulses as presented in Table 4:

Table 4: Predicted pressure fluctuation for a CV 4200

D_P	η_H[1] [-]	η_0[2] [-]	V_S [kts]	Δp [kPa]
7.75 m	1.095	0.699	24.57	5.2
8.00 m	1.090	0.707	24.61	5.6
8.20 m	1.087	0.713	24.63	5.9

Quality of the Wake Field

Few shipyards spend time and money to improve the quality of the wake field by further modifications to the aft body of the vessel. It is sometimes overseen that a wake field of good quality helps to reduce the pressure pulses of the propeller and minimizing the danger of propeller induced vibrations in the structure.

For container vessels with a capacity of about 4200 TEU a large number of wake measurements of similar hull forms are available at HSVA. To judge the quality of the wake field a special "axial wake quality factor" (AWQF) has been defined, taking into account the non-uniformity of the axial inflow to the propeller. The average AWQF for container vessels of this size is about 0.70, with a range between about 0.65 and 0.74. Higher values are more favorable.

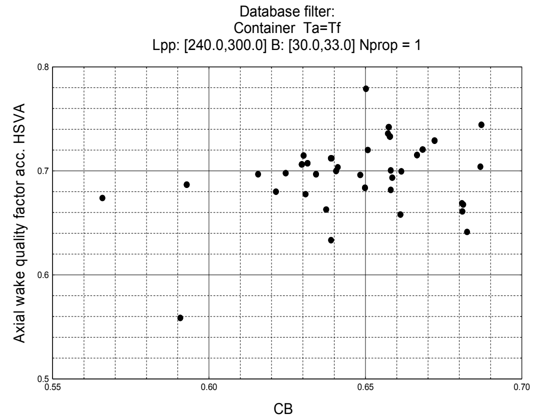

Fig. 5: Axial Wake Quality Factor of container vessels of about 4200 TEU

The expected influence of the quality of the wake field on the pressure pulses for our example 4200 TEU container vessel is presented in Table 5:

Table 5: Influence of axial quality wake factor on expected pressure pulses

D_P	AWQF [-]	Δp [kPa]
7.75 m	0.65	5.8
7.75 m	0.70	5.2
7.75 m	0.74	4.8

In this example a wake field of superior quality reduces the pressure pulses by about 0.4 kPa compared with an average quality wake field. A wake field of poor quality will increase the pressure pulses by about 0.6 kPa.

Optimization for Off-Design Conditions

Today container vessels are often being optimized for the contract condition (usually design draft) in calm water only. From the operators point of view it can be much more advantageous to optimize the vessels hull form for the actual environmental conditions and the individual operating profile expected for their new buildings.

In the following the additional power demand for actual environmental conditions has been calculated for a modern 4200 TEU container vessel. Wind, seaway, roll motions and drift according to side wind have been taken into account in this investigation.

Table 6: Environmental conditions

Wind force	Wind speed	Significant wave height	Period
Beaufort 2	2.365 m/s	Calm	—
Beaufort 4	6.90 m/s	0.88 m	4.7 s
Beaufort 6	12.6 m/s	3.25 m	9.0 s
Beaufort 8	19.3 m/s	5.00 m	11.2 s

1 η_H = hull efficiency
2 η_0 = propeller open water efficiency

Additional power demand in a seaway

Compared to other ship types, the container vessels with low block coefficient and slender lines have a comparably low additional power demand in a seaway. Some designers consider the seaworthiness as an important design constraint, thus designing fine waterline entrance angles, fore ship sections with moderate bow flare, not too extreme bulbous bows and moderate transom stern designs. Other designers, optimizing their vessels for calm water condition only and neglecting the importance of seaworthiness, come with more bow flare, pronounced bulbous bows and wide, flat transom stern designs.

The additional power demand of a 4200 TEU container vessel with good sea-keeping behavior and slender lines has been calculated by strip theory for the design speed of 24.5 knots (Fig. 6).

The additional power demand has been calculated for environmental conditions as per Table 6 and for five different angles of encounter, 0 deg (head sea, 45 deg (bow quartering), 90 deg (beam sea), 135 deg (stern quartering) and 180 deg (stern sea).

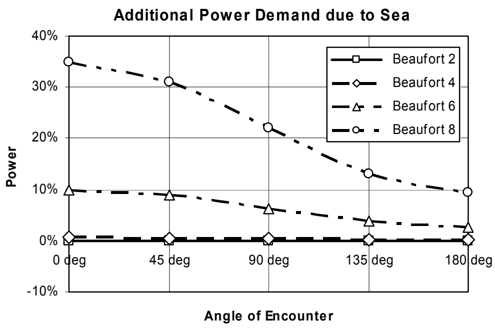

Fig. 6: Additional Power Demand due to Sea

In all sea states in the head sea condition there is the largest additional power demand due to sea. At a sea state corresponding to Beaufort 6 the additional power demand is about 10%, at Beaufort 8 this is about 35%.

Assuming the following probability distribution of the sea states, 3% for wave heights below 0.5 m, 25% for wave heights between 0.5 m and 2 m, 45% for wave heights between 2 m and 4 m and 27% for wave heights of 4 m and above, the average additional power demand due to sea state, calculated over the whole range of angles of encounter, is about 9%.

Additional power demand due to wind

Usually, both shipyards and ship owners do not care about wind resistance of container vessels. The effect of wind according to contract conditions on the trial prediction is very small. Usually a wind force according to Beaufort 0 is taken into account for the trial prediction today, in the past often a wind force according to Beaufort 2 (2.365 m/s) has been used.

Typically a wind resistance coefficient of C_{AA} = 0.8 to 0.9 is applied for the prediction. Under these conditions the wind resistance according to Beaufort 2 contributes only with 1.5% to the power demand of a 4200 TEU container vessel. The situation changes completely, when it comes to service predictions.

The additional power demand due to wind is presented in Figure 7.

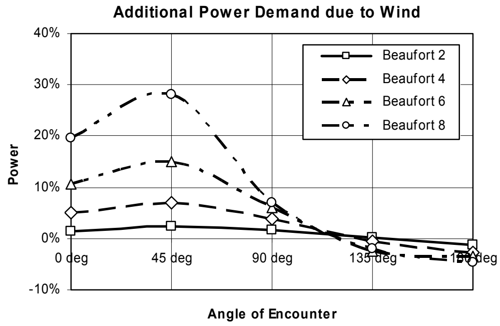

Fig. 7: Additional Power Demand due to Wind

In the bow quartering condition there is the largest additional power demand due to wind. At a wind speed of Beaufort 6 the additional power demand is about 15%, at Beaufort 8 this is about 28%.

Assuming the following probability distribution of the wind, 5% for wind Beaufort 2 and less, 50% for wind Beaufort 4, 40% for wind Beaufort 6 and 5% for wind Beaufort 8 and above, the average additional power demand due to wind, calculated over the whole range of angles of encounter, is about 4%.

Additional power demand due to drift by side wind

Container vessels with their large amount of deck cargo are exposed to the wind. In a side wind condition wind forces and moments acting on the vessel cause a drift angle and it is necessary to lay the rudder to keep the course. Due to the relative high speed of container vessels the drift and the rudder angles usually are small, e.g. below 2 deg for the drift angle, and below 4 deg for the rudder angle.

Few model test results of container vessels are available to estimate the additional power demand arising from drift by side wind. For the same wind conditions as have been used before and the same angles of encounter the body and rudder forces for the steady drift condition under these conditions have been calculated and the additional power demand has been estimated.

In the worst condition, resulting in the largest drift and rudder angles for wind Beaufort 6 the additional power demand due to drift by side wind is about 4%, at Beaufort 8 this is about 9%.

Assuming the same probability distribution as has been done before, the average additional power demand, calculated over the whole range of angles of encounter, is about 3%.

Additional power demand due to rolling

The effect of the roll motion on a container vessels power demand is almost unknown. Neither roll motions are predicted for container vessels as a standard, nor are self propulsion tests in combination with roll excitation tests performed in a systematic manner.

At HSVA for one container vessel project self propulsion tests in combination with roll excitation tests have been performed. Furthermore sea-keeping calculations have been performed to predict the significant roll angles expected for the different sea states and angles of encounter.

The test results indicate that roll motions contribute significantly to the power demand of a vessel, depending on the mean roll amplitudes and the ship speed. Based on these results, for the 4200 TEU container vessel the following power demand has been predicted for the same conditions as before.

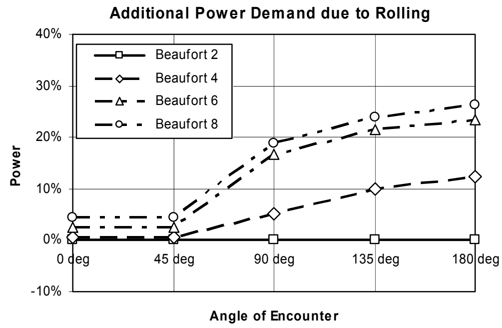

Fig. 8: Additional Power Demand due to Rolling

The additional power demand is significantly over a wide range of angles. In stern sea and stern quartering condition the largest additional power demand due to rolling occurs. At a wind speed of Beaufort 6 the additional power demand is about 23%, at Beaufort 8 this is about 26%.

Assuming the same probability distribution as has been done before, the average additional power demand due to rolling, calculated over the whole range of angles of encounter, is about 12%.

Although this kind of test is still unique at HSVA, the large increase in power demand makes it necessary to further investigate the reason for this and how to minimize the additional power demand due to roll motions of a vessel. The predictions presented in the paragraph are based on tests with regular roll motions in calm water. Most likely the additional power demand due to rolling in natural seaway will be different.

Potential for further savings

Compared to the standard trial prediction for wind Beaufort 0 as reference, we have a total additional power demand in percent for the different angles of encounter and the actual environmental conditions as is shown in Table 7.

Table 7: Total additional power demand

Wind force	0 [deg]	45 [deg]	90 [deg]	135 [deg]	180 [deg]
Bft. 2	+1%	+2%	+2%	+0%	-1%
Bft. 4	+6%	+9%	+11%	+10%	+10%
Bft. 6	+23%	+30%	+33%	+25%	+23%
Bft. 8	+61%	+74%	+57%	+38%	+32%

Assuming the same probability distribution as has been used before the average additional power demand for a 4200 TEU container vessel is about 27%.

Since nobody performed optimization of vessels taking into account real environmental conditions up to now, one can assume that larger reductions in the additional power demand should be possible. Assuming a 20% reduction of the additional power demand, this would result in reduction of fuel oil costs in the range of about 5% (20% of 27%).

On the other hand the additional power demand may even increase, if the designers and shipyards optimize the vessel without considering environmental aspects.

As an example for optimization potential, figure 9 shows typical wind resistance coefficients of a container vessel in loaded condition, which have been measured during wind tunnel tests.

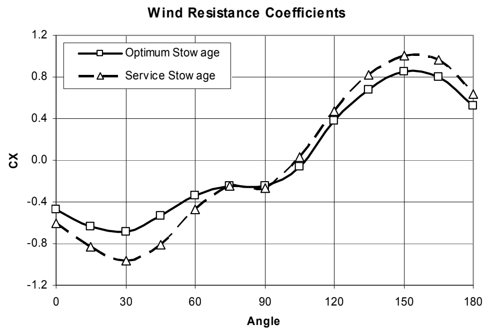

Fig. 9: Wind resistance coefficients

A set of two curves is shown: the solid line is valid for block stowage of all deck containers, which represents the best possible stowage in respect of wind resistance, and the dashed line, which is valid for more realistic stowage in service conditions, with only partial number of deck containers, different stack heights, etc. It can be seen that the difference between actual stowage and optimized stowage condition, depending on the angles of encounter, is up to between 20% and 30%.

Compared to the trial condition as reference, one can expect a speed loss of about 1 knot in a head wind condition Beaufort 6 (wind entrance angle 30 deg) for containers stowed as usual. This speed loss could be reduced roughly to the half, simply by optimizing the container stowage. This is equivalent to power savings of about 5%.

In addition to this there should be further potential for power savings by applying an aerodynamic efficient design to reduce aerodynamic drag in service conditions.

Operational Profile

A 4200 TEU container vessel typically has a design draft of about 11.0 m, and a scantling draft of about 13.0 m. The hull form, and especially the design of the bulbous bow and the transom stern, is optimized for the design draft. To fulfill high stability requirements, the waterline area has been maximized resulting in wide transoms with flat buttocks in the aft body and V-shaped frames in the fore body. Both measures in principle increase the ship resistance. To compensate for this compromise between stability and speed, often a pronounced bulbous bow is arranged, with maximum effect at the design draft and at design speed in calm water conditions.

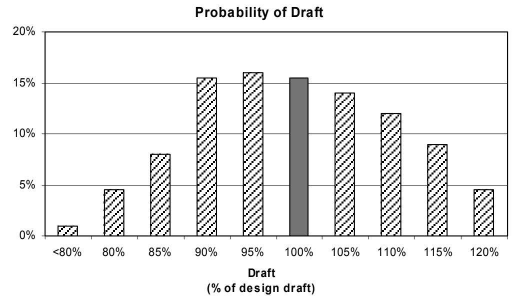

Fig. 10: Probability of operational draft distribution

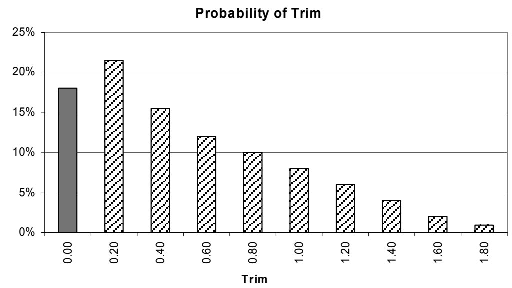

Fig. 11: Probability of operational trim distribution

A typical operational profile of such vessels is presented in the figures 10 and 11. Figure 10 shows the distribution of different drafts under service conditions, and figure 11 shows the distribution of different trim conditions in service.

Considering actual operating profiles most probably will result in different hull form designs than we have today. The hull form must not only be optimized for the design draft, but for a much wider range of drafts. In case 90% of the expected operating profile shall be covered, the performance of the vessel must be optimized between 85% and 115% of the design draft, which for our example means a draft range between 9.35 m and 12.65 m approximately.

The same yields for the trim range. In case 90% of the operating profile shall be covered, the performance of the vessel must be optimized in a trim range between zero trim and 1.3 m trim aft approximately.

Speed Reduction

The most effective measure to reduce the required propulsion power is to sail at lower speeds. Sailing at 24 knots instead of 25 knots equals to a reduction of the speed by 4% and reduces the power consumption by about 13%. Sailing at 23 knots means a speed reduction of 8% and results in a reduction of the power demand by about 26%. This means that in most cases a smaller main engine with lower investment can be installed and large savings in the fuel oil consumption can be gained. Additional savings are possible due to lower lube oil consumption (lube oil is currently expensive and short in supply). But sailing at lower speeds might require a rearrangement and reorganization of the fleet in order to maintain regular schedules, since sailing a lower speeds means that the time at sea is increased. If the available cargo quantity remains unchanged, additional vessels are required. The optimum fleet size and speed of the vessels depend on the actual fuel costs and new building costs. They must be investigated and determined thoroughly. Although the ships spend more time at sea the savings can be realized since the power consumption is proportional to the speed to the power of three, but the time at sea is proportional to the speed to the power of one only.

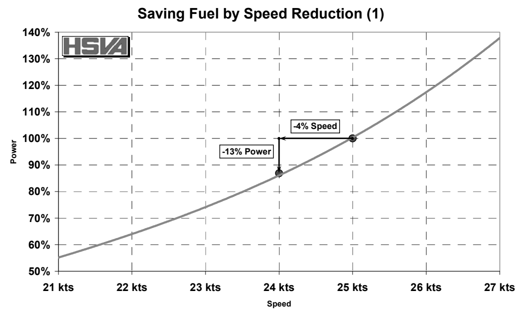

Fig. 12: Reducing the speed by 1 knot reduces the required power by 13%

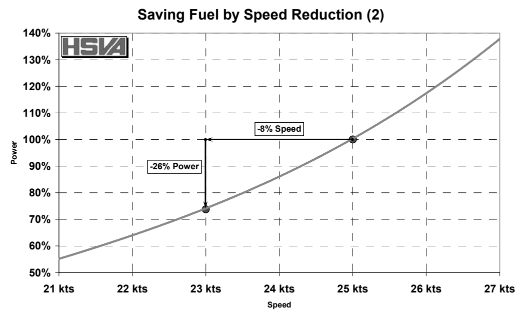

Fig. 13: Reducing the speed by 2 knots reduces the required power by 26%

Bibliography

Detlefs, H.-R.; Mewis, F.; Röpcke, H.-J. (1983): „Ein Verfahren zur Ermittlung der optimalen Trimmlage eines Schiffes", Schiffbauforschung 22, 1/1983, Rostock, 1983.

Dyne, G. (1983): "Ship Propulsion Improvement – Principles and a Survey of Alternative Propulsion Systems", Western European Graduate Education in Marine Technology, Eighth School, Aug. 1983, Gothenburg, 1983.

Germanischer Lloyd (2006): "Containerschiffe – Eine Klasse für sich" in "Tätigkeitsbericht 2006", Germanischer Lloyd, Hamburg

Harvald, Sv. Aa. (1983): "Resistance and Propulsion of Ships", A Whiley-Intersience Publication, John Whiley and Sons, New York, 1983.

HSVA (1993-2006): Several test reports regarding "Resistance, Propulsion, Wake, Cavitation of Merchant Ships".

Johannsen, Christian (2006): "HSVA Prediction Confirmed: Vortex Generator Fins Reduced the Vibration Excitation Level in Full Scale", HSVA NewsWave 2006/1; the newsletter from HSVA, available as PDF-file from www.hsva.de.

Klug, H.; Mewis, F. (2006): "Minimising Fuel Consumption", Shipping World & Shipbuilder, September 2006, p 42 – 46, London, 2006.

Mewis, Friedrich; Dr. Hollenbach, Uwe (2007): Hydrodynamische Maßnahmen zur Verringerung des Energieverbrauches im Schiffsbetrieb/ Hydrodynamic Measures for Reducing Energy Consumption during Ship Operation; paper presented at STG Sprechtag „Möglichkeiten der Energieeinsparung im Schiffsbetrieb" on 22. March 2007 in Hamburg

Mewis, Friedrich; Hollenbach, Uwe (2006): "Special Measures for Improving Propulsive Efficiency", HSVA NewsWave 2006/1; the newsletter from HSVA, available as PDF-file from www.hsva.de.

Mewis, Friedrich; Klug, Hilmar (2004): "The Challenge of Very Large Container Ships – A Hydrodynamic View", PRADS 2004 – The 9th International Symposium on Practical Design of Ships and Floating Structures, Volume 1, Seehafen Verlag, Hamburg.

Peters, H.-E.; Mewis, F. (1986): "Power Savings through a Novel Fin System", 15th SMSSH, Proceedings Vol. 1, pp 91 - 96, Varna, 1986.

Rayner, A. (2007): „Deutliche Vorteile durch Silikonbeschichtung", Schiff & Hafen / Januar 2007 / Nr. 1, Hamburg, 2007.

Schneekluth, H. (1988): „Hydromechanik zum Schiffsentwurf", Koehler Verlag, 1988.

Streckwall, Heinrich (2005): "The New Twisted Rudder HSVA TW05 Aims at Improving Propulsion Efficiency and Cavitation Performance", HSVA NewsWave 2005/2; the newsletter from HSVA, available as PDF-file from www.hsva.de.