A Critical Assessment of Measures to Improve Energy Efficiency in Containerships

Volker Bertram[1] , **Ahmet Taşdemir**[2]

volker.bertram@dnvgl.com, atasdemir@pirireis.edu.tr

[1]*DNV GL, Hamburg, Germany*
[2] *Pîrî Reis University, Istanbul, Turkey*

Abstract

Containership operators are confronted with a multitude of proposals for fuel saving measures and even more promises. Actual savings are generally much lower than quoted numbers in advertisement material and even scientific publications. Reasons for discrepancies are discussed and some guidelines for selecting suitable measures are given. There are options with significant fuel savings false promises that result in zero savings or even losses.

Keywords: Energy Efficiency, Fuel Saving, CO2, Container Ships

1. Introduction

Increasing fuel prices and legislation concerning CO2 emissions (respectively energy efficiency) have made fuel efficiency a key topic in our industry. While new designs offer much larger potential gains in energy efficiency, refit and operational measures may in- crease fuel efficiency for the fleet in service, and some of these measures offer attractively short payback times. Bulhaug et al. (2009), OCIMF (2011) and Bertram (2011) give over- views of such measures.

The relative importance of these measures depends on many factors, including ship type. For example, trim optimization is more attractive than hull maintenance for container ships, Fig. 1, Köpke & Sames (2011a). But for large tankers, OCIMF (2011) rates the fuel saving potential of hull maintenance (listed as CBM = condition-based maintenance) higher than trim optimization (listed as trim assistant), namely 2.0% versus 0.3%.

Sometimes the saving potential of an option depends on individual ship hull and propeller characteristics, giving large scatter in reported savings even for same ship type. Modern computer simulations offer substantial progress in assessing saving potential of many de- vices, allowing case-by-case assessment. For example, CFD (computational fluid dynamics) allows quantifying the effect of a propulsion improving device and gives insight ex- plaining why devices are effective in one case and counterproductive in another.

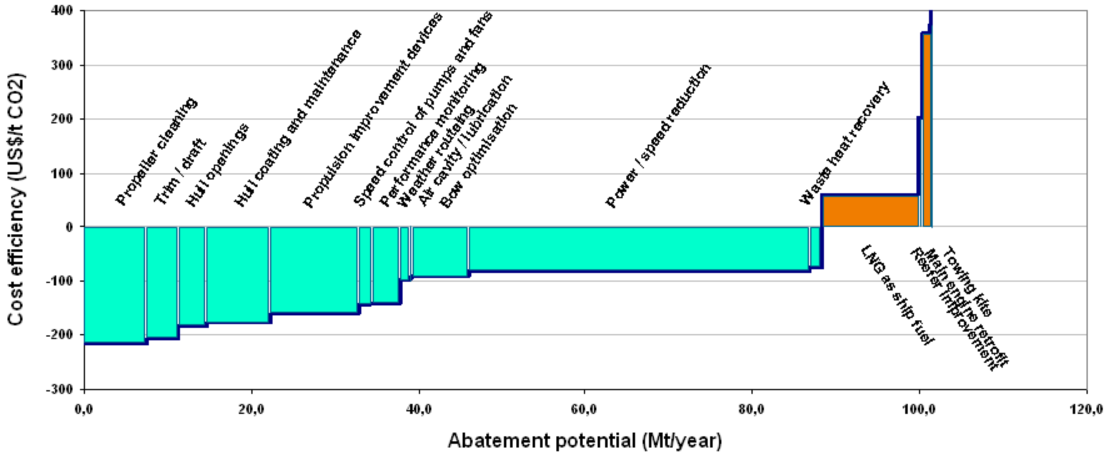


Figure 1. Marginal abatement cost curve for container ship fleet

Many publications give unrealistically optimistic potential for fuel savings. There are various reasons for this:

- The published savings are often for the best case. Quoted savings may be valid for initially bad designs, whereas hydrodynamically optimized designs would never reach these savings. This is best illustrated in a concrete example: DNV GL Mari- time Advisory Services looked at its hull optimization projects in early 2012. The achieved improvements for all projects until that date were collected in a histogram, Fig. 2.

The statistical distribution may be described in various ways:

- Hull optimization may improve the fuel efficiency of a ship by up to 20%.
- Hull optimization improves the fuel efficiency of a ship by 7% on average.
- Hull optimization improves the fuel efficiency of a ship in most projects by 4-6%.

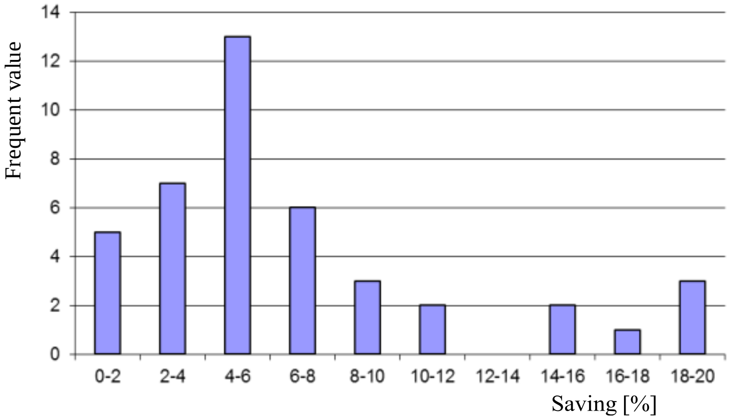


Figure 2. The potential of hull optimization varies. Gains in actual projects show a wide spectrum with 4-6% improvement as most frequent value until end of 2011

All statements are correct. However, “up to X%” is often quoted as “X%” as saving potential in subsequent reports or surveys. Generally, companies do not publish statistical distributions of savings achieved by their products. Instead, marketing strategies promote “up to” numbers which invariably lead to unrealistic expectations and subsequent disillusion.

- Numbers valid for one ship type (say bulk carriers) are taken for other ships (say containerships), where they do not apply.
- Numbers are taken for design speed and draft. Frequently encountered off-design conditions are ignored. Utilization of a fuel saving device is often incorrectly assumed to be 100% of the time at sea for a ship and 100% over fleets for global estimates.
- Saving potential may be measured for calm-water resistance, but real fuel savings apply to total fuel consumption (including added resistance in service and on-board energy consumption). Relating saving to smaller reference numbers gives higher percentage figures. Ideally all savings should be related to (an estimated) total yearly fuel consumption.
- For propulsion improving devices, published savings are based on a comparison of power requirement measured before and after conversion. Sometimes, measurements are not corrected for hull and propeller roughness, while ship and propeller were cleaned during the refit, sea state and loading condition. If measured values are corrected for a "neutral condition", the correction procedure in itself may still have an uncertainty of 2-3%.
- Saving potential is quoted based on model tests and questionable extrapolation to full scale. Model tests violate Reynolds similarity; hence boundary layers and flows at appendages in the boundary layer are not similar. Most quoted figures are based on publications (and model tests) of the 1970s and 1980s. Usually, there is no documentation on how figures were derived. In our experience, re-analyses and detailed full-scale measurements with today's technology showed always substantially lower figures.

2. Some options to improve fuel efficiency of containerships

DNV GL looked into fuel saving options for containerships, with particular focus on fleet in service. The most attractive options are identified in Sames and Köpke (2010), Köpke and Sames (2011a, b). These are discussed in the following in the order of expected payback, see Fig. 1:

a. Propeller cleaning

Propeller roughness increases in time due to cavitation, impingement and fouling. Propeller cleaning intervals should be based on performance monitoring.

b. Trim (optimization)

The wave resistance reacts very sensitively to local changes in the hull geometry. Trim optimization software, e.g. Hochkirch and Mallol (2013), can lead to significant improvement for most ship types, but particularly for container ships. Trim software based on "numerical sea trials" (viscous CFD simulation of ship with propeller at full-scale Reynolds numbers) is our recommended approach, Bertram (2014).

c. Hull openings

Bow thrusters and inlets (e.g. sea chests) may be designed better, again by using CFD. Knowledge about achievable savings is at best anecdotal. The 2nd IMO Green- house Gas study, Buhaug et al. (2009), gives 0.9-4.2% without differentiation for ship type and based on vendor information. The actual saving potential may be lower than 0.9% for many container ships. Large scatter in saving potential is expected, as losses (and thus improvement potential) will depend on local flow details. CFD analyses are recommended for assessment and guidance in re-design.

d. Hull coating and maintenance

The frictional resistance depends on the area and roughness of the wetted surface. The surface roughness is influenced by the choice of coating and appropriate hull management over the life-time of the ship. Some coatings perform very well initially and then degrade rapidly. Hull performance monitoring has evolved dynamically over the past few years, e.g. Bertram and Lampropoulos (2014). The evolving ISO 19030 (Measurement of changes in hull and propeller performance) is expected to contribute to wider use of hull (and propeller) performance monitoring and management. Hull performance monitoring requires assorted corrections (a.k.a. normalization). Corrections for actual draft and trim are very important for containerships. Simple interpolations between model test predictions give unacceptably high errors for containerships (around 10%), Krapp and Bertram (2015). Instead, extensive CFD simulations are required to give dense interpolation matrices covering the complete operation spectrum for speeds, drafts and trims. Here synergies with trim optimization software should be used.

e. Propulsion improvement devices (PIDs)

Opinions on PIDs scatter widely, from negative effects (increasing fuel consumption) to more than 10% improvements. Indeed, the effectiveness depends on local flow details (such as the strength and position of the bilge vortex in the propeller plane). The effectiveness of PIDs should be assessed on an individual case base, using full-scale CFD simulations, Hochkirch and Mallol (2013). Wake-equalizing ducts are generally not suitable for containerships, as these have already more homogeneous wakes than bulker and tankers. Pre-swirl devices can give improvements typically in the range of 1-4% based on our CFD studies.

f. Speed control of pumps and fans

Speed-controlled (a.k.a. frequency-controlled) of pumps instead of fixed rpm pumps (for cooling water and other systems with high utilization rate) decrease energy consumption for the pumps typically by 25%. The measure has attractive payback periods, but the overall saving potential is relatively small, estimated 0.1 -0.6%.

g. (Engine) Performance monitoring

Engine performance monitoring based on simulation models has developed very dynamically over the past 5 years, e.g. Freund (2012), Lampe et al. (2015). This threshold technology is expected to gain in importance and acceptance in the industry. One of the expected effects is increased awareness leading to more fuel efficient operation by the crew.

h. Weather routing

Realistic estimates for the saving potential of weather routing range from 0.1% to 1.5%, falling significantly short of vendors' claims. The added resistance in waves can be predicted only with uncertainties, which are much larger than the claimed savings due to route optimization, Bertram and Couser (2014). This renders weather routing as a most questionable option for fuel savings. Solid arguments for weather routing are rather safety of cargo and crew.

i. Air lubrication

Air lubrication has attracted considerable media and industry attention. The basic idea is that a layer of air (on part of the hull) reduces the frictional resistance. There is no consensus on the saving potential and, at present, we have no reliable third- party evaluation. Venture capital and entrepreneurial spirit are required to invest into air lubrication.

j. Bow optimization

Hull optimization has progressed over the decades from research applications to state of the art in modern ship design, Hochkirch and Bertram (2012). Modern optimization projects employ numerical sea trials (as for trim optimization), Hochkirch and Mallol (2013), looking at 10-20 thousands of variants. It is becoming common to look at spectra of operational conditions (draft-speed combinations) in the optimization. More recently, bulbous bow refit has been adopted as an attractive option to re- duce fuel consumption, Hochkirch and Bertram (2009, 2013), Hahn and Bertram (2014). It is recommended to explore fuel savings for different operational spectra before deciding on the new bow design.

k. Speed reduction (slow steaming)

Speed reduction is a very effective way to improve fuel efficiency. A 10% lower de- sign speed saves an estimated 23-25% fuel for constant delivery capacity (i.e. increased size of ship or fleet to transport the same amount of cargo per year). Slow steaming is less effective than designing for lower speed as hull, propeller and engine operate in off-design conditions and thus at lower efficiencies. Often refit measures for hull (bow refit), propeller and machinery (e.g. de-rating) are then advisable.

l. Waste heat recovery

The amount of energy that may be recovered from exhaust gas losses depends on the engines used, the exhaust gas temperature and the sulphur content in the fuel. In an expert survey, the saving potential in using heat recovery was estimated to be 2 -7% for ships without power take-in. Many ships already employ this option. Lower installed power and slow steaming reduce the potential for waste heat recovery. Refit- ting waste heat recovery is problematic due to the additional space requirements for the equipment and the already cramped conditions in most engine rooms.

3. Case studies

In following, three case studies will highlight applications of fuel saving measures in practice. The selected case studies from our project experience are "typical", representative for several projects with savings obtained ranging in the most common group
rather than the "up to" extremes.

3.1 Case study 1: Hull optimization

Ship operator Hamburg-Süd wanted the lines of a new 9600 TEU containership design optimized for fuel consumption, Hochkirch et al. (2013). Hamburg-Süd supplied records of actual operational data for a fleet of similar-sized containerships for a whole year. This database of speeds and drafts was condensed to four representative clusters of speed-draft combinations with associated weights ranging between 20 and 30%. The objective was then to reduce the combine fuel consumptions for these four operational states, considering their time share in yearly operation. A global hull optimization was performed using a fast, simplified hydrodynamic assessment of the generated hull variants. In a refinement of the hull optimization, the hydrodynamic assessment used a high-fidelity CFD code, solving the Reynolds-averaged Navier-Stokes equations (RANSE), thus capturing viscous effects directly in the simulation.

Fig. 3 compares for one operational condition the computed wave patterns of the baseline design and our optimized design. The relatively small differences in wave patterns translate into significant fuel savings. For this particular operational condition, the required power for the optimized hull was 6.5% lower than for the baseline. For final validation, model tests were conducted at Hamburg Ship Model Basin (HSVA). The baseline design and DNV GL's optimized design were tested under same conditions and full-scale predictions followed the general guidelines. The model tests confirmed that DNV GL's optimized de- sign outperformed the baseline design on all conditions of the operational profile, with expected yearly fuel savings just short of 4%.

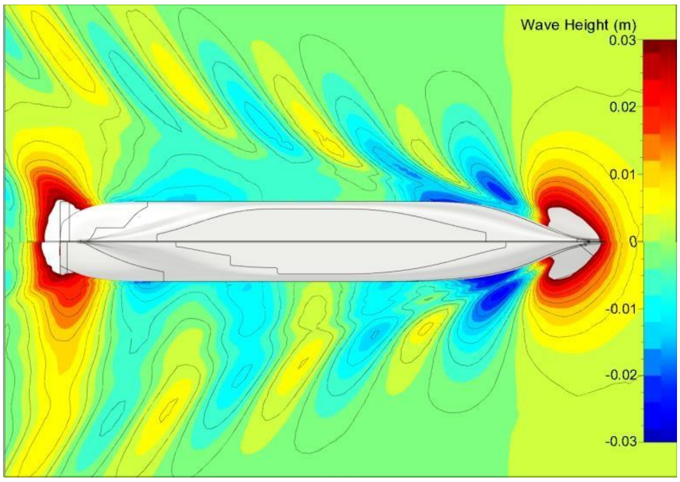


Figure 3. Wave patterns for one operational condition; baseline (top) and optimized design (bottom)

3.2 Case study 2: Bulbous row refit

While obtainable fuel savings are significantly larger for complete hull optimizations, optimization of the bulbous bow region alone offers still potentially very attractive fuel efficiency gains, especially for high powered large containerships which now operate in off- design conditions (slow steaming and partially loaded). State-of-the-art optimization for a realistic operational profile rather than a single design point opens the door to significant further fuel savings, also for refits. This was demonstrated by Hochkirch and Bertram (2013).

The ship owner realized the opportunities of a bulbous bow refit for his fleet of 13000 TEU ships.

The task was now to find the best solution. Qualitatively, the larger the cut-out is chosen, the higher are the cost for the refit, but also the potential gains. In this particular case, there were two general options for such a refit:

- Option 1: Larger cut-out covering the ship below the waterline and before the collision bulkhead
- Option 2: Smaller cut-out below the waterline and before the forward perpendicular

The ship owner supplied records of actual operational data for the ship for a whole year. This database of speeds and drafts was condensed to eight representative clusters of speed- draft combinations with associated weights ranging between 10 and 25%. The objective was then to reduce the combined fuel consumptions for these eight operational states, considering their time share in yearly operation.

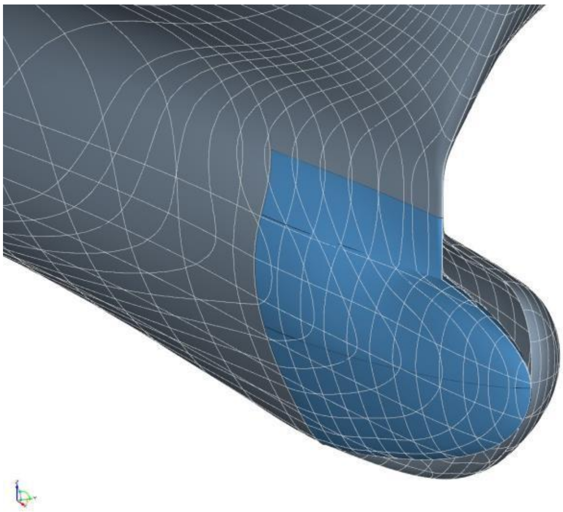


Figure 4. Original hull (port) and re-design alternative (starboard)

A parametric model was set up for the bow section, employing 26 free parameters. The high number of parameters ensured that a vast number of possible bow shapes could be created. In any case, a harmonious fit with the rest of the hull was ensured by suitable constraints on the hull-bow intersection. Roughly 20000 bow variants were investigated. Two final hull shapes were identified featuring optimal performance measures across the operational profile. As expected, the larger flexibility of Option 1 resulted also in larger possible fuel savings. Option 1 had expected gains in off-design conditions of up to 11%, yielding expected yearly fuel savings of ~3.5% for the actual operational profile. Option 2 had expected gains in off-design conditions of up to 6%, yielding expected yearly fuel savings of ~1.8% for the actual operational profile. Results were validated by “numerical sea trials” (high-fidelity CFD simulations for full-scale ship) and model tests.

Depending on size of fleet, employed repair yard and assumed fuel oil price, there are variations in payback times, but all realistic scenarios show payback times between 2 and 8 months, making this refit a good business decision by anybody’s standards.

The biggest issue in many of these projects remains the definition of the operational profile. AIS analyses for own or competitor's fleets can only reflect the past. But frequently questions concern the future and changing market conditions: What if I operate at other conditions some day? Can we change the operational profile once more?

DNV GL has developed a new tool to support better decisions in this situation. First, 5000 - 10000 vessel-specific bow designs are created and assessed for all operational conditions using CFD ("numerical towing tank"). An interactive excel-based tool allows then easy and immediate exploration of "what-if" scenarios for changing operational profiles.

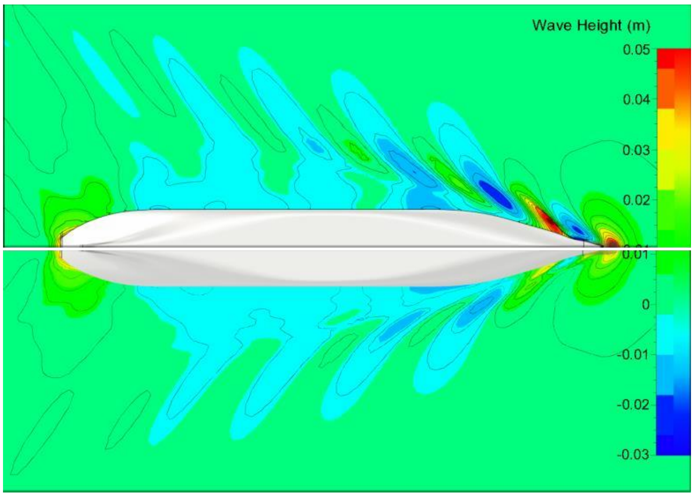


Figure 5. Off-design condition: original hull (top) and optimized Option 1 (bottom)

The input consists of the design operational profile (expressed by a matrix of 4 speeds and 3 drafts with associated relative time spent on each speed-draft combination) for which the bulbous bow shall be optimized, optional performance constraints (e.g. must reach design speed at 85% engine power), and an alternative profile (again 4 x 3 matrix of speed and draft). The tool then immediately displays estimated savings (in USD/year and % power) and payback time for the best bulbous bow for the design operational profile and the corresponding values for the alternative profile. The payback time calculation takes aspects like fleet size, conversion costs and fuel price into account. When changing input data, savings are re-computed instantaneously.

The tool allows insight into available savings for each operational condition, Fig. 6, and implications of constraints. A relaxation of required by power at design speed by 1 percent point often results in higher overall savings. It is only after seeing the achievable effect that ship operators start thinking about margins which are often unnecessarily high. Of course, the tool cannot change the volatility of the market, but it can quantify performance for a bandwidth of scenarios from worst-case to best-case scenarios, supporting more informed business decisions.

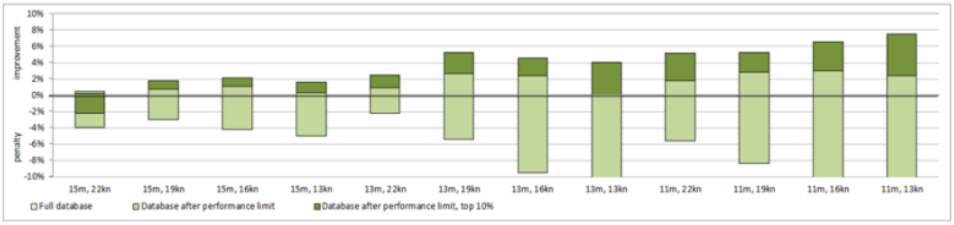


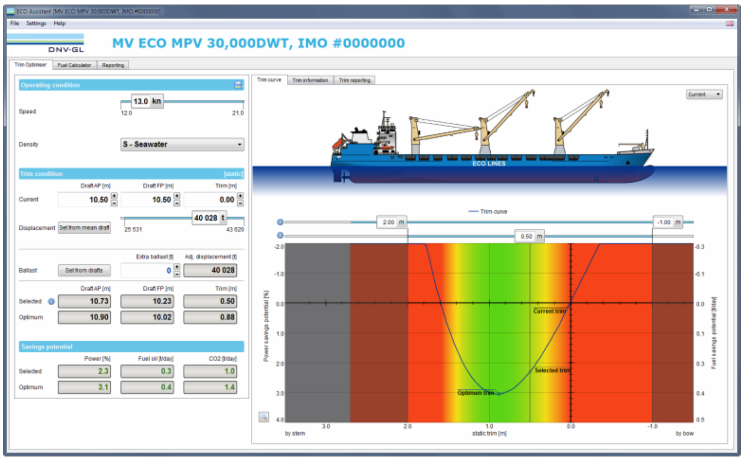
Figure 6. Relative power savings compared to reference design

3.3 Case study 3: Trim optimization

There is no single trim for a vessel that is optimum for all speeds, displacements and water depths, leave alone an optimum single-value for all ships. Finding the optimum trim for a ship is a non-trivial task. There are several commercial trim optimization tools on the market to help with this task. These vary in price, user-friendliness, fundamental approach and performance.

Compared to sensor-based trim assistance tools, CFD-based trim advisory systems do not require interfacing with on-board systems and sensors to monitor operational parameters. DNV GL's ECO-Assistant, Hansen and Hochkirch (2013), can be installed on any computer on the vessel, which makes the installation much more cost effective than sensor-based trim optimization tools. The hydrodynamic database for trim optimization is based solely on CFD simulations. The CFD simulations cover a dense matrix of speed, trim and draft values. The discrete simulation data sets are connected by a multidimensional response sur- face, i.e. a sophisticated interpolation scheme. This allows consistent interpolation for arbitrary input values within the simulated range.

The GUI (graphical user interface) is kept simple with a minimum of input: speed, (zero- speed) drafts aft and fore, and optional extra ballast. The tool then displays optimum trim, regions of good trim (in green), regions of satisfactory trim (in yellow) and regions of poor trim (in red), Fig. 7. In addition, the savings (as compared to even trim) in required power and tons of fuel and CO_2 per day are displayed. Practical constraints such as bending moment and stability are checked by other software tools. To support efficient cross-referencing, the ECO-Assistant can be integrated into a vessel's loading computer and cargo planning system.



MV ECO MPV 30,000DWT, IMO #0000000

Operating condition

Speed 13.0 kn (12.0 – 21.0)

Density S - Seawater

Trim condition [static]

	Draft AP [m]	Draft FP [m]	Trim [m]
Current	10.50	10.50	0.00

Displacement 40 028 t (25 531 – 43 620)

	Extra ballast [t]	Adj. displacement [t]
Ballast	0	40 028

	Draft AP [m]	Draft FP [m]	Trim [m]
Selected	10.73	10.23	0.50
Optimum	10.90	10.02	0.88

Savings potential

	Power [%]	Fuel oil [t/day]	CO2 [t/day]
Selected	2.3	0.3	1.0
Optimum	3.1	0.4	1.4

2.00 m
0.50 m
-1.00 m

Figure 7. The easy-to-use interface has become a trademark of ECO-Assistant. Speed, displacement (or current drafts) and optional extra ballast is all that is needed to get the best trim displayed.

The effectiveness of trim optimization systems is best assessed sea trials. Trim trials are variations of classical sea trials. Typically, two conditions are tested: One trim with relatively high fuel consumption and another trim with lower fuel consumption. Sea trials on opposite course and for different main engine rpm yield speed-power curves for both trim conditions. By comparison, the fuel savings due to trim are identified. Such trials were completed successfully by China Shipping for a 14000 TEU containership. For a trim change of 1.8 m, fuel savings of more than 10% were found in line with ECO-Assistant's prediction. Such large trim adjustments are not always possible in actual operation. However, China Ship- ping reported in long-term performance monitoring fuel savings up to 8%; typically 3-4% savings were reported.

4. Conclusions

Our experience shows that potential for fuel savings is often over-estimated, but sometimes also underestimated. Frequently, modern simulation technology can guide us:

a. Virtual try-outs are highly recommended before committing to any large investment in propulsion improving devices. CFD simulations give a solid ground for assessing the fuel saving potential of a device and hence the basis for an investment decision.
b. Optimization is a mature and powerful tool in fuel efficient designs and operation. It is mainly up to the ship operators to employ this tool to achieve major savings at relatively little expense.
c. Refitting optimized bows on containerships operating now with much lower speeds than their original design speeds is an attractive option.
d. Trim optimization is attractive for most ship types, especially large container ships. The recommended approach is using CFD for full-scale conditions to create the required hydrodynamic knowledge base.
e. CFD-based knowledge bases for trim optimization should be reused for hull performance management.

References

Bertram, V. (2011). Practical ship hydrodynamics. 2nd Ed. Oxford: Butterworth and Heinemann.

Bertram, V. (2013). Trim optimization meets hull performance monitoring. Lloyd's Maritime Academy Seminar "Hull Management and Performance", London.

Bertram, V. (2014). Trim optimization – Don't blind me with science. The Naval Architect, September, pp.66-68.

Bertram, V. and Couser, P. (2014). Computational methods for seakeeping and added resistance in waves. 13th Conf. Computer and IT Applications in the Maritime Industries (COMPIT), Redworth, pp.8-18.

Bertram, V. and Lampropoulos, V. (2014). A model for hull performance monitoring in ship operation, European Conf. Production Technologies in Shipbuilding (ECPTS), Hamburg.

Buhaug, Ø., Corbett, J.J., Endresen, Ø., Eyring, V., Faber, J., Hanayama, S., Lee, D.S., Lee, D., Lindstad, H., Markowska, A.Z., Mjelde, A., Nelissen, D., Nilsen, J., Pålsson, C., Winebrake, J.J., Wu, W.Q., Yoshida, K. (2009). Second IMO GHG study 2009. International Maritime Organization (IMO), London.

Freund, M. (2012). Holistic analysis of on-board consumption and efficiency of the energy systems of ships. PhD Thesis, Univ. Federal Armed Forces, Hamburg.

Hahn, C. and Bertram, V. (2014). Bulbous bow refits – The industry catches on. The Naval Architect, June.

Hansen, H. and Hochkirch, K. (2013). Lean ECO-Assistant production for trim optimization. 12th Conf. Computer and IT Applications in the Maritime Industries (COMPIT), Cortona, pp.76-84.

Hochkirch, K. and Bertram, V. (2009). Slow steaming bulbous bow optimization for a large containership. 10th Conf. Computer and IT Applications in the Maritime Indus- tries (COMPIT), Budapest, pp.390-398.

Hochkirch, K. and Bertram, V. (2012). Hull optimization for fuel efficiency – Past, present and future. 11th Conf. Computer and IT Applications in the Maritime Industries (COMPIT), Liege, pp.39-49.

Hochkirch, K. and Bertram, V. (2013). Bulbous bow refits – A little-known goldmine. Hansa 150/11, pp.27-29.

Hochkirch, K., Heimann, J., Bertram, V. (2013). Hull optimization for operational pro- file – The next game level. 5th Int. Conf. on Computational Methods in Marine Engineering (MARINE), Hamburg.

Hochkirch, K. and Mallol, B. (2013). On the importance of full-scale CFD simulations for ships, 12th Conf. Computer and IT Applications in the Maritime Industries (COM- PIT), Cortona, pp.85-95.

Köpke, M. and Sames, P. (2011a). Outlook on CO2 emissions of the container world fleet and possible reduction targets. 8th Annual Green Ship Conf., Copenhagen.

Köpke, M. and Sames, P. (2011b). Outlook on CO2 emissions of the worldwide containership fleet and possible reduction targets. Nonsto 2/2011, Germanischer Lloyd.

Krapp, A. and Bertram, V. (2015). Hull performance monitoring – Combining big data and simulation. 14th Conf. Computer and IT Applications in the Maritime Industries (COMPIT), Ulrichshusen, pp.57-63.

Lampe, J., Magdanz, A., Ginnetti, A. (2015). Energy simulation for waste heat recovery systems. 17th Int. Conf. Computer Applications in Shipbuilding (ICCAS), Bremen.

OCIMF (2011). GHG emission-mitigating measures for oil tankers – Part A: Review of reduction potential. Oil Companies International Marine Forum, London.

Sames, P. and Köpke, M. (2010). Future required energy efficiency of container vessels. 32nd Motorship Propulsion & Emissions Conf., Hamburg.