TARGETS

Targeted Advanced Research for Global Efficiency of Transportation Shipping

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Creation Date:	15.05.2014
Revision Date:	03.06.2014
Grant agreement no:	266008
Title:	Final Public Report M 40 (36)
Period covered:	01.6.2012 – 31.03.2014
Version	1
Actual submission date:	20.06.2014
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Security status:	Public

Contents

TARGETS – Final Public Report

Energy efficiency and environmental consideration are today's driving force for ship operators to reduce costs and become greener. Economic pressure and international legislation require a sensitive use of energy resources and a reduction of the associated emissions. Although shipping is the most environmentally-efficient means of transportation (low ratio of emitted gases over transport capacity), it attracts attention as the vast majority of ships use fuel of poor quality, a fact which in combination to the increased shipping traffic due to emergence of new economies in the international markets, is expected to raise the contribution to GHG of shipping substantially in the immediate future.

The TARGETS project aims to provide substantial improvements to ship energy efficiency by adopting a holistic approach to optimise energy generation, transmission, consumption and operational management with a focus on life-cycle issues. To achieve the goal of a ship optimised for energy consumption the TARGETS project takes a complete view at the causes of energy consumption during ship operation and identifies Energy Saving Potentials (ESP). In doing so, the project addresses:

- The most important hydrodynamic causes for energy consumption, i.e. ship resistance and propulsion;
- Promising technologies for auxiliary energy generation;
- The management of energy consumption on board a ship;
- The integration of technologies to assess energy consumption into a holistic management & simulation system which in turn will be used to optimise and thus reduce energy consumption.

The development methodology integrates component-based knowledge of resistance and propulsion at system-based level. The approach is expected to deliver significant improvements to the energy efficiency of ships that can be obtained when applying advanced design- and operational management techniques based on a Dynamic Energy Model (DEM).

The tools developed will be applied in both, ship design and operation and thus provide a basis to analyse the energy performance of a vessel over the entire life-cycle.

To address the challenging work plan, the TARGETS project consists of 6 technical workpackages dedicated to the development and analysis of:

1. Resistance improvement technologies,
2. Improved auxiliary on-board energy generation
3. Propulsion Improvement Technologies
4. Operation & Scenarios
5. Integration & Simulation
6. Benchmarking

The work plan is further supplemented by two work packages dealing with management and dissemination activities.

Energy Saving Potentials – ESPs

Energy savings can be achieved in a multitude of ways. These range from minimising energy required to overcome the resistance of a ship hull via the minimisation of propulsion losses to waste heat recovery: there are many ways to increase the efficiency of a vessel without compromising its operation.

However not all means are suitable for every vessel and thus a systematic study is needed in a case by case basis in order to find the best solutions. Some energy saving potentials will have better results in container vessels while others are more suited to fuller vessels like bulk carriers and tankers. TARGETS has investigated a large number of energy saving potentials and categorised the different identified ESPs with respect to their suitability for various applications and effect.

Resistance improvement technologies

Ship resistance is comprised from different components: (i) the pressure or form related wave resistance, (ii) the viscous drag, and (iii) the added resistance due to wind and waves. These are typically responsible for up to 70% of the power required on board a merchant vessel. Due to the different causes of the resistance components, either related to (hull) pressure or (surface) friction, they need to be considered at different stages of the vessel's life cycle. Pressure related components depending on the hullform are a design feature while viscous resistance largely hinges on the surface quality, which is initially determined by production quality and the hull coating and maintenance. Especially the latter is clearly related to the operational stage of the vessel. The same holds for added resistance due to wind and waves which can be influenced through weather routing. Figure 1 indicates the decomposition of ship resistance which is used in TARGETS to integrate this part into the overall DEM.

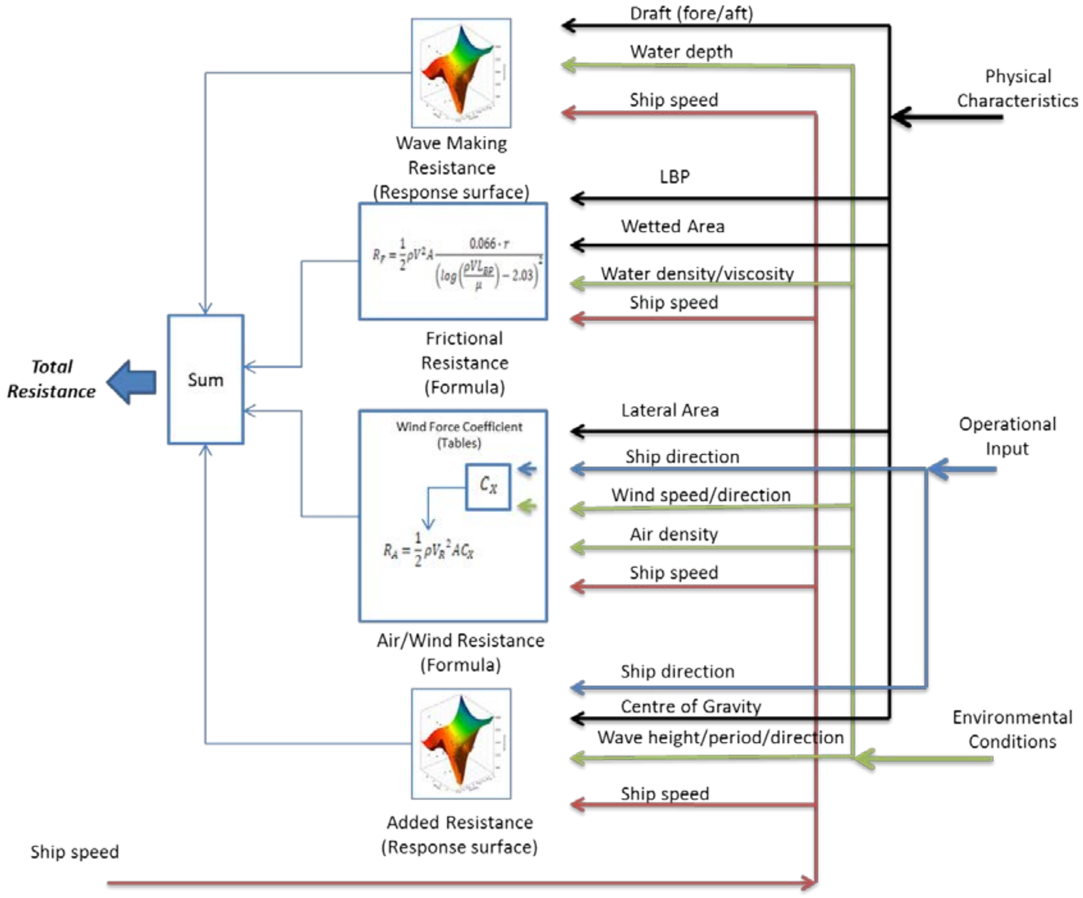

Fig. 1: "Decomposition of ship resistance"

The project addressed tool improvements as well as applications. For form related resistance, computational speed is an important factor determining the efficiency of – RANS based – optimisation processes. In TARGETS significant speed ups could be achieved for volume of fluid based free surface computations through pre-conditioning and algorithmic improvements. These were applied in different optimisation exercises, e.g. for the retro-fit of a new bulbous bow for a container vessel which is supposed to operate at lower speeds than initially designed. The following figure indicates the effect of a new bulb compared with the original shape design for higher speeds.

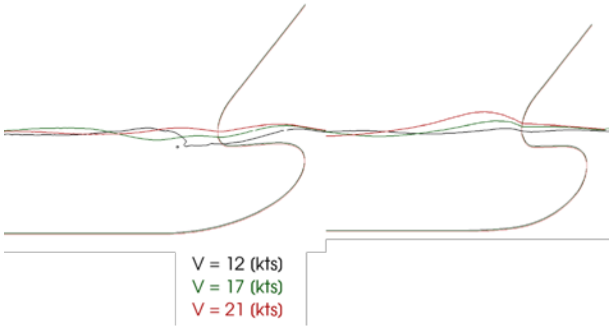

Fig. 2: "Bulb optimisation for 'slow steaming' conditions"

Additional work has been performed to assess the effect of appendages such as bilge keels or thruster openings on cargo vessels. All these contribute to the overall energy consumption which can be modelled in the DEM.

The second large resistance component is due to viscous forces which depend on two main parameters, the viscosity of the fluid and the surface quality. While the physical properties of the fluid – water – can hardly be influenced from the outside the second parameter, i.e. the quality or smoothness of the surface can be controlled technically. To assess the potential of modern coatings extensive tank tests have been run to measure the losses associated with surface deterioration and fouling. The experiments indicate the large variation of frictional resistance (Δc_F) Depending on the surface condition, significant increases up to 50% have been found for (heavy) calcareous foulings. These findings have been implemented in a scaling procedure which allows to determine the effect of surface deterioration at full scale during operation.

In addition to the experiments, new CFD models have been developed to simulate the effect of surface roughness. These have been implemented in RANS codes (FreSCo$^+$) which are now capable to predict the effect of additional surface roughness on the resistance.

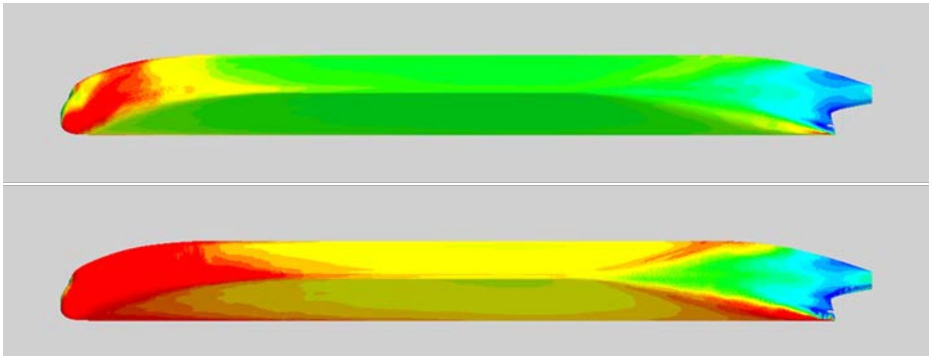

Fig. 3: "Surface friction on a bulk carrier hull for different hull roughness parameters– k_S"

Another widely discussed option to reduce friction forces on a ship hull is air lubrication. Different techniques such as micro bubbles, air film or air cavity have emerged in recent years. With full scale validation still being an issue, the TARGETS consortium worked on an assessment of these techniques by numerical simulations and generated a database of – proven – application types and potential resistance gains. A number of different ship types ranging from slender RoRo vessels to very full tanker forms have been investigated in the project. The results obtained indicate, not unexpectedly, that the effect and net gain of the air lubrication varies strongly with hull form. While full ships such as bulkers or tankers show significant benefits, the net gain obtained on slender hullforms is negligible. Fig. 4 shows CFD results obtained for a single chamber air cavity used on a tanker hull.

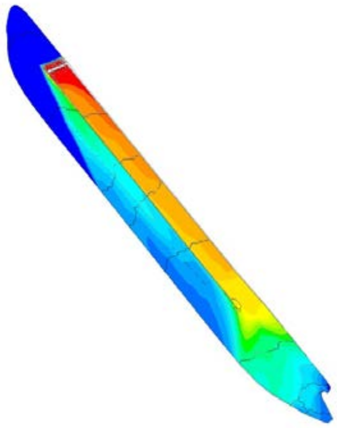

Fig. 4: "CFD simulation of a single chamber air cavity for a tanker"

With different physical laws ruling individual aspects of ship resistance, e.g. gravity and viscosity of the fluid, there is no single means to predict operational ship resistance as a total. Although modern state-of-the-art RANS codes offer the potential to compute the total resistance of a ship, this is typically limited to clearly defined, standard conditions, e.g. a new vessel during trial conditions. Further factors imposed during operation over the life cycle of a vessel include hull fouling, added resistance in a seaway, etc., still need to be superimposed, often on the basis of empirical methods. To improve the situation, TARGETS developed a number of new tools to provide better input to the overall prediction of hydrodynamic forces for a ship in operation.

Propulsion Improvement Technologies

Ship propulsion is equally contributing to hydrodynamic efficiency and hence determines energy efficiency of operation. Increasing propulsive efficiency consequently is high up on the TARGETS development agenda. Research included improvement of propeller efficiency as well as propeller-hull interaction using conventional and unconventional means of Propulsion Improvement Devices (PIDs).

In a first step, TARGETS developed a focused, high performance standard propeller series for initial design, based on an existing established propeller series data, one being the well-known Meridian Series, the second one being based on an upgraded (in terms of profile sections) version of the initial Wageningen B-Series. These were expanded in terms of number of blades, blade area ratios and pitch ratios as well as modern blade outlines (skew) and profile sections to form the Upgraded Meridian Series, a modern high performance propeller series. This extension was based entirely on CFD predictions rather than traditional model tests. Typical open water performance data and the cavitation pattern of a six-bladed propeller during tests in the cavitation tunnel are shown in Figure 5.

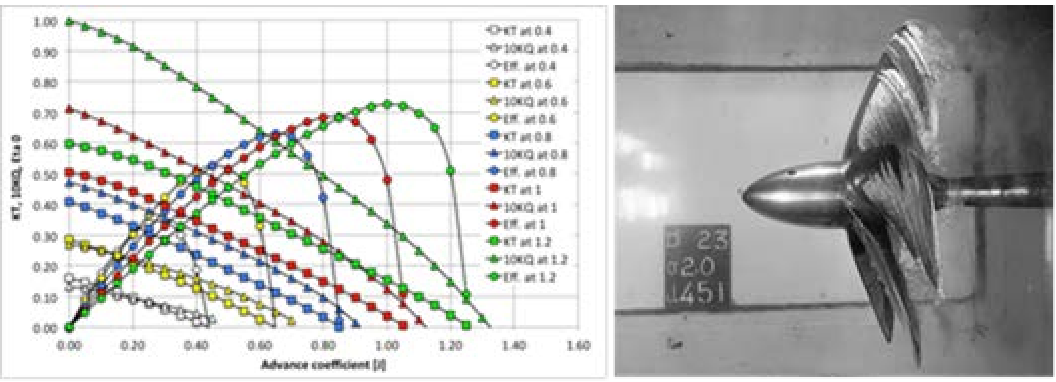

Fig. 5: "Meridian propeller series performance data (KT, 10KQ, ηo), for varying Pitch / Diameter ratio and cavitation pattern in tunnel test"

An Artificial Neural Networks (ANN) has been developed for the calculation of KT and KQ coefficients. This yielded a reliable and user-friendly format for design and analysis purposes, which can be readily integrated into the DEM.

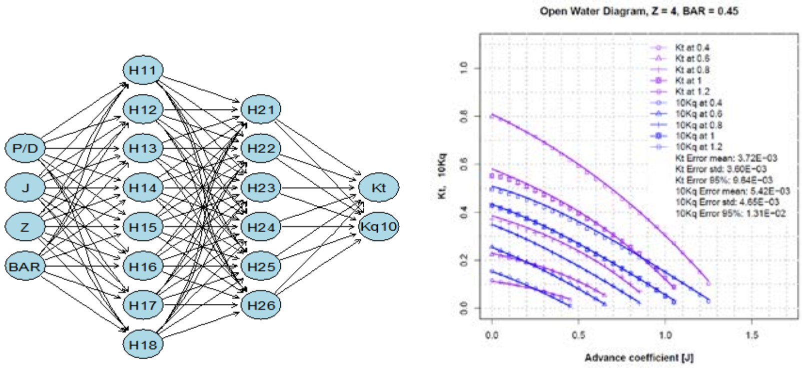

Fig. 6: "ANN analysis and resulting open water diagram for extended propeller series"

While the propeller itself is the core element determining hydrodynamic efficiency of the propulsion train, the interaction between hull and propeller offers another potential for energy savings. TARGETS has thus investigated a number of Energy Saving Devices (ESDs) including pre- and post-swirl devices to complement members of the propeller series data. Typical examples of these ESDs - shown in the following figure – have been investigated using state-of-the-art design and analysis tools, and an optimisation has been performed for the selected general test case in the project, the capesize bulk carrier<Star Aurora>.

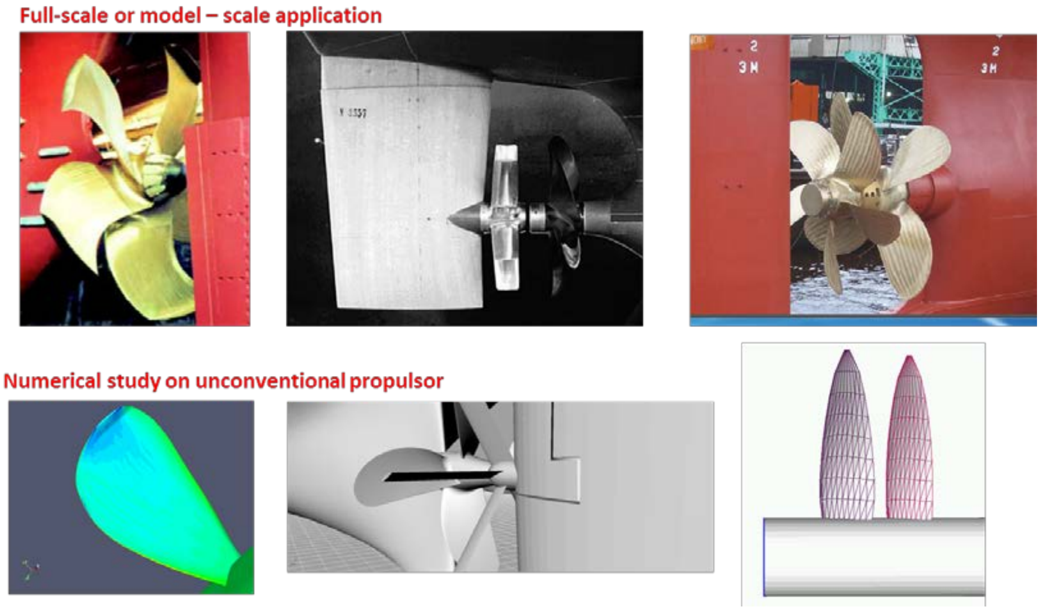

Fig. 7: "Typical Energy Saving Devices used in TARGETS"

Besides well-known ESDs such as pre- or post-swirl stators a new concept for an ESD has been addressed in form of the BLAD – Boundary Layer Alignment Device. This novel hull appendage is meant to work further upstream of the propeller and deflect outer streamlines into the propeller plane, thus reducing the typical axial flow deficiency in the 12 o'clock position of the propeller and harmonising the inflow condition. Using an asymmetric arrangement on port- and starboard side further creates a swirl against the propeller rotation to generate extra thrust. This approach allows for a more drastic change of the propeller inflow and larger gains in energy savings, especially when combined with an adapted propeller design.

The BLAD has been developed and tested for the Capesize bulk carrier <Star Aurora> applying a dedicated CFD analysis using FreSCo$^+$ to determine the local flow field upstream of the propeller. The specific shape of the wing profile sections used was adapted to the main flow direction as to maximise the momentum flux through the device. The final design is shown in the following figure. Together with an adapted propeller this yields a reduction of more than 7.5% of P_D at the design point.

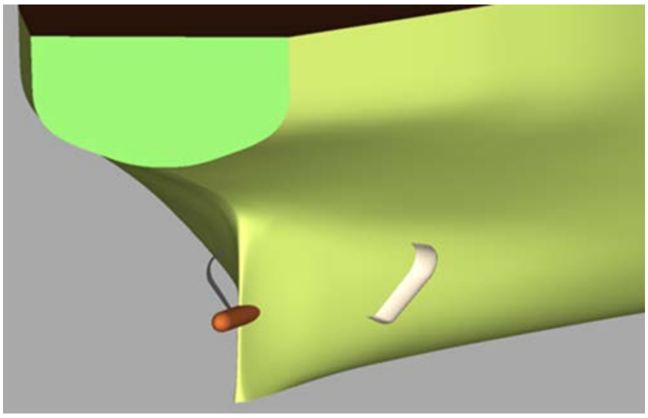

Fig. 8: "BLAD design for <Star Aurora>"

Similar to ship hulls, propeller performance will be affected by surface quality. Deterioration in form of roughness or fouling will increase losses in propeller efficiency due to increased friction. Hence propeller cleaning is an appropriate means to improve the performance of a ship in service. A new prediction algorithm based on Schulz's method was developed in TARGETS to quantify these losses and hence allow to assess the evolution of propeller performance over time during operation. The method includes an established relationship between the drag and roughness of selected commercial coatings (soft and hard) using experimentally established data from representative coated flat surfaces. The algorithm has been built in an in-house propeller analysis code

Improved auxiliary on-board energy generation

Improving the Energy efficiency of ships while at the same time reducing Green House Gas emissions is typically associated with the use of alternative fuels. TARGETS explored the usage of environmentally-friendly fuels and alternative energy sources as well as the integration of energy storage in an efficient and flexible way.

One prominent technology offering a significantly improved environmental impact are fuel cells. They are believed to offer a large potential for change of existing energy supply structures. Thanks to extensive research programs in the public sector and by various industrial companies rapid technological developments have taken place so that these technologies become more and more attractive to the maritime industry today. TARGETS looks specifically into new technical solutions, exploring the opportunities for an increased use of environmentally-friendly fuels (dual or multiple) for auxiliary uses.

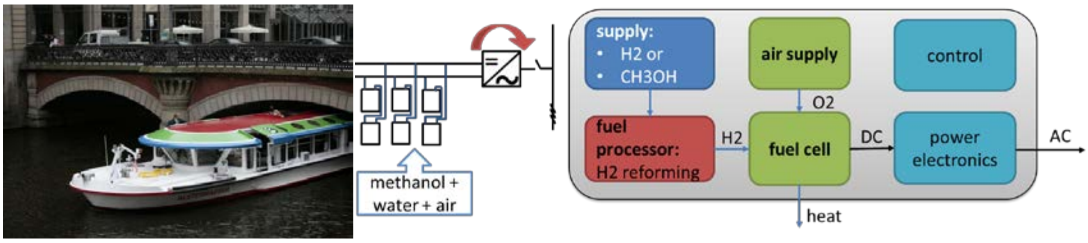

Fig. 9: "Fuel cells: Inland Vessel 'Alsterwasser' and TARGETS component model"

A complex component model was developed to describe fuel cells in the context of the overall dynamic energy model and two dedicated application cases for using fuel cells on a RoRo carrier and a container vessel to generate auxiliary energy have been developed

Wind is another source of natural energy freely available at sea. The potential of wind energy to be used for ship propulsion is substantial, and forms an attractive alternative for certain services and operational conditions. TARGETS investigated a range of possible modern "wind propulsion" options covering kites, Flettner rotors or modern rig types, either fixed wing options such as the Dyna rig or more conventional designs such as the Indosail rig. An assessment of equivalent horsepower for a Dyna rig equipped bulk carrier obtained up to 7500 kW power.

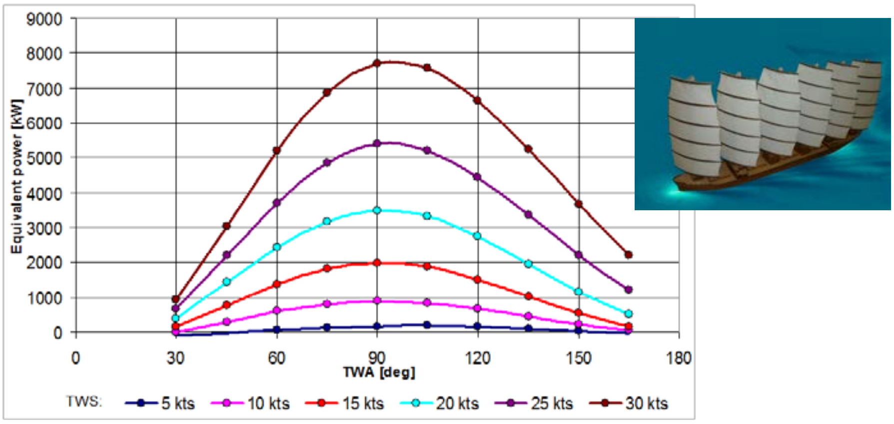

Fig. 10: "Equivalent power for a bulk carrier using (Dyna rig) sail propulsion"

Operation & Scenarios

During her lifetime a ship will experience a number of different operating conditions due to changing services, changing amount of cargo as well as changing regulations. TARGETS investigated the effects of different operational scenarios and individual system functions on the energy consumption of a vessel and consequently of methods in which energy can be saved or conserved. A number of vessels underwent Energy Audits in order to obtain a sufficient amount of data which provided further input for the energy modelling system.

A number of operational scenarios (such as optimising speed, trim / ballast quantity and taking into account environmental conditions) affecting energy efficiency onboard different TARGETS' vessels ranging from RoRo vessels to tankers were investigated with the aim of assessing their effects. Statistical evaluations of the probability of specific operational conditions were performed to measure the effect of e.g. different floating conditions (deadweight / payload), vessel trim, speeds and typical whether conditions on the design of a more flexible ship for multi-point / range operation.

The methodology applied for this considers the reference vessel's shop and sea trials reports and voyage data which were collected during numerous energy audits. The data allowed to specify fuel oil consumption, sea passage time and engine load. In a next step actual measured data during energy audits are compared with target values for the most economic speed of the vessel under the given environmental (and loading) conditions which were pre-computed numerically. The estimated economic benefit is than based on the difference in fuel consumption and sea passage time between the actual and the theoretical solution. Using a conversion factor for the Green House gas emissions allows to specify emission savings in the same way. The following figure shows some elements of this complex analysis methodology. On the left, a response surface of ship resistance as a function of speed, draft, trim and surface condition is given. This is translated into power requirements. The centre figure indicates the statistical distribution of drafts, based on the voyage data collected and the right figure shows the statistical distribution of fuel consumption per ton mile.

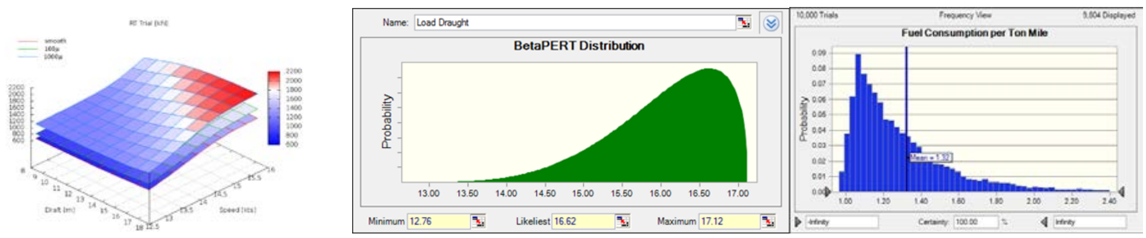

Fig. 11: "Elements of the operational anlysis"

Not surprisingly the investigations revealed that the implementation of Speed Selection Optimisation seems to be more promising in comparison to Trim and Ballast Optimisation.

Fuel Oil Consumption Reduction (%):		
	Speed Selection Optimization	Trim and Ballast Optimization
Capesize Bulk Carrier	16.0 %	1.0 %
Car Carrier	23.5 %	1.6 %
Panamax Container	57.0 %	1.6 %

Wherever reduced speed is not an option, e.g. in a regular scheduled service, CFD simulations which have been performed for the car carrier and the container ship, indicate that some gains can be obtained through trim optimisation as well. The results of the study indicated that there is no common trend between the different vessels investigated Each ship needs to be treated individually, based on the specific hull form, before deciding which trim option is best.

Integration & Simulation

While the different elements and concepts explained presented above all contribute to the overall saving of energy during operation, the full potential of combined solutions can only be unleashed when using a performance-based approach to assess the operational behaviour of ships. These modelling concepts originate from a long incubating period in the area of ship safety and are today successfully applied to model the energy and environmental performance of a ship. The Dynamic Energy Model (DEM) developed in TARGETS is such a performance based method which captures holistically the transfer, conversion and storage of energy onboard a ship as a function of its operational profile and over long periods of time or during its commercial life-cycle. The foundation of DEM is comprised by the mature knowledge of (i) the hydrodynamic performance of ships, and (ii) the energy systems onboard a ship (internal combustion engines, hydraulic and pneumatic networks, electrical networks, and HVAC systems). In this context, the main body of development is concerned with the compilation of energy modules pertaining to the performance of each system onboard, and their integration from local level to ship-level in order to create an overall energy model for the ships that will be considered in the course of the project. This concept is explained in Fig. 12.

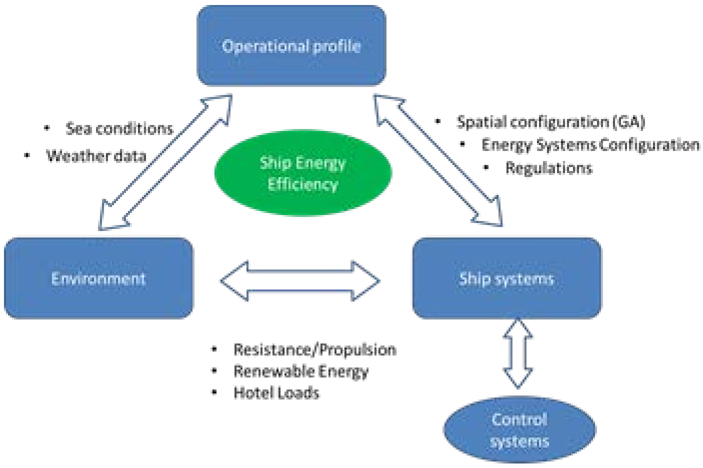

Fig. 12: "The interactions in the DEM methodology"

DEM is developed to be inherently modular, a fact justified by the need to assess alternative configurations of systems (especially during the design stage), and to identify the contribution of each system individually to the overall energy performance of the ship. The latter point is also linked to the optimisation (for a set of operational conditions) and energy management onboard, which are central to the energy performance of the ship. Moreover, the modularity of the methodology allows the integration and assessment of alternative sources of energy (solar, wind, fuel cells, etc.), which have started receiving attention in the maritime industry recently.

In TARGETS a software tool has been developed which represents all relevant system components and their functional relationships. This has been implemented in a simulation environment (iSysE) which has been upgraded with a dedicated Graphical user interface to facilitate interaction. An example is shown in figure 13. This represents simulated Fuel oil consumption and power requirements of different components over a period of time with varying operational conditions such as speed variations, engine loadings and different conditions of auxiliary engines.

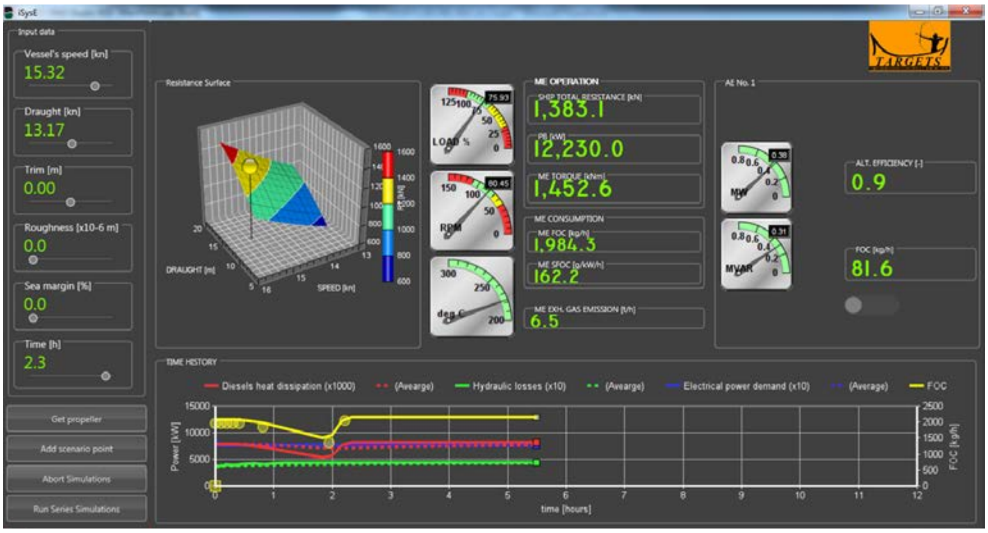

Fig. 13: "DEM Integration: Sample results of simulation in the iSysE application"

The DEM includes all relevant information on the dependencies of ship resistance and power requirements as functions of speed, trim and environmental conditions. Propeller performance data are included as well as the effects of increasing surface deterioration over time which will affect the resistance and thus the power requirements. The DEM thus allows not only to simulate the behaviour of a given ship in an "as is" condition but also investigating the effects of different technical solutions aiming to improve the efficiency of the ship, e.g. changing the propeller or retro-fitting energy saving devices as well as analysing the effects of different operational patterns.

Conclusions

Although the establishment of EEDI is an encouraging step towards the extension of existing environmental regulations and it addresses the issue from the design stage, further development is needed considering that:

- It represents the ship transportation CO2 efficiency at a single point during the life span of the ship disregarding at a stroke operational and maintenance practices;
- The specific fuel consumption of auxiliary engines has minimal impact on EEDI, a rather misleading fact since the installed electric power capacity depends on mission requirements and safety margins;
- Larger payload capacity leads to improved EEDI (the capacity term is in the denominator) and renders larger ships more environmentally friendly in comparison to smaller ones;

The TARGETS project combined the principal elements determining the use of energy consumption onboard a cargo ship and integrated them in a holistic simulation to determine optimal solutions. Advanced simulation tools to assess key elements determining the use of energy, in particular hydrodynamic tools for resistance and propulsion prediction and optimisation are combined with models for using alternative fuels and auxiliary energy converters to achieve a comprehensive dynamic energy simulation model for the complete ship. This is further accomplished by assessing a large variety of internal energy consumers through a series of dedicated energy audits, which formed the basis for benchmarking the final DEM system developed in the project. The concept is being presented to IMO for consideration during the intended assessment of the present EEDI regulations.

Further technical information on the TARGETS project can be found at: www.targets-project.eu

Hamburg, 20 June 2014, Dr.-Ing. Jochen Marzi