Targeted Advanced Research for Global Efficiency of Transportation Shipping

Technology Report

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ABSTRACT

Various energy saving technologies have been developed in the context of the TARGETS project. These technologies varied from hydrodynamic methods to full energy modelling.

Resistance improvement technologies are divided into three categories: global hull form optimisation, surface frictional property influencing technologies, and local appendage form optimisation technologies. TARGETS has developed an adjoint optimisation methodology which is based on surface sensitivity separating the geometry and optimisation search algorithms increasing the speed of the optimisation process. Air lubrication, surface patterns, new type paints were all modelled with computational methods to assess the energy reduction potential associated with each surface for various hull forms.

Propulsion improvement technologies are based on either propeller efficiency improvement devices or propeller inflow improvement devices. New propellers, tip raked propellers, contra-rotating propellers have been modelled and analysed during TARGETS in the first group, meanwhile in addition to known pre-swirl and post-swirl devices innovative BLAD device was also investigated in TARGETS.

Renewable energy generation methods, both from solar and wind energy, have been simulated. Photovoltaic cell, wind energy generation devices such as rigid sail, Flettner rotor, Dyna rig, kites were all modelled comparatively.

Fuel cells and energy storage simulation were also carried out to judge the emission reduction capabilities.

Dynamic energy modelling has been introduced as new technology into the energy efficiency as a state-of-the-art technique.

The present report gives a short introduction to these technologies and lists them in form of “data sheets” in the Appendix.

Contents

1. Introduction

The TARGETS project has developed key technologies to reduce the energy consumption of a ship and increase energy generation capability. This report reviews these technologies using the information presented in various deliverables for dissemination purposes.

2. Categorisation of Energy Efficiency Technologies

A number of key technologies have been reviewed during the TARGETS projects, and a number of key technologies have also been developed or assessed using TARGETS ship case base. Evaluating the technologies is a difficult process due to complexity of these technologies or dependence on other external elements. The technology review presented in this report categorises the energy efficiency measures into two parts:

a) Products/Shape to reduce enabling energy consumption

b) Methodologies to optimise the energy balance

The energy efficiency can be defined as the amount of work in terms of function, such as cargo carried over a distance in relation to the amount of fuel used. The fuel usage is influenced by energy production by the main and auxiliary internal combustion engines, by energy production using renewable sources, and by energy consumption in propulsion and electrical systems. These activities of energy generation or consumption can be subdivided into blocks. Any measure to increase the efficiency of energy generation or decrease energy consumption can be called energy efficiency measure or technology. An energy efficiency measure can also be categorised according to its principle application area in the overall energy generation/consumption chain. Hence broad categories of technologies can be given as:

1) Hydrodynamic technologies aiming to reduce the energy consumption in resistance,

2) Hydrodynamic technologies to improve propulsion efficiency,

3) Technologies to reduce the energy consumption through electric consumers,

4) Technologies to generate energy from renewables,

5) Technologies to improve energy generation efficiency, and

6) Technologies to improve auxiliary energy generation efficiency.

TARGETS has focussed on the first 4 categories only. This report shall deal exclusively with technologies in these four categories and present them in a common format.

Each category in the following sections will describe one or more products, shapes, or methodologies to increase the efficiency. As examples, the bulbous bow and optimisation methodology are both energy efficiency technologies.

3. Technologies to reduce the energy consumption in resistance

Hydrodynamic resistance reduction technologies are broadly based on three different approaches: viscous resistance reduction technologies based on ship underwater surface properties, pressure field improvement through hull form shape, and appendage resistance reduction.

a) Viscous Resistance Reduction Technologies

Viscous resistance accounts for a large share of the total resistance of a ship at lower speeds and becomes more important due to increasing use of slow-steaming practice. Technologies considered include the following:

- New types of paints
- Air lubrication
- Surface patterns

b) Pressure Resistance Reduction Technologies

The motion of the ship at a speed in the water creates pressure field variation on the hull surface. Integration of these pressure fields on the ship movement direction creates pressure resistance which in turn disturbs the free surface between water and air resulting in wave resistance. Hence design of hull shape is the prime importance either in terms of local/global form shapes or methodologies to find the optimum shape through advanced techniques. The technologies in consideration to reduce the pressure resistance are listed below:

- Bulbous bow
- Aft form optimisation
- Trim optimisation
- Stern transom wedges
- Ducts
- Adjoint hull form optimisation

c) Appendage Drag Reduction Technologies

Every hull has one or more appendages which result in energy consumption when the ship is in motion. Either adding these local forms or optimizing the shapes of these is measures to reduce the consumption. The following are technologies to reduce energy consumption:

- Bow thruster tunnel optimisation
- Bilge keel optimisation
- Appendage optimisation

4. Technologies to improve propulsion efficiency

A large share of the propulsion power is lost in the propulsion system in forms of propeller efficiency or hull efficiency. Hence propeller geometry and its efficiency are of prime importance. Continuous revision and improvement of propellers are made to an individual propeller or to an entire propeller series. Propulsion augmented technologies such as propeller coating, tip raked propeller, contra-rotating propeller, fixed pre- or post- swirl devices, and innovative devices such as BLAD are technologies TARGETS investigated.

- Propeller Series
- Propeller coating
- BLAD device application
- Contra-rotating propeller
- Tip raked propeller
- Fixed swirl propeller devices

5. Technologies to generate energy from renewables

Renewable energy generative technologies have a direct influence on the energy efficiency. In the TARGETS project, both solar and wind energy production technologies were given special attention. Among these technologies are:

- Photovoltaic installations
- Flettner rotor
- Dyna rig
- Fixed wing sails
- Kites

6. Technologies to reduce the energy consumption through electric consumers

Auxiliary electricity generative fuel cells and energy storage are included in TARGETS as emission reduction measures. They have a direct effect on energy efficiency in addition to significantly reducing the shipboard emissions. Such technologies include:

- Unconventional fuel cells
- Energy storage
- Fuel cell
- Fuel cell simulation

7. Energy Modelling

Lastly, a dynamic energy model (DEM) combines all energy generation, transmission and consumption elements for a given ship as well as the associated design and operation parameters into a single simulation tool. The DEM is the technology tool to integrate all the ship-board components into one holistic entity.

- Dynamic energy model

8. Conclusions

The following section presents the energy efficiency technologies introduced in this report as a collection of definition / data sheets. This collection is not exhaustive as TARGETS could only review, analyse and develop a subset of these technologies. Details of each technology are presented in related TARGETS deliverables.

Appendix – Data sheets of Energy Saving Technologies

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Bulbous Bow Optimisation for Slow Steaming:

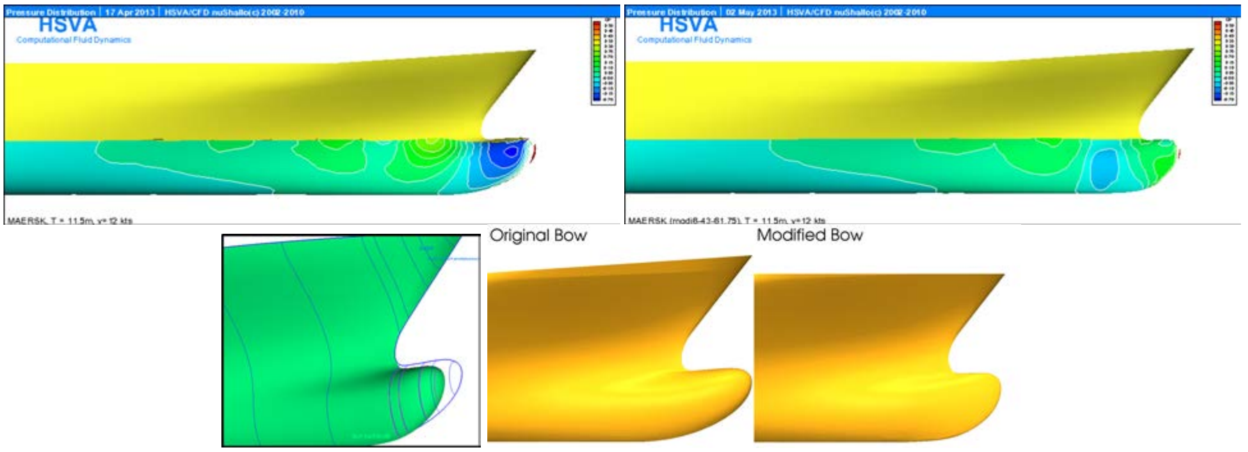
In general, the operating speeds of ships have been reduced in response to the recent economic crisis. This is especially applicable to high speed ships such as containerships. Bulbous bow forms that were optimised for higher speeds do not perform as well at lower speeds, sometimes resulting not in resistance reduction but in resistance increase. Smaller bulbous bow forms are required to reduce the bow wave. CFD-inviscid panel codes coupled with shape optimisation tools such as adjoint solver are utilised in TARGETS to reach optimum forms.

Achievable energy efficiency improvement:

Improvement on the wave resistance and total resistance depends on the speed and the draught of the original ship. However the example case reduction in resistance up to 20% is obtained. The saving potential is higher for the ships with bulbous bow designed for higher speed and performing badly in lower speed.

Sustainability for newbuilding or retrofitted ships:

Bulbous bow modifications can be utilised both for new and existing ships. High speed containerships worldwide have undergone bulbous bow retrofits to optimize the vessel resistance for the slow steaming.

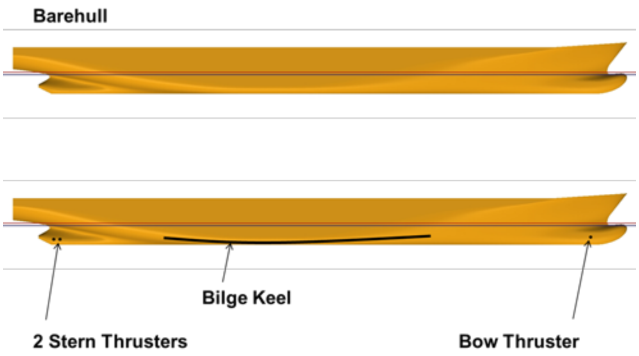


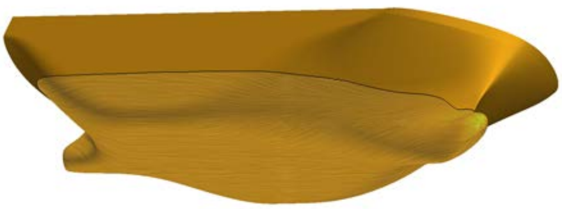
Bilge keel optimisation:

Bilge keels are utilised for roll damping and constructed from simplest and lowest resistance features by aligning the placement with the flow lines. Hence correct determination of flow lines is the prime importance. Change of trim, varying draught, and speed changes such as slow steaming effects the positioning of the bilge keel. CFD is utilised to optimise the positioning for all conditions to find the compromised position

Achievable energy efficiency improvement:
By positioning the bilge keel with the flow line 1% reduction can be achieved.

Sustainability for newbuilding or retrofitted ships:
Mainly for the newbuilding.





Bow Thruster Opening Optimisation :

Bow and stern thrusters are utilised to improve the manoeuvrability of ships. They are optimised through physical tank testing for given loading and speed conditions. However, lately off-design conditions became important for the thruster openings which may not be fully physically tested due to scale effects between the model and the full scale. CFD is a tool for off-design conditions such as bow or stern trim.

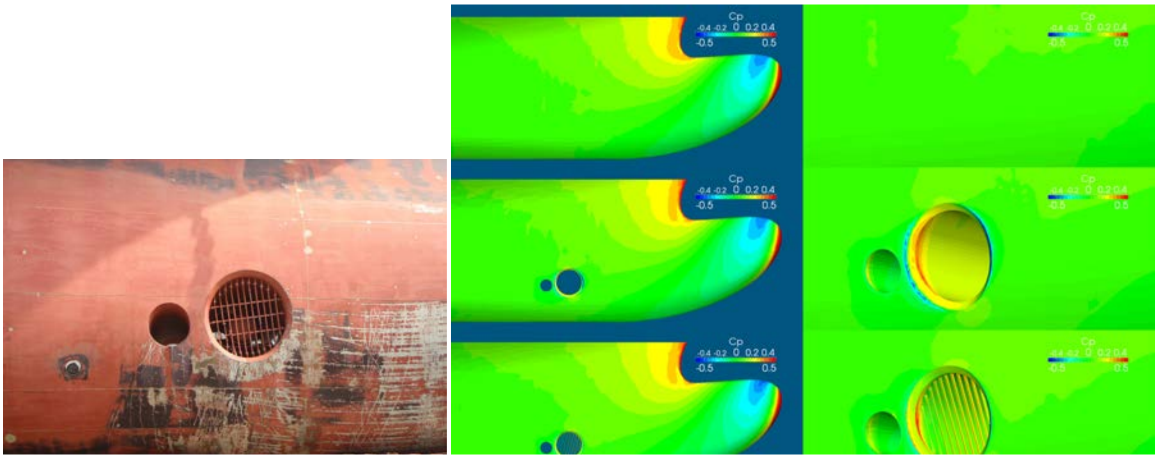
Size, location of the bow thruster opening is optimised, in addition the geometry of the opening and grill of the entrance can also be modelled through CFD although computationally very costly.

Achievable energy efficiency improvement:

Bow thruster tunnels increases the draft of bare hull about 2-3 %. Addition of grill in shape of bars is a common arrangement which is neglected in the calculations. The bars can be included in detailed CFD calculations, although larger meshes are needed and subsequently increased computation times result. A reduction resistance due to grill bars can be up to 1%.

Sustainability for newbuilding or retrofitted ships:

Design for new building can be adopted thruster optimisation through CFD. Addition of grill can be adopted both in new ships and as retrofit.



Trim Optimisation:

Trim optimisation is one of the most favourable energy efficiency improvement methods utilised. Commonly, it is either performed through model tests or through full scale testing in various conditions. However, the effects of appendages cannot be considered in either. Model tests are affected by scale effects, whereas in full scale test the inflow angle on the appendages may not be varied to align with the local flow.

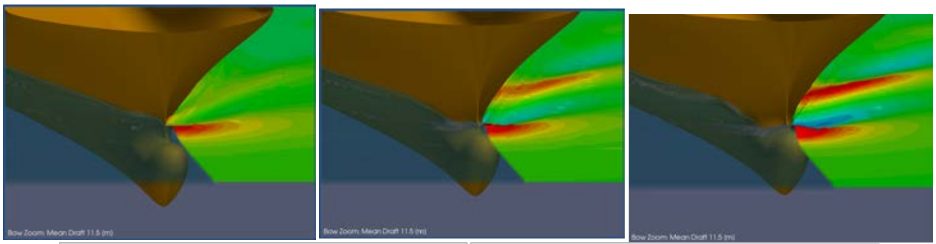
As an alternative, CFD is utilised as a tool to estimate the effects of trim including appendages. This has the advantage to optimise the position and direction of appendages such as bilge keels in different trim conditions.

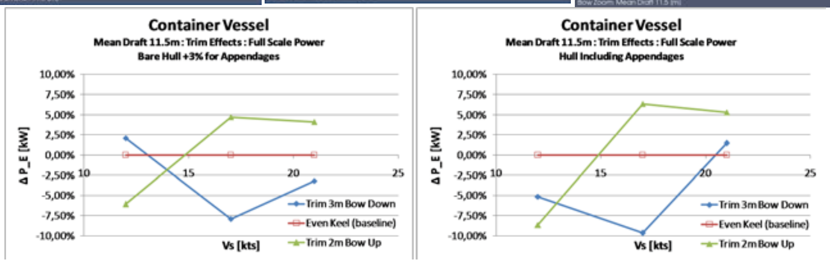
Achievable energy efficiency improvement:

A 2% reduction can be achieved by optimising the position and shape of the appendages for conventional ships. This reduction can be further increased with large/complex appendages of the high speed craft.

Sustainability for newbuilding or retrofitted ships:

Both newbuilding and retrofit options can be utilised.





Appendage Analysis:

All ship types have appendages in forms of rudders, shaft brackets, shaft barrels, bossing, bilge keels, bow thrusters, anti-pitching fins, etc. Model tests can be conducted by including most of these appendages to record the effects on the resistance. However, the appendages operate in a Reynolds number significantly different in comparison with the hull. Hence scaling of appendage drag is conducted with ad hoc methods such as beta scaling factor.

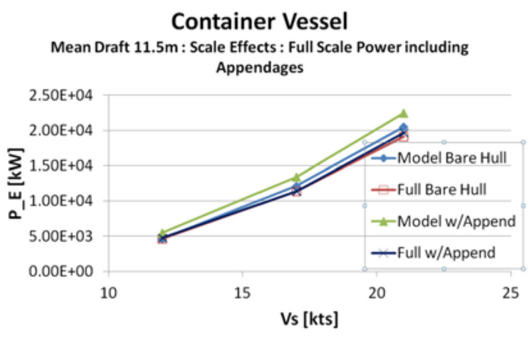
TARGETS has conducted a number of CFD analyses by modelling appendages in meshes and compared with conventional methods. There minor differences in level trim condition, however the difference are attenuated in the trimmed conditions as appendages are operating in an angle attack. Hence CFD modelling improves the estimation of the appendage drag estimations.

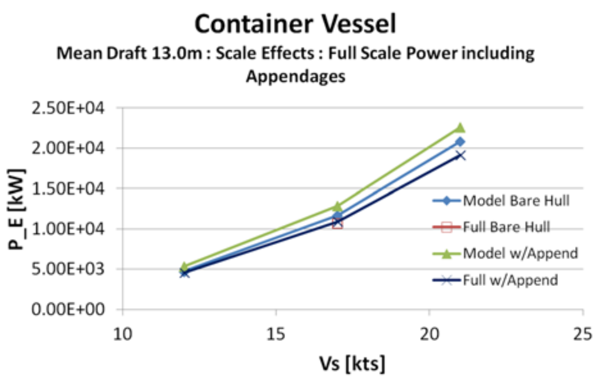
Achievable energy efficiency improvement:

The scaling of appendages enables to predict the power more precisely improving by 2-3% less uncertainty. Although it does not lead to direct reduction of power, it will lead to better selection of power train.

Sustainability for newbuilding or retrofitted ships:

Appendages can be modelled at any stage and can be retrofitted for all ships especially if loading conditions are substantially changed





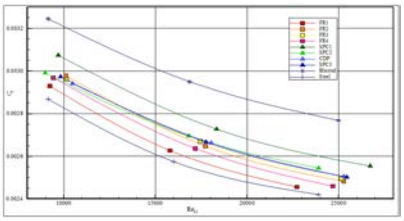
New type of paints:

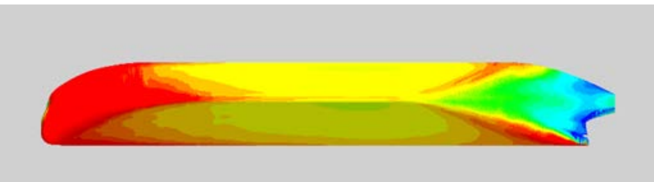
The frictional resistance of ship surface or a flat surface resistance with the same surface is highly affected by the surface properties. Newly developed foul release paints (frp), self-polishing copolymer (spc) and controlled depletion polymer (cdp) result in reduction of frictional resistance as they are more hydrodynamically smooth compared to conventional antifouling paints. Although there is a correlation between roughness amplitude and frictional resistance, in addition to roughness the roughness texture becomes important. Foul release types of paints achieve a lower frictional drag than the spc and cdp. Foul release paints are almost hydrodynamically smooth, meanwhile the roughness resistance for spc and cdp are 0.80 and 1.1 % higher; conventional antifouling is 4.4 % higher. The marine growth also results in increase of frictional resistance by 19 % increase for light slime, 31 % for heavy slime, 44 % for small calcareous slime, 53 % for medium calcareous slime and 60 % for heavy calcareous slime.

Achievable energy efficiency improvement:
Up to 50 % reduction on viscous resistance can be obtained, but CFD analysis with correct roughness modelling is required to determine the improvement

Sustainability for newbuilding or retrofitted ships:
It can be applied to both newbuilding and during the service as a retrofitting option.

smooth hull





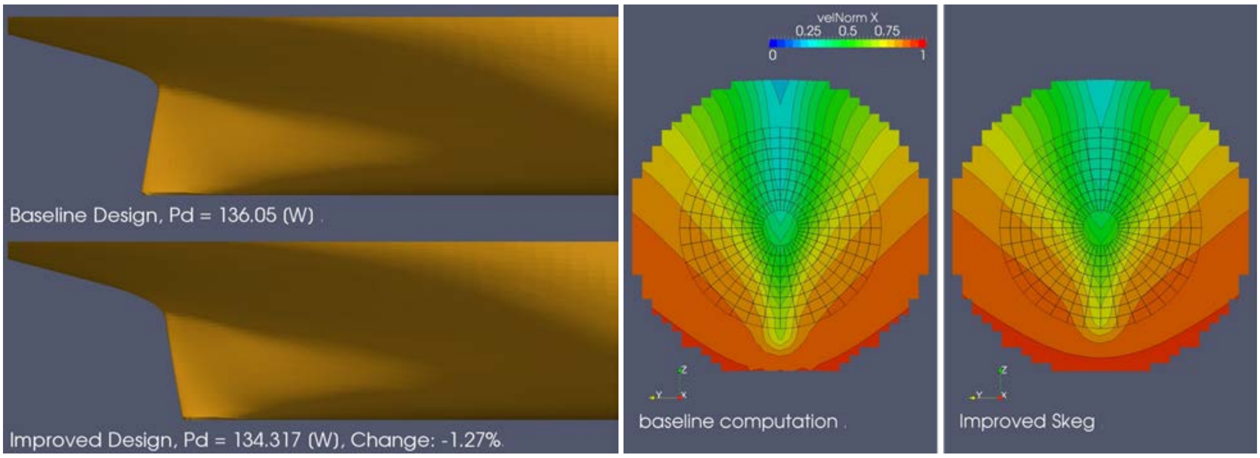
rough hull

Aft form optimisation:

The aft (stern) form should be optimized not only for the resistance but also with propulsion considerations. Propulsive efficiency can be estimated by using CFD methodologies. When combined with a powerful tool such as adjoint method, optimised forms can be obtained. Adjoint method determines the regions on the geometry where the predefined goal function is the most sensitive to change. An optimisation method based on gradient can then search for the local minimum of goal function.

Achievable energy efficiency improvement:
A 2 % reduction in delivered power can be achieved.

Sustainability for newbuilding or retrofitted ships:
It is applicable only to the new ships.



Stern transom wedges :

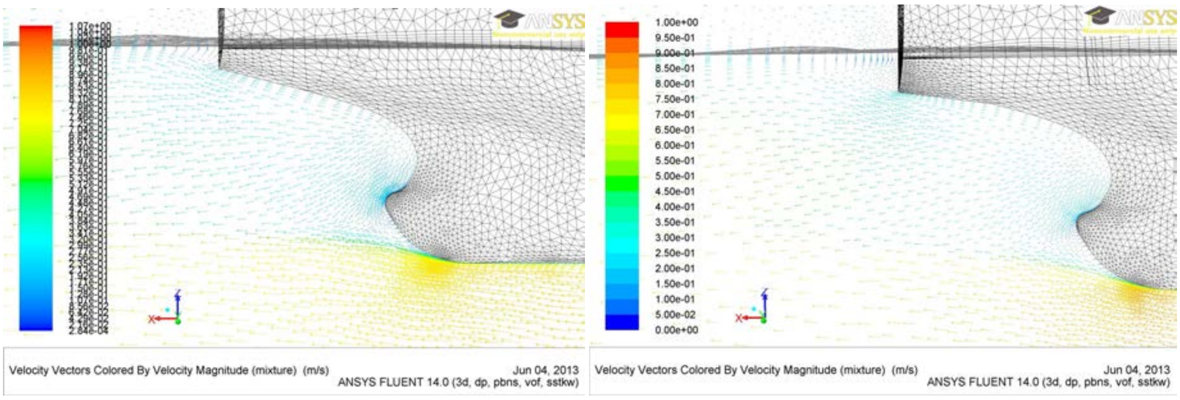
The stern wave is responsible for considerable resistance generation. If a stern wedge is adopted, stern wave position and height can be changed creating a different pressure distribution. Both stern wedge length and stern wedge depth becomes important and optimum vales of these parameters depend on the hull form, ship speed, trim and draught conditions.

Achievable energy efficiency improvement:

Depending on the speed of the vessel, improvements up to 5 % resistance reduction are possible. For the conventional slow vessels such as tankers and bulk carriers, the reduction is down to 1-2 % of the resistance.

Sustainability for newbuilding or retrofitted ships:

Both newbuilding and retrofitting is possible with this hull form variation.

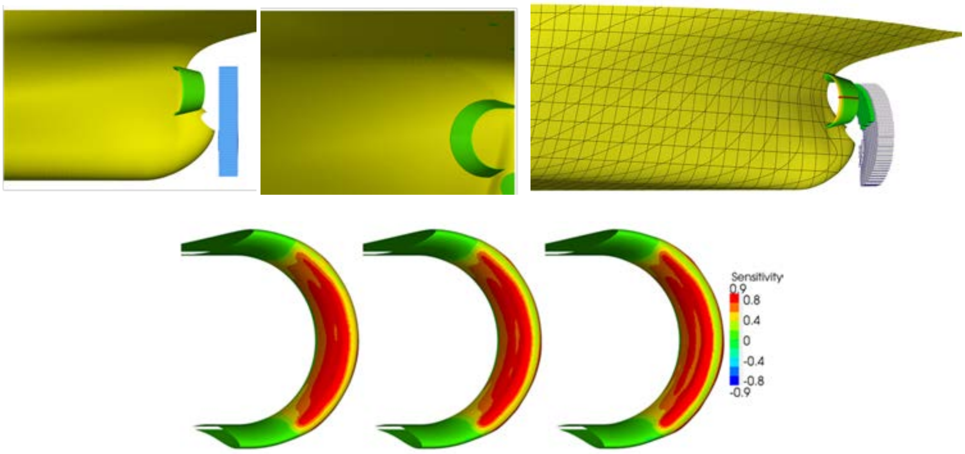


Ducts :

Ducts can be utilised for enhancing wake homogeneity. It is intended to accelerate flow within duct at the cost of a slight deceleration outside of the duct similar to Schneekluth duct. As single screw vessels are usually afflicted with a region of rather low axial velocity just around the 12 o'clock position, this interplay of acceleration / deceleration can be advantageous in terms of circumferential homogeneity of the axial propeller inflow. The axial propeller inflow has a strong impact of the fluctuation of the blade load and thus on the occurrence of cavitation and pressure pulses of high magnitude. Accordingly, several duct configurations where created by manually adapting the shape parameters of the CAD model. The initial study is supplemented by an adjoint shape optimisation study to further enhance the duct configuration.

Achievable energy efficiency improvement:
0.5 % of the hull drag can be obtained as additional thrust from the duct.

Sustainability for newbuilding or retrofitted ships:
Both newbuilding and retrofitting options are possible.

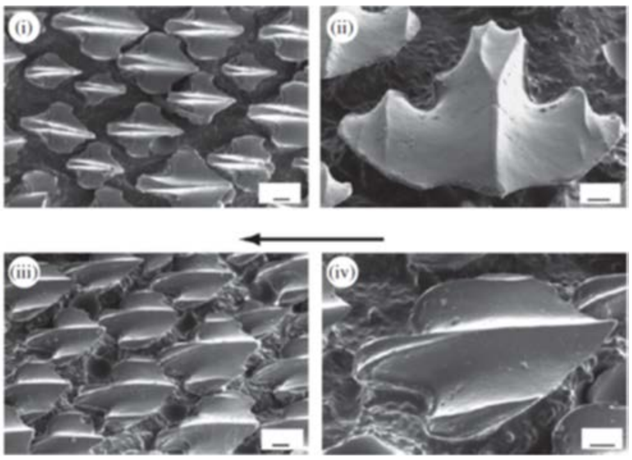


Surface patterns:

The surface patterns such as shark skin can serve as a basis for improving energy efficiency. Shark skin moves stream wise vortices away from the surface, reducing the velocities on the surface and resulting in reduced frictional resistance. The surface grooves "riblets" can be modelled as blade, triangular, and semi-circular riblets. Blade riblets are most promising; with the right range of spacing aligned with the flow lines, up to 10% reduction in frictional resistance can be achieved. As riblets should be aligned with the flow direction, change of speed or draught/trim may reduce the effectiveness. As blade height and spacing are sub-millimetre, fouling or damages have a large effect on the performance of the riblets.

Achievable energy efficiency improvement:
10 % reduction in frictional resistance is possible. However, this achievement is only possible when the surface texture is new. It is currently not possible to achieve a durable surface with the current state of the art.

Sustainability for newbuilding or retrofitted ships:
Both new ships and existing ships can benefit from the surface patterns. Use of special paints resulting in surface patterns promising.



Air Lubrication:

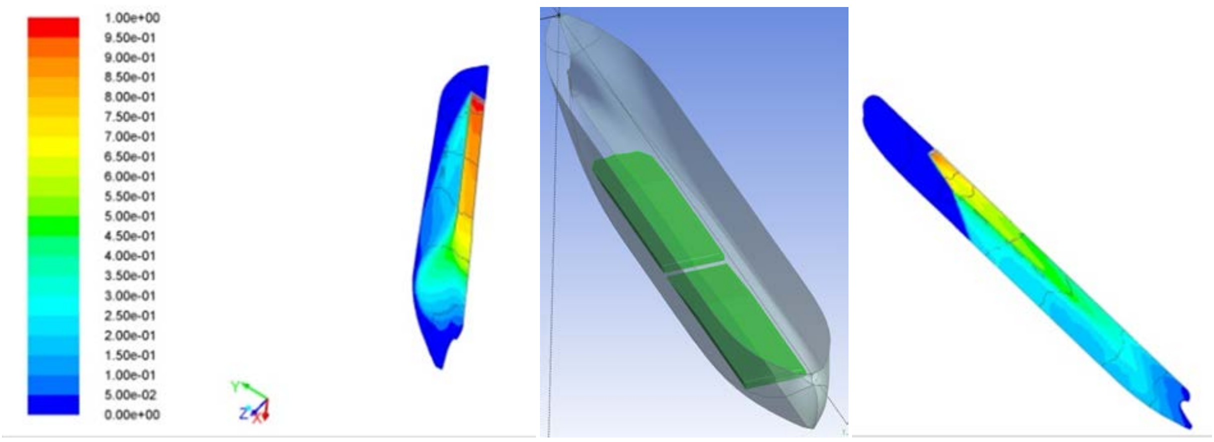
The frictional resistance of ships is the major cause for the fuel consumption, and thereby emissions. Among all the possible frictional resistance reduction methods, air lubrication is the most promising method. If air is injected along the submerged surface of a ship in small micro bubble, the boundary layer is dampened resulting in less energy loss in this layer. However achieving a stable micro bubble flow is very difficult in full scale. Instead a layer is established on the surface of the ship. This results in reduction of frictional resistance over this layer. Although air layer is an effective method, it requires quite a large amount of air to be pumped under the hull. The third available method is to create a recirculation field in an air cavity below the hull. By filling such a recirculation field, frictional and form resistance reductions can be achieved. As the air stays in the recirculation field, air consumption is considerably lower in this case.

Achievable energy efficiency improvement:

Air cavity is the most efficient technique known to reduce the frictional resistance. For conventional flat bottomed ships, saving in frictional resistance can be achieved up to 20 %. Air film is less effective achieving about 5 % less frictional resistance reduction, and also requires more air. Micro bubbles are not practicaly achievable at the current state of the art. The energy spent on the air pumps should also be taken into account.

Sustainability for newbuilding or retrofitted ships:

Air lubrication methods can be applied both to new ships and existing ships as retrofit. For a new ship, air cavity, micro bubbles and air film technique can be applied. However, for an existing ship' application of air cavity presents difficulties due to required structural changes at the bottom. Hence only air film and micro bubbles can be applied to an existing ship.

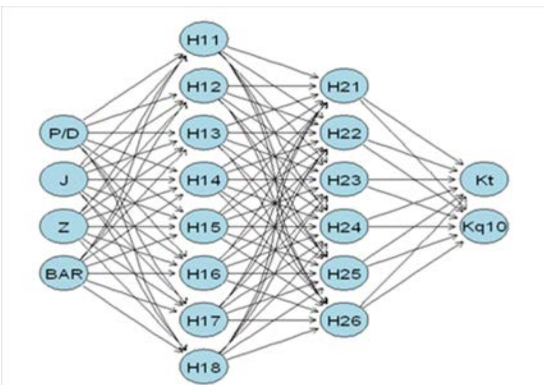


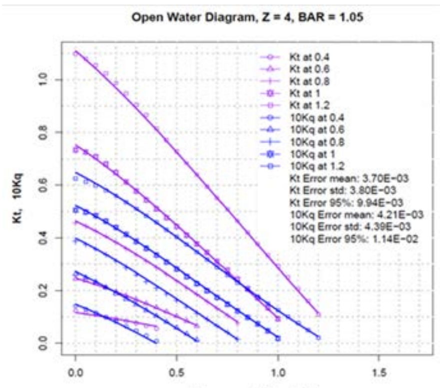
Standard systematic series data for conventional propellers:

Under the aim of providing the designers and operators with practical tools to enhance propulsive efficiency of conventional and unconventional propeller devices in the preliminary design stage is the development of "standard systematic series" data for the design/analysis of conventional propellers for commercial vessels. In addition to the provision of standardised open water performance data, more detailed investigations of the energy consumption components and pertinent parametric studies have been included as well to provide the designers with a wide spectrum of sources of information (covering techniques, plots, polynomials, and Artificial Neural Network models) for conventional propeller design and analysis. Two complementary standard propeller series have been introduced and presented in a user friendly format, namely, the upgraded "MERIDIAN" series, and the upgraded "VIRTUAL" series based on parts of the Wageningen–B Series members.

Achievable energy efficiency improvement:
Improved propeller efficiencies can be obtained form 3,4,5, and 6 bladed propellers

Sustainability for newbuilding or retrofitted ships:
Both newbuilding and retrofit options can be utilised.





Development of propeller coating technology tool:

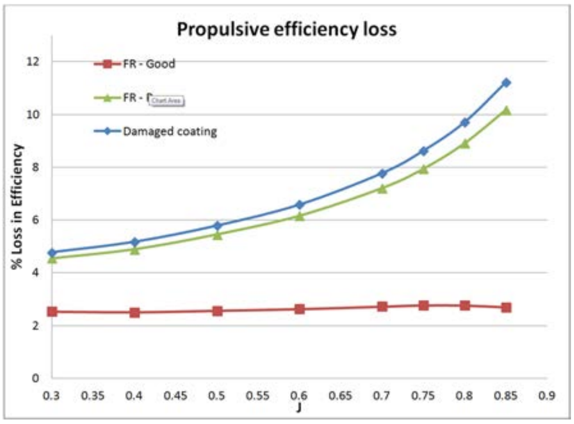
In order to improve the propulsive efficiency of a ship it is important not only to keep the hull free from bio-fouling, but also its propeller. Fouling is the attachment and growth of marine organisms on immersed surface. TARGETS developed a tool based on state-of-the-art lifting surface method to predict the performance of the propeller coating. Analysis of ship-propeller case studies can be performed with this tool to predict the performance of propeller coating.

Achievable energy efficiency improvement:

The efficiency of a coated propeller is very sensitive to the quality of the paintwork. A fouled propeller can cause 10 % loss in propeller efficiency; meanwhile good coating can limit this down to 2.5 %.

Sustainability for newbuilding or retrofitted ships:

Both newbuilding and retrofit options can be utilised.



BLAD (boundary-layer alignment) device application:

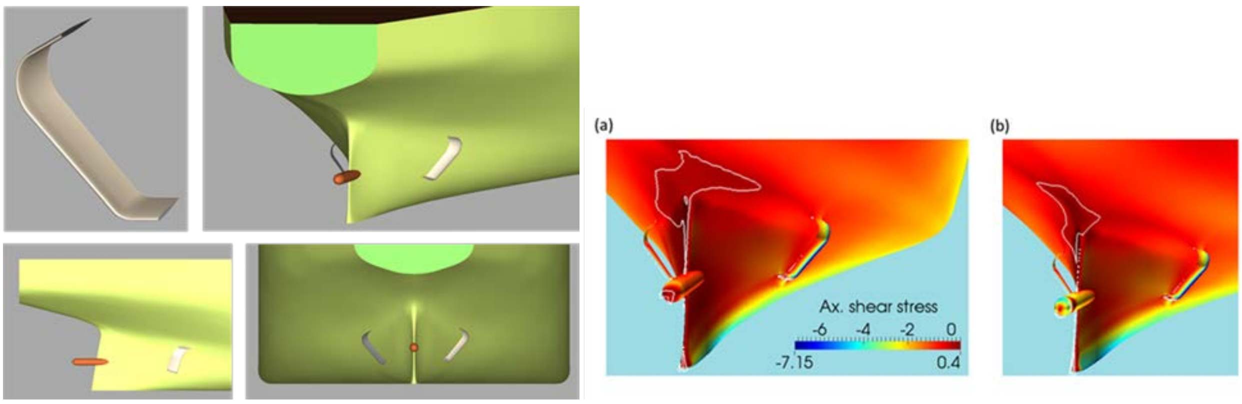
The flow conditions in the wake behind a ship play a crucial role for the propulsive efficiency. The shape of the aft ship determines the inflow into the propeller. Especially the bulky hull forms of tankers and bulk carriers suffer from massive losses of axial velocity above the propeller shaft. These inflow defects cause strong periodic variations of the local angle-of-attack of the propeller blades, accompanied by pressure fluctuations and risk of cavitation. A novel type of hull appendage for improved propulsion has been made as dubbed *BLAD* (boundary-layer alignment device). The BLAD yielded promising results with respect to power savings and efficiency gains, offering potential for further development in future research projects.

Achievable energy efficiency improvement:

2 % power reduction with BLAD only, 7.4 % reduction with BLAD and propeller redesign.

Sustainability for newbuilding or retrofitted ships:

Both newbuilding and retrofit options can be utilised.

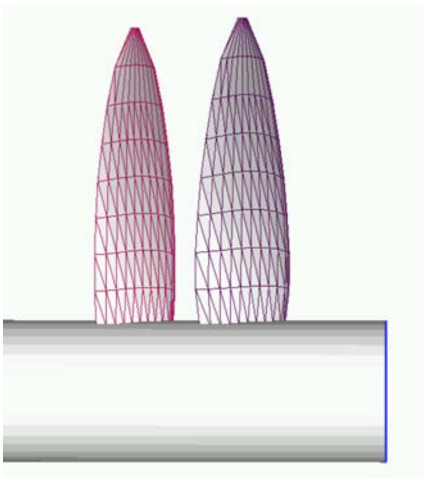


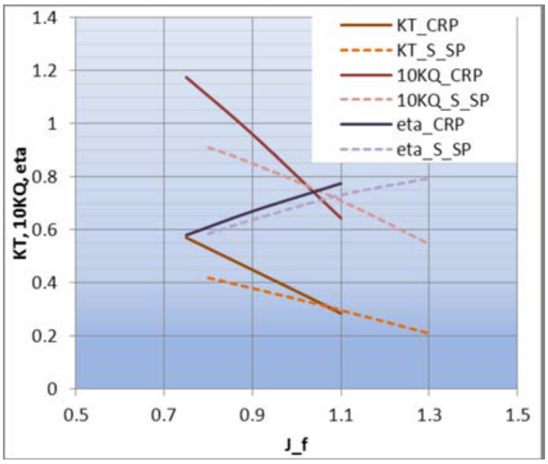
Contra-rotating propeller:

A system of contra rotating propellers (usually a pair) is supposed to recover rotational energy that would be left behind a single propeller to 100%, if no additional steady devices would serve to recover them. Compared to the single propeller case the systematic creation of geometrical data for a CRP series requires an enhanced effort. To guarantee the advantages of a CRP, two propellers must be combined properly. In other words two linked sets of geometrical data must be provided. Thus, already during the geometry definition phase, the mutual interaction of the two propellers has to be taken into account.

Achievable energy efficiency improvement:
Up to 8 % increase in the propeller efficiency.

Sustainability for newbuilding or retrofitted ships:
Both newbuilding and retrofit options can be utilised.



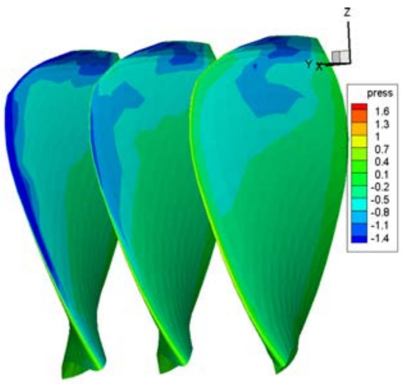


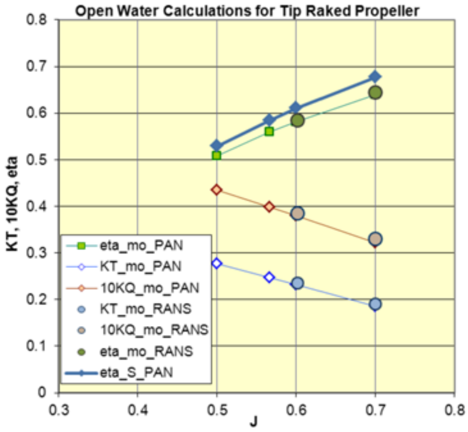
Tip raked propellers:

The tip rake propeller blade is described by a 90° bending of the blades from the vertical plane to the horizontal at the outer radii. We assumed that the blade tip is to point to the suction side. The standard geometrical parameter 'rake' is used to introduce such behaviour via the propeller main data. A tip rake propeller serving as a template for the generation of a series was obtained by a trial and error adjustment of camber and rake at the blade tip. An in-house propeller panel method was used for this process as well as in-house RANS solver FreSCo.

Achievable energy efficiency improvement:
Not clearly defined yet.

Sustainability for newbuilding or retrofitted ships:
Both newbuilding and retrofit options can be utilised.





Fixed Swirl-Propeller Devices:

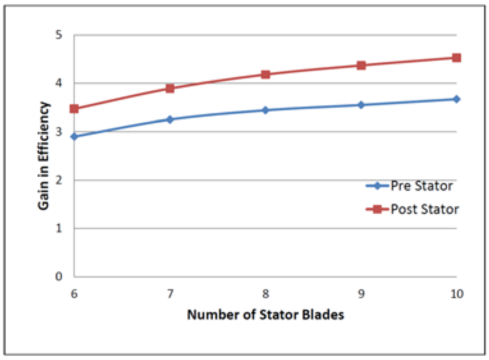
Both post-swirl (downstream stator) and pre-swirl (upstream stator) devices are designed such that the tangential velocities, which they induce in the slipstream, cancel those induced by the propeller (or rotor). The downstream stator has a negligible effect on the propeller forces but, for appropriate propulsor loading, the stator produces a net positive thrust and the propulsion efficiency becomes greater than that of the equivalent conventional propeller. On the other hand, the upstream stator produces a net negative thrust but modifies the flow to the propeller in such way that the propeller thrust is increased and, again in the right conditions, the propeller efficiency is increased.

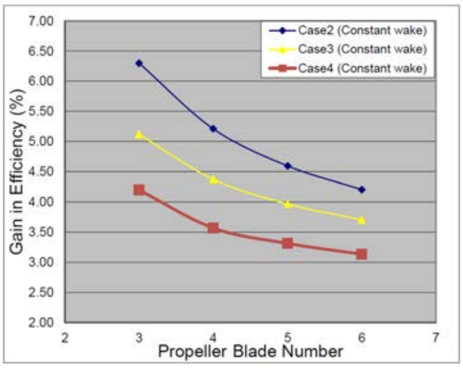
Achievable energy efficiency improvement:

Up to 6 % gain in the propulsion efficiency.

Sustainability for newbuilding or retrofitted ships:

Both newbuilding and retrofit options can be utilised.





Photovoltaic Installations:

Photovoltaic cells convert the sunlight directly into electrical energy. Ship upper decks can be equipped with photovoltaic cells for auxiliary energy generation as renewable sources. Cell types can be mono-crystalline cell, polycrystalline, amorphous cell, or tandem solar cells. Although the efficiency varies, the max efficiency is 30%. The cells must be directed into the sunlight, hence tracking system are utilised frequently.

The amount of energy that can be generated with photovoltaic systems is limited. Several projects using photovoltaic systems have been used with different alternative sources. Since the electrical board network uses alternating current, the photovoltaic cells have to be combined with an alternating-current converter in order to be connected to the AC-board-network.

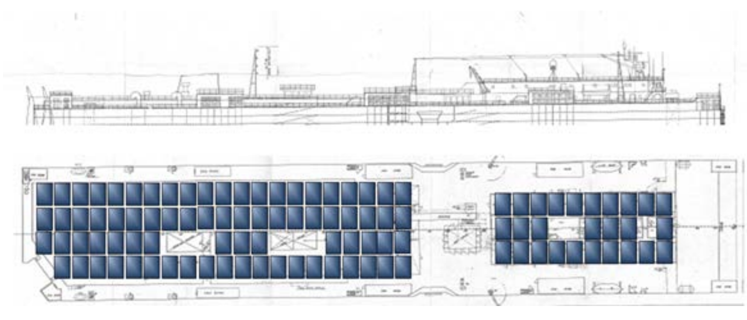
TARGETS developed simulation models of photovoltaic energy sources in various operating modes.

Achievable energy efficiency improvement:

A total maximum arrangement for a RoRo ship may produce 236.5 kW which is less than the harbour mode energy demand. Hence photovoltaic energy is unlikely to be sufficient for entire the energy need.

Sustainability for newbuilding or retrofitted ships:

Photovoltaic systems can be utilised both for the new ship and existing ships with retrofitting



Example photovoltaic cell layout for a RoRo ship

Photovoltaic cell installation

Wind Energy Utilization - Flettner Rotor:

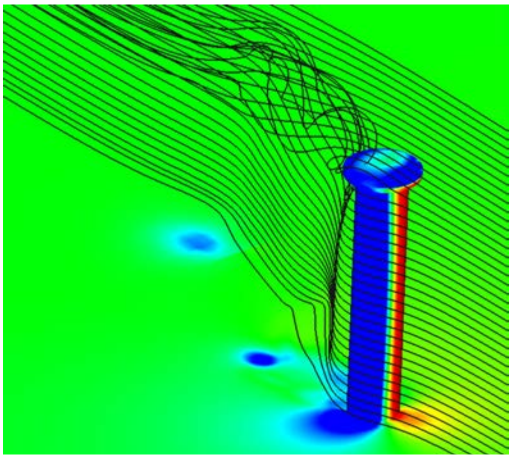
Sails were the main propulsive power until the middle of the 19th century. With the introduction of internal combustion engines and low fuel prices, wind energy was ignored for a long time. Lately, concepts on the use of wind energy were developed: Flettner rotor, rigid wing, dynarig. A Flettner rotor uses a cylindrical body spinning in a viscous fluid to create a boundary layer around itself and the boundary layer induces a more widespread circular motion of the fluid. If the body is moving through the fluid with a velocity V, the velocity of the thin layer of fluid close to the body is a little greater than V on the forward-moving side and a little less than V on the backward-moving side. This is because the induced velocity due to the boundary layer surrounding the spinning body is added to V on the forward-moving side, and subtracted from V on the backward-moving side. The rotation speed, the diameter and height of the cylinder, the ending of the cylinder in form of tip plate has effect on the performance.

Achievable energy efficiency improvement:

10-25 % saving on fuel consumption, Thrust up to 75 % of the resistance is achievable

Sustainability for newbuilding or retrofitted ships:

Although it appears that it can be applied both, the requirements such as stability, strength cannot be achieved for the retrofitting purposes. This is only practical for newbuilding.



Wind Energy Utilization – Dyna rig:

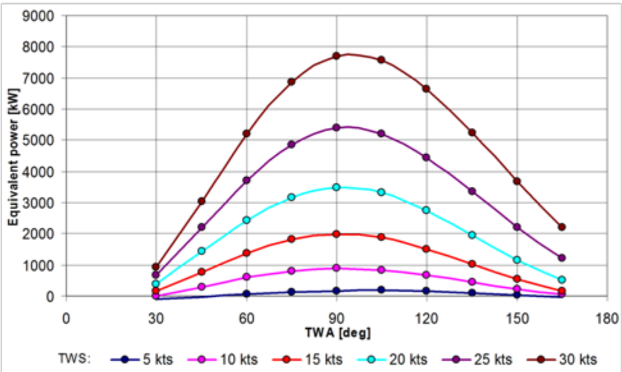
The angle of attack for a sail is varied by moving trailing edge of a Bermuda sail. Meanwhile square rigs cannot be positioned in favourable angle of attack. However, the dynarig concept is based on the self supported square sail rotated by the mast to the best angle attack. Although the lift coefficients are not so high, the large surface area of the sails ensures that large thrust forces are generated. Operationally dynarig is a simple controllable system as demonstrated 1240 ton mega yacht Maltese Falcon.

Achievable energy efficiency improvement:

Although it depends on the size of the rig, it is possible to achieve 830 kN thrust force in 90 degrees angle of attack 8000 kW equivalent power for a 4400 m2 area 40 m high 5-6 mast for a panamax bulker.

Sustainability for newbuilding or retrofitted ships:

Only for newbuilding ships.

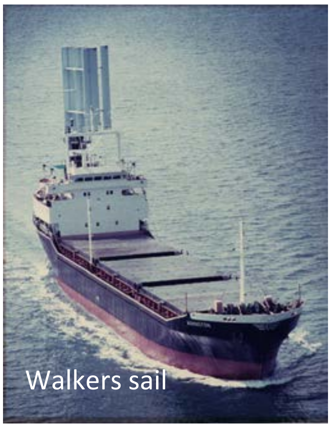


Wind Energy Utilization - Fixed wing sails:

Sails are flexible in nature, however rigid wing shaped foils can be utilised for ship thrust augmentation. A variety of geometry and configuration have been adopted and named as JAMDA rig, Indosail, Walkers sail etc. Each consists of a single foil or combination 2-3 foils with the same base. Flapped versions of rigid wings are frequently utilised. They are integrated either on top of the superstructure for the best wind conditions or on top of the main deck.

Achievable energy efficiency improvement:
Fuel oil consumption reduction in the range of 10 to 30 % is reported frequently.

Sustainability for newbuilding or retrofitted ships:
Although it appears that it can be applied to both, the requirements such as stability, strength cannot be achieved for the retrofitting purposes, hence, only for newbuilding ships.



Wind Energy Utilization - Kites:

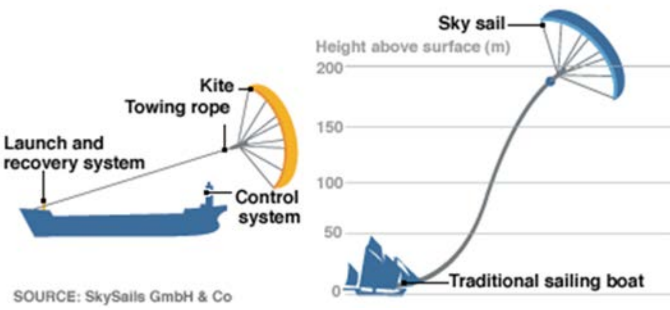
The wind speed is reduced near the water surface due to natural boundary layer on the water-air interface. Kites fly at a higher altitude than sails, and can therefore reach a higher wind speed. A kite has a single-point connection to a derrick at the forecastle area of a ship and through a tow line it transmits the wind loads into an additional propulsion force (horizontal force component) to the ship. The kite is fabricated from high strength textile and it is fitted with air cavities in order to maintain its shape and its performance. Kites are of the single-point connection to the ship, the induced motions to the ship are minimal, and no masts are needed for the kite deployment and therefore no deck space is used. Kites have operational difficulties due to structural safety, stability and crew operations.

Achievable energy efficiency improvement:

Not clearly defined yet.

Sustainability for newbuilding or retrofitted ships:

Kites can be applied both to newbuilding and retrofitting ships

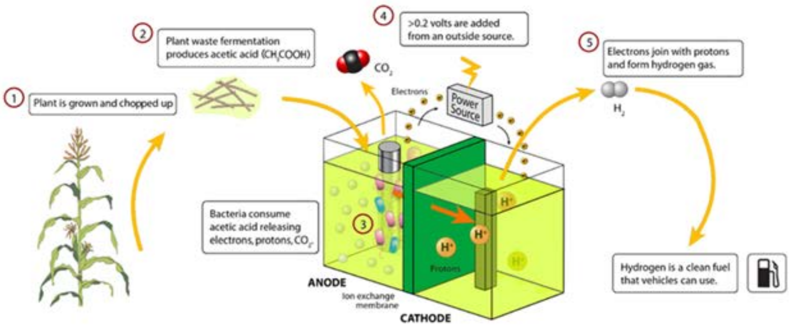


Unconventional Fuel Cell Concepts :

A microbial fuel cell (MFC) or biological fuel cell is a bio-electrochemical system that drives a current by mimicking bacterial interactions found in nature. It is a device that converts chemical energy to electrical energy by the catalytic reaction of microorganisms. A typical microbial fuel cell consists of anode and cathode compartments separated by a cation (positively charged ion) specific membrane. In the anode compartment, fuel is oxidized by microorganisms, generating electrons and protons. Electrons are transferred to the cathode compartment through an external electric circuit, while protons are transferred to the cathode compartment through the membrane. Electrons and protons are consumed in the cathode compartment, combining with oxygen to form water.

Achievable energy efficiency improvement:
Not defined satisfactorily yet.

Sustainability for newbuilding or retrofitted ships:
Both newbuilding and retrofitting.



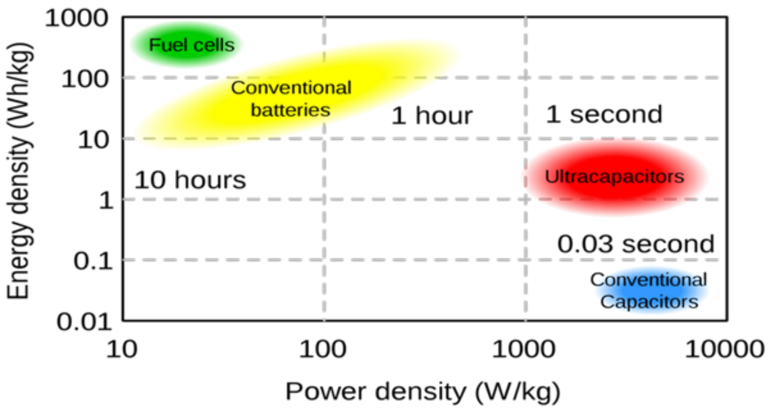
MICROBIAL ELECTROLYSIS CELL

Energy storage:

Producing energy just in time necessitates additional power requirements as operational profiles clearly demonstrate peak loads during operation of individual consumers. Peak shaving improves the utilization of a network of underlying power plants and is thus an important component in the cost reduction. Peak shaving can be applied basically in two ways. For one thing, by demand-side Management (DSM) peak loads are shifted in time and the other can production or storage facilities peak demand by consumers are themselves covered. This can result in less powerful energy generation device, reduction in SFOC, reduction in emissions. Chemical storage such as batteries, mechanical storage such as flywheels, compressed air, electro-mechanical storage, hydrogen storage can be utilised.

Achievable energy efficiency improvement:
Not clearly defined yet.

Sustainability for newbuilding or retrofitted ships:
Both newbuilding ships and retrofitting ships

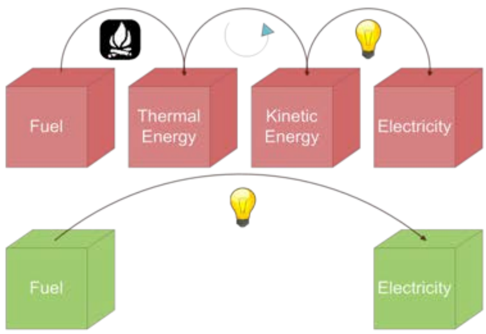


Fuel cell :

Fuel cells are electrochemical devices that convert chemical energy into electricity. Originally, hydrogen and oxygen were used for the controlled redox reaction, which generates a cell voltage, comparable to the voltage of a voltage source. In order to sum up the single cell voltages, the cells need to be connected serially. This is commonly known as stacking and leads to the cell stack, which is a series of connected cells. Because every single cell provides a voltage proportional to the fuel used, the fuel cell technology delivers a direct current. This voltage must be converted into alternating currents for onboard energy supply. Fuel cell types of alkaline fuel cell (AFC), proton exchange membrane (PEMFC), direct methanol fuel cell (DMFC), phosphoric acid fuel cell (PAFC), molten carbonate fuel cell (MCFC), solid oxide (SOFC) types have been developed.

Achievable energy efficiency improvement:
This is not a direct energy efficiency improvement.

Sustainability for newbuilding or retrofitted ships:
Both newbuilding and retrofitting ships may utilise fuel cell as generators.



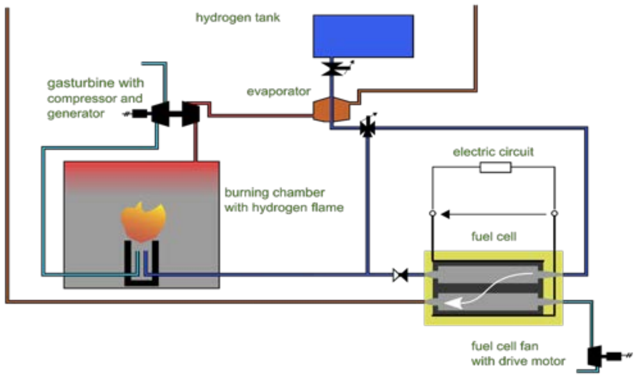
Above: power alternation for internal combustion engines; below: for fuel cells

Fuel Cell Simulation Model:

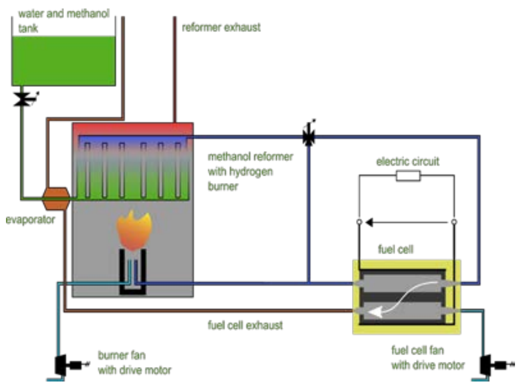
Two fuel cell simulation models have been developed in TARGETS. The first one is developed for a condition in which hydrogen is available in liquid state. The unburned hydrogen is used to run a Joule process, in which the hot exhaust gas is used to drive a gas turbine. Afterwards the exhaust gas evaporates the liquid hydrogen. The second model is operated by using a mixture of liquid methanol and water. The fuel processor reforms hydrogen out of methanol, while the necessary heat comes from burning the unutilized hydrogen. Both models are equipped with a proton exchanging membrane fuel cell type. Both systems are modelled by using mainly thermodynamic and thermochemical equations. The results generated by solving the system of equations are not linked to time; only steady state values are calculated. The methodology of the models allows for a certain power demand and for certain stack behaviour. Both models use the underlying fuel cell reaction equation of $2H_2 + O_2 \rightarrow 2H_2O$.

Achievable energy efficiency improvement:
Both models can simulate fuel cells with complex thermodynamic and thermochemical relations.

Sustainability for newbuilding or retrofitted ships:
Both newbuilding and retrofitting ships



Model 1: Fuel cell with gas turbine



Model 2: Fuel cell with methanol reformer

Dynamic Energy Model:

All energy systems onboard ships are comprised of various energy modules/components. These components can be mathematically described and analysed in terms of electrical systems, heat transfer, fluid mechanics, and control systems. A global energy system for the whole ship has to integrate all associated modules. Apart from the internal process of every energy module, the interaction with other modules and its environment could be taken into account in a comprehensive and standardised format. Simulations consider conservation of mass, momentum and energy. A time based simulation history is established by using the order of ship speed and ship loading condition, and time based response for fuel oil consumption, engine parameters including heating/cooling requirements, hence flow characteristics. Engine characteristics indicating engine load, rate of turn, exhaust gas mass and temperatures.

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.

Achievable energy efficiency improvement:

A full simulation scenario of a ship can indicate the energy efficiency improvement potential. The degree of energy efficiency shall be limited with the composition of the ship.

Sustainability for newbuilding or retrofitted ships:

Both newbuilding ships and retrofitting ships.