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Intelligent Engineering Options for Highly Fuel-Efficient Fishing Vessels

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Abstract— **The paper surveys engineering options to save fuel in fishing vessels. The main areas to consider are propulsion power and auxiliary power. Propulsion power depends on resistance and propulsive efficiency. Here, the main options for fishing vessels are given. For machinery and onboard consumers, a general discussion is followed by a description of latest simulation tools for design and operational guidance towards more fuel efficient ships. Onboard energy monitoring and fuel cells for auxiliary power are also covered.**

Keywords-energy monitoring; efficient design; resistance; propulsion

I. INTRODUCTION

Fuel prices were at an all-time high in 2008 and are expected to rise again in 2010, driven by a general increase in crude oil prices and changes in legislation that will impose higher quality fuels and surcharges on emissions. The general fuel price crunch is particularly painful for fishing vessels as fishing vessels have increasingly long distances to cover to get to lucrative fishing grounds.

One of today’s key questions for ship owners in general is fuel efficiency. Germanischer Lloyd addressed the demand for competent assistance in this field by establishing its subsidiary FutureShip in late 2008, pooling the knowledge on fuel saving and efficiency improving devices. Previous surveys for cargo ships, (Bertram, 2009), (Bertram et al., 2009), allow us to focus here on the specific options for fishing vessels.

II. KEY FUEL-SAVING OPTIONS IN HYDRODYNAMICS

We may use traditional hydrodynamic approaches to decompose the power requirements into resistance and propulsion aspects. While propeller and ship hull should be regarded as systems, the structure may help to understand where savings may be (largely) cumulative and where different devices work on the same energy loss and are thus mutually excluding alternative.

A. Reduce Resistance

There are many ways to reduce the resistance of a ship. On the most global level, there are two (almost trivial) options:

- Reduce ship size, e.g. by lightweight construction.
- Reduce speed

Neither option is discussed further here. Reducing maximum speed in the design specifications is a very effective way to reduce fuel consumption. As this is well known, we will focus on lesser known aspects in the following.

The largest levers in ship design lie in the proper selection of main dimensions and the ship lines. Experts should be consulted to assess the impact of main dimensions based on experience and data bases of ship model basins. Optimizations need to consider constraints like stability and seakeeping.

On a more detailed level, for a given speed and ship weight, all components of the ship resistance may offer fuel saving potential:

- *Frictional resistance of bare hull:* The frictional resistance (for given speed) depends mainly on the wetted surface (main dimensions and trim) and the surface roughness of the hull (average hull roughness of coating, added roughness due to fouling). Ships with severe fouling may require twice the power as with a smooth surface. Silicone-based coatings create non-stick surfaces similar to those known in Teflon coated pans. In addition to preventing marine fouling effectively, these smooth surfaces may result in additional fuel savings. Figures of up to 6% are quoted by shipping companies. An average hull roughness (AHR) of 65 μm is very good, AHR = 150 μm standard, and AHR > 200 μm sub-standard, (Hollenbach and Friesch, 2007). As a rule of thumb, every 25 µm of hull roughness corresponds to 0.7-1% of propulsion power, (N.N., 2008a).

- *Wave resistance of bare hull*: For given main dimensions, wave resistance offers large design potential. Moderate changes in lines can result in considerable changes of wave resistance. Bulbous bows should be designed based on CFD (computational fluid dynamics). In most cases, fast codes based on potential flow models suffice, (Bertram, 2000a). A formal optimization may offer 1-2% improvement even for containership hulls that are deemed already 'optimized' in limited form variations with CFD and model tests in model basins, (Abt and Harries, 2007). For fishing vessels, the potential is larger as the wave resistance accounts for a larger percentage of the total resistance, Fig.1, (Bensow, 2008). For an offshore supply vessel, which is closer to fishing vessel in shape and design process, savings of 16% were obtained in one case, Fig.2. This option is particularly attractive for new designs where the ship owner can and should specify that such an optimization is performed.
- *Residual resistance of bare hull (mainly due to flow separation)*: CFD simulations may help in finding suitable compromises between hydrodynamic and other design aspects, reducing residual resistance. However, the saving potential for wave resistance is generally much higher.

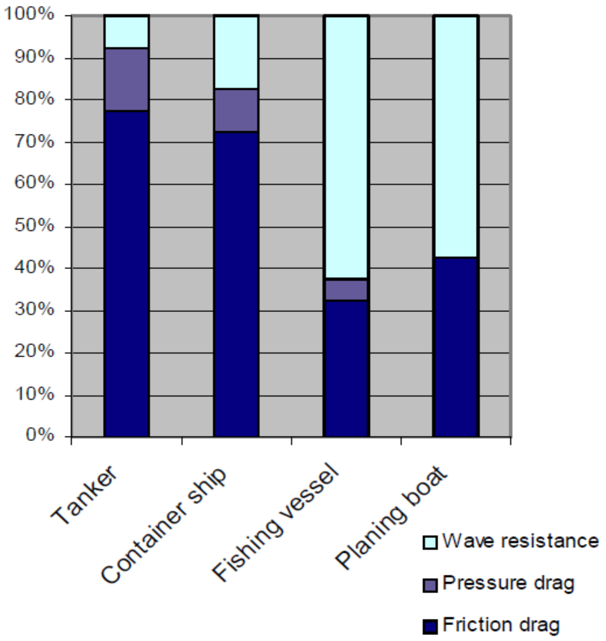


Figure 1. Resistance decomposition for various ship types, (Bensow 2008)

- *Resistance of appendages*: Appendages contribute disproportionately to the resistance of a ship. CFD simulations can determine proper alignment of appendages, Fig.3.

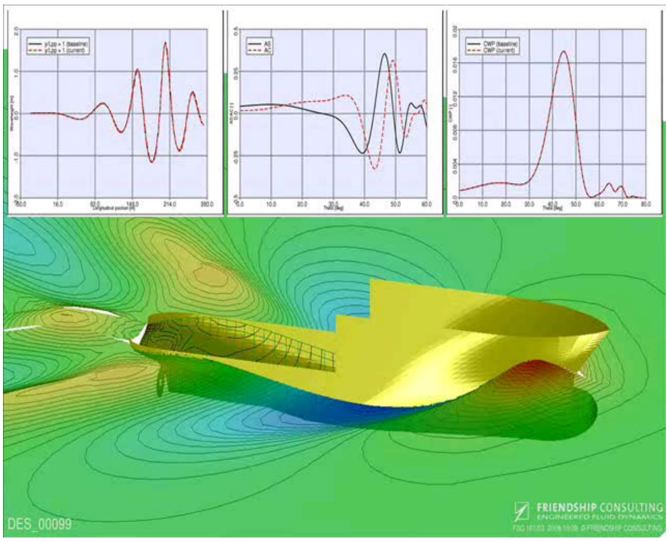


Figure 2. Hull lines optimization

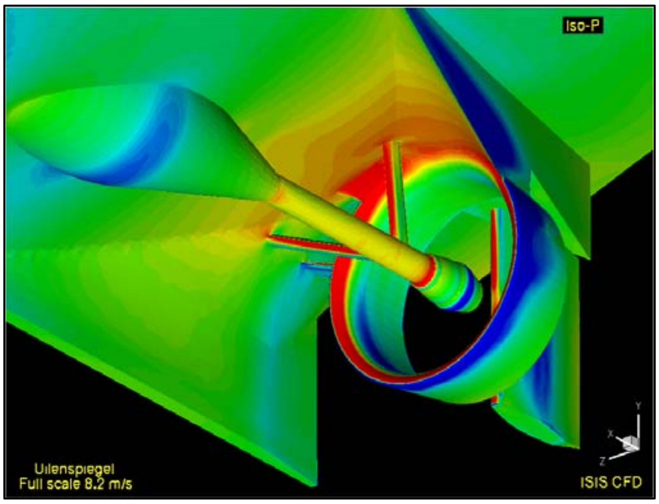


Figure 3. CFD analysis for nozzle propeller, source: ECN

- *Rudder resistance*: Rudders offer an often underestimated potential for fuel savings. More efficient rudders allow reducing rudder size, thus weight and resistance. Due to the rotational component of the propeller, conventional straight rudders at zero rudder angle encounter oblique flow angles to one side at the upper part and to the other side in the lower part. This creates opposing lift forces which cancel each other, but the associated induced drag forces add. By twisting the rudder these unnecessary drag forces can be reduced. High-efficiency rudders combine various approaches to save fuel: twisted rudders are combined with a bulb on the rudder as a streamlined continuation of the propeller hub. Savings of 2-8% are claimed by the manufacturers.
- *Added resistance due to seaway:* Intelligent routing (i.e. optimization of a ship's course and speed) may reduce the average added resistance in seaways. For example, the Ship Routing Assistance system,

(Rathje and Beiersdorf, 2005), was originally developed to avoid problems with slamming and parametric roll, but may also be used for fuel-optimal routing. However, GL experts estimate the saving potential to less than 1% for most realistic scenarios.

- *Added resistance due to shallow water:* Routing systems may also consider shallow water and the associated increased resistance.
- *Added resistance due to wind*: The saving potential in wind resistance is negligible for fishing vessels.

For each draft and speed, there is a fuel-optimum trim. For ships with large transom sterns and bulbous bows, the power requirements for the best and worst trim may differ by more than 10%, (Mewis and Hollenbach, 2007). Systematic model tests or CFD simulations are recommended to assess the best trim and the effect of different trim conditions. This is particularly attractive for series of ships, as frequently found for fishing vessels.

B. Improve Propulsion

The propeller transforms the power delivered from the main engine via the shaft into a thrust to propel the ship. Typically, only 2/3 of the delivered power is converted into thrust power. Most fishing vessels have a single controllable pitch propeller (CPP) with a nozzle for high pulling power, (Pinkster, 2004). Model tests for appendages like nozzles and propulsion improving devices suffer from scaling errors, making quantification of savings for the full-scale ship at least doubtful, (ITTC, 1999). Increasingly, CFD is used to assess hull, propeller, rudder, and appendage interaction, Fig.4.

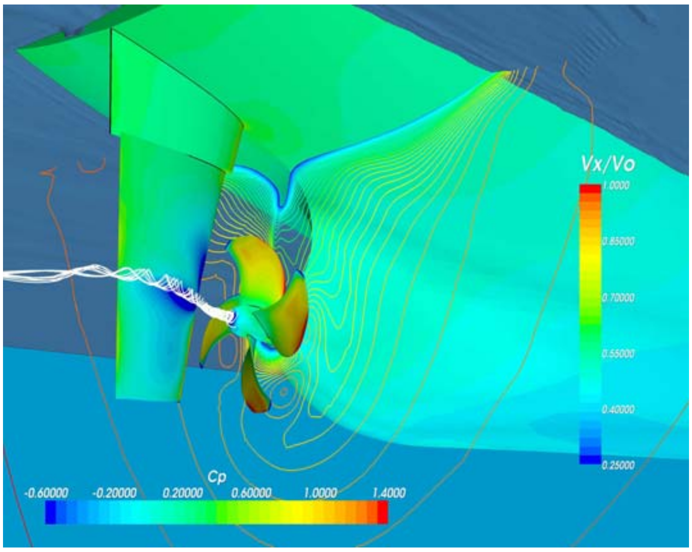


Figure 4. CFD simulation for hull + appendages

Fuel saving options for propulsion include:

- *Operate propeller in optimum efficiency point:* The propeller efficiency depends among others on rpm and pitch. CPPs can adapt pitch and thus offer advantages for ships operating over wider ranges of operational points. Savings up to 17% have been quoted due to refitting new blades on CPPs, (N.N., 2008b).
- *Reduce rotational losses:* For most ships, there is substantial rotation energy lost in the propeller slipstream. Many devices have been proposed to recover some of this energy. These can be categorized into pre-swirl (upstream of the propeller) and post-swirl (downstream of the propeller) devices. Pre-swirl devices include the SVA Potsdam (Potsdam model basin) pre-swirl fin, pre-swirl stator blades, and asymmetric aftbodies. Post-swirl devices include the Grim vane wheel, stator fins, and rudder thrust fins. Alternatively, contra-rotating propellers may recover the rotational energy losses. The devices do not appear to be attractive for fishing vessels. They involve moderate to high investment, are sometimes structurally not very robust and fuel saving claims by manufacturers are widely doubted among hydrodynamic experts.
- *Reduce frictional losses:* Smaller blades with higher blade loading decrease frictional losses, albeit at the expense of increased cavitation problems. A suitable tradeoff should be found using experienced propeller designers and numerical analyses.
- *Reduce tip vortex losses:* The pressure difference between suction side and pressure side of the propeller blade induces a vortex at the tip of the propeller. This vortex (and the associated energy losses) can be suppressed (at least partially) by tip fins similar to those often seen on aircraft wings. As most propellers for fishing vessels have nozzles, it is more important to get the propeller-nozzle interaction right. CFD is the suitable tool for this.
- *Reduce hub vortex losses:* Devices added to the propeller hub have been promoted as efficient fuel savers. Propeller boss cap fins (PBCF) were developed in Japan. The Hub Vortex Vane (HVV), developed by SVA Potsdam and Schottel, offers an alternative to PBCF. The HVV is a small vane propeller fixed to the tip of a cone shaped boss cap. Claims of 3-4% gains in propeller efficiency appear doubtful.
- *Operate propeller in better wake:* A more homogeneous wake translates then into potentially better propeller efficiency if considered for propeller design. For fishing vessels, wake equalizing devices (like Schneekluth nozzles a.k.a. wake equalizing ducts (WED), Grothues spoilers, vortex generators) do not appear to be very attractive.

III. KEY FUEL-SAVING OPTIONS IN MACHINERY

There are various options to save power in the assorted energy consuming equipment onboard ships. The saving potential depends on the ship type. For fishing vessels, more efficient electronically controlled pumps should be considered, for example. Ship engines convert only up to 45% of the fuel energy into propulsive power. The remaining energy of the fuel can be approximated as in the same amount lost in exhaust gas heat and in cooling water. There are various approaches to recuperate some of these energy losses, (Hochhaus, 2007). Exhaust heat may be used for steam generation or to fuel deep-freeze absorption chillers. Hot coolant may be used to produce fresh water from sea water.

Avoid oversized main engines. Sea margins should be adapted to ship size and intended operational trade. The sea margin may be selected based on standard seakeeping analyses or based on experience. The frequently added engine margin may be omitted altogether. Margins for occasional high-speed operation are expensive. Rarely used extra power may be better covered by falling back on the auxiliary engine power (power take-in (PTI) via shaft generator). Detailed engineering analyses can be used to assess feasibility and cost aspects of alternative configurations, (Freund et al., 2009), Fig.5. For slow-steaming ships with controllable pitch propeller, it is better to reduce the brake mean effective pressure than the rpm. Intelligent monitoring and simulation software can combine engine supplier data and standard onboard monitoring data for a given operational profile to determine optimum combinations of propeller pitch and rpm.

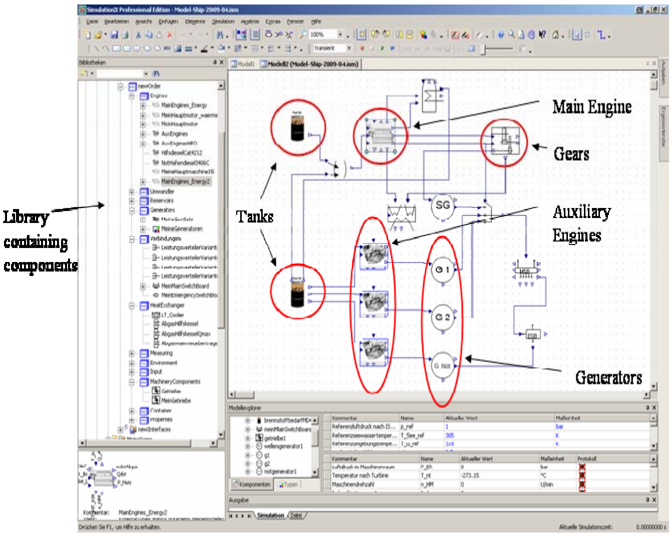
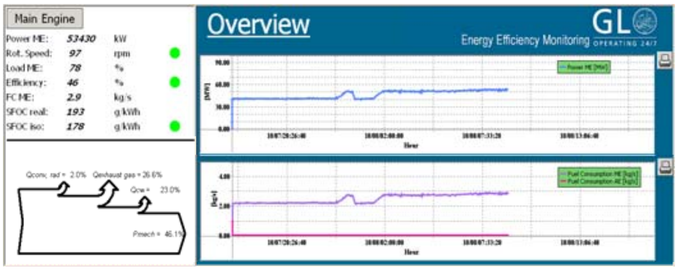


Figure 5. Machinery simulation tool

Avoid oversized auxiliary engines. Better overall energy management systems may balance the energy demand of the consumers on board reducing peak demands allowing in turn a reduction of the generator capacity. This in turn reduces the weight of the ship. Simulations of the overall machinery system are able to predict fuel consumptions for provided energy consumer profile, Fig.5. These simulations allow assessment of alternatives and ultimately better balanced energy profiles.

Our simulations are based on the software ITI SimulationX. The simulations can be adapted easily to different ships using a library of predefined machinery components. The simulations were validated for two ships, (Freund et al., 2009). The fuel consumption was calculated within 2% deviation of the reported noon data over periods of 4-8 weeks. Installed onboard, the current consumption of mechanical and electrical energy can be displayed in combination with the fuel consumption of the engines and their efficiency of power generation, (Hansen and Freund, 2010). In conjunction with the displayed time lines, the crew can evaluate their actions with regard to energy consumption, e.g. avoiding unnecessary peak loads requiring a higher number of running engines. An example is displayed in Fig.6, with the current values of the main engine displayed on the left with the related timelines on the right.


Main Engine

Power ME: 53430 kW
Rot. Speed: 97 rpm
Load ME: 78 %
Efficiency: 46 %
FC ME: 2.9 kg/s
SFOC real: 193 g/kWh
SFOC iso: 178 g/kWh

Figure 6. Energy Efficiency Monitoring display for the main engine

In the field of new energy converters and fuel cell systems there are many great possibilities for energy improvements in the future. In fact, the Icelandic government targets to develop the world's first hydrogen economy. Besides automotive and public transport, also the fishing fleet shall be operated on fuel cell systems. A first fuel cell demonstration project started on a whale watching boat in Reykjavik in 2008, Fig. 8.

Figure 7. Whale Watching Boat ELDING I

Figure 8. Passenger vessel ALSTERWASSER

For applications with strongly fluctuating loads, a hybrid fuel cell battery system (a combination of fuel cell system and battery for peak loads) was simulated for a harbour ferry in Hamburg. The efficiency of a hybrid fuel cell battery system was compared to a traditional diesel-electric propulsion system. The simulations revealed significant potential for efficiency improvements, (Gysels, 2008). In general, hybrid systems are attractive especially for transient loads. Regarding the specific load profile of the vessel, the hybrid option reduces also the engine size and operates the engine at its highest efficiency. Similarly, the transient auxiliary loads on fishery vessels offer great opportunity for the use of hybrid systems for energy efficiency improvements. Prototype projects as shown in Fig. 7 and Fig. 8 have demonstrated the suitability of fuel cell systems for auxiliary power generation and propulsion.

IV. CONCLUSIONS

There are many technical levers to save fuel for fishing vessels. Unfortunately, there is large scatter in saving potential and many claims in literature are doubtful. Despite these words of caution, there is wide consensus that significant potential for fuel saving exists and competent service providers can support ship designers, ship owners and operators in tapping into these potentials.

We focused here on technical options. However, fuel saving does not only depend on engineering options, but involves also human factors. For example, an even speed profile in operation saves fuel. This is largely a question of awareness and motivation. Fuel monitoring systems have proven to be effective in instigating more balanced ship operation with fuel savings of up to 2%.

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