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# Holistic Modeling of the Global Propulsion Energy Index in Waves for Small Craft

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**In the international regulation framework, the energy-efficient operation of ships is becoming standard. In this respect, restrictions on new construction appear to encourage improvement to existing vessels often equipped with outdated technologies. One of the relevant aspects of propulsion plant design and fleet management is the propulsion need to accomplish the design requirements in a wide set of sea states or in conflicting operative conditions (e.g., laden/ballast, sailing/trawling), requiring very different performances. A preliminary assessment of the energy efficiency of the ship system is then crucial for optimizing both the operating costs and the impact on the sea environment. A new efficiency assessment method that includes engine fuel consumption evaluated by ad hoc statistic regressions and ship resistance in calm water and in waves computed by a 3-D boundary element method is proposed. An application to a hard-chine 18 m trawler is proposed as part of a wider decision support system or weather routing algorithm.**

## INTRODUCTION

Ships are a significant source of air pollutants, such as sulfur oxides (SOx), carbon oxides (COx), and nitrogen oxides (NOx), that have a relevant impact on both some sea ecosystems and populated coastal areas, especially those close to harbors. Although the International Maritime Organization (IMO) introduced the greenhouse gas (GHG) emissions reduction in its agenda in 1995, only in recent years has this seemed to generate constraints on the design of new units (see, for instance, Coraddu et al., 2014). In addition, considering that most pollutants are strongly related to a vessel's total fuel consumption, optimizing the propulsive efficiency directly reflects as a reduction of exhaust gas emissions. From a designer's point of view, the need to improve the available methods for efficiency prediction and optimization to achieve better solutions at very preliminary design phases is clear. For example the IMO (2009a, 2009b) introduces technical and economical indexes for emissions regulation, namely, the Energy Efficiency Design Index (EEDI) and the Energy Efficiency Operational Indicator (EEOI). The former is used to assess the design of a vessel, the latter to evaluate the operational profile of a vessel. Despite the relevance of these indexes, some types of ships, such as cruise ships and working boats, are not included in the baseline values provided in the International Convention for the Prevention of Pollution from Ships (IMO, 2011). Moreover, the proposed baseline values do not take into account the environmental conditions in which ships navigate.

In this framework, a method for the assessment of the propulsive efficiency of a ship based on computational fluid dynamics (CFD) for hydrodynamics performance predictions is presented and applied to a specific ship, i.e., an existing medium-size trawler (Martelli et al., 2016).

Trawlers are workboats that need to operate in two opposite regimes. The sailing phase mainly covers the transfers of the vessel from the harbor to the fishing ground (back and forth); it is characterized by relatively high speed typically ranging from 9.0 to 12.0 knots. The trawling phase is conducted at lower speeds, from 3.5 to 4.0 knots. The propulsion system thus needs to operate in different conditions (Notti and Sala, 2012). The high fuel consumption of many important fisheries is the major constraint on their economic viability, represents a significant source of GHG emissions, and has a considerable impact on the marine environment (Suuronen et al., 2012).

Commercial fishing is presently facing economic, social, and environmental challenges, which are forcing the fishing sector to evolve toward energy efficiency, low emissions, and sustainability (Gabiña et al., 2016). In addition, a generalized over-exploitation of fishery resources often endangers the economic viability of such activities. These last push the dedicated EU Commission to prevent new construction. Moreover, the economic profitability (i.e., the revenue-to-cost ratio) can in principle be increased in two ways (Buglioni et al., 2011): increasing revenues by catching more fish or decreasing operative costs (OpEx) acting on the operation management. The latter approach reflects on both engineering design decisions for new buildings and new strategies for existing ships.

From a ship-level perspective, there are few ways to improve the overall efficiency of this specific market, namely, retrofitting the vessels that generally exploit outdated technologies (see, for instance, Sala et al., 2011) or changing the operational profile. Some examples of improvements have already been presented (Notti and Sala, 2013), such as the use of a propulsion plant with double reduction ratios, the adoption of a controllable pitch propeller (Altosole et al., 2012; Martelli et al., 2014), or the addition of a propeller nozzle. Considering the choice of the propeller configuration, note that in trawling conditions the propeller operates at low advance coefficients, implying higher loads and lower efficiency. This is one of the reasons to use ducted propellers for this

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