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Calculation of $EEDI_{weather}$ for a general cargo vessel

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ABSTRACT

The Energy Efficiency Design Index (EEDI) of a 120 m long general cargo vessel is calculated. Ship specific correction factors in the EEDI calculation guidelines from the International Maritime Organization (IMO) result in the attained EEDI of the ship studied being 22% lower than the ship's actual CO_2 emissions per transport work. Even with these correction factors, we find that the EEDI of the vessel studied would have exceeded the reference EEDI value if it had been equipped with a heavy fuel oil or marine gas/diesel oil engine instead of a natural gas engine. The EEDI in Beaufort 6 wind and waves, $EEDI_{weather}$, is also calculated, using three different calculation methods for the added resistance due to waves. Issues with the methods suggested by IMO and the International Organization for Standardization (ISO) for calculating the added resistance due to waves are pointed out.

1. Introduction

The Energy Efficiency Design Index (EEDI) is a measure of a ship's CO_2 emissions in grams per ton transported and nautical mile sailed. It was made mandatory for new ships by the International Maritime Organization (IMO) in 2011 (International Maritime Organization, 2016) as a means of reducing the carbon footprint from shipping. IMO has determined reference EEDI values as a function of capacity and requires new ships to attain certain EEDI values relative to the reference values (International Maritime Organization, 2011). For the largest ships, such as tankers above 20,000 DWT and container ships above 15,000 DWT, the EEDI is required to be 10% lower, 20% lower and 30% lower than the reference line values for building contracts placed after 01.01.2015, 01.01.2020 and 01.01.2025, respectively.

The reference line values shall be calculated as follows (International Maritime Organization, 2011, 2014b):

$$\text{Reference line value} = a \cdot b^c, \tag{1}$$

where a, b and c are the parameters given in Table 1. Reference lines for various ship types are shown in Fig. 1.

Since the EEDI is a measure of ships' CO_2 emissions in calm water, which rarely occurs on the ocean, IMO has defined an EEDI for "representative sea conditions" called $EEDI_{weather}$ (International Maritime Organization, 2014a), which is found by dividing the EEDI by a speed loss factor due to waves and wind. The representative sea condition to be used when calculating $EEDI_{weather}$ is Beaufort 6 head wind and waves (International Maritime Organization, 2012). More details on the wind and wave conditions for $EEDI_{weather}$ calculations are given in Section 4. IMO has no requirements to a ship's $EEDI_{weather}$ value, however, as of today.

The aim of the present paper is to give an example of how various ship specific factors in IMO's guidelines for EEDI calculation affect the EEDI of a vessel. In addition, we study how different methods of calculating the added resistance due to waves affect the value of $EEDI_{weather}$. We believe this is useful, as few examples of the calculation of $EEDI_{weather}$ can currently be found in the literature.

2. Case vessel

The vessel studied in the present work is the general cargo vessel Kvitbjørn, see Fig. 2, which is a realization of Rolls-Royce's Environship concept (Rolls-Royce, 2015a). Kvitbjørn was christened on April 16, 2015, with its owner, Nor Lines, calling it the "world's most environmentally friendly ship" (Nor Lines, 2015b). The main engine is a Rolls-Royce BL35:40L9PG (Rolls-Royce, 2015c), which is powered by Liquefied Natural Gas (LNG), has a maximum continuous rating (MCR) of 3940 kW, and a specific energy consumption at 750 rpm of 7480 kJ/kWh (Rolls-Royce, 2015b). Specific energy consumption can be converted to specific fuel consumption by dividing by the factor 48.000 kJ/g for LNG-powered engines (International Maritime Organization, 2014a), so the specific fuel consumption of Kvitbjørn's main engine becomes 155.8 g/kWh. Principal data of the vessel are given in Table 2.

Kvitbjørn is classed as both a general cargo ship and a ro-ro cargo ship (DNV, 2015). MARPOL Annex VI, Chapter 4, Regulation

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Table 1
Parameters for determination of reference values for various ship types (International Maritime Organization, 2011, 2014b).

Ship type	a	b	c
Bulk carrier	961.79	DWT of the ship	0.477
Gas carrier	1120.00	DWT of the ship	0.456
Tanker	1218.80	DWT of the ship	0.488
Container ship	174.22	DWT of the ship	0.201
General cargo ship	107.48	DWT of the ship	0.216
Refrigerated cargo carrier	227.01	DWT of the ship	0.244
Combination carrier	1219.00	DWT of the ship	0.488
Ro-ro cargo ship	1405.15	DWT of the ship	0.498

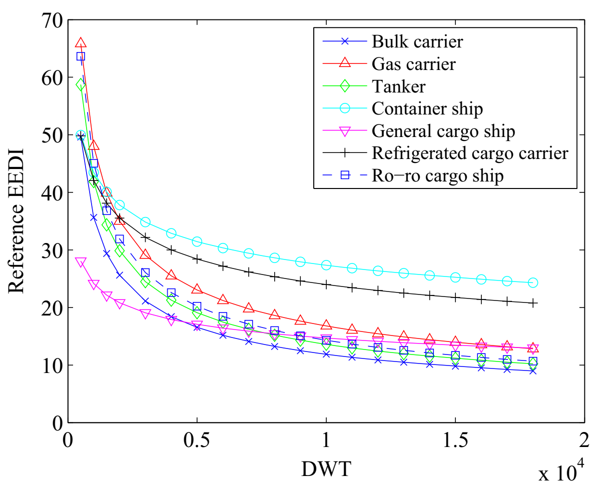

Fig. 1. Reference EEDI lines for various ship types.

Fig. 2. Kvitbjørn (Nor Lines, 2015a).

Table 2
Principal data of Kvitbjørn (Zachariassen, 2015).

Parameter	Value
Length overall	119.95 m
Length betw. perp.	117.55 m
Breadth	20.80 m
Design draught	5.50 m
Scantling draught	6.01 m
Deadweight at design draught	3900 tons
Deadweight at scantling draught	5000 tons
Gross tonnage (GT)	9132
Main engine power (MCR)	3940 kW
Service speed	14.3 knots

21.4 states that "If the design of a ship allows it to fall into more than one of the ship type definitions specified in Table 2, the required EEDI for the ship shall be the most stringent (the lowest) required EEDI". Furthermore, the deadweight of the ship used in EEDI calculations shall be the deadweight when the ship is at the summer load line draught (International Maritime Organization, 2014a). The summer load line draught is taken to be the scantling draught here. For the 5000 DWT vessel Kvitbjørn, the reference EEDI is 17.07 for general cargo ships and 20.21 for Ro-ro cargo ships. Hence, Kvitbjørn shall be considered a general cargo ship when calculating the EEDI. Required EEDI values for small general cargo ships are shown in Fig. 3. Note that since Kvitbjørn was contracted in 2011 it does not need to comply with any EEDI requirements. The EEDI of Kvitbjørn is calculated here for information purposes only.

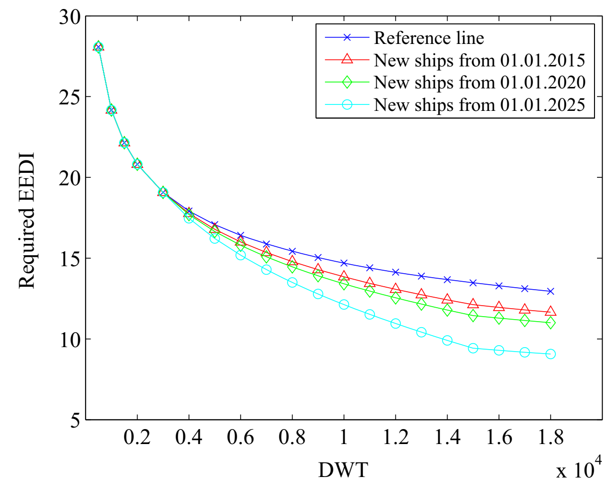

Fig. 3. Required EEDI for small general cargo ships.

3. EEDI

The attained EEDI of a ship is calculated from the following formula (International Maritime Organization, 2014a):

$$EEDI = \frac{\begin{array}{l}\prod_{j=1}^{n} f_j \cdot \left(\sum_{i=1}^{nME} P_{ME(i)} \cdot C_{FME(i)} \cdot SFC_{ME(i)}\right) + P_{AE} \cdot C_{FAE} \cdot SFC_{AE} \\ + \left(\prod_{j=1}^{n} f_j \cdot \sum_{i=1}^{nPTI} P_{PTI(i)} - \sum_{i=1}^{neff} f_{eff(i)} \cdot P_{AEeff(i)}\right) C_{FAE} \cdot SFC_{AE} \\ - \sum_{i=1}^{neff} f_{eff(i)} \cdot P_{eff(i)} \cdot C_{FME} \cdot SFC_{ME}\end{array}}{f_i \cdot f_c \cdot f_l \cdot Capacity \cdot f_w \cdot V_{ref}}, \tag{2}$$

where summation over all (1 to n) items should be done if there are more than one main engine (ME), shaft motor (PTI) or unit of innovative energy efficiency technology (eff). Subscript AE indicates auxiliary engine values. P denotes power in kW, C_F is a non-dimensional conversion factor between fuel consumption measured in grams and CO_2 emission also measured in grams based on carbon content, and SFC denotes specific fuel consumption in g/kWh. *Capacity* is for general cargo ships the deadweight in tons. V_{ref} is the ship speed in knots in calm water at the summer load line draught obtained with an engine power of P_{ME}. f_{eff} is the availability factor of innovative energy efficiency technology. The other f-factors are explained below.

Although Kvitbjørn has a hybrid shaft motor/generator (P_{PTI}/P_{PTO}) installed (Zachariassen, 2015), the EEDI is here calculated without the use of the shaft motor. As far as the authors are aware of, Kvitbjørn has no P_{eff} or P_{AEff}. The numerator in Eq. (2) hence simplifies to just the first line of the same.

P_{ME} is calculated as (International Maritime Organization, 2014a)

$$P_{ME} = 0.75 \cdot MCR, \tag{3}$$

giving $P_{ME} = 2955$ kW for Kvitbjørn. For ships with a total propulsion power below 10,000 kW, P_{AE} is calculated as (International