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Effect of Energy Efficiency Design Index on Container Vessel Design

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Abstract

EEDI (Energy Efficiency Design Index) is an index quantifying the amount of CO_2 (Carbon Dioxide) that a ship emits in relation to the goods transported. The International Maritime Organization (IMO) adopted EEDI index in order to reduce the emission of Greenhouse Gases (GHG) by shipping as a mandate to the Kyoto Protocol. All new ships over 400 gross tonnages from the 1st of January, 2013 have to fulfill the minimum criteria of the EEDI. EEDI actually defines the minimum energy efficiency level expressed in tones of CO_2 emitted per 'Capacity mile' which all news ship must comply. The aim of this paper is to find the impact of EEDI on ship design parameters and hydrodynamics for container vessels. The EEDI is calculated with the current IMO formulation and guideline. Finally, the results are presented as the effect of the variations of ship design parameters such as Length, Beam, Draught and Prismatic Coefficient on EEDI and hydrodynamics of ship. Guide lines and suggestion have also been made based on the results to achieve the required EEDI. Since this index has been criticized right from the beginning, an effort is also made to analyze the criticism against the present EEDI formulation, guideline and reference line.

Keywords: EEDI, IMO, MARPOL, GHG, Froude Number, MEPC.

1. Introduction

As a mandate to Kyoto Protocol in order to reduce global [1] CO_2 emission, Marine Environmental Protection Committee (MEPC) under IMO has developed the EEDI which has been came into force on the 1st January, 2013 to create stronger incentives for further improvements in ships' fuel consumption. Around 90% of global trade is carried by sea [2] for being the most economical mode of transport and second IMO Green House Gas (GHG) Study in 2009 [3] estimated that shipping industry in the world has emitted 1.046 million tonnes of CO_2 in 2007, which corresponds to 3.3% of the global emissions at that time. It is also estimated in the study that by 2050, in the absence of policies, CO_2 emissions from international shipping may grow by a factor of 2 to 3 as compared to the emissions in 2007 due to present trend of rise of shipbuilding industry.

The main objectives of IMO are to achieve a minimum energy efficiency level for new ships and stimulate the technical development of all the components influencing the fuel efficiency of a ship. The regulations apply to all ships of 400 gross tonnages and above. Simply EEDI is described as the emissions of a vessel under design condition divided by the transport work done in same condition. The Regulation has a set of initial values for the required EEDI which are individualized for each ship type through a reference line. The reference line of each ship type will also give the value of the required EEDI for each ship's size. Finally, the regulation includes a step–by-step phase-in scheme for reduction of the required EEDI values.

For most ship owners, shipping and ship design companies, it becomes interesting and scary in some way. Researchers like Jack Devanney along with some other researchers have already made their stands against EEDI. It is been criticized that EEDI formulation violates basic Naval Architectural Formula or hydrodynamics of ship and it actually influences to build smaller and slower vessels. It is of a great interest to investigate the ship design particulars in lieu of EEDI and to check the influence. The investigation in this paper has been carried out for Container Vessels. The impacts of EEDI on Container vessel design have been discussed thoroughly and the results with suggestion are presented for better design in terms of EEDI.

2. Brief Description of EEDI

2.1 Mathematical Formulation

The following gives the brief description and calculation procedure of EEDI [4]. Basically EEDI formula consists of four parts which gives different ship design criteria. The formulation is developed in the following manner:

$$EEDI_{attained} = \frac{CO_2 \text{Emission}}{\text{Transport work}}$$

$$= \frac{\text{Power} * \text{Specific Fuel Consumption} * CO_2 \text{Conversion Factor}}{\text{Capacity} * \text{Speed}}$$

$$= \frac{\text{Emission from Main Engine} + \text{Emission from Auxiliary Engine} + \text{Emission for running shaft motor} - \text{Efficient Tech. Reduction}}{\text{Capacity} * \text{Reference Speed}}$$

$$= \frac{\text{Emission from Main Engine} + \text{Emission from Auxiliary Engine} + \text{Emission for running shaft motor} - \text{Efficient Tech. Reduction}}{\text{Capacity} * \text{Reference Speed}}$$

$$= \Big[\big(\textstyle\prod_{j=1}^{n} f_j\big) * \big(\sum_{i=1}^{nME} P_{ME(i)} * C_{FME(i)} * SFC_{ME(i)}\big) + \big(P_{AE} * C_{FAE} * SFC_{AE}\big) + \Big(\big(\prod_{j=1}^{n} f_j * \sum_{i=1}^{nPTI} P_{PTI(i)} - \sum_{i=1}^{neff} * P_{AEeff(i)}\big) * C_{FAE} * SFC_{AE}\Big) - \big(\sum_{i=1}^{neff} f_{eff(i)} * P_{eff(i)} * C_{FME} * SFC_{ME}\big)\Big] * \frac{1}{f_i * f_c * \text{Capacity} * V_{ref} * f_w}$$

$$= \frac{kw * \frac{g_{fuel}}{kwh} * \frac{g_{CO2}}{g_{fuel}}}{\text{Tonne} * \text{knotical mile/h}}$$

$$= \frac{g_{CO2}}{\text{Tonne} * \text{knotical mile}}$$

The calculated EEDI for a ship will be called the attained EEDI. This attained EEDI must be less than the reference EEDI [5] or reference line. This reference line becomes stringent at different phases.

The Reference line values shall be calculated as follows:

$$\text{Reference line value} = a \times b^{-c} \quad (1)$$

Where a, b and c are the parameters given in Table 1 [6]. The reference line is based on the vessel database of Lloyd's Register Fair play [7]. Figure 1 gives a sample reference line for Container Vessels as per Lloyd's Register Fair play database. The present EEDI rules will be more stringent in different phases [6]. Table 2 shows the phase in scheme for reduction of required EEDI for different ship types.

Table 1. Reference line parameter value for different types of vessel

Ship type defined in regulation	a	b	c
Bulk carrier	961.79	DWT	0.477
Gas tanker	1120.0	DWT	0.456
Tanker	1218.8	DWT	0.488
Container ship	174.22	DWT	0.201
General cargo ship	107.48	DWT	0.216
Refrigerated cargo carrier	227.01	DWT	0.244
Combination carrier	1219.0	DWT	0.488

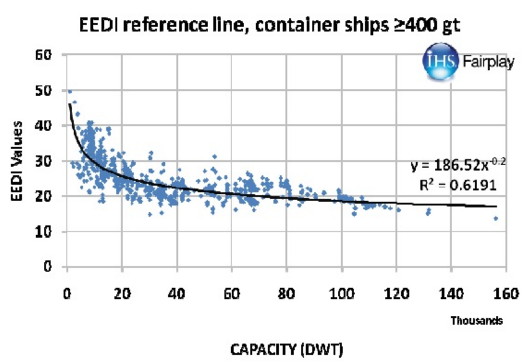

Fig. 1. Reference line sample for Container vessel

Table 2. Phase in scheme for reduction of required EEDI for different ship types.

Ship Type	Size (DWT)	Phase 0 1st Jan 2013–31st Dec 2014	Phase 1 1st Jan 2015 – 31st Dec 2019	Phase 2 1st Jan 2020–31st Dec 2024	Phase 3 1st Jan 2025–and onwards
Container ship	≥15000	0	10	20	30
	10,000– 15,000	n/a	0-10*	0-20*	0-30*

* Reduction factor to be linearly interpolated between the two values dependent upon vessel size. The lower value of the reduction factor is to be applied to the smaller ship size.

3. Impact of EEDI on ship design and hydrodynamics of ship

3.1 Methodology

In order to carry on this analysis, propulsion power is predicted by the Holtrop-Mennen [8] [9] method and EEDI (attained and reference) with current IMO adopted formulation. A parametric analysis is then made considering all hydrodynamic parameters to observe the effect on EEDI. Then EEDI is presented graphically against each parameter. Effective power (P_E)/Displacement curve is plotted against each parameter to observe whether this curve follows the attained $EEDI_{ATTAINED}$ curve or not. Since $EEDI_{ATTAINED}$ is proportional to the Power (kW)/Capacity (tonne) when Specific Fuel Consumption (SFC) and V_{REF} are constant $EEDI_{ATTAINED}$ curve should have the same trend line as the effective power (PE)/Displacement has.

It should be noted that the change of EEDI has to be calculated by considering the dependency of all parameters together to have the actual change in EEDI. As the ship design parameters and coefficients are interlinked to one another it is important to investigate the total impact. For this reason after considering the impact of individual parameters of on EEDI, best design parameters are calculated considering the dependency of those parameters to each other.

3.2 Change in EEDI for Changing rent Individual Ship Design Parameters for Container Vessel

The major ship's hydrodynamic design parameters, such as the Speed (V), Length (L_{WL}), Breadth (B_{MLD}), Draft (T), L/B ratio, B/T ratio and Prismatic coefficient (C_P) are considered in the analysis. Table 3 shows the ranges of all these parameters that have been considered in the analysis.

Table 3. Design parameters considered for to investigate the impact of speed on EEDI.

Analysis Type	V (knots)	L_{WL} (m)	Froude No. F_N	B_{MLD} (m)	T (m)	L/B	B/T	C_P
Change in Speed(V)	10-39	200	0.11-0.45	33.3	11.1	6	3	0.6
Change in Length (L_{WL})	20	100-250	0.2-0.32	16.7-41.7	5.56-13.9	6	3	0.6
Change in Beam (B_{MLD})	20	200	0.23	22.2-33.3	7.41-11.1	6-9	3	0.6
Change in Draft (T)	20	200	0.23	33.3	8.23-11.1	6	3-4	0.6
Change in L/B	20	200	0.23	22.2-33.3	7.41-11.1	6-9	3	0.6
Change in B/T	20	200	0.23	33.3	8.23-11.1	6	3-4	0.6
Change in C_P	20	200	0.23	33.3	11.1	6	3	0.55-0.7

3.2.1 Change in vessel speed (V)

The results for changing EEDI with respect to speed have shown in Figure 2 and 3 which in brief is as follows:

- Speed has a significant impact on EEDI.
- An increase in speed increases the attained EEDI drastically.
- A rapid increase in both $EEDI_{ATTAINED}$ and PE/Displacement ratio is also evident after a certain speed limit.
- Both $EEDI_{ATTAINED}$ and PE/Displacement ratio are following the similar trend line.
- $EEDI_{REFERENCE}$ cuts $EEDI_{ATTAINED}$ line at 21.3 knots meaning that with these design particulars, the vessel is not allowed a speed more than 21.3 knot/hour.

3.2.2 Change in Waterline Length (L_{WL})

The results for changing EEDI with respect to length have shown in Figure 4 which in brief is as follows:

- Length has significant impact on EEDI
- An increase in length decreases attained EEDI.
- A rapid change in $EEDI_{ATTAINED}$ and PE/Displacement ratio is also evident after a certain length.
- Both $EEDI_{ATTAINED}$ and PE/Displacement ratio are following the similar trend line.

3.2.3 Change in Breadth (B_{MLD})

The results for changing EEDI with respect to beam have shown in Figure 5 which in brief is as follows:

- An increase in beam decreases $EEDI_{ATTAINED}$.
- Beam has insignificant impact on EEDI and PE/Displacement and these two lines follow similar trend line.

3.2.4 Change in Draught (T)

The results for changing EEDI with respect to draught have shown in Figure 6 which in brief is as follows:

- An increase in draft decreases $EEDI_{ATTAINED}$.
- There is no significant or rapid change in EEDI and PE/displacement curve.

- Both $EEDI_{ATTAINED}$ and PE/Displacement ratio are following the similar trend line.

3.2.5 Change in L/B ratio

The results for changing EEDI with respect to L/B have shown in Figure 7 which in brief is as follows:

- L/B has significant impact on EEDI.
- An increase in L/B ratio increases $EEDI_{ATTAINED}$.
- Both $EEDI_{ATTAINED}$ and PE/Displacement ratio are following the similar trend line.

3.2.6 Change in B/T ratio

The results for changing EEDI with respect to L/B have shown in Figure 8 which in brief is as follows:

- B/T has insignificant impact on EEDI.
- An increase in B/T ratio increases $EEDI_{ATTAINED}$.
- Both $EEDI_{ATTAINED}$ and PE/Displacement ratio are following the similar trend line.

3.2.7 Change in C_P

The results for changing EEDI with respect to C_P have shown in Figure 9 which in brief is as follows:

- C_P has insignificant impact on EEDI and there is no significant change in EEDI and PE/Displacement curve.
- An increase in C_P increases attained EEDI.
- Both $EEDI_{ATTAINED}$ and PE/Displacement ratio are following the similar trend line.

3.3 Summary of the analysis

Based on the results as described in section 3.2, following suggestion as in table 4 for individual parameters is summarized.

Table4. Suggestion to change the individual ship parameter to improve EEDI.

Vessel type	Speed	Length	Beam	Draft	L/B	B/T	Prismatic Coefficient Cp
Container	Decrease	Increase	Increase	Increase	Decrease	Decrease	Increase

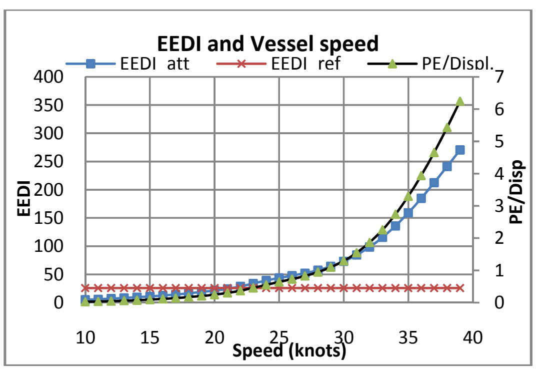

Fig. 2. EEDI for various speed and Froude No.

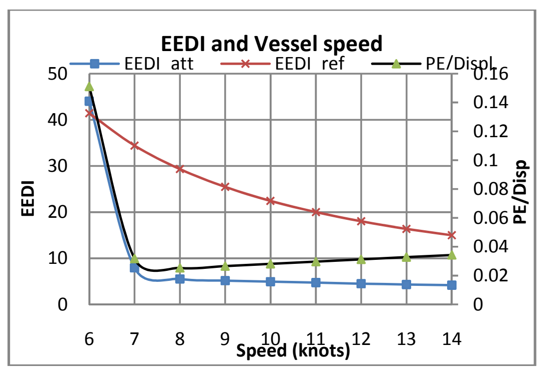

Fig. 3. EEDI at constant Froude No. (0.2) and various speed (Length variable)

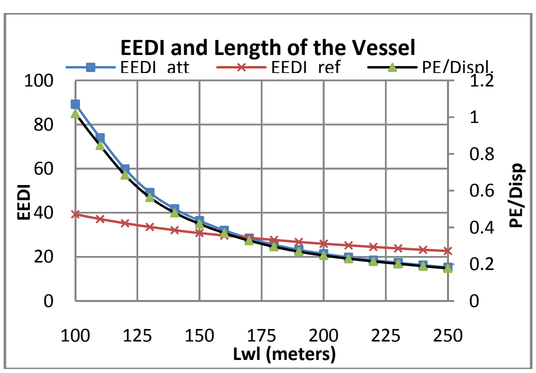

Fig. 4. Changes in EEDI for various Lengths

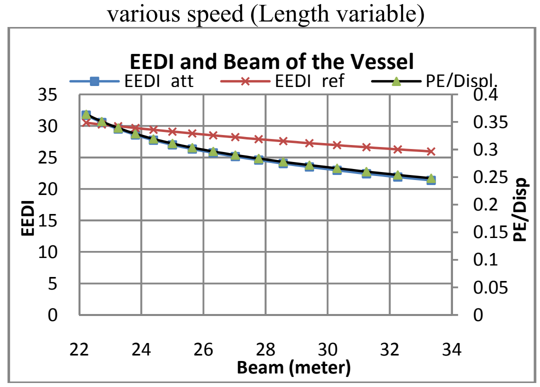

Fig. 5. Changes in EEDI for various Beams

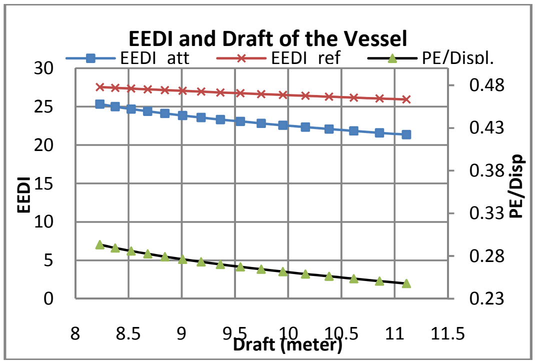

Fig. 6. Change in EEDI at various draft (T)

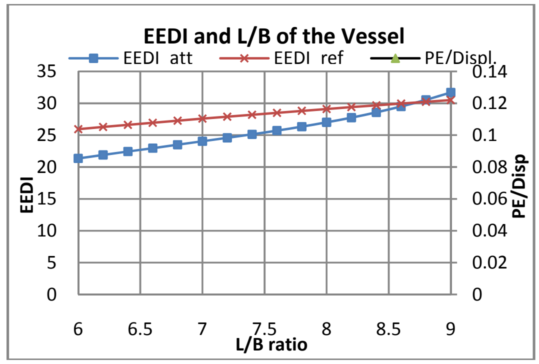

Fig. 7. Change in EEDI at various L/B ratio

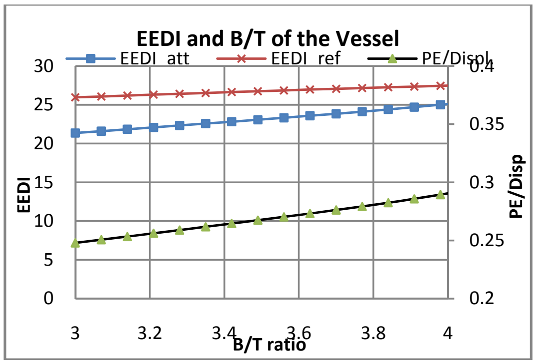

Fig. 8. Change in EEDI at various B/T ratio

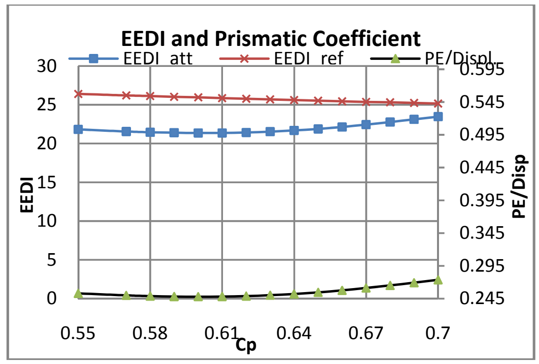

Fig. 9. Change in EEDI at various Prismatic Coefficient (C_P)

3.4 Best Design parameters for Container

In the previous section it has been shown how the individual ship design parameters should be changed in order to have better performance with respect to EEDI. But in reality these parameters are interlinked to each other. For example, while increasing length we may find better EEDI (Fig. 4). But an increase in length will change the L/B ratio for fixed beam as well and overall hydrodynamic coefficients may also be changed. This is also true for B/T ratio and other parameters. Since these hydrodynamic parameters interact each other, in order to achieve the best EEDI for a given case, a Naval Architect must go for a holistic design approach. Holistic design approach will consider the dependency of each parameter and give us the best design parameters in terms of EEDI.

Table 5 and 6 show the result of analysis of two different sized container vessels to observe maximum possible speed and capacity, where the combined impact of all the parameters are considered and optimized for the best result in terms of EEDI, Speed and Capacity.

It has been criticized that small vessels are allowed to have higher EEDI. Fig. 1 also supports this which means IMO is suggesting building small vessels. But if we look at Table 5 and 6 we will find that it is not true. Bigger vessels are allowed to have higher speed than the smaller one as per present EEDI formulation. Though the reference line allows smaller vessels to have higher EEDI does not mean that smaller vessel can attain low EEDI. The attained EEDI for small vessel is also very high (Table 5 and 6). Another major criticism against EEDI is that, it breaks the hydrodynamic rules of Naval Architecture. Fig. 2-9 shows that, $EEDI_{ATTAINED}$ curve follows the same trend as PE/Displacement. So, it can also be concluding here that, EEDI does not contradict the hydrodynamic rules of Naval Architecture.

But it is true that, no matter how we modify or improve the hull design, it will not be enough to have a vessel that will have the same present speed with 30% reduced EEDI (Phase 3 of CO_2 reduction). The present efficient hulls are good enough in most cases to comply the current phase 0 and with some modification of hull parameters and improved hull design, phase 1 requirements can be achieved without reducing the speed, but it is not possible to move further phases at present technology.

Table 5. Optimum dimension for maximum speed

Max Speed (knots)	L (m)	F_N	L/B	B (m)	B/T	T (m)	C_P	Capacity (Tonne)	R_T (kN)	$EEDI_{ATT}$	$EEDI_{REF}$
24	250	0.25	5	50	4	12.5	0.65	44824	2444	21.69	21.89
11.8	100	0.19	5	20	4	5	0.65	2868	265	37.87	37.95

Table 6. Optimum dimension for maximum capacity

Max Speed (knots)	L (m)	Fn	L/B	B (m)	B/T	T (m)	Cp	Capacity (Tonne)	R_T (kN)	$EEDI_{ATT}$	$EEDI_{REF}$
21	250	0.216	5	50	3	16.67	0.8	73558	3655	19.73	19.83
14.2	100	0.233	5	20	3	6.67	0.8	4707	389	33.83	34.36

4. Conclusions

According to IMO the adoption of EEDI will reduce up to 200 million tonnes of CO_2 from the atmosphere annually by 2020 if the world trade goes as it is today and by 2030 this number will be 420 million tonnes [2]. Though the main intention of adopting EEDI is to reduce the CO_2 emission from the shipping industry, it will also force the shipping industry to have more and more energy efficient ships. If we do not have efficient innovative technology in the near future, power and speed cut off will be the only solution to achieve required EEDI at higher phases. This may give and enormous impact on global economy since 90% of the global cargo is carried out by marine transports.

Though EEDI is not an accurate emission indicator at present, it is better to have an emission control instrument at the design stage. Different work groups at MEPC under IMO are continuing their work to eliminate the problems associated with EEDI formulation and reference line values. The committee has approved draft amendments to MARPOL Annex VI, with a view to adoption at MEPC 66, to extend the application of EEDI to ro-ro cargo and passenger ships, LNG carriers, cruise passenger ships, and to exempt ships not propelled by mechanical means. Therefore there is every confidence in the international maritime organizations, shipbuilders and owners that the EEDI will result in more energy efficient ships, in reduced emissions of GHGs, in environmental effectiveness and in a significant contribution by a global industry to the global efforts to stem climate change.

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