Clarifications on the proposed EEDI correction factor for differences in operational profile for General cargo ships as outlined in MEPC 64/4/18 and MEPC 64/INF.9

Place and date: Groningen, 6 February 2013

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Executive summary

During the 64th session of the Marine Environment Protection Committee, three correction factors were proposed to improve the inclusion of small General cargo ships into the EEDI regulatory framework. The Working Group on Air Pollution and Energy Efficiency in principle supported the proposal, and agreed to continue the measures for General cargo ships with a view to finalize it at the next session. However, a small number of delegations had some remarks concerning the proposed correction factors. The following remarks were made by the delegations:

12.23 "*Denmark reiterated its view that a correction factor including the speed should not be accepted as stated under the discussions on the ro-ro ships*".

12.24 "*A concern was expressed that the application of the proposed correction factors in terms of ship size could possibly lead to similar sized ships at the upper end of the range considered with and without correction factors*".

The aim of this research project is to examine whether the remarks are justified. To further analyse the effect of the proposed correction factor, the influence of the correction factor for a higher minimum operational speed was determined for over 30 ships over a range of speeds. The resulting plots have been analysed in detail. Therefore it was analysed whether:

- the correction factor might enable the possibility of designs with very high speed to power exponents;
- the correction factor for some designs, may result in a nearly constant EEDI across a limited speed range, whereas actual CO_2 emissions do increase when the speed is increased;
- it, in rare cases, the correction factor may lead to EEDI values that increase when the speed is reduced.

Previous reports have shown that there is a clear need for these vessels to sail at high operational speeds. This analysis shows that the use of the speed in the correction factor is not in contradiction with the principles and objectives of the EEDI. Only highly optimized ships receive a correction which is sufficient to meet the EEDI requirements. Optimization thus remains necessary.

There might occur boundary problems near the upper edge of 20.000 DWT for which the original proposed correction factor is valid. Therefore, it is proposed to drop the upper boundary of 20.000 DWT, thus valid for all General cargo ships and to include a maximum value of the volumetric Froude number of 0.6 for all General cargo ships above 3.000 DWT. This is found an effective way to avoid future excesses. The resulting factor is:

$$f_j = \frac{0.174}{Fn_{\nabla}^{\ 2.3} \cdot C_b^{\ 0.3}}$$

In which:

$$Fn_{\nabla} = \frac{V_{ref}}{\sqrt{g \cdot \nabla^{\frac{1}{3}}}}$$

Vref	Reference speed	[m/s]
g	Gravitational acceleration	[m/s^2]
∇	Displacement moulded	[m^3]

And:

$$C_b = \frac{\nabla}{L_{pp} \cdot B_m \cdot T}$$

C_b	=	Block coëfficient	[-]
∇	=	Displacement moulded	[m^3]
L_{pp}	=	Length between perpendiculars	[m]
B_m	=	Beam moulded	[m]
T	=	Draught at summer loadline	[m]

The following preconditions apply:

If f_j > 1 than f_j = 1 and if $Fn_{\nabla} > 0.6$ than $Fn_{\nabla} = 0.6$.

The analysis shows that in rare cases speed to power exponents of up to 7 do occur. However, these are the vessels which also meet the EEDI requirements without any correction factor, and which than already have a speed to power exponent of more than 6. So, it is in our opinion not the speed to power exponent in absolute terms which determines whether the correction factors behaves conveniently, but the increase in speed to power exponent.

By means of a mathematical derivation the impact of the speed to power exponent on the behaviour of the Corrected Attained EEDI curve over a range of speeds is shown. This dependency explains when the Corrected Attained EEDI is decreasing, flat or increasing. This dependency shows that in rare cases parts of the Corrected Attained EEDI curve is flat. However, for a decreasing Corrected Attained EEDI curve, the speed to power exponent needs to be lower than 3.3. For ships designed for high speeds, it is not very likely that the speed to power exponent is below 3.3 near the reference speed.

We therefore conclude, based on the outcome of this study, that the correction factor which accounts for large differences in operational profile is not in conflict with the principles of the EEDI. And, inclusion of the correction factors as proposed in MEPC 64/8/18 will improve the inclusion of small General cargo ships within the EEDI regulatory framework.

1 Introduction

During the 62nd session of the Marine Environment Protection Committee a new chapter of MARPOL ANNEX VI was adopted. This new chapter aims to reduce the emission of Greenhouse Gases by shipping and more specifically aims to reduce CO_2 emissions. One of the most noticeable aspects of the new regulations is the "Energy Efficiency Design Index", or EEDI, which defines a minimum "energy efficiency level", expressed in tons of CO_2 emitted per "Capacity mile", which all new designs should meet.

Even though the new MARPOL regulations came into force as of the first of January 2013, concerns regarding the effect of the EEDI regulations for small General cargo ships still exist. With the currently accepted formula and guidelines there continues to be a high scatter of Attained EEDI values for the smaller deadweight ranges for General cargo ships. Because of the difficulties with the derivation of a robust reference line for the smaller vessels, small General cargo ships up to 15.000 DWT have been excluded from the first phase of implementation of the EEDI requirements. In the meantime IMO invites parties to propose alternative measures or methods to improve the robustness of the EEDI methodology for small General cargo ships.

CMTI commissioned MARIN and Conoship International B.V. to investigate the cause of the poor reference line correlation for small General cargo ships and to propose alternative measures. The results of that research project included the identification of three design elements, typical for small General cargo ships, which mainly cause the high scatter. To improve the inclusion of General cargo ships up to 20.000 DWT in the EEDI regulatory framework, three correction factors were developed based on the identified normative design elements. The correction factors were proposed during the 64the session of the Marine Environment Protection Committee, by means of a submission of the Netherlands[1] and the full report of the research and related to the submission[2]. The three proposed correction factors are:

1. Factor to account for the differences in minimum required operational speed between small General cargo ships that have been optimised for different trades, f_j;

2. Factor to account for the differences between ships with and without cargo handling equipment, $f_{l;}$

3. Factor to address differences in additional class notations that can lead to relatively higher lightweights, $f_{l,Gen.Cargo}$.

[1] MEPC 64/4/18

[2] MEPC 64/INF.9

The proposed correction factors effectively reduces the scatter of attained EEDI values for small General cargo ships. For the database as used in this study, containing more than 70 recently build General cargo ships, the "R^2" factor[3] increased from was 0.403 to 0.55.

The submission as proposed by the Dutch delegation was in principle accepted. However, two delegations expressed their reservations concerning the proposal. During the 64th session of the Marine Environment Protection Committee, the following remarks were noted[4]:

12.23 "*Denmark reiterated its view that a correction factor including the speed should not be accepted as stated under the discussions on the ro-ro ships*".

12.24 "*A concern was expressed that the application of the proposed correction factors in terms of ship size could possibly lead to similar sized ships at the upper end of the range considered with and without correction factors*".

The aim of this report is to provide the results of an investigation done to verify the above stated remarks. Therefore it was analysed whether:

- the correction factor might enable the possibility of designs with very high speed to power exponents;
- the correction factor for some designs, may result in a nearly constant EEDI across a limited speed range, whereas actual CO_2 emissions do increase when the speed is increased;
- it, in rare cases, the correction factor may lead to EEDI values that increase when the speed is reduced.

In chapter 2 the consequences of not introducing a correction factor for a higher minimum required operational speed are identified. Chapter 3 deals with the comments regarding the use of speed as a correction factor. Further a maximum to the volumetric Froude number is introduced in chapter 3. In chapter 4 the different methods for smoothening the transition near the upper edge of 20.000 DWT are introduced, and a proposal is made for the most suitable method.

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[3] The R^2 coefficient, or the correlation coefficient, is a statistical measure which indicates how close the regression line approximates the real data points. A R^2 of 1 indicates a perfect fit.

[4] MEPC 64/WP.11

2 Consequence of not adopting a correction factor for higher minimum operational speed

MEPC 215 (63) states that the purpose of the EEDI is: *"to provide a fair basis for the comparison, to stimulate the development of more efficient ships in general and to establish the minimum efficiency of new ships depending on ship type and size".*

Previous research identified a very high scatter and a very low reference line correlation for small General cargo vessels. Clearly, for small General cargo vessels, up to 20.000 DWT the EEDI regulatory framework does not provide a fair comparison. In their previous report, Conoship and Marin identified a number of causes for the high scatter and the low reference line correlation and proposed to improve the fairness of the comparison by including three new correction factors. One of the proposed correction factors is a factor to correct for large differences within the operational profile of small General cargo ships regarding to sailing area and higher minimum operational speed.

The previous Conoship and Marin reports clearly indicated a number of reasons why a higher minimum required operational speed is considered to be justified[5]. Not including such a correction factor will have numerous consequences. The main consequence is that the inclusion of small General cargo ships within the EEDI framework will remain unfair as the scatter remains high. Further, without a correction factor to account for this higher minimum operational speed, building relatively small General cargo ships with a higher minimum operational speed will no longer be possible, as they will not meet the EEDI requirements. This again will have numerous consequences, as also described in the previous reports. If it is not longer possible to built these kind of vessels shipping companies and other shippers in the logistic chain have to search for alternatives:

1. Continue operations with old less environmentally friendly vessels (not only regarding CO_2, but also regarding NOx, SOx, etc.);
2. Use container vessels ("exclusively designed for carriage of containers") for the transport of general cargo for which a higher minimum operational speed is required. However as these vessels are not designed and optimized for the carriage of general cargo, there is the risk of structural damage to the ship (tank top, hatches) potentially putting the crew and the environment at risk;
3. Use a considerably larger vessel, with a reference speed equal to the required high speed of the smaller vessel. Because of the much larger size, the larger vessel might be able to comply with the EEDI regulations without the proposed correction factor for the operational profile. As a consequence, it is to be expected that more transport to and from ports is required, since the number of ports in which the larger vessel can call will be considerably lower. This will put an additional burden on the environment.

[5] MEPC 64/4/18 and MEPC 64/INF.9

Each of these alternatives will result in an increase of the CO_2 emissions. The older tonnage is often not extensively optimized and thus emits more CO_2 than newly designed optimized vessels which meet the regulations through the proposed correction factor. Using container vessels for this trade will result in higher CO_2 emissions, as the required EEDI values for container vessels allows more power be installed to reach a Vref (i.e. less hull optimization required) than in the case of a General cargo vessel for which the correction factor is applied. See example 1 below. Further, the cut-off limit for Container vessels (phase 1) is 10.000 DTW, and thus in that case for many small General cargo vessel designs there is no need to comply with the regulations. The 3rd alternative would result in an overall higher CO_2 emission. Despite its lower attained EEDI, the absolute amount of CO_2 emitted by the larger vessels is considerably higher. See example 2 below.

Also, lowering the speed until the EEDI requirement is met, without the introduction of a correction factor, and simply use more ships to provide the same transport capacity is not feasible.. The raison d'être of the fast General cargo vessels is their capability to reach a higher minimum operational speed. Without the possibility to reach this speed, shipping companies will seek refuge in the aforementioned alternatives 1 to 3, which will lead to higher CO_2 emissions.

Example 1

The first example is relating to alternative two above; using container ships for trades which are normally maintained by General cargo ships. That is; the cargo which is to be transported in that trade is other than containers, and a General cargo ship is ideally equipped to carry such cargo. Below a description of the ship. In Table 1, the main dimensions of the ships are given.

Ship A A large General cargo ship designed for a particular high speed, the reference speed is more than 17 knots. The deadweight of the ship is about 10006 tons. The EEDI is calculated following the guidelines for a General Cargo Ship.

Ship B Identical ship as Ship A, however the EEDI is calculated following the guidelines for Container ships. Conform the guidelines for calculating the EEDI for container ships, 70 percent of the DWT is used in the calculations. The reference speed is at the draught of 6.1 m., than the deadweight is 70 percent of the total deadweight.

Table 1 Main dimensions of Ship A and Ship B

		Ship A - General cargo ship	**Ship B - Container ship**
DWT	[mt]	10006	7004 (70% of total DWT)
VRef	[knots]	16.9	17.4
Lpp	[m]	125.6	125.6
Bm	[m]	21.5	21.5
Dm	[m]	9.3	9.3
Tsummer	[m]	7.38	6.10

Fn	[-]	0.252	0.255
P_{ME}	[kW]	5130	5130
P_{PTO}	[kW]	360	360
CF	[t-CO2/t-Fuel]	3.206	3.206
S.f.c.	[g/kWh]	180	180

For both vessels, the Attained and Required EEDI are calculated. In the calculations, the following assumptions are included:

1. For both vessels the constant C_F is assumed to be 3.206, corresponding with the fuel DO/GO;
2. The required electrical power is assumed to be provided by a shaftgenerator;
3. The ships are not equipped with a power take in installation, nor equipped with other energy efficient technology;
4. The ships do not have an ice class notation.

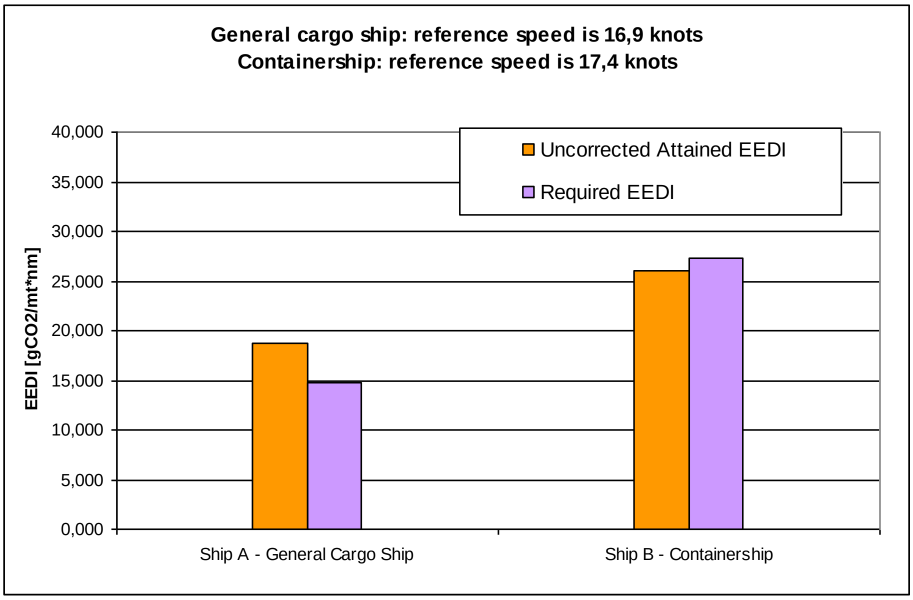


Figure 1 Comparison of EEDI values of Ship A (General cargo ship) and Ship B (Container ship)

Figure 1 above reveals that the ship type is crucial, as Ship A does not meet the requirements and Ship B meets the requirements. In fact both ships emit an equal amount of CO_2 to transport the same amount of cargo. Carrying General cargo with container ships is unwanted both because of the possible damage to the construction as well as the potential increase in CO_2 emissions (even more engine power can be installed on Ship B, and Ship B will than still meet the EEDI Requirements).

Example 2

Consider a trade in which a transport capacity of about 3500 ton and reference speed of 15.1 knots is required, with a distance between two ports of 750 nm. The vessel should be able to maintain a roundtrip within 5 days, in which 1 day in port is included. An optimized small General cargo vessel would result in a vessel with the characteristics of vessel A in table 1. This vessel is actually built and extensively optimized. To meet the EEDI regulations it does require the inclusion of a correction for the operational profile. Vessel B in table 2, is far larger and would meet the EEDI requirements without a correction factor.

Ship A A small General cargo ship designed for a particular high speed, the reference speed is 15.1 knots. The deadweight of the ship is about 3600 tons, which is optimal for the specific trade.

Ship B A large General cargo ship designed for a particular high speed, the reference speed is more than 18 knots. However, for the sake of a fair comparison the reference speed is assumed to be 15.1 knots. The deadweight of the ship is about 29700 tons, which is far too high for the specific trade.

The main particulars of both vessels can be seen in
Table 2 below.

Table 2 Main dimensions of Ship A and Ship B

		Ship A	**Ship B**
DWT	[mt]	3600	29700
VRef	[knots]	15.1	15.1
Lpp	[m]	98.2	183.3
Bm	[m]	15.6	27.8
Dm	[m]	7.4	15.5
Tsummer	[m]	5.8	11.2
Fn	[-]	0.250	0.183
P_{ME}	[kW]	2137	5419
P_{PTO}	[kW]	150	442
CF	[t-CO2/t-Fuel]	3.206	3.206
S.f.c.	[g/kWh]	180	180

For both vessels, the Attained and Required EEDI are calculated. In the calculations, the following assumptions are included:

1. For both vessels the constant C_F is assumed to be 3.206, corresponding with the fuel DO/GO;
2. The required electrical power is assumed to be provided by a shaftgenerator;
3. The ships are not equipped with a power take-in installation, nor equipped with other energy efficient technology;
4. The ships do not have an ice class notation.

In Figure 2 the resulting EEDI values, both Attained and Required, are shown. Ship A does not meet the requirements at all. Ship B meets the requirements easily. See the figure below.

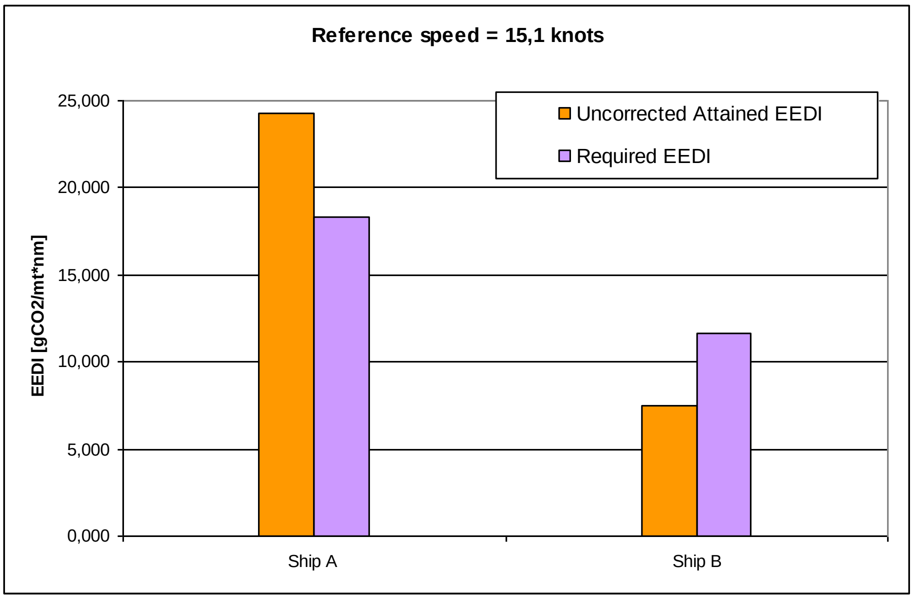


Figure 2 Comparison of EEDI values of Ship A and Ship B

Based on the Attained EEDI values of both vessels, Ship B puts less burden on the environment. However, it is not the EEDI which is to be compared for this trade, as the required cargo capacity is only 3500 tons. The actual amount of CO_2 produced for transporting 3500 tonnes of cargo between the two ports is a better reflection of the costs of the environment.

For a trade of 750 nautical miles, it takes about 50 hours at a speed of about 15.1 knots. To calculate the amount of CO_2 produced, the formula of Attained EEDI is used. The numerator of the formula is defined by the following units:

$$P_{ME} \cdot C_F \cdot S.F.C. = kW \cdot \frac{gCO_2}{gFuel} \cdot \frac{gFuel}{kWh} = \frac{gCO_2}{h}$$

So by determining the numerator of the Attained EEDI value, and by multiplying the numerator by the time required for the transportation, the amount of CO_2 produced for the specific trade can be calculated. So the total amount of CO_2 is determined by the following formula (according to the principles of EEDI):

$$(P_{ME} \cdot C_F \cdot S.F.C._{ME} + P_{AE} \cdot C_F \cdot S.F.C._{AE}) \cdot sailinghours$$

Ship B does not utilize it's full power to sail 15.1 knots with 3500 ton cargo. With use of the admiralty constant, the required power is determined to be 2826 kW. The amount of CO_2 produced for 750 nm is:

Ship A $$(2137 \cdot 180 \cdot 3.206 + 150 \cdot 180 \cdot 3.206) \cdot 50 = 65989098 gCO_2 = 65.99 \, ton \; CO_2$$

Ship B $$(2826 \cdot 180 \cdot 3.206 + 442 \cdot 180 \cdot 3.206) \cdot 50 = 94294872 gCO_2 = 94.29 \, ton \; CO_2$$

Ship B produces about 43% more CO_2 for the same trade compared to Ship A and could even be less optimized (considering the difference between attained and required EEDI) and still meet the regulations. This would result in a higher P_{ME} and thus even higher CO_2 emissions. Instead of reducing CO_2 emissions, the CO_2 emissions will increase when a trade maintained by a small optimized General cargo vessel with a higher minimum operational speed will be maintained by a larger vessel.

3 Inclusion of speed in correction factor vs. principles of EEDI

The noted remark of Danish delegation on the proposed correction factor to account for minimum operational speed was:

12.23 "*Denmark reiterated its view that a correction factor including the speed should not be accepted as stated under the discussions on the ro-ro ships*".

To analyse the effect of the proposed correction factor, the influence of the correction factor for a higher minimum operational speed was determined for over 30 ships over a range of speeds. The resulting plots have been analysed in detail. Therefore it was analysed whether:

- the correction factor might enable the possibility of designs with very high speed to power exponents;
- the correction factor for some designs, may result in a nearly constant EEDI across a limited speed range, whereas actual CO_2 emissions do increase when the speed is increased;
- it, in rare cases, the correction factor may lead to EEDI values that increase when the speed is reduced.

The results of the analysis are presented in this chapter. The chapter ends with the proposal of the inclusion of a maximum to the correction factor.

3.1 High speed to power exponents

It is true that the inclusion of a correction factor for the operational profile will lead to higher speed-power exponents, however it is a misconception that the implementation will lead to speed-to-power exponents for general cargo vessels of far above 7.

In Figure 3, a speed to power curve of a common General cargo ship is shown, by means of the blue line. The exponent of the speed to power curve is represented by means of the red curve. Up to a about 8 knots, the speed to power exponent is constant. Between 8 and 12 knots the speed to power exponent rises with a low degree. From 12 knots on the speed power exponent rises sharply. When the speed to power curve is steep, the speed to power exponent is also very high.

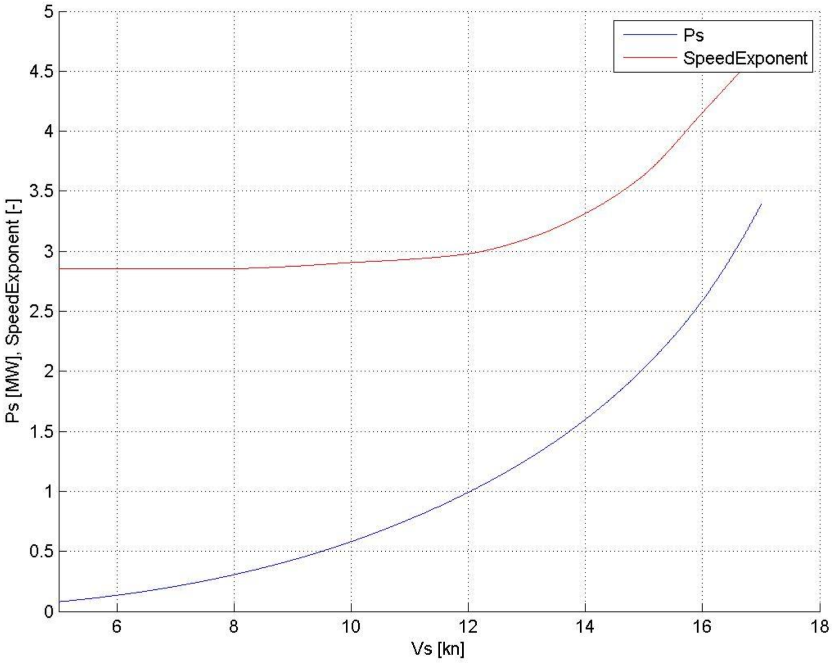


Figure 3 Speed power curve of a common vessel, with the speed to power exponent

For the vessels in the database of this research, the speed to power exponents have been determined. Ships with ice class notation were not taken into account, as the power correction factor for ice class “pollutes” the data and the subsequent analysis. Further, the vessels that don’t meet the required EEDI, even with the implementation of the correction factor are not considered, as their resulting speed-power exponent is not relevant since the regulations are not met. The speed to power exponents of the remaining vessels can be seen in the figure below. Of these ships also plots of the Corrected Attained EEDI curves can be found in the Appendices to this document. A curve of Corrected Attained EEDI value is the result of calculating the Attained EEDI and Corrected Attained EEDI over a range of speeds, and hence plotting the resulting values over this range of speeds (see further section 3.2). See Figure 4 and Appendix 1 to 18.

In Figure 4, for all 11 vessels the speed to power exponent corresponding to the reference speed is shown by the blue bars. The orange bars represent the point where the uncorrected EEDI corresponds with the Required EEDI. I.e., the maximum possible exponent without correction. The green bars represent the exponents corresponding to the speed with which the Corrected Attained EEDI equals the Required EEDI. If no green bar is shown, the correction is applied on speeds exceeding the speed where Attained EEDI equals the Required EEDI. See for example Appendix I, in which difference between a ship of which the Attained EEDI is corrected at speeds below the Required EEDI (ship 5) and a ship for which the correction factor does not apply on speeds below the speed where the Attained EEDI equals the Required EEDI.

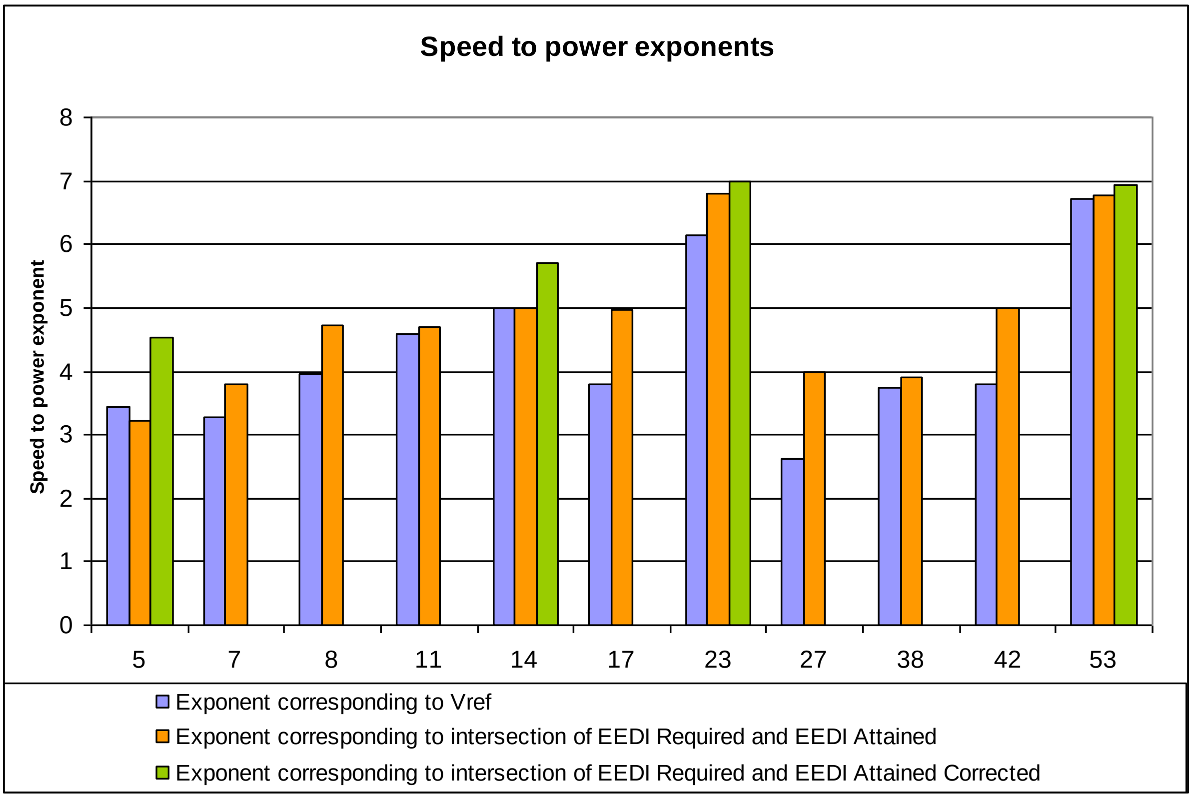


Figure 4 Speed to power exponents.

The majority of the ships in the selection, 7 out of 11, have a speed to power exponent which is between 3 and 4 near their reference speed. The rest of the ships have an exponent above 5. Two ships have an exponent of six and higher, which is considered to be high. Note that both ships do meet the requirements, even without the correction factor for higher minimum operational speed applied. This is a result of the speed to power curve of these vessels: the curve remains 'flat', until a certain speed where the slope of the curve suddenly rises quickly. The reference speed of these vessels is just in the beginning of the steep part.

Obviously with the correction factor applied, it is possible to meet the requirements with at a higher reference speed, however the possible speed to power exponent is not much higher than the exponent corresponding to the speed without correction. For the two ships with the highest exponent, the exponent increases from 6.8 to 7 and from 6.7 to 6.9. This shows that operating with high speed to power exponents does occur, but not as a result of the proposed correction factor for higher minimum operational speed.

3.2 Slope of the Attained EEDI curve

For the vessels in the database the Corrected Attained EEDI curve was analysed; that is, the curve resulting from the calculation of the Corrected Attained EEDI over a range of speeds. In the analysis the focus was on:

- whether or not for some designs, it may result in a nearly constant EEDI across a limited speed range, whereas actual CO_2 emissions do increase when the speed is increased;
- whether or not it, in rare cases, the correction factor may lead to EEDI values that increase when the speed is reduced.

In 3.2.1 it is analysed if and how often this behaviour occurs for General cargo vessels. In 3.2.2 the cause and the consequences of this effect are described.

3.2.1 Analysis of the Attained EEDI curves

For the vessels in the database the attained EEDI is calculated for a range of speeds, as if each speed was the reference speed. Vessels below 3000 dwt were excluded. Furthermore, to improve accuracy, vessels were excluded for which the available speed-power data did not sufficiently extend beyond the vessel's original reference speed. For all of these vessels also the required EEDI and the Corrected Attained EEDI are calculated. The speed-power data which we used to extrapolate around the original Vref came from model tests, or from the MARIN database.

Assumptions made for the calculations are as follows:

1. Some of the ships in the database are ships with an ice class notation. These ships are used in this research as if the ships are without ice class notation. As such the ice class correction method has not been applied.
2. The specific fuel consumption is assumed to be constant, regardless the required propulsive power corresponding with the speed.
3. The factor P_{AE} included in the calculations depends on the factor P_{ME} relating to the speed.
4. If the EEDI is calculated for a condition which is far above or below the original reference condition, the weight of an engine which is able to provide the required power might also be far above or below the actual installed engine. This has its influence on the deadweight, and as such on the EEDI. This phenomena has been accounted for. The vessel will still have the same scantling draught, volume of displacement, block coefficient and speed/power curve. The deadweight at the new engine power is found by adding the change in machinery weight to the original deadweight (with original engine). The machinery weight is calculated by: $0.01MCR + 0.69MCR^{0.7}$, with MCR in kW and the machinery weight in tons[6]. Not only the attained EEDI is affected by the change in deadweight, but also the required EEDI will change slightly with speed (engine power).

This analysis results in a large number of graphs, attached to this report in Appendices 1 to 18. The plots show that for all ships, when the speed is increased, at some point the EEDI will be corrected. However, for the majority of the ships this happens at a combination of speed and power at which they

[6] *Practical Ship Design*, D.G.M. Watson

will not meet the EEDI regulations, even when corrected. The graphs further show that for most of the vessels, also the Corrected Attained EEDI continuous to rise sharply, see for example Figure 5.

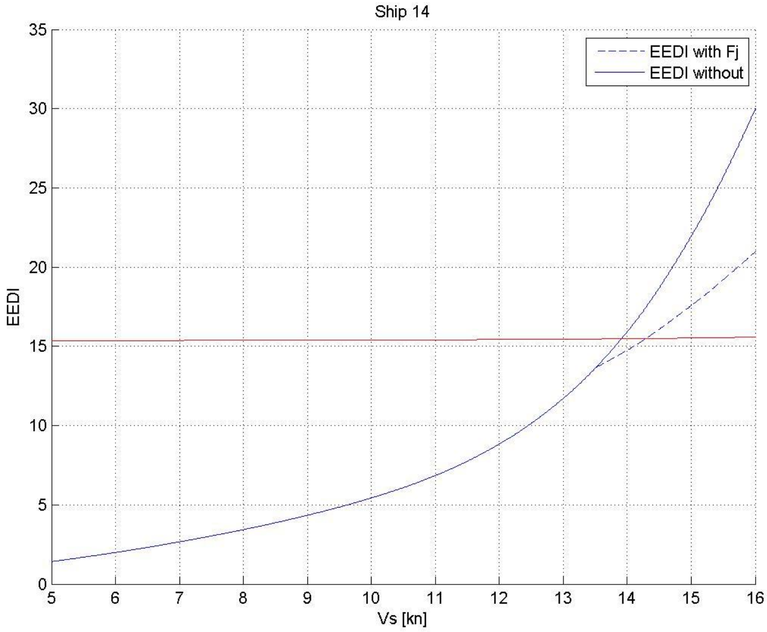


Figure 5 Required EEDI, Attained EEDI and Corrected Attained EEDI of a ship 14.l

Only for one of the vessels a very "flat" slope of the attained EEDI curve was identified, see Figure 6. For this vessel, with a reference speed of about 15.1 knots, the slope of the Corrected Attained EEDI becomes nearly flat between 12.8 and 14.5 knots.

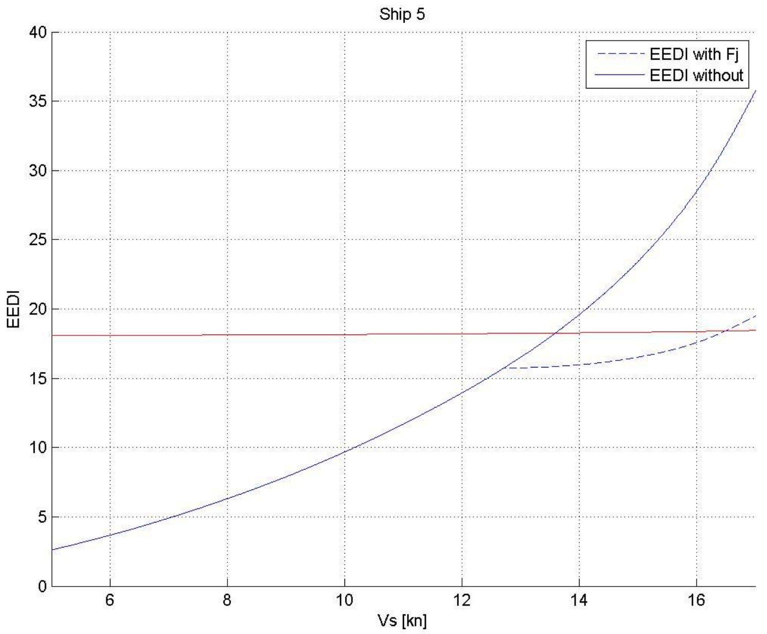


Figure 6 Required EEDI, Attained EEDI and Corrected Attained EEDI of Ship 5

A decreasing Attained EEDI at increasing speed is not identified for any of the vessels in our database. As also shown in [Sweden, MEPC65/4/XX], this behaviour could be caused by the way the auxiliary power was considered in their calculations. When the P_{AE} is kept constant, in some cases the EEDI tends to decrease when the speed is increased. There might be other causes, which will be described in the following sections.

3.2.2 Analysis of cause of the reduced slope for Attained EEDI

The Attained EEDI is dominated by the relationship between the speed, power and the deadweight. The curve of the Attained EEDI as a function of speed is dominated by the relationship between speed and power, as the capacity (deadweight) is constant over speed. The Corrected Attained EEDI curve is the result of the correction factor on the Attained EEDI curve.

The effect of the correction factor on the Attained EEDI is shown by means of a mathematical derivation. It is shown that the curve of the Attained EEDI curve is determined by the relationship between speed and power. That is, the speed to power exponent determines to a great deal the exponent of the Attained EEDI curve. This is equally the case when the correction factor is applied on the Attained EEDI curve.

In the following, the formula for calculating the EEDI is simplified (reduced) so that solely the main contributing components to EEDI remain. This is for reasons to clearly identify the main behaviour of the EEDI, but the findings are valid too when the remaining EEDI factors are included. Simplified, the EEDI can be expressed as follows:

$$EEDI = \frac{f_j \cdot P_{ME} \cdot SFC_{ME} \cdot C_{FME}}{Capacity \cdot V_{ref}} \tag{1}$$

The following simplifications and assumptions have been taken into account:

- Specific fuel consumption (SFC) is constant over speed;
- The auxiliary power is left out of consideration;
- The ship does not have an ice class notation.

Formula (1) can be subdivided in a part which is changing over speed, and a part which is (assumed to be) independent of the speed, thus *constant*:

$$EEDI = \frac{f_j \cdot P_{ME}}{V_{ref}} \cdot C_1 \quad \text{with} \quad C_1 = \frac{SFC_{ME} \cdot C_{FME}}{Capacity} \tag{2}$$

For the sake of simplicity the indices ME and ref, as used in (1) and (2) are dropped from this point on. The variables power and speed are not independent variables. The dependency of the power on the speed can, in general terms, be written as:

(3) $P = C_2 \cdot V^k$ with C_2 = constant [-]

k = speed to power exponent [-]

By substituting (3) in (2), without the indices:

(4) $$EEDI = f_j \cdot \frac{C_2 \cdot V^k}{V} \cdot C_1$$

Or:

(5) $$EEDI = f_j \cdot V^{k-1} \cdot C_1 \cdot C_2$$

The proposed factor for higher minimum operational speed is defined as:

(6) $$f_j = \frac{0.174}{F_{n\nabla}{}^{2.3} \cdot C_b{}^{0.3}}$$ with $F_{n\nabla}$ = Volumetric Froude number [-]

C_b = Block coefficient [-]

The volumetric Froude number is defined as:

(7) $$Fn_{\nabla} = \frac{V}{\sqrt{g \cdot \nabla^{\frac{1}{3}}}}$$ with

V_{ref} Reference speed [m/s]

g Gravitational acceleration [m/s^2]

∇ Displacement moulded [m^3]

By substituting (7) in (6) and by arranging the formula:

(8) $$f_j = \frac{0.174 \cdot \left(g \cdot \nabla^{\frac{1}{3}}\right)^{\frac{2.3}{2}}}{V^{2.3} \cdot C_b{}^{0.3}}$$

This can be subdivided in a part which is changing and a part which is constant, or independent of the speed:

(9) $$f_j = \frac{1}{V^{2.3}} \cdot C_3$$ with $$C_3 = \frac{0.174 \cdot \left(g \cdot \nabla^{\frac{1}{3}}\right)^{\frac{2.3}{2}}}{C_b{}^{0.3}}$$

Definition (9) can be substituted in (5):

(10) $$EEDI = \frac{V^{k-1}}{V^{2.3}} \cdot C_1 \cdot C_2 \cdot C_3$$

And this can be re-written as:

(11) $$EEDI = V^{k-3.3} \cdot C_1 \cdot C_2 \cdot C_3$$

This has the following result, if:

(12)	k	< 3.3;	Attained EEDI is decreasing with increasing speed;
	k	= 3.3;	Attained EEDI is constant, independent of speed;
	k	> 3.3;	Attained EEDI is increasing with increasing speed.

In which k is the speed to power exponent. The value of 3.3 is both a result of the definition of the Attained EEDI and the exponent of 2.3 of the volumetric Froude number in the correction factor. This explains the flat part of the Corrected Attained EEDI curve in Figure 6 on page 14. The speed to power exponent corresponding to a speed of 13.5 knots is around the value of 3.3. This also explains why the Corrected Attained EEDI curve of Ship 14 is represented by a curve with a much higher slope: the speed to power exponent corresponding to a speed of 14 knots is about 5.

3.2.3 Consequences of reduced slope for Attained EEDI

The nearly ‘flat’ part of the Corrected Attained EEDI line between 12.8 and 14.5 knots looks ‘odd’. The question is whether this low slope of the attained EEDI curve is against the principles of the EEDI regulations. A perfect instrument cannot be established and in our opinion the proposed correction factor is the best method for a fairer inclusion of small General cargo ships within the regulatory framework of the EEDI and still meet the goals of the EEDI, in which we consider the purpose of the EEDI is to[7]:

- Provide a fair comparison between vessels;
- Stimulate the development of more efficient ships.

To provide a fair comparison, the implementation of a correction factor regarding the operational profile is required. Without the correction factor the scatter remains very high; because the large differences in operational profile are still reflected in the EEDI values. On the other hand, the implementation of the proposed correction factor still requires to develop more efficient ships. The ships still need to be optimized, as without optimization they will not meet the EEDI requirements, even when the correction is implemented.

[7] Resolution MEPC.215(63)

The need for optimization is demonstrated by the following example. Both vessel A and Vessel B are Conoship designs and according to MARIN the optimization potential for both vessels is very low (see previous report[8]).

Ship A A ship designed for a particular high speed, the reference speed is more than 15 knots. The hull form is extensively optimized for the high speeds, which can be (among others) deduced from the low block coefficient and the optimized bulb. The main dimensions are not restricted by any operational limits, what emerges in a particular high length in relation with the deadweight. A high length is favourable for a low wave making resistance, which is the dominant resistance component at high speeds.

Ship B This ship is also designed for a relatively high speed, but not as high as the speed Ship A is designed for. The reference speed is 12.8 knots. The block coefficient of Ship B is higher, but lower than what is often seen for ships of comparable dimensions. The bow is designed to be able to attain good results at different speeds/draughts.

The particulars of both vessels can be seen in Table 3 below.

Table 3 Main dimensions of ships for comparison of the Attained EEDI curve

		Ship A	**Ship B**
DWT	[mt]	3600	3550
VRef	[knots]	15.1	12.8
Lpp	[m]	98.2	84.95
Bm	[m]	15.6	15.85
Dm	[m]	7.4	6.2
Tsummer	[m]	5.8	4.93
Fn	[-]	0.250	0.228
CB	[-]	0,604	0.735
Lightweight	[mt]	1880	1473
Volume	[m3]	5350	4900
Displacement summer draught	[mt]	5484	5023
Lightship / (Lpp x Bm x Dm)	[mt/m^3]	0,166	0.176

Figure 7 shows the speed to power curve of both Ship A and B. The slope of the curve of Ship A reveals that this ship is designed for a higher speed than Ship B, i.e. the slope is lower, this indicates a lower increase of the resistance at higher speeds so the increase in required power is also lower. However, at lower speeds, starting at 10 knots, the required shaft power for Ship A is higher than the required power for Ship B. This is due to the viscous resistance, which is the dominant resistance

[8] MEPC 64/INF.9

component at lower speeds. As Ship A has a higher wetted surface, the viscous resistance of Ship A becomes higher at low speeds compared to Ship B. See Figure 7.

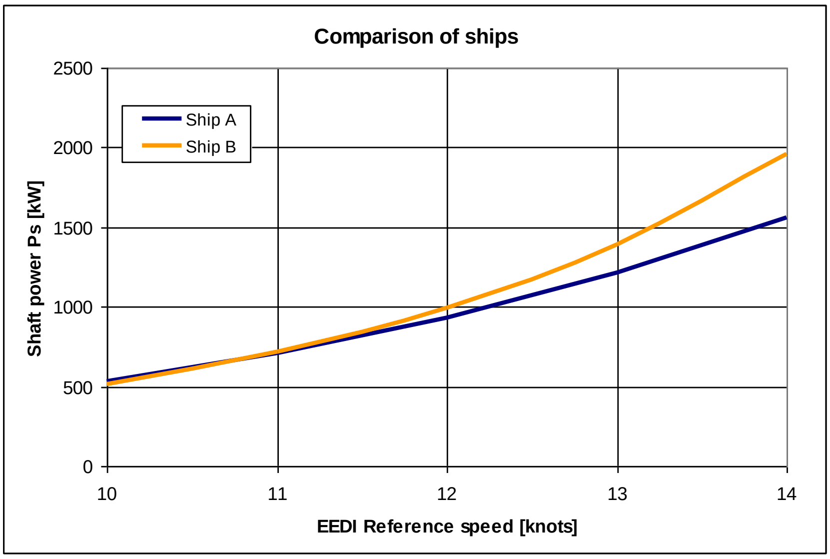


Figure 7 Speed to power curve of Ship A and Ship B.

As the slope of the speed-power curve of vessel A is lower than that of vessel B, the Corrected Attained EEDI curve will have a lower slope as well, which in extreme cases becomes nearly flat within a certain speed range. I.e. the low slope of the attained EEDI curve will only occur for vessels which are extensively optimized for higher speeds. For this vessel the wave-making resistance is low compared to other vessels in their deadweight class.

When we try to reach the reference speed of vessel A with the design of vessel B, its Corrected Attained EEDI becomes very high, even though the correction received is larger than the correction of vessel A. See Table 4 and Figure 8.

Table 4 Results of EEDI - Reference speed = 15 knots

		Ship A	Ship B
Pme	[kW]	2085	2926
Installed power	[kW]	2926	4153
Reference speed	[knots]	15	15
Attained EEDI (uncorrected)	[gCO2/(mt*nm)]	24.1	34.7
fj	[-]	0.68	0.62
Attained EEDI (Corrected)	[gCO2/(mt*nm)]	17.0	22.5
Required EEDI	[gCO2/(mt*nm)]	18.3	18.4

The required shaft power of Ship A at a reference speed of 15 knots is considerably lower than that of Ship B. This results in a considerably lower initial Attained EEDI: 24.1 of Ship A compared to 34.7 of Ship B. Ship B receives a correction which is larger than the correction of Ship A, however the correction for Ship B is by far not enough; the Corrected Attained EEDI is still 22.5 after correction, where 18.4 is required. Ship A does also receive a correction, and this correction is sufficient for Ship A to meet the requirements.

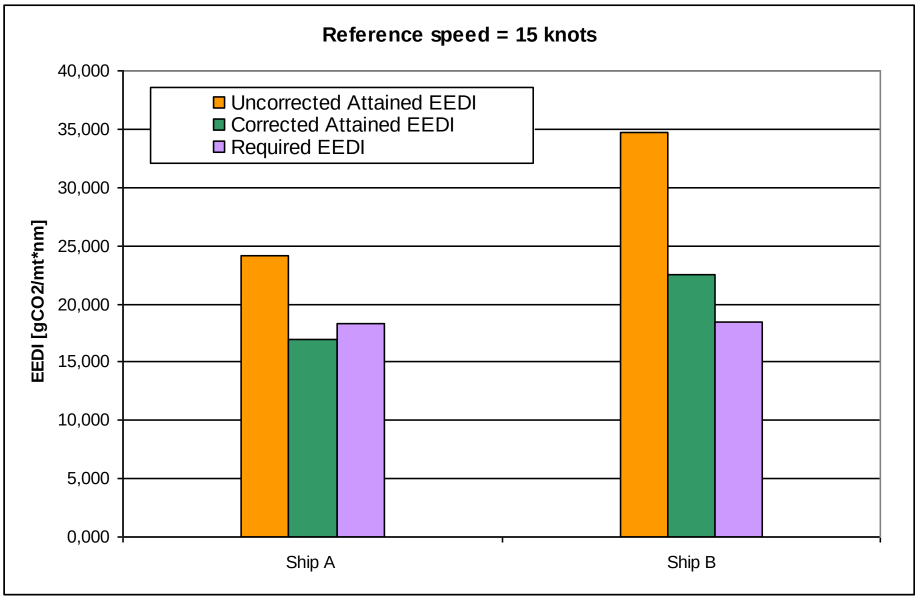


Figure 8 Comparison of Ship A and B, for a reference speed of 15 knots.

By means of this example it is shown that a ship needs to be extensively optimized to be sufficiently corrected to be able to meet the requirements. When done the other way around, i.e. using the design of vessel A for a reference speed of 12 kts. for both vessels o correction factors is applied and both ships comply. However, the design aspects of Vessel B are to be considered “optimal” with respect to its operational profile, e.g. limiting the length to maximize the operational area, etc.

Table 5 Results of EEDI - Reference speed = 12 knots

		Ship A	**Ship B**
Pme	[kW]	963	1020
Installed power	[kW]	1352	1432
Reference speed	[knots]	12	12
Attained EEDI (uncorrected)	[gCO2/(mt*nm)]	13.9	15,0
fj	[-]	1	1
Attained EEDI (Corrected)	[gCO2/(mt*nm)]	13.9	15.0
Required EEDI	[gCO2/(mt*nm)]	18.3	18.4

By taking a look at the speed power curves in Figure 7 it can be concluded that for a reference speed of 12 knots Ship A requires less shaft power P_s than Ship B. This combined with the higher deadweight of Ship A and the equal reference speed, it is not a surprise that the Uncorrected Attained EEDI of Ship A is lower compared to ship B. The Required EEDI of Ship A is slightly lower than that of Ship B, due to the higher deadweight of Ship A.

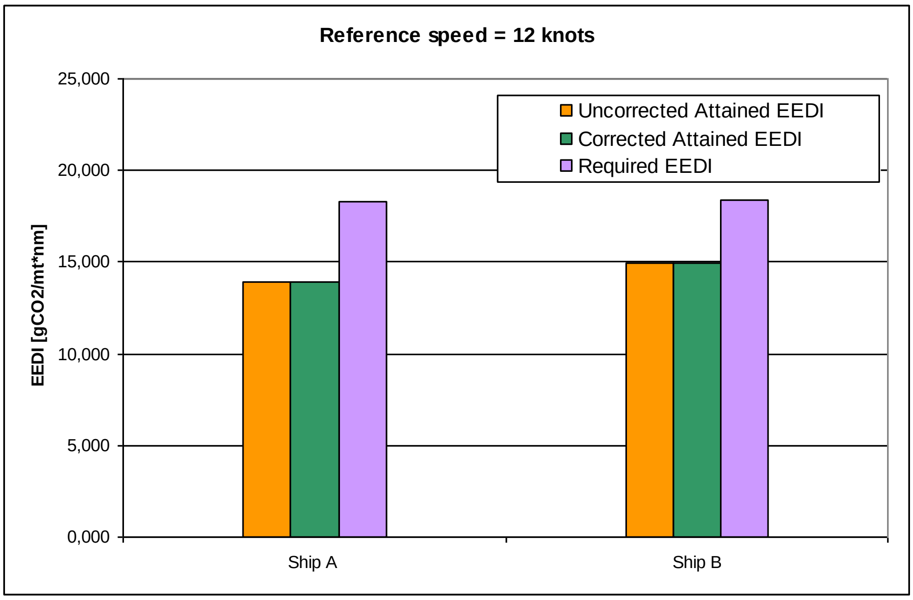


Figure 9 Comparison of Ship A and B, for a reference speed of 12 knots

3.3 Limiting the maximum value of Fnvol

The correction factor for higher minimum operational speed is intended to provide a correction for ships sailing at higher minimum operational speeds. In the previous report[9], it was shown that there are numerous examples which prove that there is a clear need for ships sailing at high speeds. The correction factor is developed with the precondition that only ships extensively optimized for high speeds do receive a correction on the Attained EEDI value which is sufficient to meet the EEDI requirements.

The background to set this precondition is the strong conviction of the project group that ships sailing at high speeds is justified, if these vessels are (relatively) very low energy consuming, that is when these vessels are extensively optimised. By setting a maximum to the correction factor, there is a strong incentive for ship designers to put much effort in the design and more especially in the optimization of the hull form of the ship. Another advantage of the maximum correction factor is that future excesses, which cannot be foreseen at the moment, are avoided. This is conform the principles of EEDI. Setting a maximum to the correction factor is not a requirement, but is proposed to reduce the amount of CO_2 emissions.

Method of limiting the correction factor

There are different methods of setting a maximum to the correction factor. It is proposed to introduce a boundary through a limitation of the volumetric Froude number Fnvol. By doing so, a limitation is set on the relation between speed and the volume of the ship, to avoid ships with a very high reference speed and a very low displacement.

[9] MEPC64/INF.9.

The volumetric Froude numbers of the vessels used for this research are presented in the figure below. See Figure 10. The highest volumetric Froude number seen in this figure is close to 0.6. It is proposed to set a maximum volumetric Froude number of 0.6. It is expected that unforeseen excesses are avoided and that the ships stay within the so called displacement mode, for which the factor was developed and stay away from any (probably purely hypothetical) planning modes.

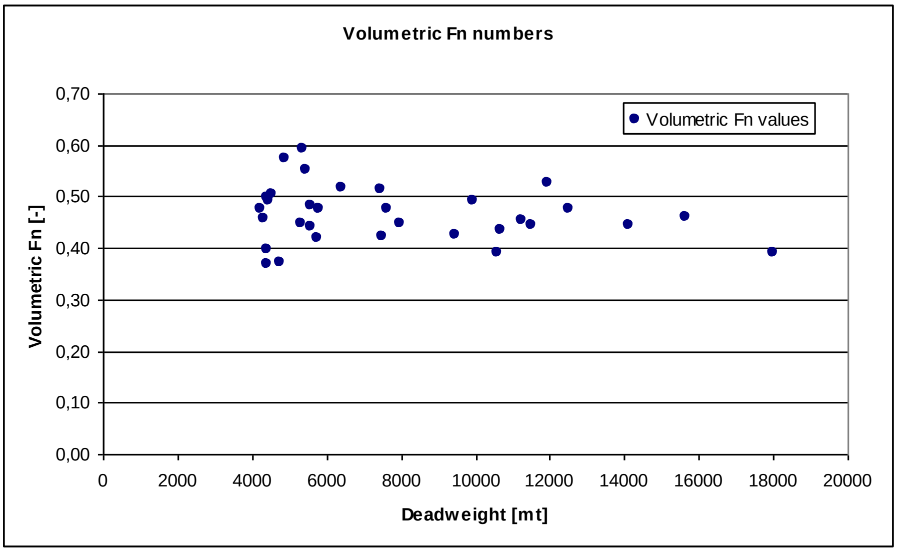


Figure 10 Values of volumetric Froude numbers of ships in database

By setting a maximum for the volumetric Froude number, the correction factor is indirectly bounded to a minimum value as well (a low correction factor results in a high correction). See the above presented definition of the correction factor f_j, which has also been introduced in the submission and the related report[10]. In the way the correction factor is formulated, the correction factor is low (resulting in a maximum correction) when the block coefficient is near 1 and the volumetric Froude number high (above 1 is possible). Commonly the block coefficient (for General cargo ships) varies between 0.5 and 0.9, with the lower values more suited for higher speeds. Again, the correction increases (than the correction factor is very low) when the volumetric Froude number increases, that is when the speed increases and the volume of displacement decreases. Implementing a maximum value to the volumetric Froude number is a very effective method to bound the correction factor to a maximum and thus to prevent unforeseen excesses, such as (theoretically) planning hulls, etc.

[10] MEPC 64/4/18 and MEPC 64/INF.9

4 Boundary effect

The noted remark of one of the delegations on the proposed correction factor to account for minimum operational speed was:

12.24 "*A concern was expressed that the application of the proposed correction factors in terms of ship size could possibly lead to similar sized ships at the upper end of the range considered with and without correction factors*".

The research project focussed on the group of ships between 3.000 and 20.000 DWT, as for this range the scatter was the highest. The objective of the research project was to find the cause of this high scatter and to propose correction factors. The proposed correction factor for operational speed was, in that respect, applicable for the range of ships with a maximum of 20.000 DWT. Thus a strict boundary might result in so-called “paragraph” ships, which is an undesired side effect.

To be able to enhance a 'smooth transition' near the edge of 20.000 DWT, it is essential to know how the correction factor 'works' for ships above 20.000 DWT. In section 4.1 an analysis is given whether there are ships above 20.000 dwt which require a correction factor to meet the EEDI requirements. In 4.2 different methods to avoid the boundary problems are discussed, and a final decision is made which methodology will be proposed.

4.1 Correction factor for General Cargo Ships >20.000 DWT

As the availability of General cargo ships above 20.000 DWT in our database is low, we searched for designs above 20.000 DWT from parties which did not participate in this project. A small number of recently delivered large General cargo ships was found. Missing particulars were determined on the basis of statistics as found in the Conoship or Marin databases. With use of the MARIN program DESP[11], a speed to power curve was produced to calculate the EEDI in the reference condition. For the particulars of one of these vessels, see Table 6 below.

[11] The computer program DESP predicts the resistance and propulsion characteristics of displacement ships, based on the Holtrop & Mennen method. The predictions are based on formulas obtained from a regression analysis on results of model experiments and sea trials.

Table 6 Particulars of a ship larger than 20.000 DWT

		Ship >20.000 DWT
DWT	[mt]	30000
VRef	[knots]	Abt. 18.1
Lpp	[m]	184
Bm	[m]	28
Dm	[m]	15.5
Tsummer	[m]	11.2
Fn	[-]	Abt. 0.219
CB	[-]	Abt. 0.716
Lightweight	[mt]	Abt. 12.250
Volume	[m3]	Abt. 41.000
Displacement summer draught	[mt]	Abt. 42.025
Lightship / (Lpp x Bm x Dm)	[mt/m^3]	Abt. 0,155

The results of the calculations are presented in Table 7 and in Figure 11. The calculations are based on the assumption that:

1. It is assumed that the fuel is DO/GO. As such, the factor C_F is equal to 3.206.
2. The total required electrical power is assumed to be provided by a shaft generator.
3. The specific fuel consumption is assumed to be constant, and assumed to be 180 g/kWh.

Table 7 Results of EEDI for ship of 30.000 DWT

		Ship A
Pme	[kW]	Abt. 11355
Installed power	[kW]	Abt. 15.800
Reference speed	[knots]	Abt. 18.1
Attained EEDI (uncorrected)	[gCO2/(mt*nm)]	12.9
fj	[-]	0.927
Attained EEDI (Corrected)	[gCO2/(mt*nm)]	12.0
Required EEDI	[gCO2/(mt*nm)]	11.6

Based on the table above and the figure below, it can be concluded that the vessel does not meet the requirements for EEDI, the Corrected Attained EEDI is slightly above the Required EEDI. It might be possible to gain some efficiency by optimizing the hull form, but it is not possible to exactly know how much due to lack of details of the ship. However, this example illustrates that there are ships above 20.000 DWT which sail at comparatively high minimal operational speeds and would benefit from the correction factor. In addition to this it must be noted that the correction factor was developed based on speed/power measurements in the MARIN database, where also some larger ships were included because no strict 20.000 DWT boundary was used. There are no indications that the hydrodynamics of General cargo ships above 20.000 DWT are any different from the smaller ones.

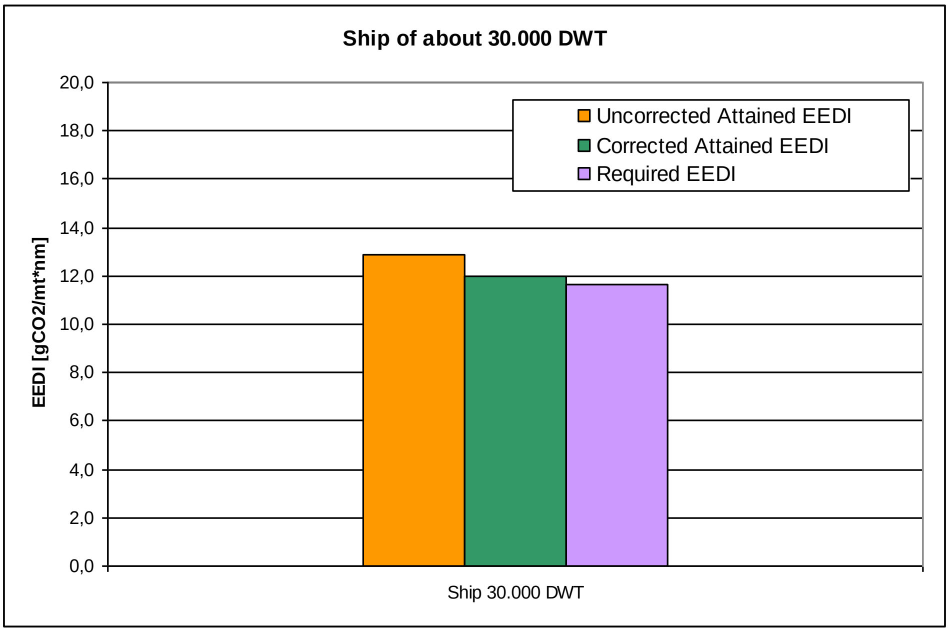


Figure 11 Results of EEDI calculation of a ship of about 30.000 DWT.

4.2 Preventing paragraph ships

To prevent the so-called “paragraph” ships, several options are possible, which were discussed during the project group meetings. For clarity all the options are shown below. The example in the previous section does make clear that there are also large, optimized General Cargo vessels that need a correction factor in order to operate at higher minimum operational speeds. In both methods the volumetric Froude number is used to limit the correction factor and to prevent the occurrence of “paragraph” ships (see also chapter 3.3).

Maximum Fnvol of 0.6 applicable from 3.000 DWT and over, not limited to 20.000 DWT

The first method is a constant maximum volumetric Froude number with a lower boundary of the range for which the correction factor is applicable, but without an upper boundary. This method is transparent and easy to introduce, and all possible boundary effects are avoided. All General Cargo Ships can receive a correction factor. See Figure 12 below. It is the opinion of the project group that this constant maximum volumetric Froude number is the most suitable, and this method is proposed.

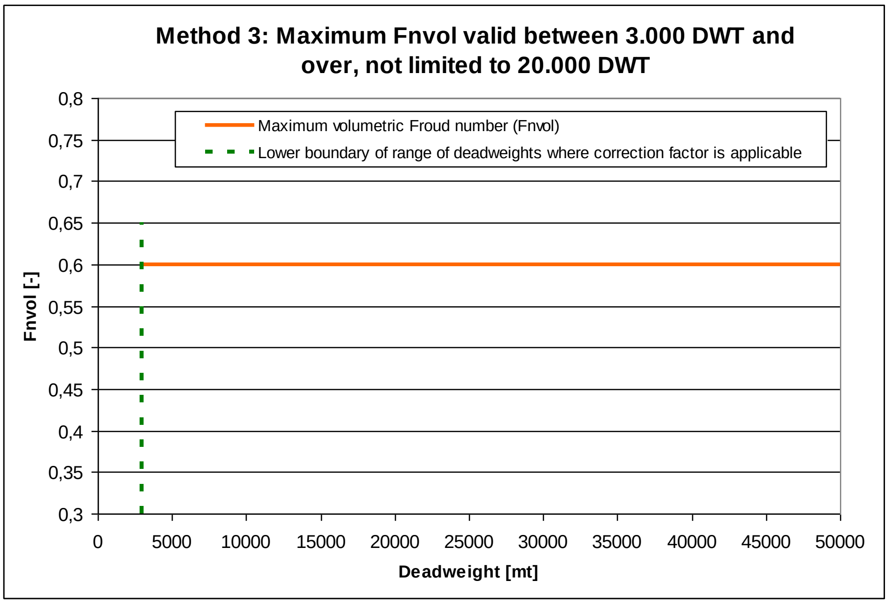


Figure 12 Visualisation of maximum Fnvol - Method 3

The proposal for the inclusion of the correction factor f_j for higher minimum operational speed is than extended with a maximum on the volumetric Froude number:

$$f_j = \frac{0.174}{Fn_{\nabla}^{\;2.3} \cdot C_b^{\;0.3}}$$

In which:

$$Fn_{\nabla} = \frac{V_{ref}}{\sqrt{g \cdot \nabla^{\frac{1}{3}}}}$$

Vref	Reference speed	[m/s]
g	Gravitational acceleration	[m/s^2]
∇	Displacement moulded	[m^3]

And:

$$C_b = \frac{\nabla}{L_{pp} \cdot B_m \cdot T}$$

C_b	=	Block coëfficient	[-]
∇	=	Displacement moulded	[m^3]
L_{pp}	=	Length between perpendiculars	[m]

B_m	=	Beam moulded	[m]
T	=	Draught at summer loadline	[m]

The following preconditions apply:

If $f_j > 1$ than $f_j = 1$ and if $Fn_\nabla > 0.6$ than $Fn_\nabla = 0.6$.

Maximum Fnvol of 0.6 applicable from 3.000 to 20.000 DWT, decreasing to 50,000 DWT

The following method of limiting the possible correction factor consists of a range of deadweights for which a constant maximum value of Fnvol is valid. For another part, between 20.000 and 50.000 DWT, the maximum is linearly decreased to a value of 0.468 at 50.000 DWT, which results in a correction factor of 1 for ships with a block coefficient of 1. As a result of this method, the boundary effects are avoided. This correction factor is avoiding any possible boundary effect near the edge of 50.000, however ships between 20.000 and 50.000 can be compensated at higher speeds. However, this methodology is less easy to apply compared to the first method. See Figure 13.

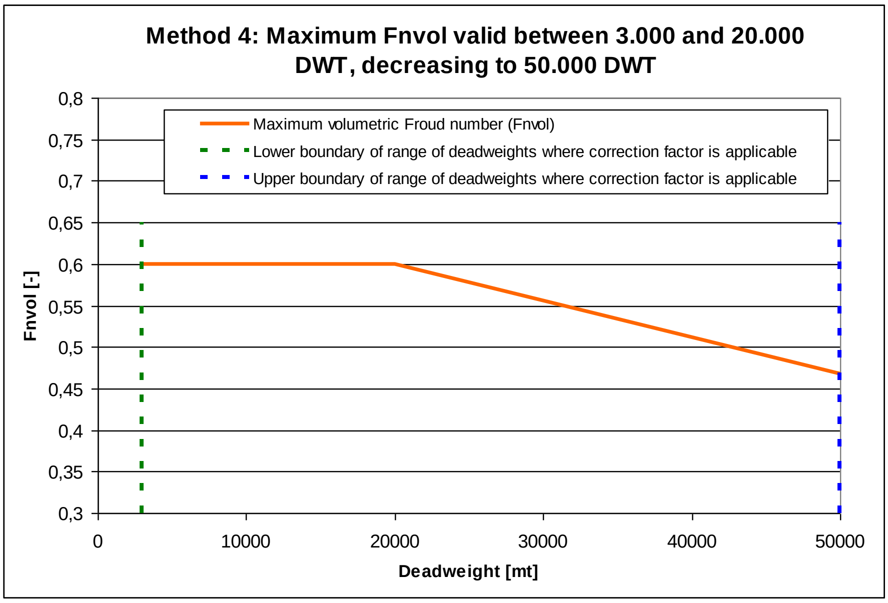


Figure 13 Visualisation of maximum Fnvol - Method 4

5 Conclusion and discussion

With reference to the concerns raised by the two delegations during MEPC 64 regarding the Dutch proposal for additional correction factors for General cargo ships, we conclude, based on an additional analysis, that the proposal does not violate the principles of the EEDI regulations. The misconceptions that the correction factor enables the possibility of extreme high speed to power exponents and that a flat or decreasing Corrected Attained EEDI curve are in conflict with the principles of EEDI have been clarified throughout the report.

High speed to power exponents of up to seven are seen for the ships in the database. These high exponents are however not a result of the proposed correction factors; the increase because of application of a correction factor exponents is low. Without the correction factor applied for the high operational speed, speed to power exponents are seen up to 6.8, for the vessels which also meet the EEDI requirements without any correction factor, even though the exponent of the speed to power curve is above 6. The difference between the speed to power exponent with and without the inclusion of the correction factor determines whether the factor is against the principles of the EEDI, not the absolute value of the exponent.

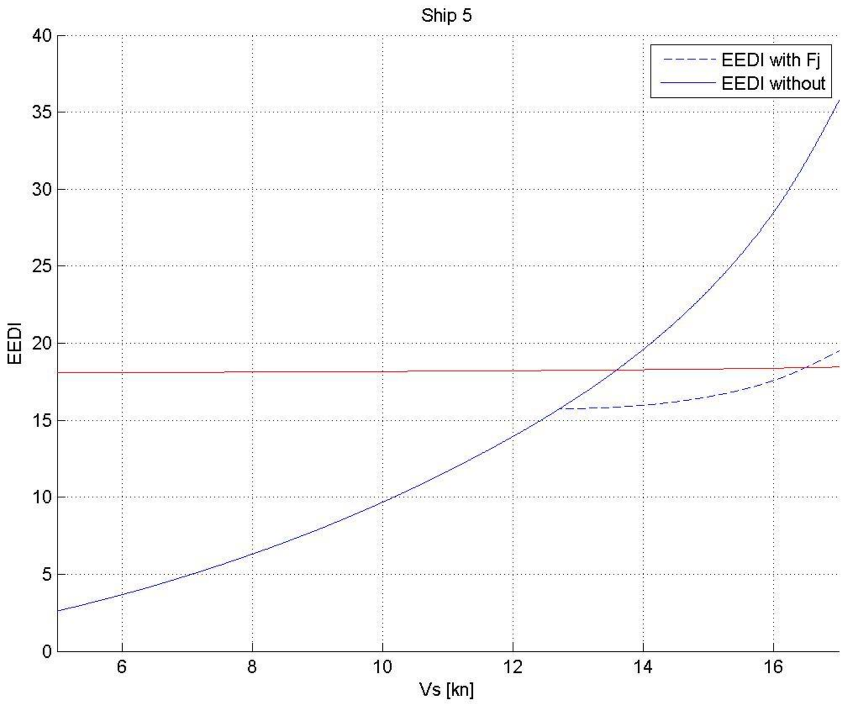
The Corrected Attained EEDI curve becomes constant when the speed to power exponent 'k' is near 3.3, and this will seldom occur. For none of the vessels in the database a flat part of the Corrected Attained EEDI curve near the reference condition is discovered. Only highly optimised vessels, specifically designed for high speed will receive a correction factor which is sufficient to meet the EEDI requirements. It is still required to extensively optimize vessels for high operational speed in order to meet the requirements, and hence to limit the amount of CO_2 emissions.

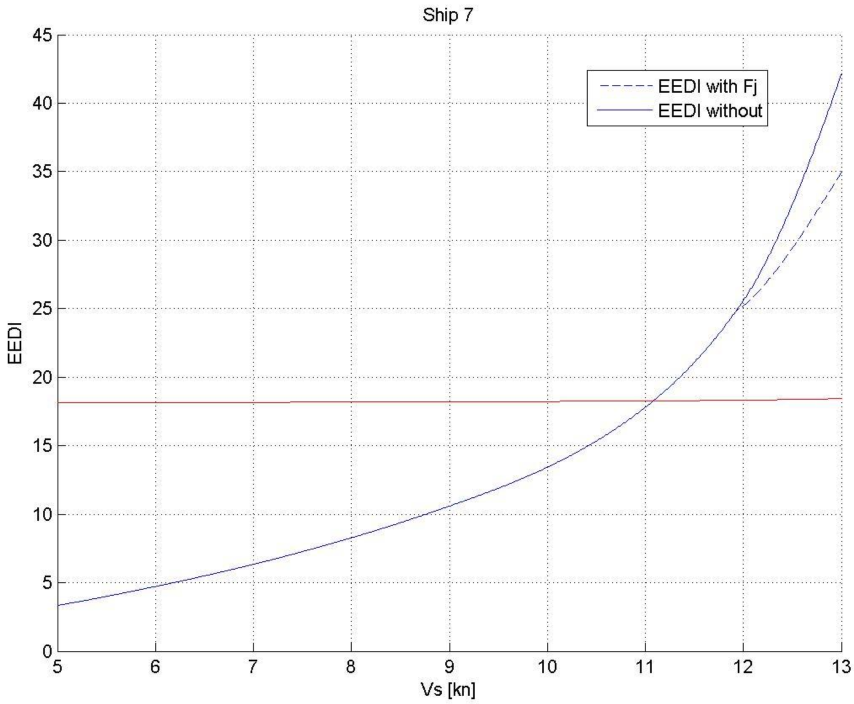
A decreasing Corrected Attained EEDI curve will only occur when the speed to power exponent 'k' is lower than 3.3. Decreasing Corrected Attained EEDI lines with increasing speed are not seen in any of the ships included in the database. In non of the figures the Attained EEDI corresponding to the reference speed is in a flat part of the Attained EEDI curve. From this we can draw the conclusion that the occurrence of a decreasing Attained EEDI line is not very likely, and a flat Attained EEDI curve will occur seldom. As a speed to power exponent of 3.3 is a very low value for ships optimized for high speed, it is not to be expected that Corrected Attained EEDI curve will decrease near the reference speed.

In order to avoid the boundary effects near the upper edge of the range of deadweights for which the correction factor is proposed to be valid, it is proposed by the project group to drop the upper edge of 20.000 DWT. The background of this decision is that it has been shown that there are General cargo ships above 20.000 DWT. which sail at higher minimum operational speed, and are optimised for that high speed, which need a correction factor to meet the EEDI requirements. As such, boundary problems are avoided, as there no longer is an upper edge.

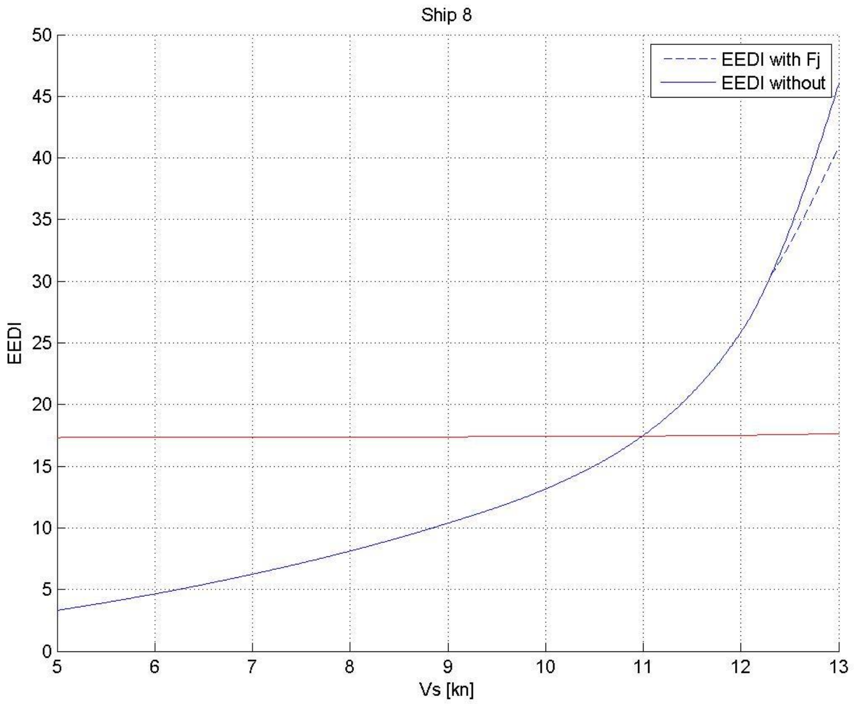
Although it is not required by the Working Group, it is proposed by the project group to introduce a maximum to the volumetric Froude number used in the correction factor, in order to avoid future unseen excesses and to bound the possible speeds, in order to bound the CO_2 emissions. It is proposed to set the maximum volumetric Froude number to a value of 0.6 valid for all General cargo ships above 3.000 dwt, for those ships to which the correction factor is applicable in the reference condition.

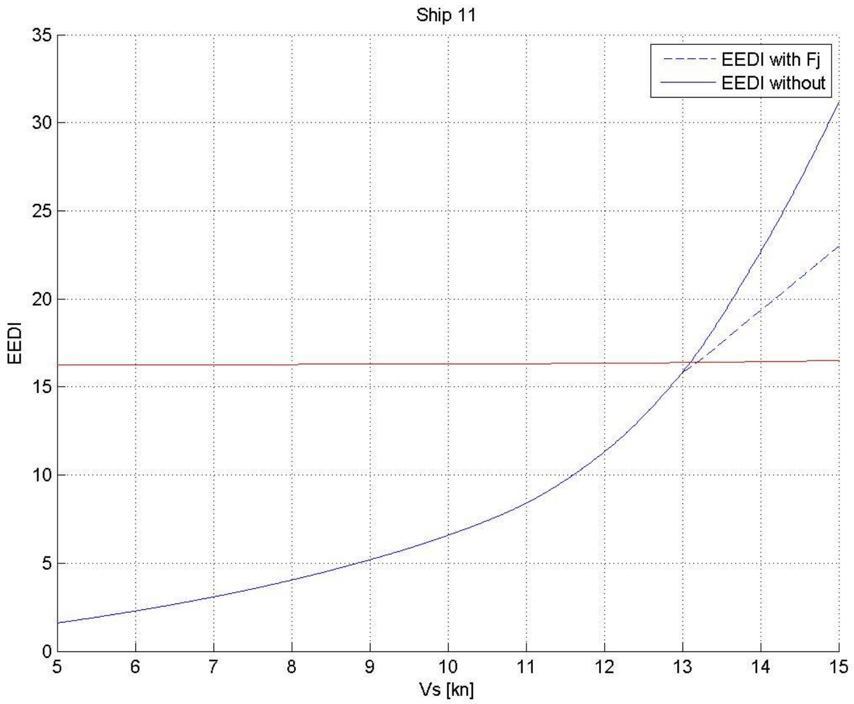
Appendix 1 *Required, Attained and Corrected Attained EEDI of Ship 5 and 7*



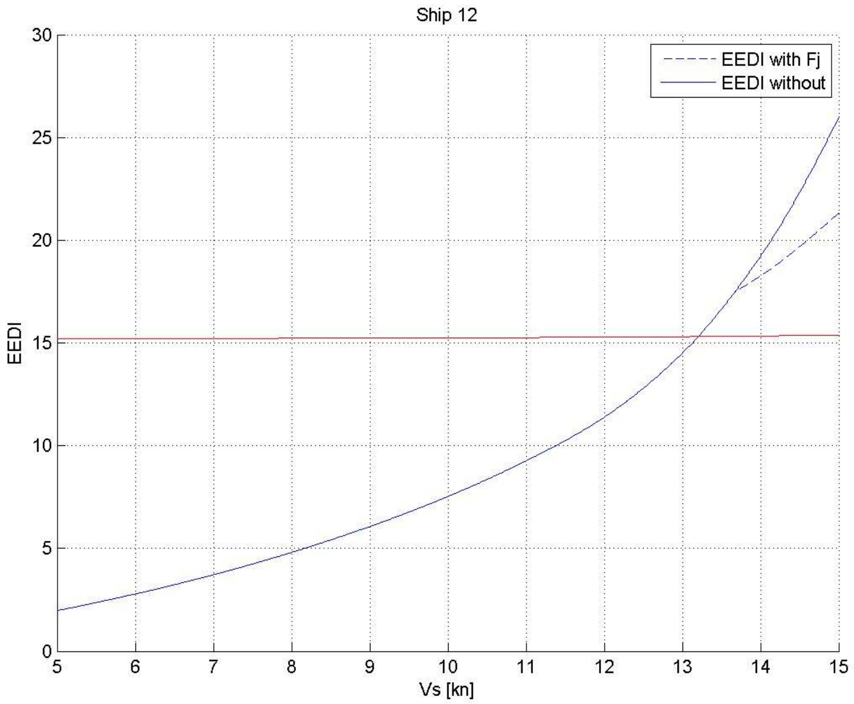


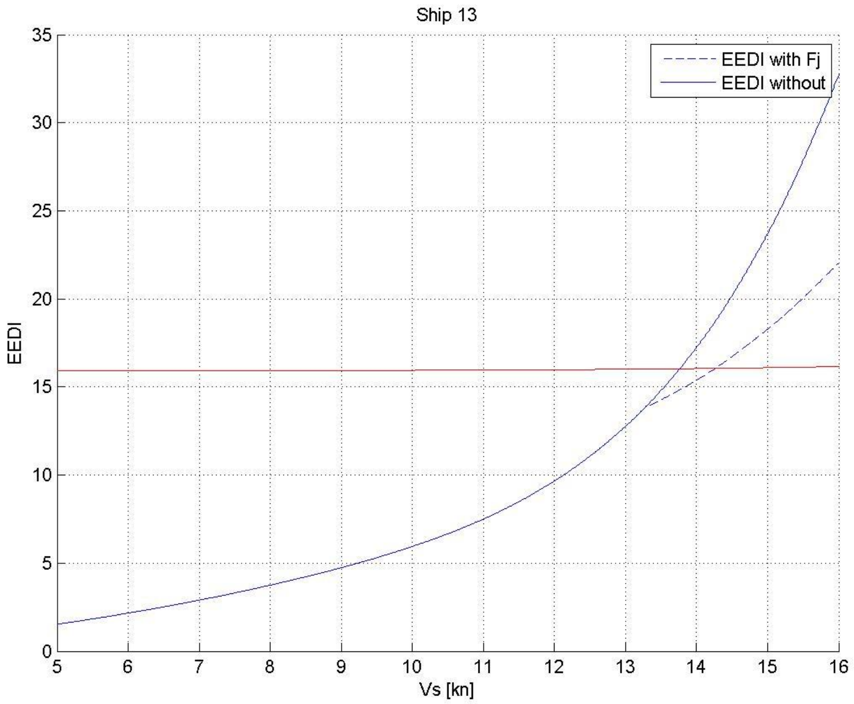
Appendix 2 *Required, Attained and Corrected Attained EEDI of Ship 8 and 11*



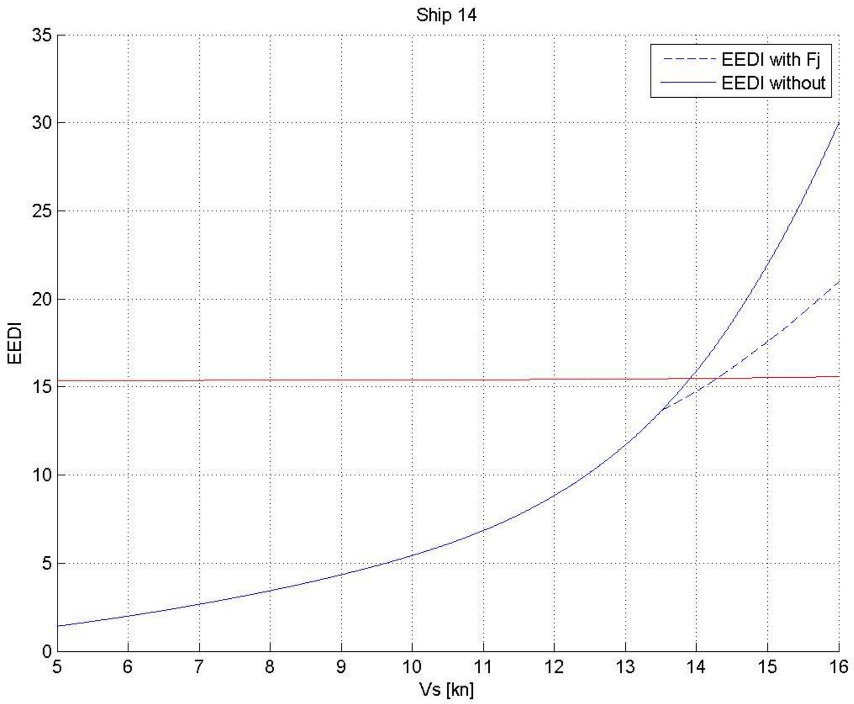


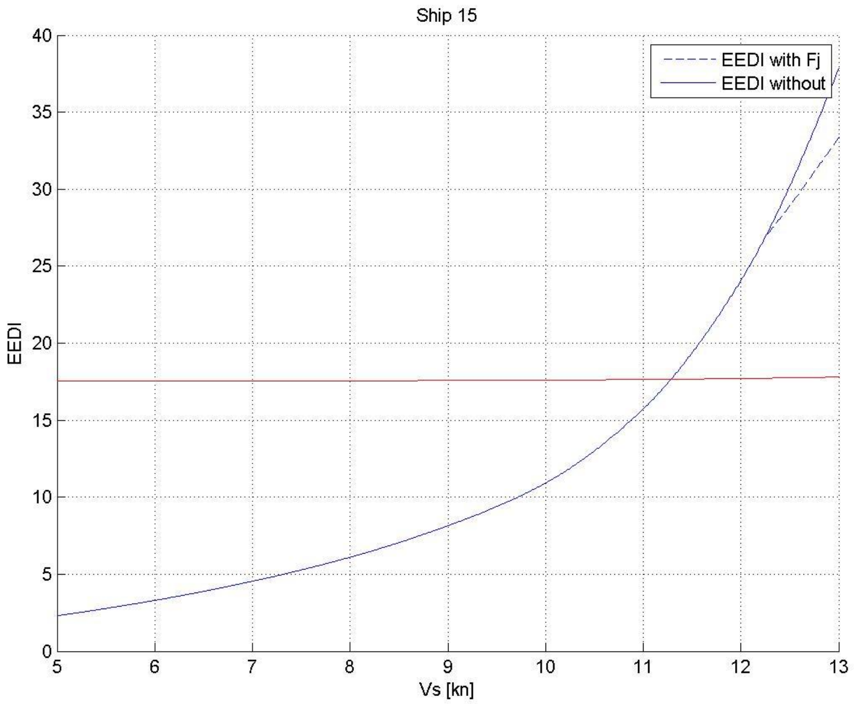
Appendix 3 *Required, Attained and Corrected Attained EEDI of Ship 12 and 13*



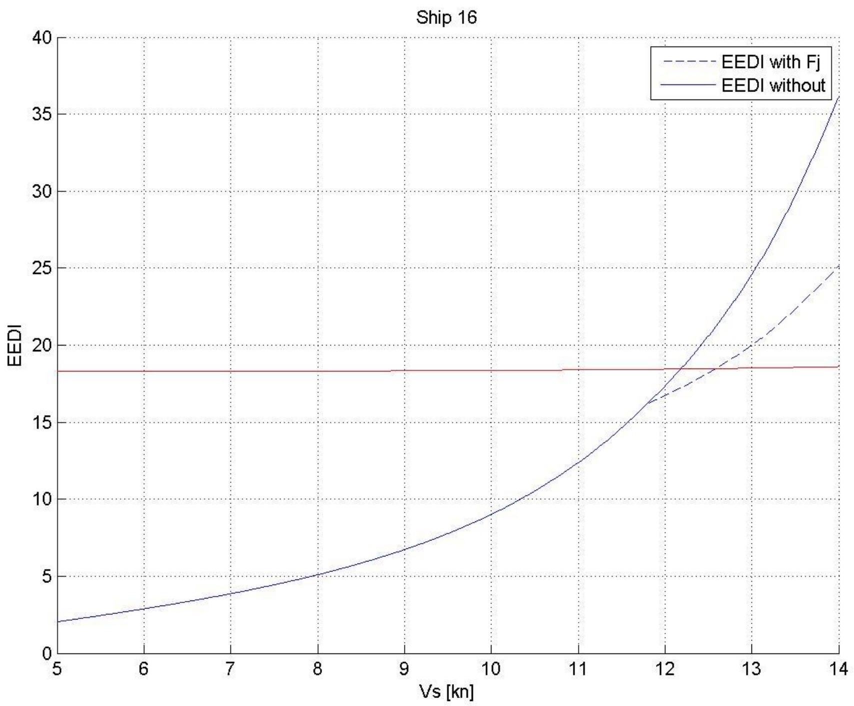


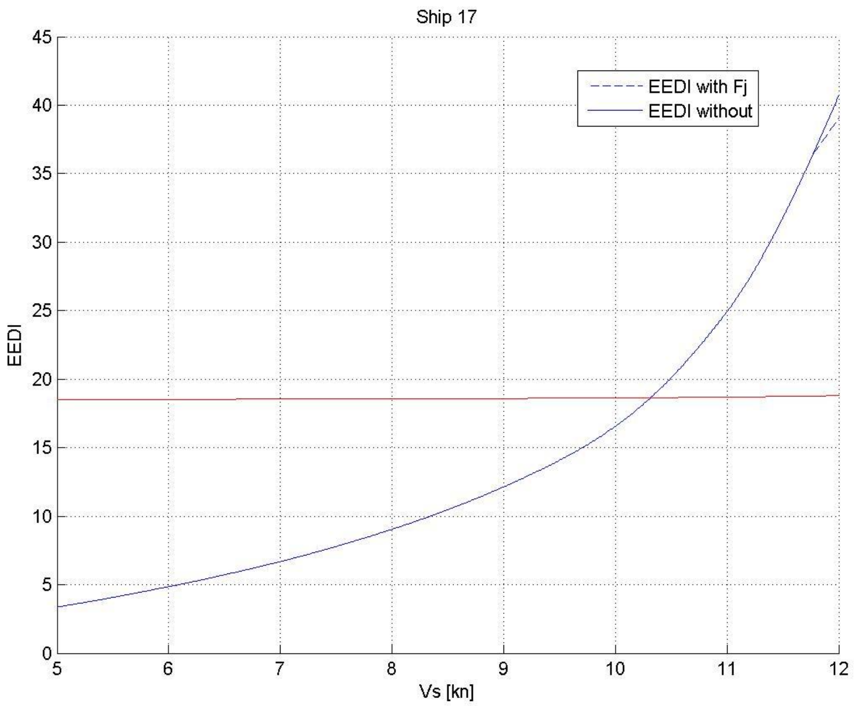
Appendix 4 *Required, Attained and Corrected Attained EEDI of Ship 14 and 15*



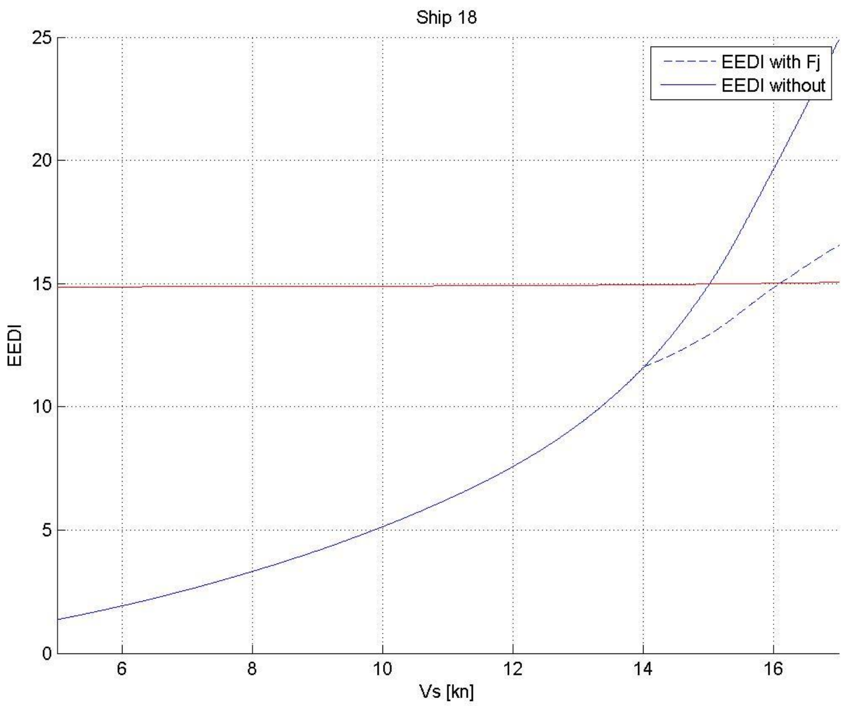


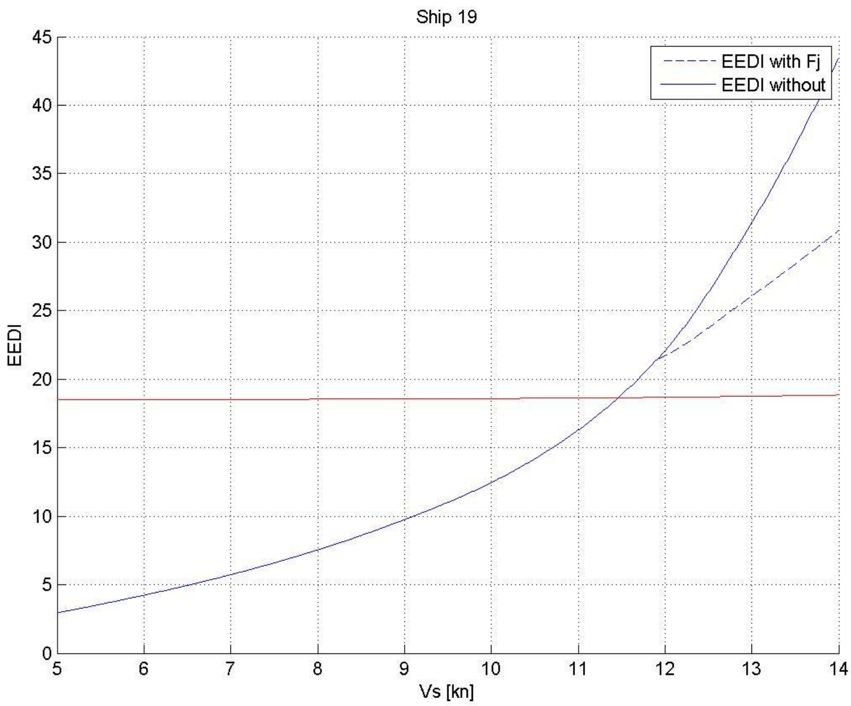
Appendix 5 *Required, Attained and Corrected Attained EEDI of Ship 16 and 17*



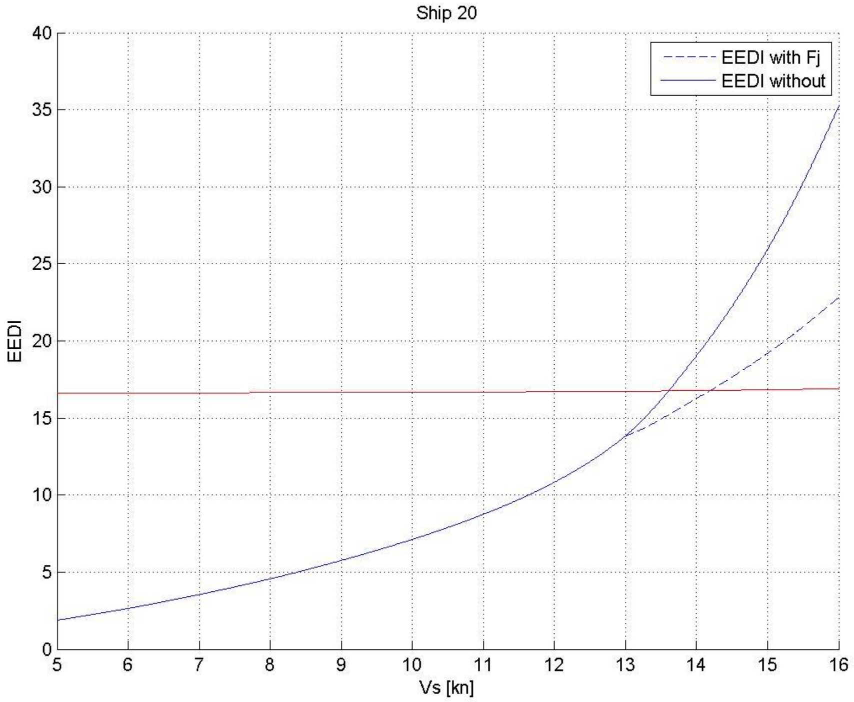


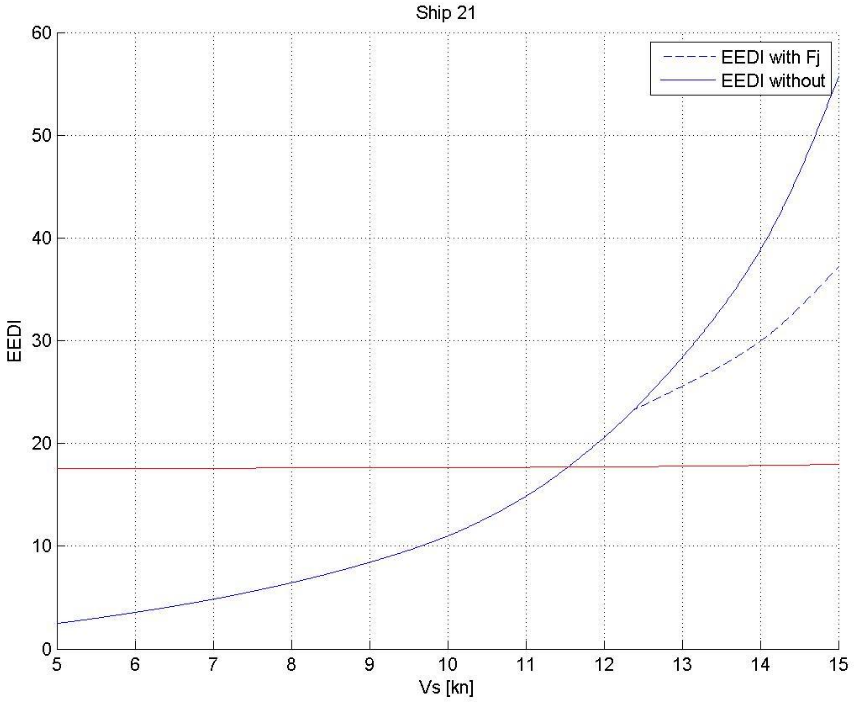
Appendix 6 *Required, Attained and Corrected Attained EEDI of Ship 18 and 19*



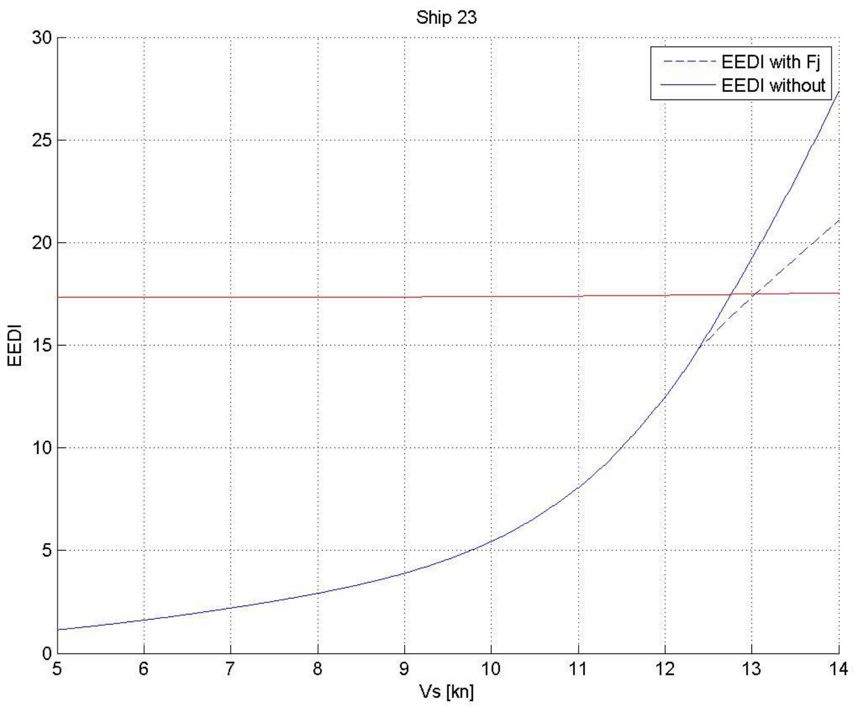


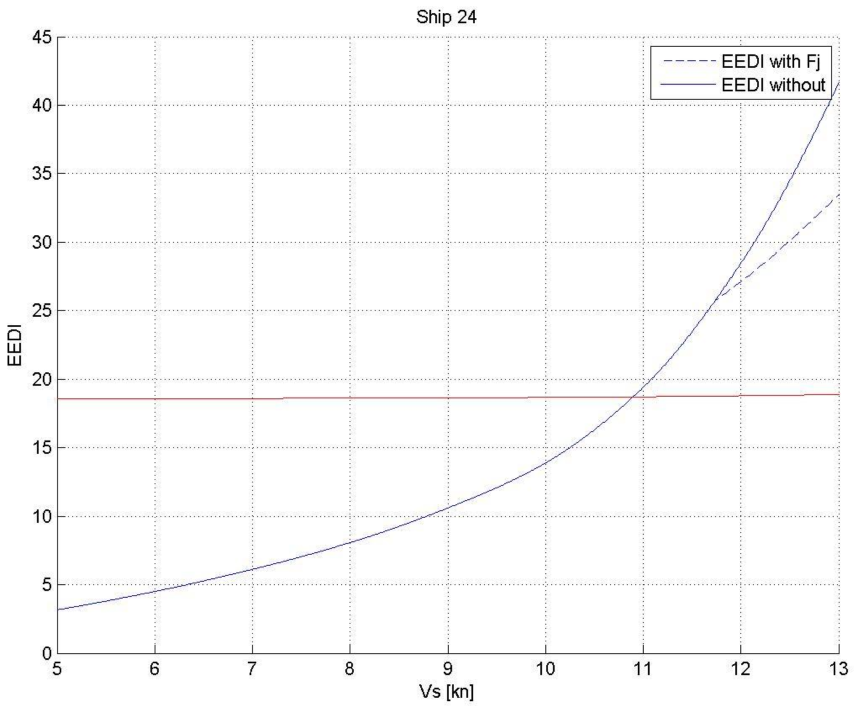
Appendix 7 *Required, Attained and Corrected Attained EEDI of Ship 20 and 21*



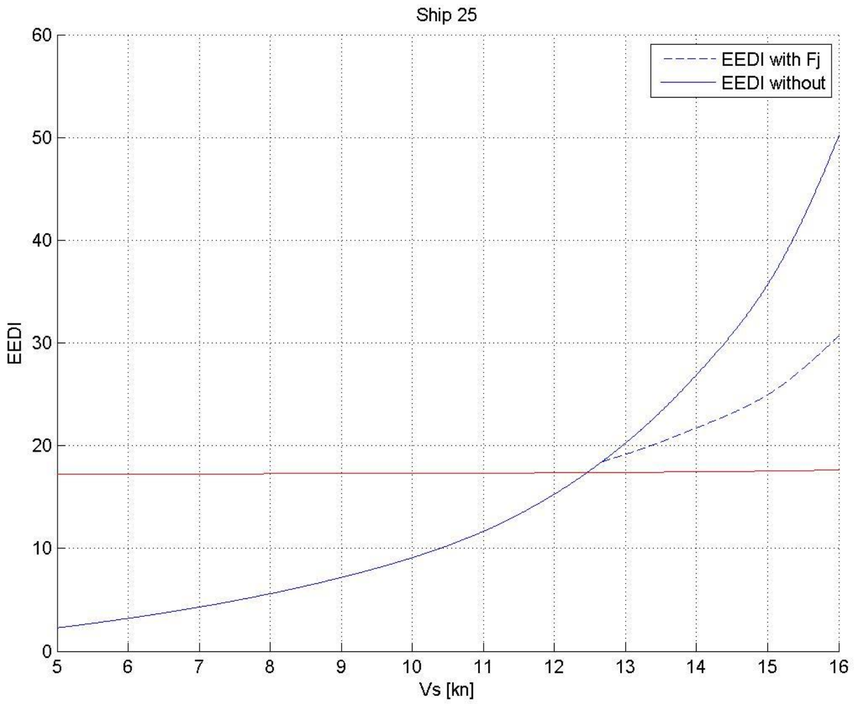


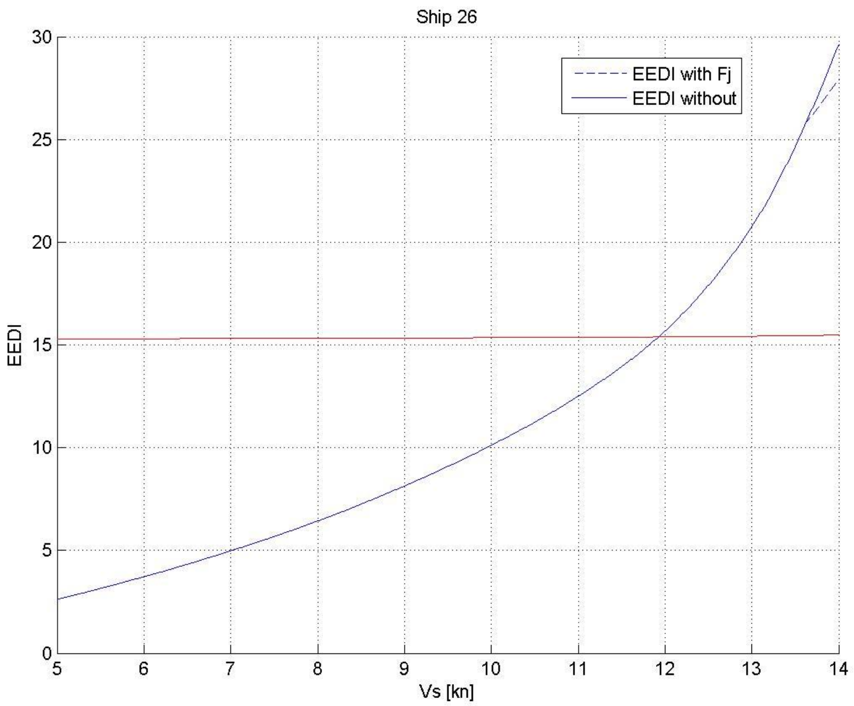
Appendix 8 ***Required, Attained and Corrected Attained EEDI of Ship 23 and 24***



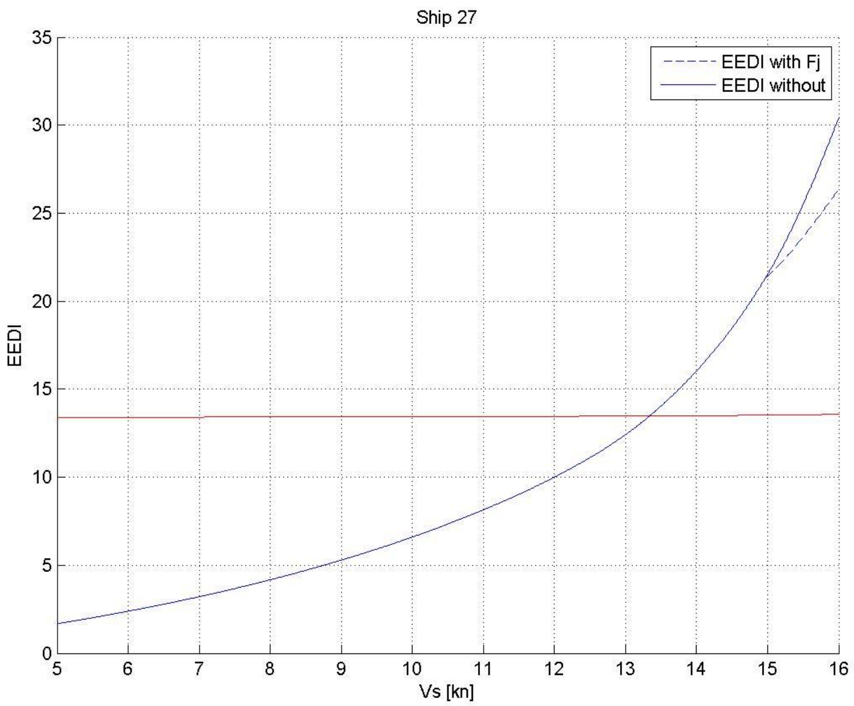


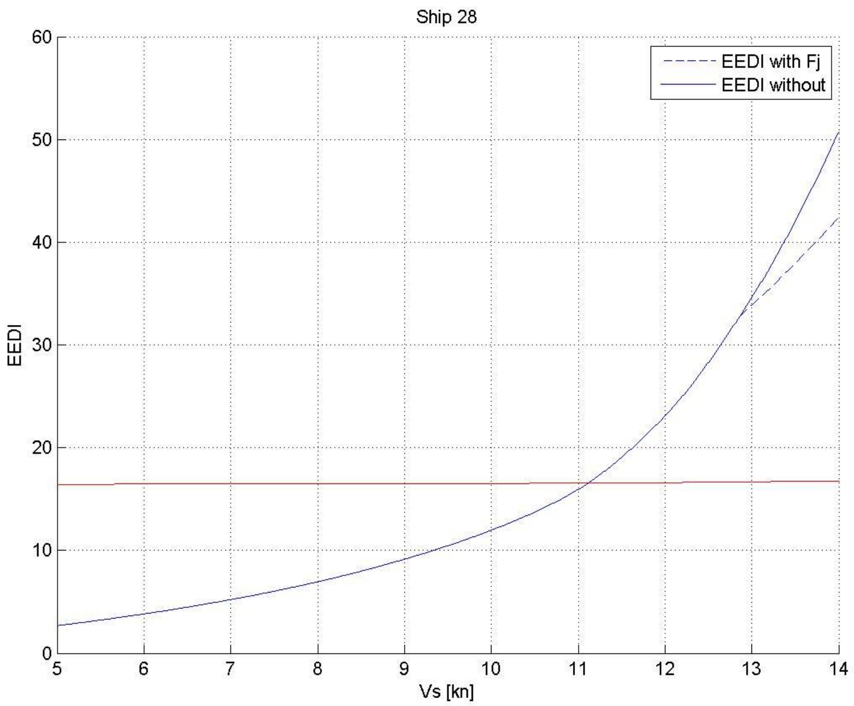
Appendix 9 ***Required, Attained and Corrected Attained EEDI of Ship 25 and 26***



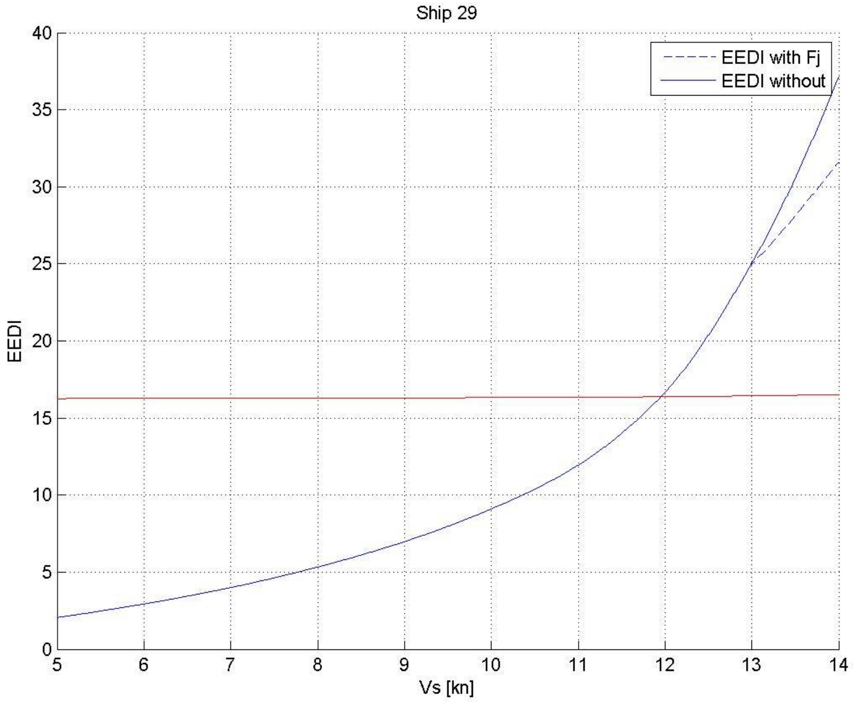


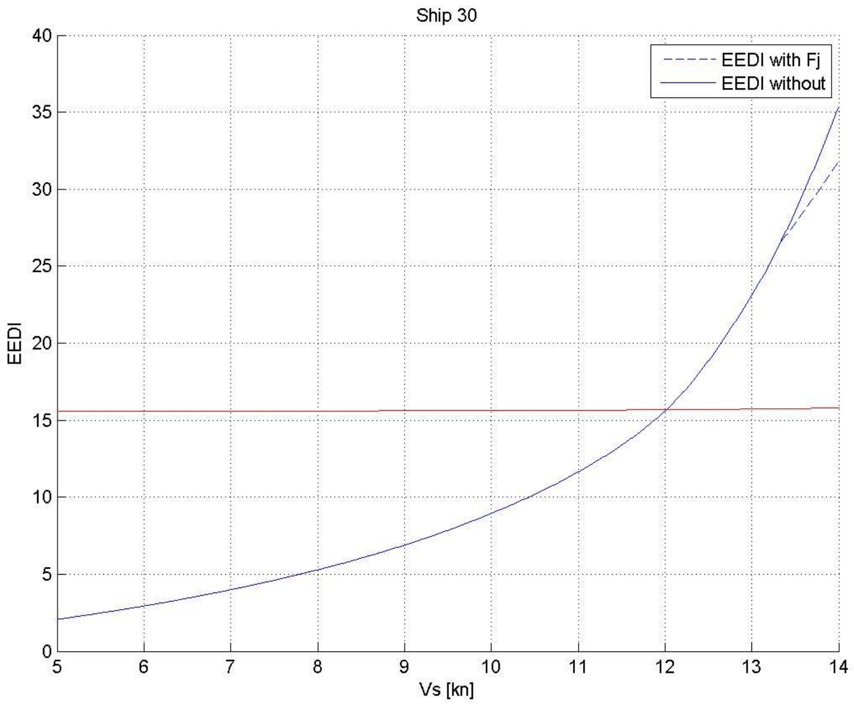
Appendix 10 ***Required, Attained and Corrected Attained EEDI of Ship 27 and 28***



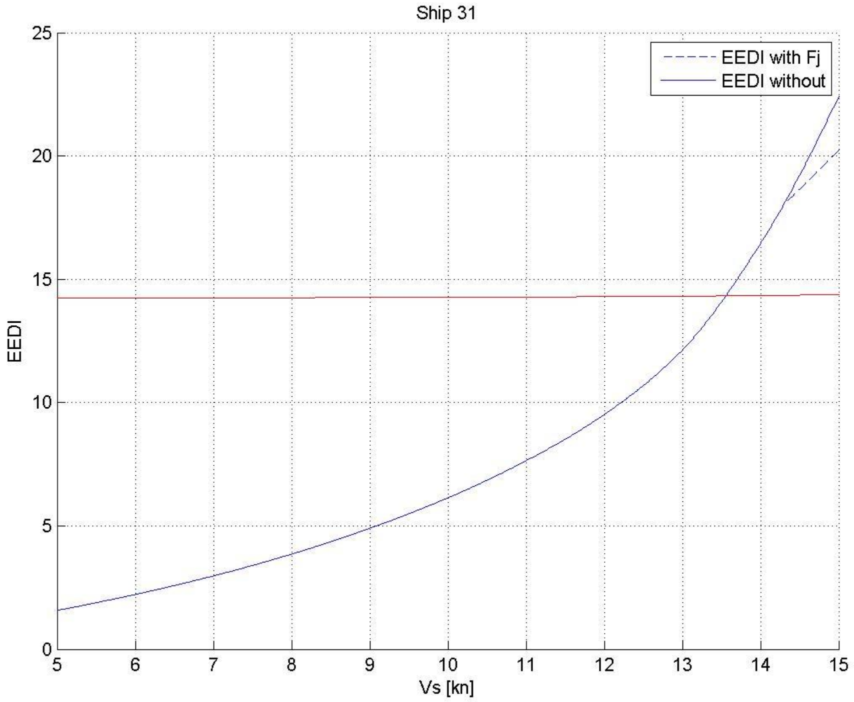


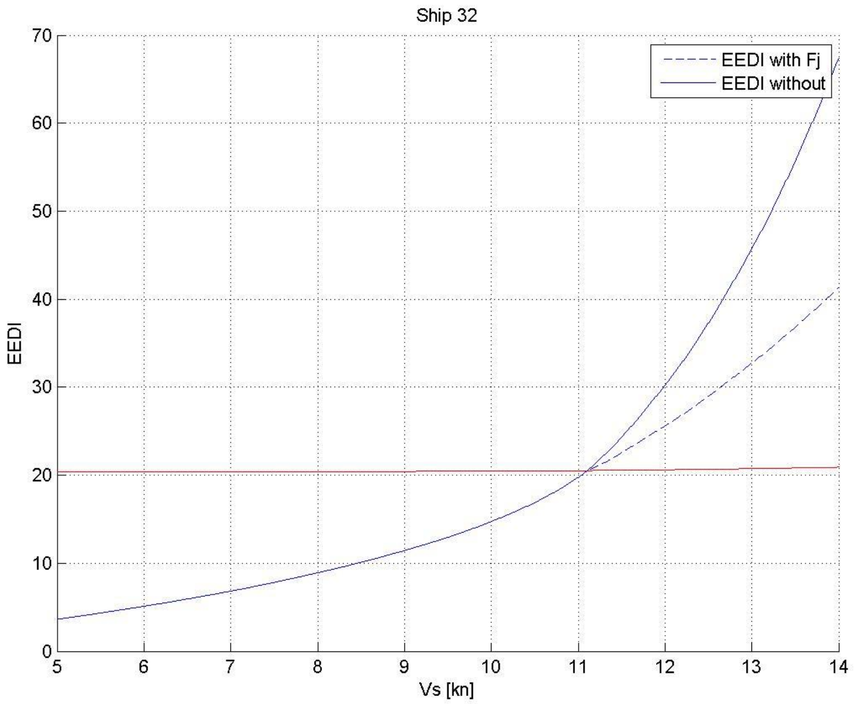
Appendix 11 ***Required, Attained and Corrected Attained EEDI of Ship 29 and 30***



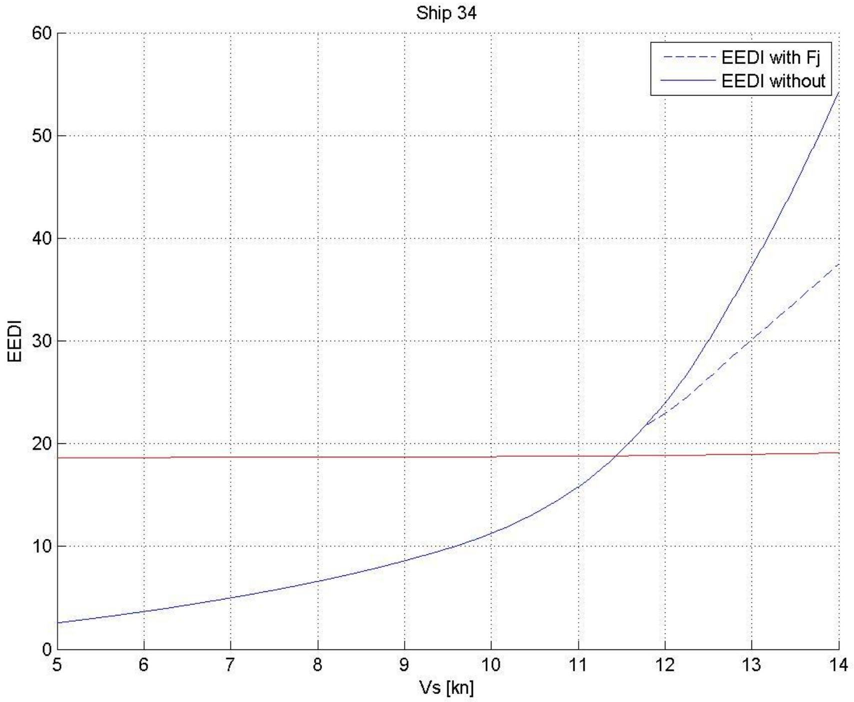


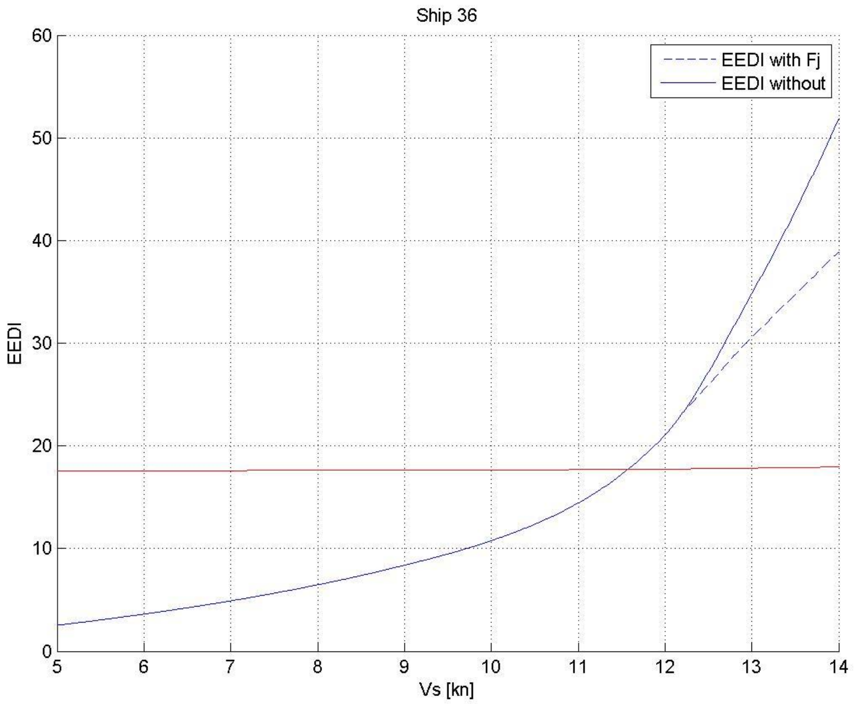
Appendix 12 *Required, Attained and Corrected Attained EEDI of Ship 31 and 32*



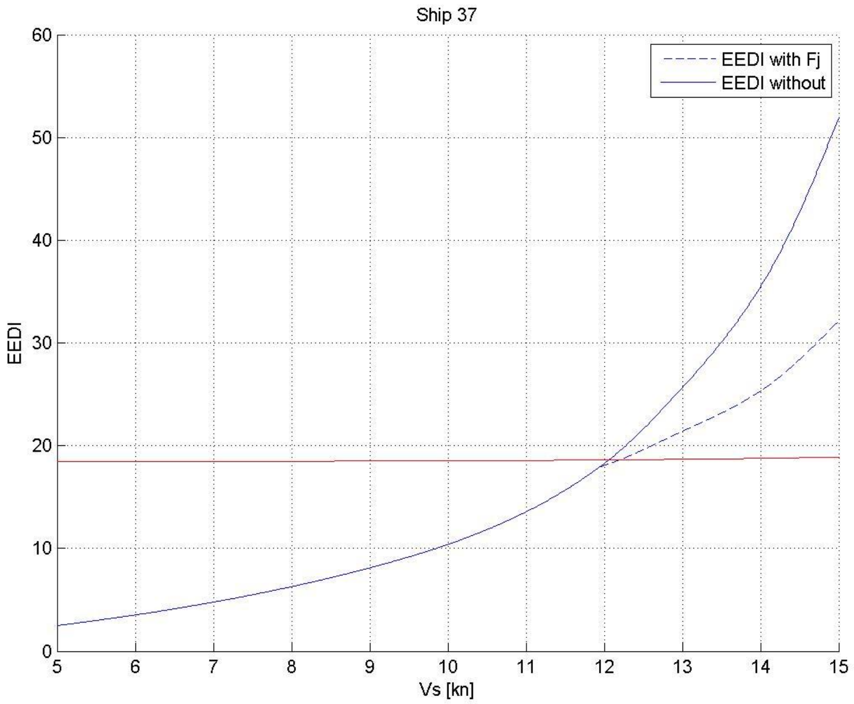


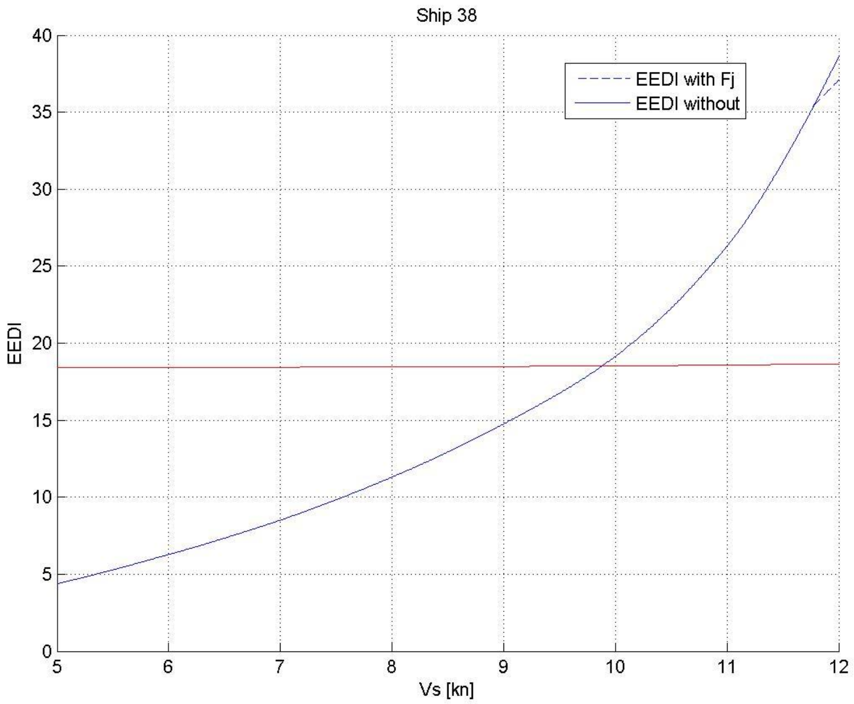
Appendix 13 ***Required, Attained and Corrected Attained EEDI of Ship 34 and 36***



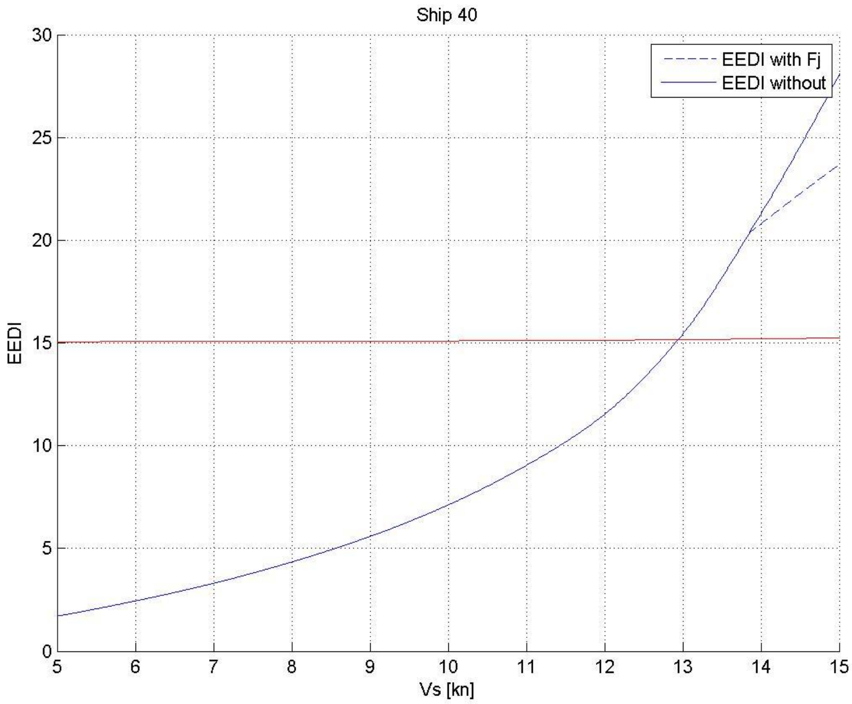


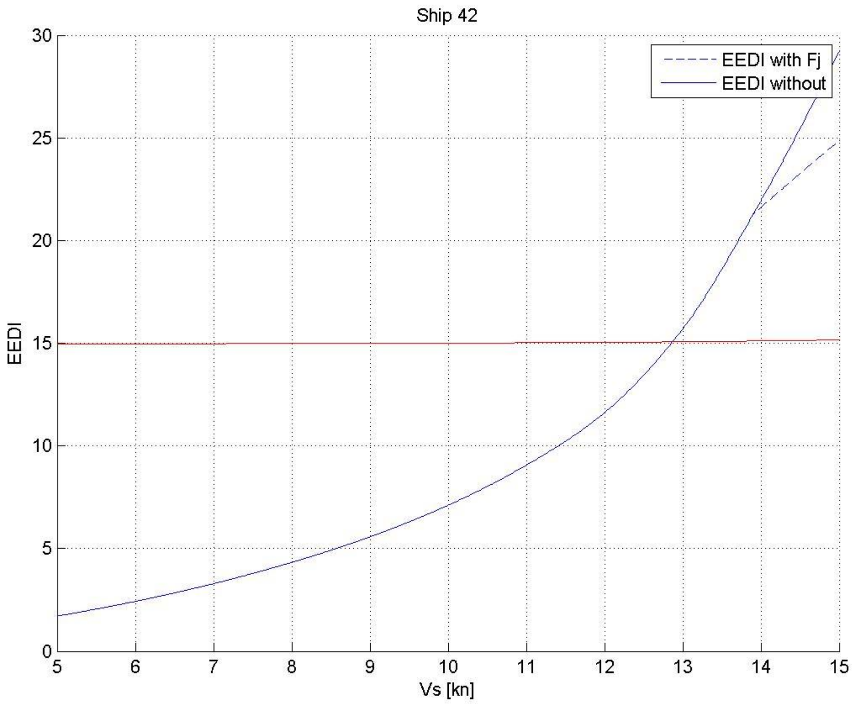
Appendix 14 ***Required, Attained and Corrected Attained EEDI of Ship 37 and 38***



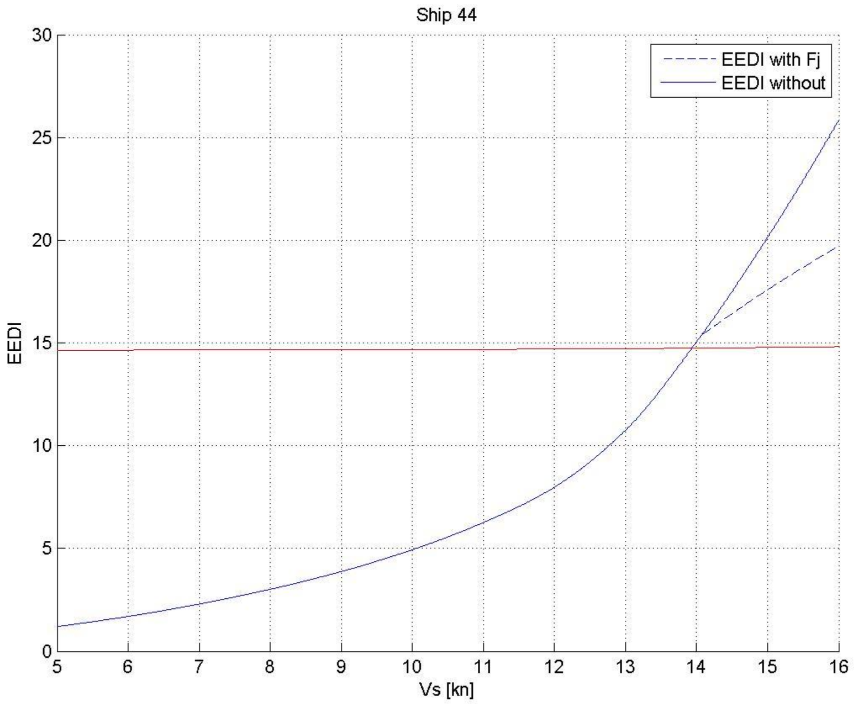


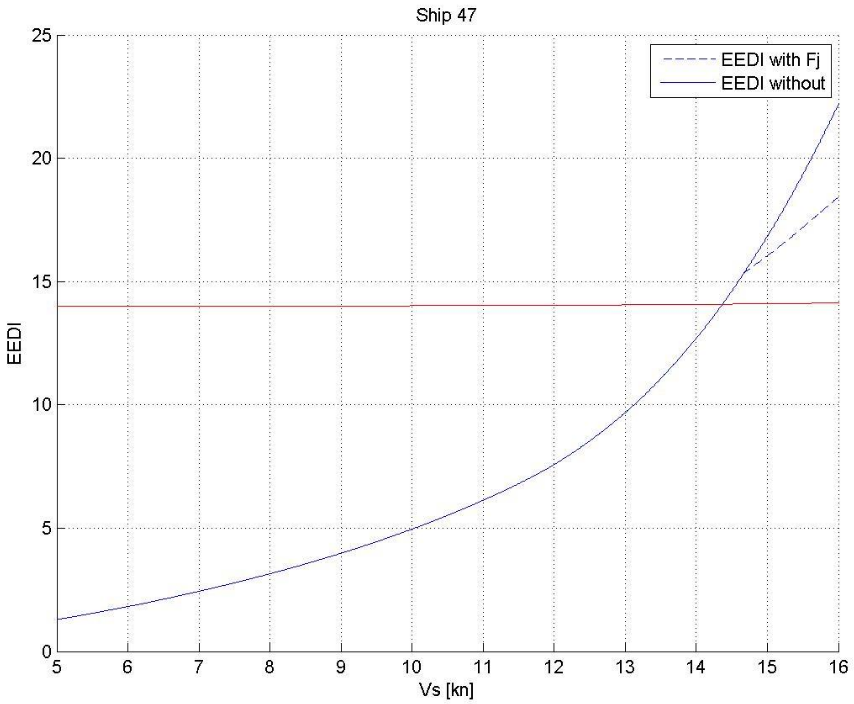
Appendix 15 *Required, Attained and Corrected Attained EEDI of Ship 40 and 42*



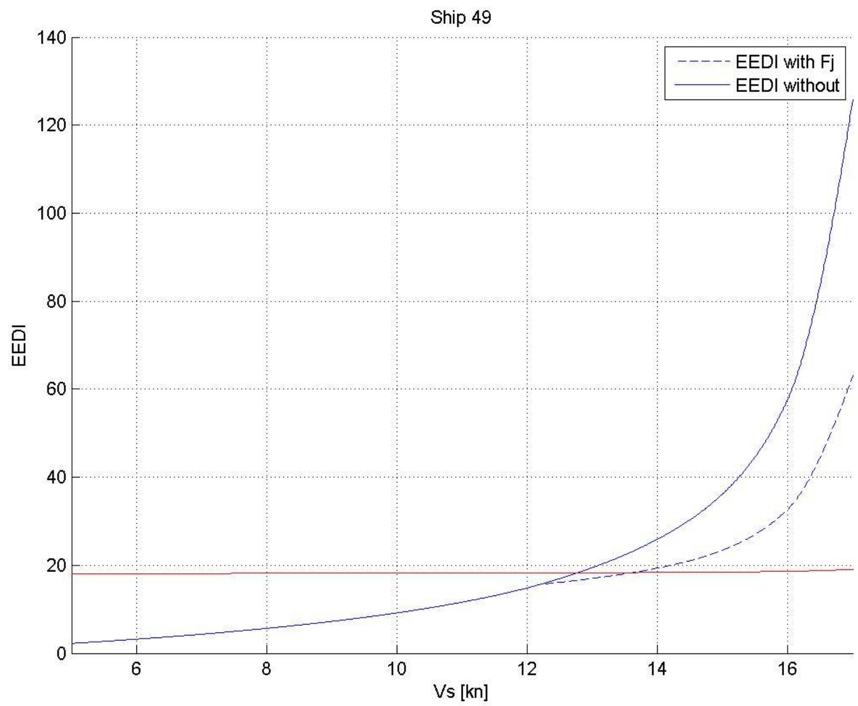


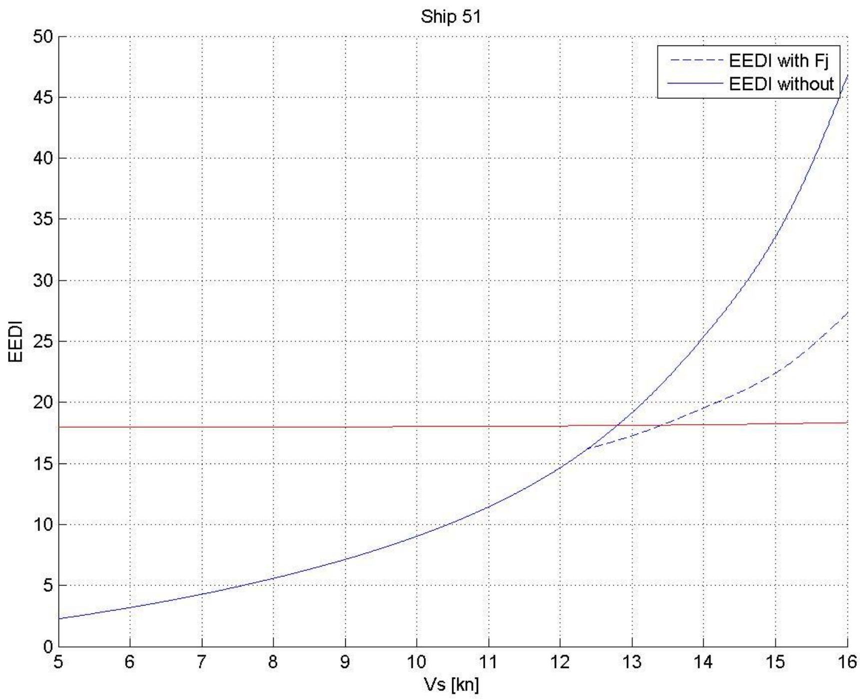
Appendix 16 ***Required, Attained and Corrected Attained EEDI of Ship 44 and 47***





Appendix 17 ***Required, Attained and Corrected Attained EEDI of Ship 49 and 51***





Appendix 18 *Required, Attained and Corrected Attained EEDI of Ship 53*