INTERSESSIONAL MEETING OF THE GREENHOUSE GAS WORKING GROUP
2nd session
Agenda item 2

GHG-WG 2/2/20
6 February 2009
ENGLISH ONLY

CONSIDERATION OF THE ENERGY EFFICIENCY DESIGN INDEX FOR NEW SHIPS

Correction coefficients f_j and f_i for EEDI for ships having an ice class

Submitted by Canada, Estonia, Finland and Norway

SUMMARY

Executive summary:	The purpose of this document is to consider the possibilities of determining one of the f_j coefficients for power and the coefficient f_i for capacity with regard to ice strengthened ships for the attained Energy Efficiency Design Index for new ships The proposed form of both coefficients is essentially the ratio between the power or capacity value of a ship designed for open water conditions only and that of the ice classed ship. The formulation of the coefficients has been investigated in this pilot study for tankers using the Lloyd's Register – Fairplay database of about 2,700 open water and ice class tankers. The analysis yielded a practical suggestion for the power and deadweight correction coefficients for tankers. Further calculations are needed for determination of the coefficients for other ship types
Strategic direction:	7.3
High-level action:	7.3.1
Planned output:	7.3.1.3
Action to be taken:	Paragraph 20
Related documents:	MEPC 58/4/7, MEPC 58/4/36, MEPC 58/WP.8 and MEPC 58/23

Background

1 The Marine Environment Protection Committee developed at its fifty-eighth session a proposal for a method of calculation of the Energy Efficiency Design Index (EEDI) for new ships, which is presented in annex 11 of the report of the meeting (MEPC 58/23).

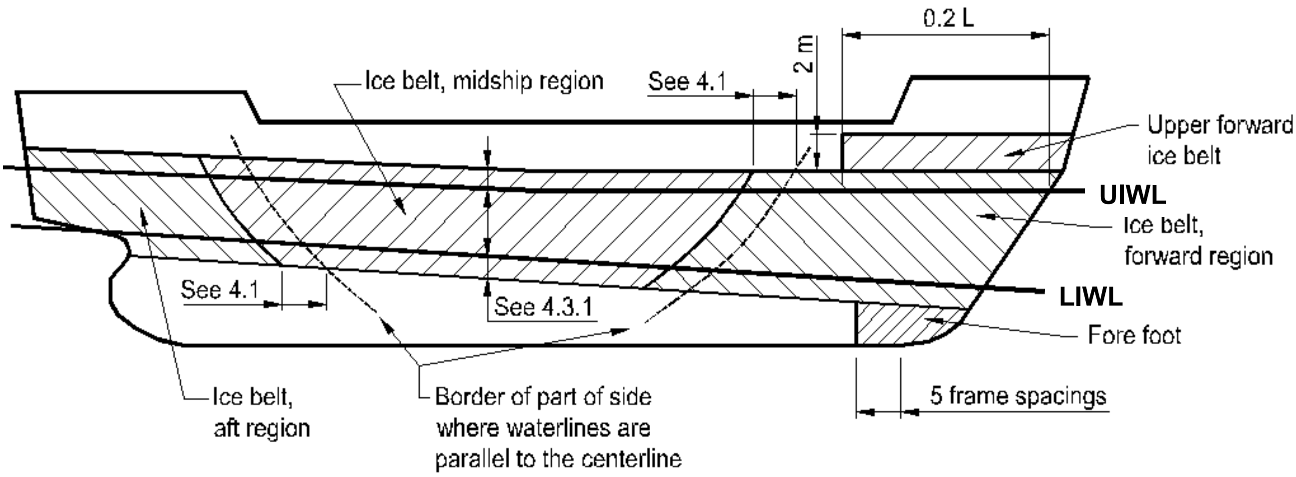
2 In section 8 of the report of the Working Group on Greenhouse Gas Emissions from Ships (MEPC 58/WP.8) it is stated, *inter alia*, that the group identified development of f_j and f_i for ice-class ships as one of the remaining tasks to be carried out concerning the new EEDI.

3 In the proposed formula, f_j represents the coefficient for ice-classed ships determined by the standard f_j "table/curve" which is to be contained in the Guidelines, and f_i is the capacity factor for any technical/regulatory limitations on the capacity of the ship. The introduction of the correction coefficients for ice-classed tonnage means that the baseline for EEDI is to be calculated based solely on ships designed for open water conditions only.

4 In this document a method for determination of the correction coefficients f_j and f_i is presented for tankers concerning ships having a Finnish-Swedish Ice Class IC, IB, IA or IA Super, or an ice class equivalent to these ice classes for safe navigation in the Baltic Sea. Further calculations are needed for determination of the coefficients for other ship types.

Ice class rules

5 Ice strengthening of ships is an essential requirement for the safe provision of transport services year round to and from countries with winter conditions. The ice class rules are introduced for this purpose. The requirements stated in the ice class rules include strengthening of the hull at the ice belt where ice loads act on the hull of the ship. The ice belt defined in the Finnish-Swedish ice class rules is shown schematically below. The ice class rules also require strengthening of the components in the propulsion machinery. The suitable strength level has been found by observing the damages that ice loads cause. If the number of damages is alarming or the damages are large, the required strength level in the ice class rules has been increased. This way a suitable safety level for icebound shipping has been developed. Ice strengthening is thus a safety measure.



6 Some ice class rules (most notably the Finnish-Swedish and Russian Register of Shipping ice class rules) also require a minimum propulsion power. The rationale behind this is that if the merchant ships have some ice performance, they can proceed some distance in ice independently and thus decrease the icebreaker assistance needed. Thus the winter navigation systems in the Baltic Sea can be optimized when it comes to the number of merchant ships, distances in ice sailed independently and the number of icebreakers. The performance of ships in ice is also a safety issue, because if the ship gets stuck in ice, it can drift aground or ice can cause extensive damages.

7 The Finnish (FMA) and Swedish (SMA) Maritime Administrations have issued ice class rules for ice strengthening of ships (see e.g., www.fma.fi -> Laws and regulations (under Information Services) -> FMA Bulletin -> Bulletin 10/10.12.2008, Finnish-Swedish Ice Class Rules, 2008). These rules are intended to be used for ice strengthening of ships navigating in the Baltic Sea area, i.e. in first year ice conditions. Four ice classes for ice strengthening of ships are given: IC, IB, IA and IA Super, where IA Super is the highest ice class. Ships having ice class IA or IA Super are intended for year-round navigation in the Baltic Sea area even in the most severe ice conditions.

8 In the Finnish-Swedish Ice Class rules the ice classes in question are described as follows:

.1 **ice class IA Super**; ships with such structure, engine output and other properties that they are normally capable of navigating in difficult ice conditions without the assistance of icebreakers;

.2 **ice class IA**; ships with such structure, engine output and other properties that they are capable of navigating in difficult ice conditions, with the assistance of icebreakers when necessary;

.3 **ice class IB**; ships with such structure, engine output and other properties that they are capable of navigating in moderate ice conditions, with the assistance of icebreakers when necessary; and

.4 **ice class IC**; ships with such structure, engine output and other properties that they are capable of navigating in light ice conditions, with the assistance of icebreakers when necessary.

9 Most of the classification societies which are members of the International Association of Classification Societies (IACS) have adopted the Finnish-Swedish Ice Class Rules in their own rules for classification of ships. However, many of them also have their own ice class rules for ice strengthening of ships. Some of them also have ice class rules for ships navigating in the Arctic, i.e. in areas where multi-year ice exists. The Arctic ice class rules have now been harmonized with the introduction of IACS Polar Class (PC) ice classes.

Equivalence of ice classes

10 Due to different nature of traffic conditions in different geographical regions in the world, no single standard exists for ice strengthening of ships. Several existing rules for ice strengthening of ships can be used. The equivalence of the most commonly used ice class rules has been agreed on by the Baltic Sea States, see HELCOM Recommendation 25/7, "Safety of Winter Navigation in the Baltic Sea Area" (see www.helcom.fi -> Recommendations -> Valid HELCOM Recommendations). A number of equivalent ice classes to the Finnish-Swedish ice classes have also been presented in FMA Bulletin 4/2.4.2007 (see www.fma.fi).

Correction coefficients f_j and f_i for EEDI for ships having an ice class

11 The question elaborated here stems from the fact that ice classed ships often have higher engine power than corresponding ships designed for open water conditions only due to the required performance in ice conditions. Ice classed ships also have a larger light ship weight due to ice strengthening of the hull and the propulsion line. Both the higher engine power and ice strengthening are features that increase the safety of the ship in ice. The constants f_j and f_i are introduced in order to make the ice classed ships comparable with corresponding ships designed

for open water conditions only. Thus the factor f_j should be formulated so that credit is given to the increased power level resulting in better ice performance of ice classed ships. At the same time the factor f_i should be developed to correct the capacity in view of the decreased cargo carrying capacity due to increased steel weight (light ship weight). It is also possible that an ice-going ship has a lower value of the block coefficient than a ship designed for open water conditions only, which decreases the cargo carrying capacity as well.

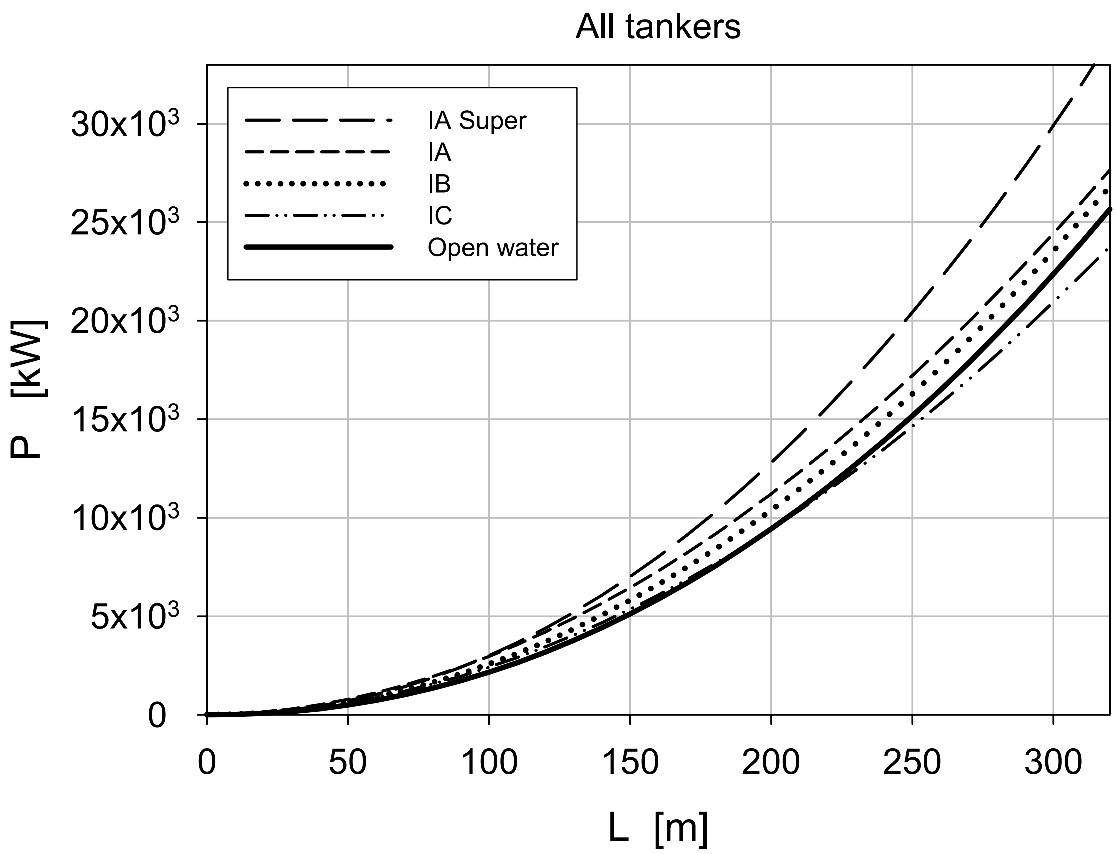
Proposals for determination of the f_j (=f_l) correction factor for the main engine power of ice strengthened ships

12 Ship data was analysed statistically in order to calculate the average propulsion power of tankers designed for open water conditions only and tankers having a Finnish-Swedish Ice Class. Only tankers were analysed in this pilot study but other ship types should be analysed once the methodology has been agreed upon. Plots of ship power versus ship length are shown in Appendix 1 to annex 1, for ships having a Finnish-Swedish ice class IA Super, IA, IB and IC as well as for ships designed for open water only. A regression curve of exponential form ($P = aL^b$) was also fitted on the data points and is shown together with the plots. The ship data is taken from a data bank of about 2700 tankers – the basis for this data base is the Lloyd's Register – Fairplay data which is complemented by ship data from the Nordic countries, especially for the ice classed tonnage. This database was also corrected due to some inaccuracies in the data. From the tanker data the LNG and LPG carriers, FPSU's and FSU's as well as some ships with exceptional power plant (e.g., tankers having a diesel-electric power plant) were removed. A lower limit was introduced and thus only ships that have a deadweight larger than 300 dwt are included in the data base. Sister ships are represented by only one of the series. The resulting number of ships in each ice class is shown in the table below.

Ship type	**Open water**	**IC**	**IB**	**IA**	**IA Super**
Bulk carrier[1)]					
Cargo carrier[1)]					
Tanker	1470	120	83	182	17
Container ship[1)]					
Ro-Ro ship[1)]					
RoPAX[1)]					
Passenger ship[1)]					

1) To be developed later.

The curve fits for engine power of tankers is shown below. The basic data and the curve fits are shown in Appendix 1 to annex 1 to this document.



13 The final form of the correction coefficient f_1 is presented in the table below (unit for the power is kW). The form of the coefficient is the average open water power calculated using the ship's actual length divided by the actual installed ship power, i.e.

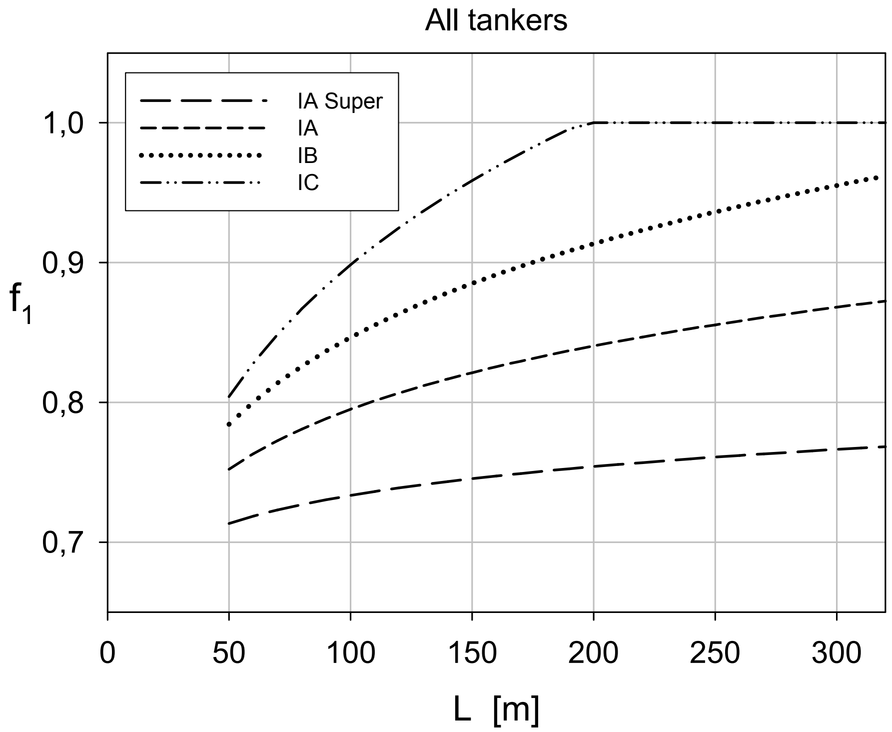
$$f_1 = \frac{P_{avg,ow}(L)}{\sum_{i=1}^{nME} P_{ME_i}},$$

where in the subscripts *avg* stands for 'average' and *ow* for 'open water'. The ship length used in the calculations is the overall length i.e. $L = L_{OA}$ (unit m). For more details of the calculation, see annex 1. The maximum value this coefficient can attain is obviously one (=1) but the lower limit is set depending on the ice class. This is because higher ice classes are required to have more power – but there should be a lower limit so that excess power over that required in the ice class rules is not unduly rewarded. The lower limit is selected based on – thus naturally not exactly – the ratio between the open water power divided by the average power of the ship in each ice class, and the ratio is calculated at the same ship length. The correction coefficient for an individual ship will attain some value between these limits depending on the actual installed total main engine power of the ship. The lower limits were reached by first deriving the average open water power and average power in each ice class – these versus ship length – and then calculating the ratio of these. Some smoothing was required to reach the final equations for the lower limit.

<table>
<tr><th rowspan="2">Ship type</th><th rowspan="2">f_1</th><th colspan="4">Limits depending on the ice class</th></tr>
<tr><th>IC</th><th>IB</th><th>IA</th><th>IA Super</th></tr>
<tr><td>Bulk carrier[1)]</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Cargo carrier[1)]</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Tanker</td><td>$\frac{0.120 \cdot L^{2.128}}{\sum_{i=1}^{nME} P_{ME_i}}$</td><td>$\begin{cases} \max 1.0 \\ \min 0.43 \cdot L^{0.16} \end{cases}$</td><td>$\begin{cases} \max 1.0 \\ \min 0.51 \cdot L^{0.11} \end{cases}$</td><td>$\begin{cases} \max 1.0 \\ \min 0.55 \cdot L^{0.08} \end{cases}$</td><td>$\begin{cases} \max 1.0 \\ \min 0.61 \cdot L^{0.04} \end{cases}$</td></tr>
<tr><td>Container ship[1)]</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Ro-Ro ship[1)]</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>RoPAX[1)]</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Passenger ship[1)]</td><td></td><td></td><td></td><td></td><td></td></tr>
</table>

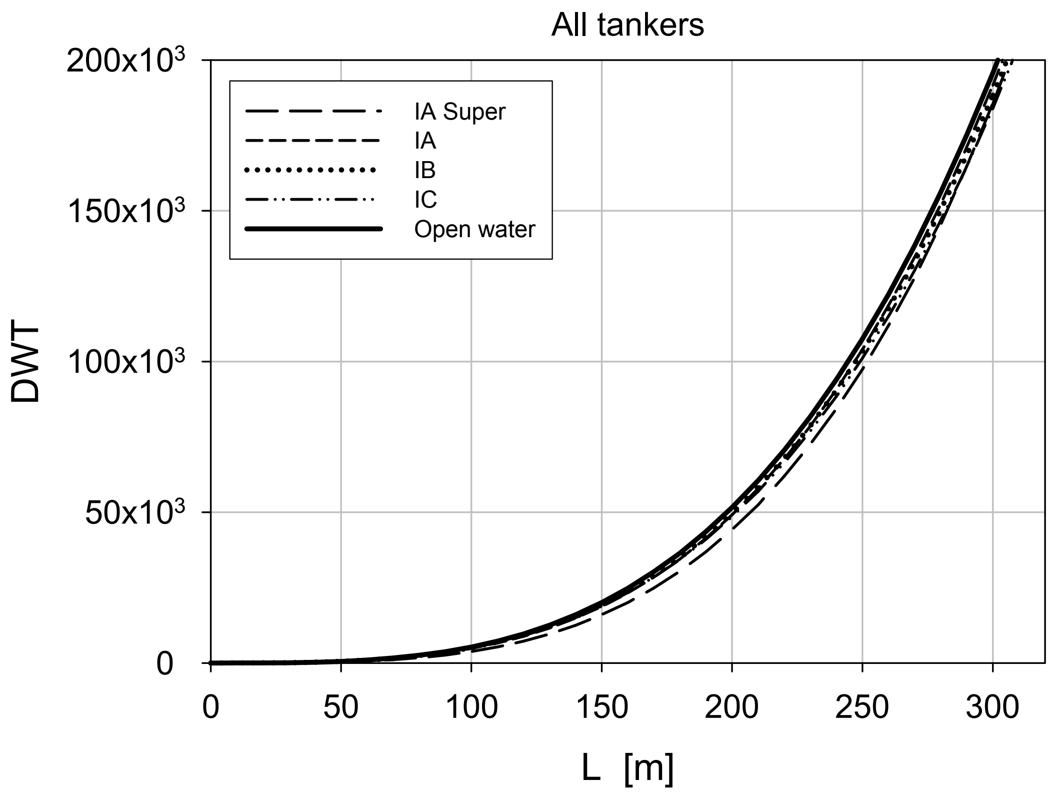
1) To be developed later.

14 The minimum value of the correction coefficients (f_1) of power for tankers is depicted in the figure below.



Proposals for determination of correction factor f_i for the capacity of ice-strengthened ships

15 Ship data was also analysed statistically in order to calculate the average deadweight of tankers designed for open water conditions only and having a Finnish-Swedish Ice Class or an equivalent ice class. Plots of ship deadweight versus ship length are shown in Appendix 2 for ships having a Finnish-Swedish ice class IA Super, IA, IB and IC as well as for ships designed for open water only. A regression curve of exponential form ($P = aL^b$) was also fitted on the data points and is shown below for the tankers.

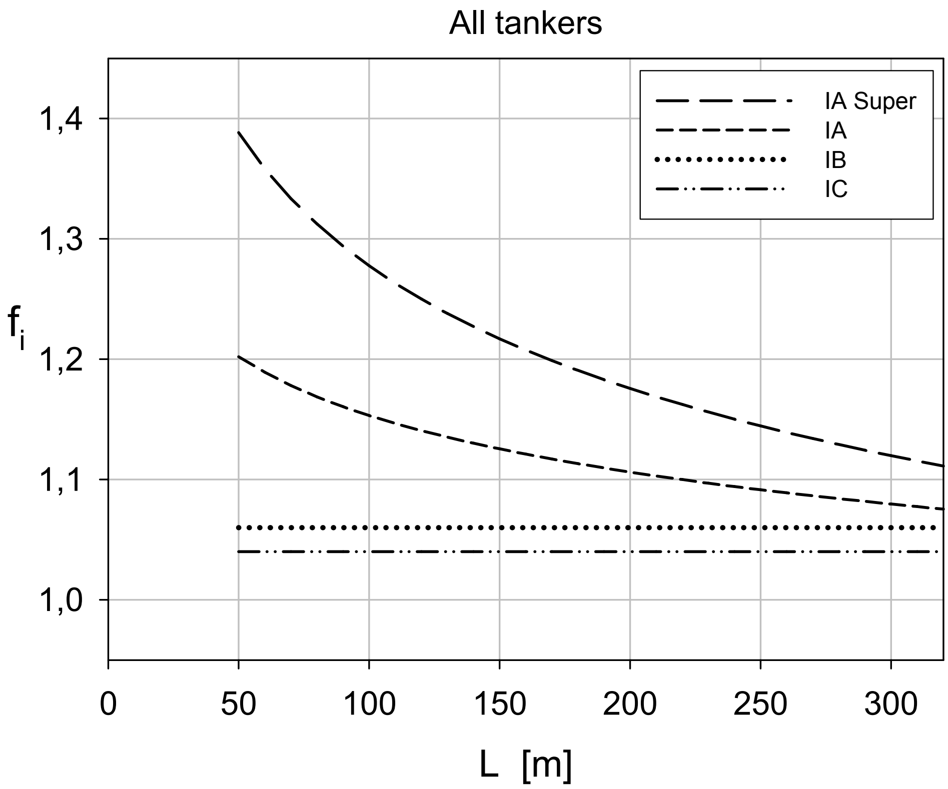


16 The final form of the correction coefficient f_i is presented in the table below (unit for deadweight is tonnes). The rationale in deducing these coefficients is the same as for the power correction, here the coefficient has an upper limit with a lower limit of one (=1). The minimum and maximum capacity correction coefficient is given for each ice class separately. The correction coefficient for an individual ship will be a figure between these values depending on the deadweight of the ship. The ship length L is the overall length of the ship i.e. L_{OA} (unit m).

Ship type	f_i	**Limits depending on the ice class**			
		IC	**IB**	**IA**	**IA Super**
Bulk carrier[1)]					
Cargo carrier[1)]					
Tanker	$\frac{0.00142 \cdot L^{3.286}}{capacity}$	$\begin{cases} \max 1.04 \\ \min 1.0 \end{cases}$	$\begin{cases} \max 1.06 \\ \min 1.0 \end{cases}$	$\begin{cases} \max 1.52 \cdot L^{-0.06} \\ \min 1.0 \end{cases}$	$\begin{cases} \max 2.22 \cdot L^{-0.12} \\ \min 1.0 \end{cases}$
Container ship[1)]					
Ro-Ro ship[1)]					
RoPAX[1)]					
Passenger ship[1)]					

1) To be developed later.

17 The maximum value of the correction coefficients of capacity for tankers (f_i) is depicted in the figure below.



Summary

18 A scheme to make ice classed ships comparable with ships designed for open water conditions only is proposed. The ice class is required for safety reasons and thus ice classed tonnage should not be handicapped by the added weight and/or power that the ice class requires. The method to make ice classed ships comparable is to introduce correction coefficients on the ship power and capacity (dwt) – the form of these coefficients is essentially a ratio between average open water value divided with the ship specific value (power or capacity). The average open water power is derived based on a large data base. As there are many ships that have values that differ considerably from the average, some limits must be placed on the correction coefficients. These limits – minimum for power correction and maximum for capacity correction – are derived so that these correspond to the average value in each ice class. More detailed information on the calculations can be found in annex 1.

19 In deriving the initial form of the correction coefficients, several questions arose. The fundamental question is the scatter in an analysis based on a large set of data points and regression through these points. This uncertainty is pronounced if the number of points used is small as is the case in several ice classes/ship types. Especially the number of ice class passenger ships is small and here the derivation of the limits will be challenging. In the case of tankers, the correlation coefficient was clearly more than 0.9 showing a good correlation which can be seen also from the plots. The ship length used in the calculations is the overall length of the ship. However, the length between perpendiculars might be a better choice for the length parameter since this is used in the ship design process. When deriving the final form of the coefficients this has to be taken into account.

Action requested of the Intersessional Meeting

20 The Intersessional Meeting is invited to consider the proposals for determination of the correction coefficients f_j and f_i presented above and decide as appropriate.

***

ANNEX

DEVELOPMENT OF COEFFICIENTS TO ACCOUNT FOR THE ICE CAPABILITY IN CALCULATING THE ATTAINED ENERGY EFFICIENCY DESIGN INDEX FOR NEW ICE CLASSED SHIPS

1 The coefficients that are proposed to be included in the attained EEDI index should make ice classed ships comparable with the corresponding open water ships. The coefficients are included in the index as follows:

EEDI index =

$$\frac{\left(f_1 \cdot \prod_{j=2}^{M} f_j\right)\left(\sum_{i=1}^{nME} C_{FMEi}\ SFC_{MEi}\ P_{MEi}\right) + C_{FAE}\ SFC^{*}_{AE}\ P_{AE} + \left(\sum_{i=1}^{nPTI} P_{PTIi} - \sum_{i=1}^{nWHR} P_{WHRi}\right) - \left(\sum_{i=1}^{neff} f_{eff} P_{eff} C_{Feff} SFC_{MEi}\right)}{(f_i \cdot Capacity) \cdot V_{ref} \cdot f_W}$$

where the first of the coefficients f_j i.e. f_1 takes into account the increased power of ice classed ships and the coefficient f_i takes into account the reduced cargo carrying capacity due to increased steel weight and also due to the ice breaking hull form – the parenthesis in the denominator is added to clarify which factor the coefficient acts on. These ice related coefficients aim at making the ice classed ships equal to open water ships.

2 The possible form of the coefficients mentioned in paragraph 1 above is analysed in the following. The analysis is restricted to only those ship types the *capacity* of which is described by the *deadweight, DWT*. The basic form of the capacity coefficient (power coefficient) is the deadweight (or propulsion power) of an open water ship divided by the deadweight (or propulsion power) of an ice class ship. The value of the open water power or deadweight is taken from an average open water ship corresponding to the ice class ship. The definition of the correspondence is that some ship parameter, denoted here symbolically as *A*, has the same value for the open water ship as for the ice class ship. The possibilities for correspondence are the same displacement, the same deadweight or the same length. As the open water values come from an average open water ship, there are two possibilities for calculating the coefficients, i.e. the ratio; either using the ratio of averages or the ratio of the average open water value divided by the actual value of the ice class ship. These definitions are in equation form (E[·] denotes the average value):

$$f_i = \frac{E\left[DWT\big|_{A_{OW}=A_i}\right]}{DWT\big|_{A_i}} \quad \text{or,} \quad f_i = \frac{E\left[DWT\big|_{A_{OW}=A_i}\right]}{E\left[DWT\big|_{A_i}\right]}$$

where the subscripts OW and i stand for Open Water and ice, respectively. These forms for the coefficient to account for the lost capacity must, however, be derived jointly with the effect of the lost displacement of ice classed ships compared with the corresponding open water ships due to the ice breaking hull form. The power correction coefficient can be defined similarly as the capacity correction coefficient. Thus the form of the coefficients to be derived below is the following:

$$f_j = f_1 = \frac{E\left[P\big|_{L_{OW}=L_i}\right]}{P\big|_{L_i}}, \qquad \begin{cases} \max 1.0 \\ \min f_i = \dfrac{E\left[P\big|_{L_{OW}=L_i}\right]}{E\left[P\big|_{L_i}\right]} \end{cases}$$

$$f_i = \frac{E\left[DWT\big|_{L_{OW}=L_i}\right]}{DWT\big|_{L_i}}, \qquad \begin{cases} \max f_1 = \dfrac{E\left[DWT\big|_{L_{OW}=L_i}\right]}{E\left[DWT\big|_{L_i}\right]} \\ \min 1.0 \end{cases}.$$

The average values in the above equations are calculated based on a data base of ship values divided into different ship types.

3 It should be noted that when calculating the EEDI index, the input data for the index are given by the ship values in question. The coefficients f_l and f_i are based, however, on average values for ice classed and open water ships. The correspondence between open water and ice classed ships is considered here to be based on ship length *L* i.e. $A \equiv L$.

Correction coefficient for better ice performance f_i (=f_l)

4 The form of the coefficient f_l was presented in paragraph 2. The main question is what is the reference open water ship power $P_{ME,OW}$? This could be defined as the power of a similar ship in way of *dwt* – but this would implicitly mean that we take $f_i = 1$. Other possibilities for the similarity are that the displacements are taken to be the same i.e. $\Delta_i = \Delta_{OW}$ or that the bulk volumes $\{LBT\}$ are taken to be the same ($\{LBT\}_i = \{LBT\}_{OW}$). These possibilities are touched upon when analysing the coefficient f_i. Here the similarity is defined as the same ship overall length i.e. $L_i = L_{OW}$.

5 Statistical ship data is now analysed in order to see what kind of correction ensues for different ice classes from the above definition. Plots of ship power versus ship length are shown in Appendix 1 for Finnish-Swedish ice classes IA Super, IA, IB and IC as well as open water ships. A regression curve of exponential form ($P = aL^b$) was also fitted on the data points and shown together with the plots. The ships come from a data base of about 2700 tankers – the basis for this data base is the Lloyd's Register – Fairplay data which is complemented by ships from Nordic countries, especially for the ice classed tonnage. From the tanker data the LNG and LPG carriers, FPSU's and FSU's as well as some ships with exceptional power (DE tankers) were removed. Sister ships are represented by one of the series. The resulting number of ships used in this study in each ice class and ship type is:

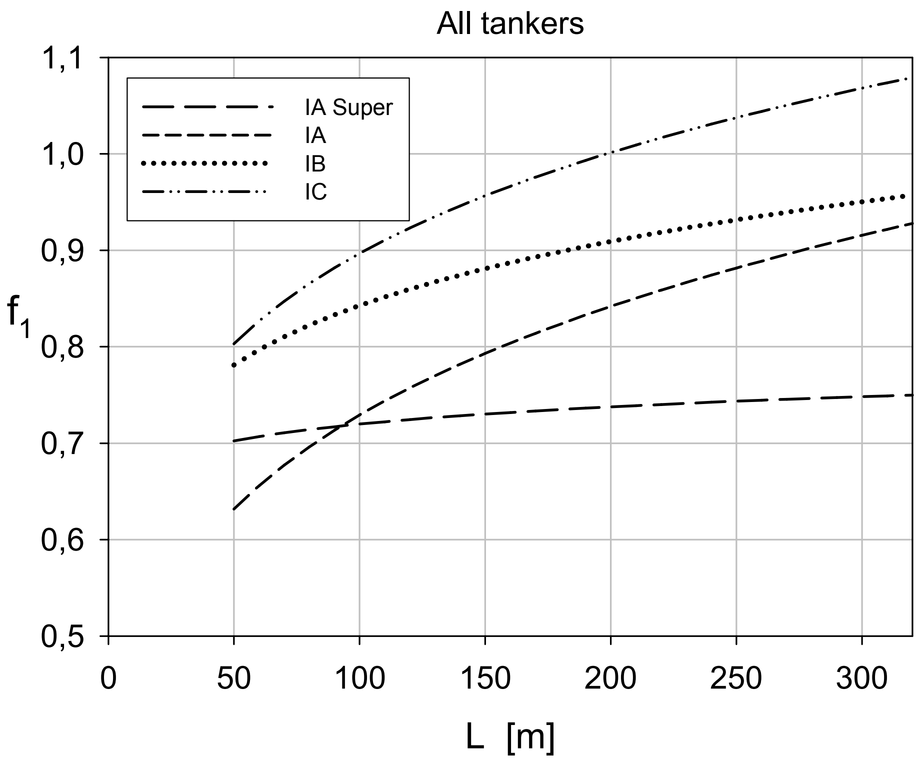
	Tankers
IA Super	17
IA	182
IB	83
IC	120
Open water	1470

The resulting data points and regression curve fits are given in Appendix 1. The curve fits give reasonable values in most cases even if some scatter exists.

6 The regression on tankers showed a good correlation and it gives the following form for the power correction coefficient for the tankers

$$f_j = \frac{0.120 \cdot L^{2.128}}{\sum_{i=1}^{nME} P_{ME_i}}.$$

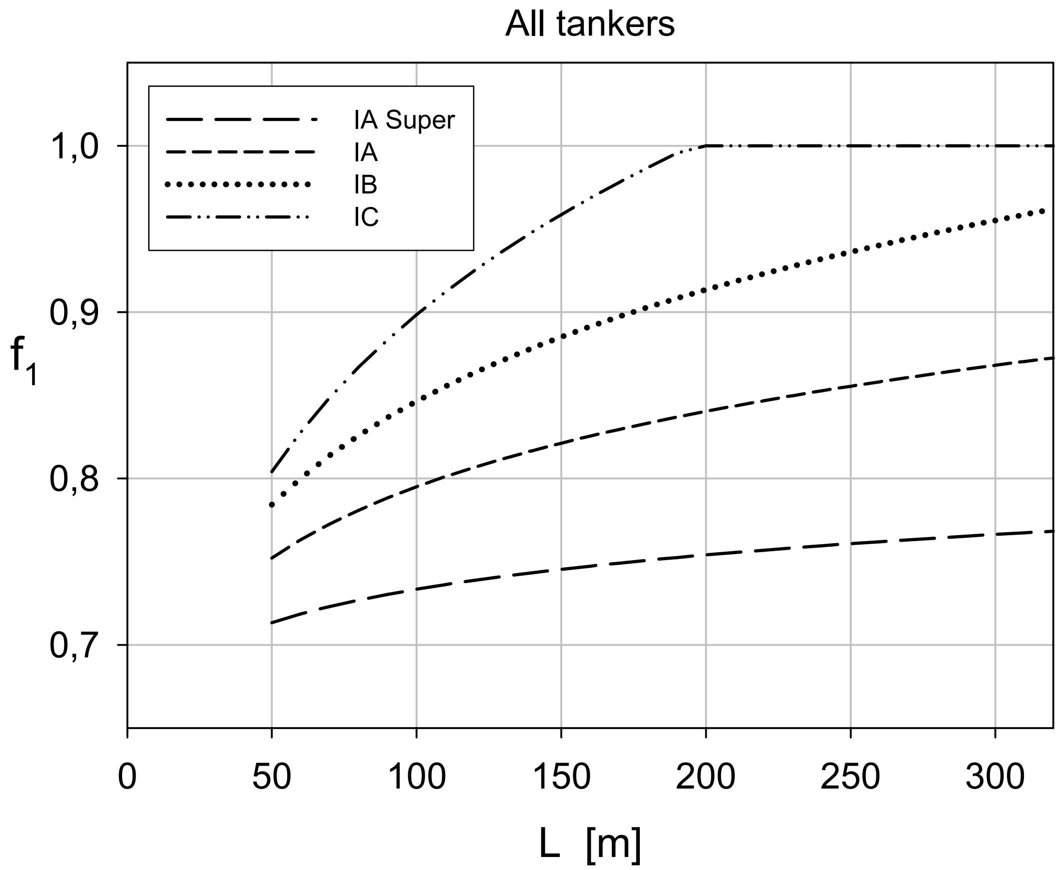
7 The form of the lower limit of the correction coefficient f_j, based on the ratio between the open water regression curve and the regression curve for each ice class, is shown below.



This plot suggests that some changes are required. The form of the upper limit of f_1 should not be larger than one (=1.0) – thus the curve for ice class IC should be corrected. Also the curves for ice classes IA and IA Super cross at ship length of about 100 m – this is also not correct.

8 The f_1 curves presented above should be smoothed in order to get a good spread of the curves. This is done by somewhat correcting each of the ice class curves. The result is shown in the plot below. Now the equations for each curve i.e. lower limit for f_1 can be given; these are:

IA Super	$0.61 \cdot L^{0.04}$
IA	$0.55 \cdot L^{0.08}$
IB	$0.51 \cdot L^{0.11}$
IC	$0.43 \cdot L^{0.16}$, max 1.0.



9 The final form of the correction coefficient f_1 for tankers can now be presented. This uses both the above definitions. Thus the power correction coefficient is given for each ice class separately as (units kW and m):

IA Super $$f_1 = \frac{0.120 \cdot L^{2.128}}{\sum_{i=1}^{nME} P_{ME_i}} \quad \begin{cases} \max 1.0 \\ \min 0.61 \cdot L^{0.04} \end{cases}$$

IA $$f_1 = \frac{0.120 \cdot L^{2.128}}{\sum_{i=1}^{nME} P_{ME_i}} \quad \begin{cases} \max 1.0 \\ \min 0.55 \cdot L^{0.08} \end{cases}$$

IB $$f_1 = \frac{0.120 \cdot L^{2.128}}{\sum_{i=1}^{nME} P_{ME_i}} \quad \begin{cases} \max 1.0 \\ \min 0.51 \cdot L^{0.11} \end{cases}$$

IC $$f_1 = \frac{0.120 \cdot L^{2.128}}{\sum_{i=1}^{nME} P_{ME_i}} \quad \begin{cases} \max 1.0 \\ \min 0.43 \cdot L^{0.16} \end{cases}$$

10 The power correction coefficient was calculated for a small selection of example ships taken from the data base. The results are shown in the table below. The values that have been determined based on the upper or lower limit are shown in bold. It can be noted that for several ships the value of the power coefficient is determined by the limits.

Ship	**Ice class**	***P* [kW]**	***L* [m]**	**P_{OW} [kW]**	$\frac{0.120 \cdot L^{2.128}}{\sum_{i=1}^{nME} P_{ME_i}}$	**final f_1**
Iman	IA Super	3960	113.0	2760	0.6970	**0.7370**
Suula	IA Super	8400	139.75	4372	0.5205	**0.7433**
Purha	IA Super	9450	169.5	6640	0.7026	**0.7490**
Stena Arctica	IA Super	16660	249.79	15372	0.9227	0.9227
Renda	IA	4350	113.01	2760	0.6346	**0.8028**
Eken	IA	5300	134.71	4038	0.7618	**0.8142**
British Emissary	IA	9480	194.0	8894	0.9381	0.9381
Omega Theodore	IA	13560	228.0	12616	0.9304	0.9304
Delta Victory	IA	14280	250.0	15400	1.0784	**1.0**
Bellona	IB	1765	87.5	1586	0.8989	0.8989
Olivia	IB	2902	111.28	2670	0.9200	0.9200
Navigo	IB	4857	144.72	4716	0.9709	0.9709
Stena Contest	IB	9466	182.5	7791	0.8231	**0.9043**
Jag Lok	IB	18623	274.19	18809	1.0100	**1.0**
Linnea	IC	3236	149.51	5060	1.5636	**1.0**
Caribbean Wind	IC	8752	178.98	7470	0.8535	**0.9861**
Venice	IC	12200	240.4	14148	1.1597	**1.0**
Nevskiy Prospect	IC	15519	249.9	15387	0.9915	**1.0**

Correction coefficient for capacity f_i

11 The decreased cargo carrying capacity of ice classed ships stems from two factors. The cargo carrying capacity is decreased because the deadweight is smaller due to increased light ship weight, *LSW*, and also because the displacement is smaller compared to ships with similar bulk volume (L_{WL} x B_{WL} x T – to be termed below as *{LBT}*). The bulk volume is smaller for ice capable ships as the breaking hull shape has more sloping ship sides and stem. The latter reduction could be described by a smaller block coefficient C_B for ice classed ships if data about the block coefficient would be available.

12 The two above factors (increased *LSW* and decreased displacement) must be analysed together. The ship displacement Δ is the sum of *LSW* and *DWT*; $\Delta = DWT + LSW$. When the hull form is further taken into account, the displacement equilibria in ice and in open water are:

$$\begin{aligned} C_{B,i} \cdot \{LBT\} &= DWT_i + LSW_i \\ C_{B,OW} \cdot \{LBT\} &= DWT_{OW} + LSW_{OW} \end{aligned}.$$

13 As the aim of the coefficient f_i is to make the open water and ice classed ships equal in view of the CO_2 index, the ice classed ships must be compared with corresponding open water ships. This sounds clear but what is meant by the correspondence? Here two definitions for the correspondence are briefly investigated; one based on displacement Δ and the other based on the bulk volume $\{LBT\}$.

14 First, assume that the correspondence of open water and ice-strengthened ships is defined based on bulk volumes being equal i.e. $\{LBT\}_i = \{LBT\}_{OW}$, Then the capacity correction equation is given as:

$$f_i = \frac{DWT_{OW}}{DWT_i} = \frac{C_{B,OW}}{C_{B,i}} + \frac{\frac{C_{B,OW}}{C_{B,i}} \cdot LSW_i - LSW_{OW}}{DWT_i}.$$

Here the quantities LSW_i, DWT_i and also $C_{B,i}$ are known to the designer but not the corresponding open water values. The ratio of the block coefficients is:

$$\frac{C_{B,i}}{C_{B,OW}} = \frac{\Delta_i}{\Delta_{OW}}.$$

This ratio is difficult to determine in statistical terms as the displacement of ships is not given in typical databanks for ships.

15 The second alternative is to use the similarity based on displacement i.e. $\Delta_i = \Delta_{OW}$. This leads to the following for the coefficient:

$$f_i = 1 + \frac{\Delta LSW}{DWT_i} = 1 + \frac{\Delta DWT}{DWT_i}.$$

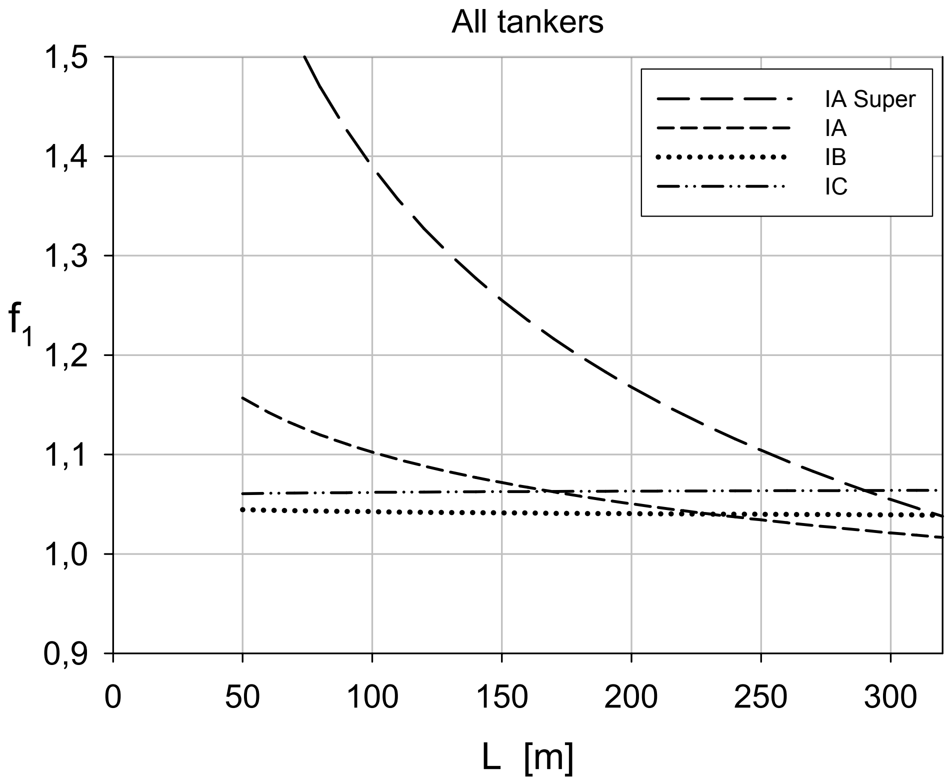
In this formulation all the quantities are given in the data banks of ships - but the problem of the deadweight difference remains as the difference should be for ships with the same displacement. In order to determine this, the deadweight versus ship displacement should be known. Thus both definitions of correspondence invoke practical problems of data availability.

16 It is assumed here that the correspondence between open water and ice classed ships is defined in terms of ship length as was done when the performance index f_I was investigated. A database of about 2,700 tankers was used in the study; the same as was used when analysing the power. The plots as well as curve fits of *DWT* versus *L* are shown in Appendix 2. It is noted directly that the *DWT* of the larger tankers is slightly underestimated as the bulk of the data is in smaller ships leading to a slightly smaller exponent value.

17 The form of the coefficient f_i is the average deadweight of an open water ship divided by the deadweight of an ice classed ship – this ratio is presented below for tankers:

$$f_i = \frac{0.00142 \cdot L^{3.286}}{capacity}.$$

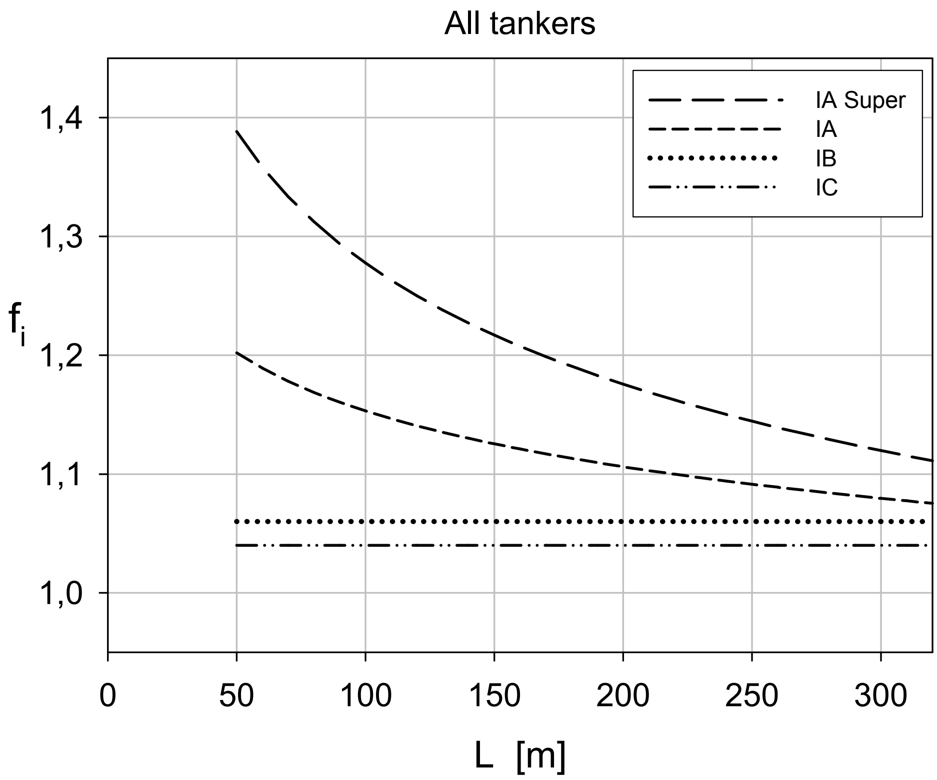
18 The curves for the upper limit of the capacity correction coefficient are presented below for tankers based on the regression curves on the capacity of open water ships and ice classed ships.



As these curves are calculated from direct regression curves, several errors can be pointed out. For tankers the curves for ice classes IB and IC are in inverse order to that expected and also the trend with length is too pronounced for higher ice classes.

19 The lower limit curves presented above should be smoothed in order to get a good spread of the curves. This is done by somewhat correcting the open water curve and at the same time correcting each of the ice class curves. The result is shown in the plots below. Here the equations for each curve can be given; these are:

Ice class	**Tanker**
IA Super	$2.22 \cdot L^{-0.12}$
IA	$1.52 \cdot L^{-0.06}$
IB	1.06
IC	1.04



20 The final form of the correction coefficient f_i can now be presented. This uses both the above definitions. Thus the capacity correction coefficient is given for each ice class separately as (units dwt and m):

Tankers

IA Super $$f_i = \frac{0.00142 \cdot L^{3.286}}{capacity}, \quad \begin{cases} \max 2.22 \cdot L^{-0.12} \\ \min 1.0 \end{cases}$$

IA $$f_i = \frac{0.00142 \cdot L^{3.286}}{capacity}, \quad \begin{cases} \max 1.52 \cdot L^{-0.06} \\ \min 1.0 \end{cases}$$

IB $$f_i = \frac{0.00142 \cdot L^{3.286}}{capacity}, \quad \begin{cases} \max 1.06 \\ \min 1.0 \end{cases}$$

IC $$f_i = \frac{0.00142 \cdot L^{3.286}}{capacity}, \quad \begin{cases} \max 1.04 \\ \min 1.0 \end{cases}.$$

21 The capacity correction coefficient was calculated for a small selection of example ships taken from the database. The results are shown in the table below. The values that have been determined based on the upper or lower limit are shown in bold. It can be noted that for several ships the value of the power coefficient is determined by the limits.

Ship	Ice class	DWT [t]	L [m]	DWT_{OW} [t]	$\frac{0.00142 \cdot L^{3.286}}{dwt}$	f_i
Iman	IA Super	6237	113.0	7601	1.2187	1.2589
Suula	IA Super	14665	139.75	15284	1.0422	1.0422
Purha	IA Super	25000	169.5	28828	1.1531	1.1531
Stena Arctica	IA Super	117100	249.79	103154	0.8809	**1.0**
Renda	IA	6269	113.01	7603	1.2129	**1.1446**
Eken	IA	13702	134.71	13546	0.9886	**1.0**
British Emissary	IA	37000	194.0	44935	1.2145	**1.1081**
Omega Theodore	IA	73673	228.0	76412	1.0372	**1.0372**
Delta Victory	IA	111006	250.0	103439	0.9318	**1.0**
Bellona	IB	3794	87.5	3279	0.8642	**1.0**
Olivia	IB	6825	111.28	7227	1.0590	1.059
Navigo	IB	16755	144.72	17145	1.0233	1.0233
Stena Contest	IB	47171	182.5	36756	0.7792	**1.0**
Jag Lok	IB	158280	274.19	140139	0.8854	**1.0**
Linnea	IC	11520	149.51	19083	1.6565	**1.04**
Caribbean Wind	IC	28750	178.98	34476	1.1992	**1.04**
Venice	IC	81408	240.4	90944	1.1171	**1.04**
Nevskiy Prospect	IC	114597	249.9	103303	0.9014	**1.0**

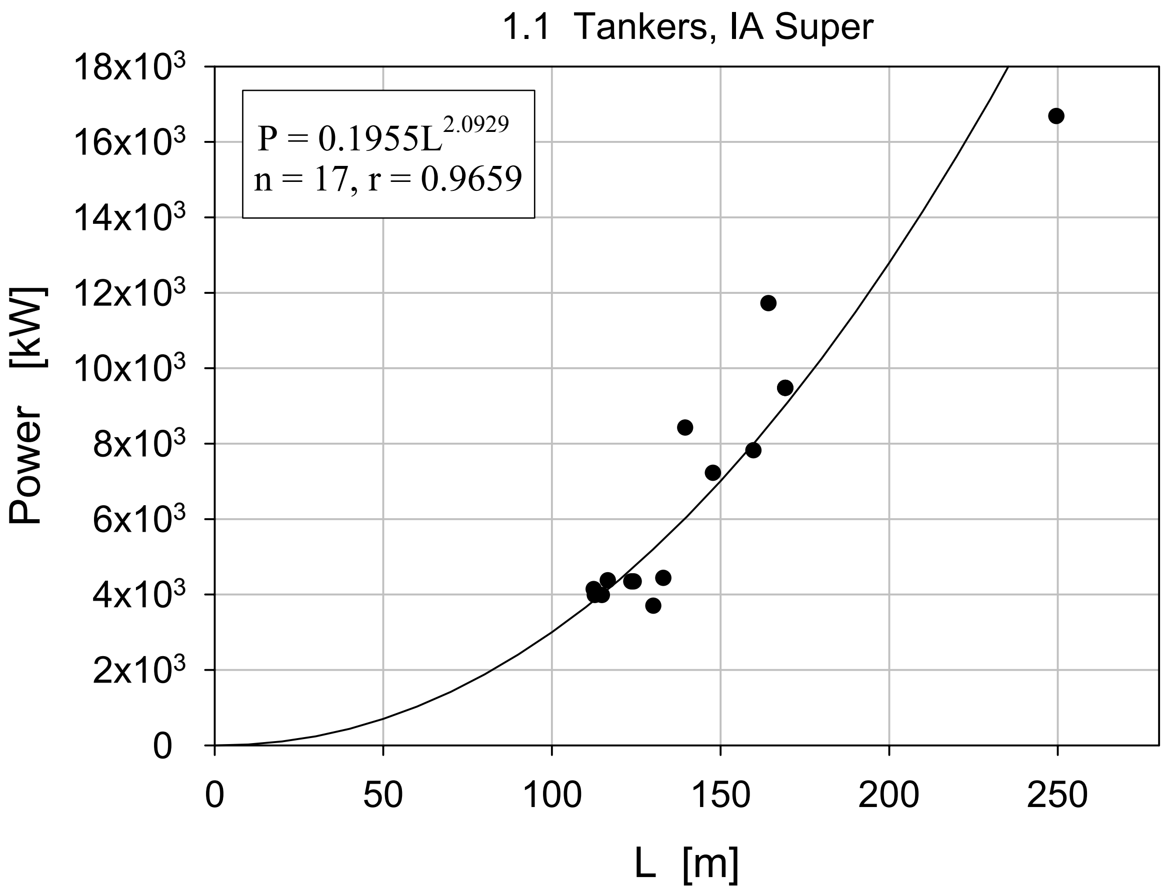
Summary

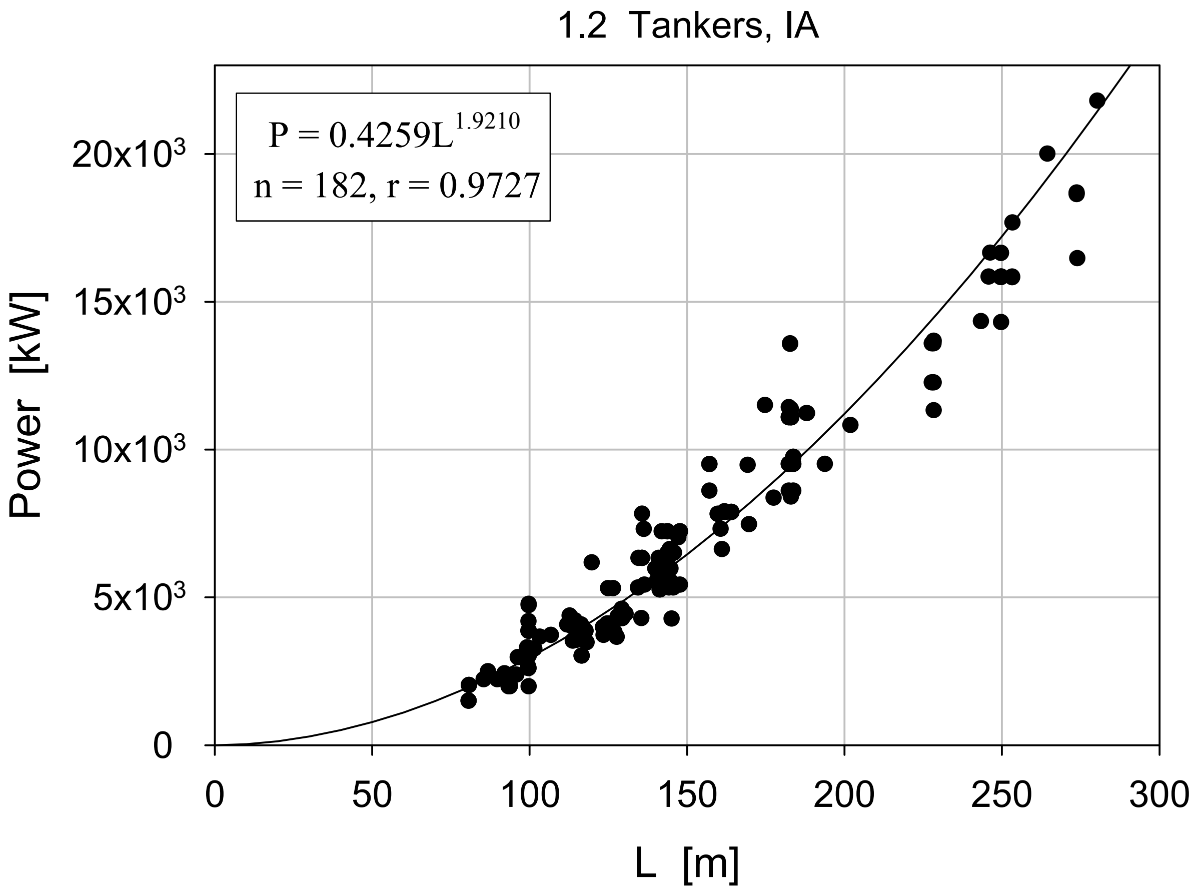
22 An analysis of the possibility to introduce correction coefficients for the attained Energy Efficiency Design Index for new ships indicated that two coefficients could be used; one for the increased power for ice performance and one for decreased deadweight due to increased light ship weight. Both the coefficients have been analysed in this study. The aim of these coefficients is to make ice strengthened ships equal to open water ships. This equal standing of open water and ice class tonnage is important in trades to ice covered waters where an ice class is required for safety reasons.

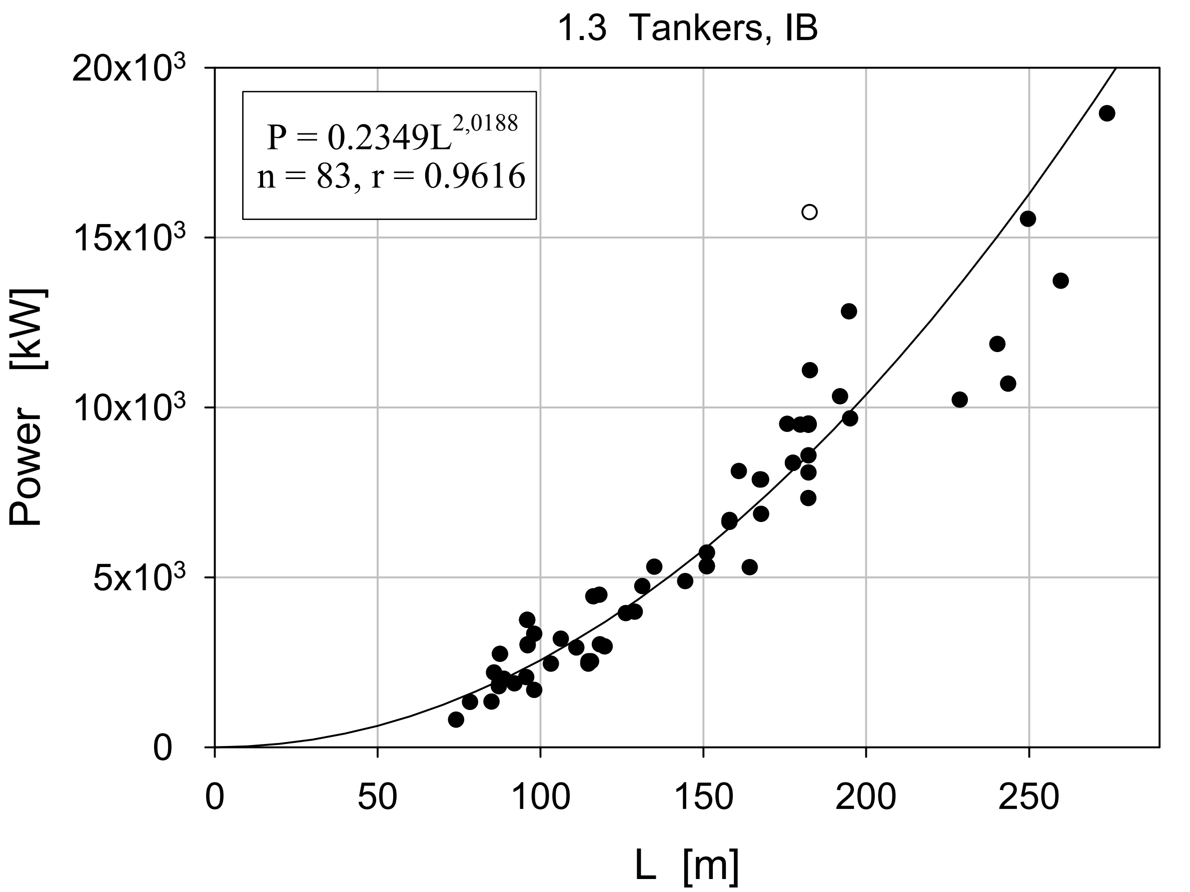
23 The form of both coefficients is essentially the ratio between the average power or capacity of the open water ship and that of the ice classed ship. The crucial question of the formulation of the coefficients is what will be used as a reference value for a corresponding open water ship. This form has been investigated here using a large database of about 2,700 open water and ice class tankers. The analysis yielded a practical suggestion for the power and deadweight correction coefficients.

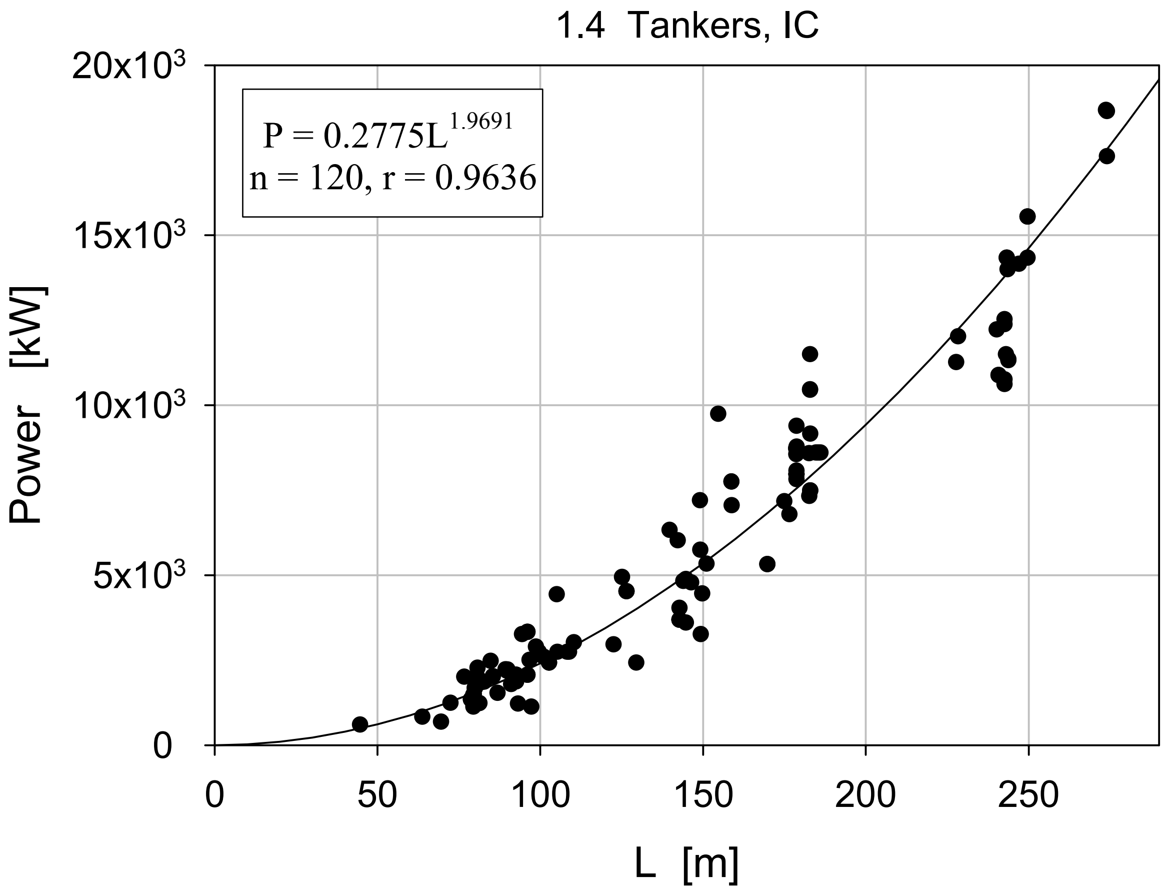
APPENDIX 1

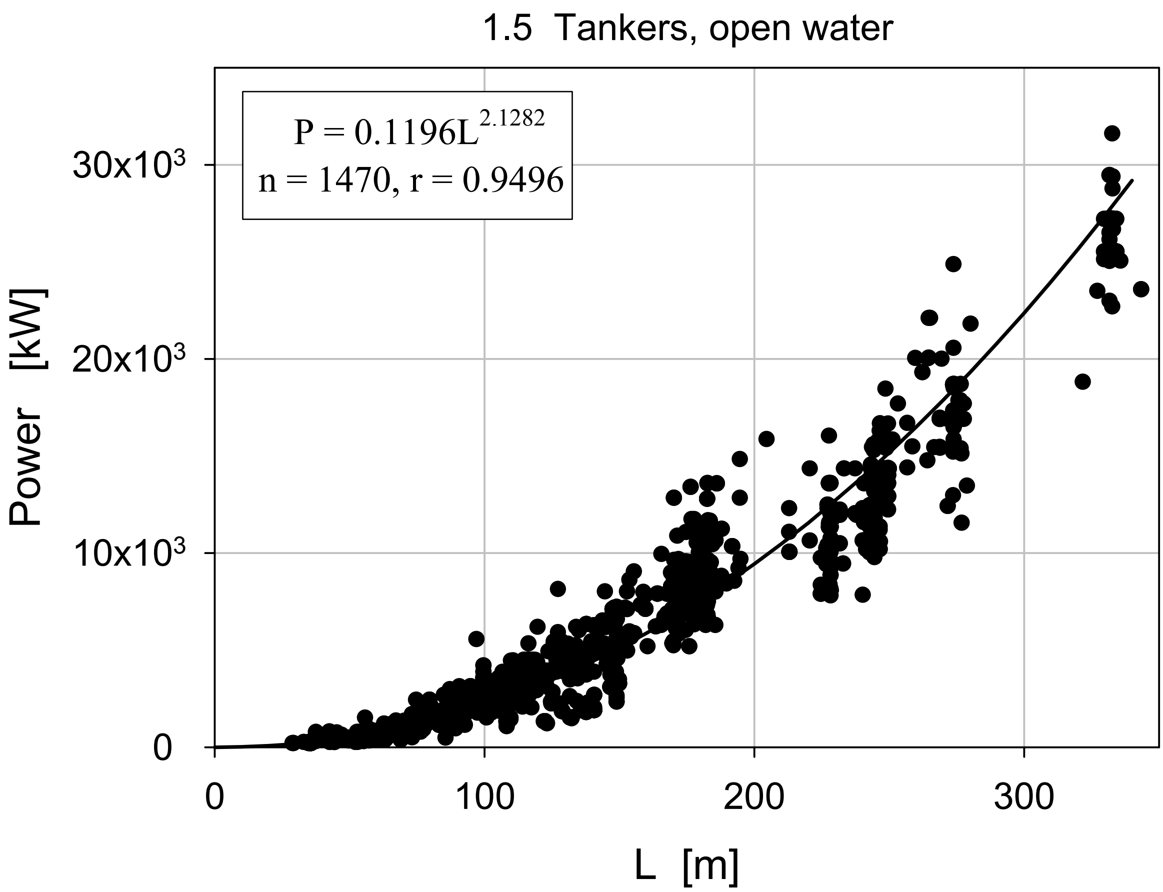
DATA ABOUT TANKER POWER VERSUS SHIP LENGTH




1.2 Tankers, IA
P = 0.4259L^1.9210
n = 182, r = 0.9727
Power [kW]
20x10³
15x10³
10x10³
5x10³
0
0
50
100
150
200
250
300
L [m]

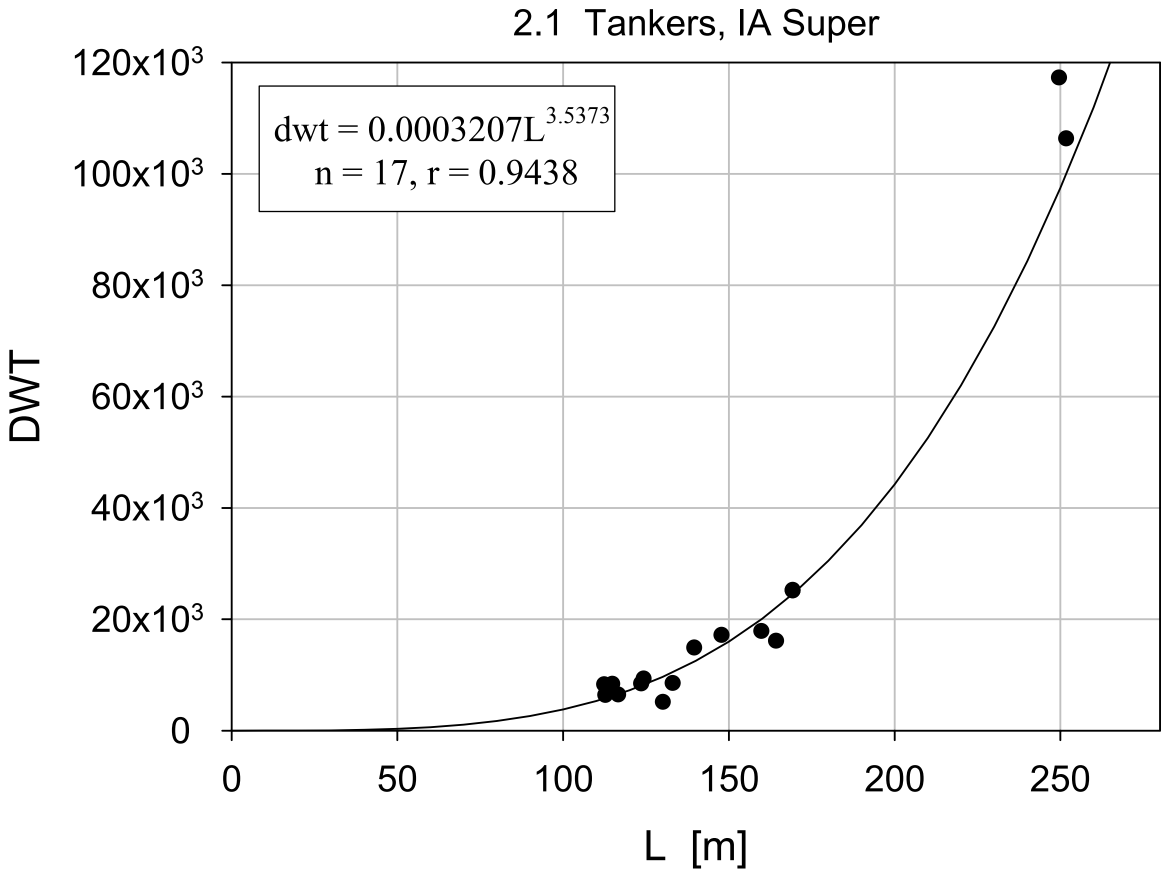

1.3 Tankers, IB
P = 0.2349L^2,0188
n = 83, r = 0.9616
Power [kW]
20x10³
15x10³
10x10³
5x10³
0
0
50
100
150
200
250
L [m]

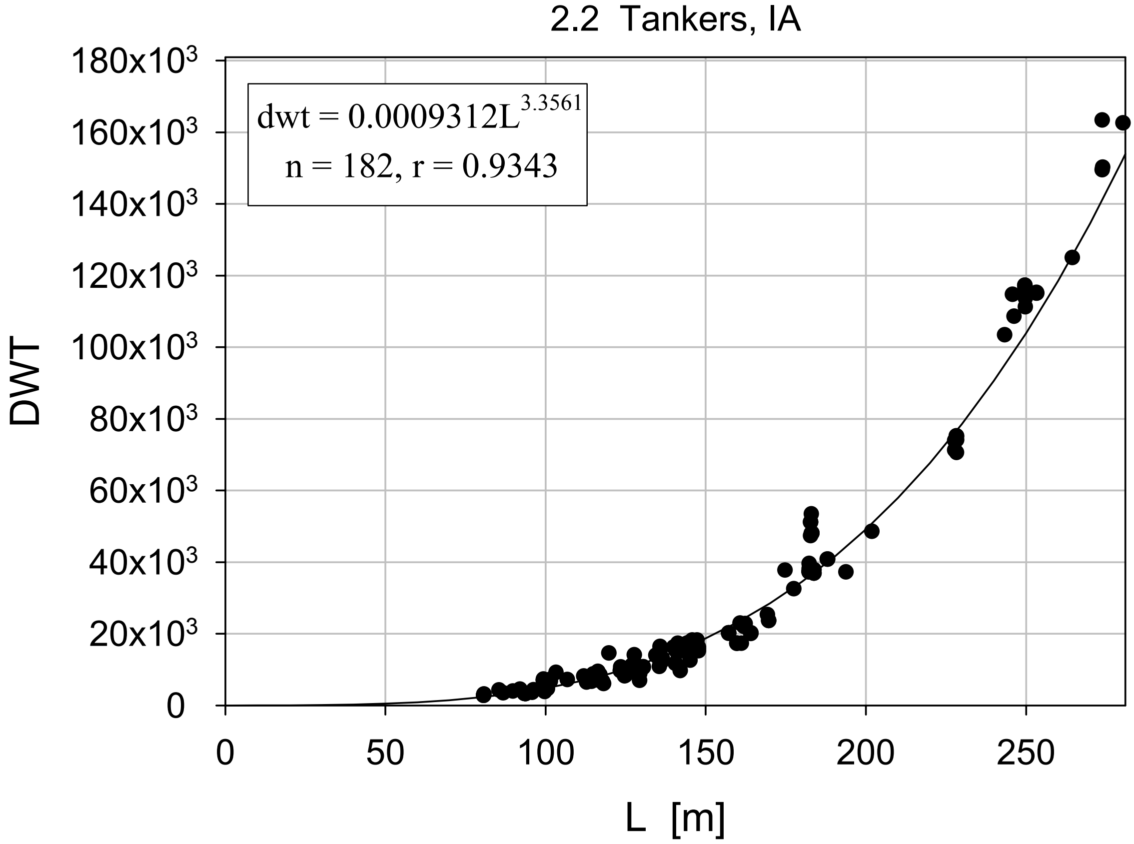

1.4 Tankers, IC
P = 0.2775L^1.9691
n = 120, r = 0.9636
Power [kW]
20x10^3
15x10^3
10x10^3
5x10^3
0
0
50
100
150
200
250
L [m]

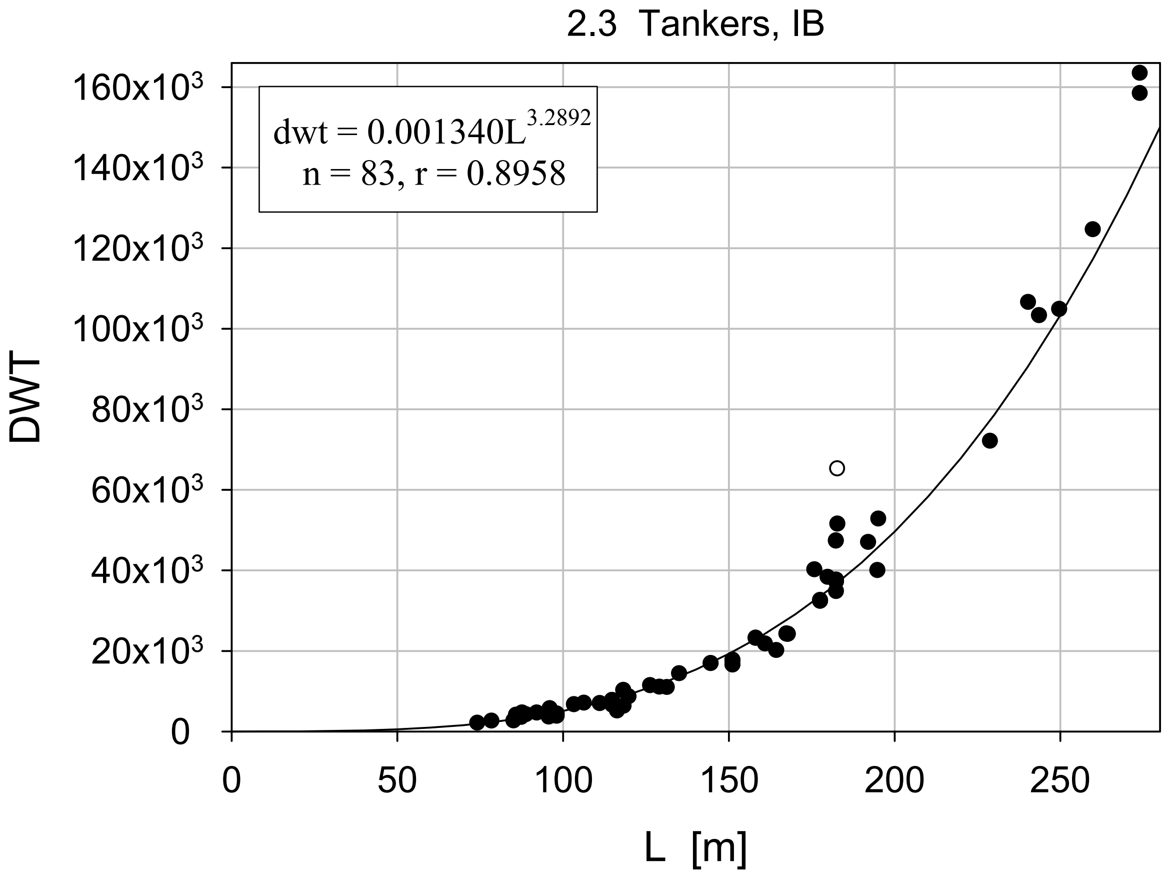

1.5 Tankers, open water
P = 0.1196L^2.1282
n = 1470, r = 0.9496
Power [kW]
30x10^3
20x10^3
10x10^3
0
0
100
200
300
L [m]

APPENDIX 2

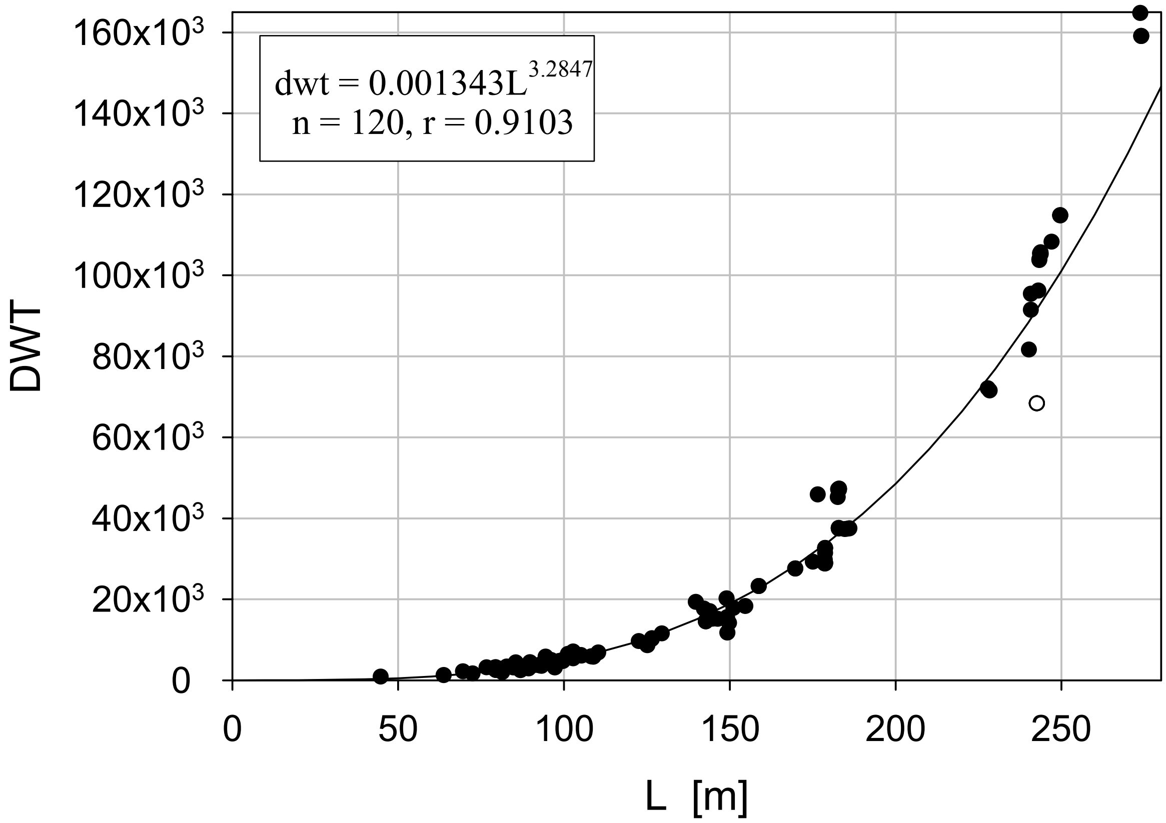
DATA ABOUT TANKER DWT VERSUS SHIP LENGTH




2.2 Tankers, IA
dwt = 0.0009312L^3.3561
n = 182, r = 0.9343
DWT
180x10³
160x10³
140x10³
120x10³
100x10³
80x10³
60x10³
40x10³
20x10³
0
0
50
100
150
200
250
L [m]


2.3 Tankers, IB
dwt = 0.001340L^3.2892
n = 83, r = 0.8958
DWT
160x10³
140x10³
120x10³
100x10³
80x10³
60x10³
40x10³
20x10³
0
0
50
100
150
200
250
L [m]

2.4 Tankers, IC



2.5 Tankers, open water