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Existing Design Trends for Tankers and Bulk Carriers - Design Changes for Improvement of the EEDI in the Future

Hans Otto Holmegaard Kristensen[1] and Marie Lützen[2]

ABSTRACT

To get an idea of the reduction in propulsion power and associated emissions by varying the speed and other ship design main parameters, a generic model for parameter studies has been developed. With only a few input parameters of which the maximum deadweight capacity is the primary one, a proposal for the main dimensions and the necessary installed power is calculated by the model. By adjusting the vessel design, i.e. the main parameters, and varying the speed it is possible to observe the influence of the different parameters on the power demand. The model can be used to calculate exhaust gas emissions from bulk carriers and tankers, including emissions of carbon dioxide (CO_2). A calculation procedure for estimating the Energy Efficiency Design Index (EEDI) is also included in the model. The IHS Fairplay World Fleet Statistics for vessels built in the period 1990–2010 are used as a basis for the generic modelling. A comprehensive regression analysis has been carried out to find the formulas to be used as a basis for the model. Furthermore, it was found during the analysis that the design trend of bulk carriers and tankers has moved in a wrong direction seen from an energy saving point of view. The block coefficient has increased during the last twenty years while the length displacement ratio ($L/displ.volume^{1/3}$) has decreased over the same period. These two design changes have resulted in an increased EEDI. This development must be changed in the coming years when the EEDI shall be reduced gradually, ending in a 30 per cent reduction in 2025. An overview of the historical development and the necessary design changes will be documented here, including a complete list of the formulas for the main dimensions found by the regression analysis.

KEYWORDS

Ship design, tankers, bulk carriers, environmental issues, Energy Efficiency Design Index (EEDI), propulsion power

INTRODUCTION

As a consequence of the increased focus on the environmental impact from shipping - especially from exhaust gas emissions - a generic computer model for tankers and bulk carriers has been developed by the Department of Mechanical Engineering at the Technical University of Denmark (DTU) and Institute of Technology and Innovation, University of Southern Denmark (SDU). On the basis of a maximum deadweight capacity (DWT), the design model calculates the principal ship particulars for a tanker or bulk carrier. From these particulars and a service speed requirement, the necessary propulsion and auxiliary power is calculated by the model. Engine characteristics (slow speed or medium speed) and different abatement technologies for reduction of exhaust gas emissions can be specified to fulfil forthcoming IMO legislation. As a result of these specifications, different types of exhaust gas emissions are calculated by the model and given as g/(DWT·nm). The suggested ship main dimensions and engine characteristics, including the service speed and power margin, can be changed individually to see the influence of these parameters on different emissions including the Energy Efficiency Design Index, EEDI.

The basis for the design model is primarily data from the IHS Fairplay database, which have been examined and analysed very intensively for the development of empirical formulas for calculation of the principal ship main dimensions. During this work ship design data for tankers and bulk carriers from the last 30-40 years have been analysed to see the design trends over

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this period. Some astonishing results, seen in relation to the EEDI, have been found for tankers and bulk carriers. These results will be presented and discussed in this paper. Using the DTU-SDU design model, parameter investigations will also be carried out to show the improvements (lower propulsion power and lower EEDI) that can be obtained by these parameter changes, so that ship designers can select more advantageous hull proportions with a lower EEDI than today´s standard.

ANALYSIS OF IHS FAIRPLAY DATA

The IHS Fairplay data have been analysed and possible outliers have been left out, i.e. vessels with obvious errors in data and vessels with abnormal hull proportions.

Tankers and bulk carriers are normally subdivided into different categories based on their deadweight. Therefore, the data in the IHS Fairplay database have been subdivided into the following segments:

1.	Small tankers and bulk carriers	(< 10,000 DWT)
2.	Handysize tankers and bulk carriers	(10,000–25,000 DWT)
3.	Handymax tankers and bulk carriers	(25,000–55,000 DWT)
4.	Panamax tankers and bulk carriers	(55,000–80,000 DWT)
5.	Aframax tankers and bulk carriers	(80,000–120,000 DWT)
6.	Suezmax tankers and bulk carriers	(120,000–170,000 DWT)
7.	Very large tankers and bulk carriers (VLCC and VLBC)	(170,000–330,000 DWT)

Equations for the following main parameters for all ship categories have been found by regression analysis of the IHS Fairplay data:

1. Length between perpendiculars, Lpp
2. Breadth, B
3. Maximum draught (summer load line draught), T
4. Depth to main deck, D
5. Lightweight coefficient, C_{lw}, defined as $C_{lw} = \dfrac{\text{Lightweight}}{\text{Lpp·B·D}}$

As Lpp, B, T and D are very closely connected with the deadweight, these parameters are expressed as functions of the maximum deadweight corresponding to the draught T. These parameters are plotted in Appendix A (tankers) and C (bulk carriers). The equations found by the regression analysis are listed in Appendices B and D.

The main particular equations have been implemented in a computer model so that the model calculates the ship main dimensions on the basis of a specified maximum deadweight. Combined with a power prediction method (Harvald 1983) included in the model, parametric studies can be carried out to see the influence on the required engine power when some of the main parameters and the speed are changed. In connection with the introduction of the power prediction procedure the method by Harvald (Harvald 1983) was updated, especially with respect to the influence of a bulbous bow on the resistance. Moreover, procedures for calculation of wake fraction and thrust deduction were updated and, finally, more accurate empirical formulas for calculation of the wetted surface were established by an update of Mumford´s formula.

Being able to investigate the engine power requirement when different ship design parameters are changed makes it also possible to see the influence on the Energy Efficiency Design Index, EEDI, as well as it is possible to investigate the influence of different propulsive parameters, such as propeller diameter, propeller type (open or ducted propeller) and engine and resistance service margins due to wind and waves.

HISTORICAL DEVELOPMENT

The different ship design main parameters for tankers and bulk carriers covering the last 30-40 years have been analysed to see the design trends over this period. However, only data for the last 20 years (1990–2010) have been used for the development of the main particular equations. During the analysis some astonishing results, seen in relation to the EEDI, have been found and these results will be presented and discussed in the following.

CALCULATION OF ACTUAL EEDI AND REFERENCE EEDI VALUES

Using the same assumptions as agreed on by IMO for EEDI reference line calculations, the EEDI has been calculated for all the ships analysed during the generic model development.

According to MEPC 62/6/4 the EEDI is calculated according to the following formula:

$$\text{Estimated EEDI value} = CF \cdot \frac{SFC_{ME} \cdot \sum_{j=1}^{NME} P_{MEi} + SFC_{AE} \cdot P_{AE}}{\text{Capacity} \cdot V_{ref}}$$

which is based on the following assumptions:

- The carbon emission factor is constant for all engines, i.e. $CF_{ME} = CF_{AE} = CF = 3.1144$ g CO_2/g fuel

- The specific fuel consumption for all ship types is constant for all main engines, i.e. $SFC_{ME} = 190$ g/kWh

- $P_{ME(i)}$ is the main engine power as defined in MEPC.1/Circ.681

- The specific fuel consumption for all ship types is constant for all auxiliary engines, i.e. $SFC_{AE} = 215$ g/kWh

- P_{AE} is the auxiliary power consumption and for cargo ships it is calculated according to paragraphs 2.5.6.1 and 2.5.6.2 of the Annex in MEPC.1/Circ.681:

    - Maximum continuous power (MCR) > 10,000 kW: $P_{AE} = 250 + 0.025 \cdot \sum_{j=1}^{NMEi} MCR_{MEi}$

    - Maximum continuous power (MCR) <= 10,000 kW: $P_{AE} = 0.05 \cdot \sum_{j=1}^{NMEi} MCR_{MEi}$

- For passenger ships with conventional propulsion systems, P_{AE} is calculated as the total installed auxiliary power according to the information in the IHS Fairplay database multiplied by 0.35

- Capacity is the maximum allowed deadweight and Vref is the obtainable speed in calm water corresponding to the maximum deadweight. During the development work by IMO of EEDI reference values, it has been assumed that the speed given in the IHS Fairplay database corresponds to approximately 75 per cent of the maximum installed engine power (MCR) at the maximum draught listed in the database, which is the reason for calculating $P_{ME(I)}$ as $0.75 \cdot MCR_{ME(i)}$

Based on the above-mentioned methodology for calculation of the EEDI reference, only data relating to existing ships of 400 GT and above from the IHS Fairplay database delivered in the period from 1 January 1999 to 1 January 2009 have been used by IMO (MEPC 62/6/4) for determination of the so-called EEDI reference curve (Figs. 1 and 2), which is the value which must not be exceeded in the future, i.e. after 2013, by new ships.
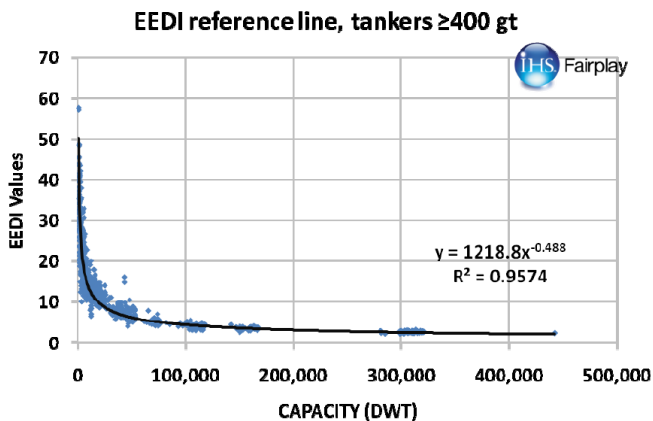
Fig. 1: EEDI reference curve for tankers. Source: MEPC 62/6/4.
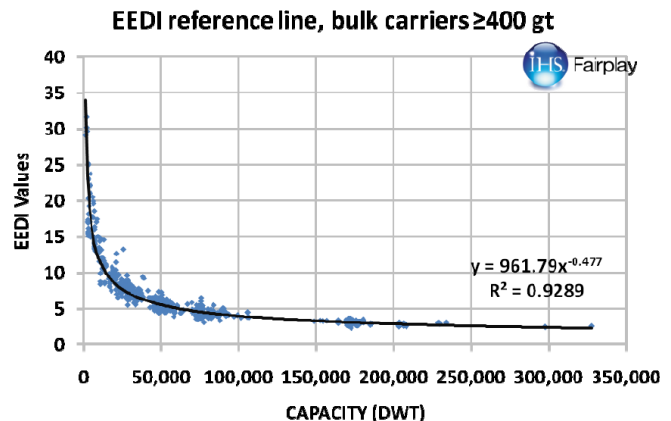
Fig. 2: EEDI reference curve for bulk carriers. Source: MEPC 62/6/4.

DEVELOPMENT OF DESIGN PARAMETERS AND EEDI FOR PANAMAX TANKERS

Analysis of the EEDI for all tankers and bulk carriers shows that the EEDI is a decreasing function of the deadweight (Figs. 1 and 2). However, looking at the actual EEDI for the different segments of tankers and bulk carriers reveals that the EEDI for each segment varies over the years of construction, especially over a period of 20–40 years.

The deadweight for Panamax tankers (in total 352) covering the period from 1971 to 2010 is shown in Fig. 3. It is seen that the deadweight has increased from approximately 55,000 tons to approximately 75,000 tons, which means that a reduction of the EEDI should be expected for Panamax tankers as the baseline for tankers is defined by the following equation (MEPC 62/6/4):

$$\text{EEDI}_{\text{ref.value}} = 1218.8 \cdot \text{DWT}^{-0.488}$$

According to this formula, the EEDI should decrease from 5.8 to 5.1 from 1971 to 2010, but the actual development of the EEDI has moved in the opposite direction, as the EEDI has slightly increased (Fig. 4). In order to find an explanation for the EEDI development, the following parameters which influence the EEDI have been analysed over the period from 1971 to 2010:

1. Speed
2. Froude number
3. Block coefficient
4. Length displacement ratio (Lpp/displ.volume$^{1/3}$)

The speed has a great influence on the propulsion power as it depends on the speed in the power of 3 to 4 – under certain conditions even higher (Kristensen 2010). This means that the EEDI depends on the speed in the power of 2 to 3. It is seen from Fig. 5 that the speed has slightly increased (approximately 1 knot) from 1971 to 2010. The Froude number has also increased in the same period (Fig. 6) as the length has not changed significantly in the same period (Fig. 7). The increase of the Froude number from approximately 0.16 to 0.17 influences the ship resistance and thus the propulsion power, which is one of the reasons why the EEDI has increased in the period from 1971 to 2010.
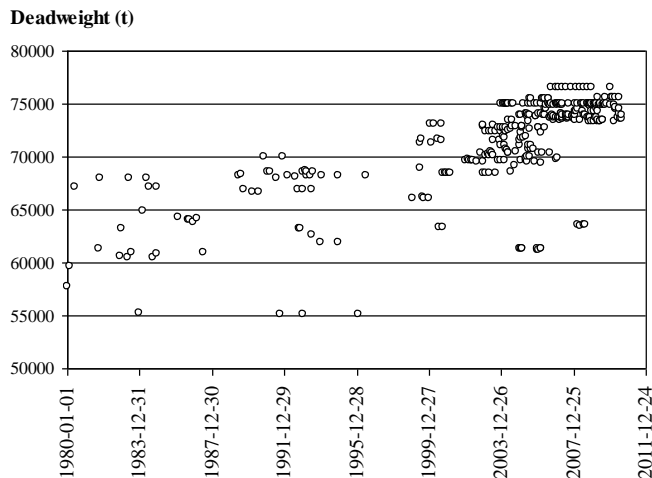
Fig. 3: Deadweight development of Panamax tankers from 1971 to 2010. Source: IHS Fairplay.
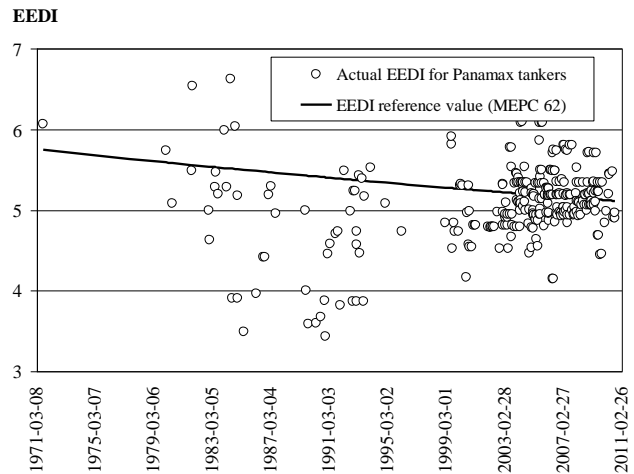
Fig. 4: Actual EEDI of Panamax tankers (1971–2010) compared with the EEDI reference value according to MEPC 62/6/4 and the actual DWT development.

The block coefficient also influences the ship resistance so that the resistance increases with increasing block coefficient. From Fig. 8 it is observed that the block coefficient has increased from approximately 0.82 to 0.86 from 1971 to 2010. From a hydrodynamic point of view the block coefficient shall decrease with increasing Froude number (Harvald 1983 and Watson and Gilfillan 1998). This is opposite to the actual development where the block coefficient and the Froude number have increased (Fig. 9). From Fig. 9 it is clear that the actual development of the block coefficient is opposite to the guidelines given by Harvald and Watson and Gilfillan.

The last non-dimensional main parameter which influences the ship resistance is the length displacement ratio. From a hydrodynamic point of view this ratio shall be as large as possible as the ship resistance/propulsion power decreases with increasing length displacement ratio. The development of the length displacement ratio since 1971 (Fig. 10) shows that the ratio has decreased from an average of approximately 5.2 to an average of approximately 5.0, which also contributes to the increase of the EEDI.

The limitations in breadth and draught imposed by the restrictions of the Panama Canal combined with a requirement of more deadweight within a limited length are the reasons why the block coefficient has increased and the length displacement ratio has decreased for Panamax tankers.
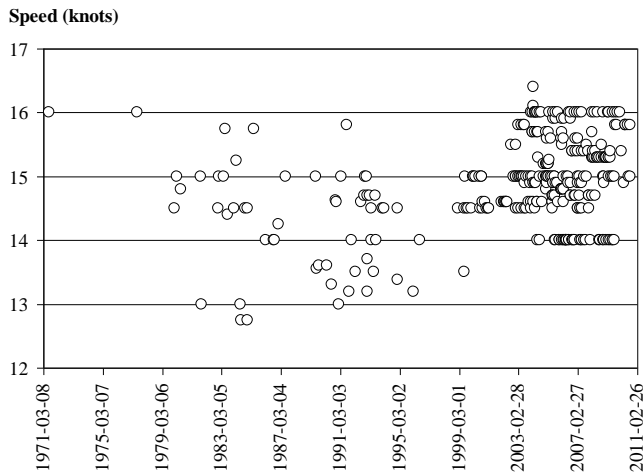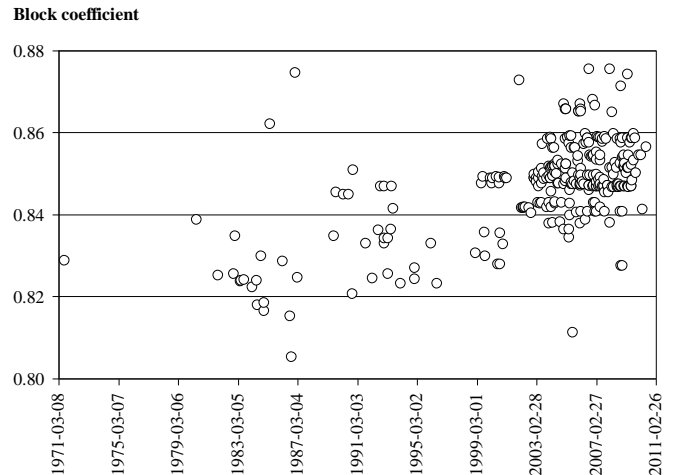

Fig. 5: Speed development of Panamax tankers from 1971 to 2010. Source: IHS Fairplay.
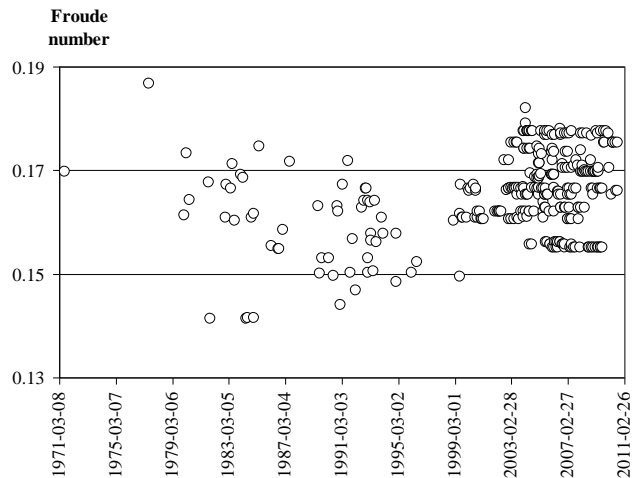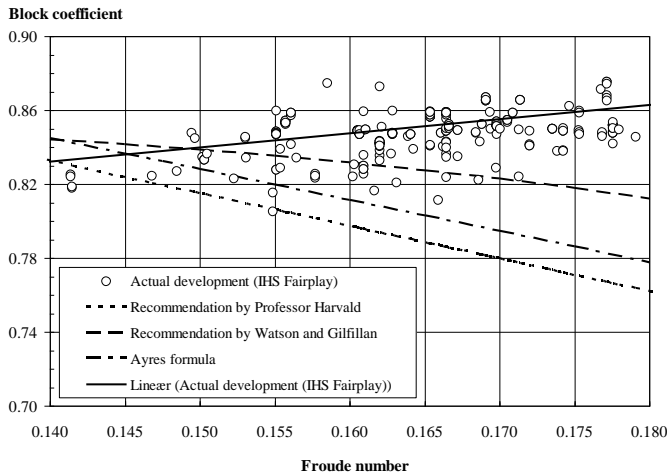

Fig. 6: Froude number development of Panamax tankers from 1971 to 2010. Source: IHS Fairplay.
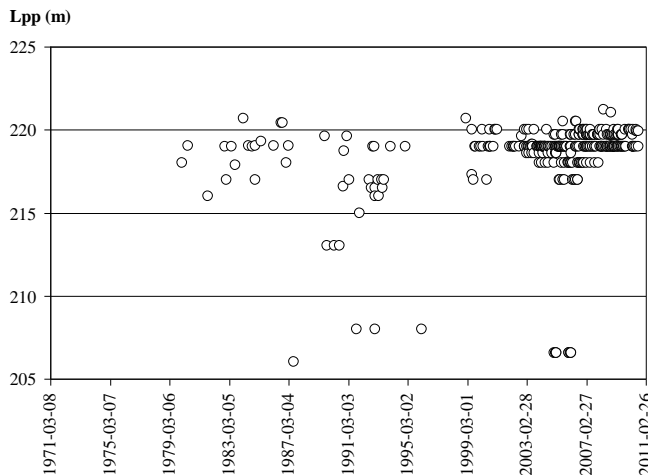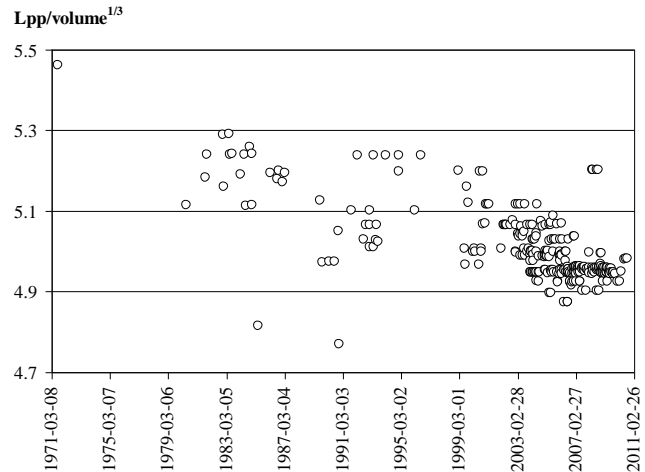

Fig. 7: Development of Lpp of Panamax tankers from 1971 to 2010. Source: IHS Fairplay.

Fig. 8: Block coefficient development of Panamax tankers from 1971 to 2010. Source: IHS Fairplay.

Fig. 9: Relationship between Froude number and block coefficient of Panamax tankers from 1971 to 2010. Source: IHS Fairplay.

Fig. 10: Development of length displacement ratio of Panamax tankers from 1971 to 2010. Source: IHS Fairplay.

DEVELOPMENT OF DESIGN PARAMETERS FOR TANKERS AND BULK CARRIERS

In the present section the development of design trends for the other tanker and bulk carrier segments will be discussed. The general increase of the block coefficient and the decrease of the length displacement ratio are also observed for the other tanker and bulk carrier segments, but not as significantly as for the Panamax tankers. The design development of deadweight, EEDI, Froude number, block coefficient and length displacement ratio for Aframax tankers are shown in Figs. 11–16. The same design trends are shown for Aframax bulk carriers in Figs. 17–20. It is interesting to observe that although the deadweight of Aframax bulk carriers has decreased over the last 20 years, the block coefficient has also in this case increased and the length displacement ratio has decreased, which in combination leads to the more unfavourable EEDI values.

In general, the following trends are observed for a large part of the tankers and bulk carriers which have been analysed:

1. The block coefficient has increased over the last 30–40 years
2. The length displacement ratio has decreased over the last 30–40 years
3. The Froude number has either been constant or has increased during the last 30–40 years

It is interesting to observe that although the deadweight of Aframax bulk carriers has decreased over the last 20 years, the block coefficient has increased and the length displacement ratio has decreased.

The design changes/trends during the last 20 years are summarised in Tables 1 and 2

	Block coefficient		Length displacement ratio		Froude number	
Ship type	**1990**	**2010**	**1990**	**2010**	**1990**	**2010**
Handymax tankers	0.80	0.81	4.9	4.5	0.18	0.18
Panamax tankers	0.83	0.86	5.1	4.95	0.16	0.17
Aframax tankers	0.82	0.84	4.9	4.7	0.155	0.16
Suezmax tankers	0.83	0.825	4.8	4.7	0.15	0.155
VLCC	0.815	0.82	4.7	4.55	0.135	0.145

**Table 1: Design changes for tankers during the last 20 years.**

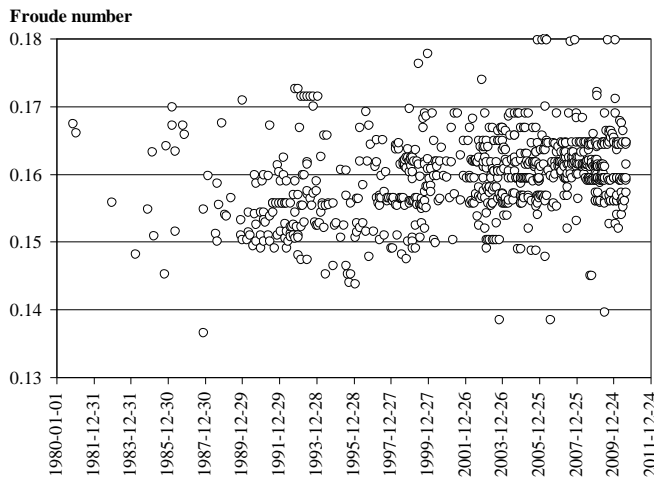|	Block coefficient		Length displacement ratio		Froude number	
Ship type	**1990**	**2010**	**1990**	**2010**	**1990**	**2010**
Panamax bulk carriers	0.84	0.87	5.1	4.6	0.16	0.17
Aframax carriers	0.81	0.87	4.85	4.8	0.155	0.16
Suezmax bulk carriers	0.84	0.86	4.8	4.85	0.145	0.145
VLBC	0.82	0.82	4.7	4.6	0.13	0.14

Table 2: Design changes for bulk carriers during the last 20 years.
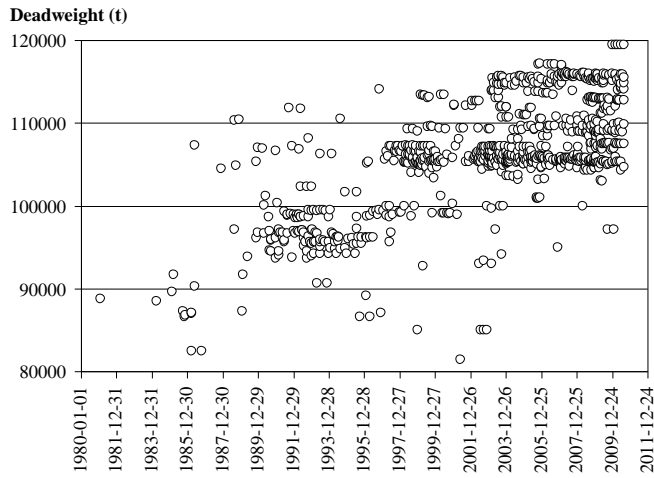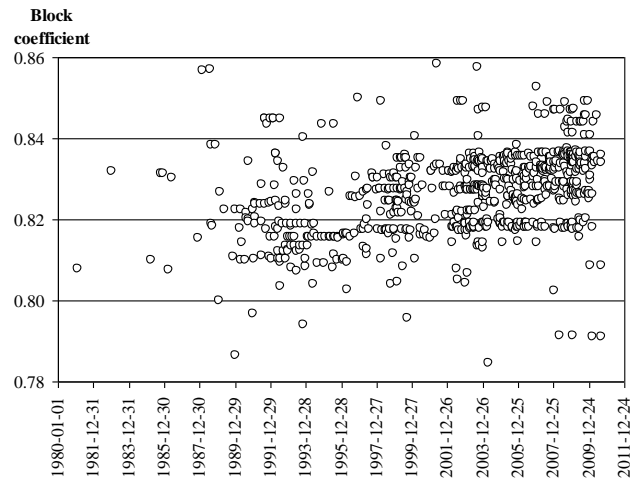
Fig. 11: Deadweight development of Aframax tankers from 1980 to 2010. Source: IHS Fairplay.
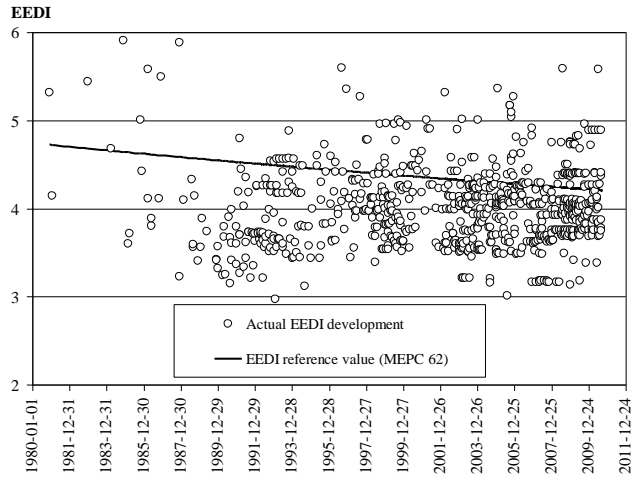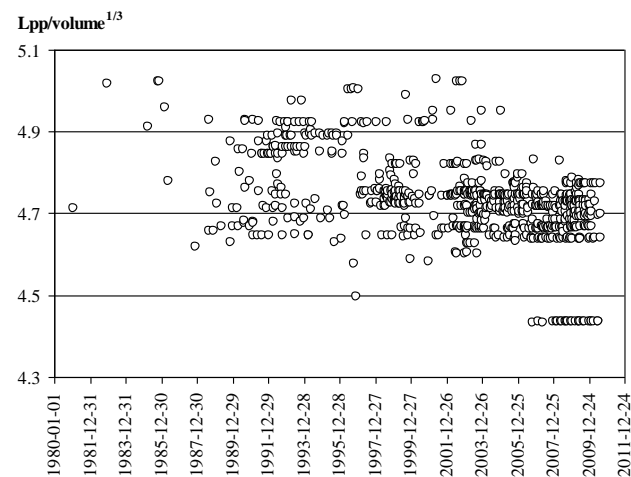

Fig. 12: Actual EEDI of Aframax tankers (1980–2010) compared with the EEDI reference value according to MEPC 62/6/4 and the actual DWT development.
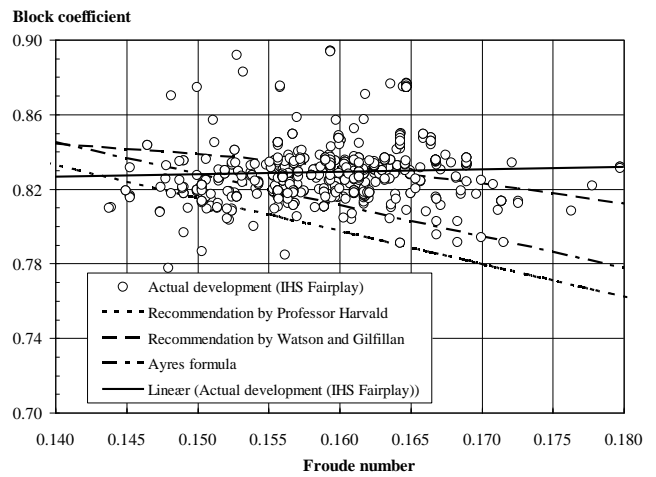

Fig. 13: Development of Froude number of Aframax tankers from 1980 to 2010. Source: IHS Fairplay.

Fig. 14: Development of block coefficient of Aframax tankers from 1980 to 2010. Source: IHS Fairplay.
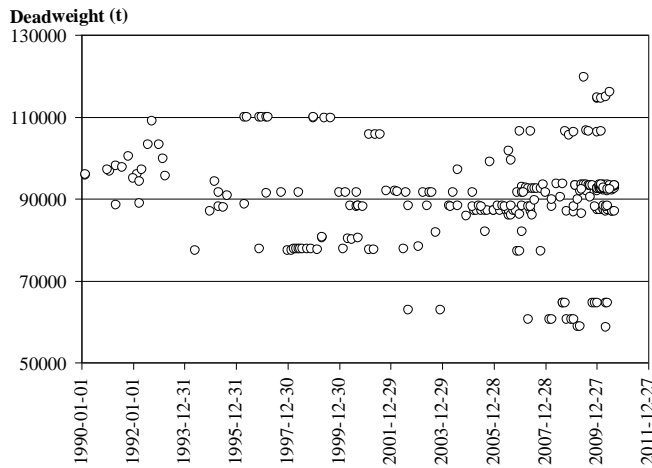

**Fig. 15: Development of length displacement ratio of Aframax tankers from 1980 to 2010.**

Fig. 16: Relationship between Froude number and block coefficient of Aframax tankers from 1980 to 2010.
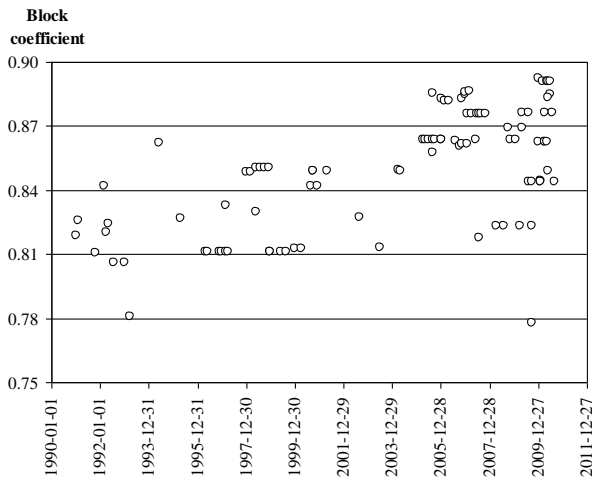
Deadweight (t)

Fig. 17: Deadweight development of Aframax bulk carriers from 1990 to 2010. Source: IHS Fairplay.

EEDI

○ Actual EEDI for Aframax bulk carriers
—— EEDI reference value (MEPC 62)
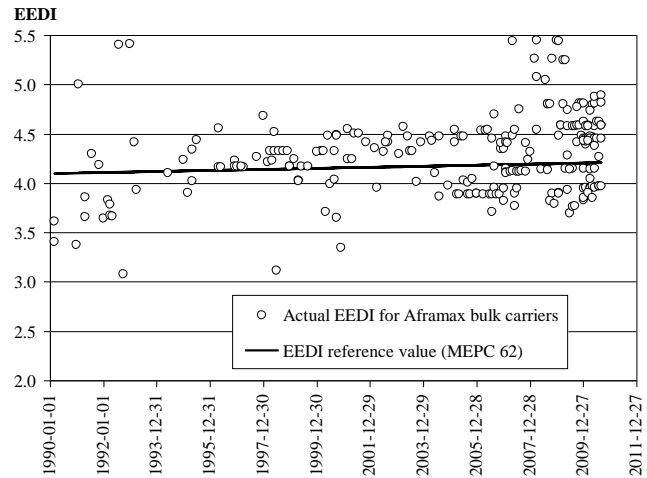
Fig. 18: Actual EEDI of Aframax bulk carriers from 1990 to 2010 compared with the EEDI reference value according to MEPC 62/6/4 and the actual DWT development.

Block coefficient

Fig. 19: Development of block coefficient of Aframax bulk carriers from 1990 to 2010.

Lpp/volume$^{1/3}$
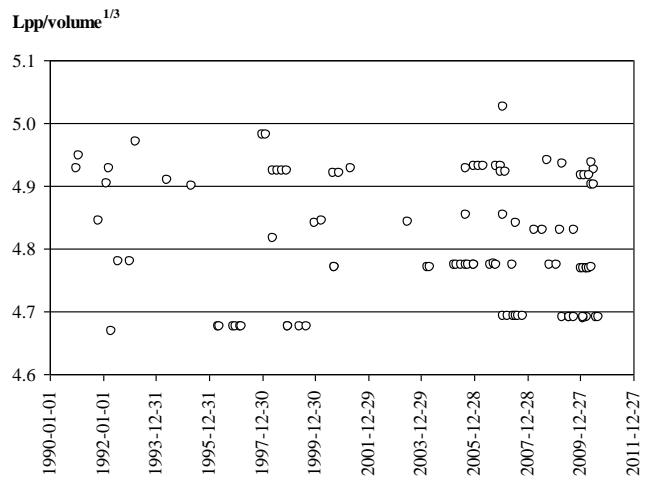
Fig. 20: Development of length displacement ratio of Aframax bulk carriers from 1990 to 2010.

PARAMETER ANALYSIS

As it has been found that the block coefficient and the length displacement ratio have changed over the last 20–40 years for tankers and bulk carriers, an analysis of systematic changes of these parameters has been carried out for a 100,000 DWT Aframax tanker by increasing the length, the breadth and the draught, both individually and in combination. The analysis has been carried out with the generic computer model developed by DTU and SDU. The results are presented in Fig. 21 where it is seen how much the propulsion power is reduced when the block coefficient and the length displacement ratio are reduced and increased, respectively. It is seen that a combined change of the length and the draught by 2 per cent decreases the propulsion power by approximately 15 per cent.

For the same changes it has also been calculated which speed is obtainable and still fulfils the expected EEDI requirement in 2013. The results of these calculations are shown in Fig. 22. An output sample from the computer model is shown in Appendix E.

The positive influence of changing the breadth is not so pronounced because the resulting increase of the length breadth ratio (B/T) increases the residual resistance of the ship, which to a certain degree counteracts the positive influence of the decrease of the block coefficient.

The positive influence of the higher draught is a combined influence due to a better B/T ratio, a lower block coefficient and the possibility of using a larger propeller diameter, as the propeller diameter is given by the following equation:

Propeller diameter = 0.395 · maximum draught + 1.3, according to Fig. 23 (Significant Ships 1990–2010).

This equation has been found by regression analysis of propeller data found in Significant Ships (Fig. 23).

—○— Increase of length and draught (Cb: 0.833 - 0.803 - 0.775) - (L/vol^1/3: 4.76 - 4.85 - 4.94)
—▲— Increase of breadth only   (Cb: 0.833 - 0.819 - 0.806) - (L/vol^1/3 = 4.76)
—●— Increase of draught only   (Cb: 0.833 - 0.817 - 0.801) - (L/vol^1/3 = 4.76)
—○— Increase of length only   (Cb: 0.833 - 0.819 - 0.806) - (L/vol^1/3: 4.76 - 4.85 - 4.94)
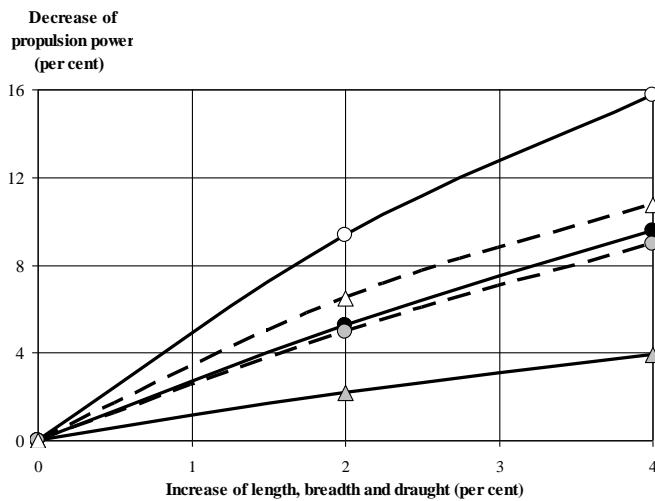—△— Increase of length and breadth (Cb: 0.833 - 0.806 - 0.780) - (L/vol^1/3: 4.76 - 4.84 - 4.93)

Fig. 21: Reduction of propulsion power at a service speed of 15 knots for a 100,000 DWT Aframax tanker by different changes of the main dimensions. When both the length and the breadth or draught are changed simultaneously, each parameter is changed by the same value in per cent.
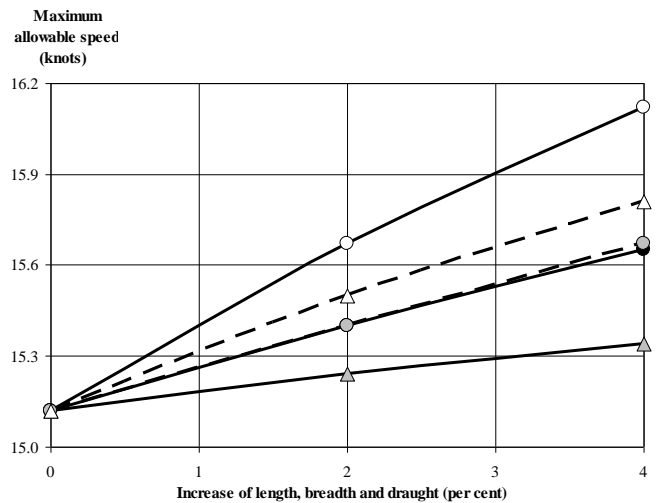
Fig. 22: Maximum allowable speed for fulfilment of expected EEDI requirement in 2013 for a 100,000 DWT Aframax tanker by different changes of the main dimensions. When both the length and the breadth or draught are changed simultaneously, each parameter is changed by the same value in per cent.
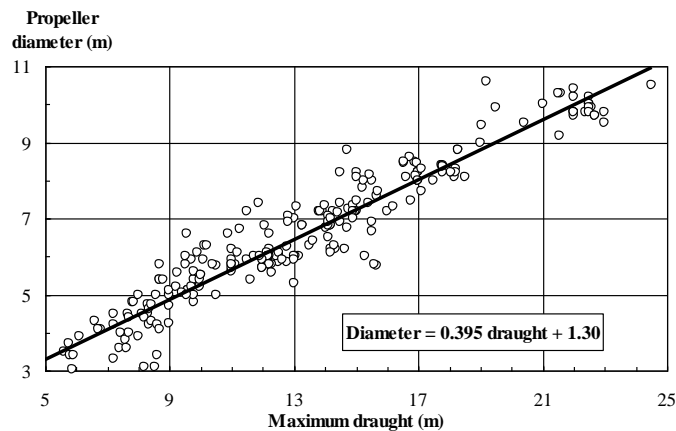

Diameter = 0.395 draught + 1.30

Fig. 23: Propeller diameter for tankers and bulk carriers (Significant Ships 1990 – 2010).

CONCLUSIONS

A historical analysis of the main dimensions (length, breadth, draught and displacement) of tankers and bulk carriers over the last 30–40 years has been carried out. This analysis has been performed for different sizes of these ships and for each size segment the development of some of the main dimensions has been found. The analysis reveals that the block coefficient for most of the ships has increased during the last 30 years. During the same period the length displacement ratio has decreased. Both factors mean that comparatively more propulsion power is needed. The Energy Efficiency Design Index (EEDI) for the analysed ships has in general increased over the last 30 years due to the higher power demand as a result of more unfavourable main dimensions. For most of the ship segments the ship speed has increased, resulting in a higher Froude number, which also increases the propulsion power and the EEDI.

Using a generic computer model which calculates the changes of propulsion power when the main dimensions of tankers and bulk carriers are changed, it can be shown that a reduction of the EEDI by 10–15 per cent is obtainable by adjusting the main dimensions, so that the block coefficient and the length displacement ratio are reduced to the level of these values approximately 30 years ago.

When designing new tankers and bulk carriers ship designers have to be very careful, so that naval architectural design rules and hydrodynamic principles are not violated. The requirement for a maximum allowable Energy Efficiency Design Index for new ships, which by nature are goal-based rules, might be a good design driver for more efficient ships in the future.

ACKNOWLEDGEMENTS

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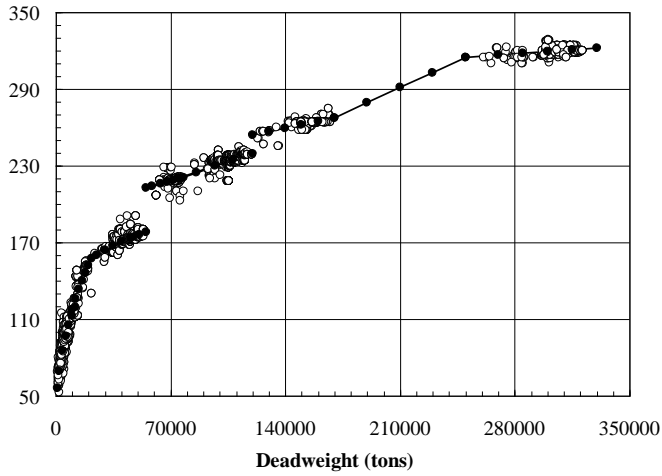
Watson, D.G.M., Practical Ship Design, Elsevier Ocean Engineering Book Series, Volume 1, 1998.

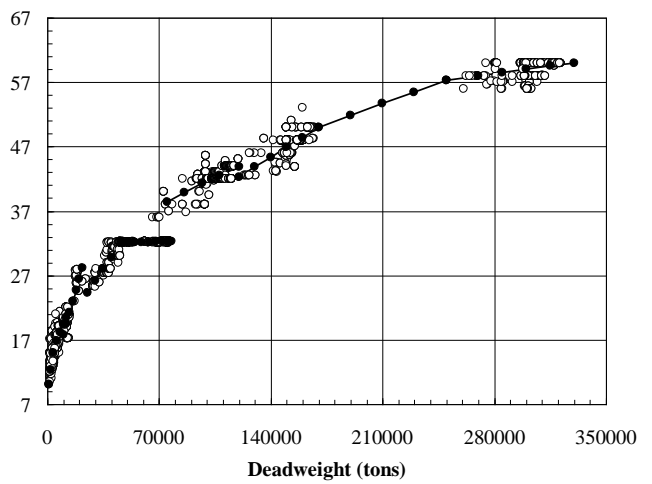Significant Ships, yearly editions from 1990 to 2010, Royal Institution of Naval Architects (RINA).

APPENDIX A - Statistical Data for Tankers
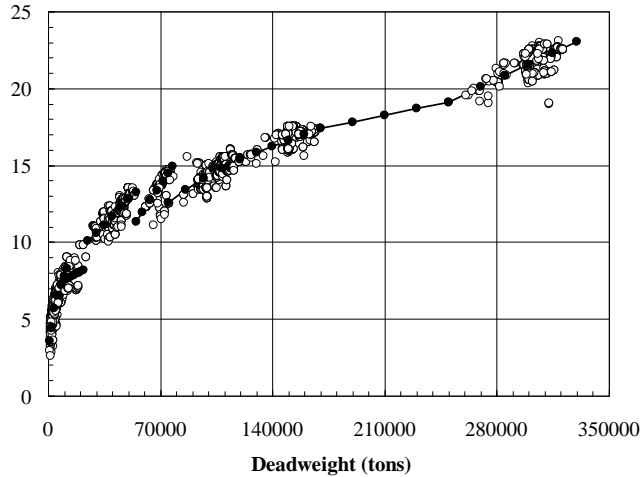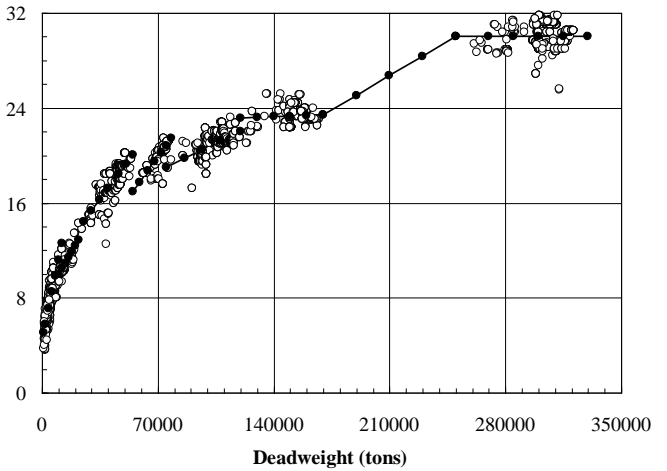
● **DTU-SDU model value**
○ **IHS Fairplay data**
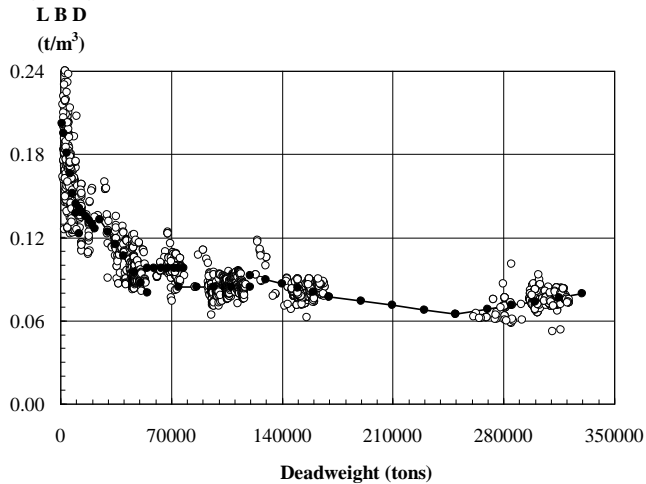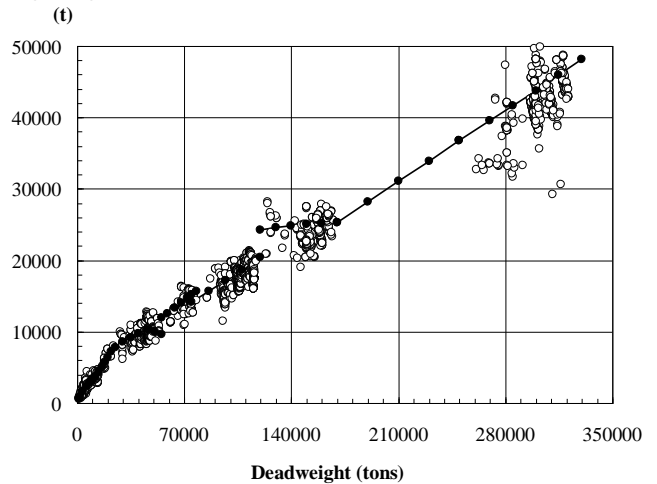
APPENDIX B - Equations for Tankers Found by Analysis of IHS Fairplay Data

Small tankers (< 10000 DWT)

Length pp	$= 6.809 \cdot DWT^{0.3048}$
Breadth	$= 1.406 \cdot DWT^{0.285}$
Depth	$= 4.4 + 0.000681 \cdot DWT$
Draught	$= 0.33 \cdot DWT^{0.343}$
Lightweight/Lpp/B/D	$= 0.2096 - 0.00000724 \cdot DWT$

Handysize tankers (10000 - 25000 DWT)

Length pp	$= 3.9537 \cdot DWT^{0.3684}$
Breadth	$= 8.99 + 0.000874 \cdot DWT$
Depth	$= 7.56 + 0.0002405 \cdot DWT$
Draught	$= 7 + 0.0000523 \cdot DWT$
Lightweight/Lpp/B/D	$= 0.1584 - 0.00000145 \cdot DWT$

Handymax tankers (25000 - 55000 DWT)

Length pp	$= 41.647 \cdot DWT^{0.133}$
Breadth	$= MIN[15.04 + 0.000369 \cdot DWT; 32.23]$
Depth	$= 9.69 + 0.000188 \cdot DWT$
Draught	$= 7.41 + 0.000106 \cdot DWT$
Lightweight/Lpp/B/D	$= 1.05 \cdot (0.1765 - 0.00000175 \cdot DWT)$

Panamax tankers (55000 - 75000 DWT)

Length pp	$= 193.26 + 0.000353 \cdot DWT$
Breadth	$= 32.23$
Depth	$= 6.14 + 0.000196 \cdot DWT$
Draught	$= 2.76 + 0.000156 \cdot DWT$
Lightweight/Lpp/B/D	$= 0.103$

Aframax tankers (75000 - 120000 DWT)

Length pp	$= 187.92 + 0.000431 \cdot DWT$
Breadth	$= 1.5658 \cdot DWT^{0.285}$
Depth	$= 13.97 + 0.000067 \cdot DWT$
Draught	$= 0.0848 \cdot DWT^{0.4454}$
Lightweight/Lpp/B/D	$= 1.05 \cdot (0.0859 - 0.0000000235 \cdot DWT)$

Suezmax tankers (120000 - 170000 DWT)

Length pp	$= 222.41 + 0.000263 \cdot DWT$
Breadth	$= 23.95 + 0.000153 \cdot DWT$
Depth	$= 22.61 + 0.000004647 \cdot DWT$
Draught	$= 0.2476 \cdot DWT^{0.353}$
Lightweight/Lpp/B/D	$= 1.05 \cdot (0.1296 - 0.000000308 \cdot DWT)$

VLCC (170000 - 250000 DWT)

Length pp	$= 267.12 + (DWT - 170000) \cdot 0.0005975$
Breadth	$= 49.96 + (DWT - 170000) \cdot 0.00009219$
Depth	$= 23.4 + (DWT - 170000) \cdot 0.0000825$
Draught	$= 17.38 + (DWT - 170000) \cdot 0.00002147$
Lightweight/Lpp/B/D	$= 1.05 \cdot (0.0772 - (DWT - 170000) \cdot 0.0000001574)$

VLCC (250000 - 330000 DWT)

Length pp	$= 293.67 + 0.000085 \cdot DWT$
Breadth	$= 49.01 + 0.0000333 \cdot DWT$
Depth	$= 30$
Draught	$= 6.85 + 0.000049 \cdot DWT$
Lightweight/Lpp/B/D	$= 1.05 \cdot (0.01912 + 0.00000018212 \cdot DWT)$

APPENDIX C - Statistical Data for Bulk Carriers

● **DTU-SDU model value**
○ **IHS Fairplay data**
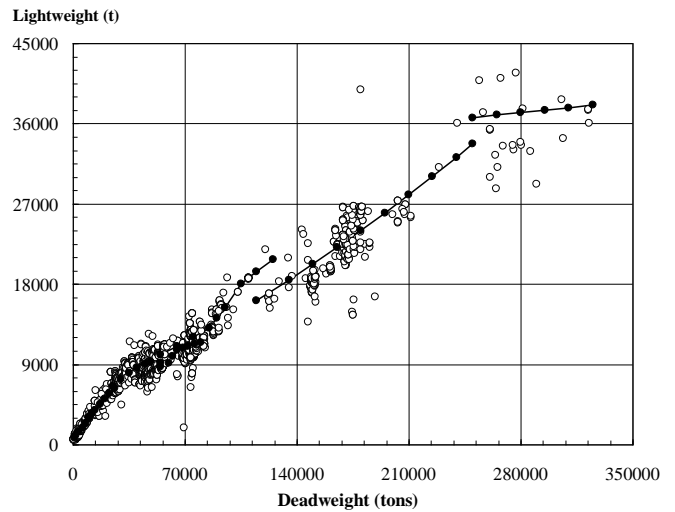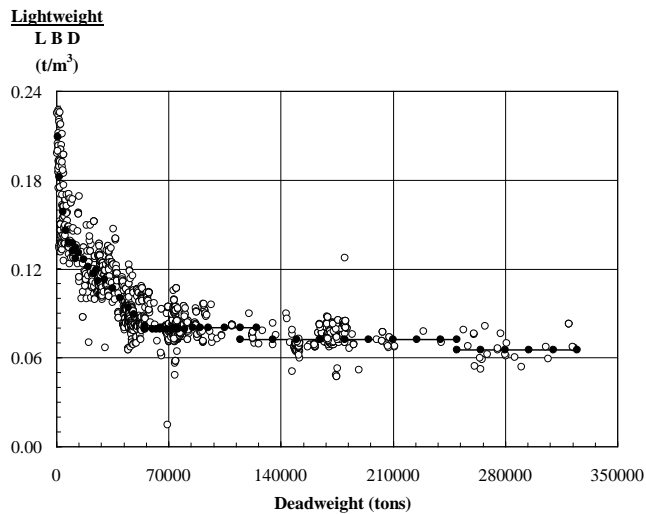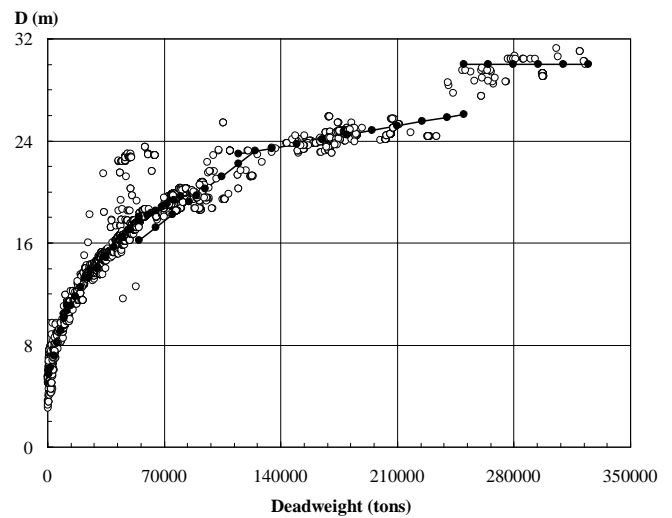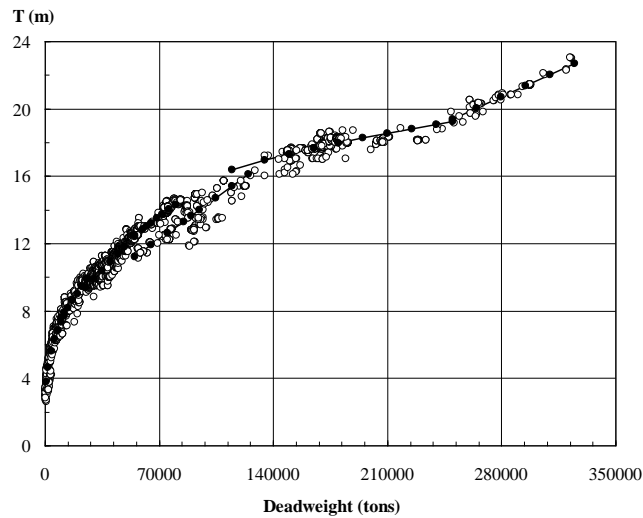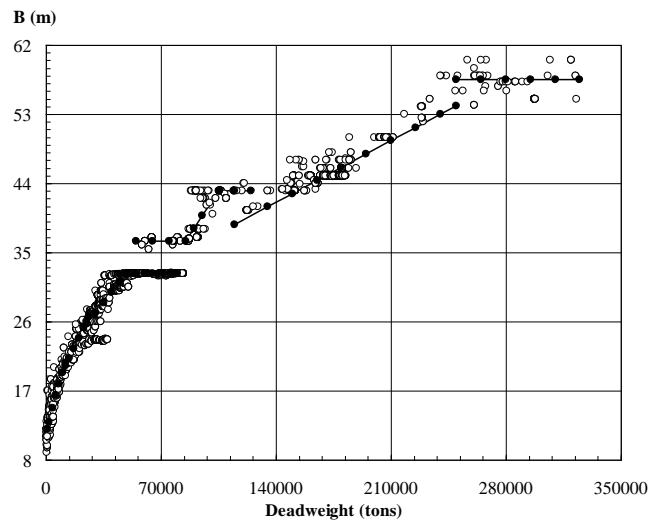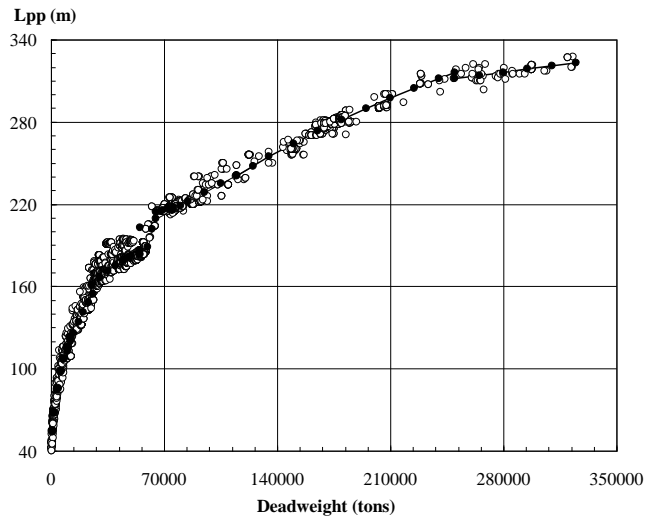
APPENDIX D - Equations for Bulk Carriers Found by Analysis of IHS Fairplay Data

Small bulk carriers (< 10000 DWT)

Length pp	$= 5.582 \cdot DWT^{0.329}$
Breadth	$= 11 + 0.001 \cdot DWT - 0.00000001675 \cdot DWT^2$
Depth	$= 5.22 + 0.000485 \cdot DWT$
Draught	$= 0.529 \cdot DWT^{0.285}$
Lightweight/Lpp/B/D	$= 0.831 \cdot DWT^{-0.2}$

Handysize bulk carriers (10000 - 25000 DWT)

Length pp	$= 5.463 \cdot DWT^{0.3285}$
Breadth	$= 14.86 + 0.00045 \cdot DWT$
Depth	$= 7.84 + 0.000232 \cdot DWT$
Draught	$= 6.2 + 0.000141 \cdot DWT$
Lightweight/Lpp/B/D	$= 0.153 - 0.00000158 \cdot DWT$

Handymax bulk carriers (25000 - 55000 DWT)

Length pp	$= 25.66 \cdot DWT^{0.1813}$
Breadth	$= MIN[18.93 + 0.000272 \cdot DWT; 32.23]$
Depth	$= 9.32 + 0.000158 \cdot DWT$
Draught	$= 6.84 + 0.000101 \cdot DWT$
Lightweight/Lpp/B/D	$= 1.05 \cdot (0.151 - 0.00000127 \cdot DWT)$

Panamax bulk carriers (55000 - 75000 DWT)

Length pp	$= 124.18 + 0.00107 \cdot DWT$	for DWT < 60000
	$= 0.00517 \cdot DWT - 121.52$	for $60000 <= DWT <= 65000$
	$= 195.16 + 0.000293 \cdot DWT$	for DWT < 80000
Breadth	$= 32.23$	
Depth	$= 13.66 + 0.0000747 \cdot DWT$	
Draught	$= 8.43 + 0.0000735 \cdot DWT$	
Lightweight/Lpp/B/D	$= 0.083$	

Aframax bulk carriers (75000 - 120000 DWT)

Length pp	$= 167.39 + 0.0006421 \cdot DWT$	
Breadth	$= 36.5$	for DWT < 85000
	$= 8.875 + 0.000325 \cdot DWT$	for $85000 < DWT < 105000$
	$= 43.0$	for DWT > 105000
Depth	$= 10.7 + 0.0001 \cdot DWT$	
Draught	$= 7.35 + DWT \cdot 0.00007$	
Lightweight/Lpp/B/D	$= 0.084$	

Suezmax tankers (120000 - 250000 DWT)

Length pp	$= 4.046 \cdot DWT^{0.3506}$
Breadth	$= 25.49 + 0.0001145 \cdot DWT$
Depth	$= 20.27 + 0.0000232 \cdot DWT$
Draught	$= 1.476 \cdot DWT^{0.2065}$
Lightweight/Lpp/B/D	$= 0.0756$

VLBC (250000 - 330000 DWT)

Length pp	$= 271.49 + 0.0001594 \cdot DWT$
Breadth	$= 57.5$
Depth	$= 30$
Draught	$= 8.32 + 0.00004424 \cdot DWT$
Lightweight/Lpp/B/D	$= 0.068$

APPENDIX E – Calculation Output from DTU-SDU Computer Model

Maximum deadweight	tons	100000	100000	100000
Elongation in percent	pct.	0	2	4
Length between pp	m	231.02	235.64	240.26
Length in waterline incl. bulbous bow	m	235.64	240.35	245.07
Breadth mld.	m	41.66	42.49	43.33
Depth	m	20.67	20.67	20.67
Design draught	m	13.19	13.21	13.22
Maximum draught	m	14.30	14.30	14.30
Design deadweight/Maximum deadweight	%	90	90	90
Maximum draught - design draught	m	1.11	1.10	1.08
Design deadweight	tons	90000	90000	90000
Lightweight coefficient	t/m^3	0.084	0.084	0.084
Lightweight	tons	17547	18256	18978
Structural enhancement (change of lightweight)	pct.	0	0	0
New lightweight	tons	17547	18256	18978
Displacement at design draught	tons	107547	108256	108978
Displacement at maximum draught	tons	117547	118256	118978
Design Dw/Maximum displacement	%	83.7	83.1	82.6
Scantling Dw/Maximum displacement	%	85.1	84.6	84.0
Block coefficient at design draught	-	0.827	0.799	0.772
Block coefficient at maximum draught	**-**	**0.833**	**0.806**	**0.780**
Lpp/Displ.$^{1/3}$ at design draught	-	4.90	4.99	5.07
Lpp/Displ.$^{1/3}$ at maximum draught	**-**	**4.76**	**4.84**	**4.93**
Midship section coefficient	-	0.995	0.995	0.995
Prismatic coefficient at design draught	-	0.831	0.803	0.776
Prismatic coefficient at maximum draught	-	0.837	0.810	0.784
Waterplane area coefficient at maximum draught	-	0.915	0.893	0.872
Wetted surface at design draught	m^2	13661	13832	14005
Wetted surface at maximum draught	m^2	14277	14452	14628
Service speed at design draught	knots	15.0	15.0	15.0
Froude number (Lwl) at service speed	-	0.160	0.159	0.157
Scantling trial speed at 75 % MCR ('reference speed')	knots	14.957	14.898	14.856
Froude number (Lwl) at 'reference speed'	-	0.160	0.158	0.156
Service allowance on resistance	pct.	15	15	15
Beaufort No.	-	0	0	0
Calculated wind speed acc. to Beaufort No.	m/s	0.0	0.0	0.0
Wind speed to be used for separate wind resistance	m/s	0.0	0.0	0.0
Wind resistance fraction of trial resistance	pct.	0	0	0
Transmission efficiency	pct.	98	98	98
Main engine power (MCR)	kW	14529	13586	12970
Main engine service rating (only if NO derated engine)	pct. MCR	90	90	90
Auxiliary power at sea at design draught	kW	613	590	574
Propeller type (1 = conventional - 2 = ducted)	(-)	1	1	1
Propeller diameter	m	6.95	6.95	6.95
Propeller loading (MCR)	kW/m^2	383	358	342
Speed dependency exponent n (power = constant V^n)	-	3.9	3.6	3.4
IMO Energy Efficiency Design Index (CO_2 emissions)	g/dwt/nm	4.33	4.07	3.90
IMO Energy Efficiency Design Index (MEPC 62)	g/dwt/nm	4.43	4.43	4.43