Propulsion trends in bulk carriers

MAN Energy Solutions
Future in the making

Modern two-stroke engine technology for one of the workhorses of global trade

Future in the making

Contents

Bulk carriers constitutes the single largest part of the world's merchant fleet when counted in deadweight tonnage. As such, the propulsion of bulk carriers deserves special attention in an industry increasingly focused on reducing emissions of greenhouse gasses.

EEDI phase 2 and 3 requirements are approaching fast and requires innovative solutions to be implemented for the propulsion of this vital workhorse of the global economy. In this paper the possibilities for future EEDI compliance will be outlined and evaluated, ensuring benefits for the environment and for the owner.

Introduction

The demand for raw materials like iron ore, copper, grain, etc., has increased considerably since the turn of the millennium. From 2000 to 2018, the cargo carried on board bulk carriers per year has almost doubled from 17,380 to 34,193 billions of tonne-miles, [1]. This is a consequence of globalisation and the great demand for raw materials in China and other developing economies in Southeast Asia, owing to the fast economic growth. This means that the Southeast Asian industry, among others, is absorbing large quantities of iron ore whereas the growing population consumes other bulk cargoes like grain and soya beans.

The bulk carrier market, therefore, has been very attractive, which caused a tremendous boost in the signing of newbuilding contracts until the latest economy crisis in 2008. As the full scale of the economic crises were realised, orders dropped significantly, first to stabilise during 2014-2015, and later to drop further due to overcapacity in the market. The development of tonnage on order for various ship types is illustrated in Fig. 1.

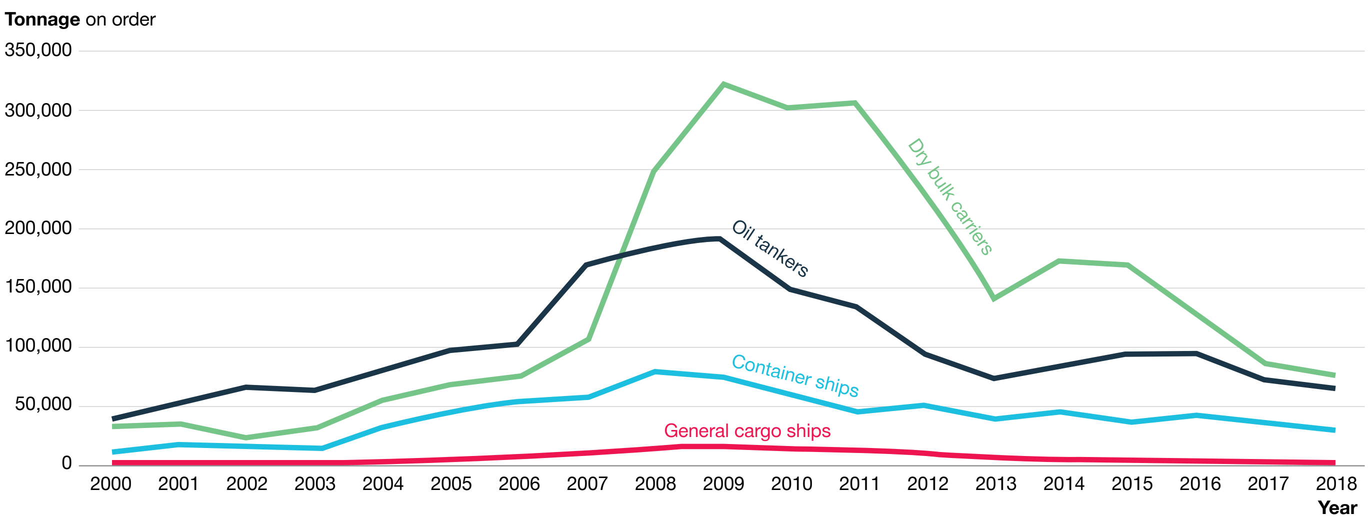

Fig. 1: The development of tonnage on order for various ship types, 2000 – 2018 [1]

The world economy is developing and freight rates are improving, significantly more efficient technologies are brought to the market, resulting in a competitive advantage for modern bulk carriers delivered now compared to the designs delivered around 2008-2010. Thanks to these factors, orders for bulk carriers are expected to rise from the present low point.

The International Maritime Organisation (IMO) introduced regulations on the Energy Efficiency Design Index (EEDI) in 2011, seeking to limit the emission of greenhouse gasses from international shipping. The requirements for efficiency are increasingly tightened through three phases:
10% reduction from the baseline has been required since phase 1 came into force in 2015, a 20% reduction is required from 2020 by phase 2, and finally a 30% reduction by phase 3 in 2025 for bulk carriers.

Phase 2 will have significant effects on the present designs of bulk carriers. Reductions of the service speed may be considered, along with increasing the propeller diameter and the application of the latest engine technology through EcoEGR, a shaft generator/PTO as well as methods for optimisation of the hull lines.

From 2025, phase 3 will require 30% reduction from the baseline. To achieve compliance with the reduction required by phase 3 further initiatives and optimisations are required. This could be implementation of energy saving devices, twin screw propulsion plants, waste heat recovery, alternative fuels, etc.

The ultra-long-stroke G-type MAN B&W engine will play an important role in ensuring EEDI compliance: As vessel speeds decrease and the propeller diameter is increased, the optimum propeller speed is reduced along with the propeller power required. The G-type engine will not only ensure significant fuel savings, but with its long stroke and resulting lower rpm it will ensure that any operational point of a bulk carrier can be contained within the layout diagram of a main engine.

This paper will illustrate the latest developments within bulk carriers delivered and explain the main particulars of various categories of bulk carriers above 5,000 deadweight tonnage (dwt). Based on an analysis of the latest deliveries, the paper will outline how various sizes of bulk carriers can attain compliance with EEDI phase 2 and 3.

Bulk carrier characteristics

Definition of a bulk carrier
In dictionaries, a bulk cargo is defined as loose cargo that is loaded directly into a vessel's hold. Bulk cargo is thus a shipment such as oil, grain, ores, beans, cement, etc., or one which is not bundled, bottled, or otherwise packed, and which is loaded without counting or marking.

A bulk carrier is therefore a ship in which the cargo is carried in bulk, rather than in barrels, bags, containers, etc., and it is usually loaded homogeneously and by gravity.

On the basis of the above definitions, there are two types of bulk carriers: the dry-bulk carrier and the wet-bulk carrier, the latter better known as a tanker.

This paper describes the dry-bulk carrier type, normally just known as bulk carrier or bulker, whereas tankers are described in the separate paper "Propulsion trends in tankers".

Bulk carriers were introduced in the 1950s and resulted in lower transportation costs, as packing of the commodities before being stacked on board was no longer needed. This was usually the case on general cargo ships.

Bulk carriers are one of the three dominating merchant ship types together with tankers and container vessels. Today, bulk carriers comprise almost 43% of the world fleet in terms of tonnage, an increase from 36% in 2010.

Bulk carriers exist in many sizes and classes, typically named after a specific passage or port they can enter. The capacity of bulk carriers spans from a few hundred dwt for coastal shipping up to 400,000 dwt of the so-called Chinamax series of very large bulk carriers (VLBC) and everything in between. A few categories are distinctive as outlined in the following section.

Bulk carrier sizes and classes

The deadweight of a vessel is the carrying capacity in metric tons (1,000 kg) including the weight of bunkers and other supplies necessary for the ship's propulsion.

The size of a bulk carrier will normally be stated as the maximum possible deadweight tonnage, which corresponds to the fully loaded deadweight at full summer saltwater draught (normally a density of 1,025 tonne/m^3), also called the scantling draught of the ship.

However, sometimes the deadweight tonnage (dwt) used refers to the design draught, which is normally less than the scantling draught and equals the average loaded ship in service. Therefore, the deadweight tonnage that refers to the design draught – which is used for design of the propulsion plant – is normally lower than the scantling-draught based deadweight tonnage.

The sizes of the bulk carriers described in this paper are based on the scantling draught, a seawater density of 1,025 tonne/m^3 and mainly on the single hull design normally used. Considerations on double hull and the implications hereof are given in the later section "Hull design of a bulk carrier".

Depending on the dwt and hull dimensions, bulk carriers can be been divided into the main- and sub-groups listed in Table 1. However, there will be some overlapping into adjacent groups, and there can be some float in the definitions depending on the tradition within the trade.

As an example of the overlap between the classes, ultra large Handymax bulk carriers have been built which are bigger than about 55,000 dwt, and today often called Supramax bulk carriers. These have a deadweight tonnage of up to about 60,000 dwt, and an overall length of max. 190 m (two Japanese harbours) but now also 200 m and a breadth of 32.2 m (Panama Canal).

Table 1: Typical main and sub classes of bulk carriers with approximate measurements. For some of the classes popular subclasses referring to designs fulfilling specific limitations are listed

Class	Size, scantling [dwt]	Typical LOA [m]	Typical max. breadth [m]	Typical max. draught [m]
Small	10,000	~115	~18	<10
Handysize	10-35,000	130-150	~26	~10
Handymax	35-55,000	150-200	32.2	10-12
Panamax	55-80,000	190-225	28-32.2	12-14
Supramax	60,000	190-200	32.2	11-13
Capesize	80-200,000	230-270	43-45	17
Kamsarmax	~84,000	229	32.2	14.4
Dunkirkmax	~175,000	289	45	~16
Very large bulk carrier	>200,000	>270	45-60	15-20
Newcastlemax (AUS)	~205,000	299.9	47-50	16.1
Chinamax	~400,000	~360	~65	22-23

For almost a century the size of the Panama Canal has been a decisive factor for the dimensions of the so-called Panamax bulk carriers. Even if the maximum length of the present lock chambers, lanes one and two, is 294.13 m (965 ft), the term Panamax-size is for a bulk carrier typically defined as 32.2/32.3 m breadth (106 ft), 225 m overall length, and no more than 12.04 m draught (39.5 ft). The reason for the smaller ship length applied is that a large part of the world's harbours and corresponding facilities are based on the length of 225 m.

Despite the opening of the third Panama locks in 2016, the old-Panamax measures maintains to be an important measure for bulk carriers as the extension is mostly focused on container vessels and other vessels carrying a relatively light cargo as e.g. LNG carriers.:
The new locks permit a maximum draught of 15.2 m, which is somewhat low compared to typical draughts of 20-22 m of bulk carriers otherwise fitting the length and beam limits of the third lane, see Table 2. Throughout this paper, the term "Panamax" will refer to the old Panama Canal dimensions.

Some Panamax bulk carriers continue to grow in cargo capacity as the pressure of worldwide competition forces shipyards to offer extra capacity. Thus, a special so-called Kamsarmax type with an increased overall length of 229 m and 84,000 dwt has been built. It is the largest size vessel able to load at the world's largest bauxite port, Port Kamsar in Equatorial Guinea.

The number of the Capesize bulk carriers, i.e. vessels with a deadweight tonnage higher than 80,000 dwt, has been increased, as the largest bulk carriers are becoming bigger and bigger. Often, the largest ones are called "Ultra Large Capesize" or just "Very Large Bulk Carrier" (VLBC). In this paper the VLBC description will be applied for bulk carriers bigger than 200,000 dwt, and China-max for the special 400,000 dwt vessels.

Bulk carrier market

Today the fleet of bulk carriers larger than 5,000 dwt accounts for more than 11,219 ships.

As can be seen from Fig. 2 and 3, showing the distribution of the bulk

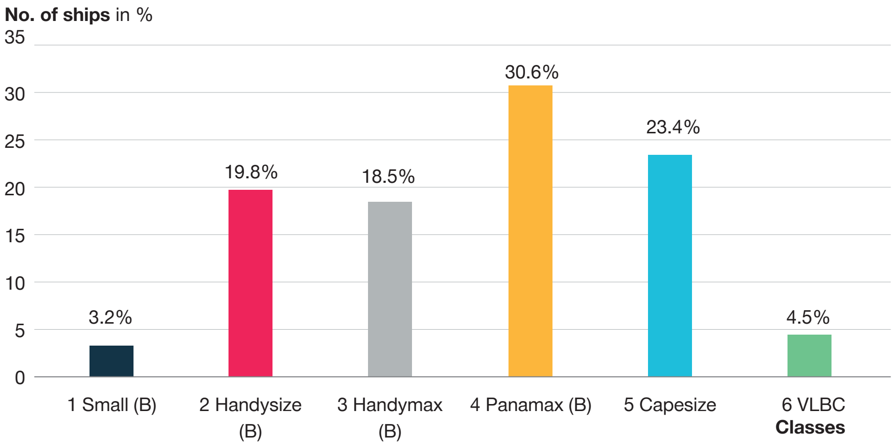

Fig. 2: Distribution of major bulk carrier classes above 5,000 dwt, by number of vessels

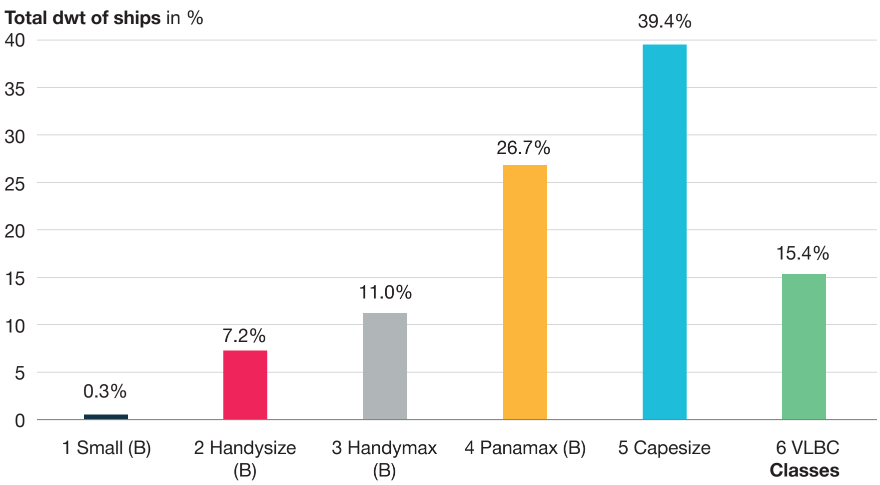

Fig. 3: Distribution of major bulk carrier classes above above 5,000 dwt, by deadweight tonnage

Table 2: Dimensions of the Panama locks.
***Draught limits are occasionally tightened depending on the water level in the nearby lakes**

	Length [m]	Breadth [m]	Draught [m]	Height [m]
Lane 1 & 2 lock dimensions	305	33.5	12.5-13.7*	
Old-Panamax vessel dimensions	294	32.2	12.04	57.9
Lane 3 lock dimensions	427	55	18.3	-
New-Panamax vessel dimensions	366	51.25	15.2*	57.9

carrier fleet in classes, more than 40% of the bulk carrier fleet – in number of ships – are smaller than 55,000 dwt, with the dominating 19.8% being Handysize vessels, followed by 18.5% Handymax. The Panamax vessels account for 30%, and the large ships, Capesize and VLBC, now account for almost 30% of the fleet, an increase compared to the past.

When comparing the total deadweight, instead of the number of ships, the distribution of bulk carrier classes changes in favour of the larger bulk carriers as Panamax, Capesize and VLBC, see Fig. 4.

A general trend is that the size of bulk carriers ordered are growing, see Table 3 showing the number of ships in percent valid for the present fleet and for ships on order by 2019. Especially the percentages of Handysize and Handymax vessels on orders are significantly lower than their representation in the present fleet.

Year of bulk carrier deliveries

Fig. 4 shows the number of bulk carriers delivered in five-year periods since the 1950s. More than 30% of all bulk carriers larger than 5,000 dwt ever delivered were delivered during the bulk carrier boom around 2010.

Age of the bulk carrier fleet

Fig. 5 shows the age distribution of the bulk carrier fleet as of 2019. The figure shows that about 25% of all bulk carriers in service today are delivered within the last five years, and 43% within a period 6-10 years ago, i.e. during the bulk carrier boom around 2010. Ships delivered more than 26 years ago constitute 5.5% of the bulk carriers in the current fleet.

Table 3: Percentage of ship classes in the fleet and on order, by number of vessels

Class	In fleet		On order		All	
Small	363	3.2%	8	0.8%	371	3.0%
Handysize	2,221	19.8%	51	5.4%	2,272	18.7%
Handymax	3,073	18.5%	122	12.9%	2,195	18.0%
Old-Panamax	3,432	30.6%	264	27.9%	3,696	30.4%
Capesize	2,621	23.4%	350	37.0%	2,971	24.4%
Large Capesize	509	4.5%	151	16.0	660	5.4%
VLBC	11,219	100%	646	100%	12,165	100%

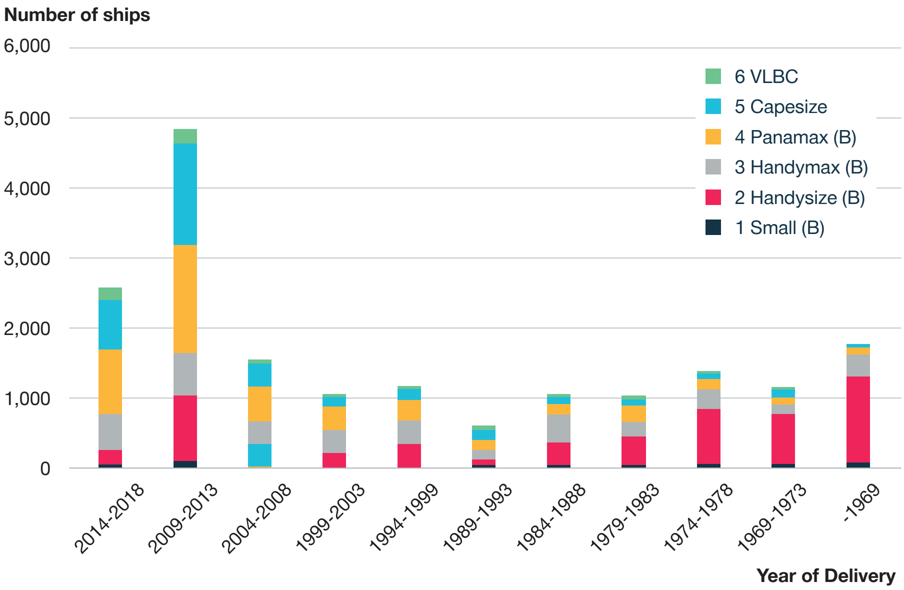

Fig. 4: Number of bulk carriers larger than 5,000 dwt delivered within 5-year periods

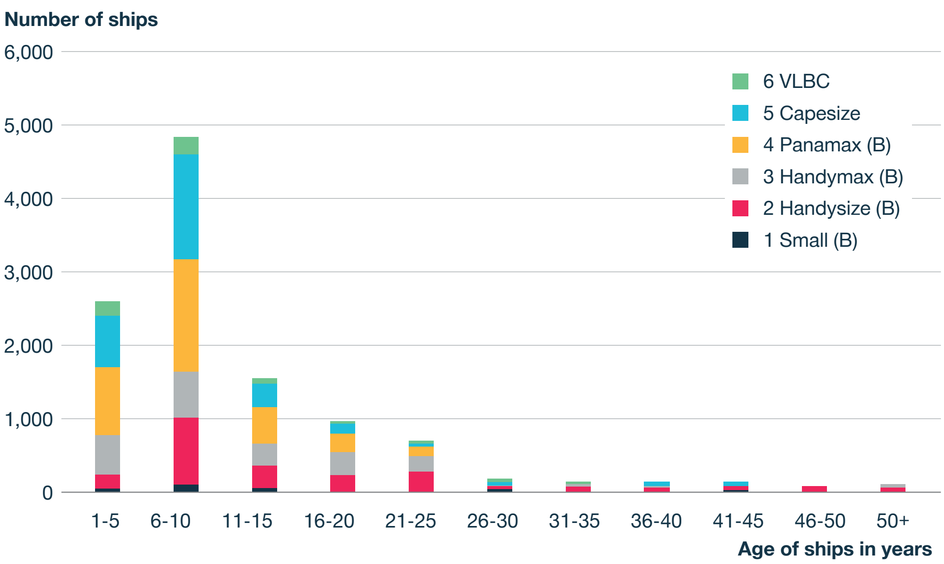

Fig. 5: Age of the bulk carrier fleet for a given 5-year period

When comparing the number of ships delivered in a given 5-year period with the age of the bulk carrier fleet today, see Fig. 6, it can be seen that 80% of the vessels are in service after 20 years, 40% after 25 years and approx. 15% after 3 years.

The average lifetime of a bulk carrier is a little less than 25 years, a shortening compared to previous times, an effect of the huge increase in capacity during the bulk carrier boom. When the market collapsed many older bulk carriers became obsolete. This is also reflected in the fact that 10% of the vessels delivered 16-20 years ago have already been scrapped.

As of 2019, the order book for bulk carriers larger than 5,000 dwt totalled 946 bulk carriers, or 95 million dwt, corresponding to 8.4% of the existing bulk carrier fleet in numbers and 11.5% in dwt.

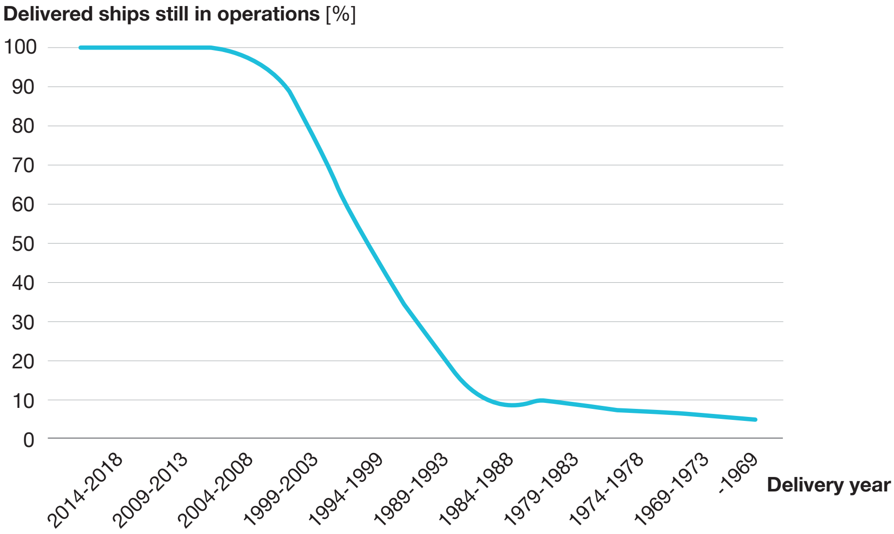

Fig. 6: Percent of bulk carriers delivered still in operation for a given 5-year period

Hull design of a bulk carrier

Since the 1960s, the standard design for bulk carriers has been a single hull ship with a double bottom, i.e. a hull with single side shells. Therefore, when talking about single or double hull, the words ‘side’, ‘skin’ or ‘side shell’ are often used instead of hull.

Debates on a requirement of double hull also for bulk carriers were ongoing in the slipstream of the debate on the requirement for tankers, but were rejected by the 78th session of the Marine Safety Committee of the IMO in 2004.

However, there can be significant operational benefits from applying a double hull (double skin) design also for bulk carriers. The use of double hull bulk carriers will give a more efficient cargo handling caused by the absence of hull frames and brackets protruding into the cargo holds, replaced by the smooth side of the inner hull. Especially for rather sticky cargos such as coal and coke, straight sides will ease the application of large machinery for emptying the holds, without a risk for damaging the major structural parts of the hull.

A number of shipyards and designers offers double hull bulk carriers. It seems that the light weight of the double hull ship will be increased only slightly, if at all, because of the use of thinner steel plates. As such, the required propulsion power will only increase slightly, if at all.

Naturally, more welding-work is needed for the double sides will increase the man-hours and, thereby, the cost of the vessel.

In all cases topside tanks will be included in the design of the holds to ensure a minimum free surface of the cargo when loaded. A shift of cargo can challenge the stability, as described in specialised literature, [2].

For safety reasons, the IMO and IACS (International Association of Classification Societies) have brought in regulations for implementation of water ingress alarms in cargo holds and forward spaces, as well as tightened the requirements on structural strength.

This happened in response to a high number of losses of bulk carriers in the late 1980es and early 1990es. These losses typically arose from water ingress into the forward hull that penetrated the bulkhead into the second hold, as the bulkhead due to corrosion and possible fatigue cracks collapsed under the increased load from the water. The ingress of water trimmed the vessel forward, which only increased the filling rate, and without notice from the crew, the vessel could almost sail itself underwater, leaving very little time for the crew to escape, [3].

An additional outcome of the many losses were the enhanced structural requirements implemented in SOLAS, as well as Common Structural Rules (CSR) developed by the IACS for bulk carrier designs. The EEDI regulations, discussed in detail in a following section, allow for a capacity correction factor for bulk carriers built according to the CSR rules. Further, a correction factor can be applied for bulk carriers with voluntary structural enhancements, [4].

Average ship particulars as a function of size

The average ship particulars have been estimated on the basis of bulk carriers built or contracted in the period 2010-2018, as reported in the IHS (Information Handling Services) Fairplay world register of ships. The statistics represent an update compared to previous editions of this paper, only showing minor changes. The only remarkable trend is a weak tendency for vessels to be slightly longer, and the service speed to be slightly lower.

Average hull design factor, F_{des}

Based on the above statistical material, the average design relationship between the ship particulars of the bulk carriers can be expressed by means of the average hull design factor, F_{des}, see Fig. 7.

$$F_{des} = L_{pp} \times B \times T_{scant} / dwt_{scant}$$

For bulk carrier sizes above Handymax size (55,000 dwt), the design factor F_{des} shown in Fig. 7 is reasonably exact, whereas the factor is less exact for smaller bulk carriers.

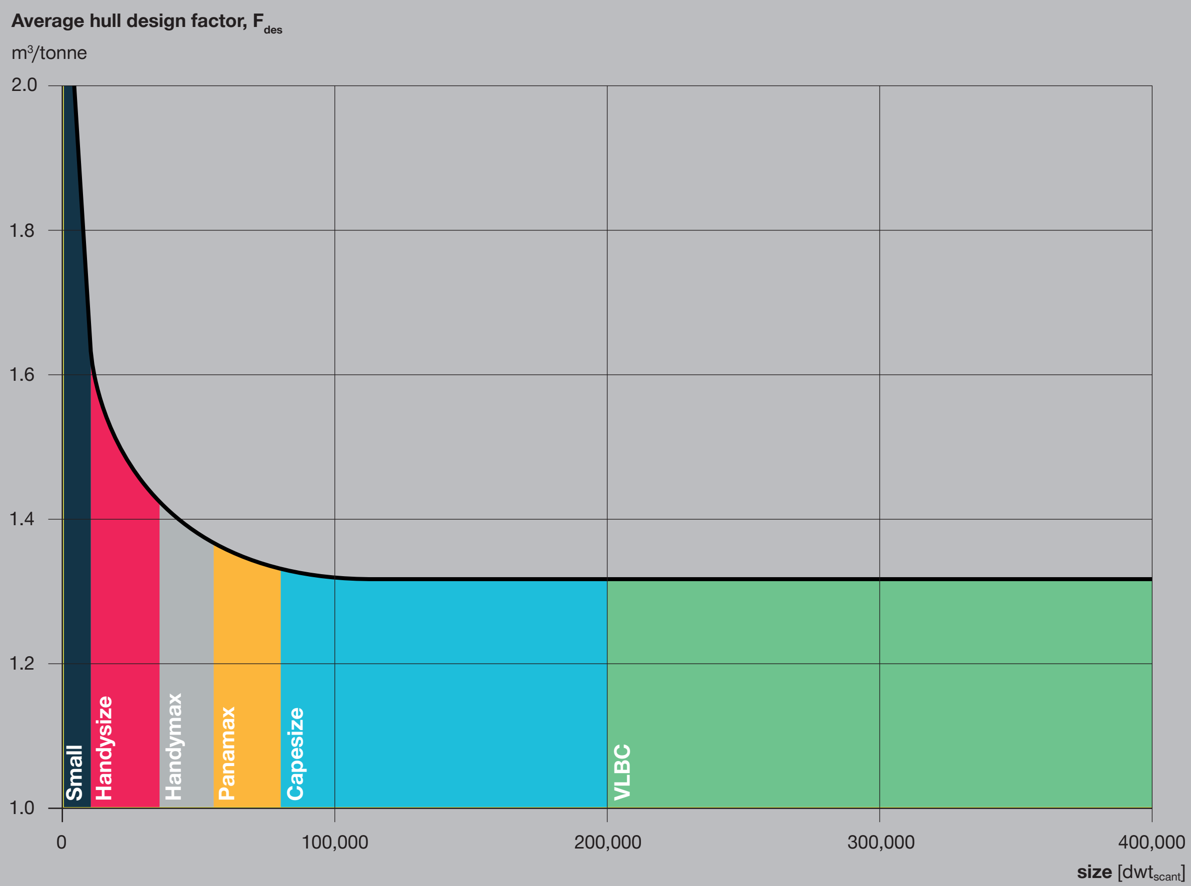

Fig. 7: Average hull design factor of bulk carriers

The length between perpendiculars, L_{pp}, breadth, B, and scantling draught T_{scant}, as a function of the ship size as represented by the dwt are illustrated in Fig. 8, 9 and 10 respectively. The figures show general trends, and variations may occur, especially for more special designs.

The three figures show an alternative ship design for a 35,000 dwt Handymax bulk carrier with a relatively narrow ship breadth B, but with a longer ship length L_{pp} and higher draught T. This narrower ship design (B_{max}=23.7 m) is used in the narrow Canadian St. Lawrence Canal to the Great Lakes. Furthermore, some of the significant subclasses of bulk carriers give rise to specific dimensions marked throughout the figures.

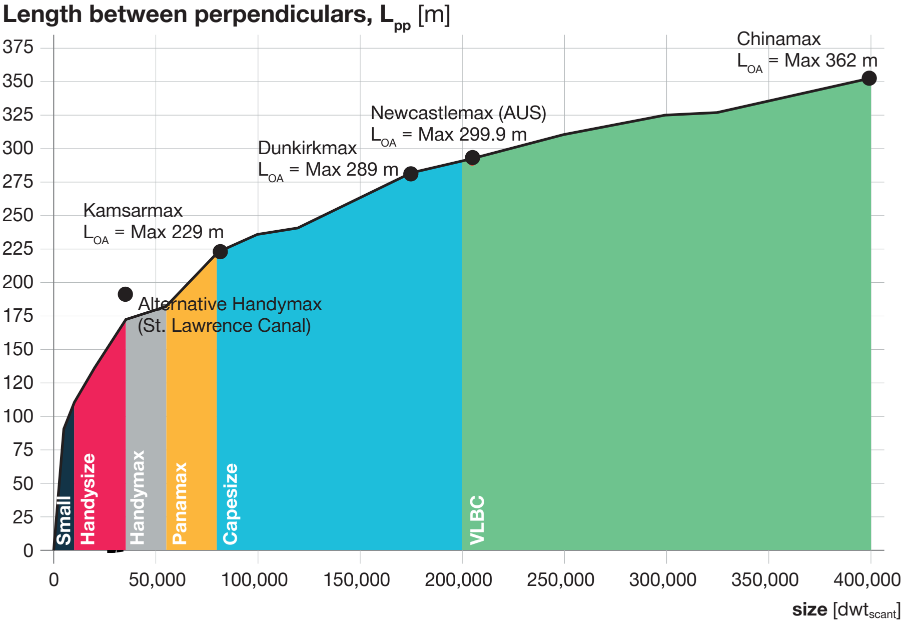

Fig. 8: Average length between perpendiculars, L_{pp}

Average design speed

Fig. 11 shows the average design speed at the design draught as reported in the IHS database. For VLBCs above 200,000 dwt, the design speed has reduced slightly after the implementation of the EEDI.

This indicates that improvements in efficiency so far have been almost sufficient to ensure compliance with the EEDI while maintaining the same design speed. Whether this is the case also in the future will be discussed in the separate section “EEDI for bulk carriers”.

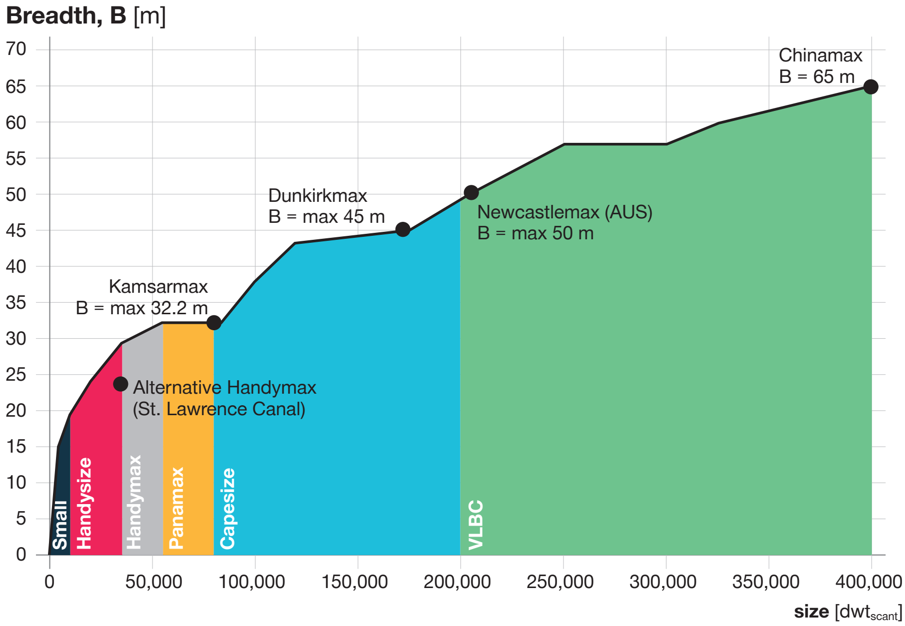

Fig. 9: Average breadth

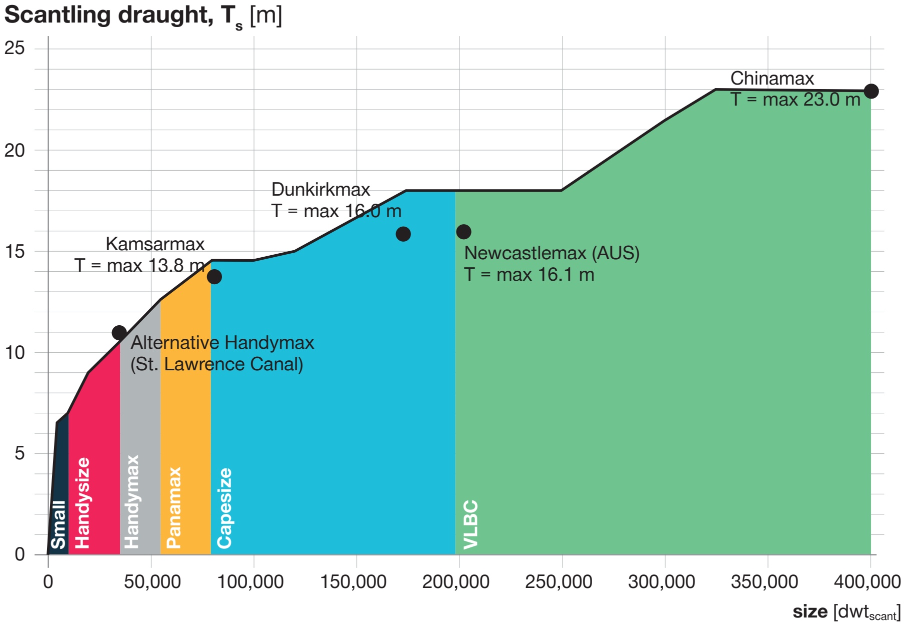

Fig. 10: Average scantling draught of bulk carriers. For Kamsarmax, Dunkrirkmax, and Newcastlemax, the maximum allowable draught in the specific ports are shown, scantling draughts are typically greater

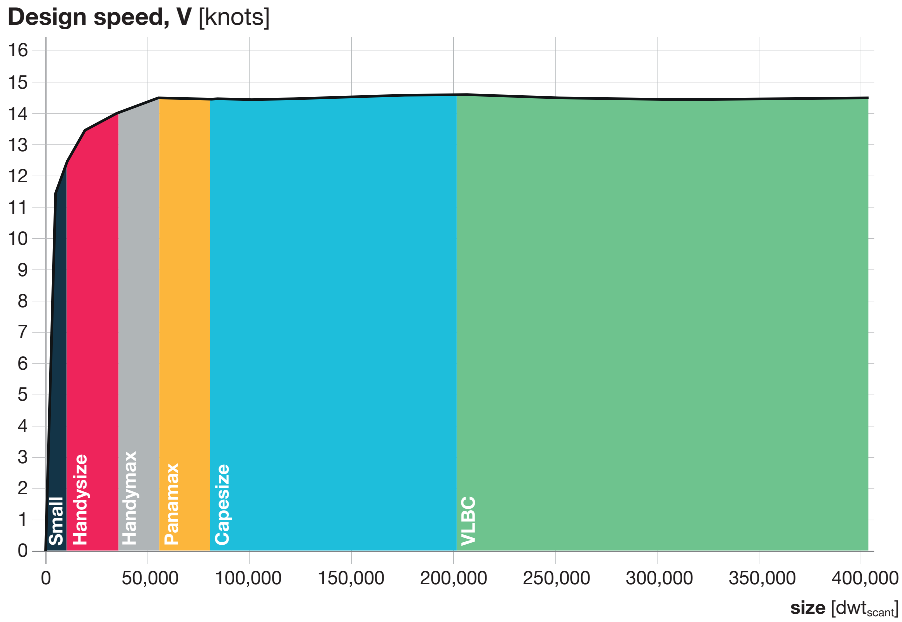

Fig. 11: Average design speed

Vessel speed V as a function of draught

Depending on the actual deadweight loaded onto the ship and corresponding displacement, the actual draught may differ from the design draught. This can influence the speed attainable for the same propulsion power, see Fig. 12.

This figure explains, among other things, why shipyards for a given vessel design/size might specify different vessel speeds. Thus, if in one case the specified design draught is low, the design vessel speed will be higher than for the same vessel type specified with a larger design draught, as for example equal to the scantling draught.

Fig. 13 illustrates the specified maximum continuous rating (SMCR) as a function of the size of the vessels delivered in 2010-2018. In general, the larger the vessel is the less power will be required per dwt, an effect further enhanced by the almost constant design speed of approx. 14.5 knots applied for vessels larger than 50,000 dwt.

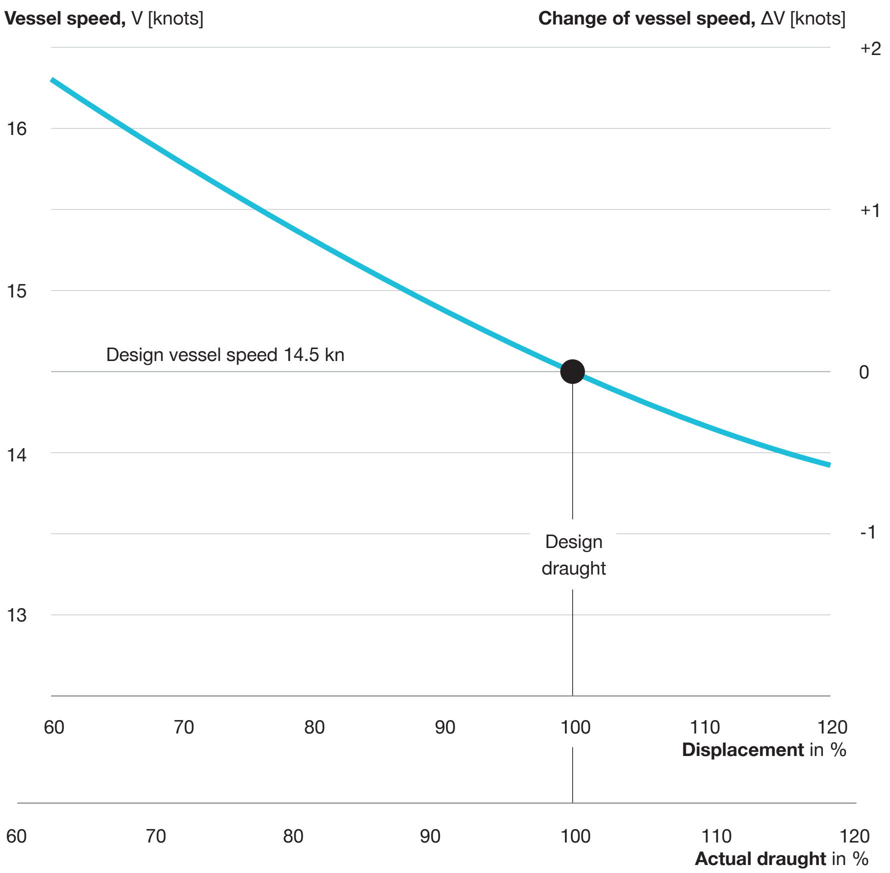

Fig. 12: Vessel speed at actual draught for the same propulsion power of bulk carriers

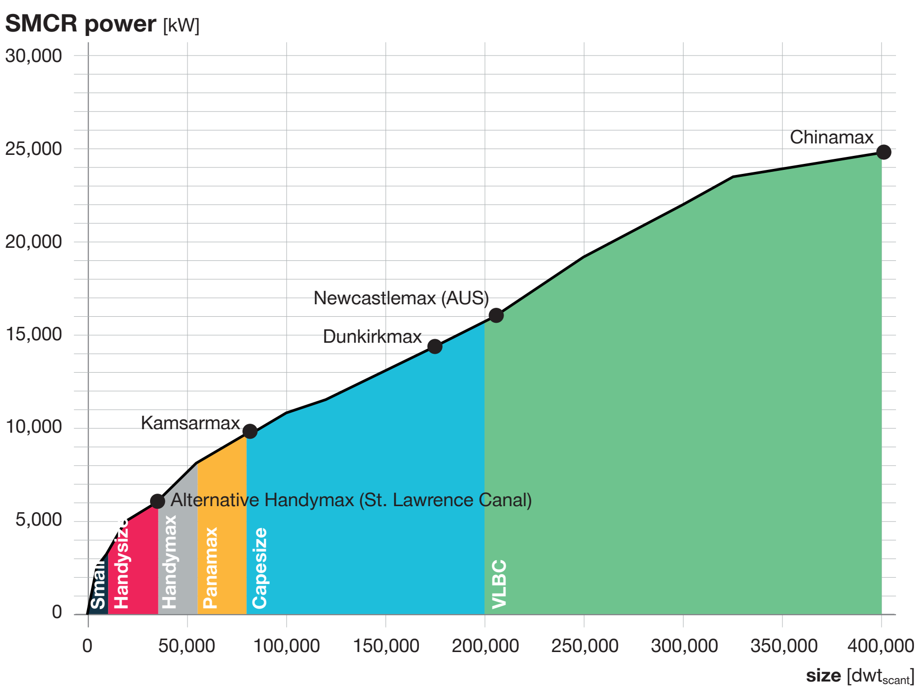

Fig. 13: Propulsion SMCR power as a function of dwt

Propulsion power demands of average bulk carriers

In general, the highest possible propulsive efficiency is obtained with the largest possible propeller diameter, d, in combination with the corresponding optimum pitch/diameter ratio p/d.

As an example, this is illustrated in Fig. 14 for a 205,000 dwt Newcastlemax bulk carrier with a service ship speed of 14.5 knots, see the black curve. The needed propulsion SMCR-power and -speed is shown for a given optimum propeller diameter d and p/d ratio.

According to the black curve, a propeller diameter of 8.3 m may have the optimum pitch/diameter ratio of 0.71, and the lowest possible SMCR shaft power of about 17,700 kW at 88 rpm.

The black curve shows that if a bigger propeller diameter of for example 9.3 m is possible, the necessary SMCR shaft power will be reduced to about 16,700 kW at 70 rpm. For the same number of propeller blades, the bigger the propeller, the lower the optimum propeller speed and power required.

The red curve shows that propulsion-wise it will always be an advantage to choose the largest possible propeller diameter. This applies even if the optimum propeller speed is too low compared to the minimum layout speed of the engine: The penalty in efficiency by adjusting the pitch for the rpm to lie within the layout diagram of the engine is smaller than the increase in efficiency gained by the larger propeller diameter.

An alternative to adjust the pitch will be to specify a three bladed propeller if permitted by cavitation performance etc. A three bladed propeller will, for the same power, have a higher optimum rpm than a four bladed, see Chapter 2 of "Basic principles of ship propulsion".

With the introduction of the ultra-long stroke G-type engine even the largest possible four bladed propellers with optimum pitch for various sizes of bulk carriers can be accommodated within the layout diagram.

Furthermore, the higher the stroke/bore ratio of a two-stroke engine, the higher the engine efficiency. This means, for example, that an ultra-long stroke engine type, such as the G70ME-C10, may have a higher efficiency compared to a super-long stroke S70ME-10.

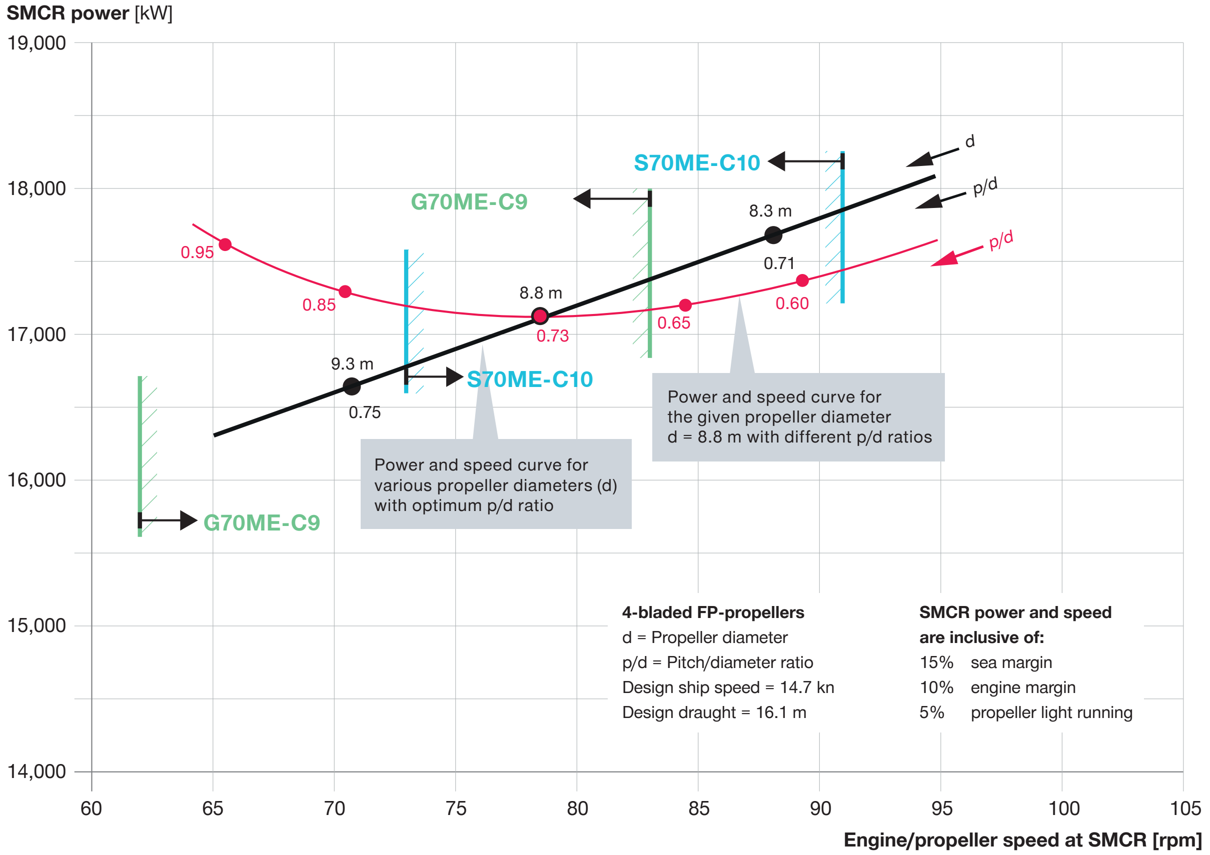

Fig. 14: Influence of propeller diameter and pitch on SMCR for a 205,000 dwt Newcastlemax bulk carrier operating at 14.5 knots

EEDI for bulk carriers

The EEDI guidelines are a mandatory instrument adopted by the IMO that ensures compliance with international requirements on CO_2 emissions of new ships. The EEDI represents the amount of CO_2 in grams emitted when transporting one deadweight tonnage of cargo for one nautical mile:

$$EEDI \approx \frac{CO_2}{Transport\ work}$$

The EEDI is calculated on the basis of cargo capacity, propulsion power, ship speed, specific fuel consumption and fuel type. However, certain correction factors are applicable, and reductions can be obtained by, for example. installing waste heat recovery systems (WHRS).

A reference index for a specific ship type is calculated based on data from ships built in the period from 2000 to 2010. According to the EEDI guidelines implemented on 1 January 2013, the required EEDI value for new ships is reduced in three phases. This leads to a final EEDI reduction of 30% (phase 3) compared to the reference value for a vessel built after 2025, see Fig. 15.

For a bulk carrier the reference and attained EEDI is calculated based on 100% utilisation of capacity (in dwt). The reference speed must be consistent with this loading of the vessel, at 75% SMCR, and with the hull in a condition as on sea trial. The attained EEDI shall not exceed the required EEDI.

There are a number of methods that can be applied to lower the EEDI attained. By derating the engine, the specific fuel consumption (SFC) is lowered as the mean effective pressure is reduced relative to the maximum (firing) pressure, which remains constant.

Engine tuning methods such as e.g. exhaust gas bypass (EGB) or high-pressure tuning (HPT) can alter the fuel curve and reduce the SFC at 75% load, the EEDI reference value. Part-load tuning will typically provide the lowest SFC at the EEDI reference value, whereas low-load tuning also will result in a reduction at this point compared to high-load tuning.

EcoEGR is a special option available for engines with EGR. Through activation of the EGR system also when in Tier II mode, it is possible to optimise the combustion parameters for optimum efficiency. The EGR plant reduces the emission of NO_X and ensures Tier II compliance. The fuel consumption can be lowered significantly in Tier II mode, as illustrated by the inclusion of EcoEGR as an option in each of the case-studies in Table 4-7.

The power installed is an additional parameter that can be reduced to achieve a lower EEDI value. This can be achieved by either lowering the vessel speed, improving the hull design to minimise resistance, by optimising the propeller efficiency, or by installing energy saving devices.

The propeller efficiency can be improved by the application of a Kappel propeller or other high-efficiency designs. Energy saving devices (ESD), typically alter the flow at the propeller, or fore or aft of it, in order to regain some of the losses on the propeller or to minimise the resistance, i.e. through the application of a rudder bulb.

Additionally, the effect on EEDI of applying alternative fuels can be significant. When considering the effect of alternative fuels, it is important to

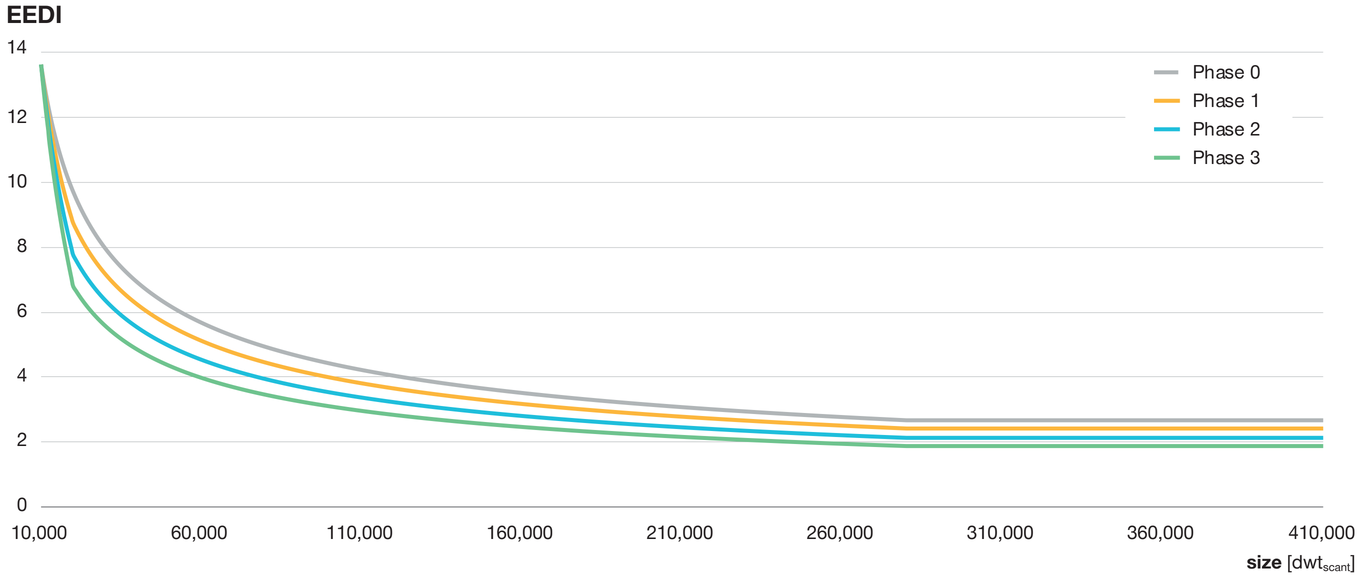

Fig. 15: EEDI requirements for bulk carriers

consider not only the carbon factor (C_F) of the considered alternative fuels, but also the lower heating value, LHV. Both these are defined by the IMO in [4]. The influence of C_F and LHV are reflected in the following equation, which can be derived from the EEDI equation. Here, the power possible to install with alternative fuels, $P_{MCR,alt}$, can be calculated based on the power allowed under the EEDI regulations with traditional MDO, $P_{MCR,oil}$:

$$P_{MCR,alt} = P_{MCR,oil}\left(\frac{C_{F,oil} \times LHV_{alt}}{C_{F,alt} \times LHV_{oil}}\right)^{3/2}$$

Which for an example with LPG and $P_{MCR,oil}$ = 10,000 kW will return a possible installed power of:

$$P_{MCR,LPG} = 10{,}000 \times \left(\frac{3.206 \times 46}{3.015 \times 42.7}\right)^{3/2}$$

$$= 12{,}260\ kW$$

Besides alternative fuels, a radical reduction to the EEDI index can be attained by constructing bulk carriers with a twin-screw propulsion plant. As the diameter of a propeller on a single screw bulk carrier is limited by the requirement that it must be submerged also when operating in ballast, the single screw propeller is highly loaded in laden condition. By introducing twin screw propulsion plants, the propeller area can be increased significantly, whereby the loading is decreased and the efficiency increased.

Calculations show that the EEDI can be reduced by 4-6% by introducing twin-screw propulsion. Twin screw propulsion plants have so far not been seen on bulk carriers but have seen some application on ultra large container vessels and LNG carriers. In the future, twin-screw plants may prove to become a substitute to alternative fuels for compliance with EEDI phase 3.

For further information on the calculation of EEDI and other environmental regulations, see Chapter 4 of the separate paper “Basic principles of ship propulsion”.

Minimum propulsion power

While lowering a ship’s installed power has been acknowledged as a method to obtain a lower EEDI value, it has also raised a concern that it could result in underpowered ships with reduced manoeuvrability in heavy weather. As a result of this, the IMO has published an assessment method for determining the minimum propulsion power required to maintain the safe manoeuvrability of ships in adverse conditions.

It should be noted that this assessment method is currently valid for phase 0 and phase 1 of EEDI. It is expected that it will also be incorporated for EEDI phase 2 which will be in force from 1 January 2020.

The minimum propulsion power required can be determined by assessment level 1 or 2.

Assessment level 1 allows for calculation of the minimum power value required based on ship type and deadweight, with value a and b according to the IMO guidelines. For a bulk carrier, the equation in Fig. 16 sets the minimum power required:

However, if the propulsion power intended is below the given minimum power line value of assessment level 1, an evaluation must be performed according to assessment level 2. Here, the actual design’s performance in head wind and waves must be considered, so far through model tests, see the IMO guidelines, [5].

If the ship cannot fulfil the criteria to either of the assessment levels, various options can be considered: Alternative fuels which lower the EEDI will allow for a more powerful engine, as illustrated above. Hull lines and the bow can be refined to minimise resistance in general and from interactions with the waves specifically. An increased light running margin may also be considered, as this will allow the engine to deliver maximum power within a broader range of operation.

Alternatively, a controllable pitch propeller can be employed, as this in principle will allow the propeller to load the engine at all points within the engine load diagram. Hereby, maximum power can be delivered in any weather condition, see Chapter 3 of the paper “Basic principles of ship propulsion”.

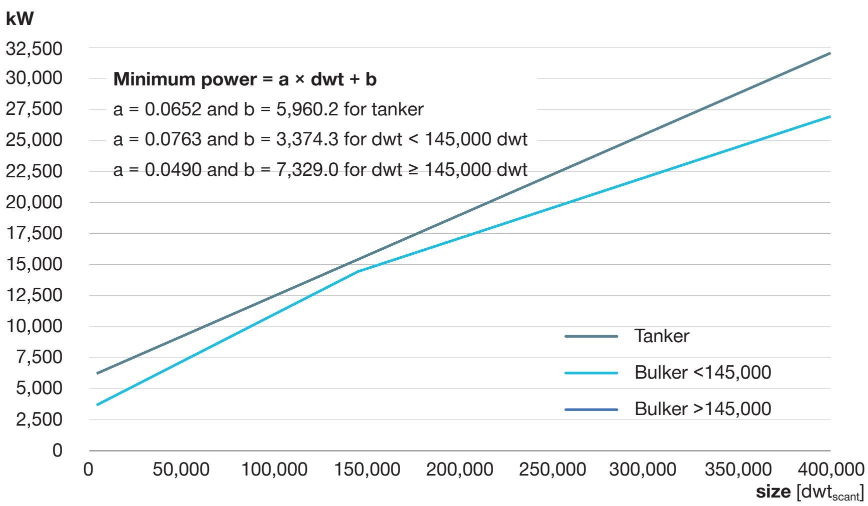

Fig 16: Assessment level 1 requirements for fulfilling minimum propulsion power requirements

Barred speed range - the dynamic limiter function

A barred speed range imposed by vibrations in the shafting must be passed sufficiently quick, in order not to damage the shafting due to vibrations resulting in excessive stresses. As the installed power on board bulk carriers is reduced to meet EEDI requirements, less power will also be available to accelerate the shafting and the ship. Hereby, considerations on sufficiently quick passage of the barred speed range have become increasingly important.

What is meant by "sufficiently quick" depends on how high the stresses in the shaft are compared to the strength of the shaft material. In general, the barred speed range must be passed within seconds, not minutes.

Furthermore, the definition of "sufficiently quick" depends on how often the barred speed range will be passed during the expected lifetime of the ship. For example, a handysize with many port calls will pass the barred speed range more frequently than a large ore carrier that mostly performs ocean crossings.

Sufficiently quick passage of the barred speed range can be a challenge especially for 5- and 6-cylinder engines. This situation, and the dynamic limiter function (DLF) dealing with it, is explained further in the separate paper "The dynamic limiter function".

The most basic guidance to avoid slow passing of the barred speed range is to avoid barred speed ranges that extend higher than 60% of engine SMCR-rpm. A more detailed approach is to ensure a BSR-power margin BSR_{PM} of at least 10% in the design, as calculated by:

$$BSR_{PM} = \frac{P_L - P_p}{P_P}$$

P_P is the power required by the bollard pull propeller curve at the upper end of the barred speed range, whereas P_L is the engine power limit without DLF at the same rpm, see Fig. 17.

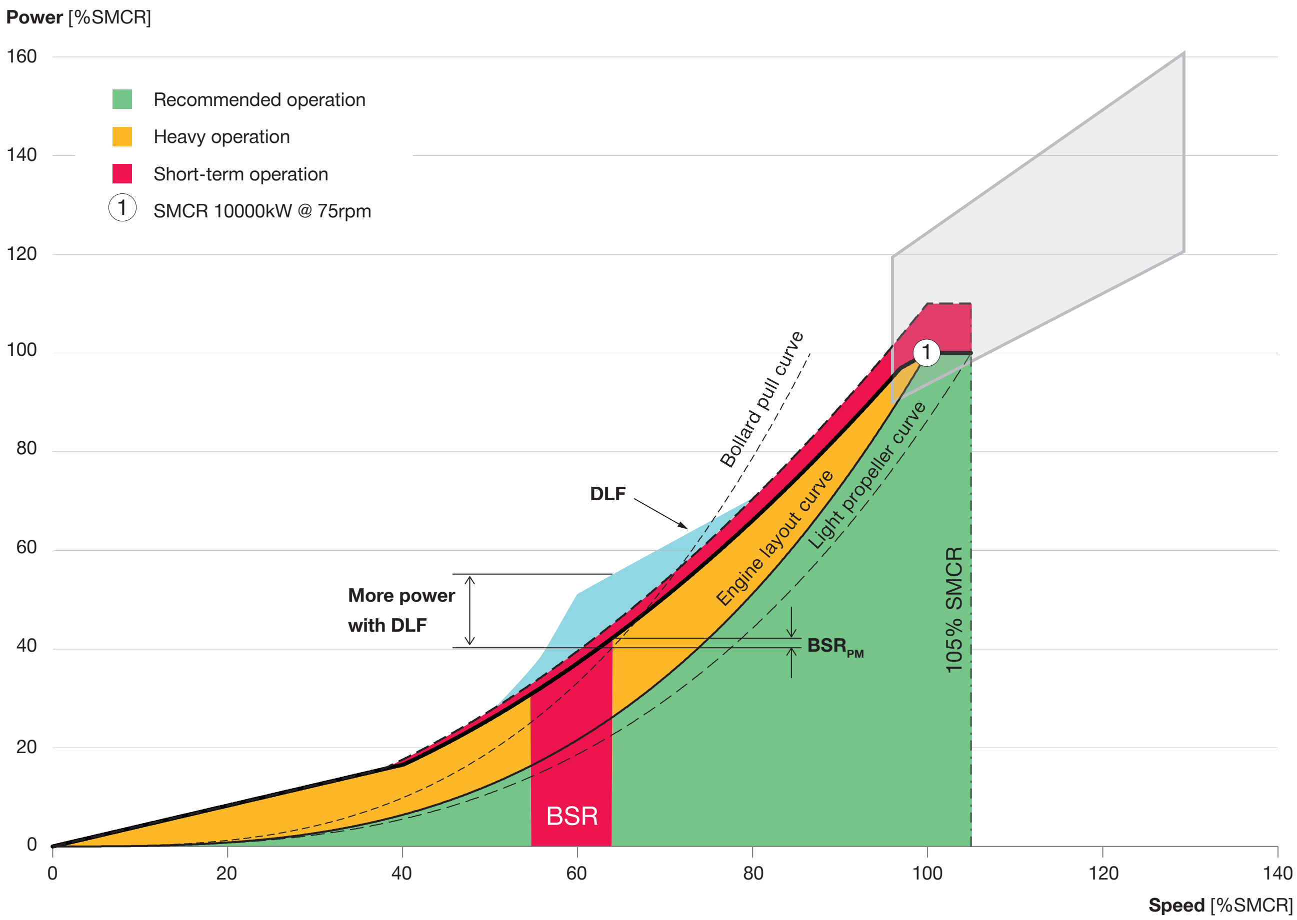

Fig. 17: Increased possibility for passage of a barred speed range with DLF

Propulsion power demand as a function of size

Based on the particulars as illustrated in Figs. 8-11 and statistics on vessels delivered recently, a power prediction has been performed for various typical sizes of bulk carriers. The outcome is an overview of possible engine types for various vessel sizes as shown in Tables 4-6.

The EEDI presented in Tables 4-6 has been calculated by including a 6% tolerance on the SFC of the main engine, and 200 g/kWh for auxiliary engines operating at 50% load as prescribed by the EEDI-regulations. The EEDI has been calculated both for traditional fuels, in merger with EcoEGR, PTO, and a combination of the two. Furthermore, the EEDI has been calculated for LPG and LNG propulsion.

The overview has been calculated for vessels with a typical design speed, and with typical sea and engine margins applied for the specific size. All cases consider a four-bladed propeller, even if three bladed propellers might be an attractive option as the ship speed decrease. Special note is to be taken of the engine margin which changes with the size of the vessel. In general, a tendency is seen towards a higher engine margin for large bulk carriers, aiming for a low SFC during normal operation at the design speed.

The higher engine margin increases the power installed on board the vessel. As such it affects the attained EEDI, as this is calculated at 75% SMCR-power, irrespective of the engine margin. This influence of the engine margin is especially reflected in the special “EEDI phase 2” row in Tables 5-6 which lists the service speed that will ensure compliance with EEDI regulations at the set engine margin.

For capesize bulk carriers above 100,000 dwt, the engine margin is

Table 4: Ship particulars, SMCR point, and suitable main engines, 5-45,000 dwt

size [dwt_{scant}]	5,000	8,000	10,000	20,000	30,000	30,000	35,000	45,000
T_{scant}	6.5	7	7.8	9	10	11	10.5	11.5
L_{oa}	95	107	117	145	170	200	180	185
L_{pp}	90	102	110	136	163	191	172	177
B	15	18.2	19.3	23.2	27	23.7	29.5	30.5
T_{design}	6	6.8	7.3	8.5	9.4	10	9.5	10.3
Sea margin	15	15	15	15	15	15	15	15
Engine margin	15	15	15	15	15	15	15	15
						St. Lar		
Average speed	**12.7**	**13**	**13**	**13.5**	**13.8**	**13.8**	**14**	**14**
IMO minimum power level 1	3,756	3,985	4,137	3,937	5,663	5,663	6,045	6,396
SMCR kW/rpm	1,800 / 157	2,370 / 148	2,550 / 129	3,940 / 109	5,090 / 99	4,950 / 98	5,760 / 97	6,400 / 90
Engine options	5S30ME-B9	5S30ME-B9	5S35ME-B9	5S40ME-C9	7G40ME-C9	7G40ME-C9	7G40ME-C9	6G45ME-C9
		6S30ME-B9		5G40ME-C9	8G40ME-C9	8G40ME-C9	6G45ME-C9	5G50ME-C9
				6S40ME-C9	5G45ME-C9	5G45ME-C9	5S50ME-C9	6S50ME-C9
EEDI [% of reference line]								
MDO	78	78	75	76	78	76	80	77
MDO + EcoEGR	76	76	73	74	75	74	77	75
MDO + PTO	74	73	70	72	73	71	75	72
MDO + EcoEGR + PTO	71	71	68	69	71	69	72	70
LPG	69	68	66	67	68	66	70	68
LNG	60	60	58	59	60	58	62	59

increased from 15%, to 20% and at 120,000 dwt to 25%. For these vessel sizes and above, the service speed must be reduced significantly compared to the present fleet, if the engine margin is to be maintained. On the other hand, compliance for a service speed of 14.5 knots can be attained with an engine margin of approximately 10%.

The present discussion on engine margin is mostly of regulatory interest. Naturally, the top speed that a vessel can attain is solely dependent on the SMCR-power of the main engine. This is irrespective if the power is labelled as power for a high service speed, or for a high engine margin. However, the engine load at which the engine is operated at in service will influence the specific fuel consumption. A high engine margin will ensure a low fuel consumption in service.

For smaller vessels which have a low service speed and a low engine margin, compliance with EEDI phase 2 is achievable through application of the latest developments within engine technology, represented by the super long-stroke S-type engine and ultra long-stroke G-type engine, combined with the electronic control of the ME engine. The camshaft-less ME engine provides many handles for optimisation of the fuel consumption compared to the mechanically controlled MC engine, on which the EEDI reference line is based.

If a reduction of service speed or engine margin is undesired for larger vessels, various options exist:

– EcoEGR can be applied to reduce the SFOC of the engine, which is especially relevant for vessels required to comply with Tier III. EcoEGR reduces the attained EEDI by 2-3 percentage point for typical bulk carrier applications.

Table 5: Ship particulars, SMCR point, and possible main engines, 55-120,000 dwt with special considerations on compliance with EEDI phase 2

size {dwt$_{scant}$]	55,000	80,000	84,000	100,000	120,000
T_{scant}	126	14.5	14.5	14.5	15
L_{oa}	189	225	229	245	250
L_{pp}	182	211	225	236	240
B	32.2	32.2	32.2	38	43
T_{design}	11.2	12.2	12.2	12.2	14
Sea margin	15	15	15	15	15
Engine margin	15	15	15	20	25
Average speed	**14.5**	**14.5**	**14.5**	**14.5**	**14.5**
IMO minimum power level 1	7,571	9,478	9,784	11,004	12,530
SMCR kW/rpm	8,049 / 89	9,500 / 81	9,700 / 80	11,180 / 78	13,050 / 76
Engine options	5S60ME-C10	8G50ME-C9	8G50ME-C9	7G60ME-C10	8G60ME-C10
	6G50ME-C9	6S60ME-C10	6S60ME-C10	6S65ME-C8	7S65ME-C8
	7S50ME-C9	6G60ME-C10	6G60ME-C10	5S70ME-C10	6S70ME-C10
	8S50ME-C9	5S65ME-C8	5S65ME-C8		5G70ME-C10
EEDI [% of reference line]					
MDO	84	81	81	83	86
MDO + EcoEGR	82	79	79	81	84
MDO + PTO	79	76	76	78	82
MDO + EcoEGR + PTO	77	74	74	76	79
LPG	74	71	71	73	76
LNG	65	62	62	64	66
Speed for phase 2 w. MDO	**14.2**	**14.3**	**14.4**	**14.2**	**14**
SMCR kW/rpm	7,388 / 87	9,250 / 80	9,450 / 79	10,400 / 76	11,480 / 73
Engine options	5S60ME-C10	8G50ME-C9	8G50ME-C9	7G60ME-C10	8G60ME-C10
	6G50ME-C9	6S60ME-C10	6S60ME-C10	6S65ME-C8	7S65ME-C8
	7S50ME-C9	6G60ME-C10	6G60ME-C10	5S70ME-C10	5S70ME-C10
	8S50ME-C9	5S65ME-C8	5S65ME-C8		5G70ME-C10
EEDI [% of reference line]	79	79	79	79	79

- A shaft generator/PTO can also be installed to reduce the EEDI, as the electric energy can be produced at the SFOC of the main engine, which is lower than the SFOC of the gensets. A PTO fully capable of covering the electric consumption on board, as defined by [4], reduces the EEDI by approx. 4-5 percentage point for typical bulk carrier applications.

In combination, EcoEGR and a PTO bring an EEDI reduction of 6-7 percentage point. By this combination, compliance with EEDI phase 2 can be attained with the traditional service speed, fuel, and high engine margin, except for the absolute largest 400,000 dwt vessels where a slight reduction of power must be considered.

For typical bulk carriers the application of LPG as alternative fuel will bring an EEDI reduction of 9-10 percentage point, whereas LNG will bring a reduction of 16-18 percentage point. Hereby, compliance with EEDI phase 2 can easily be attained without additional equipment. For LNG, EEDI phase 3 is well within reach, whereas EcoEGR and PTO must be considered for the largest vessels to be able to comply with EEDI phase 3 while powered by LPG.

If EEDI phase 3 is to be attained by traditional fuels with a traditional service speed, for vessels above 55,000 dwt it seems that both EcoEGR and PTO must be installed as well as be combined with other measures. This could be a Kappel propeller, other energy saving devises, optimisations of the hull lines, or twin screw designs.

When considering the option of a speed reduction, it is important to consider the vessel's capabilities with respect to minimum propulsion power and performance in adverse weather conditions, see the separate section "Minimum propulsion power".

Table 6: Ship particulars, SMCR point, and possible main engines, 175-400,000 dwt with special considerations on compliance with EEDI phase 2

size [dwt_{scant}]	**175,000**	**205,000**	**250,000**	**320,000**	**400,000**
T_{scant}	18.3	18.3	18.3	23	23
L_{oa}	292	299.9	330	340	362
L_{pp}	282	292	310	327	352
B	45	50	57	60	65
T_{design}	16.5	16.1	16.6	20.5	21
Sea margin	15	15	15	15	15
Engine margin	25	25	25	25	25
Average speed	**14.6**	**14.6**	**14.5**	**14.5**	**14.5**
IMO minimum power level 1	15,904	17,374	19,579	23,009	26,929
SMCR kW/rpm	16,250 / 71	17,700 / 69	19,367 / 67	22,500 / 65	26,047 / 63
Engine options	6G70ME-C10	6G70ME-C10	7G70ME-C9	8G70ME-C9	6G80ME-C10
	7G70ME-C9	7G70ME-C10	8G70ME-C9	6G80ME-C10	7G80ME-C10
	7S70ME-C10	8G70ME-C10	6G80ME-C10	7G80ME-C10	8G80ME-C10
	8S70ME-C10				
EEDI [% of reference line]					
MDO	87	87	86	87	89
MDO + EcoEGR	84	84	83	84	87
MDO + PTO	82	82	82	83	85
MDO + EcoEGR + PTO	80	80	79	81	83
LPG	76	76	75	76	78
LNG	67	67	66	67	69
Speed for phase 2 w. MDO	**14**	**14**	**14**	**13.8**	**13.6**
SMCR kW/rpm	14,410 / 69	15,405 / 66	17,340 / 64	19,424 / 62	21,641 / 60
Engine options	5G70ME-C10	6G70ME-C10	6G70ME-C9	7G70ME-C9	8G70ME-C9
	6G70ME-C10	7G70ME-C10	7G70ME-C9	8G70ME-C9	6G80ME-C10
			8G70ME-C9	6G80ME-C10	7G80ME-C10
EEDI [% of reference line]	79	79	79	79	79

Summary

Bulk carriers carry raw materials around the world and will continue to form a vital part of the global supply chain. With the application of the latest electronically controlled engine technology as represented by the ultra long-stroke G-type ME engines, EEDI phase 2 compliance can be attained for traditional fuels. Significant EEDI reductions can be achieved by including a shaft generator/PTO and/or EcoEGR, and in addition, significant economic savings will be ensured for the owner.

With the diverse range of alternative fuels that can be utilised by the two-stroke engines, and with various technical measures that lowers the energy consumption even further, the road towards EEDI phase 3 compliance is also mapped out.

The low rpm of the modern engine designs allows for larger than usual propellers to be applied, which brings large benefits to bulk carriers as the power required is greatly reduced. With these combinations of technical advantages, bulk carriers will continue to deliver the raw materials of the world.

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