Propulsion Trends in Container Vessels

Two-stroke Engines

Engineering the Future – since 1758.

MAN Diesel & Turbo

Contents

Propulsion Trends in Container Vessels

Introduction

Container vessels, tankers and bulk carriers are the three largest groups of vessels within the merchant fleet and, therefore, these market segments deserve great attention, Refs. [1] and [2].

The first three chapters of this paper deal with general container shipping, and the last four chapters deal with technical information on the propulsion system seen from the low speed engine perspective.

The use of containers started during the Second World War, and the first ship specifically designed for container transportation appeared in 1960, viz. the Supanya, of 610 teu. The amount of cargo shipped in containers has increased considerably over the last fifteen years, resulting in a rapid increase in both the number and the size of container vessels during this period.

In 1988, when the size of container ships increased to 4,500-5,000 teu, it was necessary to exceed the existing Panamax maximum breadth of 32.3 m, and thus introduce the post-Panamax size container ships. The largest container ships delivered today are of about 15,500 teu at 171,000 dwt, based on the scantling draught.

Container ships of up to 22,000 teu, may be expected in the future, but this depends on the port infrastructure and corresponding operating efficiency, which are the limiting factors on the container ship sizes today. For such very large vessels of the future, the propulsion power requirement may be up to about 100 MW/136,000 bhp, when operating at 25 knots. A 22,000 teu is currently being investigated on the drawing table by Korean shipyard STX.

Investigations conducted by a propeller maker show that propellers can be built to absorb such high powers. Single-screw vessels are therefore only being considered in our investigations as being the cheapest and most efficient solution compared with a twin-skeg/twin-screw solution.

The widening of the Panama Canal, allowed for an increase of the maximum ship beam from 32.3 m to 48.8 m, triggering a “New Panamax” class which is described in this paper.

The larger the container ship, the more time and/or equipment required for loading and unloading. As the time schedule for a container ship is very tight, possible extra time needed for loading/unloading means that, in general, larger container ships might have to operate at a proportionately higher service speed.

However, as the propulsion power needed, and thereby also fuel consumption, is proportional with the ship speed in approx. fourth power, the selected maximum average ship speed in service has not been higher than approx. 25 knots.

The optimum propeller speed is changing as well, becoming lower and lower, because the larger the propeller diameter that can be used for a ship, the lower the propulsion power demand and fuel costs, and the lower the optimum propeller speed.

All of these factors have an influence on which main engine type is selected and installed as the prime mover, and also on the size of the container vessel to be built.

The purpose of this paper – dealing with container ship sizes above 400 teu, and based on an analysis of container vessels ordered and built over the last five years – is to illustrate the latest ship particulars used for modern container ships and determine their impact on the propulsion power demand and main engine choice, using the latest MAN B&W two-stroke engine programme as the basis.

The latest drastic increase of heavy fuel oil prices has now forced some ship operators to reduce the fuel costs by cutting the top of the ship speed in service. This will, without any doubt, have an important influence on the selection of main engines for container ships in the future, and is briefly discussed in this paper.

Definition and Development of Container Vessels

Size of a container ship

The size of a container ship will normally be stated by means of the maximum number of teu-sized containers it is able to carry. The abbreviation "teu" stands for "twenty-foot equivalent unit", which is the standard container size designated by the International Standards Organisation. The length of 20 feet corresponds to about 6 metres, and the width and height of the container is about 2.44 metres. The ship dimensions, such as the ship breadth, therefore depend on the number of containers placed abreast on deck and in the holds. Thus, one extra container box abreast in a given ship design involves an increased ship breadth of about 2.5 metres.

In former days, the average-loaded teu container weighed about 10-12 tons, so the container vessels had often been dimensioned for 12-14 dwt per teu but, of course, this could vary.

However, the maximum number of teu containers to be transported is an important marketing parameter for the container vessels. Therefore, the cargo capacity used today by most yards and ship owners is equal to the maximum number of teu boxes that can be stacked on the container ship, independent of the weight of the boxes. Therefore, this way of definition of the size of the container vessels, has been used in this paper.

Development in ship size

The reason for the success of the container ship is that containerised shipping is a rational way of transporting most manufactured and semi-manufactured goods.

This rational way of handling the goods is one of the fundamental reasons for the globalisation of production. Containerisation has therefore led to an increased demand for transportation and, thus, for further containerisation.

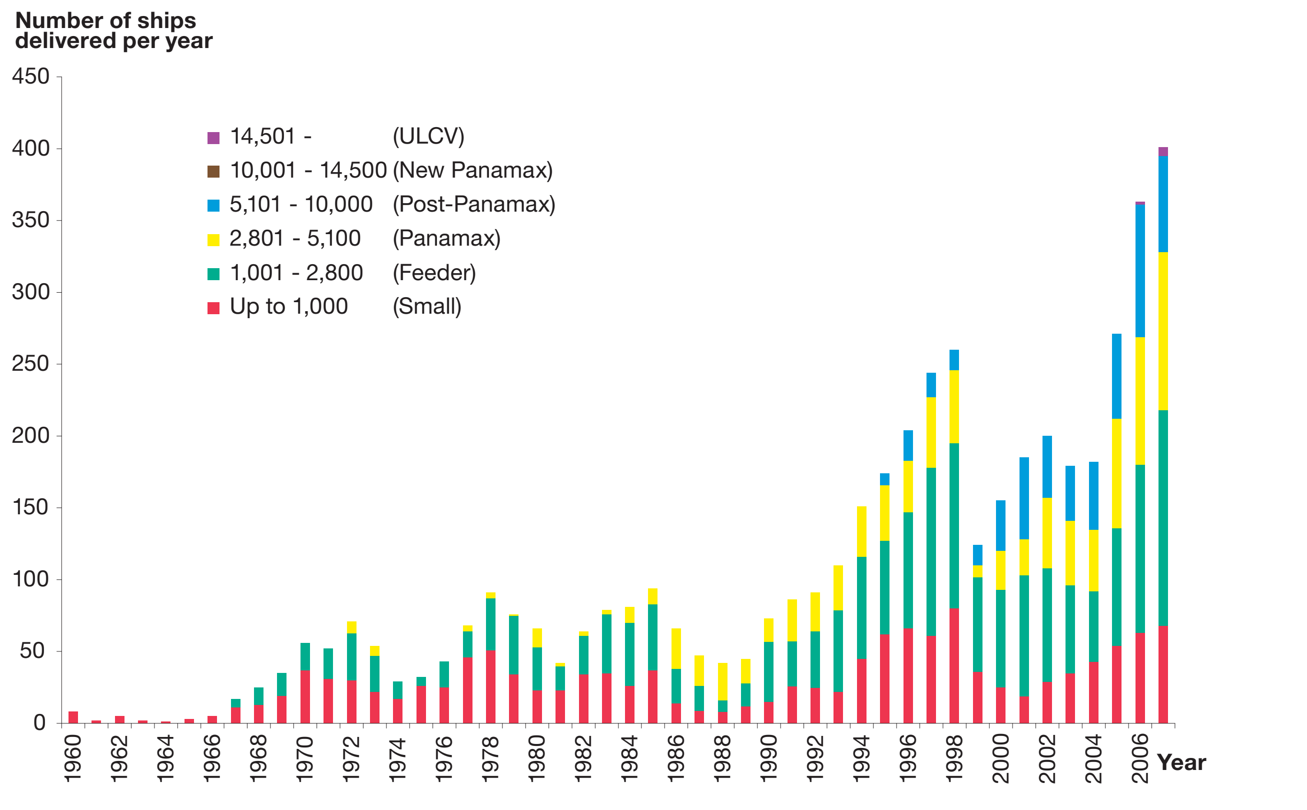

Fig. 1a: Year of container ship deliveries (number of ships)

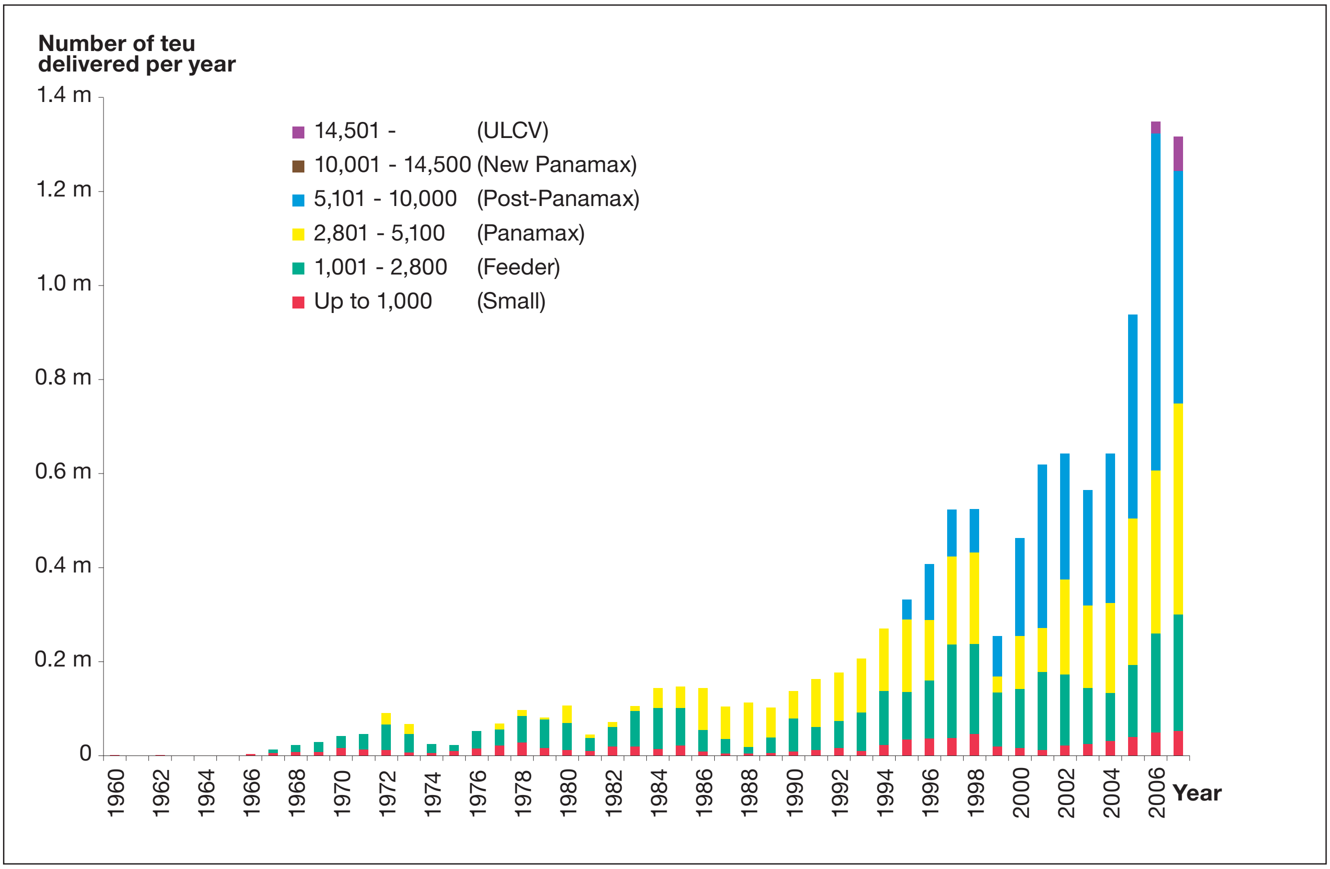

Fig. 1b: Year of container ship deliveries (number of teu)

The commercial use of containers (as we know them today) started in the second half of the 1950s with the delivery of the first ships prepared for containerised goods. Figs. 1a and 1b show container ships delivered from 1960-2007, in terms of the number of ships and teu capacity, respectively.

The development in the container market was slow until 1968, when deliveries reached 18 such vessels. Ten of these 18 ships had a capacity of 1,000-1,500 teu. In 1969, 25 ships were delivered, and the size of the largest ships increased to 1,500-2,000 teu.

In 1972, the first container ships with a capacity of more than 3,000 teu were delivered from the German Howaldtwerke Shipyard. These were the largest container ships until the delivery in 1980 of the 4,100 teu *Neptune Garnet*. Deliveries had at that time reached a level of 60-70 ships per year and, with some minor fluctuations, it stayed at this level until 1994, which saw the delivery of 143 ships.

With the *American New York*, delivered in 1984, the container ship size passed 4,600 teu. For the next 12 years, the max. container ship size was 4,500-5,000 teu (mainly because of the limitation on breadth and length imposed by the Panama Canal). However, in 1996, the *Regina Mærsk* exceeded this limit with an official capacity of 6,400 teu, and started a new development in the container ship market.

Since 1996, the maximum size of container ships has rapidly increased from 6,600 teu in 1997 to 7,200 teu in 1998, and up to 15,500 teu unofficially in ships delivered in 2006-2007. In the future, ultra large container vessels carrying up to 22,000 teu may be expected.

The increase in the max. size of container ships does not mean that the demand for small feeder and coastal container ships has decreased. Ships with capacities of less than 2,800 teu, i.e. small and feeder container ships, account for approx. 56% of the number of ships delivered in the last decade.

New products for container ships

Container ships compete with e.g. conventional reefer ships and, when the *Regina Mærsk* was delivered in 1996, it was the ship with the largest reefer capacity, with plugs for more than 700 reefer containers.

There is almost no limit to the type of commodities that can be transported in a container and/or a container ship. This is one of the reasons why the container ship market is expected to grow faster than world trade and the economy in general.

In the future, we will see new product groups being transported in containers, one example being cars. Some car manufacturers have already containerised the transport of new cars, and other car manufacturers are testing the potential for transporting up to four family cars in a 45-foot container.

High-efficiency propulsion system

Fuel prices have increased drastically over the last few years. This means that shipyards and shipowners today have increased their attention on making the propulsion system as efficient as possible in order to reduce the fuel costs of the ship. It also means that a lot of effort is used to install the most efficient propeller as possible. The bigger the propeller diameter is, the higher the obtainable propeller efficiency is.

For normal beam/draught ratios used for container ships, the single-screw propulsion solution is simpler and more efficient than the twin-skeg/twin-screw solution, and is therefore preferred.

By modifying the aft body of the ship, installation of a bigger propeller diameter is possible. However, this gives rise to a reduced optimum propeller speed, i.e. also a reduced engine speed as the propeller and the two-stroke main engine are directly coupled.

Furthermore, because of the high fuel prices, there is an incentive to reduce the ship speed in service, which again will reduce the propeller speed and thereby also the engine speed.

All this means that today, some container ships have been ordered with two-stroke main engines with a relatively low engine speed, as for example the MAN B&W super long-stroke S80 and S90 engine types, normally used for bulk carriers and tankers, instead of the short-stroke K80 and K90 engine types.

Moreover, the super long-stroke engines are born with a lower specific fuel oil consumption (SFOC) than the short-stroke engine types, which again will reduce the fuel costs (increase the engine efficiency) when using super long-stroke engines.

By extra investment in a Waste Heat Recovery (WHR) system, sometimes inclusive of a shaft motor to absorb the electricity produced, the total fuel costs of the container ship may be further reduced. With many electric power consuming reefer containers, all the electric power produced by a WHR system may be consumed, which makes it possible to leave out the expensive shaft motor on the main engine. This will reduce the investment costs of the system.

Container Ship Classes

The fleet in general today

The world container fleet consists of some 4,272 ships (January 2008) with a combined capacity of close to 11.8 million teu, and has been increased by about 30% over the last three years.

As shown above, the fleet is developing fast. The ships are growing both in number and size, and the largest container ships delivered (January 2008) have a capacity of approx. 15,500 teu.

Depending on the teu size and hull dimensions, container vessels can be divided into the following main groups or classes. However, adjacent groups will overlap and in some teu areas no container vessels are available, see Table I.

- Small Feeder ≤1,000 teu
- Feeder 1,000-2,800 teu
- Panamax 2,800-5,100 teu
- Post-Panamax 5,500-10,000 teu
- New Panamax 12,000-14,500 teu
- ULCV >14,500 teu

Container ship classes and the Panama Canal

Type of container vessel	Dimensions	Ship size, max. number of teu capacity
Small Ship breadth up to	Approx. 23.0 m	**Up to 1,000 teu**
Feeder Ship breadth	Approx. 23.0 - 30.2 m	**1,000 - 2,800 teu**
Panamax (existing) Ship breadth equal to Ship draught, tropical freshwater, up to Overall ship length, up to	**Max.** 32.2 - 32.3 m (106 ft.) 12.04 m (39.5 ft.) 294.1 m (965 ft.)	**2,800 - 5,100 teu**
Post-Panamax (existing) Ship breadth larger than 32.3 m	Approx. 39.8 - 45.6 m	**5,500 - 10,000 teu**
New Panamax Ship breadth, up to Ship draught, tropical freshwater, up to Overall ship length, up to	**Max.** 48.8 m (160 ft.) 15.2 m (50 ft.) 365.8 m (1,200 ft.)	**12,000 - 14,500 teu**
ULCV (Ultra Large Container Vessel) Ship breadth	More than 48.8 m	**More than 14,500 teu**

Existing Panama Canal **Ref. Panamax class**	The lock chambers are 305 m long and 33.5 m wide, and the max. depth of the canal is 12.5 - 13.7 m. The canal is about 86 km long, and passage takes about eight hours. The existing canal has two lanes (two set of locks) and ships are positioned in the locks by a special electrical driven locomotive. The canal was inaugurated in 1914 and its dimensions were based on the Titanic (sunk 1912) which was the largest ship of that time.
New Panama Canal **Ref. new Panamax class**	A future third lane (one set of locks) with an increased lock chamber size has been decided by the Panama Canal Authority. The lock chambers will be 427 m long, 55 m wide and 18.3 m deep. The ships will be positioned in the locks by tugs, which explain the large tolerances to be used between locks and ships. The new canal is scheduled for completion in 2014, at the 100th. anniversary of the canal, and to be in full operation in 2015.

Table I

See also Figs. 3a and 3b regarding the distribution of the container ship classes of the existing fleet today, shown in number of ships and in number of teu, respectively.

The container ships on order are in the same way shown in Figs. 3c and 3d, and discussed later.

Small feeder

Small feeder container vessels are normally applied for short sea container transportation. The beam of the small feeders is, in general, less than about 23 m.

Feeder

Feeder container vessels greater than 1,000 teu are normally applied for feeding the very large container vessels, but are also servicing markets and areas where the demand for large container vessels is too low. The beam of the feeders is, in general, 23-30.2 m.

Panamax (existing)

Until 1988, the hull dimensions of the largest container ships, the so-called Panamax-size vessels, were limited by the length and breadth of the lock chambers of the Panama Canal, i.e. a max. ship breadth (beam) of 32.3 m, a max. overall ship length of 294.1 m (965 ft), and a max. draught of 12.0 m (39.5 ft) for passing through the Canal. The corresponding maximum cargo capacity was between 4,500 and 5,100 teu.

These max. ship dimensions are also valid for passenger ships, but for other ships the maximum length is 289.6 m (950 ft). However, it should be noted that, for example, for bulk carriers and tankers, the term Panamax-size is defined as 32.2/32.3 m (106 ft) breadth, an overall length of 225.0 m for bulk carriers and 228.6 m (750 ft) for tankers, and no more than 12.0 m (39.5 ft) draught. The reason for the smaller length used for these ship types is that a large part of the world's harbours and corresponding facilities are based on these two lengths, respectively.

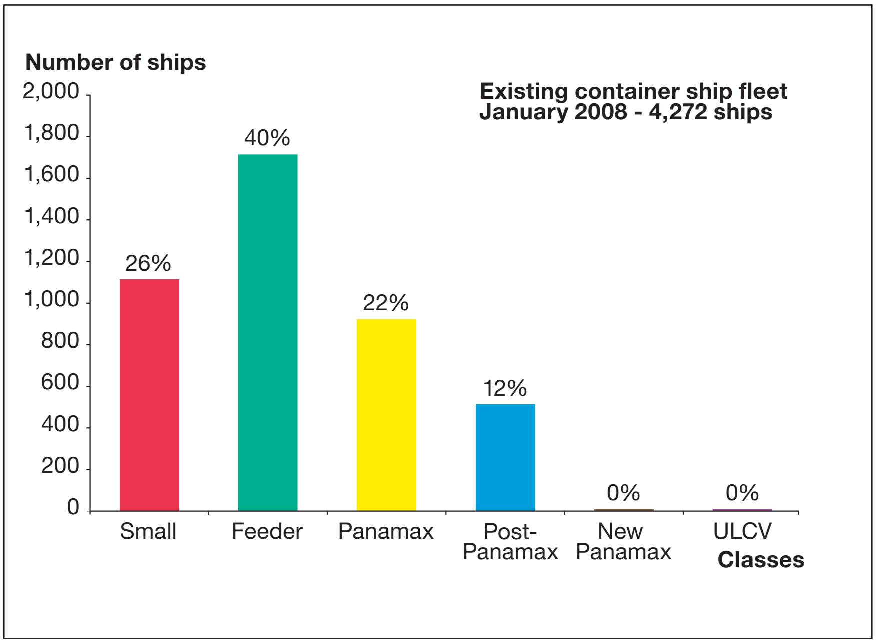

Fig. 3a: Distribution of existing fleet in container ship classes (number of ships)

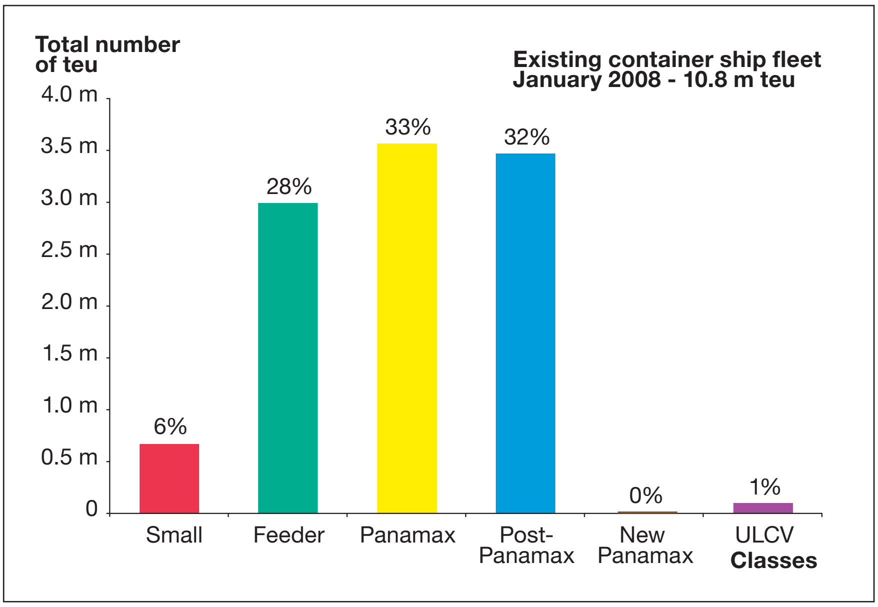

Fig. 3b: Distribution of existing fleet in container ship classes (number of teu)

Post-Panamax (existing)

In 1988, the first container ship was built with a breadth of more than 32.3 m. This was the first Post-Panamax container

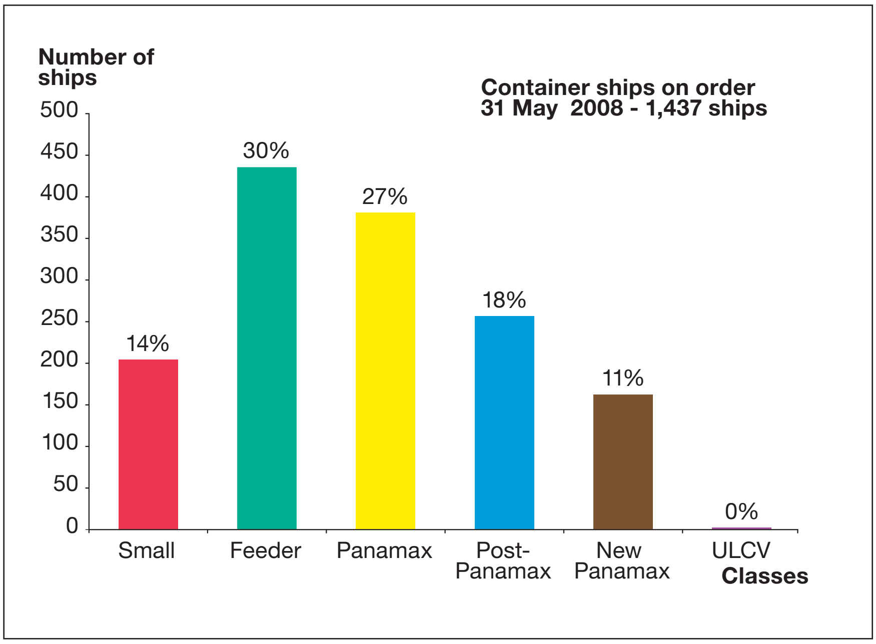

Fig. 3c: Distribution in classes of container ships on order (number of ships)

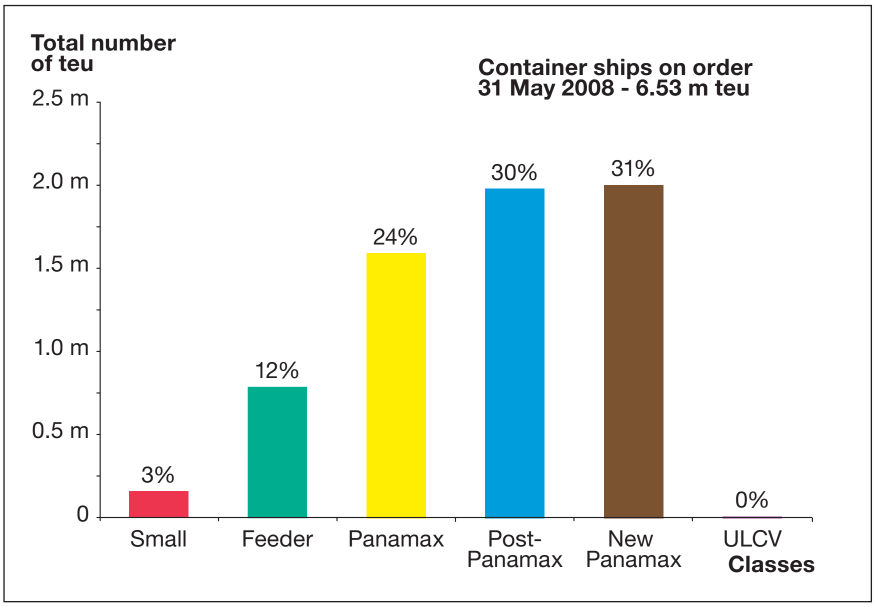

Fig. 3d: Distribution in classes of container ships on order (number of teu)

ship. The largest vessel in service with a capacity of approx. 15,500 teu has exceeded the existing Panamax beam by approx. 24 m, and is today called an Ultra Large Container Vessel (ULCV). The breadths used for the Post-Panamax container ships are 39.8-45.6 m.

New Panamax

The existing Panama Canal has for several years – since the first Post-Panamax container vessel was built in 1988 – been too small for the larger container vessels.

In order to accommodate a larger proportion of the current and future fleet, and thereby the cargo carriage through the Panama Canal, the Panama Canal Authority has decided to extend the existing two lanes with a bigger third lane with a set of increased size of lock chambers.

The lock chambers will be 427 m long, 55 m wide and 18.3 m deep, allowing passage of ships with a maximum breadth of 48.8 m, maximum passage draught of 15.2 m and an overall maximum ship length of 365.8 m.

Most of the latest generation of ordered 12,500-13,100 teu container vessels are already very close to the maximum permissible dimensions and, therefore, belongs to the New Panamax class. In the future, they will have the possibility of sailing through the new Panama Canal.

The new canal is scheduled to open in 2014 at the 100th anniversary of the existing canal, and to be fully in operation in 2015.

Ultra Large Container Vessel (ULCV)

The world's largest container vessel built is larger than the New Panamax size, and is called a ULCV (designated by MAN Diesel), and is able to transport more than 14,500 teu. The latest APM E-class container vessel, which has an unofficial size of approx. 15,500 teu, belongs to the ULCV class.

The ULCV has a breadth bigger than 48.8 m and an overall length of more than 365.8 m. Until now, only a few ULCVs have been built, and all have been built with a single-propeller propulsion system with one large propeller directly coupled to one large main engine.

The propeller maker, Mecklenburger Metalguss, had in 2006 delivered the world's largest propellers for ULCV container vessels. The six-blade 9.6 m diameter propeller weighs 131 tons, and the main engine develops 80,000 kW.

In the future, if an even larger ULCV is going to be built, it might be supposed that even larger single-propellers may be developed/built, which means that the optional, but more expensive, twin-skeg/twin-propellers systems for ULCVs will not be a necessity.

Thus, the Korean shipyard STX is working on a 22,000 teu container ship project, with an overall length of 460 m and a breadth of nearly 60 m, and also with one main engine installed. Compared with the average ship particulars described later, this ship is relatively longer and with a lower draught. The selected lower draught is probably caused by the wish to enable the ship to go into more harbours without the need for dredging of the harbours.

With its 460 m length, it will be the longest ship ever built. The longest one delivered so far was the 565,000 dwt tanker *Seawise Giant* (today *Knock Nevis,* rebuilt as an FSO (Floating Storage Offloading) in 2004) from 1976, with its overall length of 458.5 m, Ref. [1].

Container Ship Market

Distribution of the existing container fleet

Today (January 2008), the existing fleet of container ships totals approx. 4,272 ships.

As can be seen from Fig. 3a (page 10), showing the distribution in classes of the existing container fleet in service, about 66% of the ships are small and feeder container ships, 26% and 40%, respectively. The Panamax vessels account for 22% and the large ships, from Post-Panamax, New Panamax to ULCVs, account for 12% of the fleet.

When comparing the total number of teu instead of the number of ships, the distribution of container ship classes changes in favour of the large container ships, see Fig. 3b. However, the need for teu of the New Panamax and the ULCVs seems still very low.

Distribution of container ships on order

In the coming years, there will be a demand for replacement of around 50 container ships per year just to maintain the current container ship capacity. To this we might add more container ships to meet the increasing need for transportation.

At the end of May 2008, the order book accounted for 1,437 container ships, with a combined capacity of 6.5 million teu containers, corresponding to about 32% of the existing fleet in number (4,427) and 58% of the existing fleet in teu (11.3 million). The average size of the existing container ships is 2,550 teu and the average size of the ships on order is 4,550 teu.

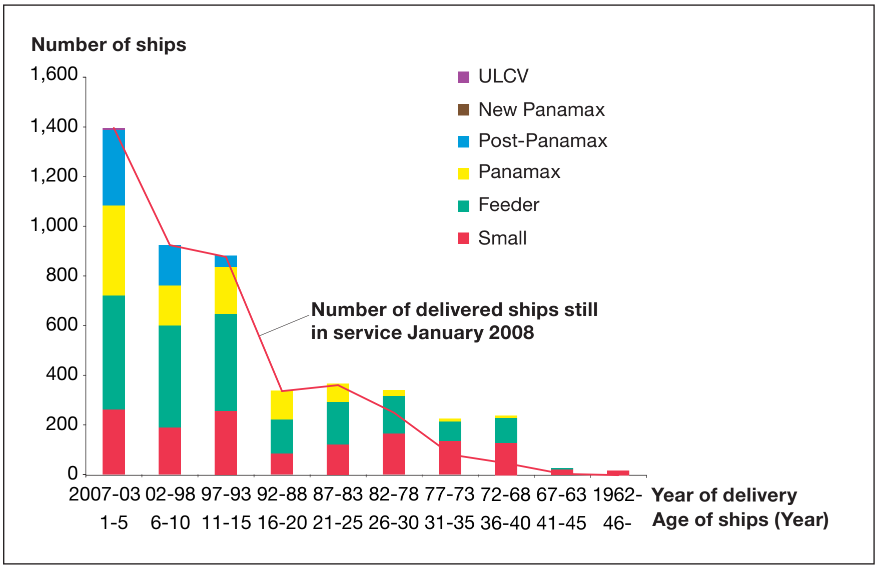

Fig. 4: Year of container ship deliveries (number of ships) and age of delivered ships still in service (curve)

As mentioned earlier, Fig. 3c shows the distribution in classes of the container ships on order, in number of ships, and Fig. 3d in number of teu at the end of May 2008. Many of these ships on order are of the New Panamax size, with 11% in number of ships and 31% in number of teu, and are to be compared with 0% in the existing fleet in service today. Furthermore, Fig. 3c shows very clearly that when large container vessels like the New Panamax container ships are ordered, even more feeder containers are also ordered.

Year of container ship deliveries

Fig. 4 shows the number of container ships delivered in different five-year periods since 1960.

As can be seen, the boom in container ship deliveries in the period of 1993-1997 has, in the last decade, been followed by an even greater boom.

Thus, about 33% of the container fleet has been delivered within the last five years.

Age of the container ship fleet

The red curve in Fig. 4 indicates the age structure of the container ship fleet as of January 2008, showing the number of ships still in operation compared con the number of ships delivered in the same period (illustrated by the columns covering five-year intervals).

When comparing the number of ships delivered with the red age curve of the container fleet in service today, it can be seen that the lifetime of almost all container ships is higher or equal to 25 years, and only about 9% are older than 25 years.

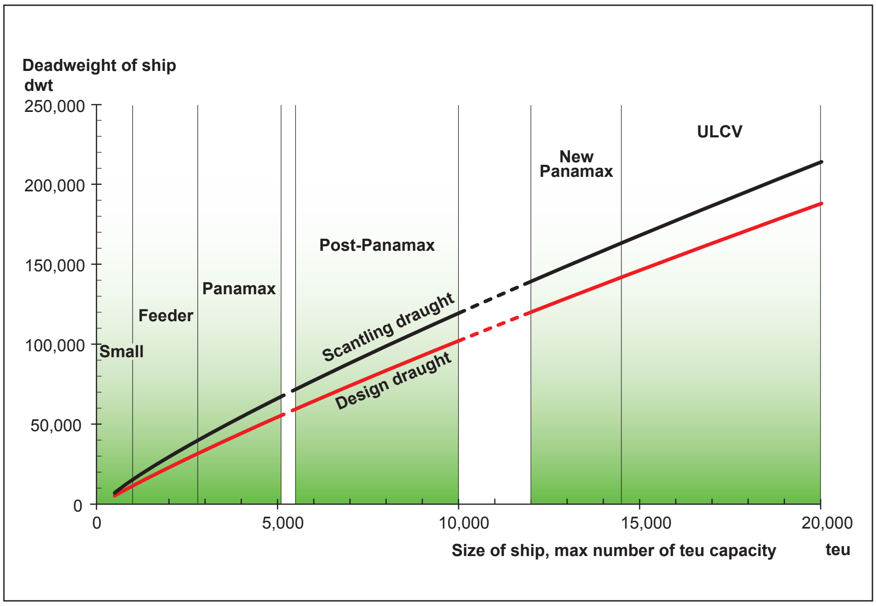

Fig. 5a: Average deadweight of container vessels

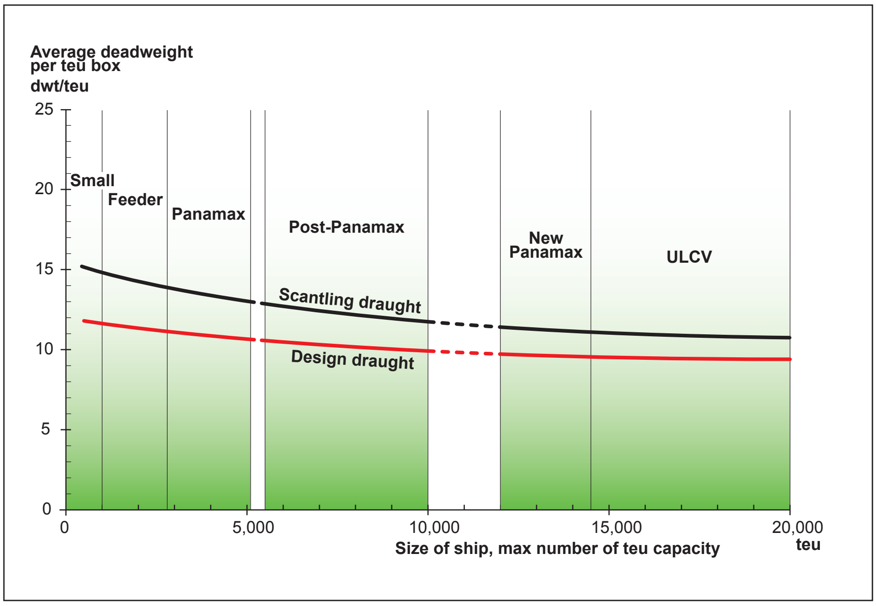

Fig. 5b: Average deadweight per teu box

Average Ship Particulars as a Function of Ship Size

On the basis of container vessels built or contracted in the period 2003-2008, as reported in the Lloyd's Register – Fairplay's "PC Register", we have estimated the average ship particulars.

Average hull design factor F_{des}

Based on the above statistical material, the average deadweight of a container vessel is stated in Fig. 5a and per teu in Fig. 5b. Furthermore, the average design relationship between the ship particulars of the container vessels can be expressed by means of the average

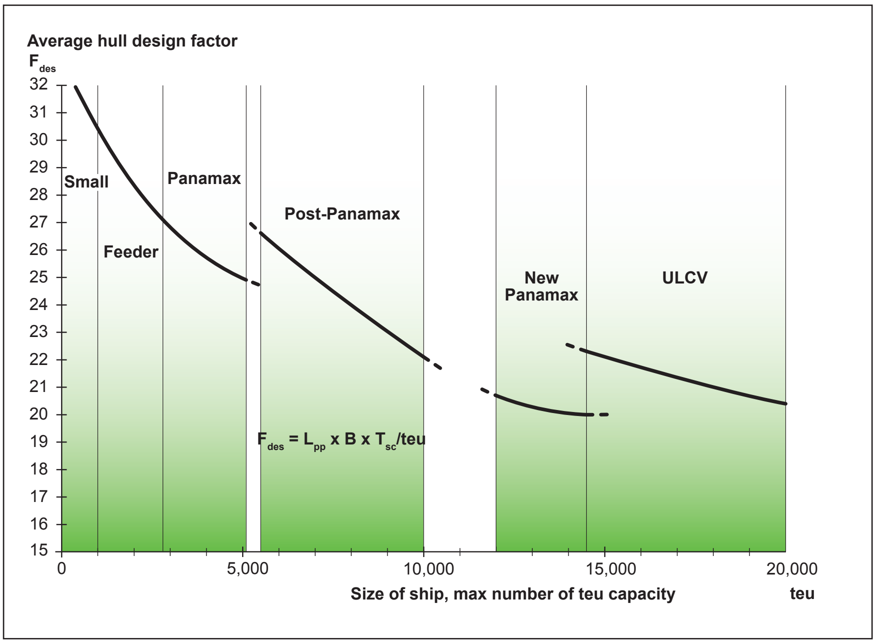

Fig. 6: Average hull design factor of container vessels

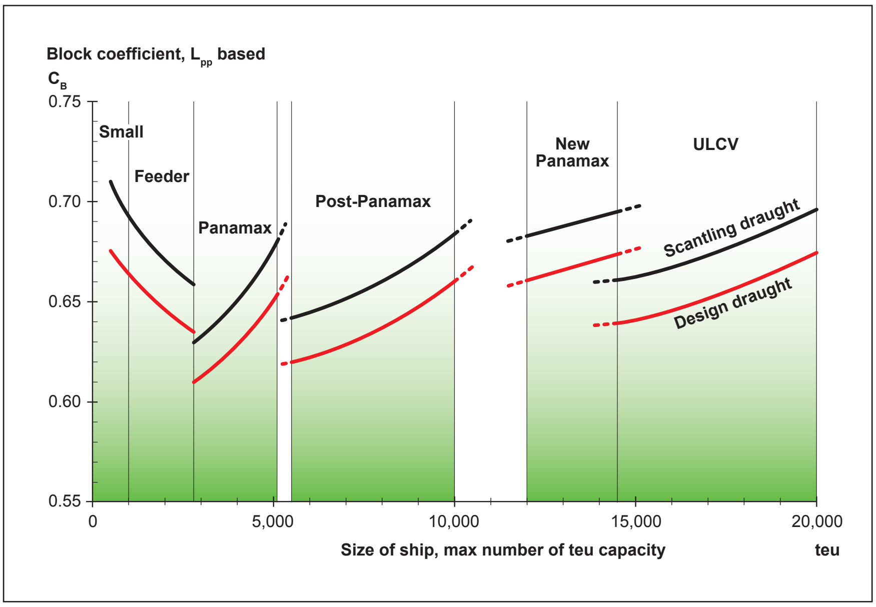

Fig. 7: Average block coefficient of container vessels

hull design factor F_{des}, see below and Fig. 6:

F_{des} = B x Lpp x Tsc /teu (m³/teu)

where

B	:	ship breadth	(m)
L_{pp}	:	length between perpendiculars	(m)
T_{sc}	:	scantling draught	(m)
teu	:	maximum number of teu to be stacked	(teu)

The design factor depends on the relevant container ship class. Based on the above design factor F_{des}, and with corresponding accuracy, any missing particular can be found as:

B:	$= F_{des} \times teu/(L_{pp} \times T_{sc})$	m
L_{pp}	$= F_{des} \times teu/(B \times T_{sc})$	m
T_{sc}	$= F_{des} \times teu/(B \times L_{pp})$	m
teu	$= B \times L_{pp} \times T_{sc}/F_{des}$	teu

The corresponding L_{pp} based average block coefficient is shown in Fig. 7 and depends very much on the container ship class.

In Figs. 8, 9 and 10, the first three ship particulars B, L_{pp} and T_{sc} (and T_{des}) are shown as a function of the ship size (teu). The main groups of container ship classes normally used are also shown. Of course, there may be some exceeding and overlapping of the groups, as shown by the dotted lines.

Fig. 8 shows very clearly that the ship breadth depends on the number of possible rows abreast of the boxes, and normally, as mentioned in previous sections, one row corresponds to about 2.5 m in ship breadth.

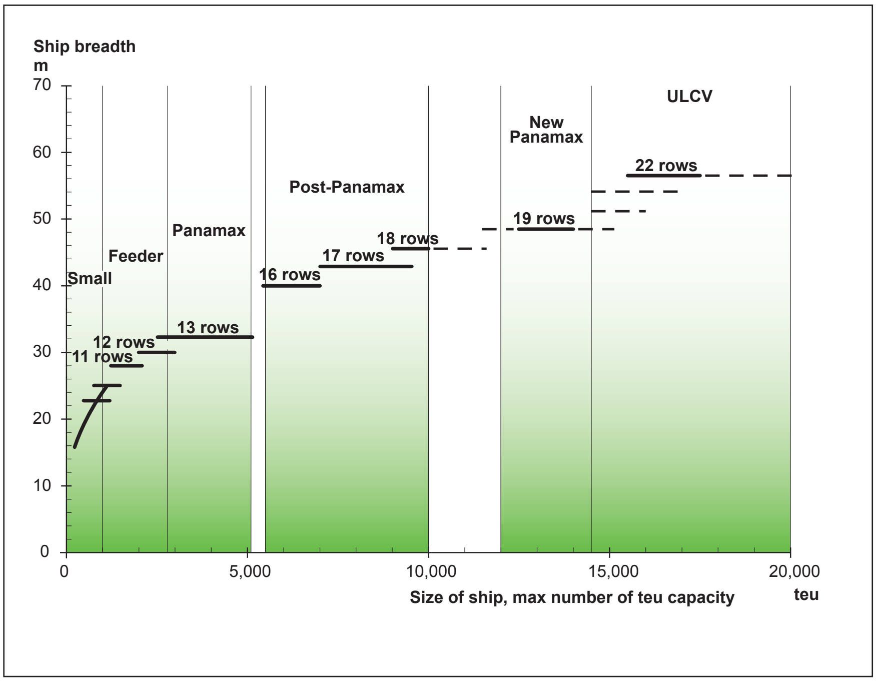

Fig. 8: Average ship breadth (beam) of container vessels

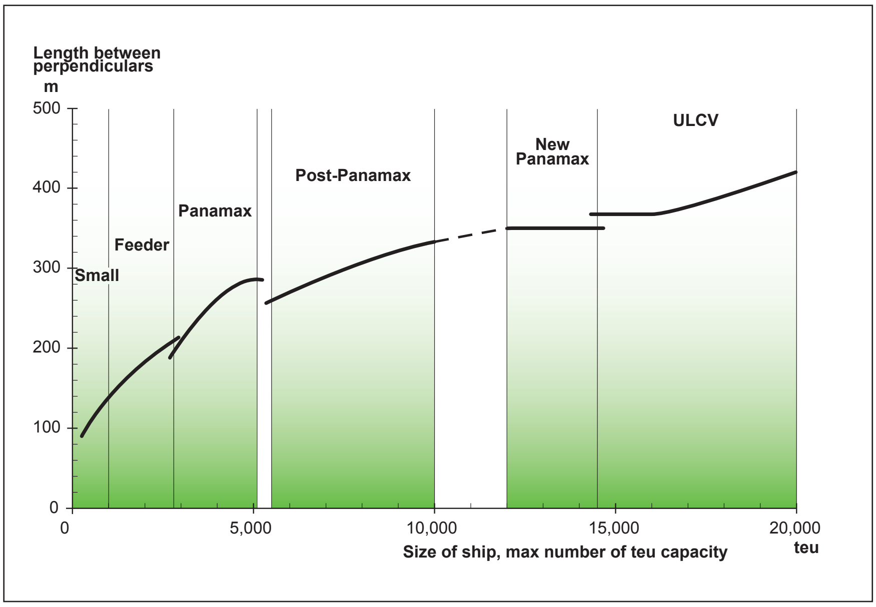

Fig. 9: Average length between perpendiculars of container vessels

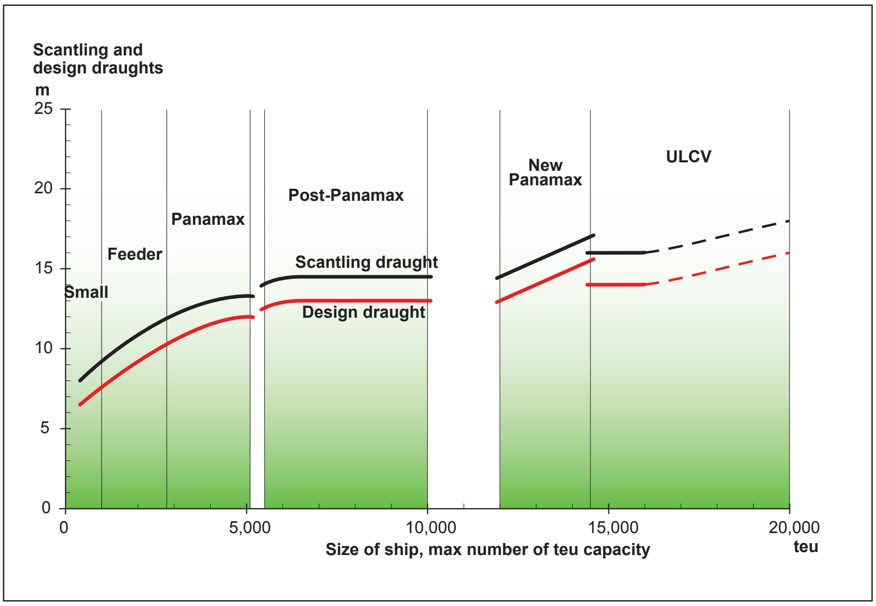

Fig. 10: Average scantling and design draughts of container vessels

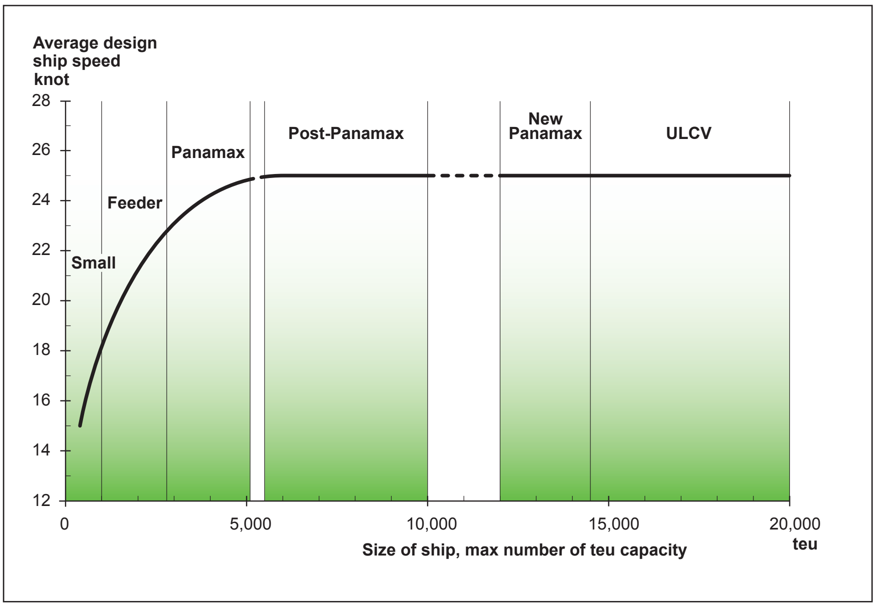

Fig. 11: Average design ship speed of container vessels

Average design ship speed V_{des}

In Fig. 11, the average ship speed Vdes, used for design of the propulsion system and valid for the design draught T_{des} of the ship, is shown as a function of the ship size.

As shown, for ships larger than approx. 5,500 teu the average design ship speed is 25.0 knots, but lower for smaller ships.

The design ship speed used for several years has been relatively high because of the relatively low fuel prices and high freight rates. However, because of the considerable increase in fuel prices over the last few years, the design ship speed might be lower in the future, or the applied ship speed in service might be reduced.

Ship speed dependent power demand of a large container vessel

Fig. 12 shows the relation between power and ship speed for a typical, modern Post-Panamax container vessel.

The frictional, eddy and air resistances are proportional with the ship speed in second power, and so is also the wave resistance in the lower ship speed range. However, in the upper ship speed range, the wave resistance might increase much more.

Therefore, the power and ship speed curve shown in Fig. 12 is very steep in the upper ship speed range. It is therefore obvious that when reducing the ship speed, the power requirement is reduced substantially.

Today, caused by the increasing fuel prices, some shipowners/operators therefore consider reducing the service ship speed of both new and existing container vessels, Ref. [3].

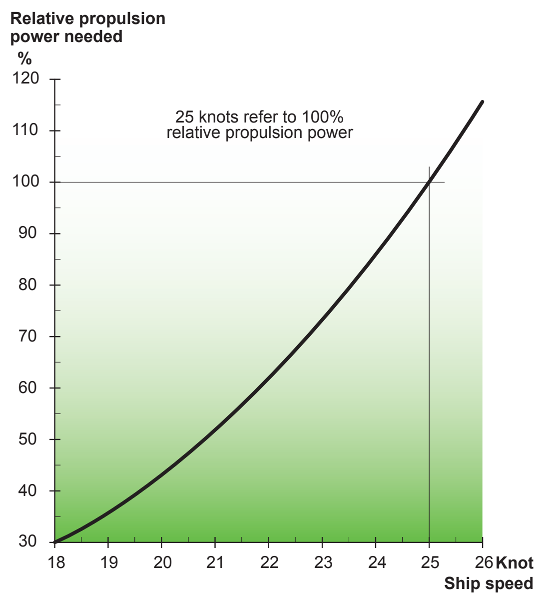

Fig. 12: Relative propulsion power needed for a large container vessel shown as a function of ship speed

Propulsion Power Demand as a Function of Ship Size

Propulsion SMCR power demand of average container vessels

Based on the average ship particulars and ship speeds already described for container ships built or contracted in the period of 2003-2008, we have made a power prediction calculation (Holtrop & Mennen's Method) for such ships in various sizes from 400 teu up to 18,000 teu.

The average ship particulars of these container ships are shown in the tables in Figs. 13-17. On this basis, and valid for the design draught and design ship speed, we have calculated the Specified Maximum Continuous Rating (SMCR) engine power needed for propulsion.

Container ship class		Small	Small	Small	Small
Ship size	teu	400	600	800	1,000
Scantling draught	m	7.7	8.3	8.9	9.1
Deadweight (scantling)	dwt	6,200	9,100	12,000	15,000
Design draught	m	6.5	7.0	7.4	7.6
Deadweight (design)	dwt	4,800	7,000	9,300	11,600
Length overall	m	107	122	140	150
Length between pp	m	100	115	130	140
Breadth	m	17,2	19.8	21.8	23.0
Sea margin	%	15	15	15	15
Engine margin	%	10	10	10	10
Average design ship speed	knots	**15.0**	**16.5**	**17.5**	**18.5**
SMCR power	kW	**3,000**	**4,870**	**6,700**	**8,800**
	1	5S35MC7	5S40ME-B9	5S50ME-B8	6S50MC-C7/ME-C7
Main engine options	2	5L35MC6	6S35ME-B9	5S46MC-C8	6S50ME-B8/B9
	3	8S26MC6	7S35MC7	6S40ME-B9	7S46MC-C7
	4		8L35MC6	8S35ME-B9	8S40ME-B9
Average ship speed -1.0 kn	knots	**14.0**	**15.5**	**16.5**	**17.5**
SMCR power	kW	**2,250**	**3,770**	**5,300**	**7,000**
	1	6S26MC6	5S35ME-B9	5S40ME-B9	5S50MC-C7/ME-C7
Main engine options	2		6S35MC7	5S42MC7	5S50ME-B8/B9
	3		6L35MC6	7S35ME-B9	6S46MC-C7
	4			8S35MC7	7S40ME-B9
Average ship speed +1.0 kn	knots	**16.0**	**17.5**	**18.5**	**19.5**
SMCR power	kW	**3,940**	**6,340**	**8,500**	**11,040**
	1	5S35ME-B9	6S40ME-B9	6S50MC-C7/ME-C7	7S50MC-C7/ME-C7
Main engine options	2	6S35MC7	6S42MC7	6S50ME-B8/B9	7S50ME-B8/B9
	3	7L35MC6	8S35ME-B9	7S46MC-C7	8S46MC-C8
	4		9S35MC7	8S40ME-B9	

Fig. 13: Ship particulars and propulsion SMCR power demand for small container vessels

Container ship class		Feeder	Feeder	Feeder	Feeder	Feeder
Ship size	teu	1,200	1,600	2,000	2,500	2,800
Scantling draught	m	9.5	10.1	10.7	11.5	12.0
Deadweight (scantling)	dwt	17,700	23,000	28,200	34,800	38,500
Design draught	m	8.0	8.6	9.2	10.0	10.6
Deadweight (design)	dwt	13,800	18,200	22,400	27,700	30,800
Length overall	m	160	182	202	209	222
Length between pp	m	149	17	190	197	210
Breadth	m	25.0	28.0	28.0	30.0	30.0
Sea margin	%	15	15	15	15	15
Engine margin	%	10	10	10	10	10
Average design ship speed	knots	19.0	20.0	21.0	22.0	22.5
SMCR power	kW	10,500	14,000	17,700	21,700	24,900
	1	6S50ME-B9	6S60MC-C8/ME-C8	6L70MC-C7/ME-C7	7L70MC-C7/ME-C7	6K80ME-C9
Main engine options	2	7S50MC-C7/ME-C7	8S50ME-B9	6S70MC-C7/ME-C7	6K80MC-C6/ME-C6	7K80MC-C6/ME-C6
	3	8S46MC-C8	9S50MC-C7/ME-B8	7S65ME-C8	7S70MC-C7/ME-C7	8L70MC-C8/ME-C8
	4	5S60MC-C7/ME-C7		8S60MC-C7/ME-C7		8S70MC-C8/ME-C8
Average ship speed -1.0 kn	knots	18.0	19.0	20.0	21.0	21.5
SMCR power	kW	8,400	11,600	14,700	18,000	20,800
	1	6S50MC-C7/ME-C7	5S60MC-C8/ME-C8	7S60MC-C7/ME-C7	6L70MC-C7/ME-C7	6K80MC-C6/ME-C6
Main engine options	2	5S50ME-B9	6S60MC-C7/ME-C7	5L70MC-C7/ME -C7	6S70MC-C7/ME-C7	7L70MC-C7/ME-C7
	3	7S46MC-C7	7S50ME-B9	6S65ME-C8	7S65ME-C8	7S70MC-C7/ME-C7
	4	5S60MC-C7/ME-C7	7S50MC-C8/ME-B8		8S60MC-C7/ME-C7	
Average ship speed +1.0 kn	knots	20.0	21.0	22.0	23.0	23.5
SMCR power	kW	13,000	17,200	21,500	26,000	30,000
	1	8S50ME-B9	6L70MC-C7/ME-C7	7L70MC-C7/ME-C7	8L70MC-C8/ME-C8	7K80ME-C9
Main engine options	2	8S50ME-B8	8S60MC-C7/ME-C7	6K80MC-C6/ME-C6	6K80ME-C9	9K80MC-C6/ME-C6
	3	6S60MC-C7/ME-C7		7S70MC-C6/ME-C6	8K80MC-C6/ME-C6	6K90ME-C9
	4				6K90MC-C6/ME-C6	

Fig. 14: Ship particulars and propulsion SMCR power demand for feeder container vessels

Container ship class Ship size	teu	Panamax 2,800	Panamax 3,500	Panamax 4,000	Panamax 4,500	Panamax 5,100
Scantling draught	m	12.0	12.7	13.0	13.3	13.5
Deadweight (scantling)	dwt	38,500	46,700	52,400	58,500	66,000
Design draught	m	10.7	11.3	11.8	12.0	12.0
Deadweight (design)	dwt	30,800	38,100	43,200	48,600	54,000
Length overall	m	211	246	269	286	294
Length between pp	m	196	232	256	271	283
Breadth	m	32.2	32.2	32.2	32.2	32.2
Sea margin	%	15	15	15	15	15
Engine margin	%	10	10	10	10	10
Average design ship speed	knots	**22.5**	**23.5**	**24.0**	**24.5**	**24.8**
SMCR power	kW	**25,000**	**31,300**	**35,500**	**40,100**	**45,000**
	1	6K80ME-C9	6K90ME9/ME-C9	7K90ME9/ME-C9	7K90ME-C9/ME9	8K90ME-C9/ME9
Main engine options	2	7K80MC-C6/ME-C6	7K90MC-C6/ME-C6	8K90MC-C6/ME-C6	9K80ME-C9	10K90MC-C6/ME-C6
	3	8L70MC-C8/ME-C8	7K80ME-C9	8K80ME-C9	9S80ME-C9	10K80ME-C9
	4	8S70MC-C8/ME-C8	9K80MC-C6/ME-C6	8K90MC-C6/ME-C6	7K98MC-C7/ME-C7	8K98MC6/ME6
	5			8S80ME-C9	6K98ME9/ME-C9 *	7K98ME9/ME-C9 *
Average ship speed -1.0 kn	knots	**21.5**	**22.5**	**23.0**	**23.5**	**23.8**
SMCR power	kW	**20,900**	**26,400**	**30,200**	**34,300**	**38,700**
	1	6K80MC-C6/ME-C6	6K90MC-C6/ME-C6	6K90ME-C9/ME9	6K90ME-C9/ME9	7K90ME-C9/ME9
Main engine options	2	7L70MC-C7/ME-C7	6K80ME-C9	7K80ME-C9	8K80ME-C9	9K90MC-C6/ME-C6
	3	7S70MC-C7/ME-C7	8K80MC-C6/ME-C6	6K98MC6/ME6	8S80ME-C9	9K80ME-C9
	4		8S70MC-C8/ME-C8	7S80ME-C9	6K98MC6/ME6	9S80ME-C9
	5					6K98ME9/ME-C9 *
Average ship speed +1.0 kn	knots	**23.5**	**24.5**	**25.0**	**25.5**	**25.8**
SMCR power	kW	**30,000**	**37,200**	**41,700**	**47,000**	**52,000**
	1	7K80ME-C9	7K98MC-C6/ME-C6	7K98MC-C7/ME-C7	8K98MC-C7/ME-C7	9K98MC-C7/ME-C7
Main engine options	2	9K80MC-C6/ME-C6	7K90ME-C9	8K90ME-C9	8K98MC7/ME7	9K98MC7/ME7
	3	6K90ME-C9	9K80ME-C9	10K80ME-C9	9K90MC-C9/ME-C9	10K90ME-C9/ME9
* Proposed	4				7K98ME9/ME-C9 *	8K98ME9/ME-C9 *

Fig. 15: Ship particulars and propulsion SMCR power demand for Panamax container vessels

Container ship class Ship size	teu	**Post-Panamax 5,500**	**Post-Panamax 6,500**	**Post-Panamax 8,000**	**Post-Panamax 10,000**
Scantling draught	m	14.0	14.5	14.5	14.5
Deadweight (scantling)	dwt	70,000	81,000	97,000	118,000
Design draught	m	12.5	13.0	13.0	13.0
Deadweight (design)	dwt	58,000	67,000	81,000	101,000
Length overall	m	276	300	323	349
Length between pp	m	263	286	308	334
Breadth	m	40.0	40.0	42.8	45.6
Sea margin	%	15	15	15	15
Engine margin	%	10	10	10	10
Average design ship speed	knots	**25.0**	**25.0**	**25.0**	**25.0**
SMCR power	kW	**49,800**	**53,900**	**60,000**	**67,700**
	1	8K98ME7	9K98MC7/ME7	10K98MC7/ME7	11K98MC7/ME7
Main engine options	2	9K90ME9/ME-C9	9K98MC-C7/ME-C7	10K98MC-C7/ME-C7	12K98MC6/ME6
	3	11K90MC-C6/ME-C6	10K98MC-C6/ME-C6	11K98MC-C6/ME-C6	12K98MC-C6/ME-C6
	4	11K80ME-C9	10K90ME9/ME-C9	11K90ME9/ME-C9	12K90ME9/ME-C9
	5		8K98ME9/ME-C9 *	9K98ME9/ME-C9 *	10K98ME9/ME-C9 *
Average ship speed -1.0 kn	knots	**24.0**	**24.0**	**24.0**	**24.0**
SMCR power	kW	**42,500**	**46,100**	**51,400**	**58,100**
	1	7K98MC7/ME7	8K98MC7/ME7	9K98MC6/ME6	10K98MC7/ME7
Main engine options	2	8K98MC6/ME6	9K90ME9/ME-C9	9K98MC-C6/ME-C6	10K98MC-C7/ME-C7
	3	8K90ME9/ME-C9	11K80ME-C9	9K98MC7/ME7	11K98MC-C6/ME-C6
	4	10K80ME-C9	9S90MC-C8/ME-C8	9K90ME9/ME-C9	11K90ME9/ME-C9
	5	9S90MC-C8/ME-C8	7K98ME9/ME-C9 *	8K98ME9/ME-C9 *	9K98ME9/ME-C9 *
Average ship speed +1.0 kn	knots	**26.0**	**26.0**	**26.0**	**26.0**
SMCR power	kW	**58,000**	**63,000**	**69,500**	**78,000**
	1	10K98MC7/ME7	11K98MC7/ME7	12K98MC7/ME7	14K98MC-C6/ME-C6
Main engine options	2	10K98MC-C7/ME-C7	11K98MC-C7/ME-C7	12K98MC-C7/ME-C7	14K98MC-C7/ME-C7
	3	11K90ME9/ME-C9	11K90ME9/ME-C9	14K98MC6/ME6	14K98MC6/ME6
	4	9K98ME9/ME-C9 *	10K98ME9/ME-C9 *	14K98MC-C6/ME-C6	14K98MC7/ME7
* Proposed	5			11K98ME9/ME-C9 *	12K98ME9/ME-C9 *

Fig. 16: Ship particulars and propulsion SMCR power demand for Post-Panamax container vessels

Container ship class Ship size	teu	New Panamax 12,500	New Panamax 14,000	ULCV 15,500	ULCV 18,000 (future)
Scantling draught	m	15.0	16.5	16.0	17.0
Deadweight (scantling)	dwt	143,000	157,000	171,000	195,000
Design draught	m	13.5	15.0	14.0	15.0
Deadweight (design)	dwt	123,000	136,000	149,000	178,000
Length overall	m	366	366	397	420
Length between pp	m	350	350	375	395
Breadth	m	48.4	48.4	56.4	56.4
Sea margin	%	15	15	15	15
Engine margin	%	10	10	10	10
Average design ship speed	knots	**25.0**	**25.0**	**25.0**	**25.0**
SMCR power	kW	**74,000**	**78,000**	**84,000**	**91,500**
	1	12K98MC7/ME7	14K98MC6/ME6	14K98MC7/ME7	14K98ME9/ME-C9 *
Main engine options	2	14K98MC-C6/ME-C6	14K98MC-C6/ME-C6	14K98MC-C7/ME-C7	
	3	14K98MC-C7/ME-C7	14K98MC7/ME7	14K98ME9/ME-C9 *	
	4	11K98ME9/ME-C9 *	14K98MC-C7/ME-C7		
	5		12K98ME9/ME-C9 *		
Average ship speed -1.0 kn	knots	**24.0**	**24.0**	**24.0**	**24.0**
SMCR power	kW	**64,000**	**67,500**	**72,000**	**79,000**
	1	11K98MC7/ME7	11K98MC7/ME7	12K98MC7/ME7	14K98MC6/ME6
Main engine options	2	11K98MC-C7/ME-C7	12K98MC6/ME6	12K98MC-C7/ME-C7	14K98MC7/ME7
	3	12K98MC6/ME6	12K98MC-C6/ME-C6	14K98MC6/ME6	14K98MC-C6/ME-C6
	4	12K98MC-C6/ME-C6	12K98MC-C7/ME-C7	14K98MC-C6/ME-C6	14K98MC-C7/ME-C7
	5	10K98ME9/ME-C9 *	10K98ME9/ME-C9 *	11K98ME9/ME-C9 *	12K98ME9/ME-C9 *
Average ship speed +1.0 kn	knots	**26.0**	**26.0**	**26.0**	**26.0**
SMCR power	kW	**85,500**	**91,000**	**97,000**	**106,000**
	1	14K98MC7/ME7	14K98ME9/ME-C9 *		
Main engine options	2	14K98ME9/ME-C9 *			
	3				
* Proposed	4				

Fig. 17: Ship particulars and propulsion SMCR power demand for New Panamax and ULCV container vessels

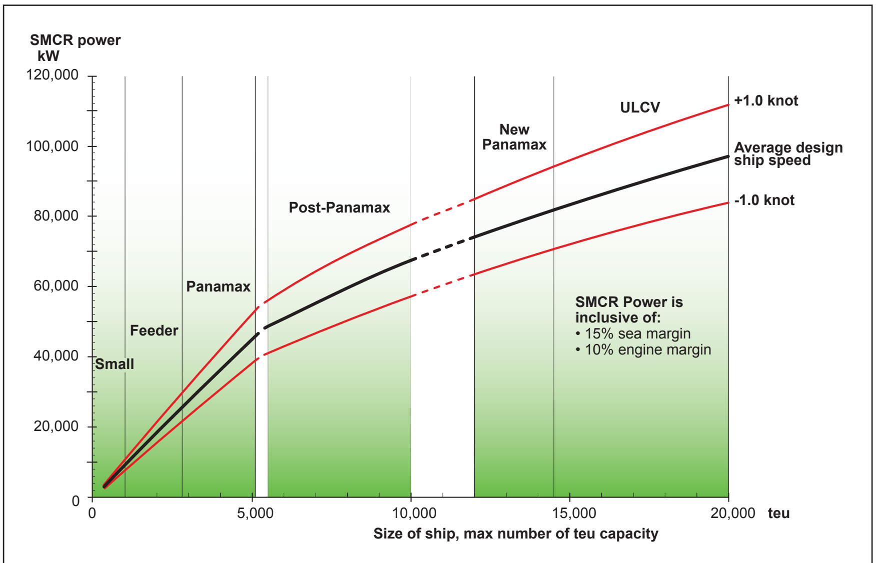

Fig. 18: Propulsion SMCR power demand of an average container vessel

For all cases, we have assumed a sea margin of 15% and an engine margin of 10%, i.e. a service rating of 90% SMCR, including a 15% sea margin.

The SMCR power results are also shown in the tables in Figs. 13-17 "Ship Particulars and Propulsion SMCR Power Demand" together with the selected main engine options. These are valid, in all cases, for single-screw container ships. The similar results valid for +/– 1.0 knots compared with the average design ship speed are also shown.

The graph in Fig. 18 shows the curve of the above-mentioned table figures of the SMCR power needed for propulsion of an average container ship. The SMCR power curves valid for +/– 1.0 knots compared with the average design ship speed are also shown.

When referring to the propulsion power demand of the average container ships as shown in Fig. 18, the similar SMCR power demand per teu box can be found rather easily, as shown in Fig. 19.

Quite surprisingly, it seems as if there is a maximum design limit of 9.0 kW/teu, which is not exceeded for average designed container ships.

For container ships larger than 5,500 teu, the average design ship speed used is 25.0 knots, whereas the ship speed is lower for smaller ships, which means that the maximum limit is not exceeded.

Relative main engine operating costs per teu box

Based on Fig. 19, the relative operating costs per teu for container ships larger than 5,500 teu are found with the 5,500 teu ship used as the basis, see Fig. 20.

The curves show that for a 16,000 teu container ship, the main engine operating costs per teu will be approx. 40% lower than that of a 5,500 teu container ship.

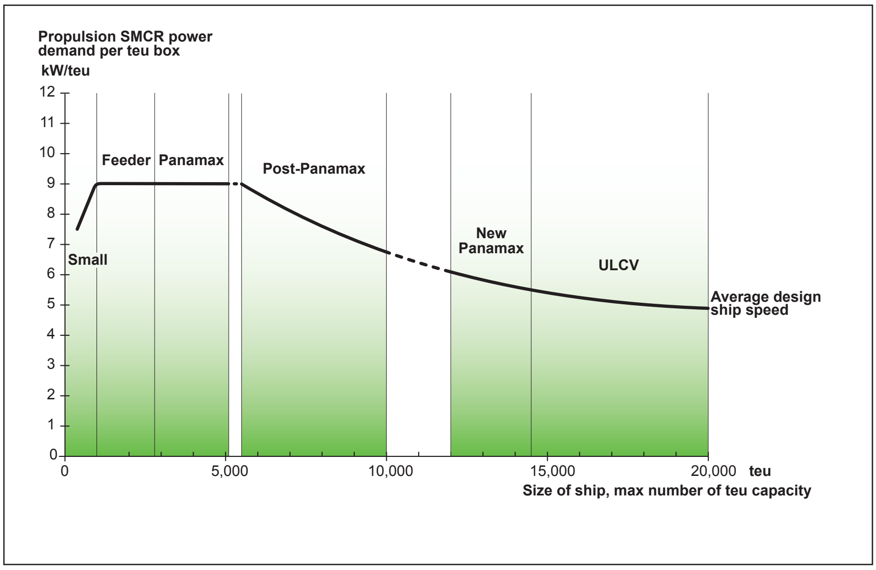

Fig. 19: Propulsion SMCR power demand per teu box of an average container vessel

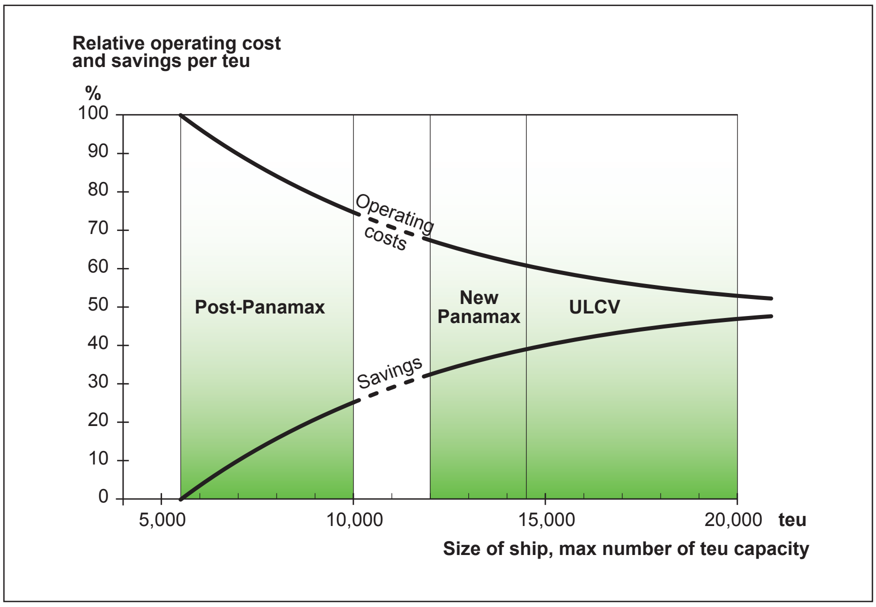

Fig. 20: Relative operating costs and savings per teu box of an average container vessel with a 5,500 teu container vessel as basis (equal ship speed)

Propulsion Power Demand of Average Container Vessels as a Function of Ship Speed

When the required ship speed is changed, the required SMCR power will change too, as previously mentioned, and other main engine options could be selected.

This trend, along with the average ship and average ship speed as the basis, is shown in detail in Figs. 21-25. See also the description below giving the results of the main engine selection for the different classes of container ships.

If for a required ship speed, the nominal MCR power needed for a given main engine is too high, it is possible to derate the engine, i.e. by using an SMCR power lower than the nominal MCR power. This would result in a lower specific fuel consumption of the engine.

Therefore, in some cases it could be of a particular advantage, when considering the high fuel price today, to select a higher mark number of the engine or to use one extra cylinder than needed and then derate the engine.

For small feeders, particularly the 5, 6 and 7 cylinders, direct-coupled MAN B&W two-stroke S50 and smaller engine bores are installed, see Fig. 21. An alternative installation also used is four-stroke engines together with a reduction gear.

For feeder container vessels, particularly the 6, 7 and 8-cylinder S50, S60 and L/S70 engine types are used, see Fig. 22.

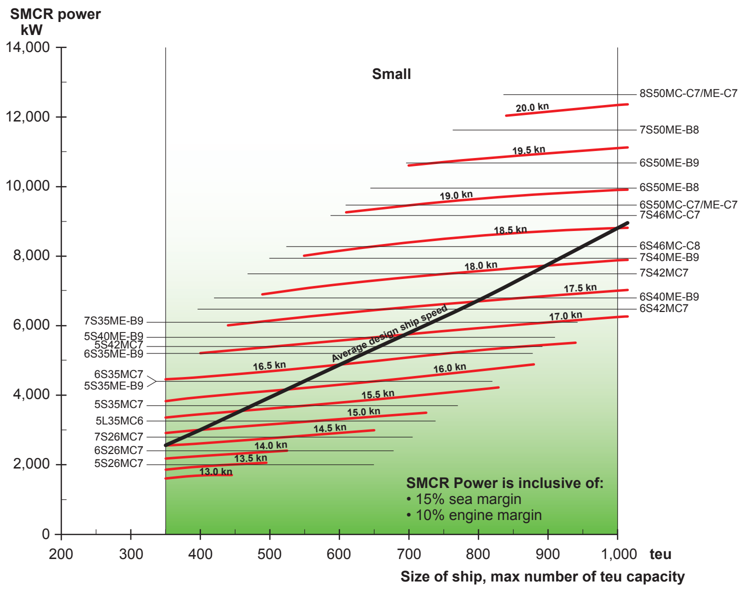

Fig. 21: Propulsion SMCR power demand of Small container vessels

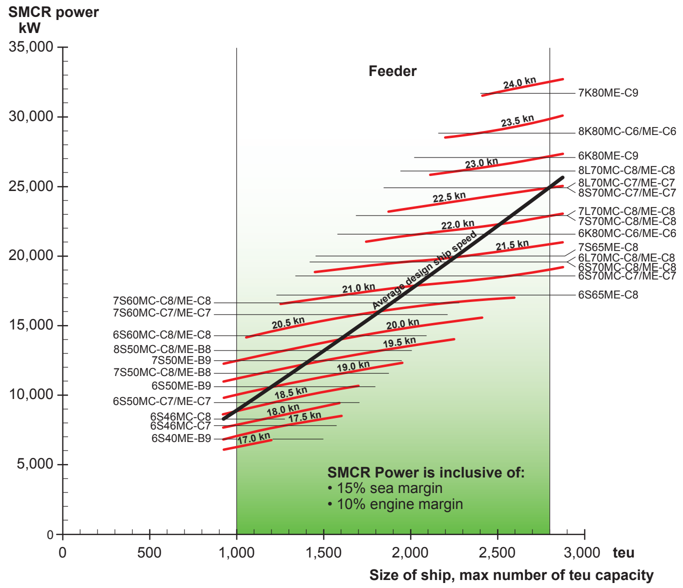

Fig. 22: Propulsion SMCR power demand of Feeder container vessels

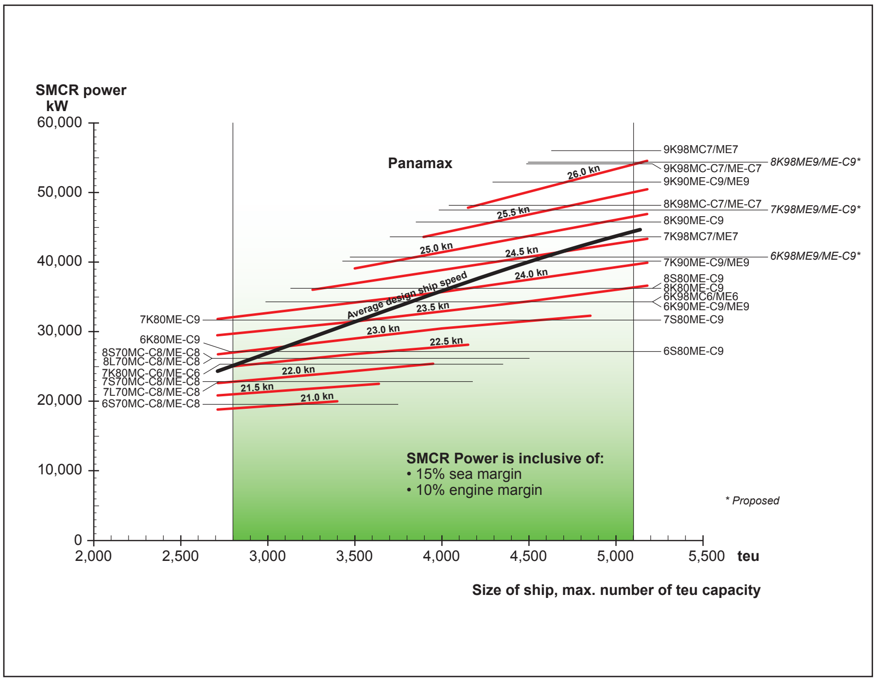

Fig. 23: Propulsion SMCR power demand of Panamax container vessels

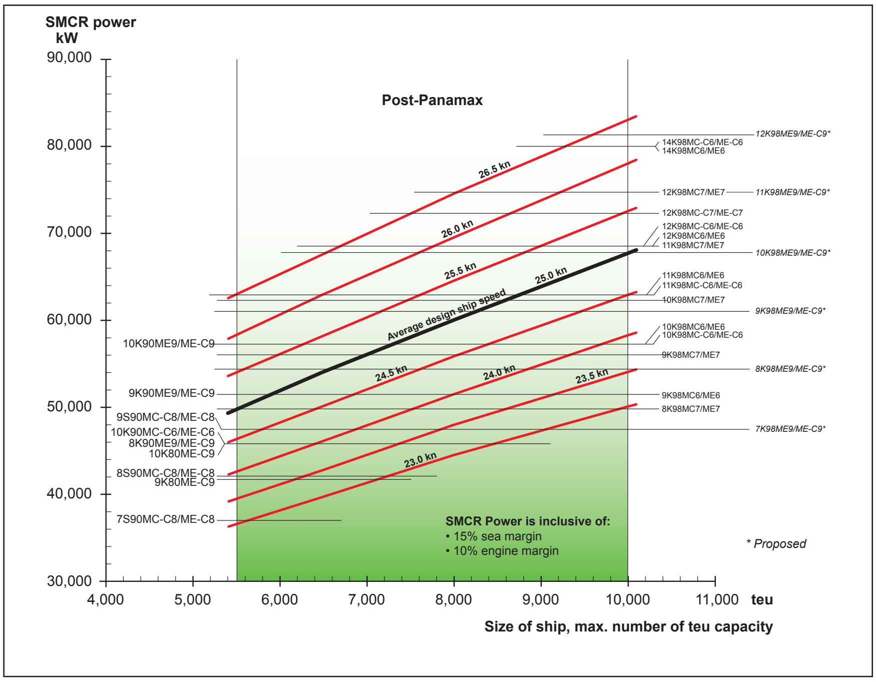

Fig. 24: Propulsion SMCR power demand of Post-Panamax container vessels

For Panamax container vessels, particularly the 7, 8 and 9-cylinder directly coupled MAN B&W two-stroke K80, K90 and K98 type engines are used, see Fig. 23. Today, we also see the S80 type engine with low engine speed to be applied for ships where it has been made possible to install a propeller with a relatively large diameter, giving increased propeller efficiency, but a lower optimum propeller/engine speed.

For Post-Panamax container ships, particularly the direct-coupled MAN B&W two-stroke engine types 10, 11 and 12K98 are used, see Fig. 24. Today, we also see the S90 with a low engine speed applied on ships where it has been made possible to install a propeller with a relatively large diameter.

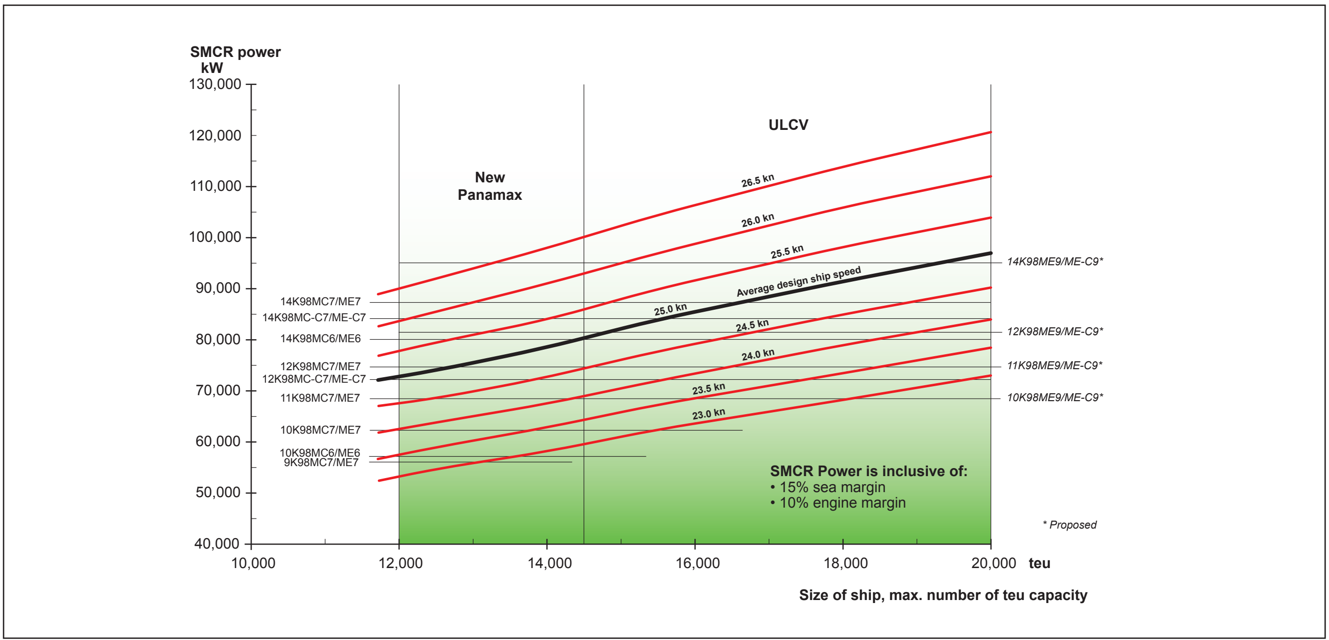

Fig. 25: Propulsion SMCR power demand of New Panamax and ULCV container vessels

For New Panamax and ULCV container ships, particularly the 10, 12 and 14K98 direct-coupled MAN B&W two-stroke engine types can be used, see Fig. 25.

Propellers for Large Single-screw Container Ships

The building of larger container ships while retaining the application of a simple single-screw hull is obviously, as already mentioned, the cheapest solution, both with regard to investments and operating costs.

Therefore, the propeller manufacturers are doing their utmost to design and produce a feasible large propeller for the present and future large container ships, because the main engine needed is already available, ref. our K98 engine types.

Also K108 types have been proposed, but they will most likely be replaced with higher-rated K98 types, designated K98ME9 and K98ME-C9, respectively.

According to one of the large propeller designers, any conceivable problem with the design of such large propellers can be overcome.

Today, there are already some foundries in the world with the capability to produce single-cast, six-bladed fixed pitch propellers up to 131 t (finished weight), and with some investment, this could be increased to 150 t.

The approximate relationship between the weight (finished), diameter, engine/propeller speed and propulsion SMCR power for a six-bladed propeller for a single-screw container ship is shown in Fig. 26. This Fig. indicates, i.a., that a 14K98ME7 with a nominal MCR of 87,220 kW at 97 r/min may need a propeller diameter of about 9.8 m with a finished weight of about 135 t.

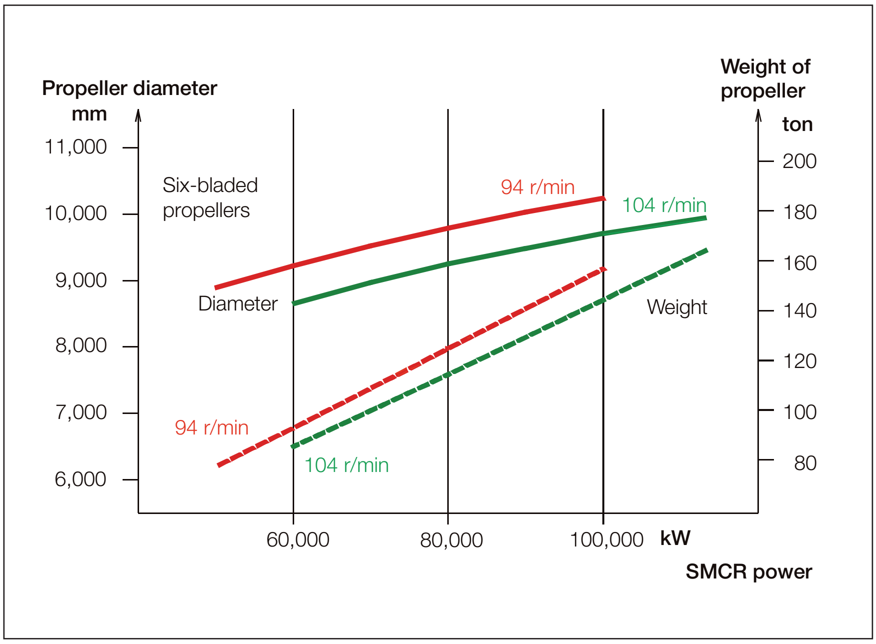

Fig. 26: Propellers for large single-screw container ships

Summary

The container ship market is an increasingly important and attractive transport market segment, which may be expected to become of even greater importance in the future.

With the expected demands on large container ships and the intended increased lock chambers and depth (dredging) of the new Panama Canal to cater for these and other big ships, the demands on the design and production of the main engines and propellers may grow.

The current MAN B&W two-stroke engine programme is well suited to meet the main engine power requirement for the container ship types and sizes that are expected to emerge in the foreseeable future, irrespective of whether the market should demand container ships designed for a lower ship speed than normally used caused by the increased fuel prices.

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5510-0040-02ppr Aug 2013 Printed in Denmark

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