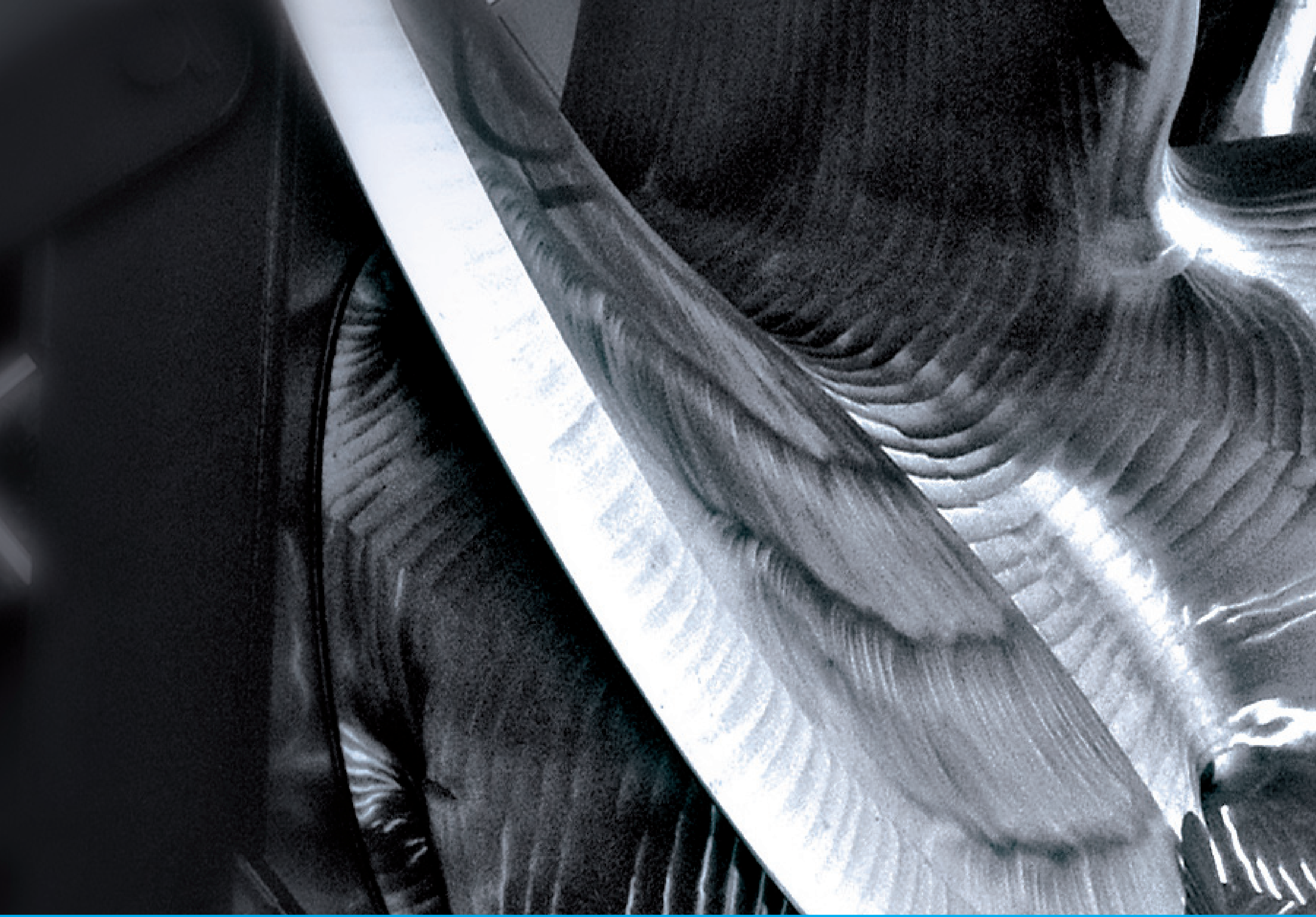

Improved Efficiency and Reduced CO_2

Engineering the Future – since 1758.

MAN Diesel & Turbo

Content

Introduction 5
Major Propeller and Main Engine Parameters 5
Propeller 6
Main engine 6
Ship with reduced design ship speed 6
Case Study 1 6
75,000 dwt Panamax Product Tanker 6
Basic case 7
Derating of main engine 8
Increased propeller diameter 8
Reduced fuel consumption per day or per voyage 8
Case Study 2 9
4,500 teu Panamax Container Vessel 9
5-propeller blades 10
4-propeller blades 10
6-propeller blades 10
Reduced fuel consumption per day 11
Reduced fuel consumption per voyage 12
Case Study 3 13
8,000 teu Post-Panamax Container Vessel 13
Propeller diameter of 8.8 m 14
Increased propeller diameter of 9.3 m 14
Reduced fuel consumption per day 15
Reduced fuel consumption per voyage 16
Summary 17

Improved Efficiency and Reduced CO_2

Introduction

One of the future goals in the marine industry is to reduce the impact of CO_2 emissions from ships in order to meet the coming stricter International Maritime Organisation (IMO) greenhouse gas emission requirements.

Two CO_2 emission indexes are being discussed at IMO, an ‘Energy Efficiency Design Index’ (EEDI) and an ‘Energy Efficiency Operational Indicator’ (EEOI). The EEDI is used to evaluate the engine and vessel design and the EEOI is used to guide the operator in developing the best practices on board.

The goal is to design future ships with a design index to be stepwise reduced in the period from 2012 to 2018 to a maximum level of possibly 70% compared with the 100% design index valid for average designed ships of today. However, it should be emphasised that neither goal nor indexes are definite yet, June 2009.

As a reduction in CO_2 emission is roughly equivalent to a reduction in fuel consumption, the goal for the manufacturers will roughly correspond to a 30% reduction in fuel consumption per voyage of future ships in normal, average service.

Based on case studies on three different ships, this Paper shows the influence on fuel consumption of derating the main engine in general and using electronically controlled engines and, particularly, of reducing the ship’s service speed in combination with selection of the optimum propeller design.

All main engines discussed are optimised/matched in compliance with the IMO Tier II emission requirements, even though an improved fuel consumption usually also means increased NO_x emissions. Furthermore, all ships have Fixed Pitch Propeller (FPP) types and the (two-stroke) main engines are directly coupled with the propeller and, therefore, have the same speed as the propeller.

In order to improve the overview of the relative changes of the fuel consumption and CO_2 emissions in this Paper, relative reduction of figures are stated with minus (-) and relative increase of figures are stated with plus (+).

The three case studies and main parameters analysed are:

1. 75,000 dwt Panamax Product Tanker at 15.1 knots ship speed
   Nominally rated 5S60MC-C8 versus derated 6S60MC-C8 and 6S60ME-C8
   - Influence of derating of engine
   - Influence of derating and increased propeller diameter
   - Influence of using electronically controlled engine

2. 4,500 teu Panamax Container Vessel at reduced ship speed
   6S80ME-C9 and 6K80ME-C9 versus 8K90MC-C6 and 9K90MC-C6
   - Influence of reduced ship speed
   - Influence of changed number of propeller blades

3. 8,000 teu Post-Panamax Container Vessel at reduced ship speed
   Derated 9S90ME-C8 versus 10K98ME7 and 12K98ME-C7
   - Influence of reduced ship speed
   - Influence of increased propeller diameter

Major Propeller and Main Engine Parameters

In general, the larger the propeller diameter, the higher the propeller efficiency and the lower the optimum propeller speed referring to an optimum ratio of the propeller pitch and propeller diameter.

When increasing the propeller pitch for a given propeller diameter, the corresponding propeller speed may be reduced and the efficiency will also be slightly reduced, but of course depending on the degree of the changed pitch. The same is valid for a reduced pitch, but here the propeller speed may increase.

The efficiency of a two-stroke main engine particularly depends on the ratio of the maximum (firing) pressure and the mean effective pressure. The higher the ratio, the higher the engine efficiency, i.e. the lower the Specific Fuel Oil Consumption (SFOC).

Furthermore, the larger the stroke/bore ratio of a two-stroke engine, the higher the engine efficiency. This means, for example, that a super long-stroke engine type, e.g. an S80ME-C9, may have a higher efficiency compared with a short-stroke engine type, e.g. a K80ME-C9.

Compared with a camshaft (mechanically) controlled engine, an electronically controlled engine has more parameters which can be adjusted during the engine operation in service. This means that the ME/ME-C engine types, compared with the MC/MC-C engine types, have relatively higher engine efficiency under low NO_x IMO Tier II operation.

When the design ship speed is reduced, the corresponding propulsion power and propeller speed will also be reduced, which again may have an influence on the above-described propeller and main engine parameters.

The following is a summary of the major parameters described:

Propeller

Larger propeller diameter involving:

- Higher propeller efficiency
- Lower optimum propeller speed (rpm)

Lower number of propeller blades involving:

- Slightly higher propeller efficiency
- Increased optimum propeller speed (rpm) (from 6 to 5 blades means approximately 10% higher rpm)

Main engine

Increased p_{max}/p_{mep} pressure ratio involving:

- Higher engine efficiency (e.g. by derating)

Larger stroke/bore ratio involving:

- Higher engine efficiency (e.g. S-type engines have higher efficiency compared with K-type engines)

Use of electronically controlled engine instead of camshaft controlled:

- Higher engine efficiency (improved control of NO_x emissions)

Ship with reduced design ship speed

Lower propulsion power demand and lower propeller speed.

Case Study 1

75,000 dwt Panamax Product Tanker

Based on a ship with unchanged ship speed, this case study illustrates the potential of reduced fuel consumption when derating a main engine and when using a four-bladed propeller with an increased propeller diameter. Together with the main engine types involved, the ship particulars in question are assumed as follows:

Main ship particulars assumed:

Scantling draught	m	14.2
Design draught	m	12.6
Length overall	m	228.6
Length between pp	m	219.0
Breadth	m	32.2
Sea margin	%	15
Engine margin	%	10
Design ship speed	kn	15.1
Type of propeller		FPP
No. of propeller blades		4
Propeller diameter	m	target

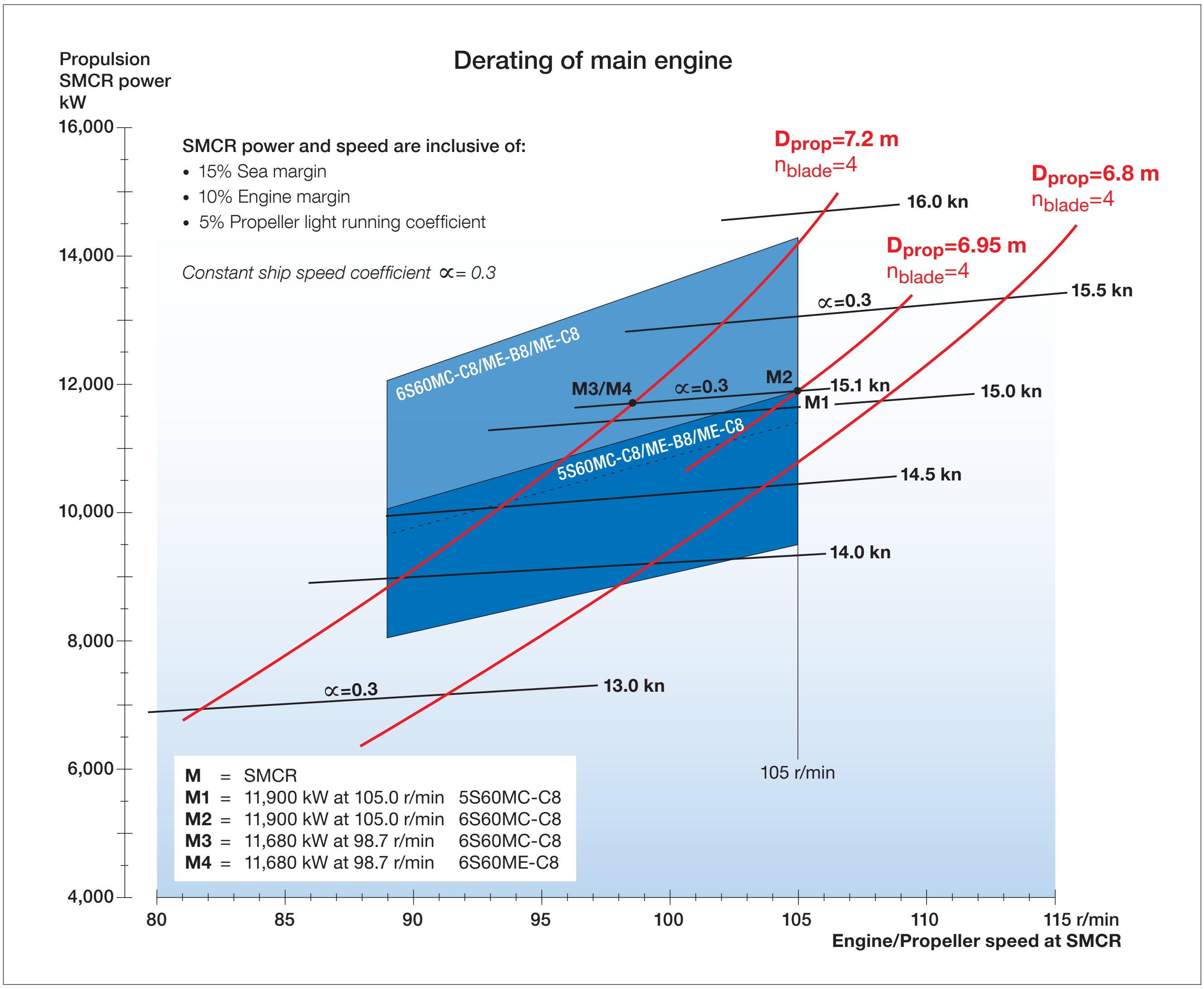

Fig. 1a: Different main engine and propeller layouts and SMCR possibilities (M1, M2, M3, M4) for a 75,000 dwt Panamax product tanker operating at the same ship speed of 15.1 knots

Basic case

As Alt. 1, the basic ship refers to a nominally rated 5S60MC-C8 main engine with SMCR = M1 = 11,900 kW x 105.0 r/min and a design ship speed of 15.1 knots, see Fig. 1a. In this figure the layout diagrams of the 5 and 6S60MC-C8/ME-C8 engine types and the SMCR points M1, M2, M3 and M4 at 15.1 knots are also drawn in together with the propeller curves valid for the three different propeller diameters of 6.8 m, 6.95 m and 7.2 m, each with four propeller blades.

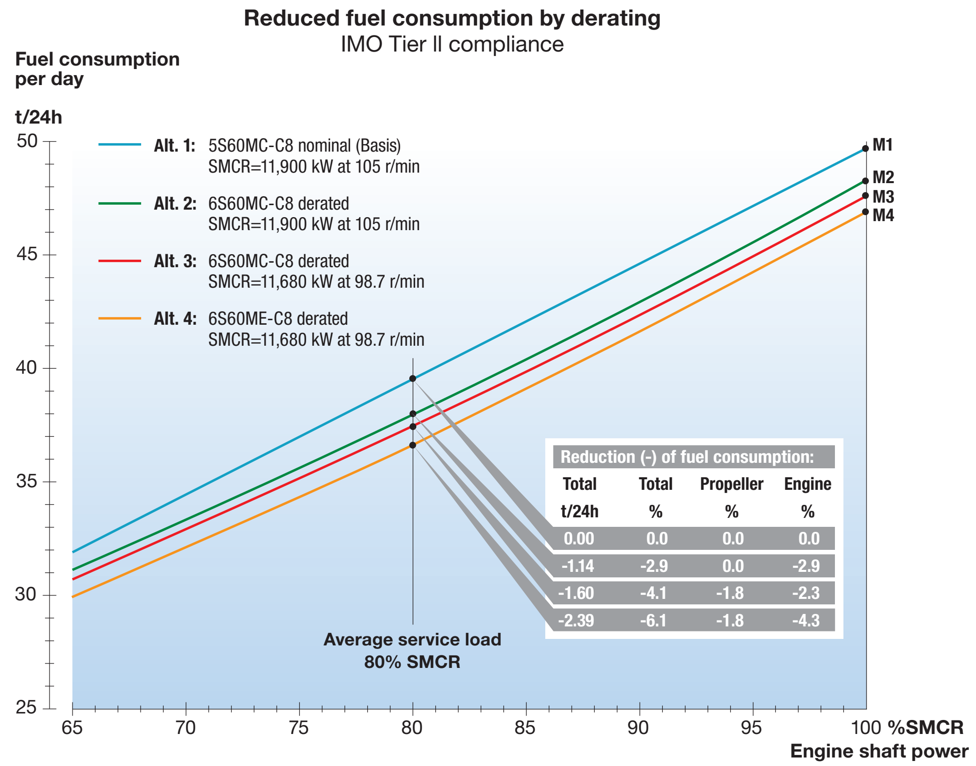

Fig. 1b: Relative fuel consumption in normal service of different derated main engines for a 75,000 dwt Panamax product tanker operating at 15.1 knots

Derating of main engine

When installing a 6S60MC-C8 as Alt. 2, i.e. with one extra cylinder, it is possible to derate this engine to the same SMCR point as the nominally rated 5S60MC-C8, i.e. with SMCR = M2 = M1, and thereby reducing the fuel consumption in service at 80% SMCR by -2.9%, see Fig. 1b.

Increased propeller diameter

Furthermore, when changing the aft-body of the ship it may be possible, as Alt. 3, to install a larger propeller diameter of 7.2 m with a corresponding SMCR = M3 = 11,680 kW x 98.7 r/min valid for a derated 6S60MC-C8.

Reduced fuel consumption per day or per voyage

Main engine 6S60MC-C8

For Alt. 3, Fig. 1b shows a reduction in the fuel consumption of -4.1%, obtained by a combination of improved propeller and main engine efficiencies.

Main engine 6S60ME-C8

A further reduction of the fuel consumption is obtained by installing an electronically controlled main engine as Alt. 4 with the same SMCR = M4 = M3. According to Fig. 1b, the total reduction achieved with a 6S60ME-C8 is -6.1%, i.e. with an extra -2% reduction in the fuel consumption compared with the 6S60MC-C8. The reason is that the ME-C type, compared with the MC-C IMO NO_x Tier II engine type, has a higher engine efficiency as a result of its improved ability to adapt to the NO_x emission requirements of IMO Tier II.

Case Study 2

4,500 teu Panamax Container Vessel

Based on a ship with unchanged propeller diameter, this case study illustrates the potential of reduced fuel consumption by lowering the design ship speed from its original 24.7 knots. The study focuses on the influence of the number of propeller blades and the corresponding impact on the selected main engine types which are able to obtain the design ship speed of 22.0 knots. Together with the main engine types involved, the ship particulars in question are assumed as follows:

Main ship particulars assumed:

Scantling draught	m	13.3
Design draught	m	12.0
Length overall	m	286
Length between pp	m	271
Breadth	m	32.2
Sea margin	%	15
Engine margin	%	10
Type of propeller		FPP
Propeller diameter	m	8.3
No. of propeller blades		target
Design ship speed	kn	target

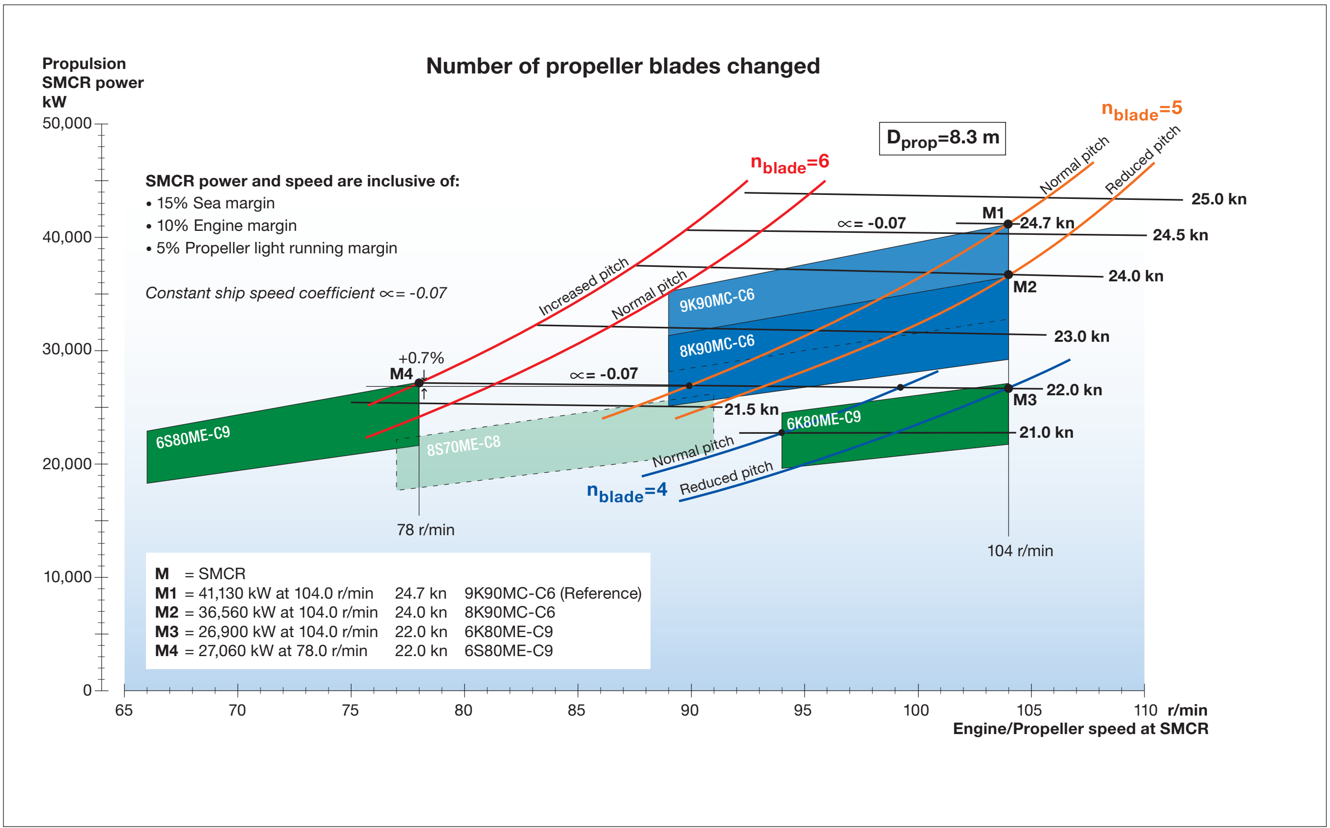

Fig. 2a: Different main engine and propeller layouts and SMCR possibilities (M1, M2, M3, M4) for a 4,500 teu Panamax container vessel with different design ship speeds

5-propeller blades

A nominally rated 9K90MC-C6 with SMCR = M1 = 41,130 kW x 104.0 r/min, a design ship speed of 24.7 knots and 5 propeller blades is used as reference, see Fig. 2a. The optimum (normal pitch) propeller curve with 5 blades through M1 indicates the corresponding SMCR power and speed point M of the main engine for lower design ship speeds.

Point M2 = 36,560 kW x 104.0 r/min is valid for a nominally rated 8K90MC-C6 placed on a propeller curve with reduced pitch and 5 propeller blades and is able to obtain the design ship speed of 24.0 knots.

At 22.0 knots the needed SMCR point is approx. 26,800 kW x 90 r/min. The drawn-in layout diagram of an 8S70ME-C8 with L1 = 26,160 kW x 91.0 r/min, and still valid for a 5-bladed propeller, indicates that the maximum design ship speed obtainable for this engine type is approx. 21.8 knots.

4-propeller blades

When reducing the number of propeller blades from 5 to 4, the corresponding optimum SMCR (normal pitch) propeller curve is moved to the right with an approx. 10% higher propeller speed and is shown together with a similar SMCR propeller curve with reduced propeller pitch.

On the latter curve through 22.0 knots, the SMCR = point M3 = 26,900 kW x 104.0 r/min is shown. This point is placed in the top of the layout diagram of the 6K80ME-C9 engine.

6-propeller blades

The corresponding SMCR = point M4 = 27,060 kW x 78.0 r/min for 22.0 knots with increased propeller pitch is also shown, but now valid for the increased number of propeller blades to be 6, which involves a reduction of the optimum propeller speed. Point M4 is equal to the nominal MCR point of the 6S80ME-C9 engine.

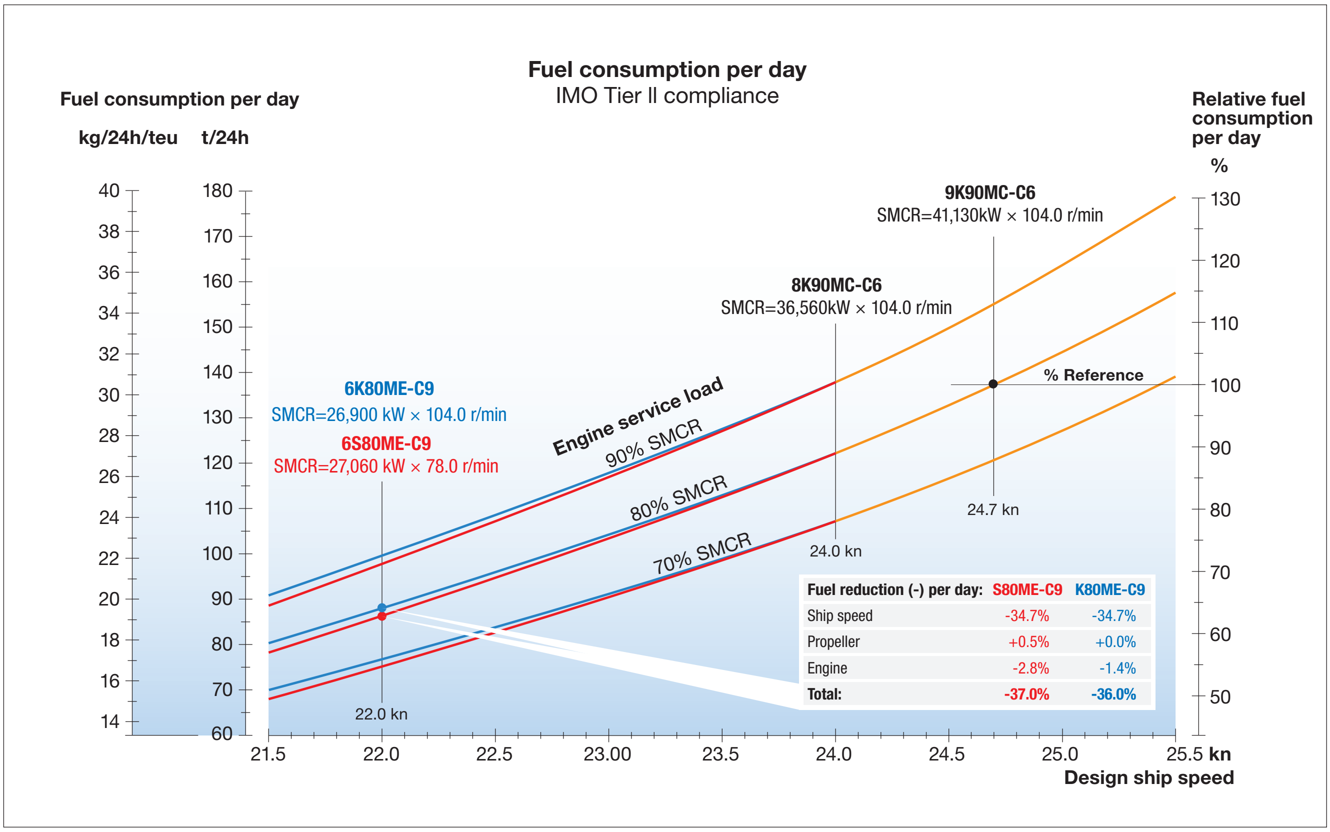

Fig. 2b: Relative fuel consumption per day of different main engines for different design ship speeds of a 4,500 teu Panamax container vessel

Reduced fuel consumption per day

The fuel consumption per day for all the above four alternative main engine cases has been calculated in compliance with IMO Tier II emission demands. The results shown as a function of the design ship speed are shown in Fig. 2b for the engine service loads of 70%, 80% and 90% SMCR.

With 24.7 knots used as a reference and referring to the service load of 80% SMCR, the curves show that it is possible to reduce the daily fuel consumption, when going from 24.7 to 22.0 knots, by approx. -36% for the 6K80ME-C9 engine and by approx. -37% for the 6S80ME-C9 engine.

The super long-stroke 6S80ME-C9 engine with a higher engine efficiency compared with the short-stroke 6K80ME-C9 can obtain a higher reduction.

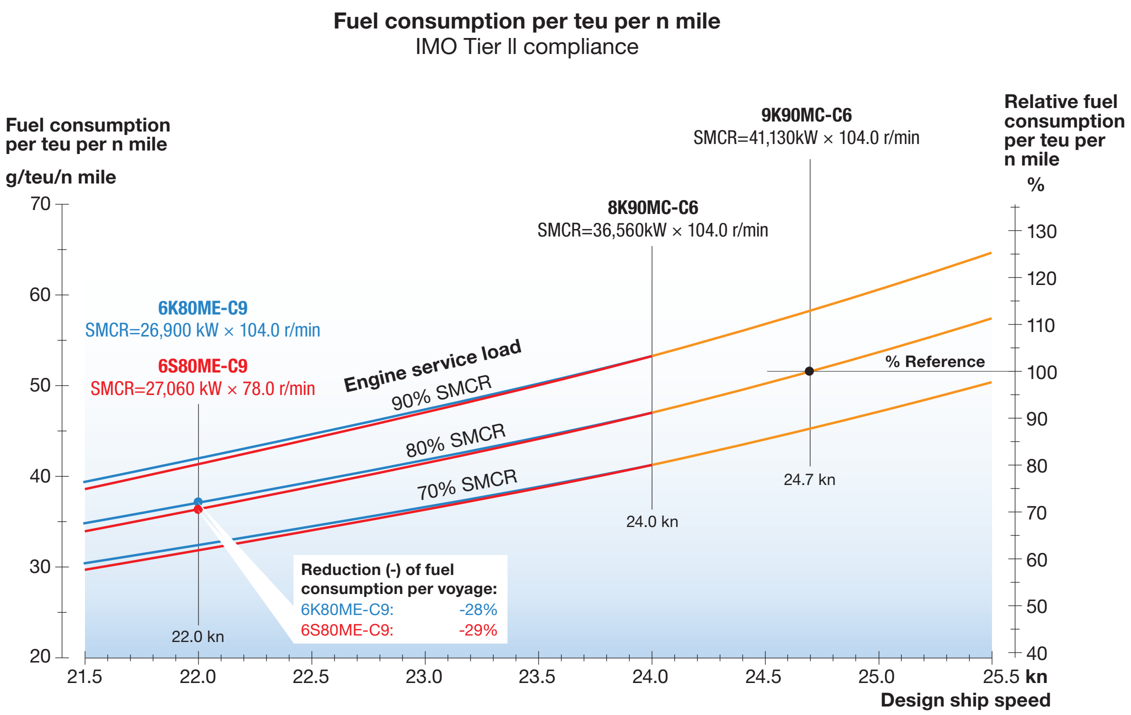

Fig. 2c: Relative fuel consumption per voyage of different main engines for different design ship speeds of a 4,500 teu Panamax container vessel

Reduced fuel consumption per voyage

Fig. 2c shows the similar fuel consumption per nautical mile, i.e. indicates the relative fuel consumption needed per voyage. The result when going from 24.7 knots to 22.0 knots is a total reduction in fuel consumption per voyage of -28% for the 6K80ME-C9 and -29% for the 6S80ME-C9.

Case Study 3

8,000 teu Post-Panamax Container Vessel

Based on 6-bladed propeller blades, but on different propeller diameter sizes, this case study illustrates the potential of reduced fuel consumption when reducing the ship speed. The study focuses on the influence of increased propeller diameters at reduced design ship speeds and the corresponding impact on the selection of main engine type.

The ship particulars in question are:

Propeller diameter of 8.8 m

Main ship particulars assumed:

Scantling draught	m	14.5
Design draught	m	13.0
Length overall	m	323
Length between pp	m	308
Breadth	m	42.8
Sea margin	%	15
Engine margin	%	10
Type of propeller		FPP
No. of propeller blades		6
Propeller diameter	m	target
Design ship speed	kn	target

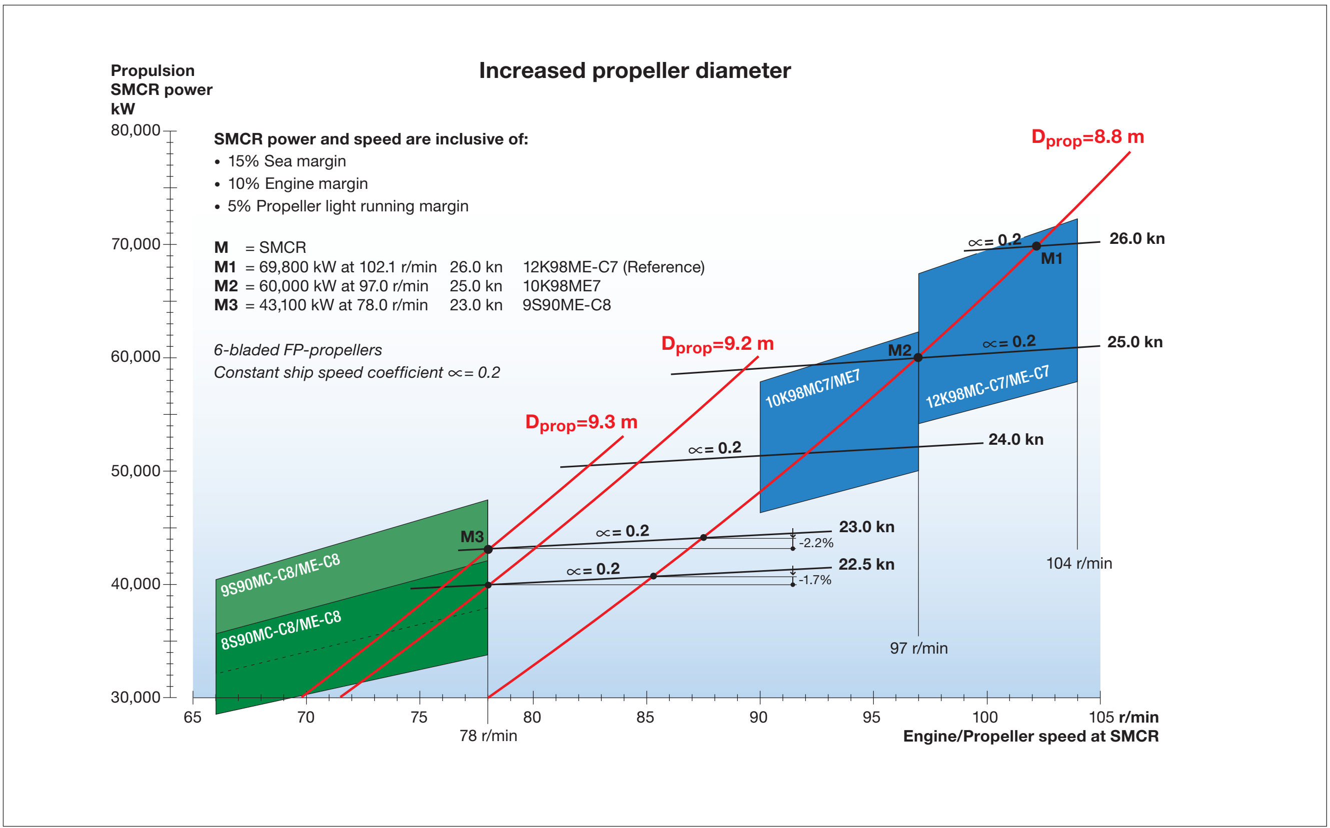

Fig. 3a: Different main engine and propeller layouts and SMCR possibilities (M1, M2, M3) for an 8,000 teu Post-Panamax container vessel with different design ship speeds

The derated 12K98ME-C7 with SMCR = M1 = 69,800 kW x 102.1 r/min is used as reference. The design ship speed is 26.0 knots and the 6-bladed propeller has a diameter of 8.8 m, see Fig. 3a.

With an unchanged propeller diameter of 8.8 m, but now with the reduced design ship speed of 25.0 knots, the required SMCR will be M2 = 60,000 kW x 97.0 r/min and will be met by a 10K98ME7 main engine.

When further reducing the design ship speed to 23.0 knots and still with the same propeller diameter of 8.8 m, the required SMCR will be approx. 44,100 kW x 87.5 r/min.

Increased propeller diameter of 9.3 m

At the reduced design ship speed of 23.0 knots, but now with an increased propeller diameter of 9.3 m, corresponding to 71.5% of the ship's design draught (approx. the maximum possible), the SMCR power and speed will be reduced to M3 = 43,100 kW x 78.0 r/min, see Fig. 3a. This propeller diameter change corresponds approximately to the constant ship speed coefficient α = 0.2.

[α = ln (43,100 kW/44,100 kW) / ln (78.0 r/min/87.5 r/min) = 0.2]

The SMCR point M3 referring to the design ship speed of 23.0 knots is met by the derated 9S90ME-C8 main engine.

Reduced fuel consumption per day

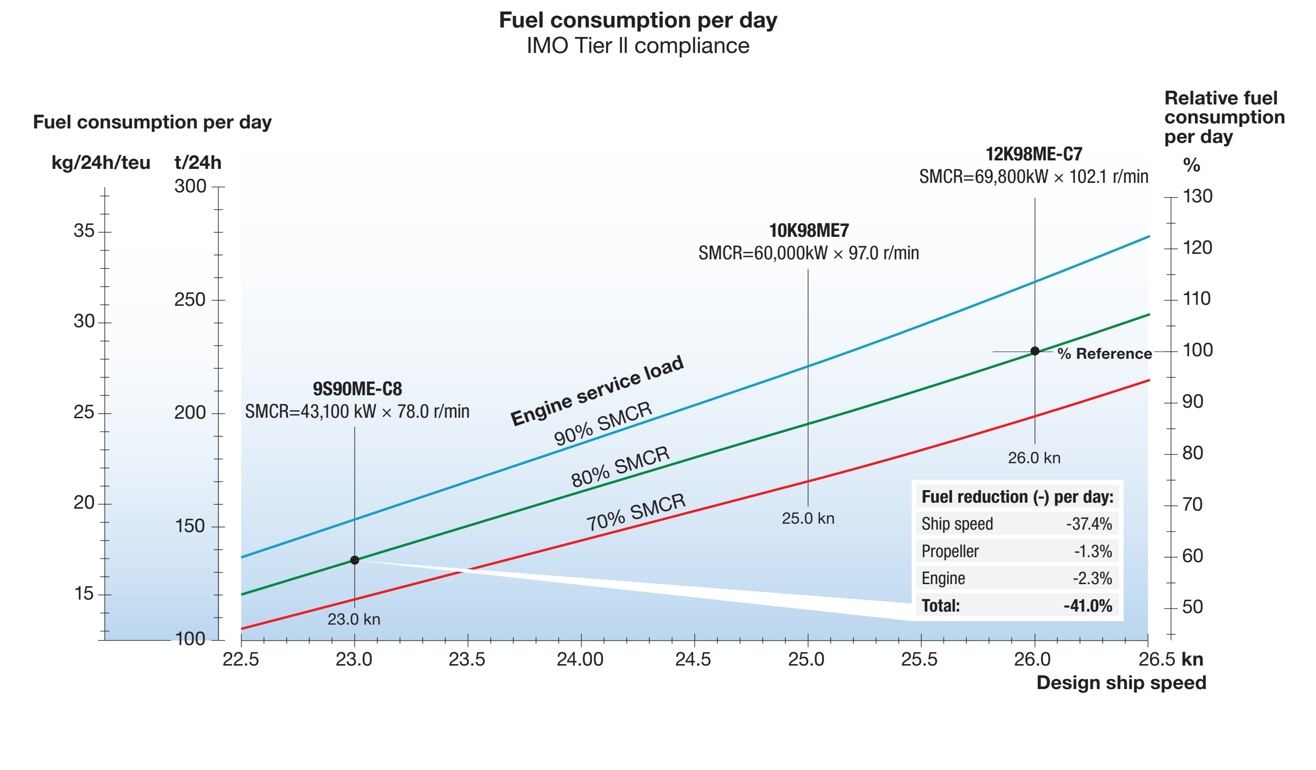

Fig. 3b: Relative fuel consumption per day of different main engines for different design ship speeds of an 8,000 teu Post-Panamax container vessel

The fuel consumption per day of all the above three alternative main engine cases has been calculated in compliance with IMO Tier II emission requirements.

The results shown as a function of the design ship speed are shown in Fig. 3b for the engine service loads of 70%, 80% and 90% SMCR, respectively.

With 26.0 knots used as reference and referring to the average service load of 80% SMCR, the fuel consumption curves show that it is possible to reduce the daily fuel consumption by approx. -41% when replacing the 12K98ME-C7 and 26.0 knots with the 9S90ME-C8 and 23.0 knots .

Of this reduction, the main influence of -37.4% results from the reduced ship speed while -1.3% results from the increased propeller efficiency, and the improved engine efficiency of the super long-stroke S90ME-C engine type, compared with the short-stroke engine type K98ME-C, adds another -2.3% of the total fuel consumption reduction.

Reduced fuel consumption per voy-

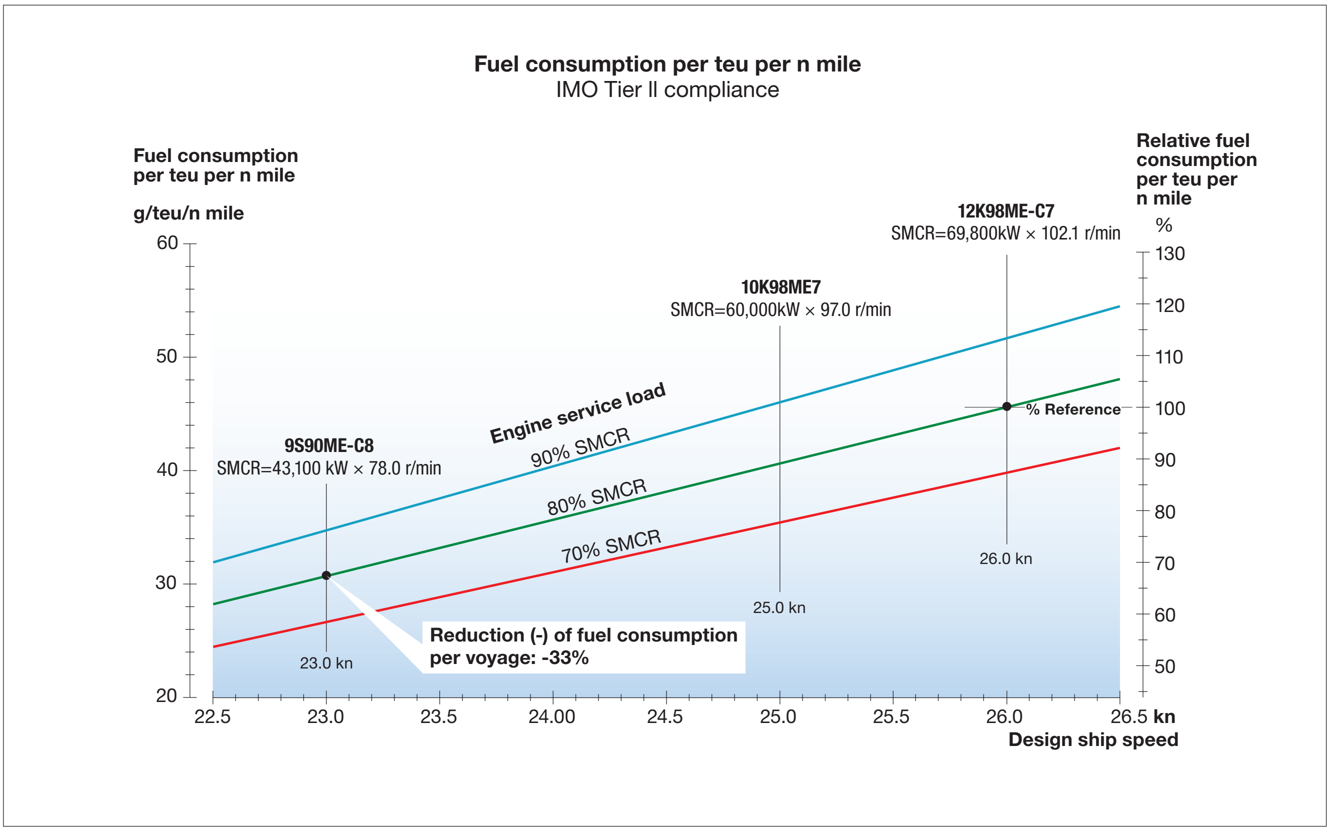

Fig. 3c: Relative fuel consumption per voyage of different main engines for different design ship speeds of an 8,000 teu Post-Panamax container vessel

age

Fig. 3c shows the similar fuel consumption per nautical mile, i.e. the relative fuel consumption needed per voyage. The result when going from 26.0 knots to 23.0 knots is a total reduction in fuel consumption per voyage of -33%.

Summary

The coming political demands for reduction of the CO_2 emissions for merchant ships may cause many attractive, but also more expensive, countermeasures on ships, as for example waste heat recovery systems. However, one of the major parameters – not to forget – is the aftbody design of the ship itself and its propeller in combination with a reduced design ship speed. For example, the combination of a reduced ship speed and an increased propeller diameter and/or a changed number of propeller blades may reveal many new possible main engine selections not normally used for container ships.

Thus, the reliable and high-efficiency super long-stroke MAN B&W two-stroke main engine types such as the S80 and S90 normally used for tankers may also be attractive solutions for the container ships of tomorrow, with around 30% reduced CO_2 emissions per voyage compared with the ships of today.

Additionally, the use of liquid natural gas (LNG) instead of heavy fuel oil may reduce the CO_2 emission by approx. 23% owing to the different chemical makeup of LNG.

This has already been included in the formulation of the design index.

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