



# Propulsion of 2,200-2,800 teu Container Vessel

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# Propulsion of 2,200-2,800 teu Container Vessel

## Introduction

The main ship particulars of 2,200-2,800 teu container vessels are normally approximately as follows: the overall ship length is 210 m, breadth 30 m and scantling draught 11.4-12.0 m, see Fig. 1.

Recent development steps have made it possible to offer solutions which will enable significantly lower transportation costs for larger feeder container vessels as outlined in the following.

One of the goals in the marine industry today is to reduce the impact of CO<sub>2</sub> emissions from ships and, therefore, to reduce the fuel consumption for the

propulsion of ships to the widest possible extent at any load.

This also means that the inherent design CO<sub>2</sub> index of a new ship, the so-called Energy Efficiency Design Index (EEDI), will be reduced. Based on an average reference of the CO<sub>2</sub> emission from existing earlier built container vessels, the CO<sub>2</sub> emission from new container vessels in gram per dwt per nautical mile must be equal to or lower than the reference emission figures valid for the specific container vessel.

This drive may often result in operation at lower than normal service ship speeds compared to earlier, resulting

in reduced propulsion power utilisation. The design ship speed at Normal Continuous Rating (NCR), including 15% sea margin, used to be as high as 22-23 knots. Today, the ship speed may be expected to be lower, possibly 19-20 knots, or even lower.

A more technically advanced development drive is to optimise the aftbody and hull lines of the ship – including bulbous bow, also considering operation in ballast condition. This makes it possible to install propellers with a larger propeller diameter and, thereby, obtaining higher propeller efficiency, but at a reduced optimum propeller speed, i.e. using less power for the same ship speed.



Fig. 1: Large feeder container ship

Furthermore, the wish to reduce fuel costs and thereby to reduce the design ship speed from 22-23 knots to about 19-20 or even lower, may involve lower main engine power, but also a demand to have lower engine speeds.

As the two-stroke main engine is directly coupled with the propeller, the introduction of the ultra long stroke G60ME-C9.2 engine with even lower than usual shaft speed than the existing S60ME-C8.2 will meet this goal. The main dimensions for these engine types, and for the existing L70ME-C8 engine, normally used in the past, are

shown in Fig. 2. Also K80 engine types were often used.

On the basis of a case study of a 2,500 teu feeder container vessel in compliance with IMO Tier II emission rules, this paper shows the influence on fuel consumption when choosing the new G60ME-C9.2 engine compared with the existing S60ME-C8.2 and the earlier and normally used larger L70ME-C8.2 engine. The layout ranges of 6 and 7G60ME-C9.3 engines compared with 6 and 7S60ME-C8.2 together with the existing 7L70ME-C8.2 are shown later in Fig. 4.

## EEDI and Major Ship and Main Engine Parameters

### Energy Efficiency Design Index (EEDI)

The IMO (International Maritime Organisation) based Energy Efficiency Design Index (EEDI) is a mandatory index required on all new ships contracted after 1 January 2013. The index is used as an instrument to fulfil international requirements regarding CO<sub>2</sub> emissions on ships. EEDI represents the amount of CO<sub>2</sub> emitted by a ship in relation to the transported cargo and is measured in gram CO<sub>2</sub> per dwt per nautical mile.

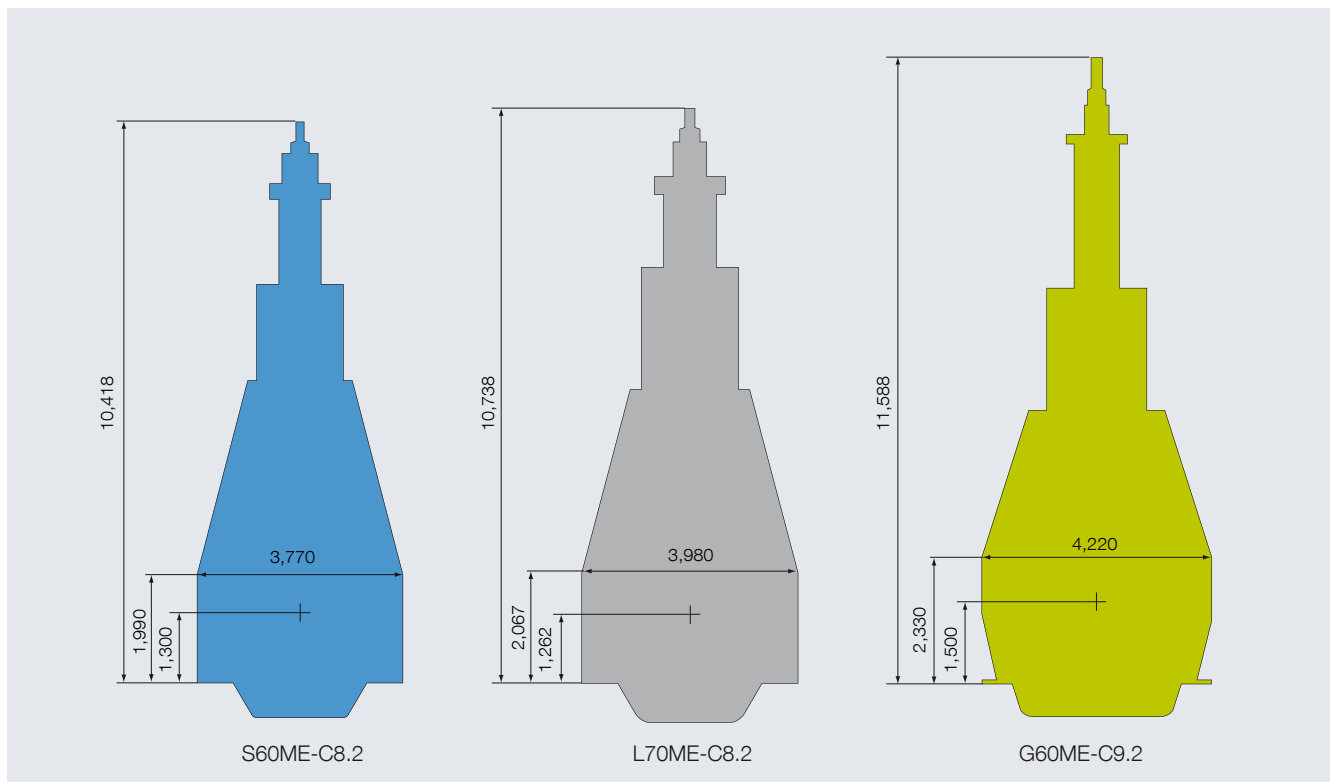


Fig. 2: Main dimensions for the new G60ME-C9.2 and existing S60ME-C8.2 engines and the L70ME-C8 applied earlier

The EEDI value for container ships is calculated on the basis of 70% of the maximum cargo capacity, propulsion power, ship speed, SFOC (Specific Fuel Oil Consumption) and fuel type. Depending on the date of contract, the EEDI is required to be a certain percentage lower than an IMO defined reference value depending on the type and capacity of the ship.

The main engine's 75% SMCR (Specified Maximum Continuous Rating) figure is as standard applied in the calculation of the EEDI figure, in which also the CO<sub>2</sub> emission from the auxiliary engines of the ship is included. However, certain correction factors are applicable, e.g. for installed waste heat recovery systems.

According to the rules finally decided on 15 July 2011, the EEDI of a new ship is reduced to a certain factor compared to a reference value. Thus, a ship built after 2025 is required to have a 30% lower EEDI than the 2013 reference figure, see later in Figs. 8 and 14.

### Major propeller and engine parameters

In general, the highest possible propulsive efficiency required to provide a given ship speed is obtained with the largest possible propeller diameter  $d$ , in combination with the corresponding, optimum pitch/diameter ratio  $p/d$ .

A lower number of propeller blades, for example when going from 5 to 4 blades if possible, means approximately 10% higher optimum propeller speed, and the propeller efficiency will be slightly increased, and vice versa when going from 5 to 6 blades, see later in Fig. 4.

As an example, this is illustrated for a 2,500 teu feeder container ship with a 5-bladed FP propeller and with a service ship speed of 19 knots, see the black curve in Fig. 3. The needed propulsion SMCR (Specified Maximum Continuous Rating) power and speed is shown for a given optimum propeller diameter  $d$  and  $p/d$  ratio.

According to the black curve, the existing propeller diameter of 6.8 m may have the optimum pitch/diameter ratio of 0.95, and the lowest possible SMCR shaft power of about 12,540 kW at about 97 r/min.

The black curve shows that if a bigger propeller diameter of 7.2 m is possible, the necessary SMCR shaft power will be reduced to about 12,280 kW at about 87 r/min, i.e. the bigger the propeller, the lower the optimum propeller speed.

If the pitch for this diameter is changed, the propulsive efficiency will be re-

duced, i.e. the necessary SMCR shaft power will increase, see the red curve.

The red curve also shows that propulsion-wise it will always be an advantage to choose the largest possible propeller diameter, even though the optimum pitch/diameter ratio would involve a too low propeller speed (in relation to the required main engine speed). Thus, when using a somewhat lower pitch/diameter ratio, compared with the optimum ratio, the propeller/engine speed may be increased and will only cause a minor extra power 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 higher the stroke/bore ratio of a two-stroke engine, the higher

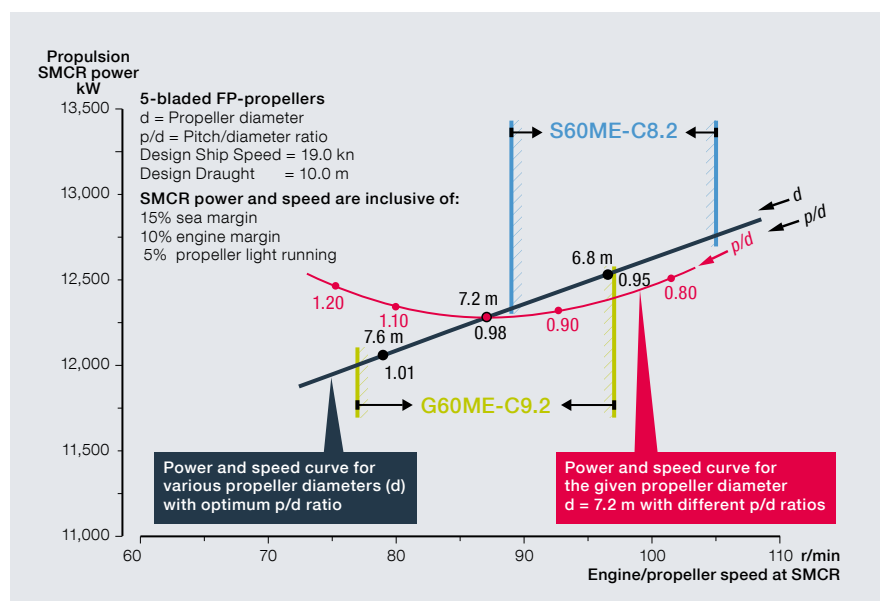


Fig. 3: Influence of propeller diameter and pitch/diameter ratio on SMCR for a 2,500 teu feeder container vessel operating at 19.0 knots

the engine efficiency. This means, for example, that an ultra long stroke engine type, as the G60ME-C9.2, may have a higher efficiency compared with a shorter stroke engine type, like a super long stroke S60ME-C8.2 and a long stroke L70ME-C8.2.

The application of new propeller design technologies may also motivate use of main engines with lower rpm. Thus, for the same propeller diameter, these propeller types can demonstrate an up to 4% improved overall efficiency gain at

the same or a slightly lower propeller speed.

This is valid for propellers with Kappel technology available at MAN Diesel & Turbo, Frederikshavn, Denmark.

Furthermore, due to lower emitted pressure impulses, the kappel propeller requires less tip clearance that can be utilised for installing an even larger propeller diameter, resulting in a further increase of the propeller efficiency.

Hence, with such a propeller type, the advantage of the new low speed G60ME-C9.2 engine can be utilised also in case a correspondingly larger propeller cannot be accommodated.

### 2,500 teu container vessel

For a new 2,500 teu feeder container ship, the following case study illustrates the potential for reducing fuel consumption by reduced ship speed and by increasing the propeller diameter and introducing the G60ME-C9.2 as main engine.

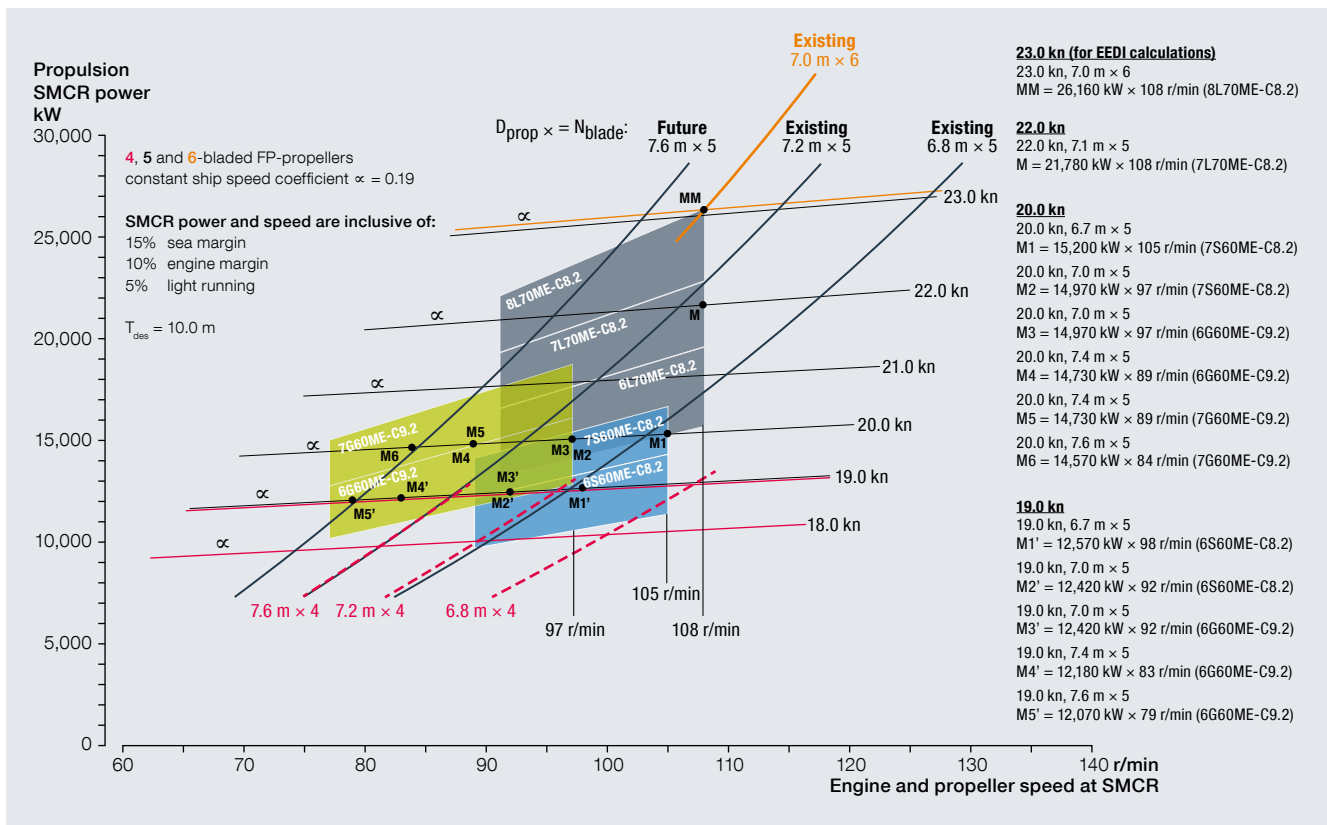


Fig. 4: Different main engine and propeller layouts and SMCR possibilities (M1, M2, M3, etc. for 20.0 knots and M1', M2', M3', etc. for 19.0 knots) for a 2,500 teu container ship operating at 20.0 knots and 19.0 knots, respectively



The ship particulars assumed are as follows:

Deadweight, scantling	dwt	34,800
Scantling draught	m	11.4
Deadweight, design	dwt	27,700
Design draught	m	10.0
Length overall	m	203.0
Length between pp	m	197.0
Breadth	m	30.0
Sea margin	%	15
Engine margin	%	10
Design ship speed	kn (22)	20.0 and 19.0
Type of propeller		FPP
No. of propeller blades		5
Propeller diameter	m	target

Based on the above-stated average ship particulars assumed, we have made a power prediction calculation (Holtrop & Mennen's Method) for different design ship speeds and propeller diameters, and the corresponding SMCR power and speed, point M, for propulsion of the container ship is found, see Fig. 4. The propeller diameter change corresponds approximately to the constant ship speed factor  $\alpha = 0.19$  [ref.  $P_{M2} = P_{M1} \times (n2/n1)^\alpha$ ].

Referring to the two reduced ship speeds of 20.0 knots and 19.0 knots, respectively, three potential main engine types, pertaining layout diagrams and SMCR points have been drawn-in in Fig. 4, and the main engine operating costs have been calculated and described.

For the reduced ship speeds, but without increasing the propeller diameter, the old S60ME-C8.2 may be relevant.

The existing L70ME-C engine type (108 r/min) has often been used in the past as prime movers in the existing 2,200-2,800 teu large feeder container ships with a

relatively high ship speed of 22.0 kn. This engine type is also included in the main engine comparisons when operating at 20.0 and 19.0 knots, respectively.

A comparison between the new G60ME-C9.2 and the existing S60ME-C8.2 and L70ME-C8.2 therefore is of major interest in this paper.

It should be noted that for the S60ME-C8.2 and the G60ME-C9.2, the ship speed stated refers to normal continuous rating NCR = 90% SMCR including 15% sea margin. If based on calm weather, i.e. without sea margin, the obtainable ship speed at NCR = 90% SMCR will be about 0.8 knots higher than the design ship speed.

If based on 75% SMCR and 70% of maximum dwt., as applied for calculation of the EEDI, the ship speed will be about 0.2 knots higher than the design ship speed, still based on calm weather conditions, i.e. without any sea margin.

As the existing L70ME-C8.2 has a relatively high SMCR power, where NCR = 90% refers to the high design ship speed of 22.0 knots, the corresponding NCR at 20.0 and 19.0 knots is lower than 90% SMCR, namely 61.7% and 51.0% SMCR, respectively.

Referring to an existing 2,500 teu container ship earlier designed for 22.0 knots and with the main engine 7L70ME-C8.2 installed, a retrofit solution of the main engine is also described later for operation at 19.0 knots.

## Main Engine Operating Costs – 20.0 knots

The calculated main engine examples are as follows:

### 20.0 kn

1	$D_{prop} = 6.7 \text{ m} \times 5$ M1 = 15,200 kW $\times$ 105 r/min 7S60ME-C8.2
2	$D_{prop} = 7.0 \text{ m} \times 5$ M2 = 14,970 kW $\times$ 97 r/min 7S60ME-C8.2
3	$D_{prop} = 7.0 \text{ m} \times 5$ M3 = 14,970 kW $\times$ 97 r/min 6G60ME-C9.2
4	$D_{prop} = 7.4 \text{ m} \times 5$ M4 = 14,730 kW $\times$ 89 r/min 6G60ME-C9.2
5	$D_{prop} = 7.4 \text{ m} \times 5$ M5 = 14,730 kW $\times$ 89 r/min 7G60ME-C9.2
6	$D_{prop} = 7.6 \text{ m} \times 5$ M6 = 14,570 kW $\times$ 84 r/min 7G60ME-C9.2

### 22.0 kn

1	$D_{prop} = 7.1 \text{ m} \times 5$ M = 21,780 kW $\times$ 108 r/min 7L70ME-C8.2
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The selected main engine examples, among others, make it possible to see the influence of the propeller diameter, installation of one extra cylinder and engine type.

The main engine fuel consumption and operating costs at  $N = \text{NCR} = 90\%$  SMCR, but  $N = 61.7\%$  SMCR for the existing 7L70ME-C8.2, have been calculated for the above seven main engine/propeller cases operating on the reduced ship speed of 20.0 knots, as often used today. Furthermore, the corresponding EEDI has been calculated

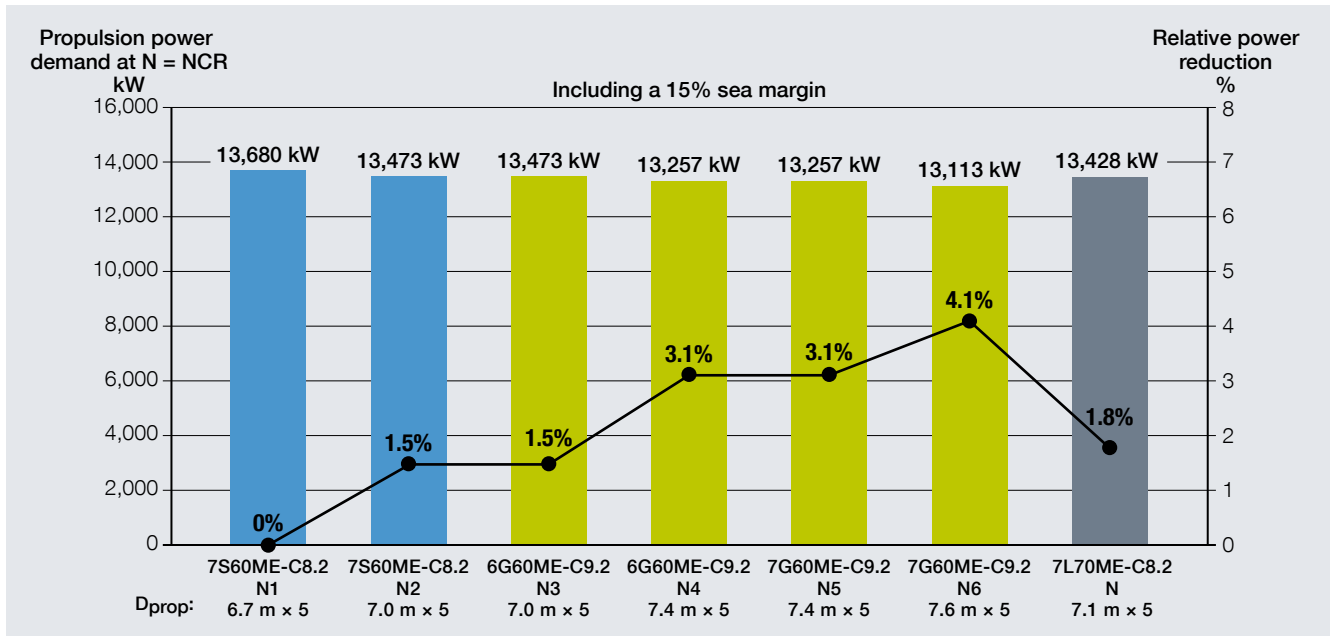


Fig. 5: Expected propulsion power demand at N=NCR = 90% SMCR for 20.0 knots (N = 61.7% SMCR for 7L70ME-C8.2)

on the basis of the 75% SMCR-related figures for 70% of max. dwt. (without sea margin).

### Fuel consumption and EEDI

Fig. 5 shows the influence of the propeller diameter with five propeller blades when going from about 6.7 m to 7.6 m. Thus, N6 for the 7G60ME-C8.2 with a 7.6 m propeller diameter has a propulsion power demand that is about 4.1% lower compared with N1 used as basis valid for the 7S60ME-C8.2. with a propeller diameter of about 6.7 m.

Fig. 6 shows the influence on the main engine efficiency, indicated by the Specific Fuel Oil Consumption, SFOC, for the seven cases. For N1 = 90% M1 used as basis with the 7S60ME-C8.2 SFOC is 164.2 g/kWh, for N5 = 90% M5 with 7G60ME-C8.2 SFOC is 160.5 g/kWh and for N = 61.7% M with 7L70ME-C8.2 SFOC is 165.4 g/kWh. In N5, the SFOC is about 2.3% lower compared with N1.

When multiplying the propulsion power demand at N (Fig. 5) with the SFOC (Fig. 6), the daily fuel consumption is found and is shown in Fig. 7. Compared with

total reduction of fuel consumption of the new 7G60ME-C9.2 at N6 is about 5.6% (see also the above-mentioned savings of 4.1% and 1.5% stated in Figs. 5 and 6).

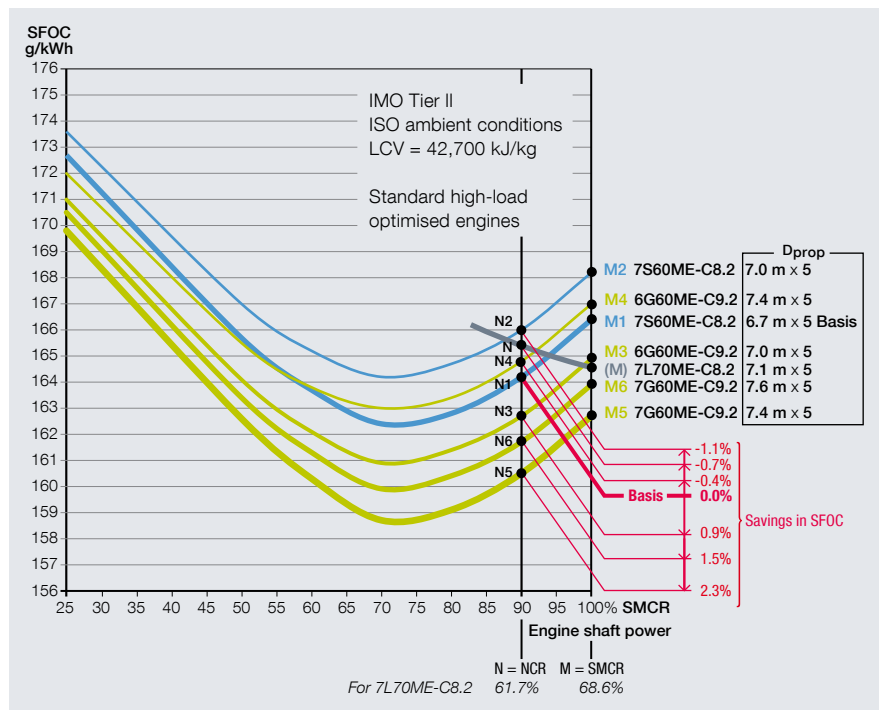


Fig. 6: Expected SFOC for 20.0 knots

The reference and the actual EEDI figures have been calculated and are shown in Fig. 8 (EEDI<sub>ref</sub> = 174.22 x max. dwt<sup>-0.201</sup>, 15 July 2011). As can be seen for all six cases with S60ME-C8.2 and G60ME-C9.2 and layouted for 20.0

knots, the actual EEDI figures are relatively low with the lowest EEDI (60%) for cases 5 and 6 with 7G60ME-C9.2. All these cases may also meet the stricter EEDI reference figure valid after 2025.

For information, the calculated EEDI valid for the old cases 7L70ME-C8.2 (22 kn.) and 8L70ME-C8.2 (23 kn.) is also shown in Fig. 8. The old 8L70ME-C8.2 (23 kn.) is more or less the reason for the 100% EEDI reference figure used today.

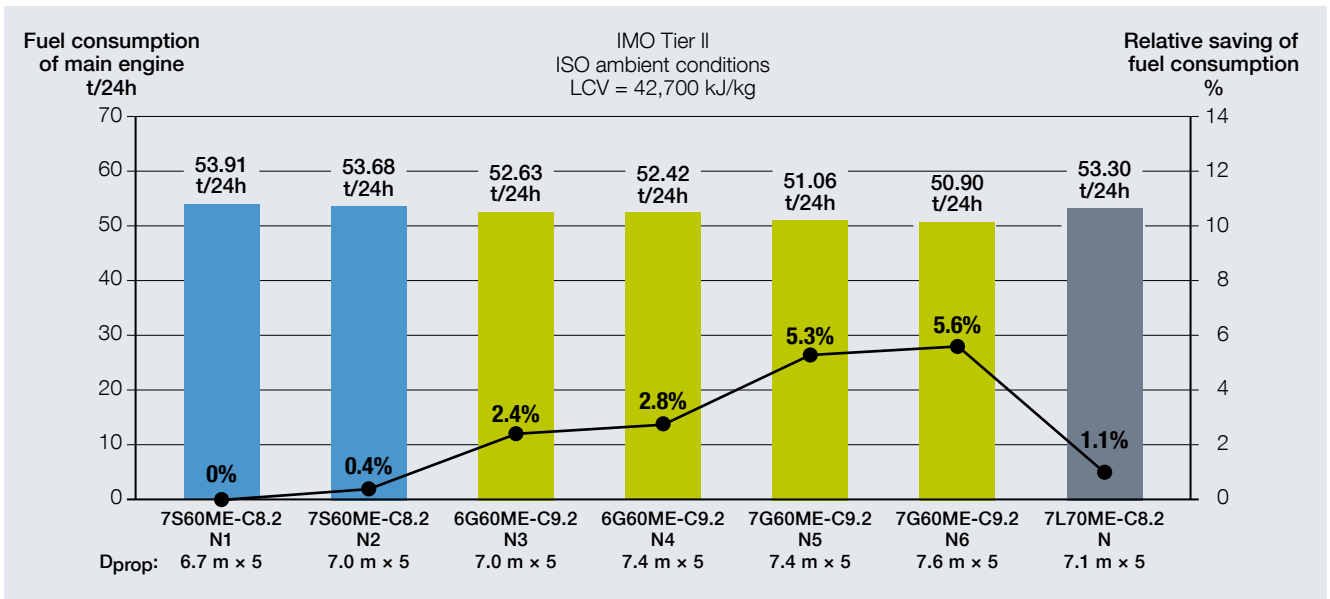


Fig. 7: Expected fuel consumption at N = NCR = 90% SMCR for 20.0 knots (N = 61.7% SMCR for 7L70ME-C8.2)

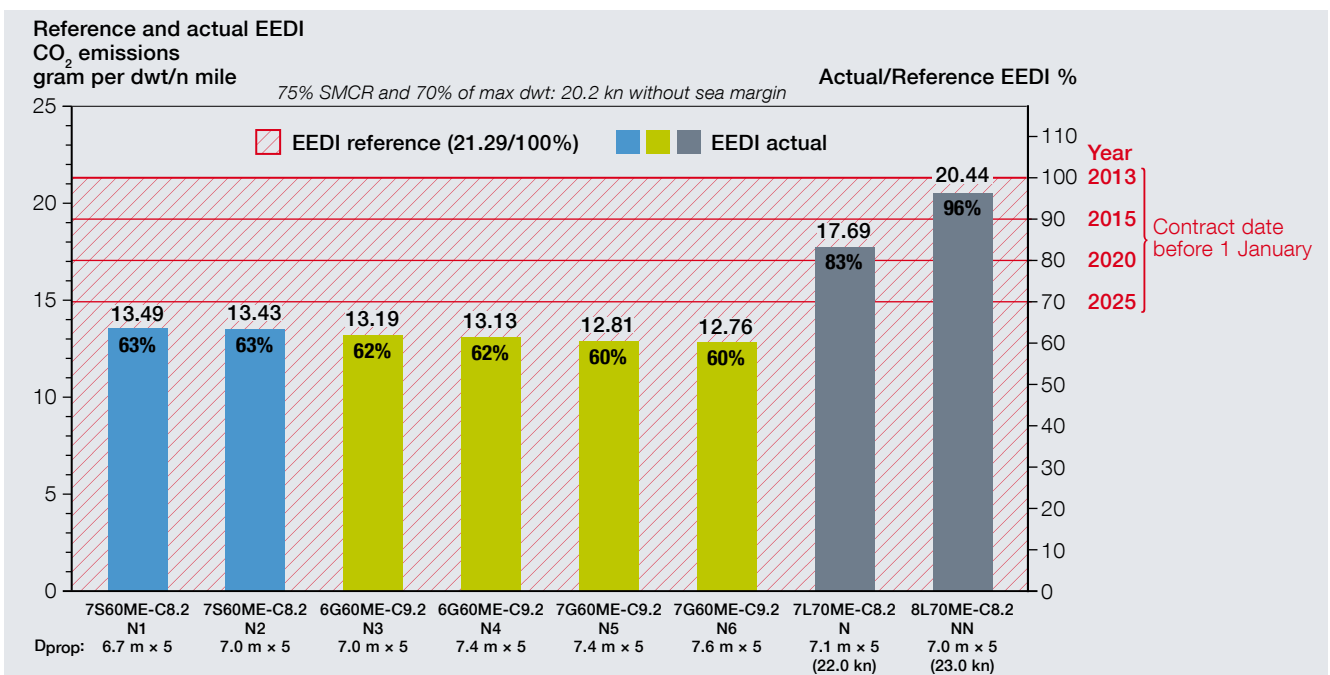


Fig. 8: Reference and actual Energy Efficiency Design Index (EEDI) for 20.0 knots

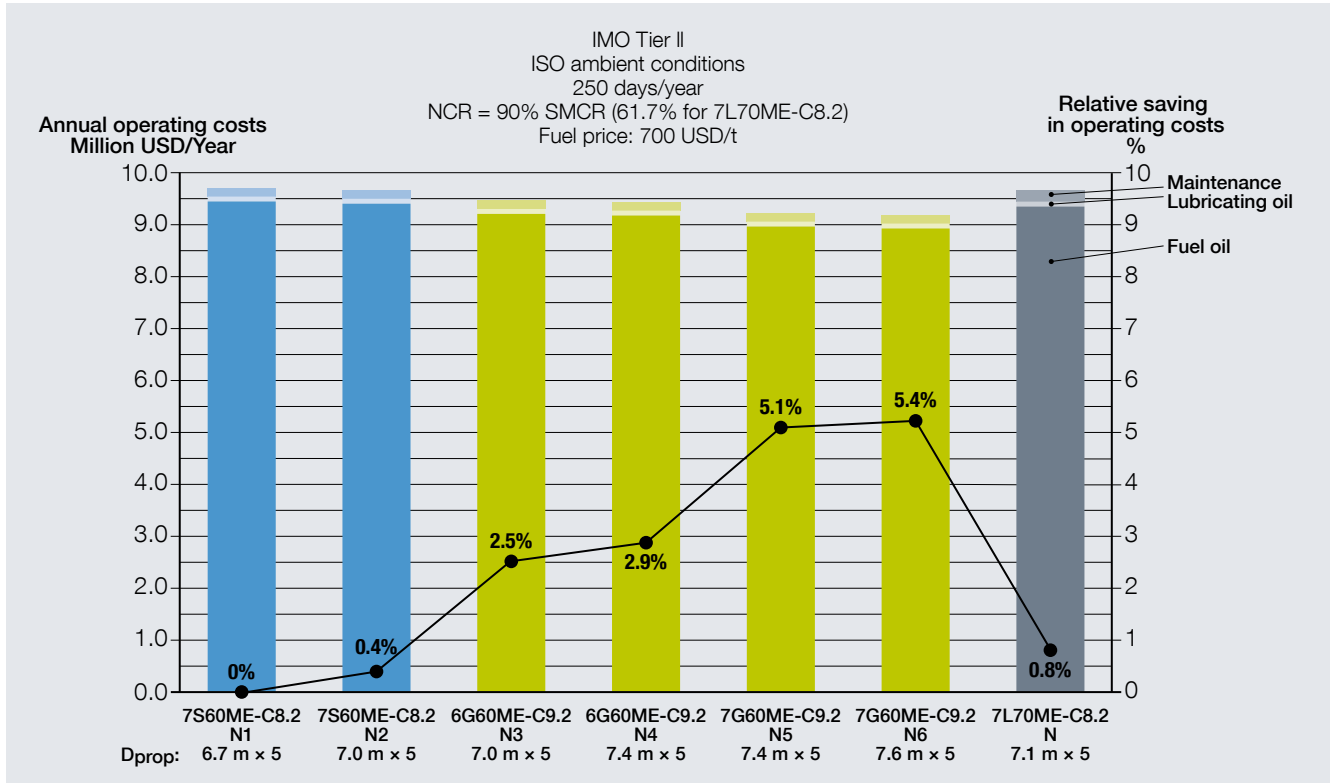


Fig. 9: Total annual main engine operating costs for 20.0 knots

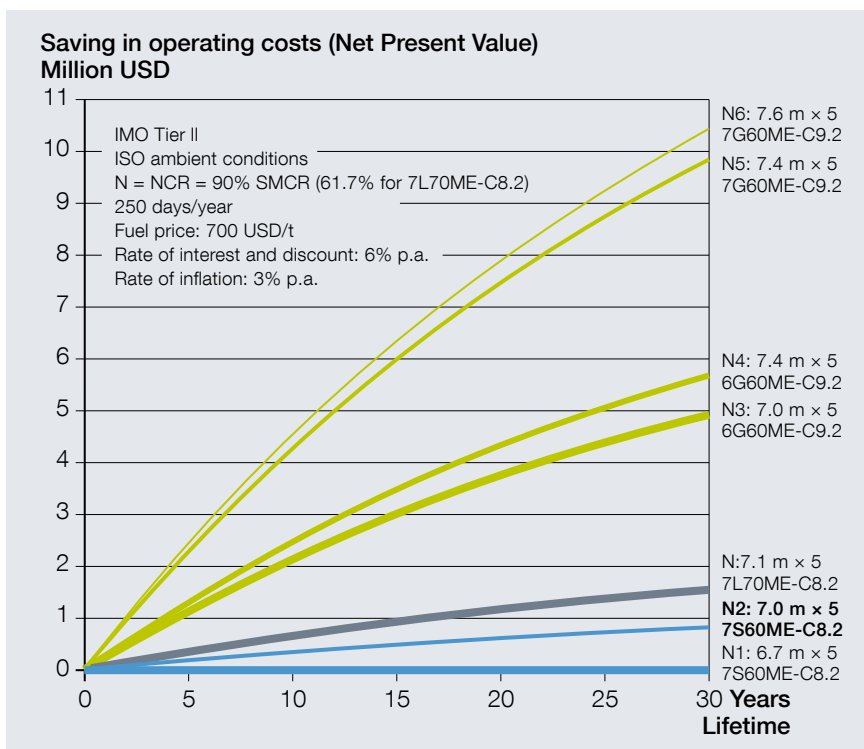


Fig. 10: Relative saving in main engine operating costs (NPV) for 20.0 knots

### Operating costs

The total main engine operating costs per year, 250 days/year, and fuel price of 700 USD/t, are shown in Fig. 9. The lube oil and maintenance costs are shown too. As can be seen, the major operating costs originate from the fuel costs – about 96%.

After some years in service, the relative savings in operating costs in Net Present Value (NPV), see Fig. 10, with the existing 7S60ME-C8.2 used as basis N1 with the propeller diameter of about 6.7 m, indicates an NPV saving for the new 7G60ME-C9.2 engine. After 25 years in operation, the saving is about 8.7 million USD for N5 with 7G60ME-C9.2 with the SMCR speed of 89.0 r/min and propeller diameter of about 7.4 m.

## Main Engine Operating Costs – 19.0 knots

The calculated main engine examples are as follows:

### 19.0 kn

1	$D_{prop} = 6.7 \text{ m} \times 5$ $M1' = 12,570 \text{ kW} \times 98 \text{ r/min}$ 6S60ME-C8.2
2	$D_{prop} = 7.0 \text{ m} \times 5$ $M2' = 12,420 \text{ kW} \times 92 \text{ r/min}$ 6S60ME-C8.2
3	$D_{prop} = 7.0 \text{ m} \times 5$ $M3' = 12,420 \text{ kW} \times 92 \text{ r/min}$ 6G60ME-C9.2
4	$D_{prop} = 7.4 \text{ m} \times 5$ $M4' = 12,180 \text{ kW} \times 83 \text{ r/min}$ 6G60ME-C9.2
5	$D_{prop} = 7.6 \text{ m} \times 5$ $M5' = 12,070 \text{ kW} \times 79 \text{ r/min}$ 6G60ME-C9.2

### 22.0 kn

1	$D_{prop} = 7.1 \text{ m} \times 5$ $M' = 21,780 \text{ kW} \times 108 \text{ r/min}$ 7L70ME-C8.2
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The main engine fuel consumption and operating costs at  $N' = \text{NCR} = 90\%$  SMCR, but  $N' = 51\%$  SMCR for the existing 7L70ME-C8.2, have been calculated for the above six main engine/propeller cases operating on the reduced ship speed of 19.0 knots, which is probably going to be a more normal choice in the future. Furthermore, the EEDI has been calculated on the basis of the 75% SMCR-related figures for 70% of max. dwt. (without sea margin).

### Fuel consumption and EEDI

Fig. 11 shows the influence of the propeller diameter with five propeller blades when going from about 6.7 m to 7.6 m. Thus, N5' for the 6G60ME-C9.2 with an about 7.6 m propeller diameter has

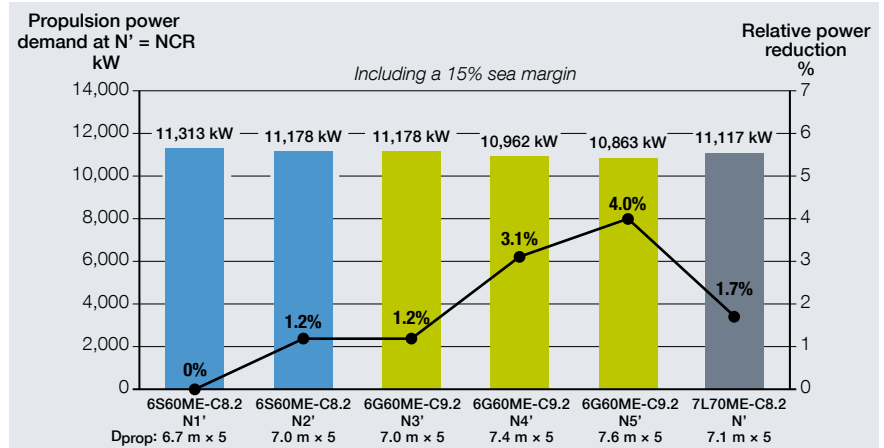


Fig. 11: Expected propulsion power demand at  $N = \text{NCR} = 90\%$  SMCR for 19.0 knots ( $N' = 51\%$  SMCR for 7L70ME-C8.2)

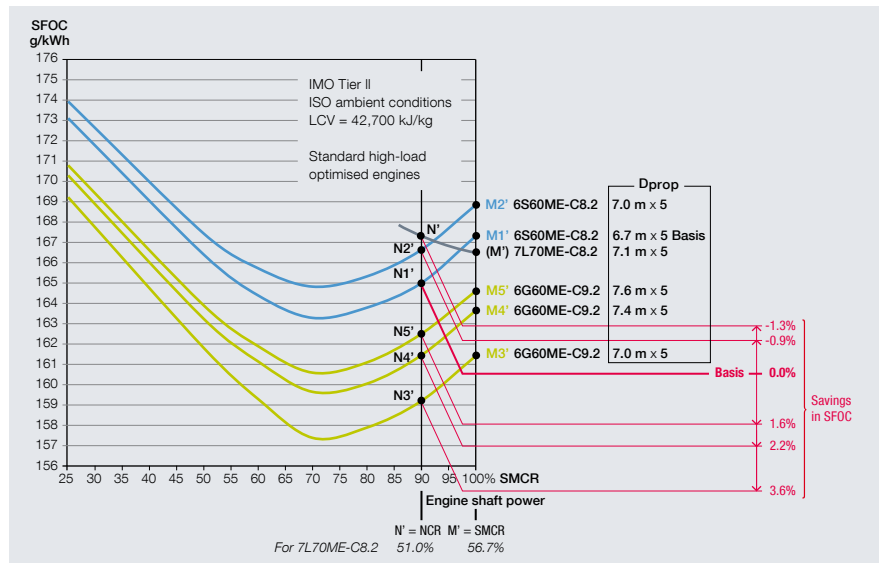


Fig. 12: Expected SFOC for 19.0 knots

a propulsion power demand that is about 4.0% lower compared with the N1' used as basis for the 6S60ME-C8.2 with an about 6.7 m propeller diameter.

Fig. 12 shows the influence on the main engine efficiency, indicated by the Specific Fuel Oil Consumption, SFOC, for the six cases. For N1' = 90% M1' with the 6S60ME-C8.2 used as basis SFOC is 165.1 g/kWh compared with the 159.2 g/kWh for N3' = 90% M3' for the 6G60ME-C9.2, i.e. an SFOC reduction

for N3' of about 3.6%. For  $N' = 51.0\%$  M' with 7L70ME-C8.2 SFOC is 167.3 g/kWh, i.e. an SFOC increase of about 1.3%.

The daily fuel consumption is found by multiplying the propulsion power demand at  $N'$  (Fig. 11) with the SFOC (Fig. 12), see Fig. 13. The total reduction of fuel consumption of the new 6G60ME-C9.2, N5' with propeller diameter 7.6 m, is about 5.5% compared with N1' for the existing 6S60ME-C8.2.

The reference and the actual EEDI figures have been calculated and are shown in Fig. 14 ( $EEDI_{ref} = 174.22 \times \text{max. dwt}^{-0.201}$ , 15 July 2011). As can be seen for all five cases with 6S60ME-C8.2 and 6G60ME-C9.2 and layouted for 19.0 knots, the actual EEDI figures are much lower than the reference figure because of the relatively low ship speed of 19.0 knots.

All these cases may also meet the stricter EEDI reference figure valid after 2025.

As for the earlier stated cases based on 20 knots, the EEDI for the old cases 7L70ME-C8.2 (22 kn.) and 8L70ME-C8.2 (23 kn.) is also shown in Fig. 14 for information.

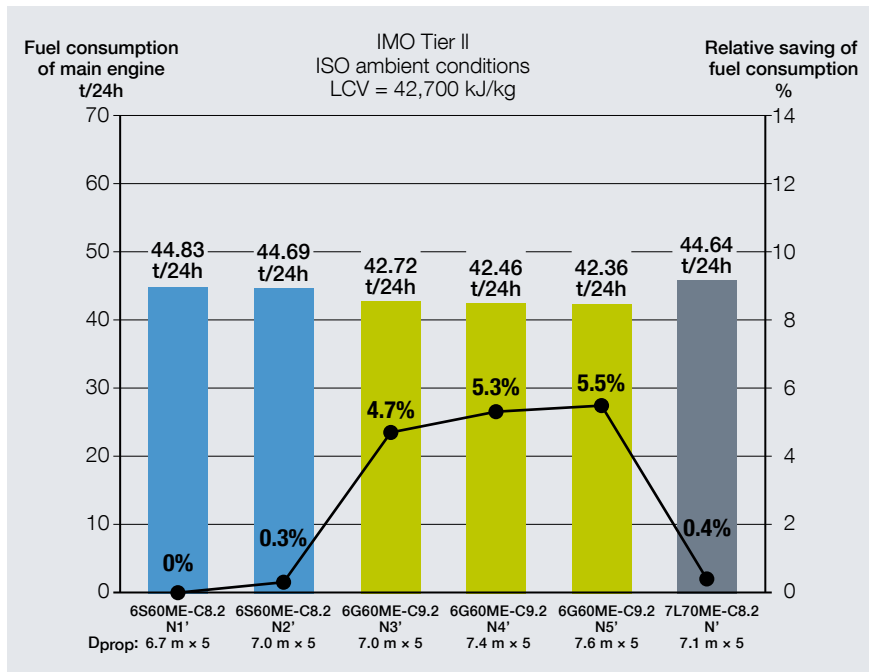


Fig. 13: Expected fuel consumption at  $N' = NCR = 90\%$  SMCR for 19.0 knots ( $N' = 51\%$  SMCR for 7L70ME-C8.2)

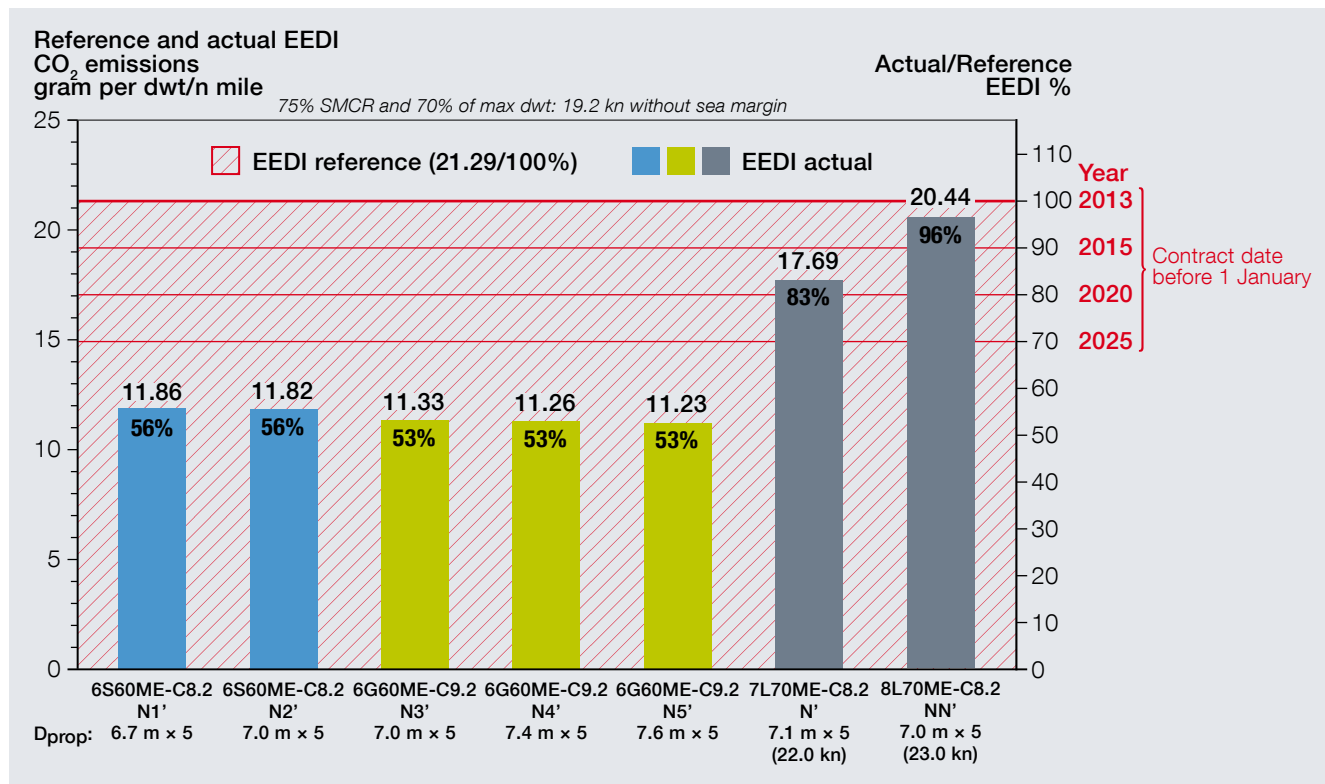


Fig. 14: Reference and actual Energy Efficiency Design Index (EEDI) for 19.0 knots

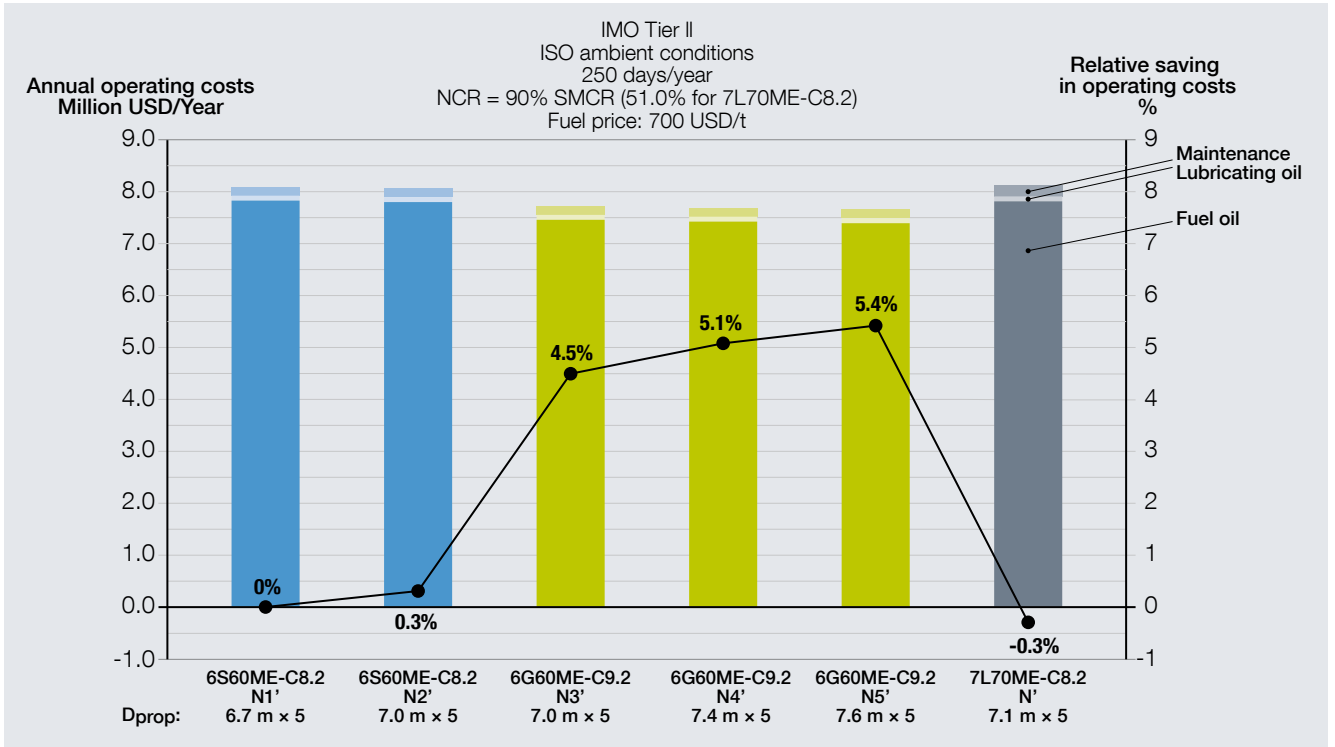


Fig. 15: Total annual main engine operating costs for 19.0 knots

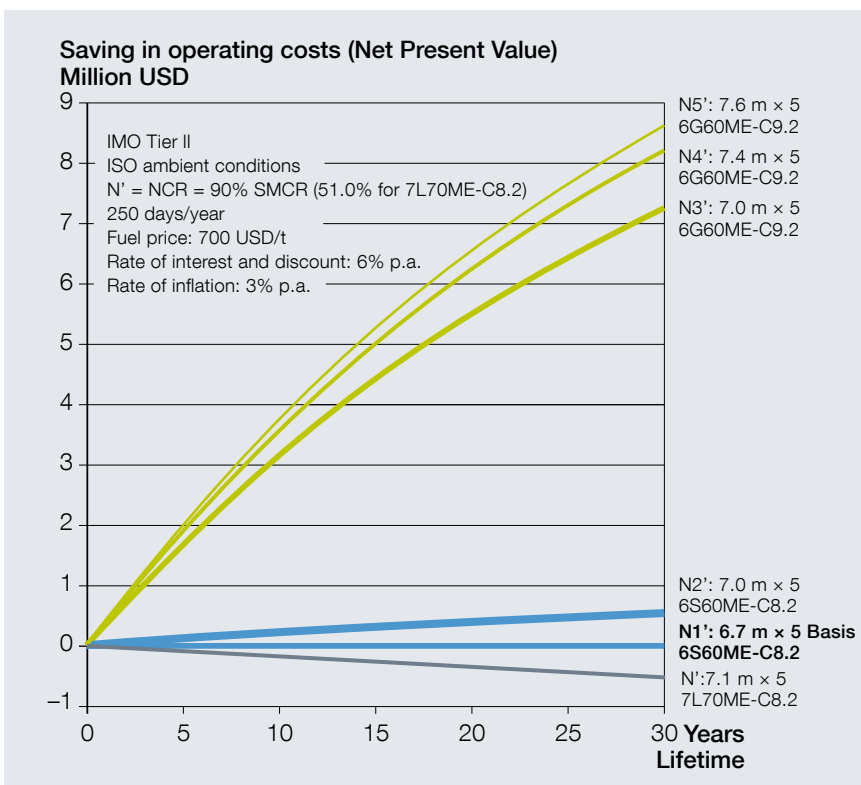


Fig. 16: Relative saving in main engine operating costs (NPV) for 19.0 knots

### Operating costs

The total main engine operating costs per year, 250 days/year, and fuel price of 700 USD/t, are shown in Fig. 15. Lube oil and maintenance costs are also shown at the top of each column. As can be seen, the major operating costs originate from the fuel costs – about 96%.

After some years in service, the relative savings in operating costs in Net Present Value, NPV, see Fig. 16, with the existing 6S60ME-C8.2 with the propeller diameter of about 6.7 m used as basis, indicates an NPV saving after some years in service for the new 6G60ME-C9.2 engine. After 25 years in operation, the saving is about 7.3 million USD for N4' with the 6G60ME-C9.2 with the SMCR speed of 83.0 r/min and propeller diameter of about 7.4 m.

### Retrofit of Existing 7L70ME-C8.2 with LL-EGB for Reduced Ship Speeds

As mentioned earlier in this paper, the container ships built a few years ago were designed for sailing in service at relatively high ship speeds, which at that time was beneficial due to the high freight rates and low fuel prices.

Today, the high fuel prices, low freight rates, and stricter EEDI demands have forced the shipowners to sail with a relatively low ship speed compared to what was originally intended, i.e. to operate the main engine continuously at reduced main engine loads.

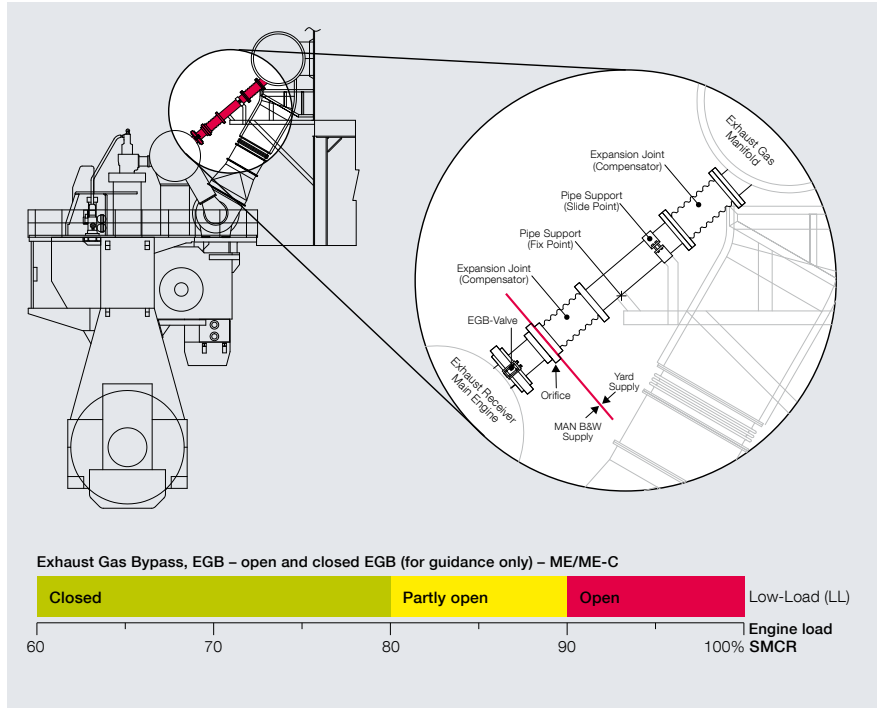


Fig. 17: Exhaust gas bypass for Low Load tuning (LL-EGB)

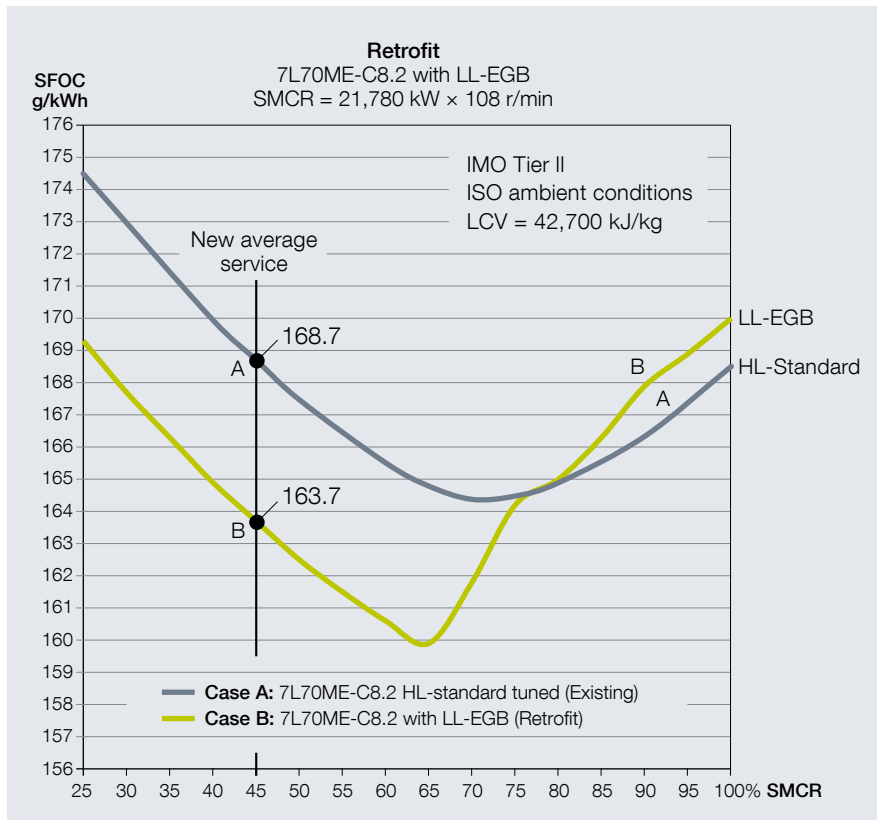


Fig. 18: SFOC reduction for 7L70ME-C8.2 with LL-EGB operating at 45% SMCR at reduced ship speed



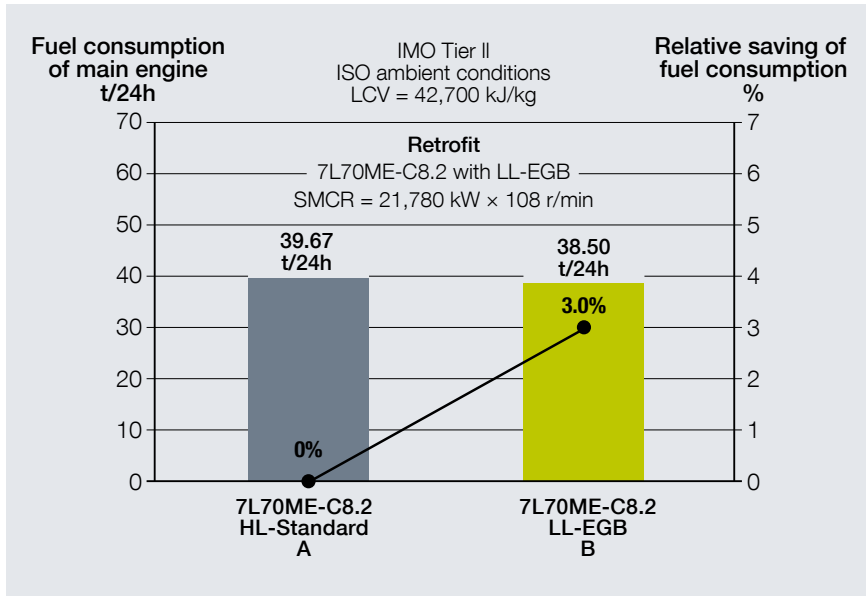


Fig. 19: Expected fuel consumption in average service on 45% SMCR

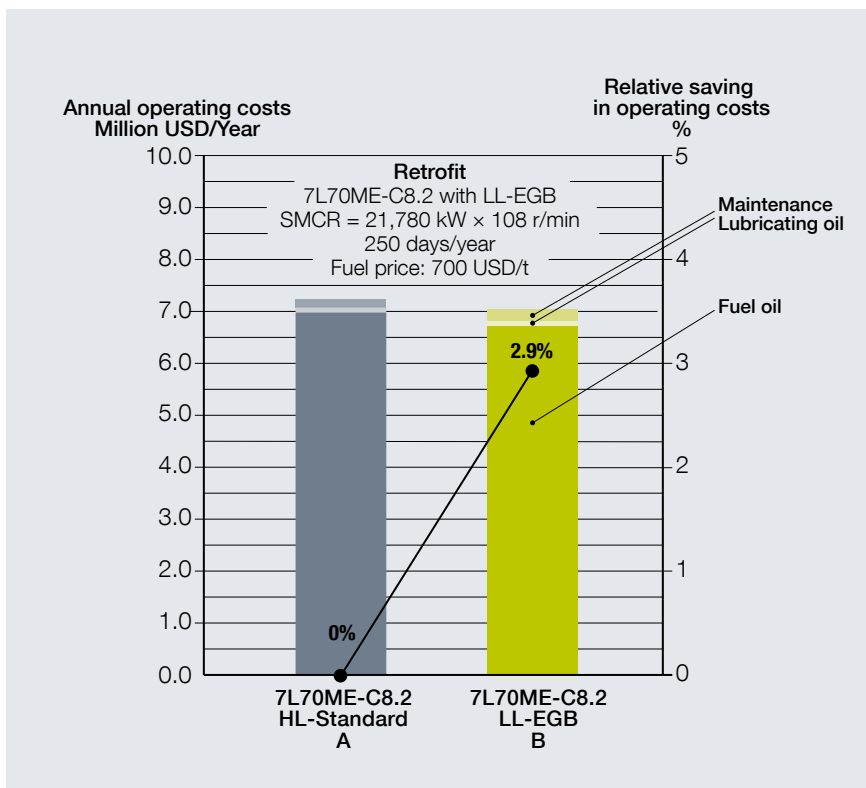


Fig. 20: Total annual main engine operating costs in average service on 45% SMCR

### Exhaust Gas Bypass – Low Load (LL-EGB)

A reduction of SFOC when operating at low loads is possible but is limited by  $\text{NO}_x$  regulations on two-stroke engines. Thus,  $\text{NO}_x$  emission will increase if the SFOC is reduced and vice versa.

Compared to a standard high load optimised ME-C engine, an SFOC reduction of 5g/kWh at low load is possible, but at the expense of a higher SFOC in the high-load range without exceeding the IMO  $\text{NO}_x$  limit.

This is possible by means of an exhaust gas bypass, low load optimised, see Fig. 17. The corresponding SFOC curve for a 7L70ME-C8.2 with SMCR = 21,780 kW x 108 r/min is shown in Fig. 18.

### Saving in operating costs and pay-back time

The existing standard high load optimised 7L70ME-C8.2 with SMCR = 21,780 kW x 108 r/min and design ship speed of 22.0 knots has been used as basis.

The SFOC and fuel consumptions have been calculated valid for the new average engine service load of 45% SMCR which more or less corresponds to the reduced average ship speed of 19 knots, case A, see Figs. 18 and 19.

The corresponding SFOC and fuel consumptions valid for LL-EGB, case B, is also shown in Figs. 18 and 19. The LL-EGB case B has an about 3% lower fuel consumption than for the HL-standard tuned engine, case A.

The annual operating costs are shown in Fig. 20, and the saving in operating

and investment costs (net present value) is shown in Fig. 21. However, the total extra investment costs needed for retrofit with LL-EGB and indicated in Fig. 21, depend very much on the existing turbochargers as some turbocharger layouts may need more comprehensive modifications than others. Each retrofit project, therefore, has to be checked individually from case to case.

In general, the payback time of the LL-EGB modification may be about 2 years.

### Summary

Traditionally, short and long stroke K80 and L70 engines, with relatively high engine speeds, have been applied as prime movers in large feeder container vessels.

Following the efficiency optimisation trends in the market, including reduced ship speeds, the possibility of using even larger propellers has been thoroughly evaluated with a view to using engines with even lower speeds for propulsion.

Container ships with lower ship speeds are indeed compatible with propellers with larger propeller diameters than the current designs, and thus high propeller efficiencies following an adaptation of the aft hull design to accommodate the larger propeller, together with optimised hull lines and bulbous bow, considering operation in ballast conditions.

Even in cases where an increased size of the propeller is limited, the use of propellers based on the new propeller technology will be an advantage.

The new and ultra long stroke G60ME-C9.2 engine type meets this trend in the large feeder container market. This paper indicates, depending on the propeller diameter used, an overall efficiency increase of up to 5-6% when using G60ME-C9.2, compared with the existing main engine type S60ME-C8.2.

The Energy Efficiency Design Index (EEDI) will also be reduced when using the G60ME-C9.2. However, the use of lower design ship speed may by itself reduce the EEDI involving that the stricter EEDI demands in the future may always be met.

For existing container ships designed for high ship speeds, the retrofit of the main engine with a LL-EGB may reduce the operating costs with about 3% when sailing at reduced ship speeds.

The payback time may be about 2 years, but depends on the existing turbocharger configuration.

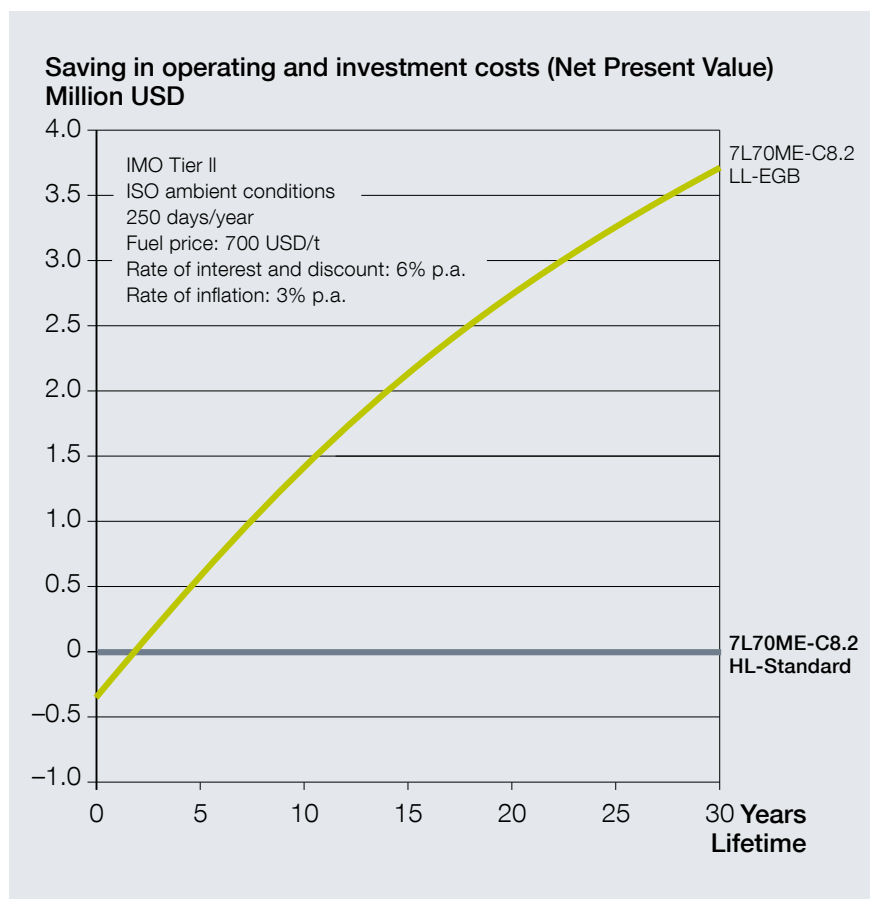


Fig. 21: Relative saving in Net Present Value costs in average service on 45% SMCR











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