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AIR POLLUTION AND ENERGY EFFICIENCY

Draft revised Guidelines for determining minimum propulsion power to maintain the manoeuvrability of ships in adverse conditions

Submitted by Denmark, Germany, Japan, Spain and IACS

SUMMARY

Executive summary:	This document provides the draft revised Guidelines for determining minimum propulsion power to maintain the manoeuvrability of ships in adverse conditions
Strategic direction:	7.3
High-level action:	7.3.2
Output:	7.3.2.4
Action to be taken:	Paragraph 2
Related documents:	MEPC 70/5/20, MEPC 70/INF.30, MEPC 70/INF.33, MEPC 70/INF.35; MEPC 71/5/13, MEPC 71/INF.29; resolutions MEPC.232(65), MEPC.255(67) and MEPC.262(68)

Introduction

1 The annex to this document provides the latest version of the draft revised Guidelines for determining minimum propulsion power to maintain the manoeuvrability of ships in adverse conditions if the outcomes of the work by the research project Energy Efficient Safe Ship Operation (SHOPERA, www.shopera.org) and the Japan's research project are taken into account.

Action requested of the Committee

2 The Committee is invited to note the information provided.

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ANNEX

DRAFT REVISED GUIDELINES FOR DETERMINING MINIMUM PROPULSION POWER TO MAINTAIN THE MANOEUVRABILITY OF SHIPS IN ADVERSE CONDITIONS

1 Purpose

1.1 The purpose of these draft revised Guidelines is to assist Administrations and Recognized Organizations (ROs) in verifying that ships, complying with EEDI requirements set out in regulations on Energy Efficiency for Ships, have sufficient propulsion and steering abilities to maintain the manoeuvrability in adverse conditions, as specified in regulation 21.5 in Chapter 4 of MARPOL Annex VI.

2 Applicability

2.1 These Guidelines are applied in the case of all new tankers, bulk carriers and combination carriers, required to comply with regulations on energy efficiency for ships according to regulation 21 of MARPOL Annex VI, with the size of equal to or more than 20,000 DWT, for Phase 2 and after.

2.2 These Guidelines are intended for ships in unrestricted navigation. For other cases, the Administration should determine appropriate Guidelines, taking the operational area and relevant restrictions into account.

3 Loading condition

3.1 These Guidelines are applied in maximum summer load condition.

4 Acceptance criteria and adverse conditions

4.1 The ship is considered to have sufficient propulsion and steering ability for manoeuvrability in adverse conditions if it satisfies the requirements of sufficient propulsion ability in seaway in accordance with the assessment procedures defined in paragraph 5.

4.2 The wind speed and the significant wave height applied as the adverse conditions are defined as follows:

Ship's length L_{pp} (m)	Wind speed (m/s)	Significant wave height h_s (m)
$L_{pp} < 200$	[19.0]	[4.5]
$200 \leq L_{pp} \leq 250$	Parameters linearly interpolated according to ship's length L_{pp}	
$L_{pp} > 250$	[22.6]	[6.0]

4.3 The assessment is performed in irregular waves described by the JONSWAP spectrum with the peak parameter 3.3 and $\cos^2$-directional spreading. The range of peak wave periods T_P applied in the assessment is from $3.6\sqrt{h_s}$ to the greater one of $5.0\sqrt{h_s}$ or 12.0 seconds, with the step of peak wave period not exceeding 0.5 seconds.

5 Assessment procedures

5.1 Compliance with the requirements 4.1 to 4.3 can be demonstrated using any of the following two assessment procedures:

.1 Minimum Power Lines, in accordance with paragraph 6; or

.2 Minimum Power Assessment, in accordance with paragraph 7.

6 Minimum Power Lines

6.1 Minimum Power Lines values of total installed MCR, in kW, for different types of ships should be calculated as follows:

Minimum Power Line Value = a x (DWT) + b

where:
DWT is the deadweight of the ship in metric tons; and
a and b are the parameters given in Table 1 for tankers, bulk carriers and combination carriers.

Table 1: Parameters a and b for determination of the minimum power line values

Ship type	**a**	**b**
Bulk carrier which DWT is less than 145,000	0.0763	3374.3
Bulk carrier which DWT is 145,000 and over	0.0490	7329.0
Tanker	0.0652	5960.2
Combination carrier	see tanker above	

6.2 The total installed MCR of all main propulsion engines should not be less than the minimum power line value, where MCR is the value specified on the EIAPP Certificate.

7 Minimum Power Assessment

7.1 Minimum Power Assessment is based on the solution of a one degree-of-freedom manoeuvring equation in longitudinal direction to demonstrate that the ship can move with the speed of [2.0 knots] through water in wind and wave directions from head to 30 degrees off-bow for a situation of weather-vaning. The assessment consists of the following steps:

.1 calculate the maximum total resistance in the longitudinal ship direction over wind and wave directions from head to 30 degrees off-bow;

.2 calculate corresponding required brake power and rotation speed of the installed engine, considering the resistance and propulsion characteristics of the ship including appendages; and

.3 check whether the required brake power does not exceed the maximum available brake power of the installed engine, defined according to the engine manufacturer data at the actual rotation speed of the installed engine.

7.2 The maximum total resistance is defined as sum of the resistance in calm-water at the [2.0 knots] forward speed $\mathrm{X_s}$ and the maximum added resistance in seaway $\mathrm{X_a}$ over wind and wave directions from head to 30 degrees off-bow.

8 Requirement

8.1 To satisfy the requirements of Minimum Power Assessment, the required brake power $\mathrm{P_B^{req}}$ in the adverse conditions at the forward speed [2.0 knots] through water should not exceed the available brake power of the installed engine $\mathrm{P_B^{av}}$ in the same conditions:

$$\mathrm{P_B^{req}} \leq \mathrm{P_B^{av}}$$

8.2 The required brake power P_B^{req} is calculated as

$$P_B^{req} = \frac{2\pi n_P Q}{\eta_s \eta_g \eta_R}$$

where

n_P (1/s)	is the propeller rotation rate in the specified adverse conditions and the specified forward speed;
Q (N·m)	is the corresponding propeller torque;
η_s	is the mechanical transmission efficiency of the propeller shaft, approved for the EEDI verification;
η_g	is the gear efficiency, approved for the EEDI verification; and
η_R	is the relative rotative efficiency.

8.3 The available brake power P_B^{av} in the adverse conditions at the forward speed is defined as the maximum engine output at the actual rotation speed, taking into account maximum torque limit, surge/air limit and all other relevant limits in accordance with the engine manufacturer's data.

9 Definition of propulsion point

9.1 The propeller rotation rate n_P and the corresponding propeller advance ratio J in the adverse conditions at the forward speed are defined from the propeller open-water characteristics by solving the following equation:

$$\frac{K_T}{J^2} = \frac{T}{\rho u_a^2 D_P^2}$$

where

K_T	is the thrust coefficient of the propeller, defined from the propeller open-water characteristics;
T (N)	is the required propeller thrust;
ρ (kg/m^3)	is the sea water density, $\rho = 1025$ kg/m^3;
u_a (m/s)	is the propeller advance speed; and
D_P (m)	is the propeller diameter.

9.2 The corresponding torque of the propeller is calculated as

$$Q = K_Q \rho n_P^2 D_P^5$$

where

K_Q	is the torque coefficient of the propeller, defined from the propeller open-water characteristics.

9.3 The propeller advance speed u_a is calculated as:

$$u_a = U(1 - w)$$

where

U (m/s)	is the forward speed [2.0 knots] through water; and
w	is the wake fraction.

10 Definition of required propeller thrust

10.1 The required propeller thrust T is defined from the equation

$$T = \frac{X_s + X_a}{1 - t}$$

where

X_s (N)	is the resistance in calm-water at the forward speed including resistance due to appendages;
X_a (N)	is the maximum added resistance in seaway X_a; and
t	is the thrust deduction taking into account suction force on the ship hull due to propeller thrust.

11 Definition of calm water characteristics

11.1 The calm-water characteristics used for the assessment, such as calm-water resistance, self-propulsion factors and propeller open-water characteristics, are defined by the methods approved for EEDI verification, including:

.1 the calm-water resistance X_s, defined from the following equation:

$$X_s = (1 + k)C_F \frac{1}{2} \rho S U^2$$

where k is the form factor, C_F is the frictional resistance coefficient, ρ is sea water density, ρ = 1025 kg/m^3, S is the wetted surface area of the hull and the appendages and U is the forward speed;

.2 the propeller thrust deduction t, wake fraction w and relative rotative efficiency η_R; and

.3 the propeller open-water characteristics $K_T(J)$ and $K_Q(J)$.

12 Definition of added resistance

12.1 The maximum added resistance in seaway X_a is defined as sum of maximum added resistance due to wind X_w, maximum added resistance due to waves X_d and maximum added rudder resistance due to manoeuvring in seaway X_r over wind and wave directions from head to 30 degrees off-bow.

13 Definition of wind resistance

13.1 The maximum added resistance due to wind $\mathrm{X_w}$ is calculated as

$$\mathrm{X_w} = 0.5\mathrm{X'_w}(\varepsilon)\rho_\mathrm{a} \mathrm{v_{wr}^2} \mathrm{A_F}$$

where

$\mathrm{X'_w}(\varepsilon)$	is the non-dimensional aerodynamic resistance coefficient;
ε (degree)	is the apparent wind angle;
ρ_a (kg/m^3)	is the air density, $\rho_\mathrm{a} = 1.2$ kg/m^3;
$\mathrm{v_{wr}}$ (m/s)	is the relative wind speed, $\mathrm{v_{wr}} = \mathrm{U} + \mathrm{v_w}\cos\mu$;
$\mathrm{v_w}$ (m/s)	is the absolute wind speed, defined by the adverse conditions in paragraph 4.2; and
$\mathrm{A_F}$ (m^2)	is the frontal windage area of the hull and superstructure.

13.2 The maximum added resistance due to wind $\mathrm{X_w}$ is defined as maximum over wind directions from head $\varepsilon = 0$ to 30 degrees off-bow $\varepsilon = 30$.

13.3 The non-dimensional aerodynamic resistance coefficient $\mathrm{X'_w}$ is defined from wind tunnel tests or equivalent methods verified by the Administrations or the Recognised Organisations. Alternatively, it can be assumed with $\mathrm{X'_w} = 1.1$, as the maximum over wind directions from head to 30 degrees off-bow. If deck cranes are installed in the ship and the lateral projected area of the deck cranes is equal to or exceeds 10% of the total lateral projected area above the waterline of the ship, $\mathrm{X'_w} = 1.4$ should be assumed instead of $\mathrm{X'_w} = 1.1$.

14 Definition of added resistance due to waves

14.1 The maximum added resistance due to waves $\mathrm{X_d}$ is defined in accordance with either

.1 expression

$$\mathrm{X_d} = 1336(5.3 + \mathrm{U})\left(\frac{\mathrm{B} \cdot \mathrm{d}}{\mathrm{L_{PP}}}\right)^{0.75} \cdot \mathrm{h_s^2}$$

where

$\mathrm{L_{PP}}$ (m)	is the length of the ship between perpendiculars;
B	is the breadth of the ship;
d	is the draft at the specified condition of loading; and
$\mathrm{h_s}$ (m)	is the significant wave height, defined according to paragraph

This expression defines the maximum added resistance over wave directions from head to 30 degrees off-bow.

.2 or spectral method

$$\mathrm{X_d} = 2\int_0^\infty \int_0^{2\pi} \frac{\mathrm{X_d}(\mathrm{U}, \mu', \omega')}{\mathrm{A}^2} \mathrm{S}_{\varsigma\varsigma}(\omega')\mathrm{D}(\mu - \mu')\, \mathrm{d}\omega'\, \mathrm{d}\mu'$$

where

$\frac{X_d}{A^2}$ (N/m²)	is the quadratic transfer function of the added resistance in regular waves and A is the wave amplitude;
$S_{\varsigma\varsigma}(\omega')$	is the seaway spectrum specified as JONSWAP spectrum with the peak parameter 3.3;
$D(\mu - \mu')$	is the spreading function of wave energy with respect to mean wave direction specified as $\cos^2$-directional spreading;
ω' (rad/s)	is the wave frequency of component;
μ (rad)	is the encountered angle between ship and wave; and
μ' (rad)	is the direction of the wave component.

14.2 The maximum added resistance due to waves X_d is defined as maximum over wave directions from head $\mu = 0$ to 30 degrees off-bow $\mu = 30$.

14.3 The added resistance in short-crested irregular head waves may be regarded as the maximum added resistance over wave directions from head to 30 degrees off-bow, because in short-crested waves, the maximum added resistance over wave directions from head waves to 30 degrees off-bow occurs in head waves.

14.4 The spreading function $D(\mu - \mu')$ is defined as $\cos^2$-directional spreading as shown in paragraph 4.3. Alternatively, long-crested seaway may be assumed with $D(\mu - \mu') = 1$; in this case, the maximum added resistance due to waves X_d can be determined by multiplying the added resistance in long-crested irregular head waves by the correction factor 1.3, to consider that maximum of the added resistance in long-crested waves does not always correspond to head wave direction.

14.5 The quadratic transfer functions of added resistance in regular waves $\frac{X_d}{A^2}$ are defined from seakeeping tests or equivalent methods verified by the Administrations or the Recognised Organisations. Alternatively, the semi-empirical method specified in appendix of this document can be used.

15 Definition of added rudder resistance due to manoeuvring in seaway

15.1 The maximum additional rudder resistance due to manoeuvring in seaway X_r may be calculated for practicality in a simplified way as

$$X_r = 0.03 \cdot T,$$ where T is the propeller thrust.

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APPENDIX

SEMI-EMPIRICAL METHOD FOR QUADRATIC TRANSFER FUNCTIONS OF ADDED RESISTANCE IN REGULAR WAVES

The method for the calculation of the quadratic transfer functions of added resistance given in this appendix can be applied to wave directions from head to beam. Therefore, this method can be used for obtaining the added resistance in short-crested irregular waves of the head mean wave direction.

The quadratic transfer functions of added resistance in regular head to beam waves $\mathrm{X}'_{\mathrm{d}} = \frac{\mathrm{X}_{\mathrm{d}}}{\mathrm{A}^2}$, N/m^2, can be calculated as a sum

$$\mathrm{X}'_{\mathrm{d}} = \mathrm{X}'_{\mathrm{dM}} + \mathrm{X}'_{\mathrm{dR}}$$

of $\mathrm{X}'_{\mathrm{dM}}$, the component of added resistance due to motion (radiation) effect, and $\mathrm{X}'_{\mathrm{dR}}$, the component of added resistance due to reflection (diffraction) effect in regular waves.

The expression of X'_{dM} is given as follows:

$$\mathrm{X}'_{\mathrm{dM}} = 4\rho g \frac{B^2}{L_{pp}} a_1 a_2 \overline{\omega}^{b_1} e^{\frac{b_1}{d_1}\left(1-\overline{\omega}^{d_1}\right)}$$

where

$$\overline{\omega} = \begin{cases} 2.142\sqrt[3]{k_{yy}}\sqrt{\frac{L_{pp}}{\lambda}}\left[1-\frac{0.111}{C_B}\left(\ln\frac{B}{d}-\ln 2.75\right)\right]\frac{(2-\cos\beta)}{3}(Fr+0.62) & \text{for } Fr < 0.1 \\ 2.142\sqrt[3]{k_{yy}}\sqrt{\frac{L_{pp}}{\lambda}}\left[1-\frac{0.111}{C_B}\left(\ln\frac{B}{d}-\ln 2.75\right)\right]\frac{(2-\cos\beta)}{3}Fr^{0.143} & \text{for } Fr \geq 0.1 \end{cases}$$

$$a_1 = 60.3 C_B^{1.34}\left(4\mathrm{k}_{\mathrm{yy}}\right)^2 \left(\frac{0.87}{C_{\mathrm{B}}}\right)^{-(1+\mathrm{Fr})\cos\beta} \left(\ln\frac{\mathrm{B}}{\mathrm{d}}\right)^{-1} \frac{(1-2\cos\beta)}{3} \quad \text{for } \frac{\pi}{2} \leq \beta \leq \pi$$

$$a_2 = \begin{cases} 0.0072 + 0.1676 Fr & \text{for } Fr < 0.12 \\ Fr^{1.5} exp(-3.5Fr) & \text{for } Fr \geq 0.12 \end{cases}$$

for $C_B > 0.75$

$$\mathrm{b}_1 = \begin{cases} 11.0 & \text{for } \overline{\omega} < 1 \\ -8.5 & \text{elsewhere} \end{cases}$$

$$\mathrm{d}_1 = \begin{cases} 566\left(\frac{\mathrm{L}_{\mathrm{PP}}}{\mathrm{B}}\right)^{-2.66} & \text{for } \overline{\omega} < 1 \\ -566\left(\frac{\mathrm{L}_{\mathrm{PP}}}{\mathrm{B}}\right)^{-2.66} \times 6 & \text{elsewhere} \end{cases}$$

for $C_B \leq 0.75$

$$\mathrm{b}_1 = \begin{cases} 11.0 & \text{for } \overline{\omega} < 1 \\ -8.5 & \text{elsewhere} \end{cases}$$

$$\mathrm{d}_1 = \begin{cases} 14.0 & \text{for } \overline{\omega} < 1 \\ -566\left(\frac{\mathrm{L}_{\mathrm{PP}}}{\mathrm{B}}\right)^{-2.66} \times 6 & \text{elsewhere} \end{cases}$$

where

β= $\pi - \mu$	is the wave direction, $\beta=\pi$ means head seas;
λ (m)	is the length of the incident wave;
B (m)	is the beam of the ship;
d (m)	is the draft of the ship; and
k_{yy}	is the non-dimensional radius of gyration of pitch.

The expression of $\mathrm{X}'_{\mathrm{dR}}$ is given as follows:

$$\mathrm{X}'_{\mathrm{dR}} = \sum_{\mathrm{i}=1}^{4} {\mathrm{X}'_{\mathrm{dR}}}^{\mathrm{i}}$$

where

${\mathrm{X}'_{\mathrm{dR}}}^{\mathrm{i}}$ is the added resistance due to reflection/diffraction effect of the S_i waterline segment, as shown in Figure 1.

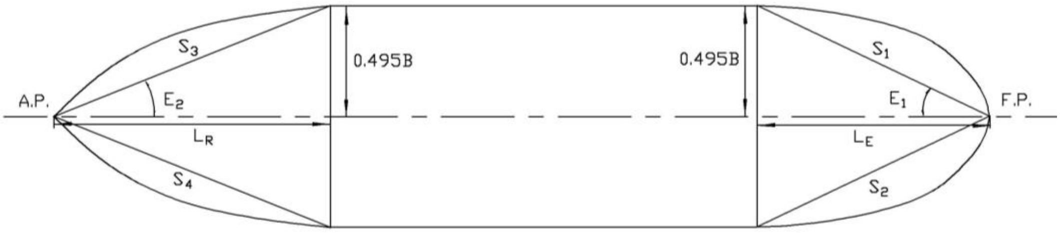

Figure 1: Sketch of the waterline profile of a ship and related definitions

when $E_1 \leq \beta \leq \pi$

$${X'_{dR}}^{1} = \frac{2.25}{4}\rho g B \alpha_{d^*}\left\{\sin^2(E_1-\beta) + \frac{2\omega_0 U}{g}\left[\cos\mathrm{E}_1\cos(E_1-\beta) - \cos\beta\right]\right\}\left(\frac{0.87}{C_B}\right)^{(1+4\sqrt{Fr})f(\beta)}$$

when $\pi - E_1 \leq \beta \leq \pi$

$${X'_{dR}}^{2} = \frac{2.25}{4}\rho g B \alpha_{d^*}\left\{\sin^2(E_1+\beta) + \frac{2\omega_0 U}{g}\left[\cos\mathrm{E}_1\cos(E_1+\beta) - \cos\beta\right]\right\}\left(\frac{0.87}{C_B}\right)^{(1+4\sqrt{Fr})f(\beta)}$$

when $0 \leq \beta \leq \pi - E_2$

$${X'_{dR}}^{3} = -\frac{2.25}{4}\rho g B \alpha_{d^*}\left\{\sin^2(E_2+\beta) + \frac{2\omega_0 U}{g}\left[\cos\mathrm{E}_2\cos(E_2+\beta) - \cos\beta\right]\right\}$$

when $0 \leq \beta \leq E_2$

$${X'_{dR}}^{4} = -\frac{2.25}{4}\rho g B \alpha_{d^*}\left\{\sin^2(E_2-\beta) + \frac{2\omega_0 U}{g}\left[\cos\mathrm{E}_2\cos(E_2-\beta) - \cos\beta\right]\right\}$$

where

ω_0 is the frequency of the incident wave;

α_{d^*} is the draft coefficient, calculated as

$$\alpha_{d^*} = \begin{cases} 0 & \text{for } \dfrac{\lambda}{\mathrm{L_{pp}}} > 2.5 \\ 1 - \exp\left[-4\pi\left(\dfrac{d^*}{\lambda} - \dfrac{d^*}{2.5L_{pp}}\right)\right] & \text{for } \dfrac{\lambda}{\mathrm{L_{pp}}} \leq 2.5 \end{cases}$$

where for S_1 and S_2 segments

$$d^* = d$$

and for S_3 and S_4 segments

$$d^* = \begin{cases} \dfrac{d\left(4+\sqrt{|\cos\beta|}\right)}{5} & \text{for } C_B \leq 0.75 \\ \dfrac{d\left(2+\sqrt{|\cos\beta|}\right)}{3} & \text{for } C_B > 0.75 \end{cases}$$

$$f(\beta) = \begin{cases} -\cos\beta & \text{for } \pi - \mathrm{E}_1 \leq \beta \leq \pi \\ 0 & \text{for } \beta < \pi - \mathrm{E}_1 \end{cases}$$