GUIDANCE NOTES
GD 34-2022

ISClass

INTERNATIONAL SHIP CLASSIFICATION

GUIDELINES ON CALCULATION AND VERIFICATION OF THE ENERGY EFFICIENCY DESIGN INDEX (EEDI) OF INTERNATIONAL SEA-GOING SHIPS

2022

Effective from 1 December 2022

CONTENTS

Chapter 1　General

1.1　General requirements

1.1.1　The purpose of these Guidelines is to provide guidance on calculating and verifying the Attained Energy Efficiency Design Index (Attained EEDI) of international sea-going ships.

1.1.2　These Guidelines are mainly developed based on the following documents:

(1) Amendments to the annex of MARPOL 73/78--inclusion of regulations on energy efficiency for ships in MARPOL Annex VI adopted by resolution MEPC.203(62), Amendments to MARPOL Annex VI and the NO_x Technical Code 2008 adopted by resolution MEPC.251(66) and Amendments to the annex of the Protocol of 1997 to amend the International Convention for the Prevention of Pollution from Ships, 1973, as Modifiend by the Protocol of 1978 relating thereto – Amendments to MARPOL Annex VI (Procedures for sampling and verification of the sulphur content of fuel oil and the Energy Efficiency Design Index(EEDI)) adopted by resolution MEPC.324(75);

(2) 2014 Guidelines on Survey and Certification of the Energy Efficiency Design Index (EEDI) adopted by resolution MEPC.254(67) and Amendments to 2014 Guidelines on Survey and Certification of the Energy Efficiency Design Index (EEDI) adopted by resolutions MEPC.261(68) and MEPC.309(73) (hereinafter referred to as IMO "2014 EEDI Verification Guidelines");

(3) 2018 Guidelines on the Method of Calculation of the Attained Energy Efficiency Design Index (EEDI) for New Ships adopted by resolution MEPC.308(73) and Amendments to 2018 Guidelines on the Method of Calculation of the Attained Energy Efficiency Design Index (EEDI) for New Ships adopted by resolutions MEPC.322(74) and MEPC.332(76) (hereinafter referred to as IMO "2018 EEDI Calculation Guidelines");

(4) Circular MEPC.1/Circ.795/Rev 5: Unified Interpretations to MARPOL Annex VI;

(5) Circular MEPC.1/Circ.850/Rev.3: Guidelines for Determining Minimum Propulsion Power to Maintain the Manoeuvrability of Ships in Adverse Conditions;

(6) International Association of Classification Societies (IACS) PR38. Rev.3: Procedure for calculation and verification of the Energy Efficiency Design Index (EEDI);

(7) ISC Rules for Green-Eco Ships;

(8) ISO 15016:2015 "Ships and marine technology-Guidelines for the assessment of speed and power performance by analysis of speed trial data".

1.1.3　The Attained Energy Efficiency Design Index (Attained EEDI) of new international sea-going ships is to be calculated in accordance with 2018 EEDI Calculation Guidelines and amendments related thereto.

1.1.4　The application for verifying the Attained Energy Efficiency Design Index (Attained EEDI) of new international sea-going ships is normally included in the plan approval application of the ship and may be submitted to the plan approval center of ISC. Where only witnessing of tank test is requested, the application may be submitted to the nearby ISC survey unit by the applicant.

1.2 Definitions

1.2.1 Definitions of ship types

(1) *Bulk carrier* means a ship which is intended primarily to carry dry cargo in bulk, including such types as ore carriers as defined in SOLAS Regulation XII/1, but excluding combination carriers.

(2) *Gas carrier* means a cargo ship, other than an LNG carrier① constructed or adapted and used for the carriage in bulk of any liquefied gas.

(3) *Tanker* means an oil tanker as defined in MARPOL Annex I, regulation 1 or a chemical tanker or a NLS (noxious liquid substance) tanker as defined in MARPOL Annex II, regulation 1.

(4) *Container ship* means a ship designed exclusively for the carriage of containers in holds and on deck.

(5) *General cargo ship* means a ship with a multi-deck or single deck hull designed primarily for the carriage of general cargo. This definition excludes specialized dry cargo ships, which are not included in the calculation of reference lines for general cargo ships, namely livestock carrier, barge carrier, heavy load carrier②, yacht carrier, nuclear fuel carrier.

(6) *Refrigerated cargo carrier* means a ship designed exclusively for the carriage of refrigerated cargoes in holds.

(7) *Combination carrier* means a ship designed to load 100% deadweight with both liquid and dry cargo (including ores) in bulk.

(8) *Passenger ship* means a ship which carries more than 12 passengers.

(9) *Ro-ro passenger ship* means a passenger ship with roll-roll spaces.

(10) *Ro-ro cargo ship* (*vehicle carrier*) means a multi-deck roll-roll cargo ship designed for the carriage of empty cars and trucks.

(11) *Ro-ro cargo ship* means a ship designed for the carriage of roll-roll cargo transportation units.

(12) *LNG carrier* means a cargo ship constructed or adapted and used for the carriage in bulk of liquefied natural gas (LNG).

(13) *Cruise passenger ship* means a passenger ship not having a cargo deck, designed exclusively for commercial transportation of passengers in overnight accommodations on a sea voyage.

1.2.2 *Category A ships* mean ships designed for operation in polar waters in at least medium first-year ice, which may include old ice inclusions, as defined in the Polar Code.

1.2.3 *Attained EEDI* means the EEDI value actually achieved by an individual ship.

---

① For the purposes of meeting statutory requirements, where a LNG carrier is delivered before 1 September 2019, it is to comply with relevant requirements for "gas carrier"; where a LNG carrier is delivered on or after 1 September 2019, it is to comply with relevant requirements for "LNG carrier".

② IACS Rec.170 may be referred to for definition scope of heavy load carrier.

1.2.4 *Required EEDI* means the maximum value of the Attained EEDI permissible for a specific ship type and size.

1.2.5 *Ship of the same type* means a ship of which hull form (expressed in the lines such as sheer plan and body plan) excluding additional hull features such as fins and of which principal particulars are identical to that of the base ship.

1.2.6 *Conventional propulsion* means a method of propulsion where a main reciprocating internal combustion engine(s) is the prime mover and coupled to a propulsion shaft either directly or through a gear box.

1.2.7 *Non-conventional propulsion* means a method of propulsion, other than conventional propulsion, including diesel-electric propulsion, turbine propulsion, and hybrid propulsion systems.

1.2.8 *Tank test* means model towing tests, model self-propulsion tests and model propeller open water tests. Numerical calculations may be accepted as equivalent to model propeller open water tests or used to complement the tank tests conducted (e.g. to evaluate the effect of additional hull features such as fins, etc., on ship's performance), with approval of ISC.

1.2.9 *Verifier* means an Administration or organization duly authorized by it, which conducts the survey and certification of the EEDI in accordance with regulations 5, 6, 7, 8 and 9 of MARPOL Annex VI and relevant guidelines.

1.2.10 *Full load draught* means the summer loadline draught or the draught corresponding to 70%DWT for container ships.

1.2.11 *New ship* means a ship:

(1) for which the building contract is placed on or after 1 January 2013; or

(2) in the absence of a building contract, the keel of which is laid, or which is at a similar stage of construction, on or after 1 July 2013; or

(3) the delivery of which is on or after 1 July 2015.

1.2.12 *A ship delivered on or after 1 September 2019* means a ship:

(1) for which the building contract is placed on or after 1 September 2015; or

(2) in the absence of a building contract, the keel of which is laid, or which is at a similar stage of construction, on or after 1 March 2016; or

(3) the delivery of which is on or after 1 September 2019.

1.2.13 *Major conversion* means a conversion of a ship to which these Guidelines apply:

(1) which substantially alters the dimensions, carrying capacity or engine power of the ship; or

(2) which changes the type of the ship; or

(3) the intent of which is substantially to prolong the life of the ship; or

(4) which otherwise so alters the ship that, if it were a new ship, it would become subject to relevant provisions of ship energy efficiency of MARPOL Annex VI not applicable to it as an existing ship; or

(5) which substantially alters the energy efficiency of the ship and includes any modifications that could cause the ship to exceed the applicable required EEDI as set out in regulation 21 of MARPOL Annex VI.

1.2.14 *Review* means the act of examining documents in order to determine identification and traceability and to confirm that requested information are present and that EEDI calculation process conforms to relevant requirements.

1.2.15 *Witness* means the attendance at scheduled key steps of the towing tank tests in accordance with the agreed Test Plan to the extent necessary to check compliance with the survey and certification requirements.

1.2.16 *Verifying Society* is a Society which conducts the survey and verification of EEDI of a ship.

1.2.17 Witnessing Society is a Society which has witnessed the towing tank test of a ship of the same type as the ship whose EEDI is verified by the Verifying Society.

1.2.18 *Witnessing protocol* is a document showing evidence of the witnessing and acceptance of the towing tank test by the Witnessing Society, with indication such as date, signature and possible remarks of the surveyor.

1.2.19 The parameters in relation to the calculation of Attained EEDI are defined in Chapter 2 of these Guidelines.

1.3 Application

1.3.1 These Guidelines apply to the following ships of 400 gross tonnage and above:

(1) bulk carrier;

(2) gas carrier;

(3) tanker;

(4) container ship;

(5) general cargo ship;

(6) refrigerated cargo carrier;

(7) combination carrier;

(8) passenger ship;

(9) ro-ro passenger ship[①];

(10) ro-ro cargo ship (vehicle carrier)[①];

(11) ro-ro cargo ship[①];

(12) LNG carrier[①];

(13) cruise passenger ship having non-conventional propulsion[①].

1.3.2 These Guidelines are not applicable to the following ships:

(1) ships with non-conventional propulsion systems listed in 1.3.1(1) to (11) above;

(2) cruise ships with conventional propulsion systems;

(3) category A ships defined in Polar Code.

1.3.3 For the purposes of statutory requirements, the time tables required by each energy efficiency reduction phase in MARPOL Annex VI which are applicable to new ships are as follows:

Table 1.3.3

Phase 0	**Phase 1**	**Phase 2**	**Phase 3**
2013.1.1-2014.12.31	2015.1.1-2019.12.31	2020.1.1-2024.12.31	On or after 2025.1.1 ①
The building contract is placed between 1 January 2013 and 31 December 2014 and the delivery is before 1 January 2019; or	The building contract is placed between 1 January 2015 and 31 December 2019 and the delivery is before 1 January 2024; or	The building contract is placed between 1 January 2020 and 31 December 2024 and the delivery is before 1 January 2029; or	(1) The building contract is placed on or after 1 January 2025; or (2) In the absence of a building contract, the keel of which is laid or which is at a similar stage of construction on or after 1 July 2025; or (3) the delivery is placed on or after 1 January 2029
The building contract is placed before 1 January 2013 and the delivery is between 1 July 2015 and 31 December 2018; or	The building contract is placed before 1 January 2015 and the delivery is between 1 January 2019 and 31 December 2023; or	The building contract is placed before 1 January 2020 and the delivery is between 1 January 2024 and 31 December 2028; or	
In the absence of a building contract, (1) the keel of which is laid or which is at a similar stage of construction between 1 July 2013 and 30 June 2015 and the delivery is placed before 1 January 2019; or (2) the keel of which is laid or which is at a similar stage of construction before 1 July 2013 and the delivery is placed between 1 July 2015 and 31 December 2018	In the absence of a building contract, (1) the keel of which is laid or which is at a similar stage of construction between 1 July 2015 and 30 June 2020 and the delivery is placed before 1 January 2024; or (2) the keel of which is laid or which is at a similar stage of construction before 1 July 2015 and the delivery is placed between 1 January 2019 and 31 December 2023	In the absence of a building contract, (1) the keel of which is laid or which is at a similar stage of construction between 1 July 2020 and 30 June 2025 and the delivery is placed before 1 January 2029; or (2) the keel of which is laid or which is at a similar stage of construction before 1 July 2020 and the delivery is placed between 1 January 2024 and 31 December 2028	

Note: ① For gas carriers, container ships, general cargo ships, LNG carriers and cruise ships with unconventional propulsion systems with a deadweight tonnage of 15,000 DWT or greater, the time table required by energy efficiency reduction Phase 3 applicable to new ships is on or after 1 April 2022.
With regard to statutory requirements, for a ship the Required EEDI of which is not required in MARPOL Annex VI, its Attained EEDI only need be verified based on EEDI technical file.

---

① For the purpose of meeting the statutory requirements, ships delivered on or after 1 September 2019 need to meet the energy efficiency reduction requirements as specified in MARPOL Annex VI.

Chapter 2 Attained EEDI Calculation

2.1 General provisions

2.1.1 These Guidelines are used to guide the calculation of the Attained EEDI for ships applicable to EEDI regulations in MARPOL Annex VI and sea-going ships engaged on international voyages applying for CDx class notations as defined in ISC Rules for Green-Eco ships.

2.2 Attained EEDI calculation formula

2.2.1 The Attained EEDI means the attained ship Energy Efficiency Design Index, which is a measure of ship energy efficiency (g/t-nmile) and calculated by the following formula:

$$\frac{\left(\prod_{j=1}^{n} f_j\right)\left(\sum_{i=1}^{nME} P_{ME(i)} \cdot C_{FME(i)} \cdot SFC_{ME(i)}\right) + \left(P_{AE} \cdot C_{FAE} \cdot SFC_{AE}{}^{*}\right) + \left(\left(\prod_{j=1}^{n} f_j \cdot \sum_{i=1}^{nPTI} P_{PTI(i)} - \sum_{i=1}^{neff} f_{eff(i)} \cdot P_{AEeff(i)}\right) C_{FAE} \cdot SFC_{AE}\right) - \left(\sum_{i=1}^{neff} f_{eff(i)} \cdot P_{eff(i)} \cdot C_{FME} \cdot SFC_{ME}{}^{**}\right)}{f_i \cdot f_c \cdot f_l \cdot Capacity \cdot f_w \cdot V_{ref} \cdot f_m}$$

* If part of the normal maximum sea load is provided by shaft generators, for that part of the power, SFC_{ME} and C_{FME} may be used instead of SFC_{AE} and C_{FAE}.

When $0.75 * \sum_{i=1}^{nPTO} P_{PTO(i)} \le P_{AE}$, $P_{AE}.C_{FAE}.SFC_{AE}$ may be replaced by:

$$(P_{AE} - 0.75 * \sum_{i=1}^{nPTO} P_{PTO(i)}).C_{FAE}.SFC_{AE} + 0.75 * \sum_{i=1}^{nPTO} P_{PTO(i)}.C_{FME(i)}.SFC_{ME(i)}$$

When $0.75 * \sum_{i=1}^{nPTO} P_{PTO(i)} > P_{AE}$, $P_{AE}.C_{FAE}.SFC_{AE}$ may be replaced by:

$$P_{AE}.C_{FME(i)}.SFC_{ME(i)}$$

** If $P_{PTI(i)} > 0$, the weighted average value of ($SFC_{ME} \cdot C_{FME}$) and ($SFC_{AE} \cdot C_{FAE}$) is to be used for calculation of P_{eff}.

2.3 Definition and selection of parameters in Attained EEDI calculation formula

2.3.1 Carbon conversion factor (C_F)

2.3.1.1 C_F is a non-dimensional conversion factor between fuel consumption and CO_2 emission based on carbon content, measured int-CO_2/t-Fuel. The subscripts *MEi* and *AEi* refer to the main and auxiliary engine(s) respectively. C_F is the carbon conversion factor corresponding to the fuel used when determining SFC listed in the applicable test report included in a Technical File as defined in NO_x Technical Code (hereinafter referred to as "test report included in a NO_x technical file"). The value of C_F is shown in Table 2.3.1.1:

Carbon Conversion Factor C_F **Table 2.3.1.1**

Type of fuel	**Reference**	**Lower calorific value(kJ/kg)**	**Carbon content**	**C_F (t-CO_2/t-Fuel)**
1. Diesel/Gas Oil	ISO 8217 Grades DMX through DMC	42,700	0.8744	3.206
2. Light Fuel Oil (LFO)	ISO 8217 Grades RMA through RMD	41,200	0.8594	3.151
3. Heavy Fuel Oil (HFO)	ISO 8217 Grades RME through RMK	40,200	0.8493	3.114
4. Liquefied Petroleum Gas (LPG)	Propane	46,300	0.8182	3.000
	Butane	45,700	0.8264	3.030
5. Liquefied Natural Gas (LNG)		48,000	0.7500	2.750
6. Methanol		19,900	0.3750	1.375
7. Ethanol		26,800	0.5217	1.913

2.3.1.2 In case of a ship equipped with a dual-fuel main or auxiliary engine, the C_F-factor for gas fuel and the C_F-factor for fuel oil are to apply and be multiplied with the specific fuel consumption of each fuel at the relevant EEDI load point.

(1) The fuel availability of gas fuel is to be calculated in accordance with the formula below:

$$f_{DFgas} = \frac{\sum_{i=1}^{ntotal} P_{total(i)}}{\sum_{i=1}^{ngasfuel} P_{gasfuel(i)}} \times \frac{V_{gas} \times \rho_{gas} \times LCV_{gas} \times K_{gas}}{\left(\sum_{i=1}^{nLiquid} V_{liquid(i)} \times \rho_{liquid(i)} \times LCV_{liquid(i)} \times K_{liquid(i)}\right) + V_{gas} \times \rho_{gas} \times LCV_{gas} \times K_{gas}}$$

$$f_{DFliquid} = 1 - f_{DFgas}$$

where: f_{DFgas} – the fuel availability ratio of gas fuel corrected for the power ratio of gas engines to total engines, f_{DFgas} is not to be greater than 1;

V_{gas} – the total net gas fuel capacity on board in m^3. If other arrangements, like exchangeable (specialized) LNG tank-containers and/or arrangements allowing frequent gas refueling are used, the capacity of the whole LNG fuelling system is to be used for V_{gas}. The boil-off rate (BOR) of gas cargo tanks can be calculated and included to V_{gas} if it is connected to the fuel gas supply system (FGSS);

V_{liquid} – the total net liquid fuel capacity on board in m^3 of liquid fuel tanks permanently connected to the ship's fuel system. If one fuel tank is disconnected by permanent sealing valves, V_{liquid} of the fuel tank can be ignored;

ρ_{gas} – the density of gas fuel in kg/m^3;

ρ_{liquid} – the density of each liquid fuel in kg/m^3;

LCV_{gas} – the low calorific value of gas fuel in kJ/kg;

LCV_{liquid} – the low calorific value of liquid fuel in kJ/kg;

K_{gas} – the filling rate for gas fuel tanks;

K_{liquid} – the filling rate for liquid fuel tanks;

P_{total} – the total installed engine power, P_{ME} and P_{AE} in kW;

$P_{gasfuel}$ – the dual fuel engine installed power, P_{ME} and P_{AE} in kW.

(2) If the total gas capacity is at least 50% of the fuel capacity dedicated to the dual fuel engines, namely $f_{DFgas} \geq 0.5$, then gas fuel is regarded as the "primary fuel", and $f_{DFgas} = 1$ and $f_{DFliquid} = 0$ for each dual fuel engine.

(3) If $f_{DFgas} < 0.5$, gas fuel is not regarded as the "primary fuel". The C_F and SFC in the EEDI calculation for each dual fuel engine (both main and auxiliary engines) are to be calculated as the weighted average of C_F and SFC for gas and liquid mode, according to f_{DFgas} and $f_{DFliquid}$, such as the original item of $P_{ME(i)} \cdot C_{FME(i)} \cdot SFC_{ME(i)}$ in the EEDI calculation is to be replaced by the formula below:

$$P_{ME(i)} \cdot (f_{DFgas(i)} \cdot (C_{FME\ pilot\ fuel(i)} \cdot SFC_{ME\ pilot\ fuel(i)} + C_{FME\ gas(i)} \cdot SFC_{ME\ gas(i)}) + f_{DFliquid(i)} \cdot C_{FME\ liquid(i)} \cdot SFC_{ME\ liquid(i)})$$

2.3.2 Ship speed (V_{ref})

2.3.2.1 V_{ref} is the ship speed, measured in knot, on deep water in the condition corresponding to the Capacity as defined in paragraph 2.3.3.1 and 2.3.3.3 (in case of passenger ships and cruise ships, this condition is to be summer load draught as provided in paragraph 2.3.4) at the shaft power of the engine(s) as defined in paragraph 2.3.5 and assuming the weather is calm with no wind and no waves.

2.3.3 Capacity

2.3.3.1 For bulk carriers, tankers, gas carriers, LNG carriers, ro-ro cargo ships (vehicle carriers), ro-ro cargo ships, ro-ro passenger ships, refrigerated cargo carriers, general cargo ships and combination carriers, deadweight is to be used as capacity.

2.3.3.2 For passenger ships and cruise passenger ships, gross tonnage in accordance with the International Convention of Tonnage Measurement of Ships 1969, annex I, regulation 3, is to be used as capacity.

2.3.3.3 For container ships, 70% of the deadweight (DWT) is to be used as capacity. EEDI values for container ships are calculated as follows:

(1) Attained EEDI value is to be calculated using 70% DWT in accordance with EEDI formula;

(2) Required EEDI value is to be calculated using 100% DWT in accordance with reference line formula.

2.3.4 Deadweight (DWT)

2.3.4.1 Deadweight means the difference in tonnes between the displacement of a ship in water of relative density of 1,025 kg/m^3 at the summer load draught and the lightweight of the ship. The summer load draught is to be taken as the maximum summer draught as certified in the stability booklet approved by the Administration or ISC.

2.3.5 Power (P)

2.3.5.1 P is the power of the main and auxiliary engines, measured in kW. The subscripts ME and AE refer to the main and auxiliary engine(s) respectively. The summation on i is for all engines with the number of engines (n_{ME}).

2.3.5.2 $P_{ME(i)}$ is 75% of the rated installed power (*MCR*) for each main engine. The *MCR* value specified on the *EIAPP* certificate is to be used for calculation. If the main engines are not required to have an *EIAPP* certificate, the *MCR* value on the nameplate is to be used for calculation.

For LNG carriers having non-conventional propulsion, $P_{ME(i)}$ is to be calculated as follows:

(1) For LNG carriers having diesel electric propulsion system, $P_{ME(i)}$ is to be calculated by the following formula:

$$P_{ME(i)} = 0.83 \times \frac{MPP_{Motor(i)}}{\eta_{(i)}}$$

where: $MPP_{Motor(i)}$ is the rated output of motor specified in the certified document, in kW.

$\eta_{(i)}$ is to be taken as the product of electrical efficiency of generator, transformer, converter, and motor, taking into consideration the weighted average as necessary. The electrical efficiency, $\eta_{(i)}$, is to be taken as 91.3% for the purpose of calculating attained EEDI. Alternatively, if the value more than 91.3% is to be applied, the $\eta_{(i)}$ is to be obtained by measurement and verified by method approved by ISC.

(2) For LNG carriers having steam turbine propulsion systems, $P_{ME(i)}$ is 83% of the rated installed power ($MCR_{SteamTurbine}$) for each steam turbine(*i*).

2.3.5.3 $P_{PTO(i)}$ — In case where a shaft generator is installed, the shaft generator power ($P_{PTO(i)}$) is 75% of the rated electrical power output for each shaft generator. In case that shaft generator(s) are installed to steam turbine, $P_{PTO(i)}$ is 83% of the rated electrical output power and the factor of 0.75 is to be replaced to 0.83.

There are two options to calculate the effect of shaft generators:

(1) Option 1: The maximum allowable deduction for the calculation of $\sum P_{ME(i)}$ is to be no more than P_{AE} as defined in paragraph 2.3.5.5. For this case, $\sum P_{ME(i)}$ is calculated as:

$$\sum_{i=1}^{nME} P_{ME(i)} = 0.75 \times \left(\sum MCR_{ME(i)} - \sum P_{PTO(i)}\right) \quad \text{with } 0.75 \times \sum P_{PTO(i)} \leq P_{AE}\text{; or}$$

(2) Option 2: Where an engine is installed with a higher rated power output than that which the propulsion system is limited to as verified by technical means, the value of $\sum P_{ME(i)}$ is to be 75% of that limited power for determining the reference speed V_{ref} defined in 2.3.2 and for EEDI calculation.

Figure 2.3.5.3 gives guidance for determination of $\sum P_{ME(i)}$.

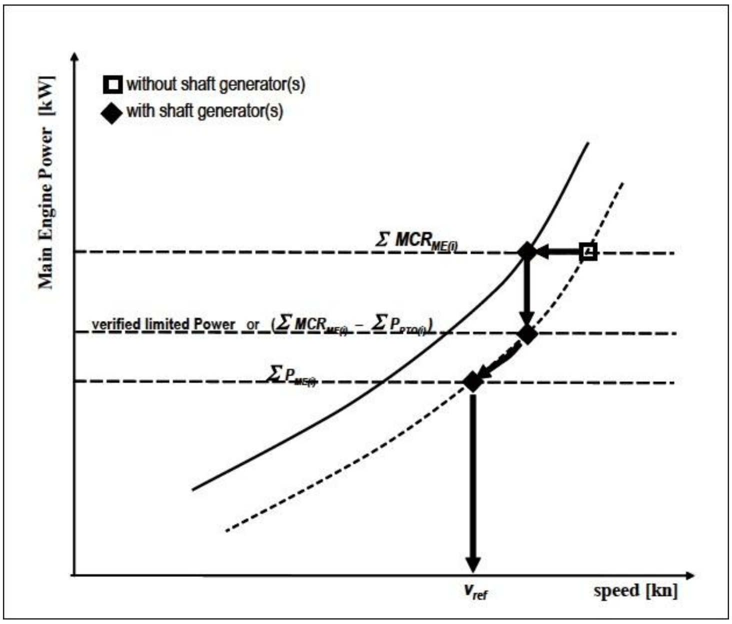


Figure 2.3.5.3 Determination of the Power $\sum P_{ME(i)}$ of a Main Engine

2.3.5.4 $P_{PTI(i)}$ — In case where shaft motor(s) are installed, $P_{PTI(i)}$ and total propulsion power are calculated as follows:

(1) $P_{PTI(i)}$ is 75% of the rated and total propulsion power consumption of each shaft motor divided by the weighted average efficiency of the generator(s), as follows:

$$\sum P_{PTI(i)} = \frac{\sum\left(0.75 \times P_{SM,\max(i)}\right)}{\eta_{\overline{Gen}}}$$

where: $P_{SM,max(i)}$ — is the rated power consumption of each shaft motor, in kW;

$\eta_{\overline{Gen}}$ — is the weighted average efficiency of the generator(s).

(2) In case that shaft motor(s) are installed to steam turbine, $P_{PTI(i)}$ is 83% of the rated power consumption and the factor of 0.75 in the above formula is to be replaced to 0.83.

(3) The total propulsion power at which V_{ref} is measured, is:

$$\sum P_{ME(i)} + \sum P_{PTI(i),shaft}$$

$$\sum P_{PTI(i),shaft} = \sum\left(0.75 \cdot P_{SM,\max(i)} \cdot \eta_{PTI(i)}\right)$$

where: $\eta_{PTI(i)}$ — is the efficiency of each shaft motor.

Where the total propulsion power as defined above is higher than 75% of the power the propulsion system is limited to by verified technical means, then 75% of the limited power is to be used as the total propulsion power for determining the reference speed, V_{ref} as defined in 2.3.2 and for EEDI calculation. Then, $\left(\sum_{i=1}^{nME} P_{ME(i)} \cdot C_{FME(i)} \cdot SFC_{ME(i)} + \sum_{i=1}^{nPTI} P_{PTI(i)} \cdot C_{FAE} \cdot SFC_{AE}\right)$ is to be replaced by 75% of the limited power multiplied by the weighted average value of ($SFC_{ME} \cdot C_{FME}$) and ($SFC_{AE} \cdot C_{FAE}$).

(4) In case of combined PTI/PTO, the normal operational mode at sea will determine which of these is to be used in the EEDI calculation. For example, if this combined system is used as a shaft generator for ships in normal operation at sea, the P_{PTO} parameter is to be used in the EEDI calculation formula and P_{PTI} equals 0.

(5) The shaft motor's chain efficiency may be taken into consideration to account for the energy losses in the equipment from the switchboard to the shaft motor, if the chain efficiency of the shaft motor is given in a verified document.

2.3.5.5 P_{AE} is the required auxiliary engine power to supply normal maximum sea load including necessary power for propulsion machinery/systems and accommodation, e.g. main engine pumps, navigational systems and equipment and living on board, but excluding the power not for propulsion machinery/systems, e.g. thrusters, cargo pumps, cargo gear, ballast pumps, reefers and cargo hold fans for maintaining cargo, in the condition where the ship engaged in voyage at the speed V_{ref} under the condition as mentioned in paragraph 2.3.2.

P_{AE} used for the calculation of Attained EEDI of ships is to be calculated by the following experience-based formulae instead of the actual auxiliary engine power.

(1) For ships with a total propulsion power ($\sum MCR_{ME(i)} + \frac{\sum P_{PTI(i)}}{0.75}$) of 10,000 kW or above, P_{AE} is defined as:

$$P_{AE\left(\sum MCR_{ME(i)} \geq 10000\text{kW}\right)} = \left(0.025 \times \left(\sum_{i=1}^{nME} MCR_{ME(i)} + \frac{\sum_{i=1}^{nPTI} P_{PTI(i)}}{0.75}\right)\right) + 250$$

(2) For ships with a total propulsion power ($\sum MCR_{ME(i)} + \frac{\sum P_{PTI(i)}}{0.75}$) below 10,000 kW, P_{AE} is defined as:

$$P_{AE\left(\sum MCR_{ME(i)} < 10000\text{kW}\right)} = 0.05 \times \left(\sum_{i=1}^{nME} MCR_{ME(i)} + \frac{\sum_{i=1}^{nPTI} P_{PTI(i)}}{0.75}\right)$$

(3) For LNG carriers with a reliquiefaction system or compressor(s), designed to be used in normal operation and essential to maintain the LNG cargo tank pressure below the maximum allowable relief valve setting of a cargo tank in normal operation, the following terms are to be added to above P_{AE} formula in accordance with ①, ② or ③ as below:

① For ships having re-liquefaction system:

$$+CargoTankCapacity_{\text{LNG}} \times BOR \times COP_{\text{reliquefy}} \times R_{\text{reliquefy}}$$

where: $CargoTankCapacity_{LNG}$ — the LNG Cargo Tank Capacity, in m^3.

BOR — the design rate of boil-off gas of entire ship per day, which is specified in the specification of the building contract.

$COP_{reliquefy}$ — the coefficient of design power performance for reliquefying boil-off gas per unit volume, calculated as follows:

$$COP_{\text{reliquefy}} = \frac{425(\text{kg/m}^3) \times 511(\text{kJ/kg})}{24(\text{h}) \times 3600(\text{sec}) \times COP_{\text{cooling}}}$$

$COP_{cooling}$ — the coefficient of design performance of reliquefaction and 0.166 is to be used. Another value calculated by the manufacturer and verified by the Administration or CCS may be used.

$R_{reliquefy}$ — the ratio of boil-off gas (BOG) to be re-liquefied to entire BOG, calculated as follows:

$$R_{\text{reliquefy}} = \frac{BOG_{\text{reliquefy}}}{BOG_{\text{total}}}$$

② For LNG carriers with direct diesel driven propulsion system or diesel electric propulsion system, having compressor(s) which are used for supplying high-pressured gas derived from boil-off gas to the installed engines (typically intended for 2-stroke dual fuel engines):

$$+COP_{\text{comp}} \times \sum_{i=1}^{nME} SFC_{ME(i),\text{gasmode}} \times \frac{P_{ME(i)}}{1000}$$

where: COP_{comp} is the design power performance of compressor and 0.33 (kWh/kg) is to be used. Another value calculated by the manufacturer and verified by the Administration or an organization recognized by the Administration may be used.

③ For LNG carriers with direct diesel driven propulsion system or diesel electric propulsion system, having compressor(s) which are used for supplying low-pressured gas derived from boil-off gas to the installed engines (typically intended for 4-stroke dual fuel engines):

$$+0.02 \times \sum_{i=1}^{nME} P_{ME(i)}$$

④ For LNG carriers having diesel electric propulsion system, $MPP_{Motor(i)}$ is to be used instead $MCR_{ME(i)}$ for P_{AE} calculation.

⑤ For LNG carriers having steam turbine propulsion system and of which electric power is primarily supplied by turbine generator closely integrated into the steam and feed water systems, P_{AE} may be treated as 0 instead of taking into account electric load in calculating $SFC_{SteamTurbine}$.

(4) For ship where the P_{AE} value calculated by (1), (2) or (3) above is significantly different from the total power used at the speed V_{ref}, e.g., in cases of passenger ships, ro-ro passenger ships and cruise passenger ships, the P_{AE} value is to be estimated by the consumed electric power (excluding

propulsion) in conditions when the ship is engaged in a voyage at the reference speed (V_{ref}) as given in the electric power table, divided by the average efficiency of the generator(s) weighted by power. As an option for other vessel types, if the difference between P_{AE} value calculated by (1), (2) or (3) above and P_{AE} based on electric power table, leads to a variation of the computed EEDI value exceeding 1%, the value for auxiliary power could be taken from the electric power table. The electric power table for EEDI calculation is to be examined and validated by ISC. Where ambient conditions affect any electrical load in the power table, the contractual ambient conditions leading to the maximum design electrical load of the installed system for the ship in general are to apply. See appendix 2 of the Guidelines for the development of electric power tables.

2.3.5.6 $P_{eff(i)}$ is the output of the innovative mechanical energy efficient technology for propulsion at 75% main engine power.

(1) Mechanical recovered waste energy directly coupled to shafts need not be measured, since the effect of the technology is directly reflected in the V_{ref}.

(2) In case of a ship equipped with a number of engines, the C_F and SFC are to be the power weighted average value of all the main engines.

(3) In case of a ship equipped with a dual-fuel engine, the C_F and SFC are to be obtained according to 2.3.1 and 2.3.7.

2.3.5.7 $P_{AEeff(i)}$ is the auxiliary power reduction due to innovative electrical energy efficient technology measured at $P_{ME(i)}$.

2.3.5.8 Figures 2.3.5.8(1) and 2.3.5.8(2) illustrate a generic marine power plant and the power used for EEDI calculation.

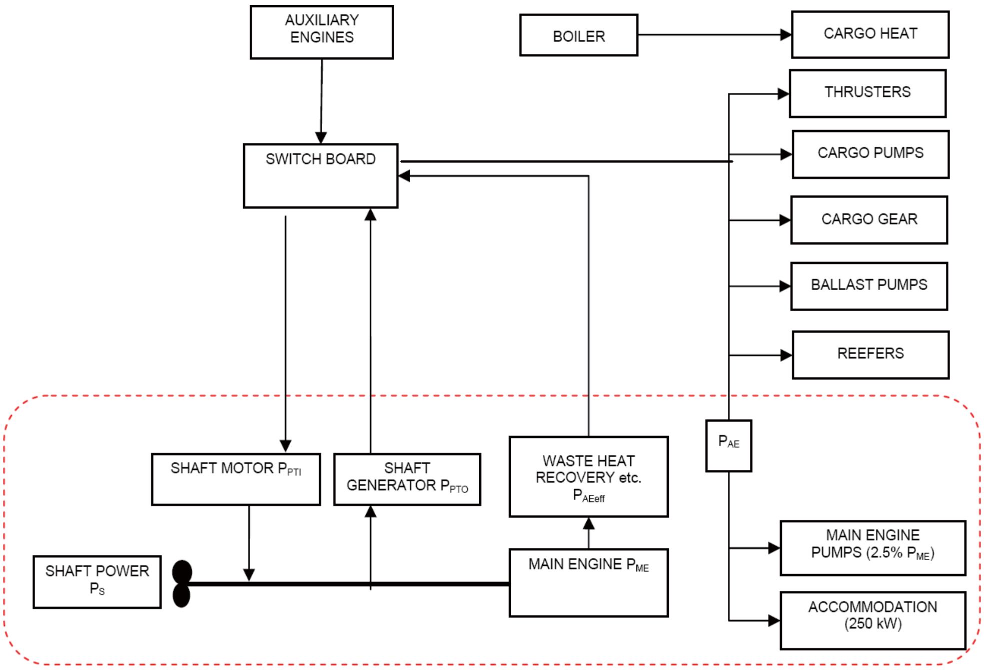


Figure 2.3.5.8(1) A Generic Marine Power Plant for Ships Having Conventional Propulsion

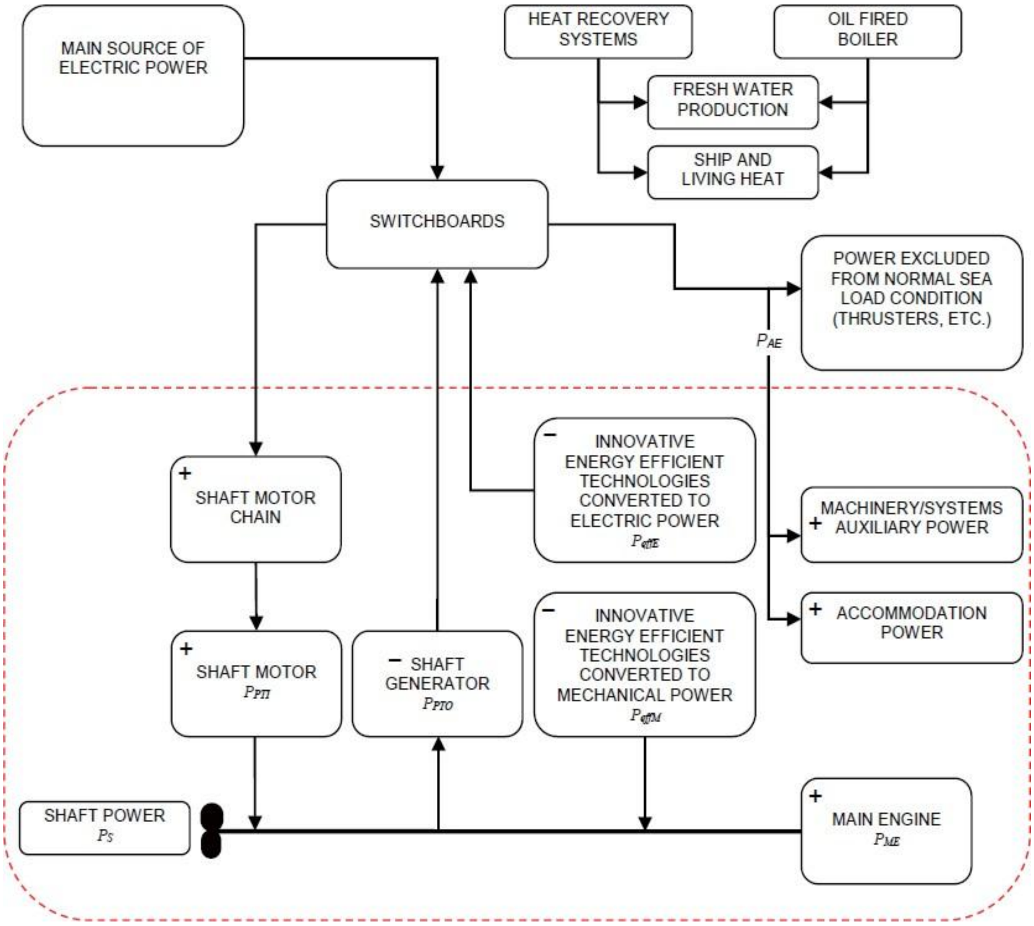


Figure 2.3.5.8(2) A Generic Marine Power Plant for a Cruise Passenger Ships Having Non-conventional Propulsion

2.3.6 The essential parameters V_{ref}, Capacity and P for determining EEDI for a ship should be consistent with each other. As for LNG carriers having diesel electric or steam turbine propulsion systems, V_{ref} is the relevant speed at 83% of MPP_{Motor} or $MCR_{SteamTubine}$ respectively.

2.3.7 Specific Fuel Consumption (SFC)

2.3.7.1 SFC is the certified specific fuel consumption, measured in g/kWh, of the engines or steam turbines. SFC_{ME} and SFC_{AE} refer to the specific fuel consumption of the main and auxiliary engine(s) respectively.

2.3.7.2 For engines certified to the E2 or E3 duty cycles of the NO_x Technical Code 2008, the engine Specific Fuel Consumption ($SFC_{ME(i)}$) is that recorded in the test report included in a NO_x technical file for the engine(s) at 75% of MCR power or its torque rating.

2.3.7.3 For engines certified to the D2 or C1 duty cycles of the NO_x Technical Code 2008, the engine Specific Fuel Consumption ($SFC_{AE(i)}$) is that recorded in the test report included in a NO_x technical file at the engine(s) at 50% of MCR power or its torque rating.

2.3.7.4 If gas fuel is used as primary fuel in accordance with paragraph 2.3.1.2, SFC in gas mode is to be used. In case that installed engine(s) have no approved NO_x Technical File tested in gas mode, the SFC of gas mode is to be submitted by the manufacturer and confirmed by ISC.

2.3.7.5 The SFC is to be corrected to the value corresponding to the ISO standard reference conditions using the standard lower calorific value of the fuel oil (42,700 kJ/kg), referring to ISO 15550:2002 and ISO 3046-1:2002.

2.3.7.6 For ships where the P_{AE} value calculated by 2.3.5.5(1) or (2) above is significantly different from the total power used at normal seagoing, e.g., conventional passenger ships, the Specific Fuel Consumption (SFC_{AE}) of the auxiliary generators is that recorded in the test report included in a NO_x technical file for the engine(s) at 75% of MCR power or its torque rating.

2.3.7.7 SFC_{AE} is the power-weighted average among $SFC_{AE(i)}$ of the respective engines i.

2.3.7.8 For those engines which do not have EIAPP certificates because its power is below 130 kW, the SFC specified by the manufacturer and endorsed by the Administration or ISC is to be used.

2.3.7.9 At the design stage, in case of unavailability of a test report in the NO_x file, the SFC specified by the manufacturer and endorsed by the Administration or ISC is to be used.

2.3.7.10 For LNG-driven engines, SFC measured in kJ/kWh is to be amended to SFC value measured in g/kWh by using the standard lower heat value of the LNG (48,000 kJ/kg) (Refer to 2006 IPCC Guidelines).

2.3.7.11 The $SFC_{SteamTurbine}$ is to be calculated and revised as follows:

(1) The $SFC_{SteamTurbine}$ is to be calculated by manufacturer and verified by the Administration or ISC as follows:

$$SFC_{SteamTurbine} = \frac{FuelConsumption}{\sum_{i=1}^{nME} P_{ME(i)}}$$

where: *Fuel consumption* is fuel consumption of boiler per hour (g/h). For ships of which electric power is primarily supplied by Turbine Generator closely integrated into the steam and feed water systems, not only P_{ME} but also electric loads corresponding to paragraph 2.3.5.5 are to be taken into account.

(2) The SFC is to be corrected to the value of LNG using the standard lower calorific value of the LNG (48,000 kJ/kg) at SNAME Condition (condition standard; air temperature 24 ℃ , inlet temperature of fan 38℃ , sea water temperature 24℃).

(3) In this correction, the difference of the boiler efficiency based on lower calorific value between test fuel and LNG is to be taken into account.

2.3.7.12 Reference lower calorific values of different fuels are given in the Table 2.3.1 of this Chapter. The reference lower calorific value corresponding to the conversion factor of the respective fuel is to be used for calculation.

2.3.8 Correction factor f_j

2.3.8.1 f_j is a correction factor to account for ship specific design elements.

2.3.8.2 For ice-classed ships, a correction factor for power is applied to compensate for negative effects caused by the increased power on EEDI of such ships. This factor is to be taken as the greater value of f_{j0} and $f_{j,min}$ as tabulated in Table 2.3.8.2, but not to be greater than 1.0.

Correction factor for power f_j for ice-classed ships **Table 2.3.8.2**

Ship type	f_{j0}	$f_{j,min}$ depending on the ice class			
		IA Super	IA	IB	IC
Tanker	$\frac{17.444 \cdot DWT^{0.5766}}{\sum_{i=1}^{nME} MCR_{ME(i)}}$	$0.2488 \cdot DWT^{0.0903}$	$0.4541 \cdot DWT^{0.0524}$	$0.7783 \cdot DWT^{0.0145}$	$0.8741 \cdot DWT^{0.0079}$
Bulk carrier	$\frac{17.207 \cdot DWT^{0.5705}}{\sum_{i=1}^{nME} MCR_{ME(i)}}$	$0.2515 \cdot DWT^{0.0851}$	$0.3918 \cdot DWT^{0.0556}$	$0.8075 \cdot DWT^{0.0071}$	$0.8573 \cdot DWT^{0.0087}$
General cargo ship	$\frac{1.974 \cdot DWT^{0.7987}}{\sum_{i=1}^{nME} MCR_{ME(i)}}$	$0.1381 \cdot DWT^{0.1435}$	$0.1574 \cdot DWT^{0.144}$	$0.3256 \cdot DWT^{0.0922}$	$0.4966 \cdot DWT^{0.0583}$
Refrigerated cargo ship	$\frac{5.598 \cdot DWT^{0.696}}{\sum_{i=1}^{nME} MCR_{ME(i)}}$	$0.5254 \cdot DWT^{0.0357}$	$0.6325 \cdot DWT^{0.0278}$	$0.7670 \cdot DWT^{0.0159}$	$0.8918 \cdot DWT^{0.0079}$

Notes: B1*, B1, B2 and B3 are ice class notations in ISC Rules for Classification of Sea-going Steel Ships, corresponding to ice classes IA Super, IA, IB and IC of Finnish Swedish Ice Class Rules (FSICR).

2.3.8.3 Alternatively, if an ice-class ship is designed and constructed based on an open water ship with same shape and size of hull with EEDI certification, the power correction factor, f_j, for ice-classed ships can be calculated by using propulsion power of the new ice-class ship required by ice-class regulations, $P_{ice\ class}$, and the existing open water ship, P_{ow}, as follows:

$$f_j = \frac{P_{ow}}{P_{ice\ class}}$$

In this case, V_{ref} should be measured at the shaft power of the engine(s) installed on the existing open water ship as defined in paragraph 2.3.5.

2.3.8.4 The power correction factor f_j, for shuttle tankers with propulsion redundancy is to be f_j = 0.77. This correction factor applies to above-mentioned shuttle tankers with propulsion redundancy and having a deadweight of 80,000 ~ 160,000 tonnes. The shuttle tankers with propulsion redundancy are tankers used for loading of crude oil from offshore installations and equipped with dual-engine and twin-propellers, need to meet the requirements for dynamic positioning and redundancy propulsion class notation.

2.3.8.5 For ro-ro cargo and ro-ro passenger ships f_{jRoRo} is calculated as follows:

$$f_{jRoRo} = \frac{1}{F_{nL}^{\alpha} \times \left(\frac{L_{pp}}{B_s}\right)^{\beta} \cdot \left(\frac{B_s}{d_s}\right)^{\gamma} \cdot \left(\frac{L_{PP}}{\nabla^{1/3}}\right)^{\delta}}\ ;\ \text{if } f_{jRoRo}>1,\ \text{ then } f_j = 1$$

where F_{nL}, the Froude number, is defined as follows:

$$F_{nL} = \frac{0.5144 \cdot V_{ref}}{\sqrt{L_{PP} \cdot g}}$$

and α, β, γ and δ, the exponents of ship types, are defined as follows:

Ship type	Exponent			
	α	β	γ	δ
Ro-ro cargo ship	2.00	0.50	0.75	1.00
Ro-ro passenger ship	2.50	0.75	0.75	1.00

2.3.8.6 The factor f_j for general cargo ships is calculated as follows:

$$f_j = \frac{0.174}{Fn_\nabla^{2.3} \cdot C_b^{0.3}} ; \text{ if } f_j > 1, \text{ then } f_j = 1$$

where:

$$Fn_\nabla = \frac{0.5144 \cdot V_{ref}}{\sqrt{g \cdot \nabla^{\frac{1}{3}}}} ; \text{ if } Fn_\nabla > 0.6, \text{ then } Fn_\nabla = 0.6$$

$$C_b = \frac{\nabla}{L_{pp} \cdot B_s \cdot d_s}$$

2.3.8.7 For other ship types not included in the above table, f_j is to be taken as 1.0.

2.3.9 Correction factor f_i

2.3.9.1 f_i is the capacity correction factor for any technical/regulatory limitation on capacity, which is used to compensate for negative effects on EEDI due to the loss of capacity, and can be assumed 1.0 if no necessity of the factor is granted.

2.3.9.2 For ice-classed ships, the capacity correction factor, f_i, for ice-classed ships having DWT as the measure of capacity should be calculated as follows:

$$f_i = f_{i(ice\ class)} \times f_{iC_b},$$

where $f_{i(ice\ class)}$ is the capacity correction factor for ice-strengthening of the ship, which can be obtained from Table 2.3.9.2(1) and f_{iC_b} is the capacity correction factor for improved ice-going capability, which should not be less than 1.0 and which should be calculated as follows:

$$f_{iC_b} = \frac{C_{b\ reference\ design}}{C_b},$$

where $C_{b\ referencedesign}$ is the average block coefficient for the ship type, which can be obtained from Table 2.3.9.2(2) for bulk carriers, tankers and general cargo ships, and

C_b is the block coefficient of the ship. For ship types other than bulk carriers, tankers and general cargo ships,

$$f_{iC_b} = 1.0$$

Capacity correction factor for ice-strengthening of the hull Table 2.3.9.2(1)

Ice class7	$f_{i(ice\ class)}$
IC	$f_{i(IC)} = 1.0041 + 58.5/DWT$
IB	$f_{i(IB)} = 1.0067 + 62.7/DWT$
IA	$f_{i(IA)} = 1.0099 + 95.1/DWT$
IA Super	$f_{i(IAS)} = 1.0151 + 228.7/DWT$

Average block coefficients $C_{b\ reference\ design}$ for bulk carriers, tankers and general cargo ships Table 2.3.9.2(2)

	Size categories				
Ship type	below 10,000 DWT	10,000 – 25,000 DWT	25,000 – 55,000 DWT	55,000 – 75,000 DWT	above 75,000 DWT
Bulk carrier	0.78	0.80	0.82	0.86	0.86
Tanker	0.78	0.78	0.80	0.83	0.83
General cargo ship	0.80				

Alternatively, the capacity correction factor for ice-strengthening of the ship ($f_{i(ice\ class)}$) can be calculated by using the formula given for the ship specific voluntary enhancement correction coefficient ($f_{i\ VSE}$) in paragraph 2.3.9.3. This formula can also be used for other ice classes than those given in Table 2.3.9.1(1).

2.3.9.3 For ships with voluntary structural enhancements, $f_{i\ VSE}$ is to be expressed as follows:

$$f_{iVSE} = \frac{DWT_{refrence\ design}}{DWT_{enhanced\ design}}$$

where: $DWT_{refrence\ design} = \Delta_{ship} - lightweight_{refrence\ design}$;

$DWT_{enhanced\ design} = \Delta_{ship} - lightweight_{enhanced\ design}$.

(1) For this calculation, the same displacement (Δ)① is to be taken for reference and enhanced designs.

(2) DWT before enhancements ($DWT_{reference\ design}$) is the deadweight prior to application of the structural enhancements. DWT after enhancements ($DWT_{enhanced\ design}$) is the deadweight following the application of voluntary structural enhancements.

(3) A change of material (e.g. from aluminum alloy to steel) or a change in grade of the same material (e.g. in steel types, grades, properties and conditions) between reference design and voluntarily enhanced design is not to be allowed for the $f_{i\ VSE}$ calculation.

① Structural and/or additional class notations such as, but not limited to, "strengthened for discharge with grabs" and "strengthened bottom for loading/unloading aground", which result in a loss of deadweight of the ship, are also seen as examples of "voluntary structural enhancements".

(1) Two sets of structural plans of the ship (one set for the reference design and the other set for the enhanced design) are to be submitted to ISC for assessment. As an alternative, only one set of structural plans of the reference design with annotations of voluntary structural enhancements may be submitted. Both sets of structural plans are to comply with the applicable regulations for the ship type.

2.3.9.4 For bulk carriers and oil tankers which are constructed according to Common Structural Rules (CSR) and assigned the CSR notation, the following capacity correction factor f_{iCSR} is to be used:

$$f_{iCSR} = 1 + (0.08 \times \frac{LWT_{CSR}}{DWT_{CSR}})$$

where: DWT_{CSR} is ship's deadweight;
LWT_{CSR} is ship's lightweight.

2.3.9.5 For other ship types not included in the table above, f_i is to be taken as 1.0.

2.3.9.6 The above factor f_i may be accumulated (multiplied).

2.3.10 Cubic capacity correction factor f_c

2.3.10.1 f_c is the cubic capacity correction factor and is to be taken as 1.0 if no necessity of the factor is granted.

2.3.10.2 For chemical tankers, f_c is to be:

$$f_c = R^{(-0.7)} - 0.014 \quad \text{for } R < 0.98\text{; or}$$
$$f_c = 1.00 \quad \text{for } R \geq 0.98$$

where: R is the ratio of the ship's DWT (in tonnes) to the total cubic capacity (in m^3) of its cargo tanks (m^3).

2.3.10.3 For gas carriers which are constructed or adapted to carry liquefied natural gas in bulk and with propulsion systems directly driven by diesel engines, the capacity correction factor f_{cLNG} is to be:

$$f_{cLNG} = R^{-0.56}$$

where: R is the ratio of the ship's DWT (in tonnes) to the total cubic capacity (in m^3) of its cargo tanks ①.

2.3.10.4 For ro-ro passenger ships having a DWT/GT-ratio of less than 0.25, the following cubic capacity correction factor, f_{cRoPax}, is to apply:

$$f_{cRoPax} = 1 + \left(\frac{\left(DWT/GT \right)}{0.25} \right)^{-0.8}$$

Where: DWT is the Capacity in ton;
GT is the gross tonnage in accordance with the International Convention of Tonnage Measurement of Ships 1969, annex I, regulation 3.

① This factor is applicable to LNG carriers defined as gas carriers in regulation 2.26 of MARPOL Annex VI (LNG carriers before 1 September 2015) and is not to be applied to LNG carriers defined in regulation 2.38 of MARPOL Annex VI.

2.3.10.5 For bulk carriers having R of less than 0.55 (e.g. wood chip carriers), the following cubic capacity correction factor is to apply:

$$f_{c\,bulk\ carriers\ designed\ to\ carry\ light\ cargoes} = R^{-0.15}$$

where: R— the capacity ratio of the deadweight of the ship (tonnes) as determined by paragraph 2.3.4 divided by the total cubic capacity of the cargo holds of the ship (m^3).

2.3.11 Correction factor f_w

2.3.11.1 f_w is a non-dimensional coefficient indicating the decrease of speed in representative sea conditions of wave height, wave frequency and wind speed (e.g., Beaufort Scale 6).

2.3.11.2 f_w is to be taken as 1.0 in calculation of the Attained EEDI specified in 2.3.3.

2.3.11.3 Where the Owner requests on a voluntary basis the application of f_w, the Attained EEDI value using f_w is to be referred to *Attained* $EEDI_{weather}$ and confirmed by ISC, and indicated in the related certificate. f_w is to be determined as follows:

(1) f_w can be determined by conducting the ship-specific simulation of its performance at representative sea conditions. The simulation methodology is to be that as prescribed in the Guidelines developed by IMO and the method and outcome for an individual ship is to be verified by the Administration or ISC.

(2) In case where the simulation is not conducted, f_w value is to be taken from the "Standard f_w" table/curve prescribed in the Guidelines developed by IMO ① .

2.3.11.4 f_w and Attained $EEDI_{weather}$ together with the representative sea conditions are to be indicated in the EEDI technical file to make a distinction from Attained EEDI required in 2.3.3.

2.3.12 Energy efficiency factor f_{eff}

2.3.12.1 f_{eff} is the availability factor of each innovative energy efficiency technology. f_{eff} for waste energy recovery system is to be taken as 1.0.

2.3.13 Length between perpendiculars (L_{pp})

2.3.13.1 L_{pp} means 96% of the total length on a waterline at 85% of the least moulded depth measured from the top of the keel, or the length from the foreside of the stem to the axis of the rudder stock on that waterline, if that were greater. For ships designed with a rake of keel, the waterline on which this length is measured is to be parallel to the designed waterline. L_{pp} is to be measured in m.

2.3.14 Correction factor f_l

2.3.14.1 f_l is the factor for general cargo ships equipped with cranes and other cargo-related gear to compensate in a loss of deadweight of the ship.

$$f_l = f_{cranes} \cdot f_{sideloader} \cdot f_{roro}$$

① Refer to Interim Guidelines for the calculation of the coefficient f_w for decrease in ship speed in a representative sea condition for trial use, approved by IMO and circulated by MEPC.1/Circ.796.

where: $f_{cranes} = 1$ if no cranes are present;
$f_{sideloader} = 1$ if no side loaders are present;
$f_{roro} = 1$ if no ro-ro ramp is present.

2.3.14.2 For cranes, f_{cranes} is defined as follows:

$$f_{cranes} = 1 + \frac{\sum_{n=1}^{n}(0.0519 \cdot SWL_n \cdot Reach_n + 32.11)}{Capacity}$$

where: SWL— Safe Working Load, as specified by crane manufacturer in t;
$Reach$ — Reach at which the Safe Working Load can be applied in m;
n — Number of cranes.

2.3.14.3 For other cargo gear such as side loaders and ro-ro ramps, the factor is to be defined as follows:

$$f_{sideloader} = \frac{Capacity_{No\ sideloaders}}{Capacity_{sideloaders}}$$

$$f_{RoRo} = \frac{Capacity_{No\ RoRo}}{Capacity_{RoRo}}$$

where: the weight of the side loaders and ro-ro ramps is to be based on a direct calculation, in analogy to the calculations as made for factor f_{iVSE}.

2.3.15 Summer load line draught d_s

2.3.15.1 d_s is the vertical distance, in metres, from the moulded baseline at mid-length to the waterline corresponding to the summer freeboard draught to be assigned to the ship.

2.3.16 Breadth B_s

2.3.16.1 B_s is the greatest moulded breadth of the ship, in metres, at or below the load line draught, d_s.

2.3.17 Volumetric displacement ∇

2.3.17.1 ∇, in cubic metres (m^3), is the volume of the moulded displacement of the ship, excluding appendages, in a ship with a metal shell, and is the volume of displacement to the outer surface of the hull in a ship with a shell of any other material, both taken at the summer load line draught, d_s, as stated in the approved stability booklet/loading manual.

2.3.18 Gravitational acceleration g

2.3.18.1 g is the gravitational acceleration, $9.81 m/s^2$.

2.3.19 Factor for ice-classed ships having IA Super and IA, f_m

2.3.19.1 For ice-classed ships having IA Super or IA, the factor, f_m, is to be taken as 1.05.

2.4 Mandatory Reporting of Attained EEDI Values and Related Information

2.4.1 In accordance with regulation 22.3 of MARPOL Annex VI, for each ship subject to regulation 24, the Administration or any organization duly authorized by it is to report the required and attained EEDI values and relevant information taking into account this Section via electronic communication.

2.4.2 Information to be reported are as follows:

(1) applicable EEDI phase (e.g. Phase 1, Phase 2, etc.);

(2) identification number (IMO Secretariat use only);

(3) ship type;

(4) common commercial size reference (see Note (3) in Table 1), if available;

(5) DWT or GT (as appropriate);

(6) year of delivery;

(7) required EEDI value;

(8) attained EEDI value;

(9) dimensional parameters (length L_{pp} (m), breadth B_s (m), and draught (m));

(10) V_{ref} (knots) and P_{ME} (kW);

(11) use of innovative technologies (4th and 5th terms in the EEDI equation, if applicable);

(12) short statement [①] describing the principal design elements or changes employed to achieve the attained EEDI (as appropriate), if available;

(13) type of fuel used in the calculation of the attained EEDI, and for dual-fuel engines, the f_{DFgas} ratio; and

(14) ice class designation (if applicable).

2.4.3 The information in paragraph 2.4.2 is not required to be reported for ships for which the required and attained EEDI values had been already reported to IMO.

2.4.4 A standardized reporting format for Mandatory Reporting of Attained EEDI Values and Related Information is presented in Table 2.4.4.

① Not subject to verification.

STANDARD FORMAT TO SUBMIT EEDI INFORMATION TO BE INCLUDED IN THE EEDI DATABASE Table 2.4.4

IMO Number (1)	Type Of ship (2)	Common Commercial size (3)	Capacity (4)		Dimensional parameters			Year of delivery	Applicable phase	Required EEDI	Attained EEDI	V_{ref} (knot) (9)	P_{ME} (kW) (10)	Type of fuel (11)	f_{DFgas} (12)	Ice class (13)	EEDI 4 th term (Installation of innovative electrical technology)		EEDI 5th term (Installation of innovative mechanical technology)		Short statement as appropriate describing the principal design elements or changes employed to achieve the attained EEDI (15)
			DWT	GT (5)	L_{pp} (m) (6)	B_s (m) (7)	Draught (m) (8)										Yes/ No	Name, outline and means/ ways of performance of technology (14)	Yes/ No	Name, outline and means/ ways of performan ce of technology (14)	

Note:

(1) IMO number to be submitted for Secretariat use only.

(2) As defined in regulation 2of MARPOL Annex VI.

(3) Common commercial size reference (TEU for container ship,CEU (RT43) for ro-ro cargo ship (vehicle carrier), cubic meter for gas carrier and LNG carrier), if available, should be provided.

(4) The exact DWT or GT, as appropriate, should be provided. The Secretariat should round the DWT or GT data up to the nearest 500 when these data are subsequently provided to MEPC. (For container ships, 100% DWT should be provided while 70% of DWT should be used when calculating the EEDI value).

(5) GT should be provided for a cruise passenger ship having non-conventional propulsion as defined in regulations 2.2.11and 2.2.19,respectively, of MARPOL Annex VI. Both DWT and GT should be provided for a ro-ro cargo ship (vehicle carrier) as defined in regulation 2.2.27 of MARPOL Annex VI .

(6) As defined in paragraph 2.2.13 of the 2018 Guidelines on the method of calculation of the attained Energy Efficiency Design Index (EEDI) for new ships (resolution MEPC.308(73), as amended). The exact L_{pp} should be provided. The Secretariat will round the L_{pp} data up to the nearest 10 when these data are subsequently provided to MEPC.

(7) As defined in paragraph 2.2.16 of the 2018 Guidelines on the method of calculation of the attained Energy Efficiency Design Index (EEDI) for new ships (resolution MEPC.308(73), as amended). The exact B_s should be provided. The Secretariat will round the B_s data up to the nearest 1 when these data are subsequently provided to MEPC.

(8) As defined in paragraph 2.2.15 of the 2018 Guidelines on the method of calculation of the attained Energy Efficiency Design Index (EEDI) for new ships (resolution MEPC.308(73), as amended). The exact draught should be provided. The Secretariat will round the draught data up to the nearest 1 when these data are subsequently provided to MEPC.

(9) As defined in paragraph 2.2.2 of the 2018 Guidelines on the method of calculation of the attained Energy Efficiency Design Index (EEDI) for new ships (resolution MEPC.308(73), as amended). The exact V_{ref} should be provided . The Secretariat will round the V_{ref} data up to the nearest 0.5 when these data are subsequently provided to MEPC.

(10) As defined in paragraph 2.2.5.1 of the 2018 Guidelines on the method of calculation of the attained Energy Efficiency Design Index (EEDI) for new ships (resolution MEPC.308(73), as amended). The exact P_{ME} should be provided. The Secretariat will round the P_{ME} data up to the nearest 100 when these data are subsequently provided to MEPC.

(11) As defined in paragraph 2.2.1 of the 2018 Guidelines on the method of calculation of the attained Energy Efficiency Design Index (EEDI) for new ships (resolution MEPC.308(73), as amended) or other (to be stated). In case of a ship equipped with a dual-fuel engine, type of "primary fuel" should be provided.

(12) As defined in paragraph 2.2.1 of the 2018 Guidelines on the method of calculation of the attained Energy Efficiency Design Index (EEDI) for new ships (resolution MEPC.308(73), as amended), if applicable.

(13) Ice class, which was used to calculate correction factors for ice-classed ships as defined in paragraphs 2.2.8.1 and 2.2.11.1 of the 2018 Guidelines on the method of calculation of the attained Energy Efficiency Design Index (EEDI) for new ships (resolution MEPC.308(73), as amended), if applicable, should be provided.

(14) In the case that the innovative energy efficiency technologies are already included in the 2013 Guidance on treatment of innovative energy efficiency technologies for calculation and verification of the attained EEDI (MEPC.1/Circ.815), the name of technology should be identified. Otherwise, name, outline and means/ways of performance of the technology should be identified.

(15) To assist the IMO in assessing relevant design trends, provide a short statement as appropriate, describing the principal design elements or changes employed to achieve the attained EEDI.

Chapter 3 EEDI Verification Process

3.1 General provisions

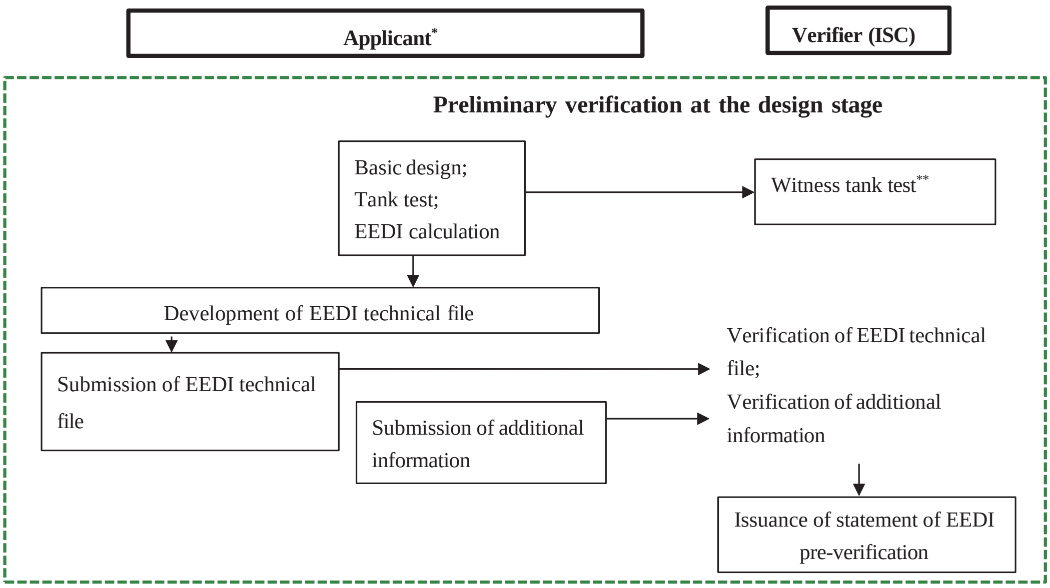
3.1.1 This Chapter applies to EEDI verification of ships applicable to EEDI regulations of MARPOL Annex VI and international sea-going ships applying for class notation of CDx in ISC Rules for Green-Eco Ships.

3.1.2 Verification of the Attained EEDI ① is to be conducted on two stages: preliminary verification at the design stage, and final verification at the sea trial stage. For points for verification of EEDI, see appendix 3.

3.1.3 The information used in the verification process may contain the submitter's confidential information which requires protection of the intellectual property of the client. After the submitter has signed a confidentiality agreement with ISC, the submitter is to provide the additional information necessary for verification to ISC upon mutually agreed terms and conditions.

3.2 Verification procedure

3.2.1 The verification procedure is shown in Figure 3.2.1(1). Flowchart for Witnessing of Tank Test is shown in Figure 3.2.1(2).



* An applicant for EEDI verification means a shipowner, shipyard or designer; an applicant for tank test means a shipowner, shipyard, designer or its entrusted tank test organization, etc.
** Refer to Figure 3.2.1(2).

① With regard to statutory requirements, for a ship the Required EEDI of which is not required in MARPOL Annex VI, its Attained EEDI only need be verified based on EEDI technical file.

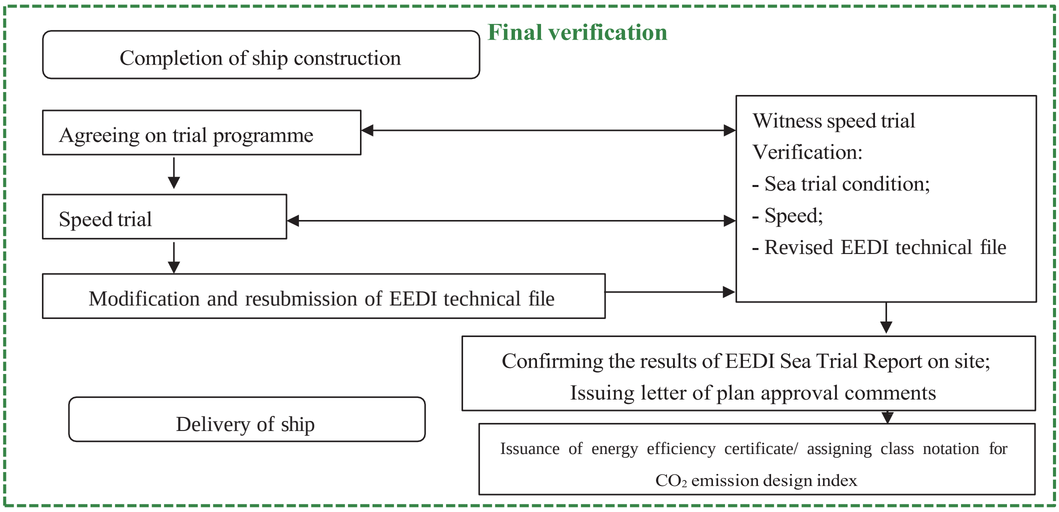


Figure 3.2.1(1) Verification Procedure

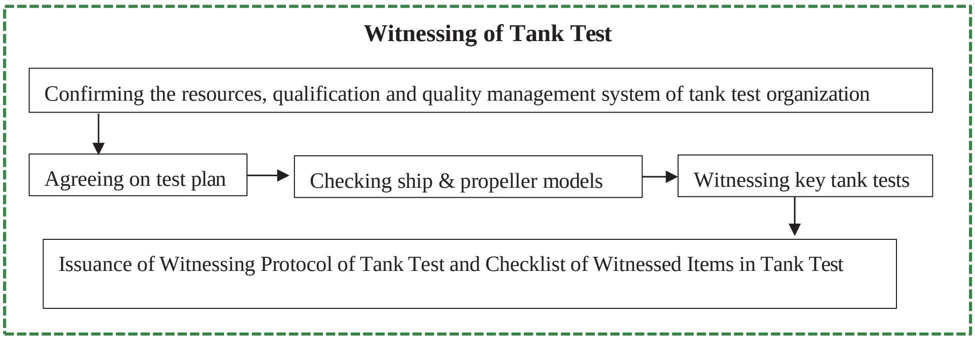


Figure 3.2.1(2) Flowchart for Witnessing of Tank Test

3.3 Document issuance

3.3.1 The Checklist of Witnessed Items in Tank Test and Witnessing Protocol of Tank Test are to be issued by ISC plan approval unit or survey unit accepting the application for witnessing tank test.

3.3.2 The Statement of EEDI Preliminary Verification, Letter of Plan Approval Comments, the Statement of Preliminary Verification of Electric Power Table for EEDI (if any) are to be issued by ISC plan approval unit accepting the application for EEDI verification.

3.3.3 Checklist for Witnessed Items in Sea Trial and the Statement of Final Verification of Electric Power Table for EEDI (if any) are to be issued by the site survey unit.

3.3.4 The Energy Efficiency Certificate is to be issued and/or the class notation for CO_2 emission design index (CDx) is to be assigned by the site survey unit after the EEDI verification is completed.

Chapter 4 Preliminary Verification

4.1 General provisions

4.1.1 Prior to submitting the application for the verification of EEDI, the applicant is to complete basic design of the ship. The preliminary verification is in general to include witnessing of tank test, the review of basic design, and the verification of EEDI technical files.

4.1.2 For the witnessing of tank test, where the applicant is not an authorized tank test organization, it is to be ensured that the tank test organization can provide relevant information and materials required for the completion of witnessing. ISC plan approval unit accepting the application of EEDI verification is to:

(1) carry out a review of the resources, qualification, quality management system and testing in relation to the towing tank used in model test for compliance with the requirements of 4.5 of this Chapter;

(2) witness the process of test (including resistance test, propeller open water test and self-propulsion test) in accordance with the plan agreed upon between the applicant and ISC survey unit;

(3) review the “additional information” to be submitted by the applicant;

(4) issue the Checklist of Witnessed Items in Tank Test and Witnessing Protocol of Tank Test after having witnessed the test, of which the Witnessing Protocol of Tank Test is to be conferred to the applicant.

4.1.3 For the review of basic design and verification of EEDI technical files, it is to be conducted by means of the examination of EEDI technical file and “additional information” of tank test submitted by the applicant, which is carried out by ISC plan approval unit accepting the application for EEDI verification. For key points for the examination of EEDI technical file, see the descriptions of Appendix 3. After verification, ISC plan approval unit is to issue the Statement of Preliminary Verification of EEDI to ISC construction survey unit and applicant of EEDI verification.

4.1.4 Further to the agreement of the submitter of the EEDI Technical File and the Shipowner, a Verifying Society may accept tank tests reports reviewed by another Society if the tank tested ship is of the same type as the ship of which the EEDI is verified.

4.1.4.1 Where ISC is the Verifying Society, copies of the following documents for ships of the same type are to be provided to the Verifying Society, with protection of the Intellectual Property Rights (IPR) in accordance with paragraph 3.1.3:

(1) calculation of the reference speed of the verified ship explicitly making reference to the speed power curves of the tank tested ship model;

(2) witnessing protocol of the tank tested ship endorsed by the surveyor of the Witnessing Society;

(3) tank test report of the tank tested ship.

4.1.4.2 On specific request of the Verifying Society (ISC), the following additional information is to be submitted: Ship lines and model particulars, loading and operating conditions of the tank tested ship as described in 4.2.7.2 of IMO "2014 Guidelines on Survey and Certification of the Energy Efficiency Design Index (EEDI)" as amended, showing that the verified ship and the tank tested ship are of the same type.

4.1.4.3 If some of the relevant information is held by the original Witnessing Society, the submitter is to authorize the Witnessing Society (ISC) to offer the information to the Verifying Society.

4.1.5 It is expected that the tank tests of a new ship performed in a tank test organization of ITTC member before 1 January 2013 have not been witnessed by a Verifier. In this case, tank test results provided by a tank test organization with quality control certified according to a recognized scheme or with experience may be accepted by ISC.

4.1.6 Tank test conducted by a tank test institution that has already been qualified by ISC as the "Supplier Engaged in Energy Efficiency Design Index (EEDI) tank test" as specified in ISC Guidelines for Management of Approval of Suppliers and Personnel Qualification may be witnessed in a flexible manner.

4.2 Documents and information

4.2.1 The following documents and information are to be submitted to ISC by the applicant (shipowner/designer, shipbuilder, authorized tank test organization or other unit):

(1) an EEDI technical file containing the necessary information for the verification and other relevant background documents, e.g. NO_x Technical File, verified technical measure to limit the propulsion output, etc.;

(2) additional information necessary for the verification.

4.2.2 The reasons for conducting a tank test or being exempted from a tank test (if applicable) for the ship applying for verification are to be indicated in the EEDI technical file containing basis design information and other relevant background documents.

4.2.3 Apart from being confirmed by ISC in compliance with the conditions for exemption from a tank test, the "additional information" (as specified in 4.4 of this Chapter) reflecting the tank test is to be submitted for the ship applying for verification.

4.3 Basic requirements for the EEDI technical file

4.3.1 The EEDI technical file for a sea-going ship engaged on international voyages is to be written at least in English. The development of EEDI technical file may refer to Appendix 1 of these Guidelines.

4.3.2 The EEDI technical file is to include at least but not limited to:

(1) relevant design parameters:

① deadweight (DWT) ; or gross tonnage (GT) for passenger and ro-ro passenger ships;

② the maximum continuous rating (*MCR*) of the main and auxiliary engines;

③ the ship speed V_{ref} for calculating EEDI;

④ the specific fuel consumption (*SFC*) of the main engine at the 75% of *MCR* power;

⑤ the specific fuel consumption (*SFC*) of the auxiliary engines at the 50% *MCR* power;

⑥ the electric power table for the EEDI (EPT-EEDI) for certain ship types (passenger and ro-ro passenger ships) is to be developed in accordance with relevant requirements and verified in accordance with Appendix 3 of these Guidelines;

(2) a power curve (kW-knot) estimated at the design stage (corrected after tank test) under the full load (note: 70% DWT for container ship) draught and under the condition of assumed no wind, no wave and no current and deep water;

(3) in the event that the sea trial is not carried out under the full load draught, a power curve (kW-knot) is to be estimated under such condition and under the condition of assumed no wind, no wave and no current and deep water by means of tank test, in addition to that required in (2) above;

(4) principal particulars, ship type and the relevant information to classify the ship into such a ship type, classification notations and the overview of propulsion system and electricity supply system on board;

(5) description of energy saving equipment;

(6) calculated value of the Attained EEDI including the calculation summary, which is to contain, at a minimum, each value of the calculation parameters and the calculation process used to determine the Attained EEDI;

(7) if the coefficient for the decrease of ship speed in representative sea conditions (f_w) is used, the calculated Attained EEDI is to be expressed as Attained $EEDI_{weather}$. The values of f_w and Attained $EEDI_{weather}$ are to be included;

(8) the cubic capacity correction factor (f_c) is to be included for chemical tankers and LNG carriers ① ;

(9) for LNG carriers ② , the following are also to be included:

① type and outline of propulsion systems (such as direct drive diesel, diesel electric, steam turbine);

② LNG cargo tank capacity and BOR (the design rate of boil-off gas of entire ship per day, which is specified in the specification of the building contract);

③ shaft power of the propeller shaft after transmission gear at 100% of the rated output of motor (MPP_{Motor}) and $\eta_{(i)}$ for diesel electric;

---

① Applicable when LNG carrier is defined as of the ship type "gas carrier".

② For the purposes of meeting the statutory requirements, this paragraph is applicable to LNG carriers delivered on or after 1 September 2019.

④ maximum continuous rated power ($MCR_{SteamTurbine}$) for steam turbine; and

⑤ $SFC_{SteamTurbine}$ for steam turbine;

(10) the correction factor (f_{iCSR}) is to be included for ships which are constructed according to Common Structural Rules (CSR);

(11) the correction factor for ship specific voluntary structural enhancement (f_{ivse}) is to be included for ships with voluntary structural enhancement. Two sets of structural plans (one set for the ship without voluntary structural enhancement and the other set for the same ship with voluntary structural enhancement) of the ship are to be submitted for assessment. Alternatively, one set of structural plans of the reference design with annotations of voluntary structural enhancement may be submitted.

(12) If the propulsion power is voluntarily limited by verified technical means, descriptions for the propulsion power limitation means are to be included.

4.3.3 If ships are equipped with dual-fuel main engine(s) or auxiliary engine(s), the C_F-factor for gas fuel and the C_F-factor for fuel oil are to be applicable, and the Specific Fuel Consumption (SFC) of the corresponding fuel is to be multiplied at the relevant EEDI load point. Consideration is also to be given to:

(1) if gas fuel is regarded as the primary fuel;

(2) in case the ship is not fully equipped with dual-fuel engines, the C_F-factor for gas (LNG) is to apply only for those installed engines that are of dual fuel type and sufficient gas fuel supply is to be available for such engines.

4.3.4 During the calculation of the Attained EEDI, the specific fuel consumption (SFC) of the main and auxiliary engines is to be quoted from the approved NOx technical file and corrected to the value corresponding to the ISO standard reference conditions using the standard lower calorific value of the fuel oil (42,700 kJ/kg), referring to ISO 15550:2002 and ISO 3046-1:2002. For the confirmation of the SFC, a copy of the approved NO_x technical file and documented summary of the correction calculations are to be submitted to ISC. In case the NOx technical file has not been approved at the time of the application for the preliminary verification, the test reports provided by manufacturers are to be used. In this case, at the time of the sea trial verification, a copy of the approved NO_x technical file and documented summary of the correction calculations are to be submitted to ISC. In the case that gas fuel is determined as primary fuel in accordance with 2.3.1.2 and that the Technical File for the installed engine(s) does not indicate the tested value in gas mode, the SFC of gas mode should be submitted by the manufacturer and confirmed by ISC.

4.3.5 The main items of basic design review include:

(1) parameters of ship and main engine related to EEDI;

(2) parameters of hull lines characteristics;

(3) hull resistance/effective power curve, self-propulsion factor, propeller parameters and open water performance curve necessary for the calculation of power curve;

(4) power curve in full load draught and ballasting conditions, estimated data of ship speed for calculating Attained EEDI.

4.4 Basic requirements for additional information

4.4.1 The additional information is to include at least but not limited to:

(1) descriptions of a tank test facility; this is to include the name of the facility, the particulars of tanks and towing equipment, and the records of calibration of each monitoring equipment, quality management system of tank test organization;

(2) lines of a model ship and an actual ship (sheer plan, body plan and half-breadth plan) and model propeller report are to be detailed enough to demonstrate the similarity between the model ship and the actual ship for the verification of the appropriateness of the tank test;

(3) lightweight of the ship and displacement for the verification of the deadweight;

(4) tank test plan; this is to include descriptions for test steps and points required to be witnessed by ISC survey unit;

(5) detailed report on the method and results of the tank test; this is to include at least the tank test results at the full load draught and ballast sea trial conditions(if sea trial is not practical at full load draught conditions) as well as the power curves at two conditions;

(6) detailed calculation process of the ship speed;

(7) The power curve of the actual ship derived from tank test is to be based on the following test data and calculated based on hull-engine-propeller interactions:

① wake fraction *w* and thrust deduction fraction *t* derived from model test results;

② relative rotative efficiency and effective power curve of the actual ship; and

③ propeller open water performance curve of the actual ship;

(8) exemption from a single tank test may be based on technical basis (e.g. applicability of the tank test results) for ships of same type; this is to include lines and tank test results of the ships of same type, and the comparison of the principal particulars of such ships and the ship in question. Appropriate technical justification is to be provided explaining why the tank test is unnecessary. In addition, omission of tank tests is acceptable for a ship for which sea trials will be carried out under the condition of full load draught, upon agreement of the shipowner and shipbuilder and with approval of ISC.

(9) Numerical calculations may be accepted as equivalent to model propeller open water tests. Numerical calculations may be submitted to justify derivation of speed power curves, where only one parent hull form have been verified with tank tests, in order to evaluate the effect of additional hull features such as fore bulb variations, fins and hydrodynamic energy saving devices. These numerical tests may include CFD calculation of propulsive efficiency at speed V_{ref} as well as hull resistance variations and propeller open water efficiency. These numerical tests are to be carried out in accordance with defined quality and technical standards (ITTC 7.5-03-01-04 at its latest revision or equivalent).The comparison of the CFD-computed values of the unmodified parent hull form with the results of the towing tank tests must be submitted for review.

4.4.2 ISC surveyors are to carry out an audit of the qualification of units conducting tank test in accordance with the requirements of Section 4.5 of this Chapter and witness the resistance test, propeller open water test and self-propulsion test. Prior to the start of the towing tank tests, the submitter is to submit a test plan to ISC survey unit. Following the indications of the agreed test plan, the submitter will notify ISC survey unit for the agreed tests to be witnessed. The submitter will advise ISC survey unit of any changes to the activities agreed in the Test Plan and provide the submitter with the towing tank test report and results of trial speed prediction.

4.4.3 Model-ship correlation method followed by the tank test organization is to be properly documented with reference to the latest version of ITTC Recommended Procedure 7.5-02-03-1.4.

4.4.4 Since detailed process of the tank tests depends on the practice of each submitter, sufficient information is to be included in the document submitted to ISC to show that the principal scheme of the towing tank test process meets the requirements of the reference documents listed in Appendix 4 and Appendix 5.

4.5 Basic requirements for towing tank used in test

4.5.1 The test organizations/units conducting model tests for the purpose of EEDI preliminary verification are to be members of ITTC [①] and their test procedures are to comply with relevant procedures of ITTC. The test units are also to be subject to ISO 9001 quality management system certification, and effective management and monitoring are to be carried out to the qualification of test personnel and services supplied by them. When in addition the towing tank test organization quality control system is not certified according to a recognized scheme (ISO 9001 or equivalent) the following additional information relative to the tank test organization is to be submitted to the ISC unit witnessing the test:

(1) descriptions of the towing tank test facility, including the name of the facility, the particulars of towing tanks and towing equipment, and the records of calibration of each monitoring equipment as described in Appendix 4;

(2) quality manual containing at least the information listed in the ITTC Sample quality manual.

4.5.2 The test used for the prediction of ship speed V_{ref} is generally conducted in the model towing tank. The dimension and water depth of the towing tank are to be suitable for the length and test speed of the model used. The model tank test is to have adequate measuring section and measuring time. Test locations are to be provided with equipment and instrumentation for resistance test, self-propulsion test and propeller open water test. Tanks are to be at least provided with the following equipment and facilities:

(1) wave generator and wave damper (necessary for the verification of f_w and Attained $EEDI_{weather}$);

(2) processing/measuring equipment of model and propeller;

(3) instruments for measuring force and speed, capable of measuring at least:

① model speed (V_m);

② total resistance of model (R_m);

① ITTC-International Towing Tank Conference.

③ propeller thrust (T_m);

④ propeller torque (Q_m);

⑤ rate of revolution of propeller (n_m);

(4) other measuring devices, e.g. trim meter, draught meter, gravimeter, wave height meter, Prandtl pitot tube and five-hole pitot tube, pressure sensor, water pressure gauge, hot-wire meter, Doppler laser velocimeter, strainmeter bridge equipment, electronic equipment (recorder, filter, analyzer), etc.

4.5.3 The test units are to have an effective management of monitoring, measuring and test equipment, regularly carrying out calibration and making records, to ensure the effectiveness of such equipment and guarantee the accuracy of test results. For the management and calibration of test equipment, refer to the requirements of ITTC 7.6-01-01. Detailed requirements for calibration of test equipment are referred to in Appendix 4.

4.5.4 For regular calibration of test instruments and evaluation of their uncertainties, refer to ITTC 7.5-01-03-01.

4.5.5 The ship model and propeller model used in the test are to comply with the requirements for EEDI verification. The ship model is to be made according to ship lines provided. It is to ensure that the model is kept good and the displacement is correct during test. For model making, refer to ITTC 7.5-01-01-01.

4.5.6 Turbulence stimulation measures are to be clearly indicated in model making documents or test documents. For the use of wires or sand strips, refer to the relevant requirements of ITTC 7.5-01-01-01.

4.5.7 Prior to test, the model's draft is to be determined, its floating control established and the preparation of relevant information regarding the model (including hull and propeller) completed. For details, refer to ITTC 7.5-01-01-01.

4.5.8 Prior to each test, the test location is to develop a test program according to ITTC recommended procedures. The test program is to include model condition, equipment installation and required parameters in resistance/self-propulsion/propeller open water tests, as well as explanations for the use of measuring instruments and measurement accuracy, test flow and data collection and analysis. The test program is also to provide a procedure for the reliability analysis of test results and indicate the information to be included in the test report. For details, refer to the requirements of ITTC 7.5-02-02-01, 7.5-02-03-01.1, 7.5-02-03-02.1.

4.5.9 The test unit is to have an effective management of data generated during test, which includes properly recording key data and results during test and showing test results (such as resistance coefficient, wake fraction, thrust deduction and delivered power curves) in diagrams with the guidance/participation of the test unit after test. Test records, test information and prediction analysis are to be archived.

4.5.10 Test locations are to have an appropriate test data management and analysis software platform. Model tank test data are to be so accumulated that the accuracy requirements for correction of the tested ship type are complied with.

Chapter 5   Final Verification

5.1   General provisions

5.1.1   The final verification of EEDI is to include:

(1) Examination of the programme of the sea trial and confirmation of sea trial conditions by site survey unit.

(2) site survey unit's witness of sea trial and ascertain the relevant parameters obtained for the final calculation of EEDI (check the electric load of consumers and producers included in the EPT-EEDI, if necessary); after the sea trial, ISC site survey unit is to review results relating verification of EEDI sea trial in the sea trial report submitted by the sea trial test organization, complete the Checklist for Witnessed Items in Sea Trial and send to plan approval unit.

(3) plan approval unit's review of the test report submitted by the test organization; confirmation that the power and speed have been corrected in accordance with ITTC Recommended Procedure 7.5-04-01-01.2 Speed and Power Trials Part 2; 2017 or ISO 15016:2015.

(4) plan approval unit's review of the EEDI technical file revised and resubmitted by the submitter. Issuance of the letter of plan approval comment after the final EEDI value is ascertained.

5.1.2   The survey unit shall issue the Energy Efficiency Certificate or assign the class notation for CO_2 emission design index (CDx) as defined in ISC Rules for Green-Eco ships after checking that the ship complies with relevant requirements according to the letter of plan approval comments issued by the plan approval unit.

5.2   Documents and information

5.2.1   The following documents are to be submitted to ISC site survey unit prior to sea trial:

(1) sea trial programme (including speed trial programme), at least including explanations for sea trial conditions, explanations for parameters to be measured, measuring method, measuring instruments and calibration of instruments, and explanations for data recording sheet, data analysis and correction method, etc.;

(2) the final displacement and the measured lightweight, or the report of final inclining test;

(3) a copy of NO_x technical file of main and auxiliary engines.

5.3   Verification of speed trial

5.3.1   Sea trial conditions are to be set according to the conditions defined in 2.3.2 as far as possible.

5.3.2   Speed trial is to be carried out based on the following requirements:

(1) ISC surveyors are to witness the process of measuring speed.

(2) The verification of speed trial is to confirm:

① propulsion and power supply system, particulars of the engines or steam turbine (for LNG carrier having steam turbine propulsion system), and other relevant items described in the EEDI technical file;

② ship draft and trim;

③ sea conditions of sea trial and other required parameters of environmental conditions;

④ testing of ship speed;

⑤ testing of shaft power and revolutions per minute (RPM) of the prime mover.

(3) Draft and trim are to be confirmed by the draft measurements taken prior to the sea trial. The draft and trim are to be as close as practical to those at the assumed conditions used for estimating the power curves.

(4) Sea conditions are to be measured in accordance with ITTC Recommended Procedure 7.5-04-01-01.1 Speed and Power Trials Part 1; 2017 or ISO 15016: 2015.

(5) Ship speed is to be measured in accordance with ITTC Recommended Procedure 7.5-04-01-01.1 Speed and Power Trials Part 1; 2017 or ISO 15016: 2015 and at more than three points of which range includes the main engine power defined in 2.2.5 of IMO 2018 EEDI Calculation Guidelines. This requirement applies individually to each ship, even if the ship is a sister ship of a parent vessel.

(6) The main engine output, shaft power of propeller shaft (for LNG carriers having diesel electric propulsion system) or steam turbine output (for LNG carrier having steam turbine propulsion system) are to be measured as follows:

① it is to be measured by a shaft power meter or a method which the engine manufacturer recommends and ISC approves. The shaft torque may be measured by means of measuring the torsional strain and the PRM of main engine (driving shaft) may be measured by pulse type meter, based on which the shaft power and main engine power may be derived;

② each testing condition may be measured in accordance with the methods recommended in GB/T 3471;

③ Other methods may be acceptable upon agreement of the shipowner and shipbuilder and with approval of ISC.

(7) The submitter is to develop power curves based on the measured ship speed and the measured output of the main engine at sea trial. For the development of the power curves, the submitter should correct the measured ship speed, if necessary, by taking into account the effects of wind, tide, waves, shallow water, displacement, water temperature and water density in accordance with ITTC Recommended Procedure 7.5-04-01-01.2 Speed and Power Trials Part 2; 2017 or ISO 15016:2015. The submitter is to submit a report on the speed trials, including details of the power curve development, to the verifier for verification.

5.3.3 ISC surveyors are to confirm the measuring items of sea trial. The data which are to be measured and recorded during sea trials include:

(1) time and duration of sea trial;

(2) draft marks readings;

(3) air and sea temperature;

(4) main engine setting;

(5) course direction (rad);

(6) speed over ground (m/s);

(7) propeller rpm (rpm);

(8) power measured (kW);

(9) relative wind velocity (m/s);

(10) relative wind direction (rad);

(11) mean wave period (seas and swell) (s);

(12) significant wave height (seas and swell) (m);

(13) incident angle of waves (seas and swell) (rad);

(14) rudder angle (rad);

(15) drift angle (rad).

5.4 Recalculation of Attained EEDI

5.4.1 The power curves obtained as a result of the sea trial and the estimated power curves at the design stage are to be compared. In case differences are observed, the Attained EEDI is to be recalculated, as necessary, in accordance with the following:

(1) for ships for which sea trial is conducted under the full load conditions, the Attained EEDI is to be recalculated using the measured ship speed at sea trial at the main engine power defined as P_{ME}.

(2) for ships for which sea trial is not conducted under the full load conditions, the Attained EEDI is to be recalculated by adjusting ship speed to the full load conditions by an appropriate correction method that is agreed by ISC.

(3) An example of possible methods of the speed adjustment is given as follows:

V_{ref} is obtained from the results of the sea trials at trial condition using the speed power curves predicted by the tank tests. The tank tests are to be carried out at both draughts: trial condition corresponding to that of the S/P trials and EEDI condition. For trial conditions the power ratio α_P between model test prediction and sea trial result is calculated for constant ship speed. Ship speed from model test prediction for EEDI condition at EEDI power multiplied with α_P is V_{ref}.

$$\alpha_P = \frac{P_{Trail,P}}{P_{Trail,S}}$$

where: $P_{Trail,P}$ — power at trial condition predicted by the tank tests;

$P_{Trail,S}$ — power at trial condition obtained by the *S/P* trials;

α_P — power ratio.

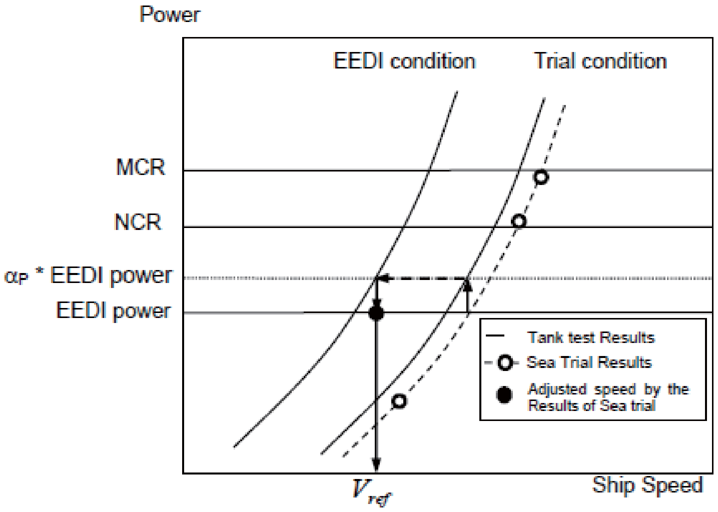


Figure 5.4.1 Example of Ship Speed Adjustment

5.4.2 In cases where the finally determined deadweight/gross tonnage differs from the designed deadweight/gross tonnage used in the EEDI calculation at the design stage, the submitter is to recalculate the Attained EEDI using the finally determined deadweight/gross tonnage. The finally determined gross tonnage is to be consistent with that indicated in the Tonnage Certificate of the ship.

5.4.3 For LNG carriers having diesel electric propulsion system, the electrical efficiency $\eta_{(i)}$ is to be taken as 91.3% for the purpose of calculating the attained EEDI. Alternatively, if a value of more than 91.3% is to be applied, $\eta_{(i)}$ is to be obtained by actual measurement and verified by a method approved by ISC.

5.4.4 In case where the Attained EEDI is calculated at the preliminary verification by using SFC based on the manufacturer's test report due to the non-availability at that time of the approved NO_x Technical file, the Attained EEDI is to be recalculated by using SFC in the approved NO_x technical file. Also, for steam turbines, the Attained EEDI is to be recalculated by using SFC confirmed by ISC.

5.4.5 The adjusted power curve and ship speed V_{ref} based on the results of sea trial, the finally determined deadweight/gross tonnage, η for LNG carriers having diesel electric propulsion system and SFC described in the approved NO_x technical file, and the recalculated Attained EEDI based on these modifications are to be confirmed.

5.4.6 It is to be confirmed that the revised Attained EEDI is calculated in accordance with Chapter 2 of these Guidelines.

5.5 Basic requirements for revised EEDI technical file

5.5.1 The submitted EEDI technical file is to include:

(1) power curve and ship speed under full load condition obtained after sea trial;

(2) Attained EEDI value of the ship and all details related to calculation parameters.

5.5.2 The sea trial report, final stability file including lightweight of the ship and displacement table based on the results of the inclining test or the lightweight check and lines of actual ship (if amended) is to be submitted at the same time in addition to the revised EEDI technical file. The power curve and ship speed under the condition of full load draught are to be calculated and determined in accordance with the measured data at sea trial, and corrected by taking into account the effects of wind, tide, waves and shallow water, in accordance with ITTC Recommended Procedure 7.5-04-01-01.2 Speed and Power Trials Part 2; 2017 or ISO 15016:2015.

5.6 Basic requirements for test organizations/units

5.6.1 The test organizations/units conducting speed trial for EEDI final verification for the purpose of obtaining the class notation for CO_2 emission design index (CDx) as defined in ISC Rules for Green-Eco Ships are to be qualified as “Suppliers Engaged in Speed Trial of Ships” specified in ISC Guidelines for Management of Approval of Suppliers and Personnel Qualification.

Chapter 6 Verification after Major Conversion

6.1 General provisions

6.1.1 In cases where a major conversion is made to a ship, the shipowner is to submit to ISC an application for an additional survey together with the EEDI technical file duly revised based on the conversion made and other relevant background documents.

6.1.2 For major conversion as mentioned in 1.2.13(1), 1.2.13(2), 1.2.13(3) and 1.2.13(5), the applicable Required EEDI after conversion is to comply with the requirements corresponding to the ship type and size of the converted ship at the date of contract, or the keel laying date or the delivery date of the existing ship.

6.1.3 For paragraph 1.2.13(4), in cases where the major conversion of a ship is so extensive that the ship is regarded as a newly constructed ship by the Administration, the applicable Required EEDI after conversion is to comply with the requirements corresponding to the ship type and size of the converted ship at the date of the contract of the conversion, or in the absence of a contract, the commencement date of the conversion.

6.1.4 Any substantial change in hull dimensions and/or capacity (e.g. change of length between perpendiculars (LPP)) is to be considered a major conversion.

6.1.5 Assuming no alteration to the ship structure, both decrease of assigned freeboard and temporary increase of assigned freeboard due to the limitation of deadweight or draft at calling port is not to be construed as a major conversion. An increase of assigned freeboard, except a temporary increase, is to be construed as a major conversion.

6.1.6 In any case, it is the Administration's authority to evaluate and decide whether an alteration is to be considered as major conversion.

6.1.7 The shipowner may, at any time, voluntarily request re-certification and reissuance of Energy Efficiency Certificate and/or the class notation for CO_2 emission design index (CDx) as defined in ISC Rules for Green-Eco Ships, on the basis of any new improvements to the ships' efficiency that are not considered to be major conversions.

6.2 Documents and information

6.2.1 The background documents are to include at least but not limited to:

(1) conversion plan and explanation related to the major conversion;

(2) EEDI parameters changed after the conversion and the technical justifications for each respective parameter;

(3) reasons for other changes made in the EEDI technical file, if any; and

(4) calculated value of the Attained EEDI with the calculation summary, which is to contain, at a minimum, each value of the calculation parameters and the calculation process used to determine the Attained EEDI after the conversion.

6.3 Verification of Attained EEDI after Major Conversion

6.3.1 ISC is to review the revised EEDI technical file and other documents submitted and verify the calculation process of the Attained EEDI to ensure that it is technically sound and reasonable and follows IMO 2018 EEDI Calculation Guidelines and/or Chapter 2 of these Guidelines.

6.3.2 For verification of the Attained EEDI after a conversion, speed trials of the ship are required by ISC, as necessary. Where speed trial is required again after the assessment, speed trail is to be carried out after conversion. Tank tests verification is to be requested if the speed trials conditions differ from the EEDI condition. In this case, numerical calculations performed in accordance with defined quality and technical standards (ITTC 7.5-03-01-04 at its latest revision or equivalent) replacing tank tests may be accepted by the verifier to quantify influence of the hull modifications.

6.3.3 For verification of the attained EEDI after a major conversion, no speed trials are necessary if the conversion or modifications don't involve a variation in speed V_{ref}. In case of conversion, if the assessment of the modified EEDI Technical File and other relevant documents leads to the conclusion that the modifications couldn't cause the ship to exceed the applicable required EEDI, speed trials will not be required. If such conclusion cannot be reached, speed trials will be required. If an Owner voluntarily applies for re-certification of EEDI with IEE Certificate reissuance and/or the class notation for CO_2 emission design index (CDx) on the basis of an improvement to the ship efficiency, speed trials are required in order to validate the attained EEDI value improvement.

Appendix 1 Sample of EEDI Technical File

1 Data

1.1 General information

Shipbuilder	XXX
Shipbuilder No.	12345
IMO No.	94111XX
Ship type	Bulk carrier
ISC CLASS No.	

1.2 Principal particulars

Length overall	250.0 m
Length between perpendiculars	240.0 m
Breadth, moulded	40.0 m
Depth, moulded	20.0 m
Summer load line draft, moulded	14.0 m
Deadweight at summer load line draft	150,000 tons

(Note: Above-mentioned moulded draft and deadweight are to be taken from stability information/freeboard calculation.)

1.3 Main engine

Manufacturer	XXX
Type	6J70A
Maximum continuous rating (MCR)	15,000 kW × 80 rpm
SFC at 75% MCR	165.0 g/kWh
Number of set	1
Fuel type	Diesel oil

(Note: This part of data is to be taken from general arrangement and NOx technical file.)

1.4 Auxiliary engine

Manufacturer	XXX
Type	5J-200
Maximum continuous rating (MCR)	600 kW × 900 rpm
SFC at 50% MCR	220.0 g/kWh
Number of sets	3
Fuel type	Diesel oil

(Note: This part of data is to be taken from general arrangement and NOx technical file.)

1.5 Shaft generator (if applicable)

Shaft generator No.			
Manufacturer			
Power ($P_{PTO(i)}$)			
Power ($P_{PTO(ii)}$)			
……			
Shaft generator efficiency η_{SG}	$\eta_{SG(i)}$	$\eta_{SG(ii)}$	……

(Note: Shaft generator No. is to be taken from system design instructions; other data are to be taken from manufacturer's documents.)

1.6 Shaft motor (if applicable)

Shaft motor No.			
Manufacturer			
Power ($P_{PTI(i)}$)			
Power ($P_{PTI(ii)}$)			
……			
Shaft motor efficiency η_{PTI}	$\eta_{PTI(i)}$	$\eta_{PTI(ii)}$	……

(Note: Shaft motor No. is to be taken from system design instructions; other data are to be taken from manufacturer's documents.)

1.7 Ship speed

Ship speed in deep water at summer load line draft at 75% of MCR	14.25 knots

(Note: It is to be taken from power curves and their calculations, see 2 below.)

2 Power curves

The power curves estimated at the design stage and modified after speed trials are shown in Figure 2.1.

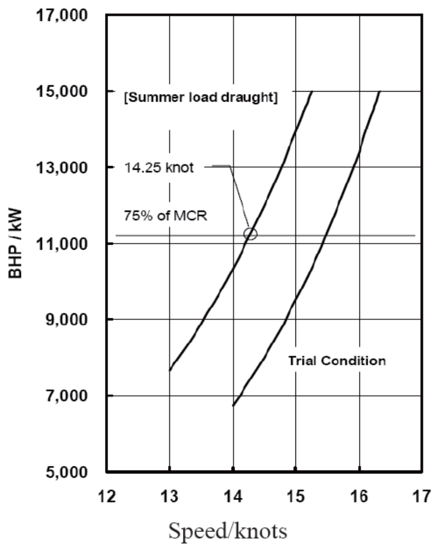


Figure 2.1 Power Curves

3 Overview of propulsion system and electric power supply system

3.1 Propulsion system

3.1.1 Main engine

Refer to subparagraph 1.3.

3.1.2 Propeller

Type	Fixed pitch propeller
Diameter	7.0 m
Number of blades	4
Number of set	1

3.2 Electric power supply system

3.2.1 Auxiliary engines

Refer to subparagraph 1.4.

3.2.2 Main generators (for shaft generators, see 1.5)

Manufacturer	XXX
Rated output	560 kW(700 kVA) × 900 rpm
Voltage	AC 450V
Number of sets	3
Weighted average efficiency of generator (η_{Gen})	

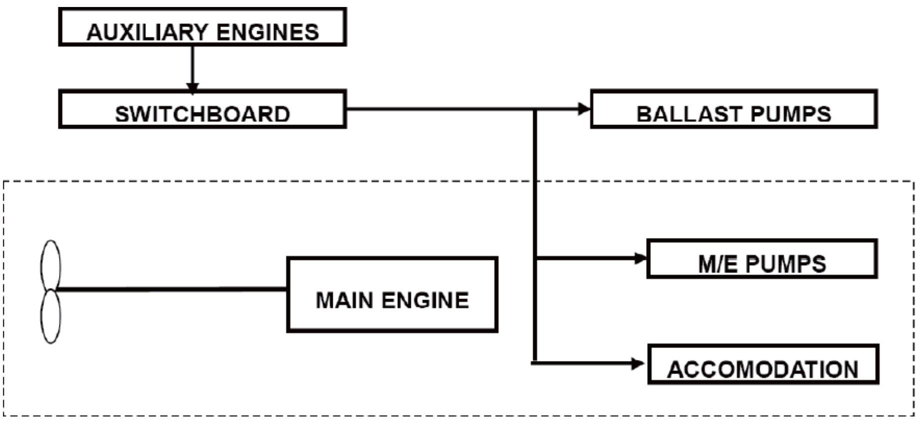


Figure 3.1 Schematic Figure of Propulsion and Electric Power Supply System

4 Estimation process of power curves at design stage

Power curves are estimated based on model test results. The flow of the estimation process is shown below.

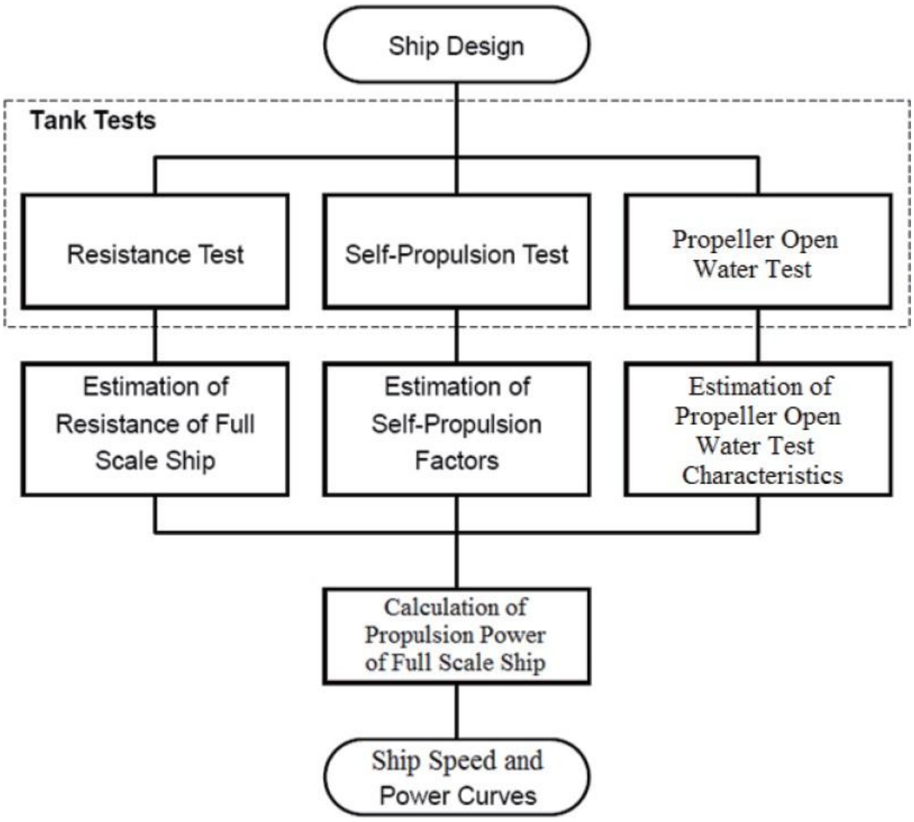


Figure 4.1 Flowchart of Process for Estimating Power Curves

5 Description of energy saving equipment

5.1 Energy saving equipment of which effects are expressed as $P_{AEeff(i)}$ and/or $P_{eff(i)}$ in the EEDI calculation formula

N/A

5.2 Other energy saving equipment

(Example)

5.2.1 Rudder fins

5.2.2 Propeller boss cap fins

……

(Specifications, schematic figures and/or photos, etc., for each piece of equipment or device are to be indicated. Alternatively, attachment of the commercial catalogue may be acceptable.)

6 Calculated value of attained EEDI

6.1 Basic data

Type of ship	Capacity DWT	Speed V_{ref} (knots)
Bulk carrier	150,000	14.25

6.2 Main engine

MCR_{ME} (kW)	Shaft generator	P_{ME} (kW)	Type of fuel	C_{FME}	SFC_{ME} (g/kWh)
15,000	N/A	11,250	Diesel oil	3.206	165.0

6.3 Auxiliary engine

P_{AE} (kW)	Type of fuel	C_{FAE}	SFC_{AE} (g/kWh)
625	Diesel oil	3.206	220.0

6.4 Ice class

N/A

6.5 Innovative electrical energy efficient technology

Innovative electric auxiliary engine (if applicable)

System No.	
Manufacturer	
Output power	
Efficient factor	

(Note: System No. is to be taken from system design instructions; other data are to be taken from manufacturer's documents.)

6.6 Innovative mechanical energy efficient technology

Innovative technology for reducing propulsion power of main engine (if applicable)

System No.	
Manufacturer	
Mechanical output	
Efficient factor	

(Note: System No. is to be taken from system design instructions; other data are to be taken from manufacturer's documents.)

6.7 Capacity correction factor

N/A

6.8 Calculated value of Attained EEDI

$$\frac{\left(\prod_{j=1}^{n} f_j\right)\left(\sum_{i=1}^{nME} P_{ME(i)} \cdot C_{FME(i)} \cdot SFC_{ME(i)}\right) + \left(P_{AE} \cdot C_{FAE} \cdot SFC_{AE}*\right) + \left(\left(\prod_{j=1}^{n} f_j \cdot \sum_{i=1}^{nPTI} P_{PTI(i)} - \sum_{i=1}^{neff} f_{eff(i)} \cdot P_{AEeff(i)}\right) C_{FAE} \cdot SFC_{AE}\right) - \left(\sum_{i=1}^{neff} f_{eff(i)} \cdot P_{eff(i)} \cdot C_{FME} \cdot SFC_{ME}**\right)}{f_i \cdot f_c \cdot f_l \cdot Capacity \cdot f_w \cdot V_{ref} \cdot f_m}$$

$$= \frac{1 \times (11250 \times 3.206 \times 165.0) + (625 \times 3.206 \times 220.0) + 0 - 0}{1 \cdot 1 \cdot 150000 \cdot 14.25 \cdot 1} = 2.99\ (g - CO2 / ton \cdot nmile)$$

Attained EEDI： 2.99 g-CO_2/ton mile

7 Calculated value of Attained $EEDI_{weather}$

7.1 Representative sea conditions

	Mean wind speed	Mean wind direction	Significant wave height	Mean period	Mean wave direction
BF6	12.6 (m/s)	0 (deg.) *	3.0 (m)	6.7 (s)	0 (deg.) *

* 0 (deg.) means the ship is heading directly into the wind/wave.

7.2 Calculated f_w value

f_w	0.900

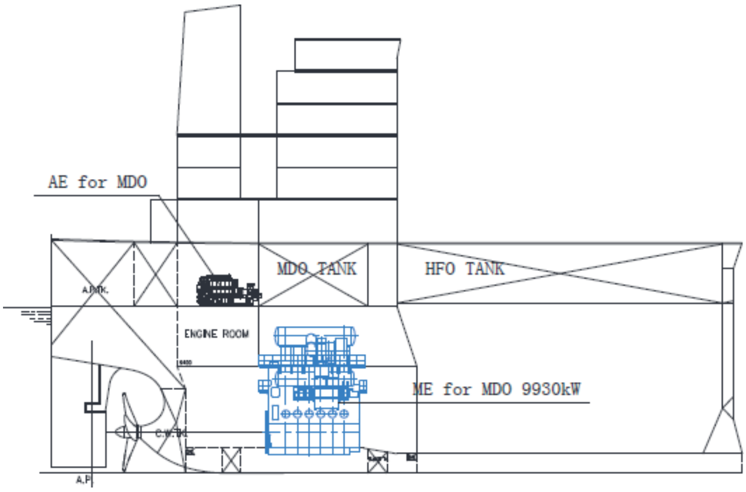
7.3 Calculated value of Attained $EEDI_{weather}$:

Attained $EEDI_{weather}$ = Attained EEDI/f_w = 2.99/0.9 = 3.32 **g-CO_2/ton mile**

Attained $EEDI_{weather}$: 3.32 g – CO_2/ton mile

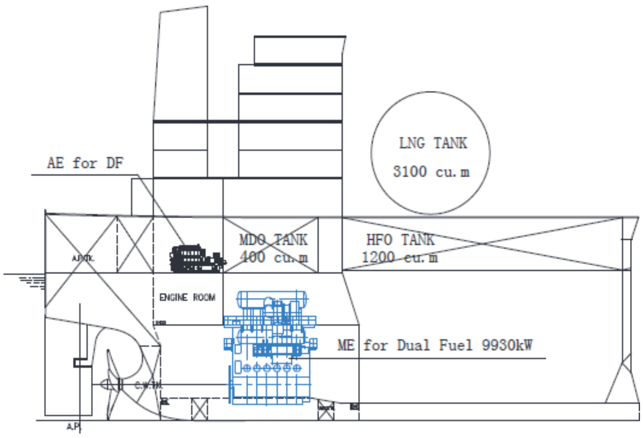
Annex 1-A
EEDI Calculation Examples for Use of Dual Fuel Engines

Case 1: Standard Kamsarmax ship, one main engine (MDO), standard auxiliary engines (MDO), no shaft generator:



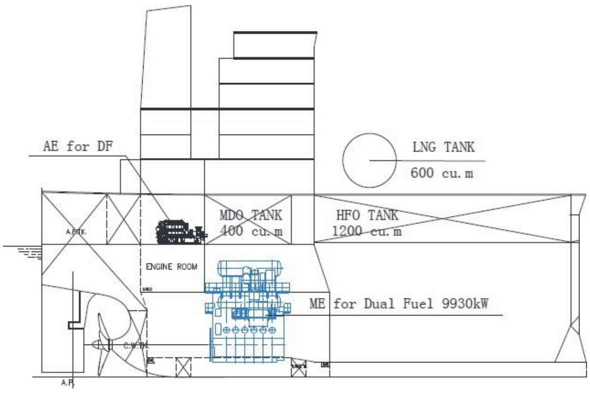
S/N	Parameter	Formula or source	Unit	Value
1	MCR_{ME}	MCR rating of main engine	kW	9930
2	Capacity	Deadweight of the ship at summer load draft	DWT	81200
3	V_{ref}	Ships speed as defined in EEDI regulation	kn	14
4	P_{ME}	$0.75 \times MCR_{ME}$	kW	7447.5
5	P_{AE}	$0.05 \times MCR_{ME}$	kW	496.5
6	C_{FME}	C_F factor of main engine using MDO	-	3.206
7	C_{FAE}	C_F factor of auxiliary engine using MDO	-	3.206
8	SFC_{ME}	Specific fuel consumption of ME at P_{ME}	g/kWh	165
9	SFC_{AE}	Specific fuel consumption of AE at P_{AE}	g/kWh	210
10	$EEDI$	$[(P_{ME} \times C_{FME} \times SFC_{ME})+(P_{AE} \times C_{FAE} \times SFC_{AE})]/(V_{ref} \times Capacity)$	gCO_2/tnm	3.76

Case 2: LNG is regarded as the "primary fuel" if dual-fuel mian engine and dual-fuel auxiliary engine (LNG, pilot fuel MDO; no shaft generator) are equipped with bigger LNG tanks.



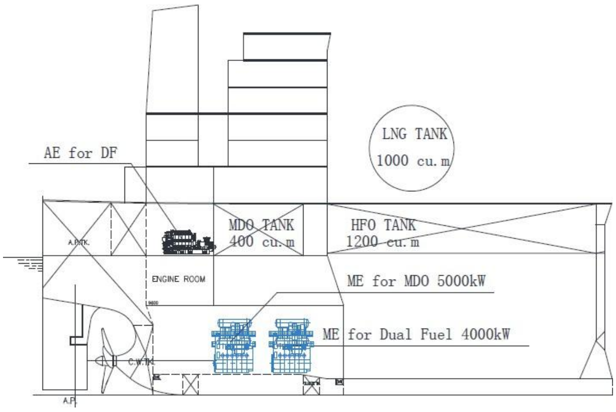
S/N	Parameter	Formula or source	Unit	Value
1	MCR_{ME}	MCR rating of main engine	kW	9930
2	*Capacity*	Deadweight of the ship at summer load draft	DWT	81200
3	V_{ref}	Ships speed as defined in EEDI regulation	kn	14
4	P_{ME}	$0.75\times MCR_{ME}$	kW	7447.5
5	P_{AE}	$0.05\times MCR_{ME}$	kW	496.5
6	$C_{FPilotfuel}$	C_F factor of pilot fuel for dual fuel ME using MDO	-	3.206
7	$C_{FAEPilotfuel}$	C_F factor of pilot fuel for auxiliary engine using MDO	-	3.206
8	C_{FLNG}	$C_F$factor of dual fuel engine using LNG	-	2.75
9	$SFC_{MEPilotfuel}$	Specific fuel consumption of pilot fuel for dual fuel ME at P_{ME}	g/kWh	6
10	$SFC_{AEPilotfuel}$	Specific fuel consumption of pilot fuel for dual fuel AE at P_{AE}	g/kWh	7
11	$SFC_{ME\ LNG}$	Specific fuel consumption of ME using LNG at P_{ME}	g/kWh	136
12	$SFC_{AE\ LNG}$	Specific fuel consumption of AE using LNG at P_{AE}	g/kWh	160
13	V_{LNG}	LNG tank capacity on board	m^3	3100
14	V_{HFO}	Heavy fuel oil tank capacity on board	m^3	1200
15	V_{MDO}	Marine diesel oil tank capacity on board	m^3	400
16	ρ_{LNG}	Density of LNG	kg/m^3	450
17	ρ_{HFO}	Density of heavy fuel oil	kg/m^3	991
18	ρ_{MDO}	Density of marine diesel oil	kg/m^3	900
19	LCV_{LNG}	Low calorific value of LNG	kJ/kg	48000
20	LCV_{HFO}	Low calorific value of heavy fuel oil	kJ/kg	40200
21	LCV_{MDO}	Low calorific value of marine diesel oil	kJ/kg	42700
22	K_{LNG}	Filling rate of LNG tank	-	0.95
23	K_{HFO}	Filling rate of heavy fuel tank	-	0.98
24	K_{MDO}	Filling rate of marine diesel tank	-	0.98
25	f_{DFgas}	$\frac{P_{ME}+P_{AE}}{P_{ME}+P_{AE}}\times\frac{V_{LNG}\times\rho_{LNG}\times LCV_{LNG}\times K_{LNG}}{V_{HFO}\times\rho_{HFO}\times LCV_{HFO}\times K_{HFO}+V_{MDO}\times\rho_{MDO}\times LCV_{MDO}\times K_{MDO}+V_{LNG}\times\rho_{LNG}\times LCV_{LNG}\times K_{LNG}}$	-	0.5068
26	*EEDI*	$[P_{ME}\times(C_{FPilotfuel}\times SFC_{ME\ Pilotfuel} + C_{FLNG}\times SFC_{ME\ LNG}) + P_{AE}\times(C_{FPilotfuel}\times SFC_{AE\ Pilotfuel} + C_{FLNG}\times SFC_{AE\ LNG})]/ (V_{ref}\times Capacity)$	gCO_2/ tnm	2.78

Case 3: LNG is not regarded as the “primary fuel” if dual-fuel main engine and dual-fuel auxiliary engine (LNG, pilot fuel MDO; no shaft generator) are equipped with smaller LNG tanks:



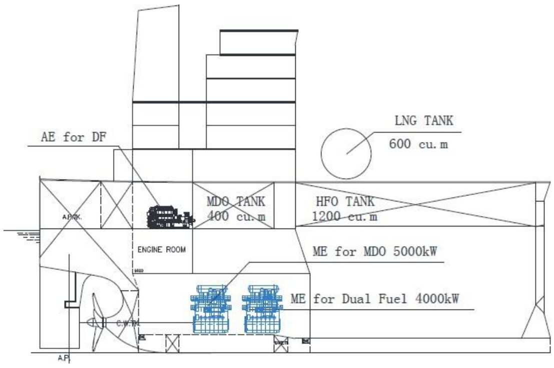
S/N	Parameter	Formula or source	Unit	Value
1	MCR_{ME}	MCR rating of main engine	kW	9930
2	*Capacity*	Deadweight of the ship at summer load draft	DWT	81200
3	V_{ref}	Ships speed as defined in EEDI regulation	kn	14
4	P_{ME}	$0.75 \times MCR_{ME}$	kW	7447.5
5	P_{AE}	$0.05 \times MCR_{ME}$	kW	496.5
6	$C_{FPilotfuel}$	C_F factor of pilot fuel for dual fuel ME using MDO	-	3.206
7	$C_{FAEPilotfuel}$	C_F factor of pilot fuel for auxiliary engine using MDO	-	3.206
8	C_{FLNG}	C_F factor of dual fuel engine using LNG	-	2.75
9	C_{FMDO}	C_F factor of dual fuel ME/AE engine using MDO	-	3.206
10	$SFC_{MEPilotfuel}$	Specific fuel consumption of pilot fuel for dual fuel Meat P_{ME}	g/kWh	6
11	$SFC_{AEPilotfuel}$	Specific fuel consumption of pilot fuel for dual fuel AE at P_{AE}	g/kWh	7
12	$SFC_{ME\ LNG}$	Specific fuel consumption of ME using LNG at P_{ME}	g/kWh	136
13	$SFC_{AE\ LNG}$	Specific fuel consumption of AE using LNG at P_{AE}	g/kWh	160
14	$SFC_{ME\ MDO}$	Specific fuel consumption of dual fuel ME using MDO at P_{ME}	g/kWh	165
15	SFC_{AEMDO}	Specific fuel consumption of dual fuel AE using MDO at P_{AE}	g/kWh	187
16	V_{LNG}	LNG tank capacity on board	m^3	600
17	V_{HFO}	Heavy fuel oil tank capacity on board	m^3	1800
18	V_{MDO}	Marine diesel oil tank capacity on board	m^3	400
19	ρ_{LNG}	Density of LNG	kg/m^3	450
20	ρ_{HFO}	Density of heavy fuel oil	kg/m^3	991
21	ρ_{MDO}	Density of marine diesel oil	kg/m^3	900
22	LCV_{LNG}	Low calorific value of LNG	kJ/kg	48000
23	LCV_{HFO}	Low calorific value of heavy fuel oil	kJ/kg	40200
24	LCV_{MDO}	Low calorific value of marine diesel oil	kJ/kg	42700
25	K_{LNG}	Filling rate of LNG tank	-	0.95
26	K_{HFO}	Filling rate of heavy fuel tank	-	0.98
27	K_{MDO}	Filling rate of marine diesel tank	-	0.98
28	f_{DFgas}	$\frac{P_{ME}+P_{AE}}{P_{ME}+P_{AE}} \times \frac{V_{LNG} \times \rho_{LNG} \times LCV_{LNG} \times K_{LNG}}{V_{HFO} \times \rho_{HFO} \times LCV_{HFO} \times K_{HFO} + V_{MDO} \times \rho_{MDO} \times LCV_{MDO} \times K_{MDO} + V_{LNG} \times \rho_{LNG} \times LCV_{LNG} \times K_{LNG}}$	-	0.1261
29	$f_{DFliquid}$	$1-f_{DFgas}$	-	0.8739
30	*EEDI*	$[P_{ME} \times [f_{DFgas} \times (C_{F\ Pilotfuel} \times SFC_{ME\ Pilotfuel} + C_{F\ LNG} \times SFC_{ME\ LNG}) + f_{DFliquid} \times C_{F\ MDO} \times SFC_{ME\ MDO}] + P_{AE} \times [f_{DFgas} \times (C_{FAEPilotfuel} \times SFC_{AE\ Pilotfuel} + C_{FLNG} \times SFC_{AE\ LNG}) + f_{DFliquid} \times C_{F\ MDO} \times SFC_{AE\ MDO}]] / (V_{ref} \times Capacity)$	gCO_2/tnm	3.61

Case 4: One dual-fuel main engine (LNG, pilot fuel MDO) and one main engine (MDO) and dual-fuel auxiliary engine (LNG, pilot fuel MDO, no shaft generator) which LNG could be regarded as "primary fuel" only for the dual-fuel main engine:



S/N	Parameter	Formula or source	Unit	Value
1	MCR_{MEMDO}	MCR rating of main engine using only MDO	kW	5000
2	MCR_{MELNG}	MCR rating of main engine using dual fuel	kW	4000
3	*Capacity*	Deadweight of the ship at summer load draft	DWT	81200
4	V_{ref}	Ships speed as defined in EEDI regulation	kn	14
5	P_{MEMDO}	$0.75 \times MCR_{MEMDO}$	kW	3750
6	P_{AELNG}	$0.75 \times MCR_{MELNG}$	kW	3000
7	P_{AE}	$0.05 \times MCR_{MEMDO} + MCR_{MELNG}$）	kW	450
8	$C_{FPilotfuel}$	C_F factor of pilot fuel for dual fuel ME using MDO	-	3.206
9	$C_{FAEPilotfuel}$	C_F factor of pilot fuel for auxiliary engine using MDO	-	3.206
10	C_{FLNG}	C_F factor of dual fuel engine using LNG	-	2.75
11	C_{FMDO}	C_F factor of dual fuel ME/AE engine using MDO	-	3.206
12	$SFC_{MEPilotfuel}$	Specific fuel consumption of pilot fuel for dual fuel ME at P_{ME}	g/kWh	6
13	$SFC_{AEPilotfuel}$	Specific fuel consumption of pilot fuel for dual fuel AE at P_{AE}	g/kWh	7
14	$SFC_{DF\ LNG}$	Specific fuel consumption of dual fuel ME using LNG at P_{ME}	g/kWh	158
15	$SFC_{AE\ LNG}$	Specific fuel consumption of AE using LNG at P_{AE}	g/kWh	160
16	$SFC_{ME\ MDO}$	Specific fuel consumption of single fuel ME at P_{ME}	g/kWh	180
17	V_{LNG}	LNG tank capacity on board	m^3	1000
18	V_{HFO}	Heavy fuel oil tank capacity on board	m^3	1200
19	V_{MDO}	Marine diesel oil tank capacity on board	m^3	400
20	ρ_{LNG}	Density of LNG	kg/m^3	450
21	ρ_{HFO}	Density of heavy fuel oil	kg/m^3	991
22	ρ_{MDO}	Density of marine diesel oil	kg/m^3	900
23	LCV_{LNG}	Low calorific value of LNG	kJ/kg	48000
24	LCV_{HFO}	Low calorific value of heavy fuel oil	kJ/kg	40200
25	LCV_{MDO}	Low calorific value of marine diesel oil	kJ/kg	42700
26	K_{LNG}	Filling rate of LNG tank	-	0.95
27	K_{HFO}	Filling rate of heavy fuel tank	-	0.98
28	K_{MDO}	Filling rate of marine diesel tank	-	0.98
29	f_{DFgas}	$\frac{P_{MEMDO}+P_{MELNG}+P_{AE}}{P_{MELNG}+P_{AE}} \times \frac{V_{LNG} \times \rho_{LNG} \times LCV_{LNG} \times K_{LNG}}{V_{HFO} \times \rho_{HFO} \times LCV_{HFO} \times K_{HFO} + V_{MDO} \times \rho_{MDO} \times LCV_{MDO} \times K_{MDO} + V_{LNG} \times \rho_{LNG} \times LCV_{LNG} \times K_{LNG}}$	-	0.5195
30	*EEDI*	$[P_{MELNG} \times (C_{FPilotfuel} \times SFC_{ME\ Pilotfuel} + C_{F\ LNG} \times SFC_{DF\ LNG}) + P_{MEMDO} \times C_{F\ MDO} \times SFC_{ME\ MDO} + P_{AE} \times (C_{FAE\ Pilotfuel} \times SFC_{AE\ Pilotfuel} + C_{F\ LNG} \times SFC_{AE\ LNG})] / (V_{ref} \times Capacity)$	gCO_2/ tnm	3.28

Case 5: One dual-fuel main engine (LNG, pilot fuel MDO), and one main engine (MDO) and dual-fuel auxiliary engine (LNG, pilot fuel MDO, no shaft generator) which LNG could not be regarded as “primary fuel” for the dual-fuel main engine:



S/N	Parameter	Formula or source	Unit	Value
1	MCR_{MEMDO}	MCR rating of main engine using only MDO	kW	5000
2	MCR_{MELNG}	MCR rating of main engine using dual fuel	kW	4000
3	*Capacity*	Deadweight of the ship at summer load draft	DWT	81200
4	V_{ref}	Ships speed as defined in EEDI regulation	kn	14
5	P_{MEMDO}	$0.75 \times MCR_{MEMDO}$	kW	3750
6	P_{AELNG}	$0.75 \times MCR_{MELNG}$	kW	3000
7	P_{AE}	$0.05 \times MCR_{MEMDO} + MCR_{MELNG}$）	kW	450
8	$C_{FPilotfuel}$	C_F factor of pilot fuel for dual fuel ME using MDO	-	3.206
9	$C_{FAEPilotfuel}$	C_F factor of pilot fuel for auxiliary engine using MDO	-	3.206
10	C_{FLNG}	C_F factor of dual fuel engine using LNG	-	2.75
11	C_{FMDO}	C_F factor of dual fuel ME/AE engine using MDO	-	2.75
12	$SFC_{MEPilotfuel}$	Specific fuel consumption of pilot fuel for dual fuel ME at P_{ME}	g/kWh	6
13	$SFC_{AEPilotfuel}$	Specific fuel consumption of pilot fuel for dual fuel AE at P_{AE}	g/kWh	7
14	$SFC_{DF\ LNG}$	Specific fuel consumption of dual fuel ME using LNG at P_{ME}	g/kWh	158
15	$SFC_{AE\ LNG}$	Specific fuel consumption of AE using LNG at P_{AE}	g/kWh	160
16	$SFC_{DF\ MDO}$	Specific fuel consumption of dual fuel ME using MDO at P_{ME}	g/kWh	185
17	$SFC_{ME\ MDO}$	Specific fuel consumption of single fuel ME at P_{ME}	g/kWh	180
18	$SFC_{AE\ MDO}$	Specific fuel consumption of AE using MDO at P_{AE}	g/kWh	187
19	V_{LNG}	LNG tank capacity on board	m^3	600
20	V_{HFO}	Heavy fuel oil tank capacity on board	m^3	1200
21	V_{MDO}	Marine diesel oil tank capacity on board	m^3	400
22	ρ_{LNG}	Density of LNG	kg/m^3	450
23	ρ_{HFO}	Density of heavy fuel oil	kg/m^3	991
24	ρ_{MDO}	Density of marine diesel oil	kg/m^3	900
25	LCV_{LNG}	Low calorific value of LNG	kJ/kg	48000
26	LCV_{HFO}	Low calorific value of heavy fuel oil	kJ/kg	40200
27	LCV_{MDO}	Low calorific value of marine diesel oil	kJ/kg	42700
28	K_{LNG}	Filling rate of LNG tank	-	0.95
29	K_{HFO}	Filling rate of heavy fuel oil	-	0.98
30	K_{MDO}	Filling rate of marine diesel tank	-	0.98
31	f_{DFgas}	$\frac{P_{MEMDO}+P_{MELNG}+P_{AE}}{P_{MELNG}+P_{AE}} \times \frac{V_{LNG} \times \rho_{LNG} \times LCV_{LNG} \times K_{LNG}}{V_{HFO} \times \rho_{HFO} \times LCV_{HFO} \times K_{HFO} + V_{MDO} \times \rho_{MDO} \times LCV_{MDO} \times K_{MDO} + V_{LNG} \times \rho_{LNG} \times LCV_{LNG} \times K_{LNG}}$	-	0.3462
32	$f_{DFliquid}$	$1-f_{DFgas}$	-	0.6538
33	*EEDI*	$[P_{MELNG} \times [f_{DFgas} \times (C_{FPilotfuel} \times SFC_{ME\ Pilotfuel} + C_{FLNG} \times SFC_{DFLNG}) + f_{DFliquid} \times C_{FMDO} \times SFC_{DF\ MDO})] + P_{MEMDO} \times C_{FMDO} \times SFC_{ME\ MDO} + P_{AE} \times [f_{DFgas} \times (C_{FAEPilotfuel} \times SFC_{AE\ Pilotfuel} + C_{FLNG} \times SFC_{AE\ LNG}) + f_{DFliquid} \times C_{FMDO} \times SFC_{AE\ MDO}]]/(V_{ref} \times Capacity)$	gCO_2/tnm	3.54

Appendix 2 Development of Electric Power Tables for EEDI (EPT-EEDI)

1 Introduction to the document "Electric Power Table for EEDI"

1.1 This Appendix contains a guideline for the document "Electric Power Table for EEDI" which is similar to the actual shipyards' load balance document, utilizing well defined criteria, providing standard format, clear loads definition and grouping, standard load factors, etc. A number of new definitions (in particular the "groups") are introduced, giving an apparent greater complexity to the calculation process. However, this intermediate step to the final calculation of P_{AE} stimulates all the parties to a deep investigation through the global figure of the auxiliary load, allowing comparisons between different ships and technologies and eventually identifying potential efficiencies improvements.

2 Auxiliary load power definition

2.1 P_{AE} is to be calculated as indicated in 2.3.5.5, Chapter 2 of the Guidelines, together with the following additional three conditions:

(1) no emergency situations (e.g., "no fire", "no flood", "no blackout", "no partial blackout");

(2) evaluation time frame of 24 hours (to account loads with intermittent use); and

(3) ship fully loaded of passengers and crew.

3 Definition of the data to be included in the Electric Power Table for EEDI

3.1 The Electric Power Table for EEDI calculation is to contain the following data elements, as appropriate:

(1) Load's group;

(2) Load's description;

(3) Load's identification tag;

(4) Load's electric circuit Identification;

(5) Load's mechanical rated power "P_m" [kW];

(6) Load's electric motor rated output power [kW];

(7) Load's electric motor efficiency "e" [/];

(8) Load's Rated electric power "P_r" [kW];

(9) Service factor of load "k_l" [/];

(10) Service factor of duty “k_d” [/];

(11) Service factor of time “k_t” [/];

(12) Service total factor of use “k_u” [/], where $k_u = k_l \cdot k_d \cdot k_t$;

(13) Load’s necessary power “P_{load}” [kW], where $P_{load} = P_r \cdot k_u$;

(14) Notes;

(15) Group’s necessary power [kW]; and

(16) Auxiliaries load’s power P_{AE} [kW].

4 Data to be included in the Electric Power Table for EEDI

4.1 Load groups

The Loads are put into defined groups, allowing a proper breakdown of the auxiliaries. This eases the verification process and makes it possible to identify those areas where load reductions might be possible. The groups are listed below:

(1) A – Hull, deck, navigation and safety services;

(2) B – Propulsion service auxiliaries;

(3) C – Auxiliary engine and main engine services;

(4) D – Ship’s general services;

(5) E – Ventilation for engine rooms and auxiliaries room;

(6) F – Air conditioning services;

(7) G – Galleys, refrigeration and laundry services;

(8) H – Accommodation services;

(9) I – Lighting and socket services;

(10) L – Entertainment services;

(11) N– Cargo loads; and

(12) M– Miscellaneous.

All the ship's loads have to be delineated in the document, excluding only P_{Aeff}, the shaft motors and shaft motors chain (while the propulsion services auxiliaries are partially included below in paragraph 4.1.2 B). Some loads (i.e. thrusters, cargo pumps, cargo gear, ballast pumps, maintaining cargo, reefers and cargo hold fans) still are included in the group for sake of transparency, however their service factor is zero in order to comply with the requirements for calculation of P_{AE} in 3.5.4 of Appendix 1, therefore making it easier to verify that all the loads have been considered in the document and there are no loads left out of the measurement.

4.1.1 A – Hull, deck, navigation and safety services

(1) Loads included in the hull services typically are: ICCP systems, mooring equipment, various doors, ballasting systems, bilge systems, stabilizing equipment, etc. Ballasting systems are indicated with service factor equal to zero to comply with the requirements for calculation of P_{AE} in 3.5.4 of Appendix 1;

(2) Loads included in the deck services typically are: deck and balcony washing systems, rescue systems, cranes, etc.;

(3) Loads included in the navigation services typically are: navigation systems, navigation's external and internal communication systems, steering systems, etc.; and

(4) Loads included in the safety services typically are: active and passive fire systems, emergency shutdown systems, public address systems, etc.

4.1.2 B – Propulsion service auxiliaries

This group typically includes: propulsion secondary cooling systems such as LT cooling pumps dedicated to shaft motors, LT cooling pumps dedicated to propulsion converters, propulsion UPSs, etc. Propulsion service loads do not include shaft motors ($P_{TI(i)}$) and the auxiliaries which are part of them (shaft motor own cooling fans and pumps, etc.) and the shaft motor chain losses and auxiliaries which are part of them (i.e. shaft motor converters including relevant auxiliaries such as converter own cooling fans and pumps, shaft motor transformers including relevant auxiliaries losses such as propulsion transformer own cooling fans and pumps, shaft motor harmonic filter including relevant auxiliaries losses, shaft motor excitation system including the relevant auxiliaries consumed power etc.). Propulsion service auxiliaries include manoeuvring propulsion equipment such as manoeuvring thrusters and their auxiliaries whose service factor is to be set to zero.

4.1.3 C – Auxiliary engine and main engine services

This group includes: cooling systems, i.e. pumps and fans for cooling circuits dedicated to alternators or propulsion shaft engines (sea water, technical water dedicated pumps, etc.), lubricating and fuel systems feeding, transfer, treatment and storage, ventilation system for combustion air supply, etc.

4.1.4 D – Ship's general services

This group includes loads which provide general services which can be shared between shaft motor, auxiliary engines and main engine and accommodation support systems. Loads typically included in this group are: cooling systems, i.e. pumping sea water, technical water main circuits, compressed air systems, fresh water generators, automation systems, etc.

4.1.5 E – Ventilation for engine rooms and auxiliaries room

This group includes all fans providing ventilation for engine rooms and auxiliary rooms that typically are: engine rooms cooling supply-exhaust fans, auxiliary rooms supply and exhaust fans. All the fans serving accommodation areas or supplying combustion air are not included in this group. This group does not include cargo hold fans, and garage supply and exhaust fans.

4.1.6 F – Air Conditioning services

All Loads that make up the air conditioning service that typically are: air conditioning chillers, air conditioning cooling and heating fluids transfer and treatment, air conditioning's air handling units ventilation, air conditioning re-heating systems with associated pumping, etc. The air conditioning chillers service factor of load, service factor of time and service factor of duty are to be set as 1 (k_l = 1, k_t = 1 and k_d = 1) in order to avoid the detailed validation of the heat load dissipation document (i.e. the chiller's electric motor rated power is to be used). However, k_d is to represent the use of spare chillers (e.g., four chillers are installed and one out four is spare then k_d = 0 for the spare chiller and k_d = 1 for the remaining three chillers), but only when the number of spare chillers is clearly demonstrated via the heat load dissipation document.

4.1.7 G – Galleys, refrigeration and laundry services

All Loads related to the galleys, pantries refrigeration and laundry services that typically are: galleys various machines, cooking appliances, galleys' cleaning machines, galleys auxiliaries, refrigerated room systems including refrigeration compressors with auxiliaries, air coolers, etc.

4.1.8 H – Accommodation services

All Loads related to the accommodation services of passengers and crew that typically are: crew and passengers' transportation systems, i.e. lifts, escalators, etc., environmental services, i.e. black and grey water collecting, transfer, treatment, storage, discharge, waste systems including collecting, transfer, treatment, storage, etc., accommodation fluids transfers, i.e. sanitary hot and cold water pumping, etc., treatment units, pools systems, saunas, gym equipment, etc.

4.1.9 I – Lighting and socket services

All Loads related to the lighting, entertainment and socket services. As the quantity of lighting circuits and sockets within the ship may be significantly high, it is not practically feasible to list all the lighting circuits and points in the EPT for EEDI. Therefore circuits are to be grouped into subgroups aimed to identify possible improvements of efficient use of power. The subgroups are:

(1) lighting for 1) cabins, 2) corridors, 3) technical rooms/stairs, 4) public spaces/stairs, 5) engine rooms and auxiliaries' room, 6) external areas, 7) garages and 8) cargo spaces. All have to be divided by main vertical zone; and

(2) power sockets for 1) cabins, 2) corridors, 3) technical rooms/stairs, 4) public spaces/stairs, 5) engine rooms and auxiliaries' room, 6) garages and 7) cargo spaces. All have to be divided by main vertical zone.

The calculation criteria for complex groups (e.g., cabin lighting and power sockets) subgroups are to be included via an explanatory note, indicating the load composition (e.g., lights of typical cabins, TV, hair dryer, fridge, etc.).

4.1.10 L – Entertainment services

This group includes all loads related to the entertainment services that typically are: public spaces audio and video equipment, theatre stage equipment, IT systems for offices, video games, etc.

4.1.11 N – Cargo loads

This group will contain all cargo loads such as cargo pumps, cargo gear, maintaining cargo, cargo reefers loads, cargo hold fans and garage fans for sake of transparency. However, the service factor of this group is to be set to zero.

4.1.12 M – Miscellaneous

This group will contain all loads which have not been associated to the above-mentioned groups but still are contributing to the overall load calculation of the normal maximum sea load.

4.2 Loads description

This identifies the loads (for example "sea water pump").

4.3 Loads identification tag

This tag identifies the loads according to the shipyard's standards tagging system. For example, the "PTI1 fresh water pump" identification tag is "SYYIA/C" for an example ship and shipyard. This data provides a unique identifier for each load.

4.4 Loads electric circuit identification

This is the tag of the electric circuit supplying the load. Such information allows the data validation process.

4.5 Loads mechanical rated power "P_m"[kW]

This data is to be indicated in the document only when the electric load is made by an electric motor driving a mechanical load (for example a fan, a pump, etc.). This is the rated power of the mechanical device driven by an electric motor.

4.6 Loads electric motor rated output power [kW]

The output power of the electric motor as per maker's nameplate or technical specification. This data does not take part in the calculation but is useful to highlight potential over rating of the combination motor-mechanical load.

4.7 Loads electric motor efficiency "e" [/]

This data is to be entered in the document only when the electric load is made by an electric motor driving a mechanical load.

4.8 Loads rated electric power "P_r" [kW]

Typically the maximum electric power absorbed at the load electric terminals at which the load has been designed for its service, as indicated on the maker's nameplate and/or in the maker's technical specification. When the electric load is made by an electric motor driving a mechanical load, the load's rated electric power is: $P_r = P_m / e$ [kW].

4.9 Service factor of load "k_l" [/]

It provides the reduction from the loads rated electric power to loads necessary electric power that is to be made when the load absorbs less power than its rated power. For example, in case of electric motor driving a mechanical load, a fan could be designed with some power margin, leading to the fact that the fan rated mechanical power exceeds the power requested by the duct system it serves. Another example is when a pump rated power exceed the power needed for pumping in its delivery fluid circuit. Another example in case of electric self-regulating semi-conductors: electric heating system is oversized and the rated power exceeds the power absorbed, according a factor k_l.

4.10 Service factor of duty "k_d" [/]

Factor of duty is to be used when a function is provided by more than one load. As all loads have to be included in the EPT for EEDI, this factor provides a correct summation of the loads. For example when two pumps serve the same circuit and they run in duty/standby, their k_d factor will be ½ and ½. When three compressors serve the same circuit and one runs in duty and two in standby, then k_d is 1/3, 1/3 and 1/3.

4.11 Service factor of time "k_t" [/]

A factor of time based on the shipyard's evaluation about the load duty along 24 hours of ship's navigation as defined at paragraph 3. For example the entertainment loads operate at their power for a limited period of time, 4 hours out 24 hours; as a consequence $k_t = 4/24$. For example, the sea water cooling pumps operate at their power all the time during the navigation at V_{ref}. As a consequence $k_t = 1$.

4.12 Service total factor of use "k_u" [/]

The total factor of use that takes into consideration all the service factors: $k_u = k_l \cdot k_d \cdot k_t$.

4.13 Loads necessary power "P_{load}" [kW]

The individual user contribution to the auxiliary load power is $P_{load} = P_r \cdot k_u$.

4.14 Notes

A note, as free text, could be included in the document to provide explanations to ISC.

4.15 Groups necessary power [kW]

The summation of the "loads necessary power" from group A to N. This is an intermediate step which is not strictly necessary for the calculation of P_{AE}. However, it is useful to allow a quantitative analysis of the P_{AE}, providing a standard breakdown for analysis and potential improvements of energy saving.

4.16 Auxiliaries load's power P_{AE} [kW]

Auxiliaries load's power P_{AE} is the summation of the "load's necessary power" of all the loads divided by the average efficiency of the generator(s) weighted by power.

$$P_{AE} = \Sigma P_{load(i)}/(\text{average efficiency of the generator(s) weighted by power})$$

5 Layout and organization of the data indicated in the "Electric Power Table for EEDI"

5.1 The document "Electric Power Table for EEDI" is to include general information (i.e. ship's name, project name, document references, etc.) and a table with:

(1) one row containing column titles;

(2) one column for table row ID;

(3) one column for the groups identification ("A", "B", etc.) as indicated in paragraphs 4.1.1 to 4.1.12 of these Guidelines;

(4) one column for the group descriptions as indicated in paragraphs 4.1.1 to 4.1.12 of these Guidelines;

(5) one column each for items in paragraphs 4.2 to 4.14 of these Guidelines (e.g., "load tag", etc.);

(6) one row dedicated to each individual load;

(7) the summation results (i.e. summation of powers) including data from paragraphs 4.15 to 4.16 of these Guidelines; and

(8) explanatory notes.

An example of an Electric Power Table for EEDI for a cruise postal vessel which transports passengers and have a car garage and reefer holds for fish trade transportation is indicated below. The data indicated and the type of ship is for reference only.

ELECTRIC POWER TABLE FOR EEDI HULL "EXAMPLE" PROJECT "EXAMPLE" (NMSL=Normal Maximun Sea Load)

id	Load group	Load description	Load identification tag	Load electric circuit Identification	Load mechanical rated power "Pm" [kW]	Load electric motor rated output power [kW]	Load electric motor efficiency "e" [/]	Load Rated electric power "Pr" [kW]	service factor of load "kl" [/]	service factor of duty "kd" [/]	service factor of time "kt" [/]	service total factor of use "ku" [/]	Load necessary power "Pload" [kW]	Note
1	A	Hull cathodic protection Fwd	xxx	yyy	n.a.	n.a.	n.a.	5.2	1	1	1*	1	5.2	*in use 24hours/day
2	A	Hull cathodic protection mid	xxx	yyy	n.a.	n.a.	n.a.	7.0	1	1	1*	1	7	*in use 24hours/day
3	A	Hull cathodic protection aft	xxx	yyy	n.a.	n.a.	n.a.	4.8	1	1	1*	1	4.8	*in use 24hours/day
4	A	Ballast pump 3	xxx	yyy	30	36	0.92	32.6	0.9	0.5	1	0*	0	*not in use at **NMSL** see para 2.5.6 of Circ.681
5	A	Fwd Stb mooring winch motor n.1	xxx	yyy	90	150	0.92	97.8	0.8	1	0*	0*	0	*not in use at **NMSL** see para 2.5.6 of Circ.681
6	A	WTDs system main control panel	xxx	yyy	n.a.	n.a.	n.a.	0.5	1	1	1*	1	0.5	*in use 24hours/day
7	A	WTD 1, deck D frame 150	xxx	yyy	1.2	3	0.91	1.3	0.7	1	0.104*	0.0728	0.096	*180 secs to open/close x 100 opening a day
8	A	WTD 5, deck D frame 210	xxx	yyy	1.2	3	0.91	1.3	0.7	1	0.156*	0.1092	0.14	*180 secs to open/close x 150 opening a day
9	A	Stabilisers control unit	xxx	yyy	n.a.	n.a.	n.a.	0.7	1	1	1*	1	0.7	*in use 24hours/day
10	A	Stabilisers Hydraulic pack power pump 1	xxx	yyy	80	90	0.9	88.9	0.9	1	0*	0	0	*NMSL=> calm sea,=> stabiliser not in use
11	A	S-band Radar 1 controller	xxx	yyy	n.a.	n.a.	n.a.	0.4	1	1	1*	1	0.4	*in use 24hours/day
12	A	S-band Radar 1 motor	xxx	yyy	0.8	1	0.92	0.9	1	1	1*	1	0.9	*in use 24hours/day
13	A	Fire detection system bridge main unit	xxx	yyy	n.a.	n.a.	n.a.	1.5	1	1	1*	1	1.5	*in use 24hours/day
14	A	Fire detection system ECR unit	xxx	yyy	n.a.	n.a.	n.a.	0.9	1	1	1*	1	0.9	*in use 24hours/day
15	A	High pressure water fog contol unit	xxx	yyy	n.a.	n.a.	n.a.	1.2	1	1	1*	1	1.2	*in use 24hours/day
16	A	High pressure water fog engines rooms pump 1a	xxx	yyy	25	30	0.93	26.9	0.9	0.5	0*	0	0	*NMSL=> not emergency =>Load not in use
17	A	High pressure water fog engines rooms pump 1b	xxx	yyy	25	30	0.93	26.9	0.9	0.5	0*	0	0	* not emergency situations
18	B	PTi port fresh water pump 1	xxx	yyy	30	36	0.92	32.6	0.9	0.5*	1	0.45	14.7	* pump1,2 one is duty and one is stand-by
19	B	PTi port fresh water pump 2	xxx	yyy	30	36	0.92	32.6	0.9	0.5*	1	0.45	14.7	* pump1,2 one is duty and one is stand-by
20	B	Thrusters control system	xxx	yyy	n.a.	n.a.	n.a.	0.5	1	1	1*	1	0.5	in use 24hours/day (even if thruster motor isn't)
21	B	Bow thruster 1	xxx	yyy	3000	3000	0.96	3125.0	1	1	0*	0	0	*NMSL=>thrusters motor are not in use
22	B	PEM port cooling fan 1	xxx	yyy	20	25	0.93	21.5	0.9	1	n.a.	n.a	n.a.*	*this load is included in the propulsion chain data
23	C	HT circulation pump 1 DG 3	xxx	yyy	8	10	0.92	8.7	0.9	0.5*	1	0.45	3.9	* pump1,2 one is duty and one is stand-by
24	C	HT circulation pump 2 DG 3	xxx	yyy	8	10	0.92	8.7	0.9	0.5*	1	0.45	3.9	* pump1,2 one is duty and one is stand-by
25	C	DG3 combustion air fan	xxx	yyy	28	35	0.92	30.4	0.9	1	1*	0.9	27.4	*in use 24hours/day
26	C	DG3 exhaust gas boiler circulationg pump	xxx	yyy	6	8	0.93	6.5	0.8	1	1*	0.8	5.2	*in use 24hours/day
27	C	Alternator 3 external cooling fan	xxx	yyy	3	5	0.93	3.2	0.8	1	1*	0.8	2.75	*in use 24hours/day
28	C	fuel feed fwd booster pump a	xxx	yyy	7	9	0.92	7.6	0.9	0.5*	1	0.45	3.4	* pump1,2 one is duty and one is stand-by
29	C	fuel feed fwd booster pump b	xxx	yyy	7	9	0.92	7.6	0.9	0.5*	1	0.45	3.4	* pump1,2 one is duty and one is stand-by
30	D	Fwd main LT cooling pump 1	xxx	yyy	120	150	0.95	126.3	0.9	0.5*	1	0.45	56.8	* pump1,2 one is duty and one is stand-by
31	D	Fwd main LT cooling pump 2	xxx	yyy	120	150	0.95	126.3	0.9	0.5*	1	0.45	56.8	* pump1,2 one is duty and one is stand-by
32	E	FWD engine room supply fan 1	xxx	yyy	87.8	110	0.93	94.4	0.95	1	1*	0.95	89.7	*in use 24hours/day
33	E	FWD engine room exhaust fan 1	xxx	yyy	75	86	0.93	80.6	0.96	1	1*	0.96	77.4	*in use 24hours/day
34	E	purifier room supply fan 1	xxx	yyy	60	70	0.93	64.5	0.96	0.5	1*	0.48	31.0	*in use 24hours/day
35	E	purifier room supply fan 2	xxx	yyy	60	70	0.93	64.5	0.96	0.5	1*	0.48	31.0	*in use 24hours/day
36	F	HVAC chiller a	xxx	yyy	1450	1600	0.95	1526.3	1	2/3*	1	0.66	1007.4	*1 Chiller is spare; see heat load dissipation doc.
37	F	HVAC chiller b	xxx	yyy	1450	1600	0.95	1526.3	1	2/3*	1	0.66	1007.4	*1 Chiller is spare; see heat load dissipation doc.
38	F	HVAC chiller C	xxx	yyy	1450	1600	0.95	1526.3	1	2/3*	1	0.66	1007.4	*1 Chiller is spare; see heat load dissipation doc.
39	F	A.H.U. Ac station 5.4 supply fan	xxx	yyy	50	60	0.93	53.8	0.9	1	1*	0.9	48.4	*in use 24hours/day
40	F	A.H.U. Ac station 5.4 exhaust fan	xxx	yyy	45	55	0.93	48.4	0.9	1	1*	0.9	43.5	*in use 24hours/day
41	F	Chilled water pump a	xxx	yyy	80	90	0.93	86.0	0.88	0.5*	1	0.44	37.8	* pump1,2 one is duty and one is stand-by
42	F	Chilled water pump b	xxx	yyy	80	90	0.93	86.0	0.88	0.5*	1	0.44	37.8	* pump1,2 one is duty and one is stand-by
43	G	Italian's espresso coffee machine	xxx	yyy	n.a.	n.a.	n.a.	7.0	0.9	1	0.2*	0.18	1.3	*in use 4.8hours/day
44	G	deep freezer machine	xxx	yyy	n.a.	n.a.	n.a.	20.0	0.8	1	0.16*	0.128	3.2	*in use 4hours/day
45	G	washing machine 1	xxx	yyy	n.a.	n.a.	n.a.	8.0	0.8	1	0.33*	0.264	3.2	*in use 8hours/day
46	H	lift pax mid 4	xxx	yyy	30	40	0.93	32.3	0.5	1	0.175*	0.0875	0.9	*in use 4hours/day
47	H	vaccum collecting system 4 pump a	xxx	yyy	10	13	0.92	10.9	0.9	1	1*	0.9	8.7	*in use 24hours/day
48	H	sewage treatmet system 1 pump 1	xxx	yyy	15	17	0.93	16.1	0.9	1	1*	0.9	8.7	*in use 24hours/day
49	H	Gym running machine	xxx	yyy	n.a.	n.a.	n.a.	2.5	1	1	0.3*	0.3	0.8	*in use 7.2hours/day
50	I	Cabin's lighting MVZ3	n.a.	n.a.	n.a.	n.a.	n.a.	80*	1	1	1	1	80.0	* see explainatory note
51	I	corridors ligthing MVZ3	n.a.	n.a.	n.a.	n.a.	n.a.	10*	1	1	1	1	10.0	* see explainatory note
52	I	Cabin's sockets MVZ3	n.a.	n.a.	n.a.	n.a.	n.a.	5*	1	1	1	1	5.0	* see explainatory note
53	L	Main Theatre audio booster amplifier	xxx	yyy	n.a.	n.a.	n.a.	15.0	1	1	0.3*	0.3	4.5	*in use 7.2hours/day
54	L	Video wall atrium	xxx	yyy	n.a.	n.a.	n.a.	2.0	1	1	0.3*	0.3	0.6	*in use 7.2hours/day
55	M	Car Garage supply fan1	xxx	yyy	28	35	0.92	30.4	0.9	1	1*	0*	0	*not in use at **NMSL** see para 2.5.6 of Circ.681
56	M	Fish transportation refeer hold n.2	xxx	yyy	25	30	0.93	26.9	0.9	0.5	0*	0*	0	*not in use at **NMSL** see para 2.5.6 of Circ.681
57	N	Sliding glass roof	xxx	yyy	30	40	0.93	32.3	0.9	1	0.3*	0.27	0.2	*in use 7.2hours/day
											ΣPload(i)=		**3764**	

PAE **=3764/(weighted average efficiency of generator(s)) [kW]** Group's necessary power (group A=22.9kW, B=29.8kW,C=49.9kW, D=113.7kW, E=229kW , F=3189kW, G=7.6kW, H=19kW, I=95kW, L=5.1kW, M=0kW, N=0.22kW)

Appendix 3 Review and Witness Points

Ref.	Function	Survey method	Reference document	Documentation to be submitted to ISC	Remarks
01	EEDI Technical File	Review	2.3 of the Guidelines	Relevant information required by 2.3 of the Guidelines	
02	Limitation of power	Review	2.3.5.3 of the Guidelines	Verification file of limitation technical means	Only if means of limitation are fitted
03	Electric Power Table	Review	Appendix 2 and 7 of the Guidelines	EPT-EEDI form	Only if P_{AE} is significantly different from the values computed in accordance with Chapter 2 of the Guidelines
04	Calibration of towing tank test measuring equipment	Review & witness	Appendix 4 of the Guidelines	Calibration reports	Check at random that measuring devices are well identified and that calibration reports are currently valid
05	Model tests – ship model	Review & witness	Appendix 5 of the Guidelines	Ship lines plan & offsets table Ship model report	
06	Model tests – propeller model	Review & witness	Appendix 5 of the Guidelines	Propeller model report	
07	Model tests – Resistance test, Propulsion test, Propeller open water test	Review & witness	Appendix 5 of the Guidelines	Towing tank tests report	Propeller open water test is not needed if a stock propeller is used. In this case, the open water characteristics of the stock propeller are to be annexed to the towing tank tests report
08	Model-ship extrapolation and correction	Review	Latest version of ITTC 7.5-02-03-01.4 1978 ITTC performance prediction method; Appendix 5 of the Guidelines	Extrapolation and correlation calculation report	Check that the power-speed curves obtained for the EEDI condition and sea trial condition are obtained using the same calculation and correlation methods
09	Numerical calculations replacing towing tank tests	Review	Latest version of ITTC 7.5-03-01-04 or equivalent	Report of calculations	Verification calculations replacing model tests
10	Check of power of equipment listed in EPT-EEDI form prior to sea trials	Witness	Appendix 2 of the Guidelines		Only if P_{AE} is computed from EPT

Ref.	Function	Survey method	Reference document	Documentation to be submitted to ISC	Remarks
11	Programme of sea trials	Review	5.2.1 of the Guidelines	Programme of sea trials	Check minimum number of measurement points (3) Check the EEDI condition in EPT (if P_{AE} is computed from EPT)
12	Sea trials	Witness	ITTC 7.5-04-01-01.1 (latest revision)or ISO 15016：2015		Check: • Propulsion power, particulars of the engines • Draught and trim • Sea conditions • Ship speed • Shaft power & rpm Check operation of means of limitations of engines or shaft power (if fitted) Check the power consumption of selected consumers included in sea trials condition EPT (if P_{AE} is computed from EPT)
13	Sea trials – corrections calculation	Review	ITTC 7.5-04-01-01.2 or ISO 15016：2015	Sea trials report	Check that the displacement and trim of the ship in sea trial condition has been obtained with sufficient accuracy Check compliance with ISO 15016:2015 or ITTC Recommended Procedure 7.5-04-01- 01.2
14	Sea trials – adjustment from trial condition to EEDI condition	Review	5.4.1(2) of the Guidelines	Power curves after sea trial	Check that the power curve estimated for EEDI condition is obtained by power adjustment
15	EEDI Technical File – revised after sea trials	Review	5.4.2 to 5.4.5 of the Guidelines	Revised EEDI Technical File	Check that the file has been updated according to sea trials results

Appendix 4 Verifying the Calibration of Model Test Equipment

1. Measuring Equipment

1.1 Measuring equipment instruments are to have their individual records in which the following data are to be placed: name of equipment, manufacturer, model, series, laboratory identification number and status (verified, calibration, indication)

1.2 Moreover the information about the date of last and next calibration or verification is to be placed on this record. All the data are to be signed by authorised officer.

2. Measuring Standards

2.1 Measuring standards used in laboratory for calibration purposes are to be confirmed and verified by Weights and Measures Office at appropriate intervals.

2.2 All measuring standards used in laboratory for the confirmation purposes are to be supported by certificates, reports or data sheets for the equipment confirming the source, uncertainty and conditions under which the results were obtained.

3. Calibration

3.1 The calibration methods may differ from institution to institution, depending on the particular measurement equipment. The calibration is to comprise the whole measuring chain (gauge, amplifier, data acquisition system etc.).

3.2 The laboratory is to ensure that the calibration tests are carried out using certified measuring standards having a known valid relationship to international or nationally recognized standards.

(1) Calibration Report

Calibration reports are to include identification of certificate for measuring standards, description of environmental conditions, calibration factor or calibration curve, uncertainty of measurement, minimum and maximum capacity for which the error of measuring instrument is within specified (acceptable) limits.

(2) Intervals of Confirmation

The measuring equipment (including measuring standards) is to be confirmed at appropriate (usually periodical) intervals, established on the basis of their stability, purpose and wear. The intervals are to be such that confirmation is carried out again prior to any probable change in the equipment accuracy, which is important for the equipment reliability. Depending on the results of preceding calibrations, the confirmation period may be shortened, if necessary, to ensure the continuous accuracy of the measuring equipment. The laboratory is to have specific objective criteria for decisions concerning the choice of intervals of confirmation.

(3) Non - Conforming Equipment

Any item of measuring equipment

- that has suffered damage,

- that has been overloaded or mishandled,

- that shows any malfunction,

- whose proper functioning is subject to doubt,

- that has exceeded its designated confirmation interval, or

- the integrity of whose seal has been violated, is to be removed from service by segregation, clear labelling or cancelling. Such equipment is not to be returned to service until the reasons for its nonconformity have been eliminated and it is confirmed again. If the results of calibration prior to any adjustment or repair were such as to indicate a risk of significant errors in any of the measurements made with the equipment before the calibration, the laboratory is to take the necessary corrective action.

4. Instrumentation

4.1 Especially the documentation on the calibration of the following Instrumentation is to be shown.

(1) Carriage Speed

The carriage speed is to be calibrated as a distance against time. Period between the calibrations is to be in accordance with the internal procedure of the towing tank test organization.

(2) Water Temperature

Measured by calibrated thermometer with certificate (accuracy 0.1℃).

(3) Trim Measurement

Calibrated against a length standard. Period between the calibrations is to be in accordance with the internal procedure of the towing tank test organization.

(4) Resistance Test

Resistance Test is a force measurement. It is to be calibrated against a standard weight. Calibration is normally before each test series.

(5) Propulsion Test

During Self Propulsion Test torque, thrust and rate of revolutions are measured. Thrust and Torque are calibrated against a standard weight. Rate of revolution is normally measured by a pulse tachometer and an electronic counter which can be calibrated e.g. by an oscillograph. Period between the calibrations is to be in accordance with the internal procedure of the towing tank test organization.

(6) Propeller Open Water Test

During Propeller Open Water Test torque, thrust and rate of revolutions are measured. Thrust and Torque are calibrated against a standard weight. Rate of revolution is normally measured by a pulse tachometer and an electronic counter which can be calibrated e.g. by an oscillograph. Period between the calibrations is to be in accordance with the internal procedure of the towing tank test organization.

5 Measuring and Calibration Forms

Examples of measuring and calibration forms are given in the Annexes 4-A and 4-B.

Annex 4-A SAMPLE OF MEASURING EQUIPMENT CARD

QM 4.10.5.1	Measurement Equipment Card		Laboratory Identification Number	

Equipment		Manufacturer		Model	
		Serial No.		Date of Purchase	
		Basic range			

		Status	
Work Instructions		Calibrated	☐
Calibration Instructions		Indication	☐
Verified at		Verified	☐

Date of Check	Certificate. No.	Period	Date of Next Check	Responsible	Department	Approval

ANNEX 4-B SAMPLE OF CALIBRATION CERTIFICATE

QM 4.10.6.2	**CALIBRATION CERTIFICATE for** PROPELLER	**NO.**	
		LIN	

Calibration Instructions		Calibrated by :	
Date of calibration		Checked by :	

Measurement combination

DYNAMOMETER	Manufacturer		Model	
LIN	Serial No		Date of purchased	
	Work instruction		Last calibration	

Cable

	Manufacturer		Model	
AMPLIFIER	Serial No		Date of purchased	
LIN	Work instruction		Type of transducer	
	Excitation		Frequency of excit.	
Thrust :	Amp. gain		Zero not load	
Torque :	Amp. gain		Zero not load	

Cable

A/C TRANSDUCER	Manufacturer		Model	
LIN	Serial No		Date of purchased	
	Work instruction		Certificate No	

	Mass		Certificate No	
MEASUREMENT	Length arm of force		Certificate No	
STANDARDS	Voltmeter		Certificate No	

QM

4.10.6.2

CALIBRATION RESULTS

Environmental condition

Place of test: [ ]

Temperature : Initial [ ] final [ ]

Dampness : Initial [ ] final [ ]

Computation results of calibrations test

Executed program	procedure	certificate NO.
[ ]	[ ]	[ ]

	Thrust	Torque
Drift :	[ ]	[ ]
Non Linearity errors :	[ ]	[ ]
Hysteresis :	[ ]	[ ]
Precision errors :	[ ]	[ ]
Total uncertainty :	[ ]	[ ]
Calibration factor :	[ ]	[ ]

Calibration requests :

Specified limits of	Thrust	Torque
errors :	[ ]	[ ]
Maximum capacity :	[ ]	[ ]
Minimum capacity :	[ ]	[ ]

Note : tests and computations results are included in report [ ]

Prepared by : .... Approved by : .... Date : ....

Appendix 5 Review and Witnessing of Model Test Procedures

1. Ship Model

1.1 Hydrodynamic Criteria

1.1.1 *Model Size*: The model should generally be as large as possible for the size of the towing tank taking into consideration wall, blockage and finite depth effects, as well as model mass and the maximum speed of the towing carriage.

1.1.2 *Reynolds Number*: The Reynolds Number is to be above 2.5×10^5.

1.1.3 *Turbulence Stimulator*: In order to ensure turbulent flow, turbulence stimulators have to be applied.

1.2 Manufacture Accuracy

With regard to accuracy the ship model is to comply with the criteria given in ITTC Recommended Procedure 7.5-01-01-01, Ship Models, including the check of main dimension, surface finish, stations and waterlines and displacement.

1.3 Documentation in the report

The report given by the submitter is at least to include:

· Identification (model number or similar)

· Materials of construction

· Principal dimensions

· Length between perpendiculars (L_{pp})

· Length of waterline (L_{ww})

· Breadth (B)

· Draught (T)

· For multihull vessels, longitudinal and transverse hull spacing

· Design displacement (Δ) (kg, fresh water)

· Hydrostatics, including water plane area and wetted surface area

· Details of turbulence stimulation

· Details of appendages

· Tolerances of manufacture

2. Propeller Model

2.1 Propeller Model Accuracy

The Manufacturing Tolerances of Propellers for Propulsion Tests are given in ITTC Recommended Procedures 7.5-01-01-01, Ship Models Chapter 3.1.2. Propellers having diameter (D) typically from 150 mm to 300 mm is to be finished to the following tolerances:

· Diameter (D) ±0.10 mm

· Thickness (t) ±0.10 mm

· Blade width (c) ±0.20 mm

· Mean pitch at each radius (P/D): ±0.5% of design value

2.2 Documentation in the report

The report given by the submitter is at least to include:

· Identification (model number or similar)

· Materials of construction

· Principal dimensions

· Diameter

· Pitch-Diameter Ratio (P/D)

· Expanded blade Area Ratio (A_E/A_0)

· Thickness Ratio (t/D)

· Hub/Boss Diameter (d_h)

· Tolerances of manufacture

3. Model Tests

3.1 Resistance Test

The Resistance Test is to be performed according to ITTC Recommended Procedure 7.5-02-02-01 Resistance Test. The report given by the submitter is at least to include:

· Model Hull Specification:

- Identification (model number or similar)
- Loading condition
- Turbulence stimulation method
- Model scale
- Main dimensions and hydrostatics.

· Particulars of the towing tank, including length, breadth and water depth

· Test date

· Parametric data for the test:

- Water temperature
- Water density
- Kinematic viscosity of the water
- Form factor

· For each speed, the following measured and extrapolated data is to be given as a minimum:

- Model speed
- Resistance of the model
- Sinkage fore and aft, or sinkage and trim

3.2 Propulsion Test

The Propulsion Test is to be performed according to ITTC Recommended Procedure 7.5-02-03-01.1. The report given by the submitter is at least to include:

· Model Hull Specification:

- Identification (model number or similar)
- Loading condition
- Turbulence stimulation method
- Model scale
- Main dimensions and hydrostatics.

· Model Propeller Specification:

- Identification (model number or similar)
- Model Scale
- Main dimensions and particulars

· Particulars of the towing tank, including length, breadth and water depth

· Test date

· Parametric data for the test:

- Water temperature
- Water density
- Kinematic viscosity of the water
- Form factor
- Appendage drag scale effect correction factor

· For each speed the following measured data and extrapolated data is to be given as a minimum:

- Model speed
- External tow force
- Propeller thrust,
- Propeller torque
- Rate of revolutions.
- Sinkage fore and aft, or sinkage and trim
- delivered power P_D.

3.3 Propeller Open Water Test

The Propeller Open Water Test is to be performed according to ITTC Recommended Procedure 7.5-02-03-02.1 Open Water Test. The report given by the submitter is at least to include:

· Model Propeller Specification:

- Identification (model number or similar)
- Model scale
- Main dimensions and particulars
- Immersion of centreline of propeller shaft in the case of towing tank

· Particulars of the towing tank or cavitation tunnel, including length, breadth and water depth or test section length, breadth and height

· Test date

· Parametric data for the test:

- Water temperature
- Water density
- Kinematic viscosity of the water
- Reynolds Number (based on propeller blade chord at 0.7*R*)

· For each speed the following measured data and extrapolated data is to be given as a minimum:

- Speed
- Thrust of the propeller
- Torque of the propeller
- Rate of revolution
- Force of nozzle in the direction of the propeller shaft (in case of ducted propeller)

· Propeller Open Water Diagram

4. Speed Trial Prediction

The principal steps of the Speed Trial Prediction Calculation are given in ITTC Recommended Procedure 7.5 - 02 - 03 -1.4 ITTC 1978 Trial Prediction Method (in its latest reviewed version of 2011). It is to be based on a Resistance Test, a Propulsion Test and an Open Water Characteristics of the used model propeller during the tests and the Propeller Open Water Characteristics of the final propeller. The report given by the submitter is at least to include:

· Model Hull Specification:

- Identification (model number or similar)
- Loading condition
- Turbulence stimulation method
- Model scale
- Main dimensions and hydrostatics

· Model Propeller Specification:
- Main dimensions and particulars

· Particulars of the towing tank, including length, breadth and water depth

· Resistance Test Identification (Test No. or similar)

· Propulsion Test Identification (Test No. or similar)

· Open Water Characteristics of the model propeller

· Open Water Characteristics of ship propeller

· Ship Specification:

- Projected wind area
- Wind resistance coefficient
- Assumed BF

· For each speed the following calculated data is to be given as a minimum:

- Ship speed
- Model wake coefficient
- Ship wake coefficient
- Propeller thrust on ship
- Propeller torque on ship
- Rate of revolutions on ship
- Predicted power on ship (delivered power on Propeller(s) P_D)
- Sinkage fore and aft, or sinkage and trim

Appendix 6 EEDI Ship Trial Based on ISO15016:2015

Chapter 1 General

1.1 General provisions

1.1.1 This Appendix is intended to provide guidance for speed trial and test report for EEDI final verification at ship trial stage.

1.1.2 The purpose of EEDI speed trial (hereinafter referred to as trial) is to obtain EEDI speed/power curve so as to verify ship speed as well as shaft power, torque and rpm corresponding to each speed.

1.1.3 Trial verification includes:

(1) Propulsion system, engine characteristics and other related projects mentioned in EEDI technical files;

(2) Displacement and trim;

(3) Trial condition;

(4) Speed; and

(5) Shaft power of main engine.

1.2 Plans and documents

1.2.1 Following plans and documents are to be submitted to the classification society.

(1) Trial program;

(2) Final displacement table;

(3) Final light weight data or copy of deadweight inspection report;

(4) Copy of NOx technical file;

(5) Calibration report of measuring instrument;

(6) Ship displacement and trim data;

(7) Speed/power test report (model test);

(8) Speed correction calculation report (including dates of last docking and hull and propeller cleaning).

Plans and documents mentioned in above (1) to (7) are to be submitted to trial witness of the classification society prior to trial, and (1) is to be approved by the trial witness. On completion of trial, (8) is to be submitted for approval by EEDI verifier.

1.3 Definitions

1.3.1 Following definitions and terms apply to the Guidelines:

(1) *Brake power* is power delivered by the output coupling of the propulsion machinery before passing through any speed-reducing and transmission devices;

(2) *Shaft power* is net power supplied by the propulsion machinery to the propulsion shafting after passing through all speed- reducing and other devices and after power for all attached auxiliaries has been taken off and accounting for losses in shaft between propeller and the location of power measurement at the shaft;

(3) *Delivered power* is effective power delivered to the propeller for ship propulsion;

(4) *Contract power* is brake power or shaft power that is stipulated in the new build or conversion contract between the Shipbuilder and the Owner;

(5) *Contract speed* is the ship's speed to be achieved as agreed within the terms of the new build/ conversion contract;

(6) *Double run* is two consecutive speed runs at the same power setting on reciprocal headings;

(7) *EEDI* is Energy Efficiency Design Index introduced in Amendments to MARPOL Annex VI adopted by Resolution MEPC.203(62);

(8) *EEDI power* is main engine brake power that is defined in 2014 Guidelines on the method of calculation of the attained energy efficiency design index (EEDI) for new ships adopted by Resolution MEPC.245(66);

(9) *EEDI speed* is ship speed that is defined in 2014 Guidelines on the method of calculation of the attained energy efficiency design index (EEDI) for new ships adopted by Resolution MEPC.245(66);

(10) *Ideal conditions* are ideal weather and sea conditions, i.e. no wind, no waves, no current and deep water of 15°C;

(11) *Power setting* is setting of engine throttle and propeller shaft speed for fixed pitch propellers, setting of the pitch angle for controllable pitch propellers;

(12) *Propeller pitch* is the design pitch for a fixed pitch propeller;

(13) *Pitch angle* is the operating pitch angle of a CPP;

(14) *Measured ship speed* is average ship speed obtained according to sailing distance and sailing time between the starting position and ending position of the voyage;

(15) *Sister ships* are ships with identical main dimensions, body lines, appendages and propulsion system built in a series by the same Shipyard, and applicable to the same tank test according to EEDI Inspection Guidance;

(16) *S/P trials* are speed and power trials to establish the relationship between power and speed for a particular ship;

(17) *S/P trial agenda* is document outlining the scope of a particular S/P trial;

(18) *Speed run* is ship's track with specified heading, distance and duration for which the measured ship's speed and shaft power are calculated;

(19) *Tank tests* are model tank tests for the prediction of the speed power relation for the stipulated conditions;

(20) *Trial log* is all the data recorded before, during and after S/P trial;

(21) *Zero pitch* is the CPP blade angle at which the pitch angle at the representative radius is equivalent to zero.

1.3.2 In this Appendix, unless otherwise specified, the angle unit is rad and the speed unit is m/s.

1.4 Nomenclature and abbreviations

1.4.1 Nomenclature

A_{LV}	lateral projected area above the waterline including superstructures
A_M	midship section area under water
A_{OD}	lateral projected area of superstructures above upper deck
a_Q, b_Q, c_Q	factors for the torque coefficient curve
a_T, b_T, c_T	factors for the thrust coefficient curve
A_{XV}	transverse projected area above the waterline including superstructures in square metres
B	ship's breadth
$B(x)$	sectional breadth
B_f	bluntness coefficient
C_{AA}	wind resistance coefficient; C_{AA0} means the wind resistance coefficient in head wind
C_B	block coefficient
C_F	frictional resistance coefficient for the actual water temperature and water density
C_{F0}	the frictional resistance coefficient for the reference water temperature and water density

C_{MC}	horizontal distance from midship section to centre of lateral projected area A_{LV}, where + means forward from midship
C_{Pv}	vertical prismatic coefficient
C_{T0}	total resistance coefficient for the reference water temperature and water density
C_U	coefficient of advance speed
D	propeller diameter
E	directional spectrum
e_i	scale correlation factor of the wake fraction
F_D	skin friction correction force same as in the normal self-propulsion tests
F_r	Froude number
F_X	external tow force measured during load variation test
g	acceleration of gravity
G	angular distribution function
h	water depth
$H_1(m)$	function to be determined by the distribution of singularities $\sigma(x)$ which represents a periodical disturbance by the ship
$H_{1/3}$	significant wave height
H_{BR}	height of top of superstructure (bridge etc.)
H_C	height from waterline to center of lateral projected area A_{LV}
$H_{S1/3}$	significant height of local swell
$H_{W1/3}$	significant height of local wind driven waves
(i)	run number
I_1	modified Bessel function of the first kind of order 1
J	propeller advance coefficient
J_{id}	propeller advance coefficient in the ideal condition
J_{ms}	propeller advance coefficient in the trial condition
k	wave number
K_1	modified Bessel function of the second kind of order 1
K_Q	torque coefficient
K_{Qid}	torque coefficient in the ideal condition
K_{Qms}	torque coefficient in the trial condition
K_T	thrust coefficient
K_{Tid}	thrust coefficient in the ideal condition
K_{Tms}	thrust coefficient in the trial condition
k_{yy}	non-dimensional radius of gyration in the lateral direction
L_{BWL}	distance of the bow to 95% of maximum breadth on the waterline

L_{OA}	ship's length overall
L_{PP}	ship's length between perpendiculars
MCR	Maximum Continuous Rating
m_n	n^{th} moment of frequency spectrum
n_{id}	corrected propeller shaft speed
n_{ms}	measured propeller shaft speed
P_1	power corresponding to displacement volume ∇_1 during the S/P trial
P_2	power corresponding to displacement volume ∇_2 used in the tank test
P_{Bms}	measured brake power
P_{Did}	delivered power in the ideal condition
P_{Dms}	delivered power in the trial condition
$P_{Full,P}$	power at full load/stipulated condition predicted by the tank tests
$P_{Full,S}$	power at full load/stipulated condition obtained by the S/P trials
P_{Sms}	measured shaft power
$P_{Trial,P}$	power at the trial condition predicted by the tank tests
$P_{Trial,S}$	power at the trial condition obtained by the S/P trials
R_{AA}	resistance increase due to relative wind
R_{AS}	resistance increase due to deviation of water temperature and water density
R_{AW}	resistance increase due to waves
R_{AWL}	mean resistance increase in long crested irregular waves
R_{AWM}	mean resistance increase in regular waves based on Maruo's theory, which is calculated from the radiation and diffraction components
R_{AWR}	correction term of R_{AWM}
R_F	frictional resistance for the actual water temperature and water density
R_{F0}	frictional resistance for the reference water temperature and water density
R_{id}	resistance in the ideal condition
R_{ms}	resistance in the trial condition
R_{T0}	total resistance for the reference water temperature and water density
R_{wave}	mean resistance increase in regular waves
R_{wave}^{EXP}	mean resistance increase in regular waves measured in the tank tests
s	directional spreading parameter
S	wetted surface area
S_S	full scale wetted surface, the same value as used in the normal self-propulsion test
S_η	frequency spectrum

t	thrust deduction factor
T_C	period of variation of current speed
T_{deep}	draught; for a trim condition T_{deep} is the deepest draught
t_{id}	thrust deduction factor in the ideal condition
T_M	draught at midships
t_{ms}	thrust deduction factor in the trial condition
V'_{WR}	corrected relative wind velocity at the vertical position of the anemometer
V'_{WT}	averaged true wind velocity at the vertical position of the anemometer
V_A	speed of flow into propeller
V_C	current speed
V_G	measured ship's speed over ground
V_{G1}	measured ship's speed over the ground on the first of four runs
V_{G2}	measured ship's speed over the ground on the second of four runs
V_{G3}	measured ship's speed over the ground on the third of four runs
V_{G4}	measured ship's speed over the ground on the fourth of four runs
V_S	ship's speed through the water
V_{WR}	relative wind velocity
V_{WRref}	relative wind velocity at the reference height
V_{WT}	true wind velocity
V_{WTref}	true wind velocity at the reference height
w_M	model wake fraction
w_{Mid}	model wake fraction in the ideal condition
w_{Mms}	model wake fraction in the trial condition
w_S	full-scale wake fraction
w_{Sid}	full-scale wake fraction in the ideal condition
w_{Sms}	full-scale wake fraction in the trial condition
x	longitudinal coordinate
Z_a	vertical position of the anemometer
Z_{ref}	reference height for the wind resistance coefficients
Z_Γ	vertical displacement relative to waves in steady motion
α_P	power ratio
α_T	effect of draught and encounter frequency
α	angle between ship's heading and component waves; 0 means head waves
β_W	slope of the line element d_l along the water line
Γ	Gamma function
ΔP	required correction for power

ΔR	total resistance increase
Δt	deviation of the thrust deduction factor
ΔV	decrease of ship's speed due to shallow water
Δw_M	deviation of the wake fraction
$\Delta \eta_R$	deviation of the relative rotative efficiency
ζ_A	wave amplitude
η_D	propulsive efficiency coefficient
η_{Did}	propulsive efficiency coefficient in ideal condition
η_{Dms}	propulsive efficiency coefficient in trial condition
η_M	transmission efficiency
η_O	propeller open water efficiency
η_{Oid}	propeller efficiency in the ideal condition
η_{Oms}	propeller efficiency in the trial condition
η_R	relative rotative efficiency
η_{Rid}	relative rotative efficiency in the ideal condition
η_{Rms}	relative rotative efficiency in the trial condition
η_S	shaft efficiency
θ_m	angle between ship's heading and wave direction relative to the bow; 0 means head waves
λ	scale factor
μ	smoothing range
ξ_n, ξ_V	derived considering the load variation effect as described in Appendix 6-J
ξ_P	derived considering the load variation effect as described in Appendix 6-J
ρ_A	mass density of air
ρ_M	water density in the model test
ρ_S	water density for the actual water temperature and salt content
ρ_{S0}	water density for the reference water temperature and salt content
τ_P	load factor equal to K_T/J^2
τ_{Pid}	load factor in the ideal condition
τ_{Pms}	load factor in the trial condition
ψ	ship's heading
ψ'_{WR}	corrected relative wind direction at the vertical position of the anemometer
ψ'_{WT}	averaged true wind direction at the vertical position of the anemometer
ψ_{WR}	relative wind direction; 0 means head winds
ψ_{WRref}	relative wind direction at the reference height
ψ_{WT}	true wind direction in Earth system

ω	circular frequency of regular waves
ω_E	circular wave frequency of encounter
∇_1	displacement volume during the S/P trial
∇_2	displacement volume used in the tank test

1.4.2 Abbreviations

FPP	fixed pitch propeller
CPP	Controllable pitch propeller
IMO	International Maritime Organization
ITTC	International Towing Tank Conference
JASNAOE	The Japan Society of Naval Architects and Ocean Engineers
JONSWAP	Joint North Sea Wave Project
MEPC	Marine Environmental Protection Committee in IMO
SNAJ	The Society of Naval Architects of Japan
SNAME	The Society of Naval Architects and Marine Engineers, USA
STA-Group	An international group of owners, shipyards, research institutes, classification societies and universities studying and improving sea trial procedures and Sea Trial Analyses (STA)

Chapter 2 Trial Organization Management and Procedures

2.1 Trial team

2.1.1 The trial team consists of the trial leader, the owner's representative, the appointed persons responsible for the S/P trial measurements and, if the ship requires EEDI, the verifier.

2.1.2 The trial leader is duly authorized (shipbuilder's representative) person responsible for the execution of all phases of the S/P trials including the pre-trial preparation.

2.1.3 The trial team is responsible for correct measurements and reporting of the S/P trials according to this Appendix and for the analysis of the measured data to derive the ship's speed and power at the stipulated conditions. The Trial Team is responsible for the following:

(1) conducting an inspection of the ship, including the condition of the hull and propeller(s)/ propulsor(s), prior to the commencement of the S/P trial;

(2) the provision, installation, operation and removal of all necessary trial instrumentation and temporary cabling;

(3) providing the ship's master and the owner's representative with a preliminary data package and initial analysis before disembarking;

(4) and delivering a final report on completion of full analysis of the measurements taken during the trial.

2.1.4 The testing unit is to have supplier qualification certificate approved by the verifier, or testing personnel with training certificate or corresponding test certificate.

2.2 Pre-trial meeting

2.2.1 Before departure, a pre-trial meeting is to be held to fix the S/P trial agenda. Participants are to include shipowner, shipbuilder and verifier, etc. During this meeting, following items are to be addressed.

(1) trial date;

(2) important speed correction method to be used for calculating actual ship speed and submitting trial report;

(3) to determine test procedure and measurement data according to proposed speed correction method.

2.3 Responsibilities

2.3.1 Shipbuilder's responsibilities

2.3.1.1 The shipbuilder is responsible for the overall trial co-ordination. A pre-trial meeting between the trial team and the ship's crew is to be held to discuss the various trial events and to resolve any outstanding issues.

2.3.1.2 On completion of shipbuilding, the shipbuilder is responsible for the planning, conduct and evaluation of the S/P trials. The shipbuilder is to ensure that:

(1) an appropriately authorized trial leader is appointed to oversee all aspects of the S/P trial;

(2) all permits and certificates required for the ship to go to sea are provided;

(3) all qualified personnel necessary for operating the ship and all engines, systems and equipment required during the sea trials, are on board;

(4) all regulatory bodies: the classification society, the owner, ship agents, suppliers, subcontractors, harbor facilities, departments organizing the supply of provisions, fuel, water, towage, etc., necessary for conducting these trials, have been informed, are available and on board when required;

(5) all safety measures have been checked;

(6) all fixed, portable and individual material (for crew, trial personnel and guests) is on board and operative;

(7) any safety systems for conducting safe S/P trials have been checked in accordance with the administrative requirements;

(8) an inclining test has been performed and/or at least a preliminary stability booklet including the S/P trials condition has been approved, in accordance with the SOLAS Convention;

(9) all ship data relevant for the S/P trials preparation, conduct, analysis and reporting are made available to the trial team prior to the S/P trials. This data is to include the information requested in Appendix 6-A as well as the results of the tank tests for this ship at trial draught and trim, EEDI draught and trim and Contract draught and trim.

2.3.1.3 Speed and power measurements and analysis are to be conducted by persons acknowledged as competent to perform those tasks, as agreed between the shipbuilder, the owner and the verifier (where applicable).

2.3.1.4 The Shipbuilder is to arrange for divers to inspect the ship's hull and propulsor(s) if necessary.

2.3.1.5 The trial leader is to maintain contact with the trial team on the preparation, execution and results of the S/P trials.

2.3.2 Shipowner's responsibilities

2.3.2.1 Prior to trial, the shipowner's representative is to attend the pre-trial meeting organized by the trial team to determine S/P test agenda, including important information such as trial date, measurement location, measurement method and speed correction method.

2.3.2.2 During trial, the shipowner’s representative is to be on board ship and ensure that communication is readily available to settle any issue arising during trial.

2.3.3 Classification society’s responsibilities

2.3.3.1 As verifier, the classification society is to attend the pre-trial meeting organized by the trial team prior to trial to determine S/P test agenda, including important information such as trial date, measurement location, measurement method and speed correction method, and approve the trial program.

2.3.3.2 During trial, the classification society personnel are to witness recorded data according to Appendix 6-A Table 6-A.2 Trial Status Record and Table 6-A.3 Trial Voyage Data.

2.3.3.3 On completion of trial, the classification society personnel are to approve the speed measurement report.

Chapter 3 Trial Preparations

3.1 General provisions

3.1.1 The purpose of trial is to obtain ship speed data and corresponding data such as shaft power, torque and rpm, etc. for EEDI final verification at trial stage.

3.2 Ship's condition during trial

3.2.1 Ship

3.2.1.1 The ship is to have a clean hull and propeller(s) for the sea trial. Hull roughness and marine growth can increase the resistance of the ship significantly, but are not corrected for in S/P trials.

3.2.1.2 Prior to undocking, the underwater part of hull is to be painted, and the hull and propeller surface are to be intact and cleaned.

3.2.1.3 After undocking, the ship is to carry out trial as quick as possible.

3.2.1.4 The dates of last docking and hull and propeller cleaning are to be recorded in the S/P trials report.

3.2.2 Loading condition

3.2.2.1 The ship is to be brought into a loading condition that is as close as possible to EEDI condition or displacement and trim condition of full load department (for tanker), or contract condition and/or the condition at which tank tests have been carried out.

3.2.2.2 If it is not practicable, the difference between the ship's actual displacement and the required displacement is to be less than 2% of the required displacement. If tank test results are used for the analysis of the S/P trials, when the deviation of the actual displacement during the S/P trials is within 2% of the displacement used during the tank test, displacement correction method in Appendix 6-G may be adopted. If the deviation is more than 2%, displacement correction method in Appendix 6-G is not applicable.

3.2.2.3 The trim is to be maintained within very narrow limits, i.e.

—for the even keel condition, trim is to be less than 0.1% L_{PP};

—for the trimmed trial condition, the fore draught is to be within ± 0.1 m of the ship's condition for which tank test results are available.

Where L_{PP} is length between perpendiculars, in m.

3.2.2.4 The trial loading condition is to be measured at zero ship's speed and draught is to be recorded, which are to be confirmed by the verifier surveyor.

3.2.2.5 The ship's draught, trim and displacement are to be obtained immediately prior to the S/P trials by averaging the ship draught mark readings at the perpendiculars and midships port and starboard, or displacement determination is to be conducted either by reading the internal draught measurement system or by evaluating all tank soundings.

3.2.2.6 Stability and strength check is to be carried out for ship trial loading condition and ballast condition.

3.3 Trial boundary conditions

3.3.1 General provisions

3.3.1.1 During the trial, there must be weather and sea conditions that deviate from EEDI ideal condition or contract condition.

3.3.1.2 Although there are correction methods in this Appendix for certain deviations from EEDI ideal condition or contract condition, these methods are only valid up to certain limits.

3.3.1.3 In order to reduce the effects of external condition on trial and arrive at reliable S/P trial results, it is to minimize the number of influencing factors and influencing level, and the boundary conditions are not to exceed the values given in this Appendix.

3.3.2 Location

3.3.2.1 High wind and sea state in combination with a heading deviating from head waves and following waves can require the use of excessive rudder deflections to maintain heading which cause excessive fluctuations in shaft torque, propeller shaft speed and measured ship's speed.

3.3.2.2 The S/P trials are to be conducted in a location where the environmental conditions are expected to be constant and have only the smallest possible impact on the ship in order to avoid unexpected environmental effects in the S/P trial results.

3.3.2.4 The S/P trial range is to be located in a sheltered area (i.e. limited wind, waves and current).

3.3.2.5 The area is to be broad with minimized influence of currents and free from hindrance by other ships.

3.3.3 Wind

3.3.3.1 The wind velocity during the S/P trial is not to be higher than:

(1) Beaufort number 6 for ships with $L_{PP} > 100$m;

(2) Beaufort number 5 for ships with $L_{PP} \leqslant 100$m.

3.3.4 Sea state

3.3.4.1 The total significant wave height is derived from following formula:

$$H_{1/3} = \sqrt{H_{W1/3}^2 + H_{S1/3}^2} \tag{3.1}$$

where: $H_{1/3}$—the total significant wave height, in m;

$H_{W1/3}$—the significant height of local wind driven waves, in m;

$H_{S1/3}$—the significant height of local swell, in m.

3.3.4.2 For all correction methods related to waves, the following empirical criteria are to be applied in relation to ship's length in order to determine the maximum allowable correction for resistance increases due to waves.

(1) When the wave spectrum encountered during the S/P trials is measured:

$$H_{1/3} \leq 2.25\sqrt{L_{PP}/100} \tag{3.2}$$

(2) When the wave height is derived from visual observations:

$$H_{1/3} \leq 1.50\sqrt{L_{PP}/100} \tag{3.3}$$

(3) When use is made of transfer functions of added resistance from dedicated model tests, the wave spectrum encountered during the S/P trials is to be measured unless the wave height is less than:

$$H_{1/3} \leq 0.50\sqrt{L_{PP}/100} \tag{3.4}$$

where, in each case:

L_{PP}—Pthe ship's length between perpendiculars, in m;

$H_{1/3}$— the total significant wave height, in m;

$H_{W1/3}$— the significant height of local wind driven waves, in m;

$H_{S1/3}$— the significant height of local swell, in m.

3.3.4.3 The above limits are illustrated in Figure 3.3.4.3. It is recommended that trial sea condition do not exceed above limits. If the actual value exceeds the upper limit, wave resistance increase is to be corrected according to upper limit.

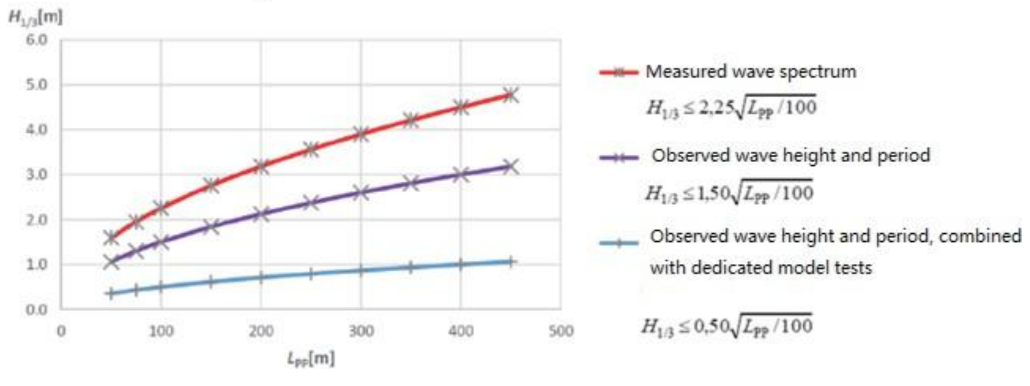


Figure 3.3.4.3 Limits for wave height during S/P trials

3.3.4.4 The directions of the waves and swells may be derived from visual observations in all cases.

3.3.5 Water depth

3.3.5.1 There are correction methods that compensate for shallow water effects. However, it is preferable to avoid the corrections by selecting a suitable S/P trial location.

3.3.5.2 If the water depth, *h*, in the S/P trial area is not less than the larger of the values obtained from the following two formulae, it is considered that the water depth requirement is complied with.

$$h = 3\sqrt{B \cdot T_M} \text{ and } h = 2.75\frac{V_S^2}{g} \quad (3.5)$$

where: h — wather depth, in m;
B — ship's breadth, in mm;
T_M — ship draught at midships, in m;
V_S — ship draught at midship, in m/s;
g — ship draught at midship, in nm/s^2.

3.3.5.3 If the above water depth requirement can not be fulfilled, corrections can be made to the measured speed to compensate for shallow water effects.The value of water depth, *h*, to be used for correction is not to be less than the larger value obtained from the following two formulae:

$$h = 2\sqrt{B \cdot T_M} \text{ and } h = 2\frac{V_S^2}{g} \quad (3.6)$$

For details, see Appendix 6-H.

3.3.5.4 Furthermore, significant variations in the bottom contours are to be avoided. The actual water depth during each speed run is to be read from the ship's instruments or the sea chart and recorded in the trial log.

3.3.6 Current

3.3.6.1 Ideally S/P trials are to be conducted in a location where the current speed and direction are essentially uniform throughout the trial area. Influence of currents on ship peed is to be avoided as far as possible.

3.3.6.2 In cases of current time history deviating from the assumed parabolic/sinusoidal trend and the change of the current speed within the timespan of one Double Run is more than 0.5 knots, neither of the correction methods in Appendix 6-E are applicable. Areas where this may occur are to be avoided for S/P trials.

3.4 Tank test information

3.4.1 The quality and accuracy of tank tests play a large role in the outcome of full scale S/P trials. For some ship types, sea trials are normally carried out in ballast condition, whereas EEDI condition and contractual condition are normally defined as the design loaded condition. For the conversion from ballast trial results to EEDI condition and contractual condition, the difference between the ballast and loaded tank test curves is used. Therefore, an accurate tank test and a validated consistent method for extrapolation to full scale are required.

3.4.2 The tank tests are to be conducted according to the following criteria:

(1) Tank tests are to be conducted at the contract draught & trim and the EEDI draught & trim as well as the trial draught & trim.

(2) Tank tests following the scheme of ITTC Recommended Procedures for Resistance and Propulsion Tank tests, including load variation tests, are to be conducted.

(3) The same methods, procedures and empirical coefficients are to be used to extrapolate the model scale values to full scale for all draughts and trims. Where different empirical coefficients for the different draughts are used, full details are to be recorded in the tank test report, including justification by means of full scale S/P trial data for the specific ship type, size, loading condition, tank test facility and evaluation method.

3.5 Basic information

3.5.1 Prior to trial, relevant data in Appendix 6-A is to be recorded and provided to the shipbuilder, shipowner and verifier (if applicable).

3.5.2 During S/P trial, relevant data on S/P and runs in Appendix 6-A is to be recorded.

3.6 Instrumentation installation and calibration

3.6.1 Measurement of shaft power and shaft speed

3.6.1.1 The shaft power is to be derived from torque and propeller shaft speed. Shaft torque can be measured by means of a calibrated permanent torque sensor or strain gauges on the shaft, or in a manner recommended by the manufacturer and approved by the certification authority. Other methods are allowed upon agreement between shipowner and shipbuilder and approval of the certification authority. Shaft speed is measured by revolution meter. The instrumentation for measuring shaft torque and shaft speed is to have synchronous testing function. If there is no such function, synchronous signal control is to be used for multi-shaft measurement.

3.6.1.2 All measuring instruments are to have calibration or verification certificate issued by national legal metrological department.

3.6.1.3 The shaft material properties, e.g. the *G*-Modulus, are to be fully described and documented by the Shipbuilder. *G*-Modulus is to be the actual value provided by the shaft manufacturer. If no certificate based on an actual shaft torsional test is available, the *G*-Modulus of 82400 N/mm^2 is to be used.

3.6.1.4 The shaft diameter used in the power calculation is to be derived from the shaft circumference measured at the location of the torsion meter. In the case of controllable pitch propeller(s), there might be a drilling diameter to be taken into account (to be supplied by Shipbuilder).

3.6.1.5 When shaft torque/shaft power is measured, the smooth length of measured shaft section is generally not less than 0.5m, and the radial periphery of shaft is generally not less than 0.2m. Before shaft torque measurement system is installed, oil stains on shaft segment surface is to be cleaned and surface paint on the measured shaft segment is to be removed. The measured shaft segment surface is to be polished by fine sandpaper. Afeter installation is completed, the torsion meter’s zero torque readings are to be determined since there is a residual torque in the shaft, which is resting on the line shaft bearings. The torsion meter zero setting is to be carried out in accordance with its maker's instructions. If not specified otherwise, the zero torque value is determined with the ship at rest by turning the shaft ahead and astern and taking the mean of these two readings as the zero value.

3.6.2 Global positioning system (GPS)

3.6.2.1 The ship's position and speed are to be measured by a global positioning system such as GPS. The positioning system is to be operated in the differential mode to ensure sufficient accuracy. Position and speed are to be monitored and stored continuously.

3.6.3 Ship condition measurement

3.6.3.1 The ship's draught, trim and displacement are to be obtained immediately prior to the S/P trials by averaging the ship draught mark readings at the perpendiculars and midships port and starboard.

3.6.3.2 In the event that reading the draught marks will be unsafe or provide an inaccurate result, displacement determination is to be conducted either by reading the internal draught measurement system or by evaluating all tank soundings.

3.6.3.3 Displacement is to be derived from the Bonjean data or using quadratic equations with hydrostatic data, taking into consideration the hog/sag using the draught data (forward, aft and at half length) and the density of the water.

3.6.4 Anemometer

3.6.4.1 The ship's own anemometer is to be used. However, if not available, However, if the on-board anemometer is not available, a trial anemometer temporarily installed by the test team may be used. The anemometer is to be as clear as possible from the superstructure.

3.6.5 Wave measurement

3.6.5.1 Preferably, the wave height, wave period and direction of waves induced by local wind and swell originating from remote wind, are to be measured during the S/P trials. For this purpose, wave buoys in the S/P trial area or instruments on-board the ship such as wave radar, lidar or wave scanner may be used. The wave measurement equipment is to be calibrated and the accuracy is to be validated and documented.

3.6.5.2 If, for the wave correction, use is made of transfer functions of added resistance in waves derived from model tests for the subject ship, the wave spectrum encountered during the S/P trials is to be measured unless the wave height satisfies $H_{1/3} \leq 0.50\sqrt{L_{PP}/100}$ (see 3.3.4).

3.6.5.3 If use is made of the empirical wave correction methods described in Appendix 6-D (without specific model tests), and if the wave heights satisfy $H_{1/3} \leq 1.50\sqrt{L_{PP}/100}$ (see 3.3.4), the encountered wave heights, periods and directions of both wind waves and swells may be determined from observations by multiple experienced mariners, including the owner's representative and the verifier.

3.6.6 Density and temperature measurement

3.6.6.1 The local water temperature and density are to be recorded to enable the calculation of the ship's displacement and corrections with regard to viscosity. The temperature is to be taken at water inlet level. Air temperature and pressure are to be measured using a calibrated thermometer and barometer respectively.

3.6.7 Current

3.6.7.1 Current speed is to be determined as part of the evaluation of each run.

3.6.7.2 When using the 'Mean of means' method, after the two (2) Double Runs with the same power setting, the current speed is calculated from the measured speed at each run and the 'Mean of means' value of those two (2) Double Runs (see Appendix 6-E.3).

3.6.7.3 Alternatively the 'Iterative' method may be utilized to establish the current speed (see Appendix 6-E.2).

3.6.8 Measurement of hull bow vertical acceleration

3.6.8.1 Hull bow vertical acceleration is to be measured by acceleration sensor. The sensor is to have a certificate of calibration or verification issued by national legal metrological department.

3.6.8.2 Acceleration sensors are to be installed at designated positions which are determined by the verifier, shipowner and shipbuilder. The sensor shaft is to be parallel with hull shaft as far as possible and fixed with hull to prevent sensor moving during measurement. When bow vertical acceleration is measured, acceleration sensor is to be installed on longitudinal midsection. The sensor cable is not to be too long and high temperature is to be avoided during laying. Appropriate measures are to be taken to prevent extrusion when passing through door and window.

3.6.8.3 During speed measurement, hull bow vertical acceleration is to be monitored and stored continuously, and the mean value of all monitored data of each run is to be taken as measured value of hull bow vertical acceleration of the run.

Chapter 4 Conduct of the Trial

4.1   General provisions

4.1.1 On the day of and during the S/P trial, a number of pre-requisites are to be met in order to arrive at reliable trial results. In this Chapter, an overview is given of the minimum requirements.

4.2 Initiation

4.2.1 Prior to the S/P trials，the weather forecast is to be studied.

4.2.2 Where wave height, period or wave directions are derived from visual observation, the schedule for the S/P Trials is to be arranged such that all speed runs around EEDI power are conducted by daylight.

4.2.3 The engine plant configuration during the S/P trial is to be consistent with the normal ship operation at sea.

4.2.4 Prior to the S/P trials, the following actions are to be taken at zero speed through the water:

(1) draught reading and calculation of displacement;

(2) zero setting of shaft torque meter;

(3) measuring water temperature and density.

4.3 Ship’s track during trial

4.3.1 The S/P trial runs are to be conducted over the same ground area. For each base course, each speed run is to be commenced (COMEX) and completed (FINEX) at the same place.

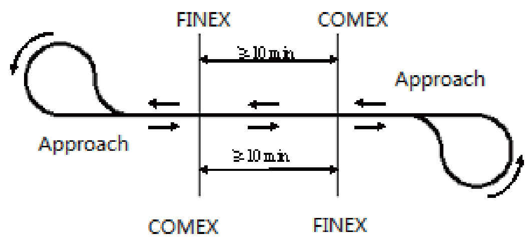


Figure 4.3.1 Path of ship during Double Run

4.3.2 Modified Williamson turns or similar types of manoeuver are to be executed between each run to return the ship to the reciprocal heading on, or parallel to, the trial baseline. Parallel means within one ship’s length of the trial baseline.

4.3.3 Engine throttles, rpm setting(s) or pitch setting(s) are not to be altered during this period. The rudder angle used in this manoeuver is to be such that the ship’s speed loss in the turn is minimized.

4.4 Run duration and timing

4.4.1 The S/P Trial duration is to be long enough to accommodate a speed/power measurement within the required accuracy. The run duration is to be the same for all speed runs with a minimum of ten (10) minutes. The speed runs for the same power setting are to be evenly distributed in time.

4.5 Trial direction

4.5.1 The speed runs are to be carried out by heading into and following the dominant wave direction. Consequently, once the heading for the speed run and the reciprocal heading for the return run are fixed, the selected tracks are to be maintained very precisely throughout the S/P trial.

4.5.2 It is imperative that extremely tight control is exercised during the execution of the S/P trials, and the ship heading angle variation for each run is to be strictly limited to ±3°.

4.6 Steering

4.6.1 An experienced helmsman or adaptive autopilot will be required to maintain heading during each speed run. Minimum rudder angles are to be used while maintaining a steady heading.

4.6.2 During the speed run, the maximum amplitude of rudder used is to be not more than 5°.

4.7 Approach

4.7.1 The S/P trial approach is to be long enough to ensure a steady state of ship condition prior to commencement of each speed run. During the approach run, the ship is to be kept on course with minimum rudder angles.

4.7.2 In order to verify that the ship reached steady condition, the measured values of propeller shaft speed, shaft torque and ship speed at the control position are to be monitored. When all three values are stable, the ship condition is to be deemed steady.

4.8 Number of speed runs

4.8.1 All S/P trials are to be carried out using Double Runs, i.e. each run is to be followed by a return run in exactly the opposite direction and at the same engine settings.

4.8.2 The number of speed runs required depends on the current correction method to be applied (see Appendix 6-E), i.e. "iterative" method and "mean of means" method.

4.8.3 The runs at EEDI power are to be conducted in daylight to enable a clear visual observation of the wave conditions. For trials in which the encountered wave spectrum and the wave direction (both wind waves and swells) are derived by measurements, these runs may also be conducted without daylight.

4.8.4 "Iterative" method

4.8.4.1 If "iterative" method is used to correct measured data, to determine the speed/power curve for the first ship of a ship series, a minimum of four(4) Double Runs at three (3) different power settings are required.

4.8.4.2 These power settings are to be adequately distributed within the power range of 65% *MCR* and 100% *MCR* and comprise at least:

(1) Two(2) Double Runs for the first ship and one(1) Double Run (at the same power setting) for sister ships around EEDI / Contract power;

(2) One(1) Double Run below EEDI/Contract power; and

(3) One(1) Double Run above EEDI/Contract power.

If the wave height is around the limiting conditions and significant ship motions are observed, one (1) additional Double Run at that power setting is to be conducted.

4.8.5 "Mean of means" method

4.8.5.1 If "mean of means" method is used to correct measured data, to determine the speed/power curve for the first ship of a ship series, a minimum of six (6) Double Runs at three (3) different power settings are required.

4.8.5.2 These power settings are to be adequately distributed within the power range of 65% *MCR* and 100% *MCR* and comprise at least:

(1) Two(2) Double Runs around EEDI/Contract power;

(2) Two(2) Double Runs below EEDI/Contract power; and

(3) Two(2) Double Runs above EEDI/Contract power.

4.8.5.3 Two (2) Double Runs compensate for the effect of current and second order current variations. In order to obtain sufficient accuracy, the time intervals between each run at the same power setting are to be more or less the same (time interval deviation of 25% is allowed).

4.8.5.4 If the results of the S/P trials of the first ship of a series are acceptable, the second and following sister ships may be subjected to a reduced speed trial program. For such sister ships, it is sufficient to conduct three (3) Double Runs at three (3) different power settings.

4.8.5.5 These power settings are to be adequately distributed within the power range of 65% *MCR* and 100% *MCR* and comprise at least:

(1) One(1) Double Run around EEDI/Contract power;

(2) One(1) Double Run below EEDI/Contract power; and

(3) One(1) Double Run above EEDI/Contract power.

4.8.5.6 In order to ensure sufficient accuracy for speed correction, if "Mean of means" method is used, it is recommended that a minimum of two (2) Double Runs at one (1) power setting is required.

4.8.5.7 If the wave height is around the limiting conditions and significant ship motions are observed, and/or current variations of above 0.2 knots are encountered, one (1) additional Double Run at that power setting is to be conducted.

Chapter 5 Data Acquisition

5.1 General provisions

5.1.1 The ship's speed and power characteristics are extremely sensitive to factors such as hull and propeller condition, ship displacement, shallow water effects, sea state and wind velocity. Consequently, these factors are to be monitored and documented to the greatest possible extent.

5.1.3 During the S/P trials, two types of data acquisition are to be used, i.e. automated, by means of a data acquisition system, and the manual recording of information by means of a log sheet.

5.1.4 In general, data to be acquired maybe divided into general data which are applicable to all speed runs and specific data that are varying throughout every run.

5.2 Trial measurement operation

5.2.1 In order to obtain speed/power curve, speed, shaft power, shaft torque and rpm at different engine power are to be measured, and the engine power is to be selected according to the requirements of Section 4.8, Chapter 4.

5.2.2 Each speed measurement is to keep propeller speed and other engine parameters fixed. When the ship turns on completion of measurement, in order to avoid too much speed reduction, the steering number is to be as few as possible and the steering is to be within the scope of ±5°.

5.2.3 Speed can be measured by electronic tracking device, GPS or other equivalent methods.

5.2.4 Shaft torque and rpm are to be measured together with speed to determine shaft power.

5.2.5 Shaft torque is to be measured by means of a torsion meter, i.e. shaft torsion deformation is measured on a shaft with known length. The internal and external diameters of shaft and torsion modulus of shaft material are to be known during measurement.

5.1.6 Rpm is generally measured by magnetic head method.

5.1.7 Shaft torque and rpm are to be sampled at least once per second and the average value is to be taken during test.

5.1.8 Shaft power P_S is to be calculated according to following formula:

$$P_S = Q \times n / 9550 \quad \text{kW}$$

Where: Q —— torque of real ship, in N·m;
n —— shaft speed, in rpm.

5.3 General data

5.3.1 Prior to the trial, the data specified below are to be recorded, based on measurements where relevant:

(1) Area of trial (in latitude/longitude co-ordinates)

(2) Weather condition;

(3) Water temperature and density;

(4) Air temperature;

(5) Vertical position of the anemometer above waterline;

(6) Fore, midships and aft draughts;

(7) Displacement calculated from the draughts;

(8) Trim calculated from the draughts;

(9) Transverse projected area above the waterline including superstructures;

(10) Lateral projected area of superstructures above upper deck (Fujiwara) + height of superstructure;

(11) Lateral projected area above the waterline including superstructures (Fujiwara) + position of centre of gravity;

(12) Bow acceleration (STAWAVE-1).

5.3.2 In order to verify the wind data measured during the S/P trials, it is recommended to record the absolute wind velocity and direction at shore based station(s) or as measured directly prior to and after finalizing the speed trials while the ship is stopped.

5.4 Data on each run

5.4.1 For each trial run, following data are to be measured and recorded:

(1) Date;

(2) Clock time at commencement;

(3) Time elapsed over the speed run;

(4) Ship's heading;

(5) Measured ship's speed over ground calculated from start and end position of the run and the elapsed time of the speed run;

(6) Propeller shaft speed;

(7) Propeller shaft torque and/or power;

(8) Propeller pitch in case of CPP;

(9) Relative wind velocity and direction by anemometer;

(10) Mean wave period, significant wave height and direction of wind driven seas;

(11) Mean swell period, significant swell height and direction of local swell waves;

(12) Mean water depth.

5.5 Data acquisition

5.5.1 Data acquisition includes automatic acquisition and manual data record.

5.5.2 The acquisition system is to record time histories of the measurements described in 5.5.3.1 in order to assure quality control and to provide information that will allow for the development of uncertainty analysis.

5.5.3 Record data

5.5.3.1 The following parameters, as a minimum, are to be continuously recorded during each speed run:

(1) Time;

(2) Propeller shaft torque or power;

(3) Propeller shaft speed;

(4) Pitch of CPP;

(5) Ship's position;

(6) Ship's heading;

(7) Measured ship's speed over ground;

(8) Relative wind direction;

(9) Relative wind velocity.

5.5.3.2 Above parameters, except for (4), are to be recorded continuously.

5.5.4 System requirements

5.5.4.1 The data acquisition system is to:

(1) Record all available parameters simultaneously;

(2) Perform a time trace recording with a sampling rate of at least 1 Hz;

(3) Display time traces of the trial parameters specified in 5.4.1;

(4) Calculating statistics (mean, minimum, maximum and standard deviation).

5.5.4.2 At the end of each run, the data acquisition system is to display all recorded time histories to facilitate evaluation of the quality and consistency of the acquired trial data and store the readings for subsequent graphical presentation.

5.5.4.3 Furthermore, the acquisition system is to present the following statistical values for each of the measured data:

(1) Trial start time;

(2) Number of samples taken;

(3) Average value;

(4) Maximum value;

(5) Minimum value;

(6) Standard deviation.

5.5.4.4 Filtering of the run data is recommended to avoid “spikes” in the recorded time histories. Chauvent’s criterion, which provides a ratio of maximum acceptable deviation to precision index as a function of the number of readings (N), is to be used. Readings are automatically rejected from use in the data analysis when they fall outside the selected mean value bandwidth.

5.5.5 Location

5.5.5.1 The data acquisition system is to be located on the bridge or other suitable locations.

5.5.6 Manual data collection

5.5.6.1 For those parameters that are not measured and recorded automatically by means of the data acquisition system or for parameters that need be additionally recorded manually, manual data collection using a log sheet is required.

5.5.6.2 The log sheet is important from two aspects:

(1) First, to complete the dataset, and

(2) Second, to provide a backup for the automated measurements and give a written overview of the measurements.

5.5.6.3 It is important that the parameters that vary with time are to be recorded every few minutes so that the average can be determined over the run period.

5.5.6.4 An example of a log sheet to be used is shown at Appendix 6-A. The sign conventions to be used for wind and wave direction are illustrated in Figures 5.5.6.4 and 5.5.6.5.

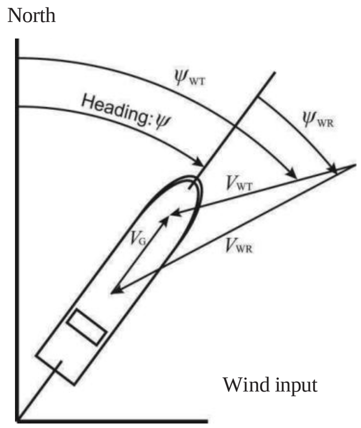


Figure 5.5.6.4 Sign convention for wind direction

5.5.6.5 The wind direction is defined as the direction from which the wind is blowing. Zero (0) degrees on the bow and positive to starboard (clockwise).
Input parameters:

- ψ — ship's heading, in °;
- ψ_{WR} —relative wind direction, in °, 0 means head winds;
- V_{WR} —relative wind velocity, in m/s;
- V_G — measured ship's speed over ground, in m/s.

Computed parameters:

- ψ_{WT} —true wind direction in Earth system, in °;
- V_{WT} —true wind velocity, in m/s.

5.5.6.6 The wave direction is defined as the direction relative to the ship's heading from which the wave fronts are approaching. Zero (0) degrees on the bow and positive to starboard (clockwise).
Input parameters:

- ψ — ship's heading, in °;
- θ_m — angle between ship's heading and wave direction relative to the bow, in °, 0 means head waves;
- V_G — measured ship's speed over ground, in m/s.

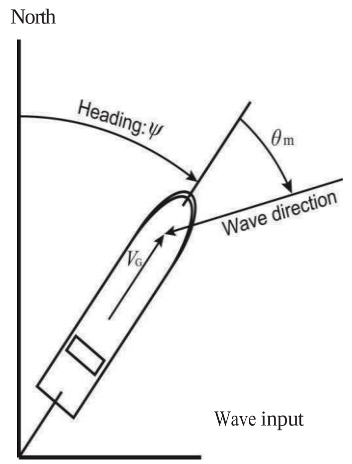


Figure 5.5.6.5 Sign convention for wave direction

Chapter 6 Trial Data Analysis

6.1 General provisions

This Chapter describes the essential procedures to analyze the results of S/P trials.
The analysis includes corrections to power and speed for environmental influences during S/P trials. This Appendix offers different methods of correction, details of which are described in corresponding Appendix.

6.2 Description of the analysis procedure

6.2.1 After completion of the S/P trials, the measured data is to be processed in the following sequence:

(1) Derive the mean value of power, rpm, torque and speed for each speed run;

(2) The average speed component in the heading direction of each run is found from the DGPS recorded start and end positions of the run and the elapsed time;

(3) The true wind velocity and direction for each Double Run is calculated;

(4) correction to power for resistance increase due to wind and waves (see Appendix 6-C and Appendix 6-D);

(5) correction to power for water temperature and water density (see Appendix 6-F);

(6) correction to speed for current effect (see Appendix 6-E);

(7) correction to speed for the effect of shallow water (see Appendix 6-H);

(8) correction to power for displacement (see Appendix 6-G);

(9) Determine the final speed-power relationship at sea trial draught as follows: Use the speed/ power curve from the tank tests for the specific ship design at the trial draught. Shift this curve along the power axis to find the best fit with all corrected speed/power points according to the least squares method. When more than three(3) power settings are obtained, it is acceptable to find the best fit with all corrected speed/power points using the 'least squares' method;

(10) Intersect the curve at the specified power to derive the ship's speed at trial draught in the ideal conditions;

(11) Apply conversions of speed/power curve from the trial condition to other stipulated load conditions (see Appendix 6-I).

(12) Apply corrections for the contractual weather conditions if these deviate from the ideal conditions.

(13) Submit test results.

6.2.2 Details of data analysis procedure are given in 6.3 of this Chapter.

6.2.3 For power evaluation, direct power method is to be used.

6.2.4 Details of correction methods, including the choice of a suitable correction method, are given in Appendixes.

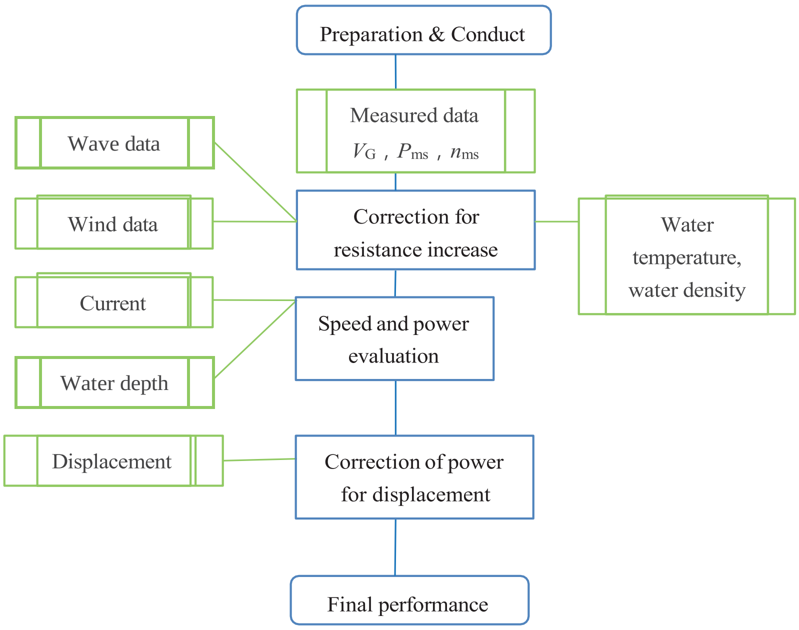


Figure 6.2.1 Flow chart of analysis

6.3 Data analysis

6.3.1 Resistance data derived from the acquired data

6.3.1.1 The resistance values of each run are to be corrected for environmental influences by estimating the resistance increase ΔR as:

$$\Delta R = R_{AA} + R_{AW} + R_{AS} \tag{6.1}$$

where: ΔR — total resistance increase, in N;

R_{AA} — resistance increase due to relative wind, in N (see Appendix 6-C);

R_{AW} — resistance increase due to waves, in N (see Appendix 6-D);

R_{AS} — resistance increase due to deviation of water temperature and water density, in N (see Appendix 6-F).

6.3.2 Evaluation of the acquired data

6.3.2.1 The evaluation of the acquired data consists of the calculation of the resistance value associated with the measured power value separately for every single run of the speed trials.

6.3.3 Evaluation based on Direct Power Method

6.3.3.1 To derive the speed/power performance of the ship from the measured speed over the ground V_G, power P_{ms} and propeller shaft speed n_{ms}, the 'direct power' method is to be used.

6.3.3.2 The analysis is based on the delivered power. The relationship between delivered power in the trial condition P_{Dms} and measured power is described in the following formula:

$$P_{Dms} = P_{Sms} \cdot \eta_S \tag{6.2}$$

where: P_{Dms} — delivered power in the trial condition, in kW;
P_{Sms} — measured shaft power , in kW;
η_S — shaft efficiency.

or:

$$P_{Dms} = P_{Bms} \cdot \eta_M \tag{6.3}$$

where: P_{Dms} — delivered power in the trial condition, in kW;
P_{Bms} — measured brake power, in kW;
η_M — transmission efficiency.

6.3.3.3 In this method, the delivered power P_{Dms} is directly corrected with the power increase ΔP due to resistance increase ΔR in the trial condition.

$$P_{Did} = P_{Dms} - \Delta P \tag{6.4}$$

where: P_{Did} — delivered power in the ideal condition， in kW;
P_{Dms} — delivered power in the trial condition， in kW;
ΔP—required correction for power， in kW.

The required correction for power ΔP is calculated by the following formula:

$$\Delta P = \frac{\Delta R V_S}{\eta_{Did}} + P_{Dms}\left(1 - \frac{\eta_{Dms}}{\eta_{Did}}\right) \tag{6.5}$$

where: ΔP — required correction for power， in kW;
ΔR — total resistance increase， in N;
V_S — ship's speed through the water， in m/s;
P_{Dms} — delivered power in the trial condition， in kW;
η_{Dms} — propulsive efficiency coefficient in the trial condition;
η_{Did} — propulsive efficiency coefficient in the ideal condition.

6.3.3.4 The propulsive efficiency coefficient in the ideal condition η_{Did} is obtained from standard towing tank test and interpolated to the speed V_S.

6.3.3.5 The effect of resistance increase on the propeller loading and thus on the propulsive efficiency coefficient η_{Dms} is derived considering the load variation effect.

6.3.3.6 The propulsive efficiency is assumed to vary linearly with the added resistance according to:

$$\frac{\eta_{Dms}}{\eta_{Did}} = \xi_P \frac{\Delta R}{R_{id}} + 1 \tag{6.6}$$

where: η_{Dms} — propulsive efficiency coefficient in the trial condition;
η_{Did} — propulsive efficiency coefficient in the ideal condition;
ξ_P — derived considering the load variation effect as described in Appendix 6-J;
ΔR — total resistance increase， in N;
R_{id} — resistance in the ideal condition， in N.

6.3.3.7 This leads to the expression for the corrected delivered power:

$$P_{Did} = P_{Dms} - \frac{\Delta R V_S}{\eta_{Did}} \left(1 - \frac{P_{Dms}}{P_{Did}} \xi_P \right) \tag{6.7}$$

6.3.3.8 Then, the following quadratic equation is obtained by transforming equation:

$$P_{Did}^2 - \left(P_{Dms} - \frac{\Delta R V_S}{\eta_{Did}} \right) P_{Did} - P_{Dms} \frac{\Delta R V_S}{\eta_{Did}} \xi_P = 0 \tag{6.8}$$

Finally, P_{Did} is obtained as follows under the condition $P_{Dms} - \frac{\Delta R V_S}{\eta_{Did}} > 0$.

$$P_{Did} = \frac{1}{2} \left(P_{Dms} - \frac{\Delta R V_S}{\eta_{Did}} + \sqrt{\left(P_{Dms} - \frac{\Delta R V_S}{\eta_{Did}} \right)^2 + 4 P_{Dms} \frac{\Delta R V_S}{\eta_{Did}} \xi_P} \right) \tag{6.9}$$

where: P_{Did} — delivered power in the ideal condition, in kW;
P_{Dms} — delivered power in the trial condition, in kW;
ΔR — total resistance increase, in N;
V_S — ship speed through the water, in m/s;
η_{Did} — propulsive efficiency coefficient in the ideal condition;
ξ_P is derived considering the load variation effect as described in Appendix 6-J.

6.3.3.9 The correction of the propeller shaft speed is also carried out considering the load variation effect.

6.3.3.10 With the P_{Did} found as described above, the correction on propeller shaft speed is:

$$\frac{\Delta n}{n_{id}} = \xi_n \frac{P_{Dms} - P_{Did}}{P_{Did}} + \xi_V \frac{\Delta V}{V_S} \tag{6.10}$$

$$\Delta n = n_{ms} - n_{id} \tag{6.11}$$

6.3.3.11 From this follows that the corrected propeller shaft speed n_{id} is

$$n_{id} = \frac{n_{ms}}{\xi_n \frac{P_{Dms} - P_{Did}}{P_{Did}} + \xi_V \frac{\Delta V}{V_S} + 1} \tag{6.12}$$

where: n_{ms} — measured propeller shaft speed, in rpm;
n_{id} — corrected propeller shaft speed, in rpm;
P_{Did} — delivered power in the ideal condition, in kW;
P_{Dms} — delivered power in the trial condition, in kW;
ξ_n and ξ_V are derived considering the load variation effect as described in Appendix 6-J;
V_S — ship's speed through the water, in m/s;
ΔV — decrease of ship's speed due to shallow water, determined in Appendix 6-H.

6.3.3.12 The analysis in Apppendix 6-K is useful to deepen the technological knowledge, since this calculation is based on the full-scale wake fraction.

6.3.4 Correction of the measured ship's speed due to the effect of current

6.3.4.1 The current effect is corrected by subtracting the current speed V_C from the measured ship's speed over the ground V_G at each run as follows:

$$V_S = V_G - V_C \tag{6.13}$$

where: V_S — ship's speed through the water, in knots;
V_G — measured ship's speed over ground, in knots;
V_C — current speed, in knots.

The current correction can be applied by two (2) different methods:

(1) "Iterative" method

Based on the assumption that the current speed varies with a semi-diurnal period, a current curve as a function of time will be created. In the same process, a regression curve representing the relationship between the ship's speed through the water (formula 6.13) and corrected power (clause 6.3.3) is determined. So both current curve and regression curve are created in one process. The regression curve has no relation with the speed/power curve from the tank tests.

The analysis of the direct power method as described in 6.3.3 is to be repeated after the value of V_S has been derived by the current correction analysis.

(2) "Mean of means" method

Based on the assumption that for a given power setting, the current speed varies parabolically, the influence of current is accounted for by applying the 'Mean of means' method for each set of runs with the same power setting.

The details of the 'Iterative' method and the 'Mean of means' method are given in Appendix 6-E.

6.3.5 Correction of the ship's speed due to the effects of shallow water

6.3.5.1 The speed correction for shallow water is applied in accordance with Appendix 6-H.

6.3.6 Correction of the ship's performance due to the effects of displacement

6.3.6.1 Displacement and trim are, in general, factors that can be adjusted to stipulated values at the time of the trials. However, there may be significant reasons for discrepancies and small deviations in displacement i.e. within 2% of the required value, are to be corrected in accordance with Appendix 6-G.

6.3.7 Conversion of power curve from trial condition to EEDI condition and contract condition (if any)

6.3.7.1 Fors some ships such as dry cargo ships, it is difficult to conduct S/P trials at EEDI condition and contract condition (if any). For such cases, S/P trials at ballast condition are performed and the speed/power curve is converted to that of the EEDI condition and contract condition (if any) using the power curves based on the tank tests.

6.3.7.2 The conversion method from the trial condition to EEDI condition and contract condition is shown at Appendix 6-I.

6.4 Example of trial data analysis

Example of trial data analysis is shown in Table 6.4.

Example of trial data analysis

Table 6.4

Date of sea trial	2017/2/25	Hull													
Shipbuilder's name	Shipyard	L_{OA}	L_{PP}	L_{BWL}	B	T_A	T_{F1}	T_{F2}	Δ_1	Δ_2	k_{yy}	A_M	A_{XV}	A_{LV}	A_{OD}
Ship number	15016	m	m	m	m	m	m	m	ton	ton		m^2	m^2	m^2	m^2
Ship name	M/V	-	320.00	40.00	60.00	19.90	19.90	-	301000	300000	-	1190.0	1000.0	-	-
Ship type	VLCC	Hull						Propeller	Efficiency				Height for wind		MCR
Draft condition	Full(EEDI draught)	H_C	H_{BR}	C_{MC}	T_M	trim	C_B	D	η_M	η_{R0}	$1-t_0$	$1-w_{M0}$	Z_{ref}	Z_a	P_{MCR}
Trim condition	Even keel	m	m	m	m	m		m					m	m	kW
Sea trial site	ISO BAY	-	-	-	19.9	0.0		9.86	0.970	-	-	-	10.00	40.00	22065
Weather	Fine	Depth	Water temperature		Density		Restrictions								
Beaufort number	4	h	T_W		ρ	ρ_A	$(\Delta_1-\Delta_2)/\Delta_2$	$trim/T_M$	$T_{F1}-T_{F2}$	h_{MIN}	h_{MAX}	Beaufort number		V_W	$H_{1/3}$
Method of measurement	Visual observations	m	℃		kg/m^3	kg/m^3	%	%	m					m/s	m
Date of print	2014/7/9 17:53	500.0	15.00		1025.88	1.23	0.3%	-0.5%	-	-	-	6		13.80	2.68

Analysis method option	
Wind correction	Appendix 6-C.1.1 and Appendix 6-C.2.2
Wave correction	Appendix 6-D.1
Current correction	Appendix 6-E.2

Measured or observed data												Ref., Eq. No.
1	Main engine output setting			70%		85%		100%				
2	Run number			1	2	3	4	5	6	7	8	
3	Course direction	(deg)	Ψ_0	0.0	180.0	0.0	180.0	0.0	180.0			measured
4	Mid time of each run	(hour)	t_i	15.07	17.40	19.67	21.85	23.98	26.07			measured
5	Ship speed over the ground	(knots)	V_G	13.923	13.088	14.707	15.357	14.460	15.766			measured
6	Propeller shaft speed	(rpm)	n	66.03	66.26	70.31	70.62	73.95	74.41			measured
7	Brake power	(kW)	P_{SM}	15513	15425	18790	18777	21918	22074			measured
8	Relative wind velocity at anemometer height	(m/s)	V_{WR}	13.68	3.56	14.07	3.95	13.95	4.06			measured
9	Relative wind direction at anemometer height	(deg)	Ψ_{WR}	14.8	-79.1	14.4	-62.3	14.5	-59.7			measured
10	True wind velocity at anemometer height	(m/s)	V_{WT}	7.0	7.0	7.0	7.0	7.0	7.0			(C.2)
11	True wind direction at anemometer height	(deg)	Ψ_{WT}	30.0	30.0	30.0	30.0	29.9	30.0			(C.3)
12	True wind velocity at anemometer height (double run average)	(m/s)	$V'_{WT(i/i+1)}$	7.0	7.0	7.0	7.0	7.0	7.0			(C.4)
13	True wind direction at anemometer height (double run average)	(deg)	$\Psi'_{WT(i/i+1)}$	30.0	30.0	30.0	30.0	30.0	30.0			(C.5)
14	Relative wind velocity at anemometer height (double run average)	(m/s)	$V'_{WR(i)}$	13.68	3.56	14.07	3.95	13.95	4.05			(C.6)
15	Relative wind direction at anemometer height (double run average)	(deg)	$\Psi'_{WR(i)}$	14.8	-79.1	14.4	-62.3	14.5	-59.7			(C.7)
16	True wind velocity at reference height	(m/s)	V_{WTref}	5.74	5.74	5.74	5.74	5.74	5.74			(C.8)
17	Relative wind velocity at reference height	(m/s)	V_{WRref}	12.47	3.36	12.86	4.10	12.74	4.25			(C.9)
18	Relative wind direction at reference height	(deg)	Ψ_{WRref}	13.3	-58.5	12.9	-44.4	13.0	-42.5			(C.10)
19	Wind resistance coefficient		C_{AA}	0.92	0.38	0.92	0.58	0.92	0.60			Appendix 6-C.2
20	Mean wave period (Seas)	(s)	T_{wm}									measured
21	Significant wave height (Seas) (measured)	(m)	$H_{w1/3}$	0.7	0.7	0.7	0.7	0.7	0.7			measured
22	Significant wave height (Seas) (used)	(m)	$H_{w1/3}$	0.7	0.7	0.7	0.7	0.7	0.7			measured
23	Incident angle of wave (Seas)	(deg)	χ_w	30.0	-150.0	30.0	-150.0	30.0	-150.0			measured

24	Mean wave period (Swell)	(s)	T_{sm}									measured
25	Significant wave height (Swell) (measured)	(m)	$H_{s1/3}$	1.00	1.00	1.00	1.00	1.00	1.00			measured
26	Significant wave height (Swell) (used)	(m)	$H_{s1/3}$	1.00	1.00	1.00	1.00	1.00	1.00			measured
27	Incident angle of wave (Swell)	(deg)	χ_S	0.0	180.0	0.0	180.0	0.0	180.0			measured
28	Significant wave height (measured)	(m)	$H_{1/3}$	1.22	1.22	1.22	1.22	1.22	1.22			synthetic H
29	Significant wave height (used)	(m)	$H_{1/3}$	1.22	1.22	1.22	1.22	1.22	1.22			allowable
30	Delivered power	(kW)	P_{DM}	15047	14962	18226	18214	21261	21411			(6.2) or (6.3)
31	Ship speed through the water	(knots)	V_S	13.506	13.506	15.032	15.032	15.113	15.113			mean value of V_G
32	Current velocity	(knots)	V_C	0.418	-0.418	-0.325	0.325	-0.653	0.653			$V_C=V_G-V_S$

Resistance data												**Ref., Eq. No.**
33	Resistance increase due to wind	(kN)	R_{AA}	56.95	-24.55	59.23	-31.49	58.51	-32.78			(C.1)
34	Resistance increase due to waves	(kN)	R_{AW}	68.80	0.00	68.80	0.00	68.80	0.00			(D.1)
35	Resistance increase due to deviation of water temperature and density	(kN)	R_{AS}	0.00	0.00	0.00	0.00	0.00	0.00			(E.1)
36	Total resistance increase	(kN)	ΔR	125.79	-24.55	128.08	-31.49	127.36	-32.78			(6.1)

Direct power method (1)												**Ref., Eq. No.**
37	Propulsive efficiency coefficient in ideal condition		η_{D0}	0.694	0.673	0.717	0.696	0.685	0.665			Tank test
38	Load variation effect		ε_P	-0.207	-0.207	-0.207	-0.207	-0.207	-0.207			Appendix 6-J
39	Delivered power	(kW)	P_{Did}	13497.8	15267.1	16529.8	18634.3	19488.6	21872.6			(6.9)
40	Load variation effect		ε_n	0.248	0.248	0.248	0.248	0.248	0.248			Appendix 6-J
41	Load variation effect		ε_v	0.193	0.193	0.193	0.193	0.193	0.193			Appendix 6-J
42	Propeller shaft speed	(rpm)	N_{id}	64.23	66.57	68.52	71.01	72.35	74.78			(6.12)

Current correction: specified in Appendix 6-E.2												Ref., Eq. No.
43	Averaged ship speed	(knots)	V_{Gm}		13.506		15.032		15.113			mean value of V_G
44	Averaged brake power	(kW)	P_{Bm}		14830		18100		21325			mean of P_{Did}/η_T
45	Brake power on curve	(kW)	P’	13933	15727	16900	19210	20123	22527			V_G→(E.2)
46	Averaged brake power on curve	(kW)	P'_{Bm}		14830		18100		21325			mean value of P’
47	Ship speed corrected for current	(knots)	V'_S	13.459	13.988	14.335	14.905	15.127	15.678			(E.5)
48	Current velocity	(knots)	V'_C	0.465	0.899	0.372	-0.451	-0.667	-0.089			(E.4)
49	Current velocity on current curve	(knots)	V_C	0.465	0.899	0.372	-0.451	-0.667	-0.089			(E.1)

Direct power method (2): the procedure stipulated in the second paragraph from the last of paragraph 6.3.3												Ref., Eq. No.
50	Delivered power	(kW)	P_{Did}	13521	15266	16568	18630	19518	21869			(6.9)
51	Propeller shaft speed	(rpm)	N_{id}	64.24	66.59	68.61	71.01	82.35	74.80			(6.12)

Current correction (2): specified in Appendix 6-E.2												Ref., Eq. No.
52	Ship speed corrected for current	(knots)	V'_S	13.446	13.980	14.351	14.899	15.122	15.681			(E.5)
53	Current velocity	(knots)	V'_C	0.477	0.891	0.356	-0.458	-0.662	-0.086			(E.4)
54	Current velocity on current curve	(knots)	V_C	0.477	0.891	0.356	-0.458	-0.662	-0.086			(E.1)

Shallow water correction												Ref., Eq. No.
55	Minimum water depth	(m)	h_{MIN}	-	-	-	-	-	-			para. 3.3.5
56	Maximum water depth	(m)	h_{MAX}	-	-	-	-	-	-			para.3.3.5
57	Water depth (used)	(m)	h									para.3.3.5
58	Decrease of ship speed due to shallow water	(knots)	ΔV									Appendix 6-H
59	Ship speed through the water in deep water	(knots)	V_S									(H.1)→V_S

Displacement correction												Ref., Eq. No.
60	Delivered power	(kW)	P_{DC}	13491	15232	16532	18589	19474	21821			(G.1)

Final performance												Ref., Eq. No.
61	Propeller shaft speed	(rpm)	n_c	64.24	66.59	68.61	71.01	82.35	74.80			copied from 51
62	Ship speed through the water	(knots)	V_S	13.446	13.980	14.351	14.899	15.122	15.681			copied from 52
63	Brake power	(kW)	P_{BC}	13908	15703	17043	19163	20077	22495			P_{DC}/η_M

6.5 Trial report

6.5.1 In the trial report, an overview is to be given of the trial conditions and all corrections that have been applied as necessary to arrive at the EEDI condition and contract condition (if any).

6.5.2 The trial report is to contain all relevant information to carry out the data analysis. It is to be written in such a way that all results can be reproduced.

6.5.3 The trial report is to contain the following sub clauses:

(1) Trial report summary, including ship particulars, propeller details, engine data, details of hull appendages and rudder(s);

(2) EEDI conditions, including EEDI speed, power and displacement;

(3) Contract condition (if any), including contract speed, power and displacement;

(4) A description of the instrumentation, describing instrument set-up and calibration procedures, location of sensors (e.g. anemometer), etc.;

(5) Description of the trial site. This gives information on geography, water depth, etc.;

(6) Environmental parameters, listing the measured/observed environmental conditions at the site during the S/P trials such as wave height and period, wave direction, air pressure, wind direction, wind velocity, air temperature, water temperature, water density, etc.;

(7) Trial results of each speed run

① Date and time at start of speed run;

② Run number;

③ Ship’s positions;

④ Ship’s heading;

⑤ Run duration;

⑥ Mean value of measured ship speed;

⑦ Mean value and standard deviation of torque (per shaft);

⑧ Mean value and standard deviation of shaft rpm (per shaft);

⑨ Mean value and standard deviation of shaft power (per shaft);

⑩ Relative wind velocity and direction;

⑪ Significant wave height, mean period and direction;

⑫ Water depth;

(8) Analysis and correction methods. The analysis and correction of the measured trial data are to be conducted in compliance with this Chapter;

(9) Conclusions/recommendations.

Appendix 6-A General Information and Trial Log Sheet

Before the start of the sea trial, the trial login data are to be filled and submitted to the relevant parties for confirmation. Among them, the record sheet of primary ship parameters is shown in Table 6-A.1, and the record sheet of speed trial condition is shown in Table 6-A.2.

Record Sheet of Primary Ship Parameters **Table 6-A.1**

Speed trial log data			
Ship name IMO Nr. Ship type Shipbuilder			
Main scantling	Waterline length L_{WL} m Ship's length between perpendiculars L_{PP} m Moulded breadth B m Moulded depth D m	Main engine	Type No. Rated power kW Rated speed rpm Power for propulsion kW Reduction ratio
Design loading condition	Draught forward d_F m Draught aft d_A m Mean draught d_M m Volume of displacement ∇ m^3 Block coefficient C_B Prismatic coefficient C_P Midsection coefficient C_M Longitudinal position of buoyant center x_C Area of wetted surface of hull S m^2	Auxiliary engine	Type No. Rated power kW Rated speed rpm …… Type No. Rated power kW Rated speed rpm
Tonnag	Gross tonnage GT Deadweight DWT t	Propeller parameter	No. of propellers Type(FPP/CPP) Diameter D_P m Pitch diameter ratio P/D_P Number of blades Z Area ratio A_E/A_0 Rated speed rpm Material Direction of rotation (looking from aft) Number of blades
Hull condition	Last date of hull cleaning (mm/yyyy) Surface condition of hull Surface condition of propeller	Shaft(s)	G modulus N/mm (default = 82400 N/mm) Diameter(inside) mm Diameter (outside) mm Shaft efficiency η_S
Hull appendages	Area of wetted surface bilge keels m^2 Area of wetted surface rudder(s) m^2 Area of wetted surface other appendages m^2		

Record Sheet of Speed Trial Condition **Table 6-A.2**

Speed trail log data		
Date of trial		
Location of trial (longitude, latitude)		
Weather(visual observation)		
Environmental Condition	Vertical position of anemometer above waterline m	
	Water temperature ℃	
	Waer density kg/m^3	
	Air temperature ℃	
	Air density kg/m^3	
	Air pressure hPa, mbar	
Ship condition	Draught forward PS m	
	Draught forward SB m	
	Draught aft PS m	
	Draught aft SB m	
	Draught midship PS m	
	Draught midship SB m	
	Trim	
	Displacement ton	
	Cross sectional area including superstructures above waterline m^2	
	Lateral projected area including superstructures above waterline(Fujiwara) m^2	
	Lateral projected area of superstructures above upper deck(Fujiwara) m^2	

The sea trial starts, tests are to be conducted in accordance with the requirements of the sea trial programme, and data of the runs are to be recorded and submitted to the relevant parties for confirmation. The record sheet of the trial runs is shown in Table 6-A.3.

Data Sheet of Speed Trial Runs **Table 6-A.3**

Run Nr.		-	1	2	3	4	5	6	7	8	9	10	11	12
Power setting		%MCR												
Date		yyyy-mm-dd												
Start time of run		hh:mm												
Direction: Forward/Return		-												
Heading		°												
Run duration		mm:ss												
Measured ship's speed		knots												
Relative wind	Velocity	m/s												
	Direction	°												
Waves	Significant wave height	m												
	Direction	°												
	Period	s												
Swell	Significant wave height	m												
	Direction	°												
	Period	s												
Propeller PS	Power	kW												
	Shaft speed	rpm												
	Pitch of CPP	°												
Propeller SB	Power	kW												
	Shaft speed	rpm												
	Pitch of CPP	°												
Vert. G force at bow (if the correction method in D.2 is used)		m/s^2												
Water depth		m												

Appendix 6-B Beaufort Scale for Wind Velocity

This table is only intended as a guide to show roughly what may be expected in the open sea, remote from land. It shall never be used in the reverse way; i.e., for logging or reporting the state of the sea. In enclosed waters, or when near land, with an off-shore wind, wave heights will be smaller and the waves steeper. Figures in brackets indicate the probable maximum height of waves.

Wind Scale **Table 6-B.1**

Beaufort nunber	Decriptive term	Velocity equivalent at a standard height of 10 metres above open flat ground				Specifications			Probable wave height	
		Mean velocity kn	m/s	km/h	m.p.h	Land	Sea	Coast	m	ft
0	Calm	<1	0-0.2	<1	<1	Calm; smoke rises vertically	Sea like a mirror	Calm	-	-
1	Light air	1-3	0.3-1.5	1-5	1-3	Direction of wind shown by smoke drift but not by wind vanes	Ripples with the appearance of scales are formed, but without foam crests	Fishing smack just has steerage way	0.1 (0.1)	¼ (¼)
2	Light breeze	4-6	1.6-3.3	6-11	4-7	Wind felt on face; leaves rustle; ordinary vanes moved by wind	Small wavelets, still short but more pronounced; crests have a glassy appearance and do not break	of smacks which then travel at about 1~2 knots	0.2 (0.3)	½ (1)
3	Gentle breeze	7-10	3.4-5.4	12-19	8-12	Leaves and small twigs in constant motion; wind ex- tends light flag	Large wavelets; crests begin to break; foam of glassy appearance; perhaps scattered white horses	Smacks begin to careen and travel about 3~4 knots	0.6 (1)	2 (3)
4	Moderate breeze	11-16	5.5-7.9	20-28	13-18	Raises dust and loose paper; small branches are moved	Small waves, becoming longer; fairly frequent white horses	Good working breeze, smacks carry all canvas with good list	1 (1.5)	3½ (5)
5	Fresh breeze	17-21	8.0-10.7	29-38	19-24	Small trees in leaf begin to sway; crested wavelets form on inland waters	Moderate waves, taking a more pronounced long form; many white horses are formed (chance of some spray)	Smacks shorten sail	2 (2.5)	6 (8½)
6	Strong breeze	22-27	10.8-13.8	39-49	25-31	Large branches in motion; whistling heard in telegraph wires; umbrellas used with difficulty	Large waves begin to form; the white foam crests are more extensive everywhere (probably some spray)	Smacks have double reef in mainsail; care required when fishing	3 (4)	9½ (13)
7	Near gale	28-33	13.9-17.1	50-61	32-38	Whole trees in motion; inconvenience felt when walking against wind	Sea heaps up and white foam from breaking waves begins to be blown in streaks along the direction of the wind	Smacks remain in harbour and those at sea lie to	4 (5.5)	13½ (19)

Beaufort nunber	Decriptive term	Velocity equivalent at a standard height of 10 metres above open flat ground				Specifications			Probable wave height	
		Mean velocity kn	m/s	km/h	m.p.h	Land	Sea	Coast	m	ft
8	Gale	34-40	17.2-20.7	62-74	39-46	Breaks twigs off trees; generally impedes progress	Moderately high waves of greater length; edges of crests begin to break into the spindrift; the foam is blown in well-marked streaks along the direction of the wind	All smacks make for harbour, if near	5.5 (7.5)	18 (25)
9	Strong gale	41-47	20.8-24.4	75-88	47-54	Slight structural damage occurs (chimney pots and slates removed)	High waves; dense streaks of foam along the direction of the wind; crests of waves begin to topple, tumble and roll over; spray may affect visibility	-	7 (10)	23 (32)
10	Storm	48-55	24.5-28.4	89-102	55-63	Seldom experienced inland; trees uprooted; considerable structural damage occurs	Very high waves with long over- hanging crests; the resulting foam, in great patches, is blown in dense white streaks along the direction of the wind; on the whole, the surface of the sea takes on a white appearance; the tumbling of the sea becomes heavy and shock- like; visibility affected	-	9 (12.5)	29 (41)
11	Violent storm	55-63	28.5-32.6	103-117	64-72	Very rarely experienced; accompanied by wide- spread damage	Exceptionally high waves (small and medium-sized ships might be for a time lost to view behind the waves); the sea is completely covered with long white patches of foam lying along the direction of the wind; everywhere the edges of the wave crests are blown into froth; visibility affected	-	11.5 (16)	37 (52)
12	Hurricane	64 and over	32.7and over	118 and over	73 and over	-	The air is filled with foam and spray; sea completely white with driving spray; visibility very seriously affected	-	14 (-)	45 (-)

State of the Sea **Table 6-B.2**

Code	Descriptive terms	Wave height m
0	Calm (glassy)	0
1	Calm(rippled)	0~0.1
2	Smooth(wavelets)	0.1~0.5
3	Slight	0.5~1.25
4	Moderate	1.25~2.5
5	Rough	2.5~4
6	Very rough	4~6
7	High	6~9
8	Very high	9~14
9	Phenomenal	Over 14

Note: The bound of the wave height shall be assigned for the lower code figure; e.g. a height of 4 m is coded as 5.

Appendix 6-C Resistance Increase due to Wind

The resistance increase due to wind is calculated by:

$$R_{AA} = 0.5\rho_A \cdot C_{AA}\left(\psi_{WRref}\right) \cdot A_{XV} \cdot V_{WRref}^2 - 0.5\rho_A \cdot C_{AA}\left(0\right) \cdot A_{XV} \cdot V_G^2 \qquad (C.1)$$

where: R_{AA}—— the resistance increase due to relative wind, in N;
A_{XV}—— the transverse projected area above the waterline including superstructures, in m^2;
C_{AA}—— the wind resistance coefficient;
$C_{AA}(0)$——the wind resistance coefficient in head wind,i.e. when the relative wind direction is 0°;
V_G—— the measured ship's speed over ground, in m/s;
V_{WRref}—— the relative wind velocity at the reference height, in m/s;
ψ_{WRref}—— the relative wind direction at the reference height, in °;
ρ_A—— the mass density of air, in kg/m^3.

The evaluation of wind data is explained in detail in C.1 of this Appendix.

The wind resistance coefficient is based on the data derived from model tests in a wind tunnel. In cases where a database is available covering ships of similar type, such data may be used instead of carrying out wind tunnel model tests. Alternatively, statistical regression formulae concerning wind resistance coefficients of various ship types have been developed. The recommended methods are described in C.2 of this Appendix.

C.1 Evaluation of wind data

By nature wind velocity and direction vary in time and therefore they are defined by their mean value over a selected period.

For S/P trials it is assumed that the wind condition is steady i.e. that velocity and direction are reasonably constant over the duration of each run. The mean values of direction and velocity recorded during every run are then used as the 'actual' values for that run.

C.1.1 Averaging process for the true wind velocity and direction

Usually, the relative wind velocity and direction are measured by the on-board anemometer, which is generally located on the radar mast on top of the bridge. Both wind velocity and direction at this location may be affected by the geometry of the ship, in particular the shape of the superstructure.

The true wind vector for each speed run is found from the ship's heading and speed over the ground and the measured relative wind velocity and direction. By averaging the true wind vectors over both speed runs of the Double Run, the true wind vector for the run-set is found. This run-set averaged true wind vector shall be used to recalculate the relative wind vector for each speed run of the set.

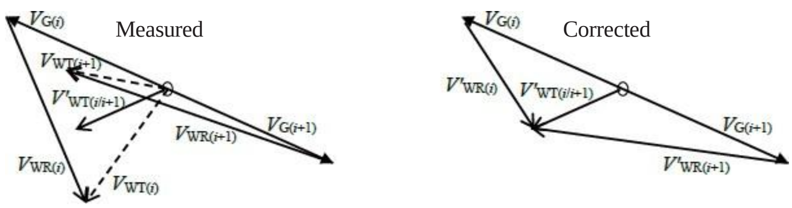


Figure C.1.1 True wind vectors and relative wind vectors

The true wind velocity and direction at the vertical position of the anemometer are calculated by:

$$V_{WT} = \sqrt{V_{WR}^2 + V_G^2 - 2V_{WR}V_G \cos\psi_{WR}} \tag{C.2}$$

$$\psi_{WT} = \tan^{-1}\left\{\frac{V_{WR}\sin(\psi_{WR}+\psi) - V_G\sin(\psi)}{V_{WR}\cos(\psi_{WR}+\psi) - V_G\cos(\psi)}\right\} \quad \text{for } V_{WR}\cos(\psi_{WR}+\psi) - V_G\cos(\psi) \geq 0$$

$$\psi_{WT} = \tan^{-1}\left\{\frac{V_{WR}\sin(\psi_{WR}+\psi) - V_G\sin(\psi)}{V_{WR}\cos(\psi_{WR}+\psi) - V_G\cos(\psi)}\right\} + 180 \quad \text{for } V_{WR}\cos(\psi_{WR}+\psi) - V_G\cos(\psi) < 0 \tag{C.3}$$

where: V_G—— the measured ship's speed over ground, in m/s;
V_{WR}—— the mean value of the measured relative wind velocity at the vertical position of the anemometer, in m/s;
V_{WT}—— the true wind velocity at the vertical position of the anemometer, in m/s;
ψ —— the ship's heading, in°;
ψ_{WR}—— the mean value of the measured relative wind direction at the vertical position of the anemometer, in °;
ψ_{WT}—— the mean value of the measured relative wind direction at the vertical position of the anemometer, in°.

The true wind velocity and direction are corrected by an averaging process over both runs of the Double Run.

$$V'_{WT(i/i+1)} = \sqrt{\left(\frac{V_{WT(i)}\cos\psi_{WT(i)} + V_{WT(i+1)}\cos\psi_{WT(i+1)}}{2}\right)^2 + \left(\frac{V_{WT(i)}\sin\psi_{WT(i)} + V_{WT(i+1)}\sin\psi_{WT(i+1)}}{2}\right)^2} \tag{C.4}$$

$$\psi'_{WT(i/i+1)} = \tan^{-1}\left\{\frac{V_{WT(i)}\sin\psi_{WT(i)} + V_{WT(i+1)}\sin\psi_{WT(i+1)}}{V_{WT(i)}\cos\psi_{WT(i)} + V_{WT(i+1)}\cos\psi_{WT(i+1)}}\right\} \quad \text{for } V_{WT(i)}\cos\psi_{WT(i)} + V_{WT(i+1)}\cos\psi_{WT(i+1)} \geq 0$$

$$\psi'_{WT(i/i+1)} = \tan^{-1}\left\{\frac{V_{WT(i)}\sin\psi_{WT(i)} + V_{WT(i+1)}\sin\psi_{WT(i+1)}}{V_{WT(i)}\cos\psi_{WT(i)} + V_{WT(i+1)}\cos\psi_{WT(i+1)}}\right\} + 180 \quad \text{for } V_{WT(i)}\cos\psi_{WT(i)} + V_{WT(i+1)}\cos\psi_{WT(i+1)} < 0 \tag{C.5}$$

$$V'_{WR(i)} = \sqrt{V'^2_{WT(i)} + V^2_{G(i)} + 2V'_{WT(i)}V_{G(i)}\cos\left(\psi'_{WT(i)} - \psi_{(i)}\right)} \tag{C.6}$$

$$\psi'_{WR(i)} = \tan^{-1}\left\{\frac{V'_{WT(i)}\sin\left(\psi'_{WT(i)}-\psi_{(i)}\right)}{V_{G(i)}+V'_{WT(i)}\cos\left(\psi'_{WT(i)}-\psi_{(i)}\right)}\right\} \quad \text{for } V_{G(i)}+V'_{WT(i)}\cos\left(\psi'_{WT(i)}-\psi_{(i)}\right)\geq 0$$

$$\psi'_{WR(i)} = \tan^{-1}\left\{\frac{V'_{WT(i)}\sin\left(\psi'_{WT(i)}-\psi_{(i)}\right)}{V_{G(i)}+V'_{WT(i)}\cos\left(\psi'_{WT(i)}-\psi_{(i)}\right)}\right\}+180 \quad \text{for } V_{G(i)}+V'_{WT(i)}\cos\left(\psi'_{WT(i)}-\psi_{(i)}\right)< 0 \qquad \text{(C.7)}$$

where: V_G—— the measured ship's speed over ground, in m/s;
V_{WT}—— the true wind velocity at the vertical position of the anemometer, in m/s;
V'_{WT}—— the averaged true wind velocity at the vertical position of the anemometer, in m/s;
V'_{WR}—— the corrected relative wind velocity at the vertical position of the anemometer, in m/s;
ψ —— the ship's heading, in°;
ψ_{WT}—— the true wind direction at the vertical position of the anemometer, in°;
ψ'_{WT}—— the averaged true wind direction at the vertical position of the anemometer, in °;
ψ'_{WR}—— the corrected relative wind direction at the vertical position of the anemometer, in °;
i —— the run number.

And then true wind velocity $V_{WT(i)}$, true wind direction $\psi_{WT(i)}$, relative wind velocity $V_{WR(i)}$ and relative wind direction $\psi_{WR(i)}$ are replaced by $V'_{WT(i)}$, $\psi'_{WT(i)}$, $V'_{WR(i)}$ and $\psi'_{WR(i)}$.

The true wind velocity and directions are to be checked by taking the following into consideration:

(1) The consistency of the curves of true wind velocity and direction with time during each run.

(2) The consistency of the curves of air temperature and atmospheric pressure with time during each run.

(3) Publicly available weather information.

C.1.2 Consistency of the curves of true

The wind effect on the ship consists of two components: shear flow and uniform flow. Shear flow is the natural wind. Uniform flow is the relative speed between still air and the ship's own motion.

To calculate the wind resistance, the wind velocity and direction at the reference height of the wind tunnel tests on which the wind resistance coefficients are based, shall be used. Therefore the wind velocity and direction at the vertical position of the anemometer shall be corrected to those at the reference height.

The difference between the vertical position of the anemometer and the reference height for the wind resistance is to be corrected by means of the wind velocity profile given by:

$$V_{WTref} = V_{WT}\left(\frac{Z_{ref}}{Z_a}\right)^{\frac{1}{7}} \qquad \text{(C.8)}$$

where: V_{WTref}—— the true wind velocity at the reference height, in m/s;
V_{WT}—— the true wind velocity at the vertical position of the anemometer, in m/s;
Z_{ref}—— the reference height for the wind resistance coefficients, in m;
Z_a—— the vertical position of the anemometer, in m.

The reference height for the wind resistance coefficients Z_{ref} is selected as the corresponding height for the wind resistance coefficient from wind tunnel tests.

The relative wind velocity at the reference height is calculated by:

$$V_{WRref} = \sqrt{V_{WTref}^2 + V_G^2 - 2V_{WTref}V_G \cos(\psi_{WT} - \psi)} \quad \text{(C.9)}$$

The relative wind direction at the reference height is calculated by:

$$\begin{aligned} \psi_{WRref} &= \tan^{-1}\left\{\frac{V_{WTref}\sin(\psi_{WT} - \psi)}{V_G + V_{WTref}\cos(\psi_{WT} - \psi)}\right\} \quad \text{for } V_G + V_{WTref}\cos(\psi_{WT} - \psi) \geq 0 \\ \psi_{WRref} &= \tan^{-1}\left\{\frac{V_{WTref}\sin(\psi_{WT} - \psi)}{V_G + V_{WTref}\cos(\psi_{WT} - \psi)}\right\} + 180 \quad \text{for } V_G + V_{WTref}\cos(\psi_{WT} - \psi) < 0 \end{aligned} \quad \text{(C10)}$$

Where: V_G—— the measured ship's speed over ground, in m/s;
V_{WRref}—— the relative wind velocity at the reference height, in m/s;
V_{WTref}—— the true wind velocity at the reference height, in m/s;
ψ —— the ship's heading, in°;
ψ_{WRref}—— the relative wind direction at the reference height, in°;
ψ_{WT}—— the true wind direction at the vertical position of the anemometer, in°.

C.2 Wind resistance coefficients

The wind resistance coefficients determined by the following methods are to be used.

C.2.1 Wind tunnel test

If wind tunnel test results are available, the wind resistance coefficient evaluated by these tests is to be used.

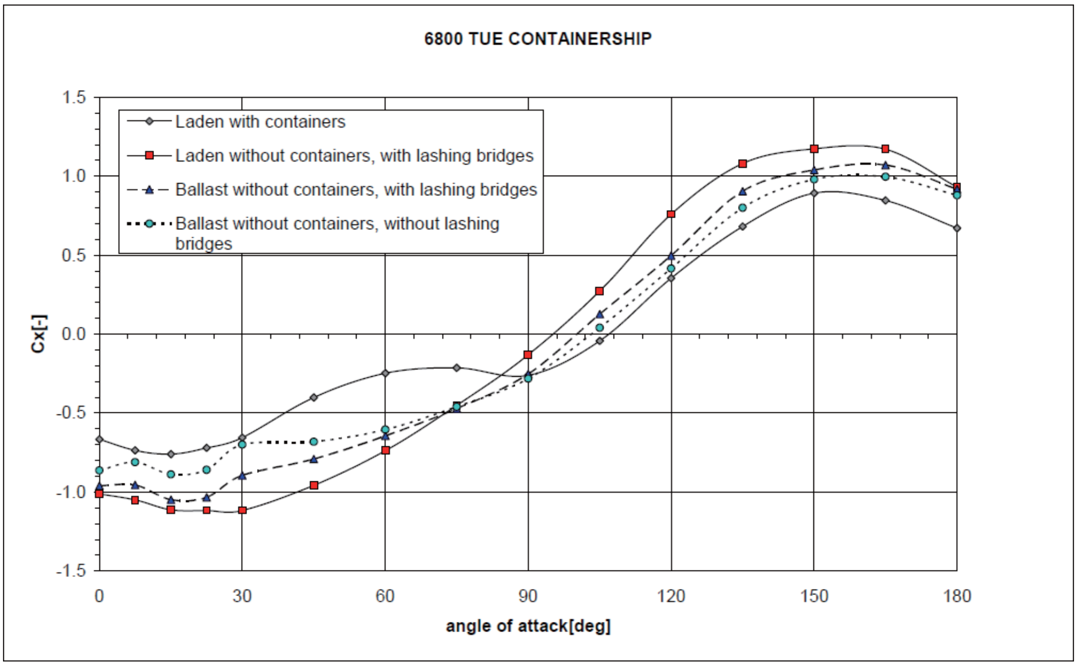
C.2.2 Data set on the wind resistance coefficient

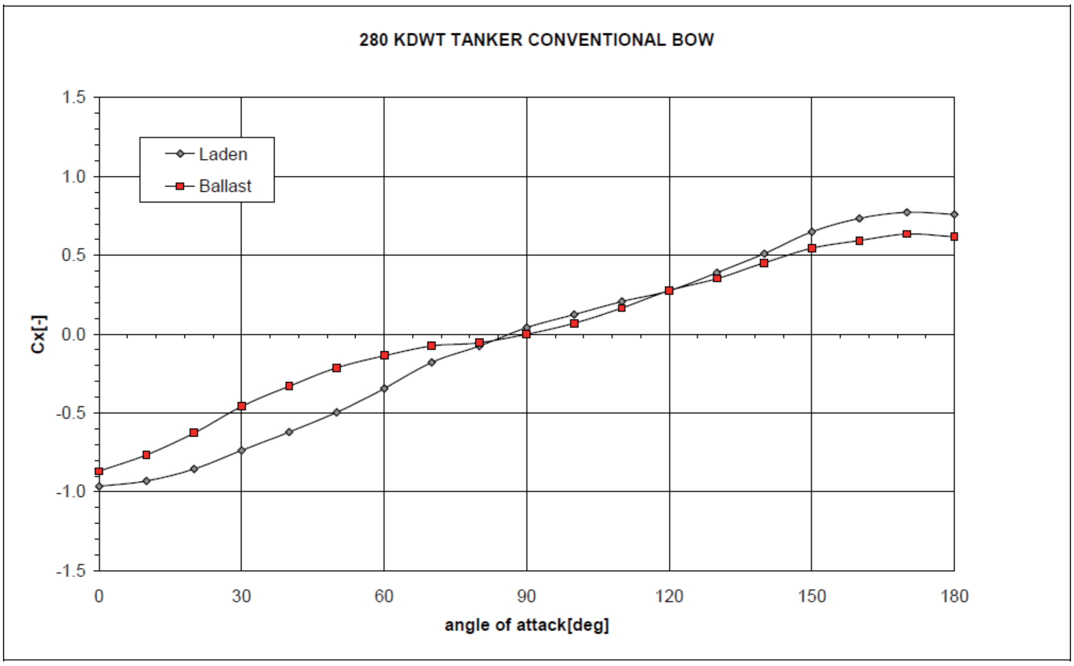
A data set of wind resistance coefficients has been prepared by STA-JIP. Data is available for; Tankers, LNG carriers, container ships, car carriers, ferry/cruise ships, general cargo ships and bulk carriers as shown in Table C.2.2. The wind resistance coefficients, where $C_{AA} = -C_X$, for each ship type, are shown in Figure C.2.2(1).

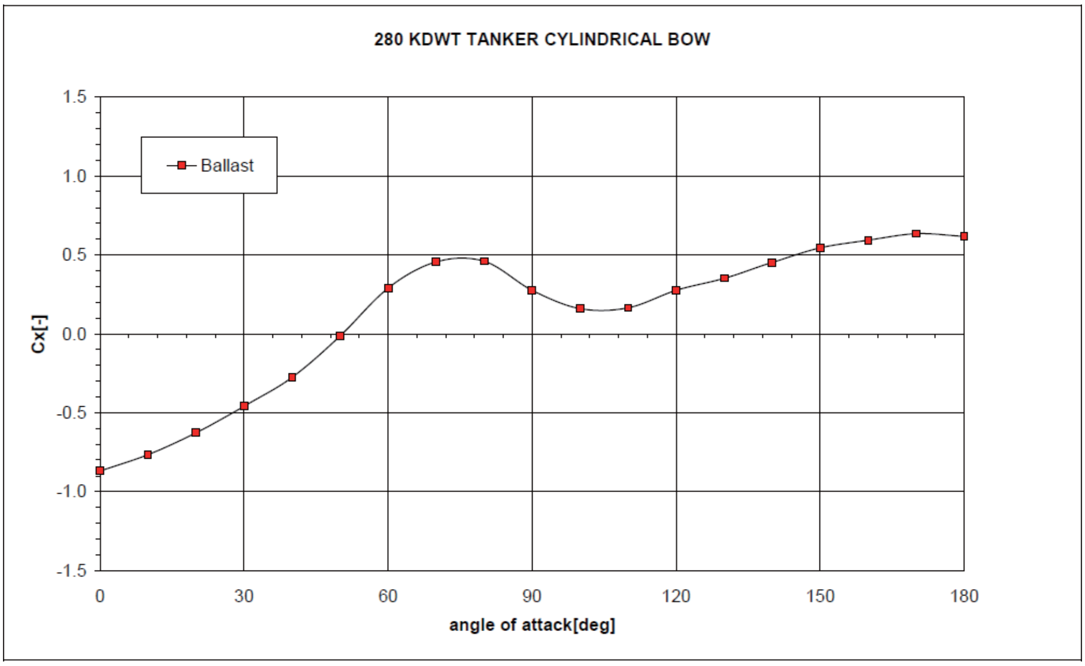
Before making use of these coefficients, the ship type, shape and outfitting are to be carefully evaluated and compared with the geometry of the ship for which the data set has been prepared, as illustrated at Figure C.2.2(2). The data provided is limited to the present-day common ship types. The database is not suitable for special ships such as; tugs, offshore supply vessels, fishery vessels and fast craft, all of which have very individual geometries.

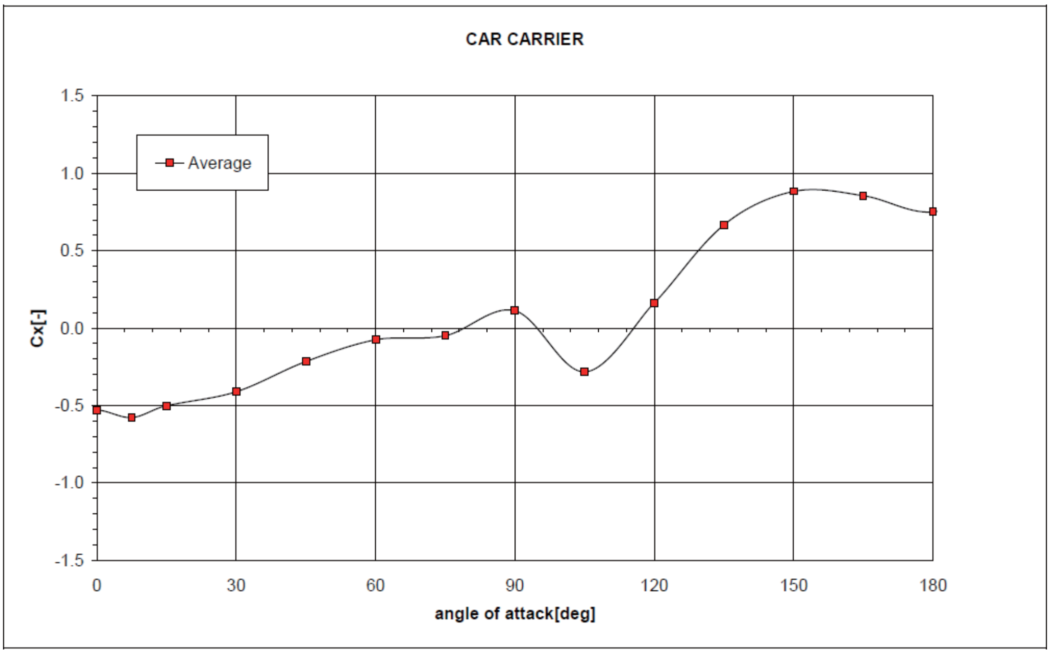
Ship types included in the data set **Table 6-C.2.2**

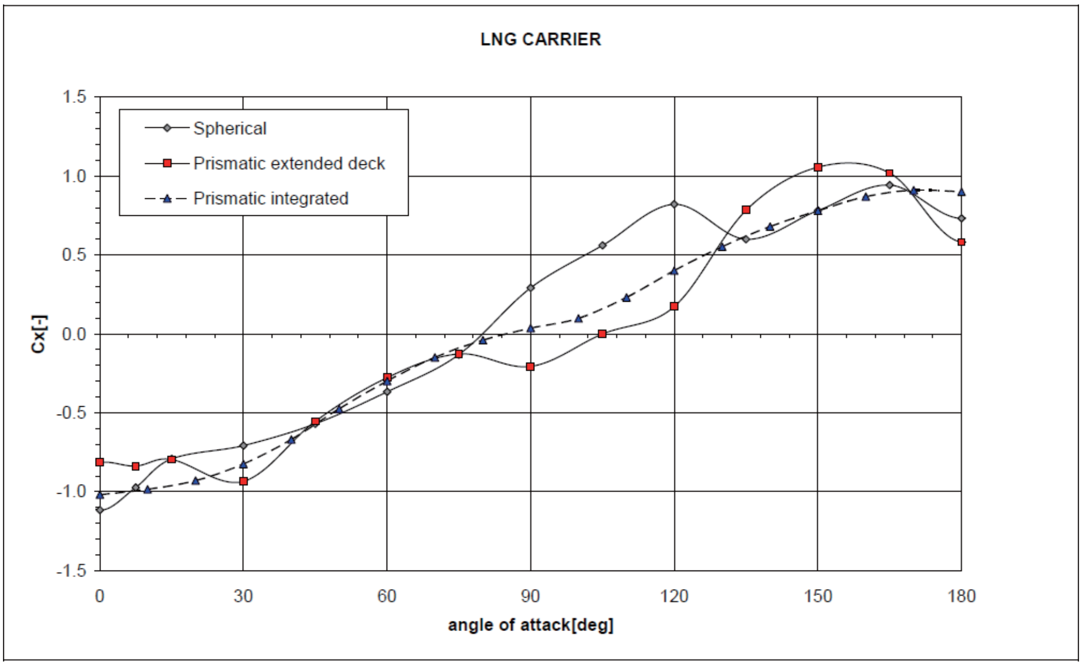
Ship type	Loading condition	Superstructure	Test ship
tanker conventional bow	laden	normal	280kDWT
tanker conventional bow	ballast	normal	280kDWT
tanker cylindrical bow	ballast	normal	280kDWT
LNG carrier	average	prismatic integrated	125k-m^3
LNG carrier	average	prismatic extended deck	138k-m^3
LNG carrier	average	spherical	125k-m^3
container ship	laden	with containers	6800TEU
container ship	laden	without containers, with lashing bridges	6800TEU
container ship	ballast	with lashing bridges	6800TEU
container ship	ballast	without lashing bridges	6800 TEU
car carrier	average	normal	Autosky
ferry/cruise ship	average	normal	
general cargo ship	average	normal	
bulk carrier	ballast	normal	350 m bulk carrier
bulk carrier	laden	normal	350 m bulk carrier

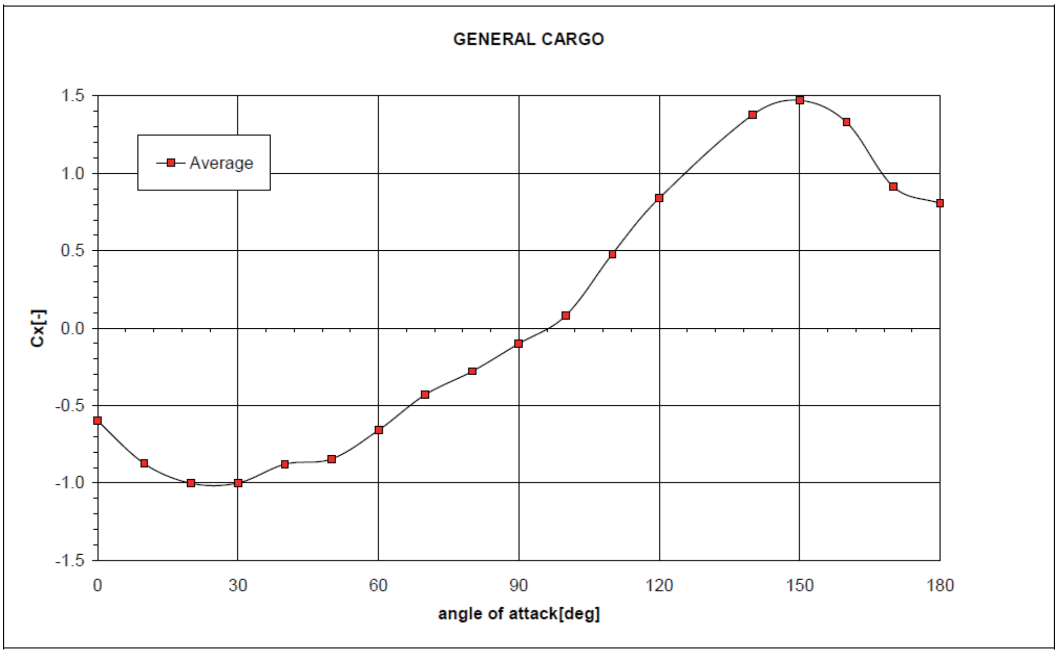

6800 TUE CONTAINERSHIP
Laden with containers
Laden without containers, with lashing bridges
Ballast without containers, with lashing bridges
Ballast without containers, without lashing bridges
Cx[-]
1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5
0
30
60
90
120
150
180
angle of attack[deg]

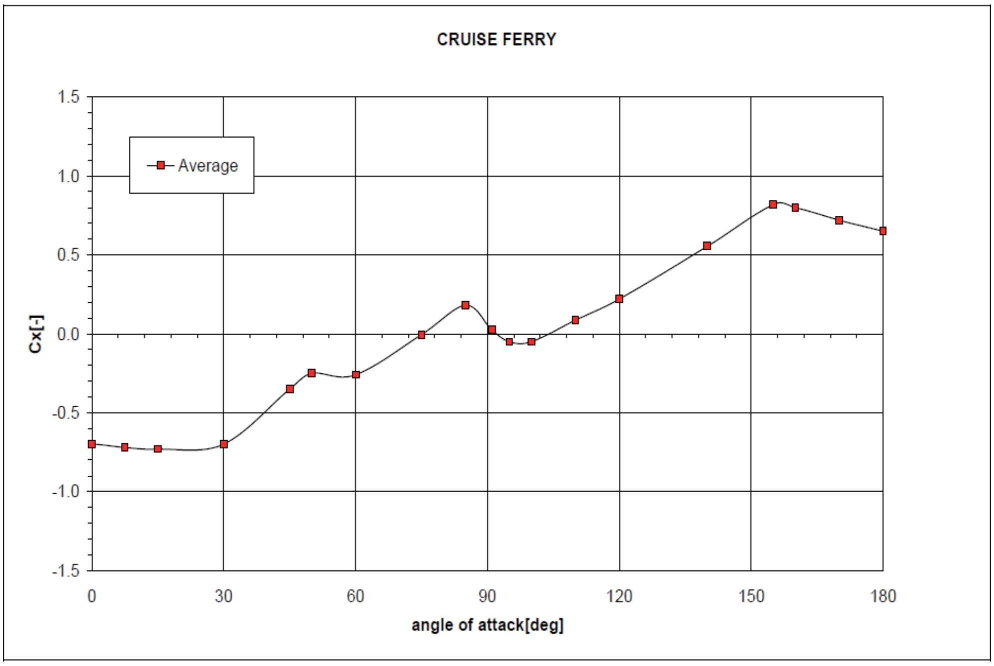

280 KDWT TANKER CONVENTIONAL BOW
Laden
Ballast
Cx[-]
1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5
0
30
60
90
120
150
180
angle of attack[deg]

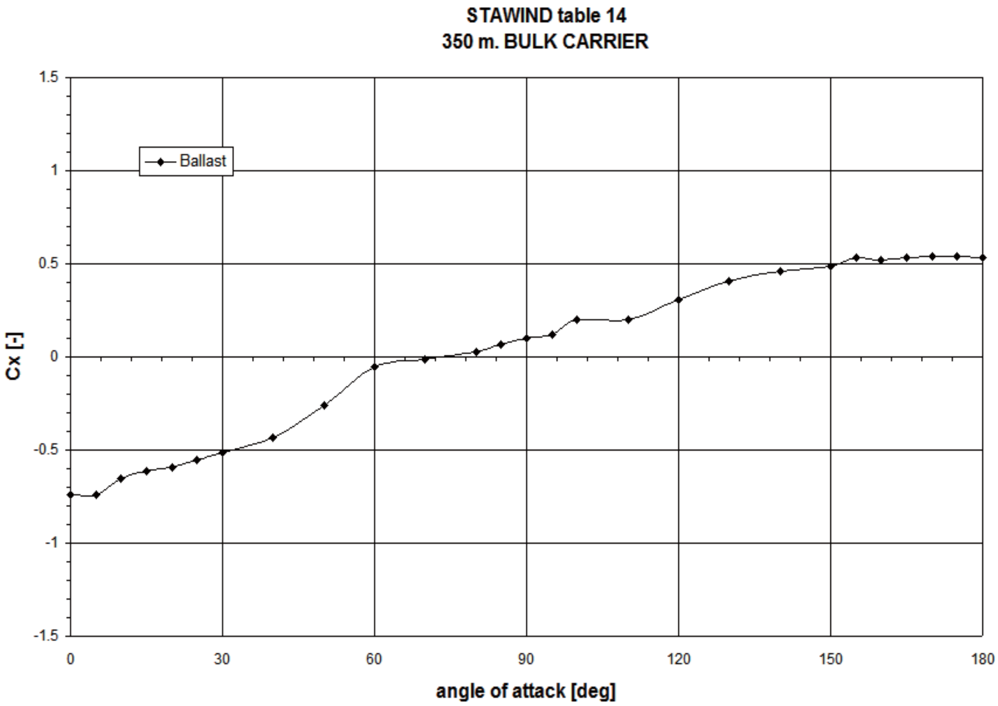

280 KDWT TANKER CYLINDRICAL BOW
Ballast
Cx[-]
1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5
0
30
60
90
120
150
180
angle of attack[deg]


CAR CARRIER
Average
Cx[-]
1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5
0
30
60
90
120
150
180
angle of attack[deg]


LNG CARRIER
Spherical
Prismatic extended deck
Prismatic integrated
Cx[-]
1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5
0
30
60
90
120
150
180
angle of attack[deg]


GENERAL CARGO
Average
Cx[-]
1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5
0
30
60
90
120
150
180
angle of attack[deg]


CRUISE FERRY
Average
Cx[-]
angle of attack[deg]
1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5
0
30
60
90
120
150
180


STAWIND table 14
350 m. BULK CARRIER
Ballast
Cx [-]
angle of attack [deg]
1.5
1
0.5
0
-0.5
-1
-1.5
0
30
60
90
120
150
180

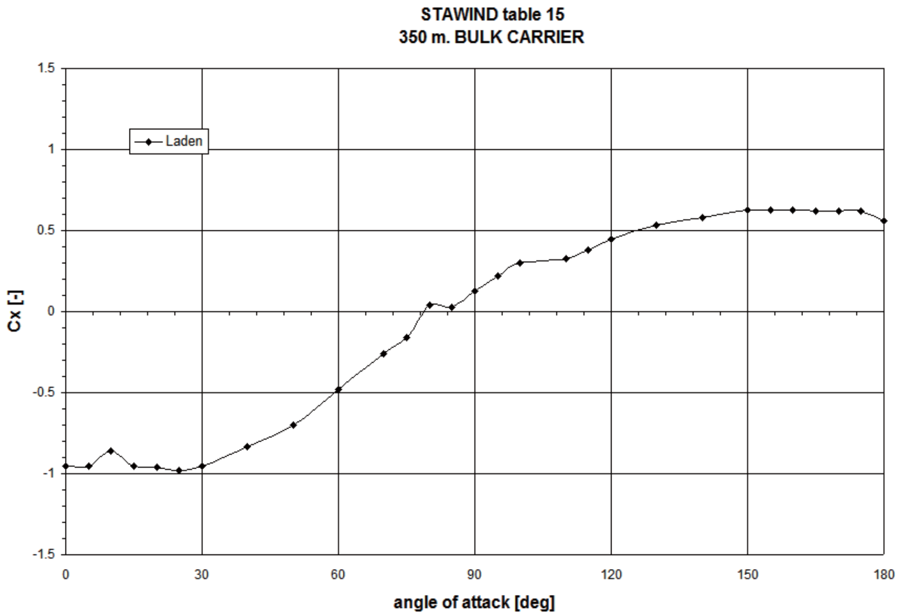
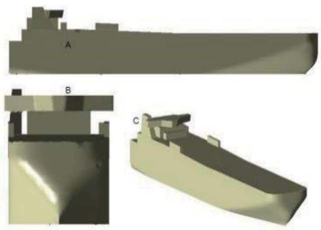
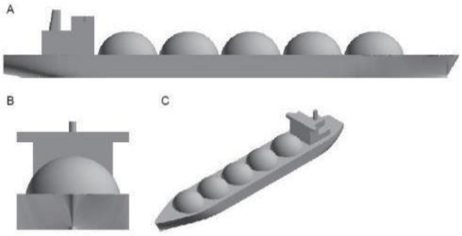


Figure C.2.2(1) Wind resistance coefficients for representative ship types

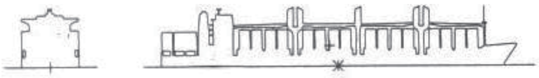
	
a) **Container ship, Laden with containers**	b) **Container ship, Ballast without containers**
	
c) **280k DWT Tanker conventional bow, Laden**	d) **280k DWT Tanker conventional bow, Ballast**
	
e) **280k DWT Tanker cylindrical bow, Ballast**	f) **Car carrier**

g) **LNG carrier prismatic extended deck**

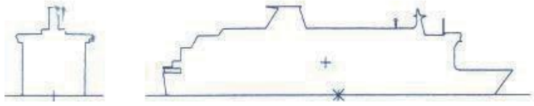
h) **LNG carrier prismatic integrated deck**



i) **LNG carrier spherical**



j) **General cargo ship**



k) **Cruise ferry**

Figure C.2.2(2) Ship profiles

C.2.3 Regression formula by Fujiwara et al.

Regression formula based on wind tunnel tests developed by Fujiwara et al.:

$$C_{AA}(\psi_{WR}) = C_{LF}\cos\psi_{WR} + C_{XLI}\left(\sin\psi_{WR} - \frac{1}{2}\sin\psi_{WR}\cos^2\psi_{WR}\right)\sin\psi_{WR}\cos\psi_{WR} + C_{ALF}\sin\psi_{WR}\cos^3\psi_{WR} \quad \text{(C.11)}$$

with: for $0 \le \psi_{WR} < 90^{\circ}$,

$$C_{LF} = \beta_{10} + \beta_{11}\frac{A_{LV}}{L_{OA}B} + \beta_{12}\frac{C_{MC}}{L_{OA}} \quad \text{(C.12)}$$

$$C_{XLI} = \delta_{10} + \delta_{11}\frac{A_{LV}}{L_{OA}H_{BR}} + \delta_{12}\frac{A_{XV}}{BH_{BR}} \quad \text{(C.13)}$$

$$C_{ALF} = \varepsilon_{10} + \varepsilon_{11}\frac{A_{OD}}{A_{LV}} + \varepsilon_{12}\frac{B}{L_{OA}} \quad \text{(C.14)}$$

for $90 < \psi_{WR} \le 180^{\circ}$,

$$C_{LF} = \beta_{20} + \beta_{21}\frac{B}{L_{OA}} + \beta_{22}\frac{H_C}{L_{OA}} + \beta_{23}\frac{A_{OD}}{L_{OA}^{\ 2}} + \beta_{24}\frac{A_{XV}}{B^2} \quad \text{(C.15)}$$

$$C_{XLI} = \delta_{20} + \delta_{21}\frac{A_{LV}}{L_{OA}H_{BR}} + \delta_{22}\frac{A_{XV}}{A_{LV}} + \delta_{23}\frac{B}{L_{OA}} + \delta_{24}\frac{A_{XV}}{BH_{BR}} \qquad (C.16)$$

$$C_{ALF} = \varepsilon_{20} + \varepsilon_{21}\frac{A_{OD}}{A_{LV}} \qquad (C.17)$$

for $\psi_{WR} = 90^{\circ}$

$$C_{AA}(90) = \frac{1}{2}\{C_{AA}(90-\mu) + C_{AA}(90+\mu)\} \qquad (C.18)$$

where: $C_{AA(\psi_{WR})}$——the wind resistance coefficient;

ψ_{WR}——the relative wind direction, in°;

L_{OA}——the ship's length overall, in m;

B ——the ship's breadth, in m;

A_{OD}——the lateral projected area of superstructures above upper deck, in m^2;

A_{XV}——the transverse projected area above the waterline including superstructures, in m^2;

A_{LV}——the lateral projected area above the waterline including superstructures, in m^2;

C_{MC}——the horizontal distance from midship section to centre of lateral projected area A_{LV}, where + means forward from midship, in m;

H_{BR}——the height of top of superstructure (bridge etc.), in m;

H_C——the height from waterline to centre of lateral projected area A_{LV}, in m;

μ ——the smoothing range, in °, normally 10°.

The non-dimensional parameters β_{ij}, δ_{ij} and ε_{ij} used in the formulae are shown in Table 6-C.2.3(1).

Non-dimensional parameters β_{ij}, δ_{ij} and ε_{ij} Table 6-C.2.3(1)

	i	*j*				
		0	1	2	3	4
β_{ij}	1	0.922	-0.507	-1.162	-	-
	2	-0.018	5.091	-10.367	3.011	0.341
δ_{ij}	1	-0.458	-3.245	2.313	-	-
	2	1.901	-12.727	-24.407	40.310	5.481
ε_{ij}	1	0.585	0.906	-3.239	-	-
	2	0.314	1.117	-	-	-

The coordinate system and sign conventions are shown in Figure C.2.3(2).

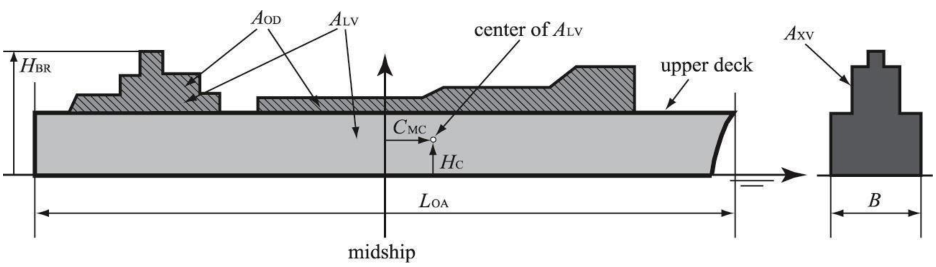


Figure C.2.3(2) Input parameters for regression formula by Fujiwara et al.

Appendix 6-D Resistance Increase due to Waves

Irregular waves are represented as linear superposition of the components of regular waves. Therefore the mean resistance increase in short crested irregular waves R_{AW} is calculated by linear superposition of the directional wave spectrum E and the response function of the mean resistance increase in regular waves R_{wave}.

$$R_{AW} = 2\int_0^{2\pi}\int_0^{\infty}\frac{R_{wave}(\omega,\alpha,V_S)}{\zeta_A^2}E(\omega,\alpha)d_{\omega}d_{\alpha} \qquad \text{(D.1)}$$

Where: R_{AW}—— the mean resistance increase in short crested irregular waves, in N;
R_{wave}—— the mean resistance increase in regular waves, in N;
ζ_A—— the wave amplitude, in m;
ω —— the circular frequency of regular waves, in rad/s;
α —— the angle between ship's heading and component waves in rad; 0 means head waves;
V_S—— the ship's speed through the water, in m/s;
E —— the directional spectrum, in m^2s.

If the directional spectrum is measured at sea trials by a sensor and the accuracy is confirmed, the measured directional spectrum is to be available. If the directional spectrum is not measured, it is to be calculated by the following relationship:

$$E = S_{\eta}(\omega)G(\alpha) \qquad \text{(D.2)}$$

where: S_{η}—— the frequency spectrum, in m^2s, as described in formula (D.3);
G —— the angular distribution function.

The standard form of the frequency spectrum and the angular distribution function are assumed for the calculation. For wind waves the modified Pierson-Moskowitz type frequency spectrum of ITTC 1978, shown in formula (D.3), is to be applied.

$$S_{\eta}(\omega) = \frac{A_{fw}}{\omega^5}\exp\left(-\frac{B_{fw}}{\omega^4}\right) \qquad \text{(D.3)}$$

$$A_{fw} = 173\frac{H_{1/3}^2}{T_{01}^4} \qquad \text{(D.4)}$$

$$B_{fw} = \frac{691}{T_{01}^4} \qquad \text{(D.5)}$$

For the narrow band wave spectrum (e.g. North Sea), the JONSWAP frequency spectrum shown in formula (D.6) is generally applied.

$$S_{\eta}(\omega) = \frac{A_{fs}}{\omega^5}\exp\left(-\frac{B_{fs}}{\omega^4}\right)3.3^{\exp\left\{-0.5\left(1.3T_{01}\frac{\omega}{2\pi}-1\right)^2/\sigma_f^2\right\}} \qquad \text{(D.6)}$$

$$A_{fs} = (2\pi)^4 \frac{0.072 H_{1/3}^2}{T_{01}^4} \quad \text{(D.7)}$$

$$B_{fs} = (2\pi)^4 \frac{0.44}{T_{01}^4} \quad \text{(D.8)}$$

$$\begin{aligned} \sigma_f &= 0.07 \quad \text{for} \quad \omega \le \frac{2\pi}{1.3T_{01}} \\ \sigma_f &= 0.09 \quad \text{for} \quad \omega > \frac{2\pi}{1.3T_{01}} \end{aligned} \quad \text{(D.9)}$$

where: $T_{01} = 2\pi \frac{m_0}{m_1}$ (D.10)

$H_{1/3}$ —— the significant wave height, in m;
ω —— the circular frequency of regular waves, in rad/s;
m_n—— the n^{th} moment of frequency spectrum.

For the angular distribution function the cosine-power type shown in formula (D.11) is generally applied; e.g. s = 1 (for wind waves) and s = 75 (for swells) are used in practice.

$$G(\alpha) = \frac{2^{2s}}{\pi} \frac{\Gamma^2(s+1)}{\Gamma(2s+1)} \cos^{2s}(\alpha - \theta_m) \quad -\frac{\pi}{2} \le \alpha - \theta_m \le \frac{\pi}{2} \quad \text{(D.11)}$$

where: s —— the directional spreading parameter;
Γ——the Gamma function;
α——the angle between ship's heading and component waves, in rad, 0 means head waves;
θ_m——the primary wave direction, in rad, 0 means head waves.

For wind waves and swells R_{AW} is calculated for each with different wave height, period and direction.

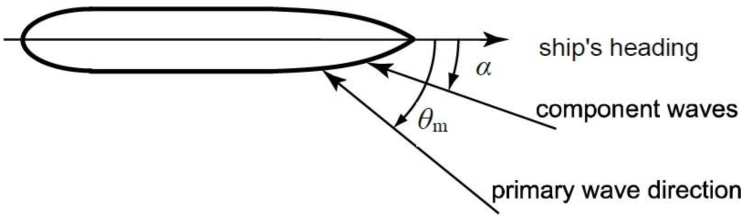


Figure D.0 Ship's heading and wave direction

In calculating resistance increase due to waves, one of following methods is to be used:

In the event that the pitch and heave during a run have been small the "simplified estimation method", prescribed in D.1, maybe used.

Otherwise, an "empirical estimation method" for the frequency response function, prescribed in D.2, may be used for correction. This empirical transfer function covers both the mean resistance increase due to wave reflection and the motion induced resistance.

If the C_P (longitudinal prismatic coefficient) and C_{WP} (water plane area coefficient) curves are available, then the "theoretical method with simplified tank tests in short waves", as prescribed in D.3, may be used.

The most reliable way to determine the decrease of ship's speed in waves is to carry out sea keeping tests, at various speeds, in regular waves of constant height but different wave lengths and directions. When the transfer functions of sea keeping tests, as prescribed in D.4, are available, they are to be used for correction of the S/P trials.

D.1 Simplified correction method for ships with limited heave and pitch during the speed runs (STAWAVE-1)

A dedicated and simplified method to estimate the added resistance in waves with limited input data has been developed specifically for speed trial conditions with present day ships.

Speed trials are conducted in low to mild sea states with restricted wave heights. In head waves the encounter frequency of the waves is high. In these conditions the effect of wave induced motions can be neglected and the added resistance is dominated by the wave reflection of the hull on the waterline. The water line geometry is approximated based on the ship beam and the length of the bow section on the water line (Figure D.1).

Formula (D.12) estimates the resistance increase in head waves provided that heave and pitch are small. The application is restricted to waves in the bow sector (less than ±45 deg. off the bow). For wave directions outside this sector no wave correction is applied.

$$R_{AWL} = \frac{1}{16}\rho_S g H_{1/3}^2 B \sqrt{\frac{B}{L_{BWL}}} \tag{D.12}$$

where: s —— the directional spreading parameter;

R_{AWL}—— the mean resistance increase in long crested irregular waves, in N;

ρ_S—— the water density in full scale, in kg/m^3;

g —— the acceleration of gravity, in m/s^2;

B —— the ship's breadth, in m;

$H_{1/3}$—— the significant wave height, in m;

L_{BWL}—— the distance of the bow to 95% of maximum breadth on the waterline, in m, shown in Figure D.1.

with the following restriction:

(1) Significant wave height $H_{1/3}$: $H_{1/3} \le 2.25\sqrt{L_{PP}/100}$;

(2) Heave and pitch during speed/power trial are small; (vertical acceleration at bow < 0.05g);

(3) wave direction is from ahead (within 0 to ±45 (°)).

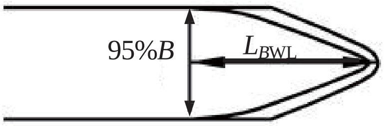


Figure D. 1 Definition for the distance of the bow to 95% of maximum beam on the waterline

D.2 Empirical correction method with frequency response function for ships which heave and pitch during the speed runs(STAWAVE-2)

An empirical method has been developed to approximate the transfer function R_{wave} of the mean resistance increase in regular head waves by using the main parameters such as ship dimensions and speed (see Figure D.2).

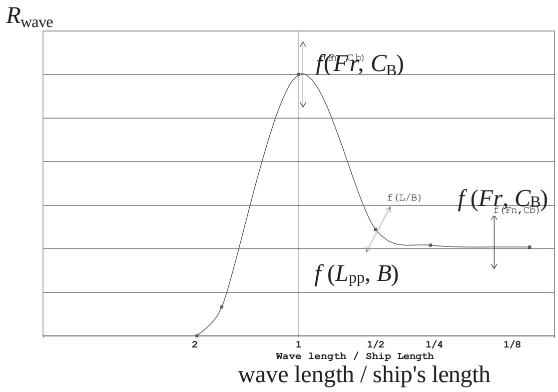


Figure D.2 Parametric transfer function of mean resistance increase in regular waves

This empirical transfer function R_{wave} covers both the mean resistance increase due to wave reflection R_{AWRL} and the motion induced resistance R_{AWML}.

$$R_{wave} = R_{AWML} + R_{AWRL} \tag{D.13}$$

The components are calculated as shown in the following formulae.

$$R_{AWML} = 4\rho_S g \zeta_A^2 \frac{B^2}{L_{PP}} \overline{r_{aw}}(\omega) \tag{D.14}$$

with:

$$\overline{r_{aw}}(\omega) = \overline{\omega}^{b_1} \exp\left\{\frac{b_1}{d_1}\left(1 - \overline{\omega}^{d_1}\right)\right\} a_1 Fr^{1.50} \exp(-3.50 Fr) \tag{D.15}$$

$$\overline{\omega} = \frac{\sqrt{\frac{L_{PP}}{g}} \sqrt[3]{k_{yy}}}{1.17 Fr^{-0.143}} \omega \tag{D.16}$$

$$a_1 = 60.3 C_B^{1.34} \tag{D.17}$$

$$b_1 = \begin{cases} 11.0 & \text{for } \overline{\omega} < 1 \\ -8.50 & \text{elsewhere} \end{cases} \tag{D.18}$$

$$d_1 = \begin{cases} 14.0 & \text{for } \overline{\omega} < 1 \\ -566\left(\dfrac{L_{PP}}{B}\right)^{-2.66} & \text{elsewhere} \end{cases} \tag{D.19}$$

and:

$$R_{AWRL} = \frac{1}{2}\rho_S g \zeta_A^2 B \alpha_1(\omega) \tag{D.20}$$

$$\alpha_1(\omega) = \frac{\pi^2 I_1^2(1.5kT_M)}{\pi^2 I_1^2(1.5kT_M) + K_1^2(1.5kT_M)} f_1 \tag{D.21}$$

$$f_1 = 0.692\left(\frac{V_S}{\sqrt{T_M g}}\right)^{0.769} + 1.81C_B^{\,6.95} \tag{D.22}$$

where: ρ_S—— the water density in full scale, in kg/m^3;
g —— the acceleration of gravity, in m/s^2;
ζ_A—— the wave amplitude, in m;
L_{PP}—— the ship's length between perpendiculars, in m;
B —— the ship's breadth, in m;
T_M—— the draught at midships, in m;
C_B—— the block coefficient;
F_r—— the Froude number;
V_S—— the ship's speed through the water, in m/s;
k_{yy}—— the non-dimensional radius of gyration in the lateral direction;
I_1—— the modified Bessel function of the first kind of order 1;
K_1—— the modified Bessel function of the second kind of order 1;
k —— the wave number, in rad/m.

With the following restrictions:

(1) L_{PP}>75m;

(2) $4.0 < \dfrac{L_{PP}}{B} < 9.0$;

(3) $2.2 < \dfrac{B}{T_M} < 9.0$;

(4) $0.10 < F_r < 0.30$;

(5) $0.50 < C_B < 0.90$;

(1) wave direction is from ahead (within 0 to ±45 °).

The method is applicable to the mean resistance increase in long crested irregular head waves R_{AWL} (see Formula (D.23)). The application is restricted to waves in the bow section to ±45° off bow waves which are treated as head waves for this method. Waves outside the ±45° sector are omitted from the wave correction in this method.

$$R_{AWL} = 2\int_0^{\infty} \frac{R_{wave}(\omega; V_S)}{\zeta_A^2} S_\eta(\omega) d_\omega \quad \text{(D.23)}$$

where: R_{AWL} —— the mean resistance increase in long crested irregular waves, in N, as substitute for R_{AW};
R_{wave}—— the mean resistance increase in regular waves, in N;
ζ_A—— the wave amplitude, in m;
ω —— the circular frequency of regular waves, in rad/s;
V_S—— the ship's speed through the water, in m/s;
S_η—— the frequency spectrum in m^2s, for wind waves modified Pierson-Moskowitz type is known for the expression(see formula (D.3)).

D.3 Theoretical method with simplified tank tests in short waves

The application of this method is restricted to the certain ship types of container ship, bulk carrier, tanker or ro-ro cargo ship (vehicle carrier), whose length is more than 190 m.

The application is also restricted to waves encountered in the bow sector (within 0 to ±45 ° off the bow). For wave directions outside this sector no wave correction is applied.

Applying the theoretical method, the mean resistance increase in regular waves R_{wave} is calculated from the components of the mean resistance increase based on Maruo's theory R_{AWM} and its correction term which is primarily applicable to short waves R_{AWR}.

$$R_{wave} = R_{AWM} + R_{AWR} \quad \text{(D.24)}$$

where: R_{AWM}—— the mean resistance increase in regular waves based on Maruo's theory, in N, which is calculated from the radiation and diffraction components;
R_{AWR}—— the correction term of R_{AWM}, in N.

R_{AWR} is to be calculated with high accuracy because the mean resistance increase in short waves is the dominant factor for the evaluation of the mean resistance increase in irregular waves.
The expression of R_{AWM} is given in the following formulae:

$$R_{AWM} = 4\pi\rho_S\left(-\int_{-\infty}^{m_c} + \int_{m_d}^{\infty}\right)\left|H_1(m)\right|^2 \frac{(m+k_0\tau)^2(m+k\cos\alpha)}{\sqrt{(m+k_0\tau)^4 - m^2k_0^2}}dm \qquad \text{for } \tau \geq \frac{1}{4} \quad \text{(D.25)}$$

$$R_{AWM} = 4\pi\rho_S\left(-\int_{-\infty}^{m_c} + \int_{m_d}^{m_b} + \int_{m_a}^{\infty}\right)\left|H_1(m)\right|^2 \frac{(m+k_0\tau)^2(m+k\cos\alpha)}{\sqrt{(m+k_0\tau)^4 - m^2k_0^2}}dm \qquad \text{for } \tau < \frac{1}{4} \quad \text{(D.26)}$$

where: $\tau = \frac{\omega_E V_S}{g}$ (D.27)

$$k = \frac{\omega^2}{g} \tag{D.28}$$

$$k_0 = \frac{g}{V_S^2} \tag{D.29}$$

$$\omega_E = \omega + kV_S \cos\alpha \tag{D.30}$$

$$m_a = \frac{k_0\left(1-2\tau+\sqrt{1-4\tau}\right)}{2} \tag{D.31}$$

$$m_b = \frac{k_0\left(1-2\tau-\sqrt{1-4\tau}\right)}{2} \tag{D.32}$$

$$m_c = -\frac{k_0\left(1+2\tau+\sqrt{1+4\tau}\right)}{2} \tag{D.33}$$

$$m_d = -\frac{k_0\left(1+2\tau-\sqrt{1+4\tau}\right)}{2} \tag{D.34}$$

$$H_1(m) = \int_L \sigma(x) e^{imx} dx \tag{D.35}$$

where: ρ_S —— the water density in full scale, in kg/m^3;
g —— the acceleration of gravity, in m/s^2;
V_S—— the ship's speed through the water, in m/s;
ω —— the circular frequency of regular waves, in rad/s;
ω_E—— the circular wave frequency of encounter, in rad/s;
α —— the encounter angle of incident waves, in rad, 0 means head waves;
$H_{1(m)}$—— the function, in m^3/s, to be determined by the distribution of singularities $\sigma(x)$ which represents a periodical disturbance by the ship. The distribution of singularities $\sigma(x)$ is, as a practical treatment, calculated by the application of slender body theory, as shown in the following formula, in which the singularity is concentrated at a depth of $C_{Pv}TM$, and the semi-infinite integration of R_{AWM} is calculated paying attention to its convergence.

$$\sigma(x) = -\frac{1}{4\pi}\left(i\omega_E - V_S \frac{\partial}{\partial_X}\right)\left\{Z_\Gamma(x) B(x)\right\} \tag{D.36}$$

where: $B(x)$ —— the sectional breadth, in m;
C_{Pv}—— the vertical prismatic coefficient;
T_M—— the draught at midships, in m;
x —— the longitudinal coordinate, in m;
ω_E—— the circular wave frequency of encounter, in rad/s;
V_S—— the ship's speed through the water, in m/s;
Z_Γ—— the vertical displacement relative to waves in steady motion, in m.

The expression of R_{AWR} is given by Tsujimoto et al. The calculation method introduces an experimental coefficient in short waves into the calculation in terms of accuracy and takes into account the effect of the bow shape above the water.

$$R_{AWRR} = \frac{1}{2}\rho_S g \zeta_A^2 B B_f \alpha_T \left(1 + C_U Fr\right) \tag{D.37}$$

where: ρ_S——the water density in full scale, in kg/m^3;

g ——the acceleration of gravity, in m/s^2;

ζ_A——the wave amplitude, in m;

B ——the ship's breadth, in m;

B_f——the bluntness coefficient, as calculated in formula D.41;

C_U——the coefficient of advance speed;

F_r ——the Froude number;

α_T——the effect of draught and encounter frequency, as calculated in formula D.38.

$$\alpha_T = \frac{\pi^2 I_1^2\left(k_e T_{deep}\right)}{\pi^2 I_1^2\left(k_e T_{deep}\right) + K_1^2\left(k_e T_{deep}\right)} \tag{D.38}$$

$$k_e = k\left(1 + \Omega\cos\alpha\right)^2 \tag{D.39}$$

$$\Omega = \frac{\omega V_S}{g} \tag{D.40}$$

$$B_f = \frac{1}{B}\left\{\int_I \sin^2\left(\alpha + \beta_W\right)\sin\beta_W dl + \int_{II} \sin^2\left(\alpha - \beta_W\right)\sin\beta_W dl\right\} \tag{D.41}$$

where: I_1—— the modified Bessel function of the first kind of order 1;

K_1—— the modified Bessel function of the second kind of order 1;

k—— the wave number, in rad/m;

T_{deep}—— the draught, in m, for a trim condition T_{deep} is the deepest draught;

g —— the acceleration of gravity, in m/s^2;

V_S—— the ship's speed through the water, in m/s;

ω —— the circular frequency of regular waves, in rad/s;

α —— the encounter angle of incident waves in rad, 0 means head waves;

β_W—— the slope of the line element d_l along the water line, in rad.

and domains of the integration (I & II) are shown in Figure D.3(1). When B_f is less than 0, then R_{wave} = 0 is assumed.

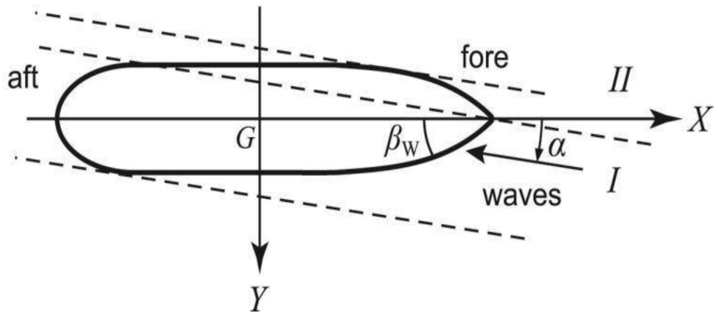


Figure D.3(1) Coordinate system for wave reflection

The coefficient of the advance speed in oblique waves $C_{U(\alpha)}$ is calculated on the basis of the empirical relation line shown in Figure D.3(2), which has been obtained by tank tests of various ship types following the procedures in D.4. When $C_{U(\alpha=0)}$ is obtained by tank tests the relation used in oblique waves is shifted parallel to the empirical relation line, as formulae (D.42) and (D.43). This is illustrated in Figure D.3(3) for both fine and blunt ships.

$$C_U = -310B_f + 68 \qquad for\, B_f < \frac{58}{310} \tag{D.42}$$

$$C_U = 10 \qquad for\, B_f \geq \frac{58}{310} \tag{D.43}$$

The empirical relation line in Figure D.3(2) was obtained as follows. C_U is derived from the result of tank tests and R_{AWR}, as formula (D.44).

$$C_U = \frac{1}{Fr}\left\{\frac{R_{wave}^{EXP}(Fr) - R_{AWM}(Fr)}{\frac{1}{2}\rho_S g \zeta_A^2 B B_f \alpha_T} - 1\right\} \tag{D.44}$$

with: I_1——the modified Bessel function of the first kind of order 1;

R_{wave}^{EXP}——the mean resistance increase in regular waves measured in the tank tests, in N;

F_r——the Froude number;

R_{AWM}——the mean resistance increase in regular waves based on Maruo's theory, in N, which is calculated from the radiation and diffraction components;

ρ_S——the water density in full scale, in kg/m^3;

g——the acceleration of gravity, in m/s^2;

ζ_A——wave amplitude, in m;

B——ship's breadth, in m;

B_f——as calculated in formula (D.41);

α_T——the effect of draught and encounter frequency, as calculated in formula(D.38).

The aforementioned coefficient $C_U(\alpha=0)$ determined by simplified tank tests which is to be carried out in short waves since R_{AWR} is mainly affected by short waves. The tank tests are to be conducted for the specific ship geometry at the trial draughts and trim; and at contractual draughts if required. The number of wave frequencies is one in short waves. The length of short waves is to be $0.5L_{PP}$ or less. The wave height corresponding to a sea state of Beaufort number 6, i.e. incident wave height: 3m, is to be adopted. However, upper or lower limitation of the wave height can be set as the wave height to the ship's length ratio ($2\zeta_A/L_{PP}$) being 1/100 when reasonable restraint exists for suitable reasons, such as deck wetness etc. In any case the wave steepness (a ratio of the wave height to the wave length) is to be 1/20 or less to avoid non-linear wave behaviour. Incident waves are to be measured for ten waves or more under steady conditions. The test set-up and procedure are to follow ITTC 7.5-02 07-02.2.

The coefficient of advance speed C_U is determined by the 'least squares' method (see Figure D.3(4)).

The tank tests are to be conducted for at least three different Froude Numbers (F_r). F_r is to be selected such that the speeds during the sea trials lie between the lowest and the highest selected F_r.

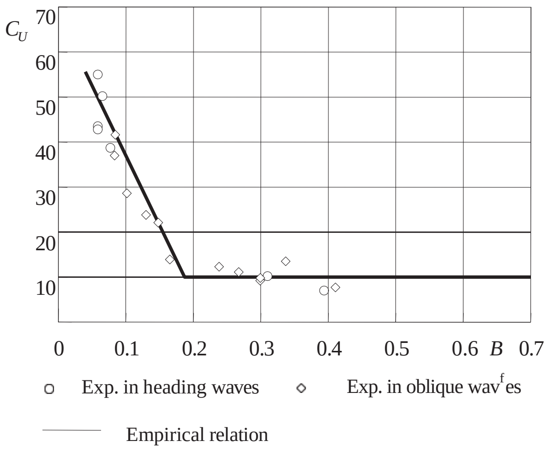


Figure D. 3(2) Relation between the coefficient of advance speed on the added resistance due to wave reflection and the bluntness coefficient for a conventional hull form above water

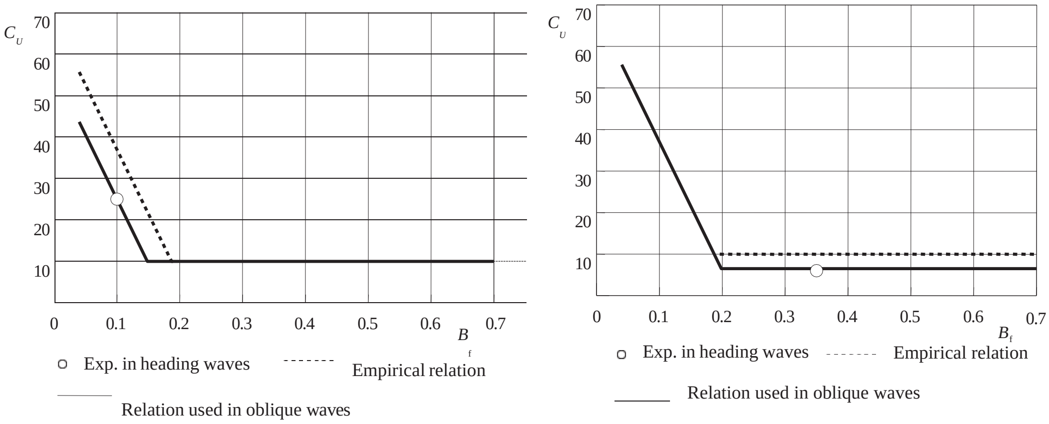


Figure D.3(3) Shift of the empirical relation in oblique waves
(left; for fine ship B_f < 58/310, right; for blunt ship $B_f \geqslant$ 58/310)

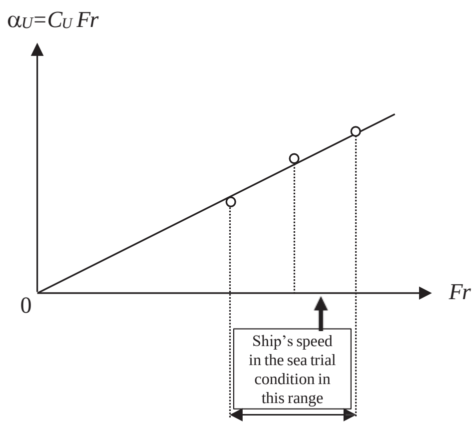


Figure D.3(4) Relation between effect of advance speed (α_U=$C_U F_r$) and Froude number F_r

D.4 Seakeeping model tests

Transfer functions of the resistance increase in waves (R_{wave}) may be derived from the tank tests in regular waves. The tank tests have to be conducted for the specific ship geometry at the trial draughts and trim; and at contractual draughts if required. A minimum of two different ship's speed (V_S) covering the speed range tested in the speed/power trials have to be tank tested.

If the trials are not conducted in head seas and following seas, the tank tests shall not only comprise head and following waves but also the relevant oblique wave conditions. A maximum interval of incident wave angle shall be 30° for head to beam seas (0°~90°) but may be larger for beam to following seas (90°~180°).

These tests shall be performed for a combination of circular frequency of regular waves (ω), angle between ship heading and incident regular waves (α) and ship's speed through the water (V_S) based on the following: A minimum of 5 wave lengths in the range of $0.5L_{PP}$ and less than $2.0L_{PP}$. The test set-up and procedure shall follow ITTC 7.5-02 07-02.2.

Appendix 6-E Effect of Current

E.1 General provisions

Considering the nature of currents, the current speed shall be estimated from the measured ship's speed at each run.

There are two methods to account for the effect of current.
(1) The 'Iterative' method, where the current speed is assumed as a semi durational phenomenon.
(2) The 'Mean of means' method, where current speed is assumed to vary parabolically within a given power setting.

E.2 'Iterative' method

In the 'Iterative' method, the current speed is assumed to vary with, inter alia, the semidiurnal period. A current curve is determined as a function of time as follows:

$$V_C = V_{C,C}\cos\left(\frac{2\pi}{T_C}t\right) + V_{C,S}\sin\left(\frac{2\pi}{T_C}t\right) + V_{C,T}t + V_{C,0} \quad \text{(E.1)}$$

where: V_C—— the current speed, in kn;
T_C—— the period of variation of current speed;
t —— the time for each run.
and unknown factors $V_{C,C}$, $V_{C,S}$, $V_{C,T}$ and $V_{C,0}$.

The most dominant period is the lunar semidiurnal period of 0.51753 day (12 hours, 25 minutes and 12 seconds).

The ship's speed through the water is derived from a regression curve (E.2) which represents the relationship between the ship's speed through the water and its power corrected in accordance with 12.2.3 and is defined as follows:

Stage 1: first approximation of ship's speed through the water

$$P(V_S) = a + bV_S^q \quad \text{(E.2)}$$

Therefore:

$$V_S = \sqrt[q]{\frac{P(V_S) - a}{b}} \quad \text{(E.3)}$$

where: $P(V_S)$ ——the regression curve;
V_S——the ship's speed through the water in knots;
and unknown factors a, b and q.

The initial value of V_S shall be taken as the average of the measured ship's speeds V'_G of a Double Run. As a first approximation of the regression curve representing the relationship between ship's speed and power, a mean curve is derived by determining the unknown factors, a, b and q of formula (E.2) by fitting the formula (E.2) to combinations of the initial value of V_S and averaged corrected power P'_{id} by the least squares method.

The ship's speed on the mean curve at the corrected power for each run is calculated as the updated ship's speed through the water V_S from the formula (E.3) applying the coefficients obtained as described above.

Stage 2: calculation of current velocity

Current speed at the time for each run V'_C is calculated by subtracting the updated ship's speed through the water V_S from the measured ship's speed over the ground V_G.

$$V_C' = V_G - V_S \tag{E.4}$$

A current curve is obtained by determining the unknown factors $V_{C,C}$, $V_{C,S}$, $V_{C,T}$ and $V_{C,0}$ of formula (E.1) by fitting the formula (E.1) to the combinations of time and current speed obtained from formula (E.4) by the 'least squares' method.

Stage 3: calculation of ship's speed through the water

The ship's speed, corrected for current V'_S, is calculated by subtracting the updated current speed V_C from the measured ship's speed over the ground V_G.

$$V_S' = V_G - V_C \tag{E.5}$$

The updated regression curve representing the relationship between ship's speed and power is obtained by determining new factors of formula (E.2) by fitting the formula (E.2) to the combination of ship's speed obtained from formula (E.5) and corrected power by the "least squares" method again.

The ship's speed through the water at the corrected power for each run is recalculated as the updated one from the formula (E.3), and the processes of Stage 2 and Stage 3 are then repeated until $\sum\left(P\left(V_S'\right)_i - P_{idi}\right)^2$ is minimized:

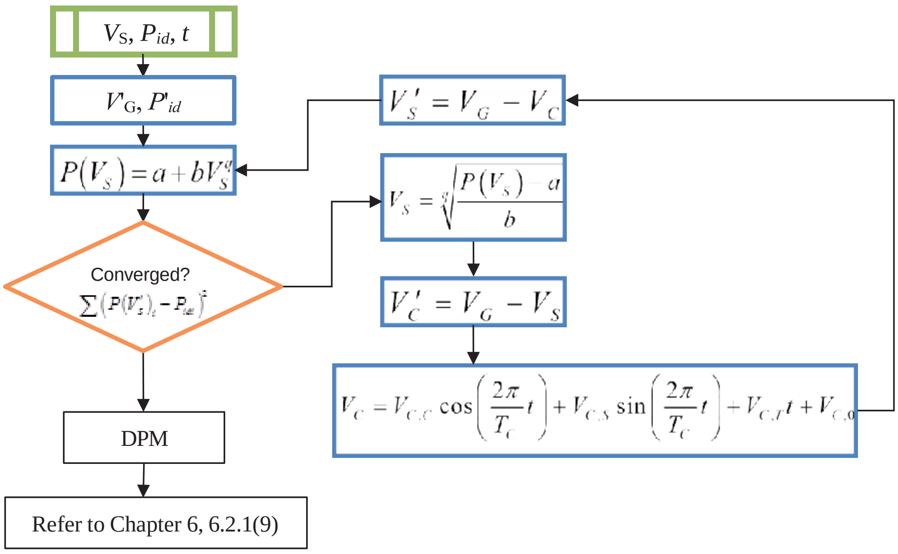


Figure E.2 Flow chart of the "Iterative"method

E.3 "Mean of means" method

If two Double Runs, i.e. four runs, are carried out, the "Mean of means" method can be used.

This method assumes that the current speed varies parabolically over the time, and the following formula is used to account for the current effect:

$$V_S = \frac{V_{G1} + 3V_{G2} + 3V_{G3} + V_{G4}}{8} \tag{E.6}$$

where: V_S——the ship's speed through the water, in knots;
V_{G1}——the measured ship's speed over the ground on the first of four runs, in knots;
V_{G2}——the measured ship's speed over the ground on the second of four runs, in knots;
V_{G3}——the measured ship's speed over the ground on the third of four runs, in knots;
V_{G4}——the measured ship's speed over the ground on the fourth of four runs, in knots.

If the current speed varies parabolically, a current curve is defined as a quadratic function of the time.

$$V_C = V_{C,2}t^2 - V_{C,1}t + V_{C,0} \tag{E.7}$$

where: $V_{C,0}$, $V_{C,1}$ and $V_{C,2}$ are unknown factors.

If two Double Runs, i.e. four runs, are conducted, the following relationship is derived for each run from formula (E.7).

$$V_{G1} = V_S + \left\{V_{C,2}(t+3\Delta t)^2 - V_{C,1}(t+3\Delta t) + V_{C,0}\right\} \tag{E.8}$$

$$V_{G2} = V_S - \left\{V_{C,2}(t+\Delta t)^2 - V_{C,1}(t+\Delta t) + V_{C,0}\right\} \tag{E.9}$$

$$V_{G3} = V_S + \left\{V_{C,2}(t-\Delta t)^2 - V_{C,1}(t-\Delta t) + V_{C,0}\right\} \tag{E.10}$$

$$V_{G4} = V_S - \left\{V_{C,2}(t-3\Delta t)^2 - V_{C,1}(t-3\Delta t) + V_{C,0}\right\} \tag{E.11}$$

where: V_S——the ship's speed through the water, in knots;
V_{G1}——the measured ship's speed over the ground on the first of four runs, in knots;
V_{G2}——the measured ship's speed over the ground on the second of four runs, in knots;
V_{G3}——the measured ship's speed over the ground on the third of four runs, in knots;
V_{G4}——the measured ship's speed over the ground on the fourth of four runs, in knots;
t ——the start time of the first speed run of a power setting;
Δt——half of the elapsed time between two successive runs.

The current effect is accounted for by substituting the above four formulae from (E.8) to (E.11) for the formula (E.6).

The ship's speed through the water is the "Mean of means" of the two Double Runs.

The current speed for each individual speed run shall be checked by comparing the "Mean of means" result at one power setting.

The propeller shaft speed and power shall be averaged over the two runs of each Double Run and then over the Double Runs for the same power setting.

If a simplied speed trial test procedure as described in 4.7.2 is used, i.e., only one Double Run is conducted for each main engine power setting, the following formula is used to account for the current effect:

$$V_S = \frac{V_{G1} + V_{G2}}{2} \tag{E.12}$$

where: V_S—— the ship's speed through the water, in knots;
V_{G1}—— the measured ship's speed over the ground on the first of two runs, in knots;
V_{G2}—— the measured ship's speed over the ground on the second of two runs, in knots.

The current speed for each run is derived from the following formula:

$$V_C = V_G - V_S \tag{E.13}$$

where: V_C—— the current speed, in knots;
V_S—— the ship's speed through the water, in knots.

Appendix 6-F Effect of Water Temperature and Water Density

Both water temperature and water density affect the viscosity of the water and thus the ship resistance.

The prediction calculations of S/P trials are usually based on a temperature of the seawater of 15°C and a density of 1026 kg/m^3. For EEDI correction, those base figures shall be used.

The effects of water temperature and water density are calculated as follows.

$$R_{AS} = R_{T0}\left(\frac{\rho_S}{\rho_{S0}} - 1\right) - R_F\left(\frac{C_{F0}}{C_F} - 1\right) \quad \text{(F.1)}$$

with:

$$R_F = \frac{1}{2}\rho_S S V_S^2 C_F \quad \text{(F.2)}$$

$$R_{F0} = \frac{1}{2}\rho_{S0} S V_S^2 C_{F0} \quad \text{(F.3)}$$

$$R_{T0} = \frac{1}{2}\rho_{S0} S V_S^2 C_{T0} \quad \text{(F.4)}$$

where: R_{AS}——the resistance increase due to deviation of water temperature and water density, in N;
C_F——the frictional resistance coefficient for the actual water temperature and water density,

$$C_F = \frac{0.075}{\left(\log\left(\frac{V_S L_{PP}}{v_a}\right) - 2\right)^2};$$

C_{F0}——the frictional resistance coefficient for the reference water temperature and water density, taken from the tank test report;
C_{T0}——the total resistance coefficient for the reference water temperature and water density, taken from the tank test report;
R_F——the frictional resistance for the actual water temperature and water density, in N;
R_{F0}——the frictional resistance for the reference water temperature and water density, in N;
R_{T0}——the total resistance for the reference water temperature and water density, in N;
S——the wetted surface area in m^2; V_S is the ship's speed through the water, in m/s;
ρ_S——the water density for the actual water temperature and salt content, in kg/m^3;
ρ_{S0}——the water density for the reference water temperature and salt content, in kg/m^3;
V_S——the ship's speed through the water, in m/s;
L_{PP}——the ship's length between perpendiculars, in m;
v_a——Viscosity coefficient, in m^2/s, can be obtained from the table according to the water temperature.

Appendix 6-G Effect of Ship Condition

G.1 Displacement and trim

Generally, displacement and trim are to be adjusted to the required values during S/P trial, but may vary due to specific reasons.

The difference between the ship's actual displacement and the required displacement is not to be more than 2% of the required displacement.

If the displacement of the ship at the S/P trial differs from the required displacement within the limit of 2%, the following formula is to be applied to the power values of each run:

$$P_2 = P_1\left(\frac{\nabla_2}{\nabla_1}\right)^{2/3} \qquad \text{(G.1)}$$

Where: P_1——the power corresponding to displacement volume ∇_1 during the S/P trial, in kW;
P_2——the power corresponding to displacement volume ∇_2 used in the tank test, in kW;
∇_1——the displacement volume during the S/P trial in m^3;
∇_2——the displacement volume used in the tank test, in m^3.

During the trial, the trim shall be maintained within very narrow limits and normally not corrected. However, a model test for varying trim with reference to a constant displacement may also be performed, if the results of the test are available for the hull under consideration.

G.2 Hull and Propeller surface roughness

If the trial is carried out within a reasonable period of time after the final paint of the hull and the polishing of the propeller, the change of surface roughness should be minimal and its effect on the ship's speed may be negligible.

If the trial is conducted after a long interval after undocking, the effect of surface roughness cannot be ignored, but some of the methods used to correct this effect cannot be proved scientific, so the resulting correction results cannot be accepted.

Appendix 6-H Effect of Water Depth

The following formula (H.1) given by Lackenby is to be used to determine the ship's speed decrease $\Delta V_S / V_S$ due to shallow water based on the parameters $\sqrt{A_M} / h$ and $V_S^2 / (gh)$.

$$\frac{\Delta V_S}{V_S} = 0.1242(\frac{A_M}{h^2} - 0.05) + 1 - (\tanh \frac{gh}{V_S^2})^{1/2} \quad \frac{A_M}{h^2} \geqslant 0.05 \qquad \text{(H.1)}$$

where: A_M —— the midship section area under water, in m^2;

g —— the acceleration of gravity, in m/s^2;

h —— the water depth, in m;

V_S—— the ship's speed through the water, in m/s;

ΔV_S—— the decrease of ship's speed due to shallow water in m/s.

The value of water depth h to be used for correction is not to be less than the larger value obtained from the following two formulae:

$$h = 2\sqrt{B \cdot T_M} \text{ and } h = 2\frac{V_S^2}{g} \qquad \text{(H.2)}$$

Appendix 6-I Conversion from Trial Condition to EEDI Condition or Contractual Condition (if any)

For ships whose trials are not performed at EEDI condition or contractual condition, the trial results need be converted to that of EEDI condition or contractual condition (if any) by use of the tank test results.

The speed/power curve for other stipulated condition(s) is obtained from the results of the S/P trials at 'trial condition' by using the speed-power curves predicted by the tank tests. The tank tests are to be carried out at both conditions: 'trial condition', corresponding to the actual condition during the S/P trials, and any other stipulated condition.

Using the speed/power curve obtained from the S/P trials in the trial condition, the conversion of ship's speed from the trial condition to the other stipulated condition is to be carried out by the power ratio α_P defined in formula (I.1).

The adjusted power at full load condition ($P_{Full,S}$) is to be calculated by formula (I.2).

$$\alpha_P = \frac{P_{Trial,P}}{P_{Trial,S}} \quad \text{(I.1)}$$

$$P_{Full,S} = \frac{P_{Full,P}}{\alpha_P} \quad \text{(I.2)}$$

where: $P_{Trial,P}$——the power at the trial condition predicted by the tank tests, in kW;
$P_{Trial,S}$——the power at the trial condition obtained by the S/P trials, in kW;
$P_{Full,P}$——the power at full load/stipulated condition predicted by the tank tests, in kW;
$P_{Full,S}$——the power at full load/stipulated condition obtained by the S/P trials, in kW;
α_P——the power ratio.

Figure I.1 shows an example of scheme of the conversion to derive the resulting ship's speed at full load/stipulated condition $V_{Full,S}$ at 75%*MCR*.

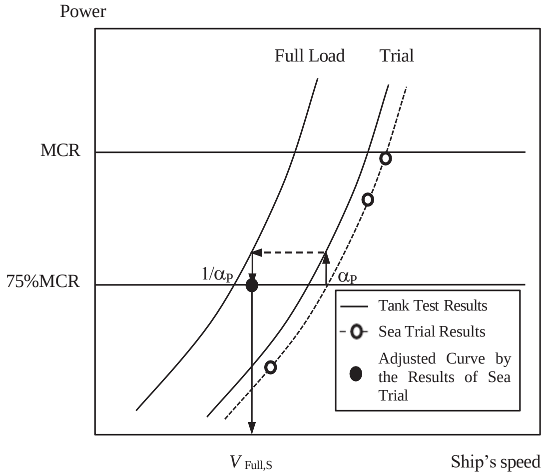


Figure I.1 Example of scheme of conversion from trial condition to other stipulated load condition at 75% *MCR*

Appendix 6-J Derivation of Load Variation Coefficients

J.1 Hull and propeller surface roughness

The load variation test includes at least 4 self-propulsion test runs, each one at a different propeller shaft speed while keeping the model's speed constant. The propeller shaft speeds are to be selected such that:

$$\frac{\Delta R}{R_{id}} \approx [-0.1 \quad 0 \quad 0.1 \quad 0.2] \tag{J.1}$$

where:

$$\Delta R = (F_D - F_X)\lambda^3 \frac{\rho_S}{\rho_M} \tag{J.2}$$

where: ΔR——the resistance increase, in N;
R_{id}——the full scale resistance at the actual speed from resistance test, in N;
F_X——the external tow force measured during load variation test, in N;
F_D——the skin friction correction force same as in the normal self-propulsion tests, in N;
λ——the scale factor; ρ_S is the water density in full scale, in kg/m^3;
ρ_M——the water density in the model test, in kg/m^3.

The "added resistance" in the load variation test has to be accounted for in the post processing. For example, if the standard self-propulsion test is carried out and processed according to ITTC 7.5-02-03-01.4 (1978 ITTC Performance Prediction Method) at tow force F_D, the measured data is processed according to the mentioned procedure, i.e., C_{TS} is replaced by C_{TSadd}.

$$C_{TSadd} = C_{TS} + \frac{\Delta R}{1/2\,\rho_S V_S^2 S_S} \tag{J.3}$$

where: ρ_S——the water density in full scale, in kg/m^3;
ΔR——the resistance increase, in N;
V_S——the full scale ship's speed, in m/s;
S_S——the full scale wetted surface in square metres, the same value as used in the normal self-propulsion test.

In this way the added resistance is reflected in the propeller load K_T/J^2, and as a consequence in J_{TS}, n_S, P_{DS}, η_{DS} and η_D.

J.2 Dependency of propulsive efficiency with resistance increase

The propulsive efficiency coefficient in the ideal condition η_{Did} , is obtained from standard towing tank test and interpolated to the speed V_S.

The fraction between the propulsive efficiency η_{Dms} from the load variation test and that from the normal self-propulsion test η_{Did} is plotted against the added resistance fraction $\Delta R/R_{id}$ (with the ideal condition R_{id} in the denominator). Each η_{Dms} is to be treated as well as η_{Did} in the verification process. The variable ξ_P is the slope of the linear curve going through {0,1} and fitted to the data points by the "least squares" method.

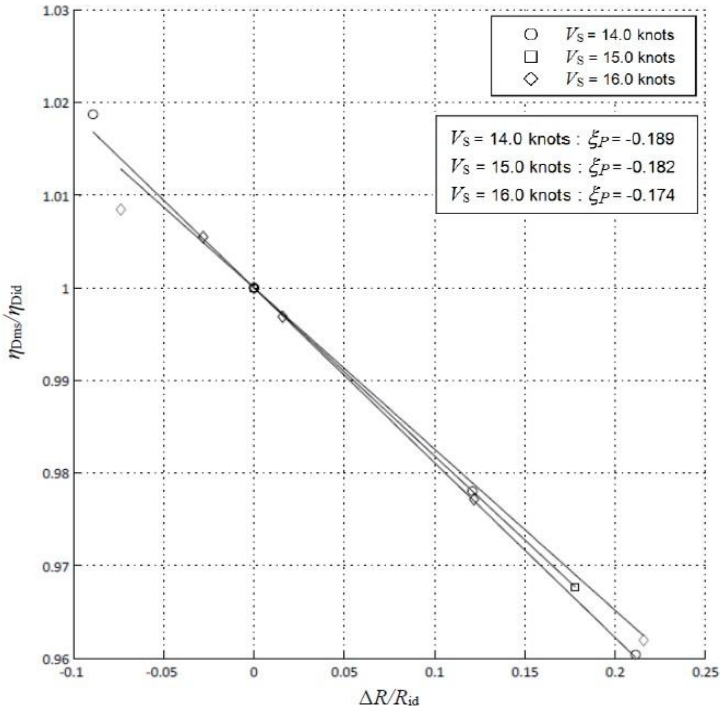


Figure J.2 Example of the approximate η_{Dms}/η_{Did} - $\Delta R/R_{id}$ curve fitted by the "least squares" method

The propulsive efficiency is assumed to vary linearly with the added resistance according to:

$$\frac{\eta_{Dms}}{\eta_{Did}} = \xi_P \frac{\Delta R}{R_{id}} + 1 \tag{J.4}$$

where: η_{Dms}——the propulsive efficiency coefficient in the trial condition;
η_{Did}——the propulsive efficiency coefficient in the ideal condition;
ξ_P——derived from the load variation test;
ΔR——the resistance increase, in N;
R_{id}——the resistance in the ideal condition, in N.

This leads to the expression for the corrected delivered power:

$$P_{Did} = P_{Dms} - \frac{\Delta R \cdot V_S}{\eta_{Did}} \cdot \left(1 - \frac{P_{Dms}}{P_{Did}} \cdot \xi_P\right) \tag{J.5}$$

$$P_{Did} = \frac{1}{2}\left(P_{Dms} - \frac{\Delta R \cdot V_S}{\eta_{Did}} + \sqrt{\left(P_{Dms} - \frac{\Delta R \cdot V_S}{\eta_{Did}}\right)^2 + 4P_{Dms}\frac{\Delta R \cdot V_S}{\eta_{Did}} \cdot \xi_P}\right) \tag{J.6}$$

Where: P_{Did}——the delivered power in the ideal condition, in kW;
P_{Dms}——the delivered power in the trial condition, in kW;
ΔR——the resistance increase, in N;
V_S——the ship's speed through the water, in m/s;
η_{Did}——the propulsive efficiency coefficient in the ideal condition;
ξ_P——derived from the load variation test.

J.3 Dependency of propeller shaft speed with power increase

Similarly, the effect on propeller shaft speed $\Delta n/n_{id}$ is plotted against $\Delta P_D/P_{Did}$ (with the ideal condition n and P_{Did} in the denominators). The variable ξ_n is the slope of the linear curve going through {0,1} and fitted to the data points with "least squares" method.

With the *P* found as described above, the correction to propeller shaft speed is:

$$\frac{\Delta n}{n_{id}} = \xi_n \frac{P_{Dms} - P_{Did}}{P_{Did}} + \xi_V \frac{\Delta V}{V_S} \tag{J.7}$$

where:

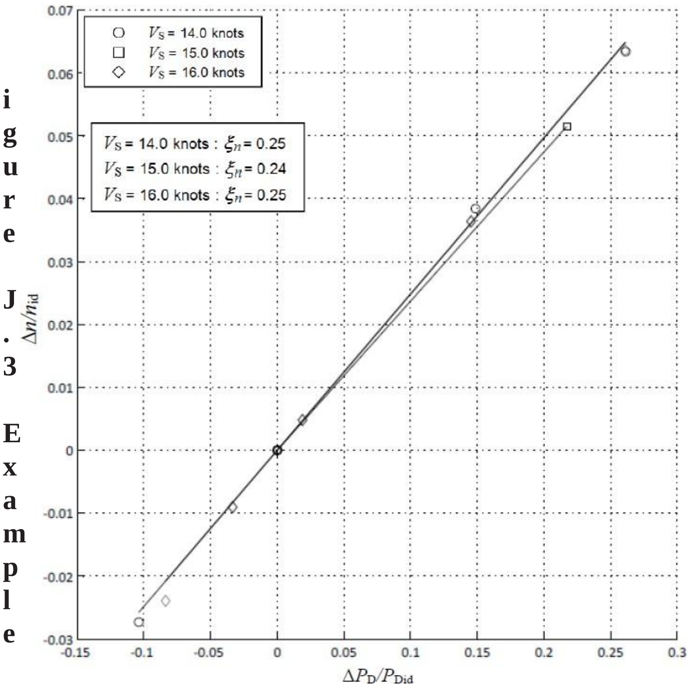
$$n_{id} = \frac{n_{ms}}{\xi_n \cdot \frac{P_{Dms} - P_{Did}}{P_{Did}} + \xi_V \cdot \frac{\Delta V}{V_S} + 1} \tag{J.8}$$

$$\Delta n = n_{ms} - n_{id} \tag{J.9}$$

and:

n_{ms}——the measured propeller shaft speed, in r/s;
n_{id}——the corrected propeller shaft speed in, r/s;
P_{Did}——the delivered power in the ideal condition, in kW;
P_{Dms}——the delivered power in the trial condition, in kW;
ξ_n, ξ_V——derived from load variation test;
V_S——the ship's speed through the water in m/s;
ΔV——the speed correction due to shallow water, in m/s, determined in Appendix G.

Figure J.3 Example of t



(J.9)

Figure J.3 Example of the approximate $\Delta n/n_{id}$ - $\Delta P_D/P_{Did}$ curve fitted using the "least squares" method

J.4 Dependency of propeller shaft speed with speed change

The propeller shaft speed n from the load variation test is plotted against the resistance $R_{id}+\Delta R$. The corresponding curves for other speeds are assumed to be parallel to this line and go through the point $\{R_{id}, n\}$ from the calm water self-propulsion test. The intersection of these lines with a constant resistance gives the rpm dependency of speed. The slope of the $\Delta n/n$ -$\Delta V/V$ curve fitted using the "least squares" method is ξ_V.

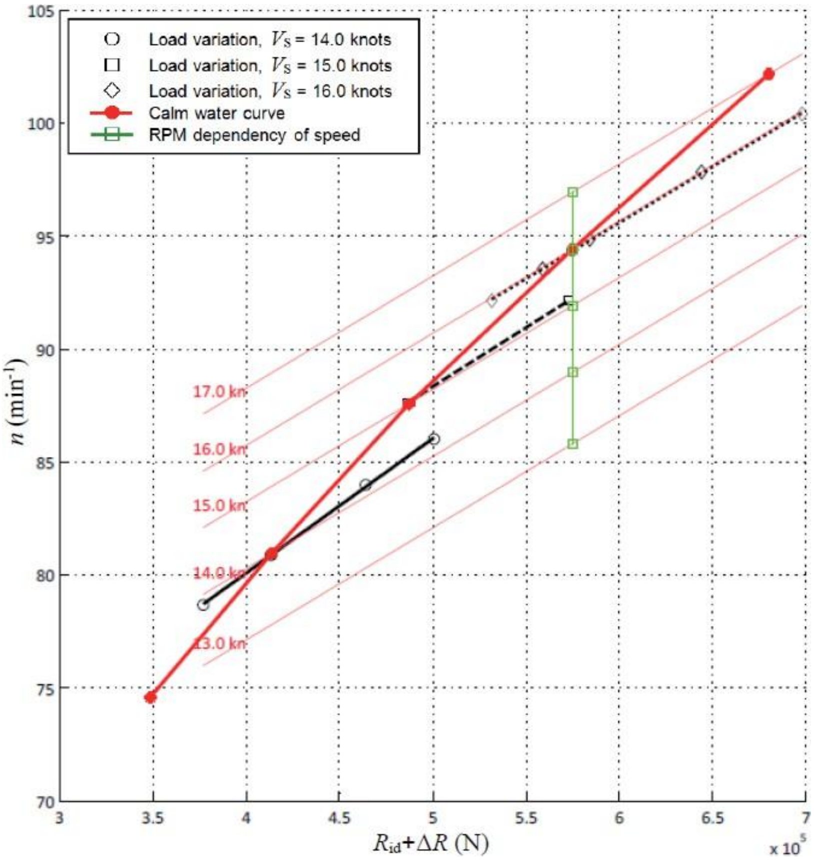


Figure J.4 Example of the effect of load variation and ship's speed on propeller shaft speed

In case there is no load variation test available it is allowable that the self-propulsion factors considering load variation effect are assumed to be equal to the self-propulsion factors for the ideal condition. This is because deviations of self-propulsion factors due to load variation effect are negligibly small in comparison with the deviations of the propeller efficiency due to load variation effect. The variation of η_O may be derived by ITTC 7.5-02-03-01.4 (2011).

Appendix 6-K Analysis of Direct Power Method

K.1 Propulsive efficiency correction

Propulsive efficiency coefficient η_D is generally calculated using propeller efficiency η_O and self-propulsion factors η_R, t and w_S:

$$\eta_D = \eta_O \eta_R \frac{1-t}{1-w_S} \tag{K.1}$$

where: η_D——the propulsive efficiency coefficient;
η_O——the propeller open water efficiency;
η_R——the relative rotative efficiency;
t——the thrust deduction factor;
w_S——the full-scale wake fraction, which may be calculated according to ITTC procedure 7.5-02-03-01.4, 1978 ITTC Performance Prediction method.

The full-scale wake fraction w_S is derived from model wake fraction w_M by taking a scale correlation factor of the wake fraction e_i into account.

$$1 - w_S = (1 - w_M) e_i \tag{K.2}$$

where: w_S——the full-scale wake fraction;
w_M——the model wake fraction;
e_i——the scale correlation factor of the wake fraction.

The self-propulsion factors η_R, t and w_S are obtained from the results of model self-propulsion tests.

Each self-propulsion factor for the trial condition η_{Rms}, t_{ms} and w_{Sms} is obtained by adding the deviation of each factor between the trial and the ideal condition $\Delta\eta_R$, Δt and Δw_M to each factor for the ideal condition η_{Rid}, t_{id} and w_{Mid} respectively. The deviations $\Delta\eta_R$, Δt and Δw_M are derived from the functions of $\Delta R/R_{id}$ based on the results of the self-propulsion test with load variation effect using resistance increase ΔR and total resistance in the ideal condition R_{id}.

$$\eta_{Rms} = \eta_{Rid} + \Delta\eta_R (\Delta R / R_{id}) \tag{K.3}$$

$$t_{ms} = t_{id} + \Delta t (\Delta R / R_{id}) \tag{K.4}$$

$$w_{Mms} = w_{Mid} + \Delta w_M (\Delta R / R_{id}) \tag{K.5}$$

where: η_{Rms}——the relative rotative efficiency in the trial condition;
t_{ms}——the thrust deduction factor in the trial condition;
w_{Mms}——the model wake fraction in the trial condition;
η_{Rid}——the relative rotative efficiency in the ideal condition;
t_{id}——the thrust deduction factor in the ideal condition;
w_{Mid}——the model wake fraction in the ideal condition;
$\Delta\eta_R$——the deviation of relative rotative efficiency;
Δt——the deviation of thrust deduction factor;

Δw_M——the deviation of wake fraction;
ΔR——the resistance increase, in N;
R_{id}——the resistance in the ideal condition, in N.

The functions of $\Delta R/R_{id}$ representing the deviations of self-propulsion factors $\Delta\eta_R$, Δt and Δw_M, are mentioned in K.2 in detail.

It is permitted that $\Delta\eta_R$, Δt and Δw_M are set to zero, because these values are negligibly small in comparison with the deviation of η_O due to the load variation effect.

In applying the above formulae (K.3) to (K.5), the total resistance R_{id} required by the above formulae is to be derived from the measured data.

Propeller efficiency η_O and full-scale wake fraction w_S are determined using propeller open water characteristics for the ship's fitted propeller, i.e. curves of thrust coefficient, torque coefficient and load factor, according to the following procedure.

Thrust coefficient, torque coefficient and load factor are described by the following formulae:

$$K_T = a_T J^2 + b_T J + c_T \quad \text{(K.6)}$$

$$K_Q = a_Q J^2 + b_Q J + c_Q \quad \text{(K.7)}$$

$$\tau_P = a_T + b_T / J + c_T / J^2 \quad \text{(K.8)}$$

where: K_T——the thrust coefficient;
K_Q——the torque coefficient;
τ_P——the load factor equal to K_T/J^2;
J——the propeller advance coefficient;
a_T, b_T, c_T——the factors for the thrust coefficient curve;
a_Q, b_Q, c_Q——the factors for the torque coefficient curve.

The torque coefficient in the trial condition K_{Qms} is calculated by the following formula:

$$K_{Qms} = \frac{P_{Dms}}{2\pi\rho_S n_{ms}^3 D^5}\eta_{Rms} \quad \text{(K.9)}$$

where: K_{Qms}——the torque coefficient in the trial condition;
P_{Dms}——the delivered power in the trial condition, in W;
ρ_S——the water density, in kg/m^3;
n_{ms}——the measured propeller shaft speed, in r/s;
D——the propeller diameter, in m;
η_{Rms}——the relative rotative efficiency in the trial condition.

The propeller advance coefficient J_{ms} is determined by the formula (K.10) using the torque coefficient K_{Qms} obtained from formula (K.9).

$$J_{ms} = \frac{-b_Q - \sqrt{b_Q^2 - 4a_Q\left(c_Q - K_{Qms}\right)}}{2a_Q} \quad \text{(K.10)}$$

where: J_{ms}——the propeller advance coefficient in the trial condition;
K_{Qms}——the torque coefficient in the trial condition;
a_Q, b_Q, c_Q——the factors for the torque coefficient curve.

The thrust coefficient in the trial condition K_{Tms} is obtained by the formula (K.6) using the propeller advance coefficient J_{ms}.

Therefore, the propeller efficiency η_{Oms} is:

$$\eta_{Oms} = \frac{J_{ms}}{2\pi} \frac{K_{Tms}}{K_{Qms}} \tag{K.11}$$

where: η_{Oms}——the propeller efficiency in the trial condition;
J_{ms}——the propeller advance coefficient in the trial condition;
K_{Tms}——the thrust coefficient in the trial condition;
K_{Qms}——the torque coefficient in the trial condition.

The load factor τ_{Pms} is:

$$\tau_{Pms} = \frac{K_{Tms}}{J_{ms}^2} \tag{K.12}$$

where: τ_{Pms}——the load factor in the trial condition;
J_{ms}——the propeller advance coefficient in the trial condition;
K_{Tms}——the thrust coefficient in the trial condition.

The speed of flow into propeller V_A is:

$$V_A = J_{ms} n_{ms} D \tag{K.13}$$

where: V_A——the speed of flow into propeller, in m/s;
J_{ms}——the propeller advance coefficient in the trial condition;
n_{ms}——the measured propeller shaft speed, in r/s;
D——the propeller diameter, in m.

And the full-scale wake fraction is:

$$1 - w_{Sms} = \frac{V_A}{V_S} \tag{K.14}$$

where: w_{Sms}——the full-scale wake fraction in the trial condition;
V_A——the speed of flow into propeller, in m/s;
V_S——the ship's speed through the water, in m/s.

The total resistance in the trial condition R_{ms} is also estimated using the load factor in the trial condition τ_{Pms}:

$$R_{ms} = \tau_{Pms} \left(1 - t_{ms}\right)\left(1 - w_{Sms}\right)^2 \rho_S V_S^2 D^2 \tag{K.15}$$

where: R_{ms}——the resistance in the trial condition, in N;
τ_{Pms}——the load factor in the trial condition;

t_{ms}——the thrust deduction factor in the trial condition;
w_{Sms}——the full-scale wake fraction in the trial condition;
ρ_S——the water density, in kg/m^3;
V_S——the ship's speed through the water in m/s;
D——the propeller diameter, in m.

The total resistance in the ideal condition R_{id} is obtained by subtracting the resistance increase ΔR from the total resistance in the trial condition R_{ms}:

$$R_{id} = R_{ms} - \Delta R \tag{K.16}$$

where: R_{id}——the resistance in the ideal condition, in N;
R_{ms}——the resistance in the trial condition, in N;
ΔR——the resistance increase, in N.

Using formulae (K.3), (K.4) and (K.5), the self-propulsion factors are calculated.

The load factor in the ideal condition τ_{Pid} is calculated by the following formula:

$$\tau_{Pid} = \frac{R_{id}}{(1-t_{id})(1-w_{Sid})^2 \rho_S V_S^2 D^2} \tag{K.17}$$

where: τ_{Pid}——the load factor in the ideal condition;
R_{id}——the resistance in the ideal condition, in N;
t_{id}——the thrust deduction factor in the ideal condition;
w_{Sid}——the full-scale wake fraction in the ideal condition;
ρ_S——the water density, in kg/m^3;
V_S——the ship's speed through the water, in m/s;
D——the propeller diameter, in m.

The propeller advance coefficient J_{id} is determined by the formula (K.18) using the load factor τ_{Pid} obtained from formula (K.17).

$$J_{id} = \frac{-b_T - \sqrt{b_T^2 - 4(a_T - \tau_{Pid})c_T}}{2(a_T - \tau_{Pid})} \tag{K.18}$$

where: J_{id}——the propeller advance coefficient in the ideal condition;
τ_{Pid}——the load factor in the ideal condition;
a_T, b_T, c_T——the factors for the thrust coefficient curve.

The thrust coefficient K_{Tid} and the torque coefficient K_{Qid} are obtained by the formulae (K.6) and (K.7) respectively using the propeller advance coefficient J_{id}.

Therefore, the propeller efficiency η_{Oid} is:

$$\eta_{Oid} = \frac{J_{id}}{2\pi}\frac{K_{Tid}}{K_{Qid}} \tag{K.19}$$

where: η_{Oid}——the propeller efficiency in the ideal condition;
J_{id}——the propeller advance coefficient in the ideal condition;
K_{Tid}——the thrust coefficient in the ideal condition;
K_{Qid}——the torque coefficient in the ideal condition.

The full-scale wake fraction in the ideal condition is calculated by the following formula:

$$1 - w_{Sid} = (1 - w_{Mid})e_i \tag{K.20}$$

The scale correlation factor of wake fraction included in formula (K.20) is obtained using the full-scale and model wake fractions in the trial conditions:

$$e_i = \frac{1 - w_{Sms}}{1 - w_{Mms}} \tag{K.21}$$

where: w_{Sid}——the full-scale wake fraction in the ideal condition;
w_{Mid}——the model wake fraction in the ideal condition;
w_{Sms}——the full-scale wake fraction in the trial condition;
w_{Mms}——the model wake fraction in the trial condition;
e_i——the scale correlation factor of the wake fraction.

Finally, the corrected propeller shaft speed n_{id} is derived from the propeller advance coefficient in the ideal condition and the open water characteristics of the actual propeller.

$$n_{id} = \frac{V_S(1 - w_{Sid})}{J_{id}D} \tag{K.22}$$

where: n_{id}——the propeller shaft speed in the ideal condition, in r/s;
V_S——the ship's speed through the water, in m/s;
w_{Sid}——the full-scale wake fraction in the ideal condition;
J_{id}——the propeller advance coefficient in the ideal condition;
D——the propeller diameter, in m.

Applying the analysis process in Figure K.1, the value of V_S, and thus the values of η_{Rid}, t_{id} and w_{Mid} are known after the analysis of the current velocity.

Additionally, the value of $\Delta R/R_{id}$, and thus the values of $\Delta\eta_R$, Δt and Δw_M are known after the analysis using the Direct Power Method. Therefore, the analysis by direct power method is to be repeated after the value of V_S is obtained by the current analysis described in 12.2.4.

For the above evaluation by the direct power method, the mean value of V_G for Double Run or "Mean of means" value of V_G for two Double Runs is to be used as the initial value, and the values of $\Delta\eta_R$, Δt and Δw_M are set to zero.

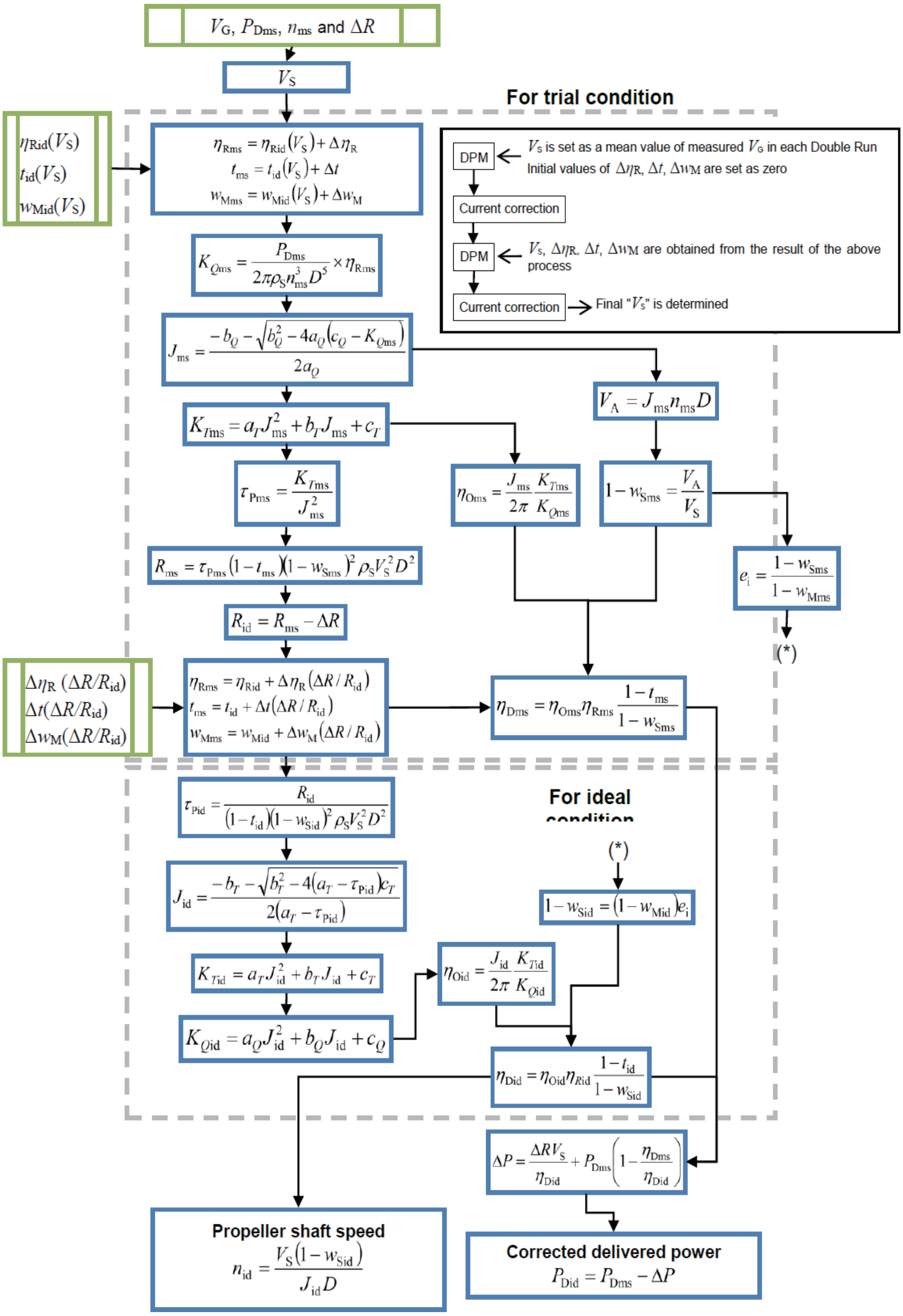


Figure 10.1 Flow chart of evaluation based on Direct Power Method

K.2 Application of load variation test results

In order to determine each component of propulsive efficiency coefficient η_D, propeller open water tests, resistance and self-propulsion tests are carried out at trial draught and evaluated according to the tank's normal procedures. In addition, a self-propulsion test with load variation effect may be carried out at the trial draught and, as a minimum, one speed close to the predicted EEDI speed (75% *MCR*). This speed is to be one of the speeds tested in the normal self-propulsion test.

The self-propulsion test with load variation effect includes at least 4 self-propulsion test runs, each one at a different propeller shaft speed while keeping the model's speed constant. The propeller shaft speed is to be selected such that:

$$\frac{\Delta R}{R_{id}} \approx [-0.1 \quad 0 \quad 0.1 \quad 0.2] \tag{K.23}$$

where:

$$\Delta R = (F_D - F_X)\lambda^3 \frac{\rho_S}{\rho_M} \tag{K.24}$$

where: ΔR——the resistance increase, in N;

R_{id}——the full scale resistance at the actual speed from resistance test, in N;

F_X——the external tow force measured during load variation test, in N;

F_D——the skin friction correction force same as in the normal self-propulsion tests, in N;

λ——the scale factor;

ρ_S——the water density in full scale, in kg/m^3;

ρ_M——the water density in the model test, in kg/m^3.

Each self-propulsion factor obtained from the procedure mentioned above is to be expressed as a function of $\Delta R/R_{id}$ as follows:

$$\Delta\eta_R = \xi_R\left(\frac{\Delta R}{R_{id}}\right)^2 + \zeta_R\frac{\Delta R}{R_{id}} \tag{K.25}$$

$$\Delta t = \xi_t\left(\frac{\Delta R}{R_{id}}\right)^2 + \zeta_t\frac{\Delta R}{R_{id}} \tag{K.26}$$

$$\Delta w = \xi_w\left(\frac{\Delta R}{R_{id}}\right)^2 + \zeta_w\frac{\Delta R}{R_{id}} \tag{K.27}$$

where: $\Delta\eta_R$——the deviation of the relative rotative efficiency;

Δt——the deviation of the thrust deduction factor;

Δw_M——the deviation of the wake fraction;

ΔR——the resistance increase, in N;

R_{id}——the resistance in the ideal condition, in N; ξ_R, ξ_t, ξ_w, ζ_R, ζ_t and ζ_w are unknown factors, and determined with the 'least squares' method.

Appendix 7 Guidelines for Validation of Electric Power Tables for EEDI (EPT-EEDI)

1 Objectives

The purpose of these Guidelines is to assist Surveyors in the validation of ship's Electric Power Tables for Energy Efficiency Design Index (EPT-EEDI). These guidelines will also assist shipowners, shipbuilders, ship designers, and manufacturers in understanding the procedures for the EPT-EEDI validation.

2 Definitions

2.1 *Validation* for the purpose of these Guidelines means review of submitted documents and survey during construction and sea trials.

2.2 *Standard EPT-EEDI-Form* refers to the layout given in Annex that contains the EPT-EEDI results that will be the subject of validation. Other supporting documents submitted for this purpose will be used as reference only and will not be subject to validation.

2.3 *Ship service and engine-room loads* refer to all the load groups which are needed for the hull, deck, navigation and safety services, propulsion and auxiliary engine services, engine-room ventilation and auxiliaries and ship's general services.

2.4 *Diversity factor* is the ratio of the "total installed load power" and the "actual load power" for continuous loads and intermittent loads. This factor is equivalent to the product of service factors for load, duty and time.

3 Application

3.1 These Guidelines are applicable to ships as described in 2.3.5.5(4), Chapter 2 of the Guidelines.

3.2 The steps of the validation process include:

(1) Review of documents during the design stage

① Check if all relevant loads are listed in the EPT;

② Check if reasonable service factors are used; and

③ Check the correctness of the P_{AE} calculation based on the data given in the EPT.

(2) Survey of installed systems and components during the construction stage

① Check if a randomly selected set of installed systems and components are correctly listed with their characteristics in the EPT.

(3) Survey of sea trials

① Check if selected units/loads specified in EPT conform to the actual condition.

4 Supporting documents

4.1 The applicant is to provide as a minimum the ship's electric balance load analysis.

4.2 Such information may contain the shipbuilder's or the ship designer's confidential information. Therefore, after the validation, the Surveyor is to return all or part of such information to the applicant at the applicant's request.

4.3 A special EEDI condition during sea trials may be needed and defined for each ship and included into the approved sea trial schedule. For this condition, a special column is to be inserted into the EPT.

5 Procedures for validation

5.1 General

5.1.1 P_{AE} is to be calculated in accordance with the EPT-EEDI in Appendix 2 of the Guidelines. EPT-EEDI validation is to be conducted in two stages: preliminary validation at the design stage and final validation during sea trials. The validation process is presented in Figure 5.1.1.

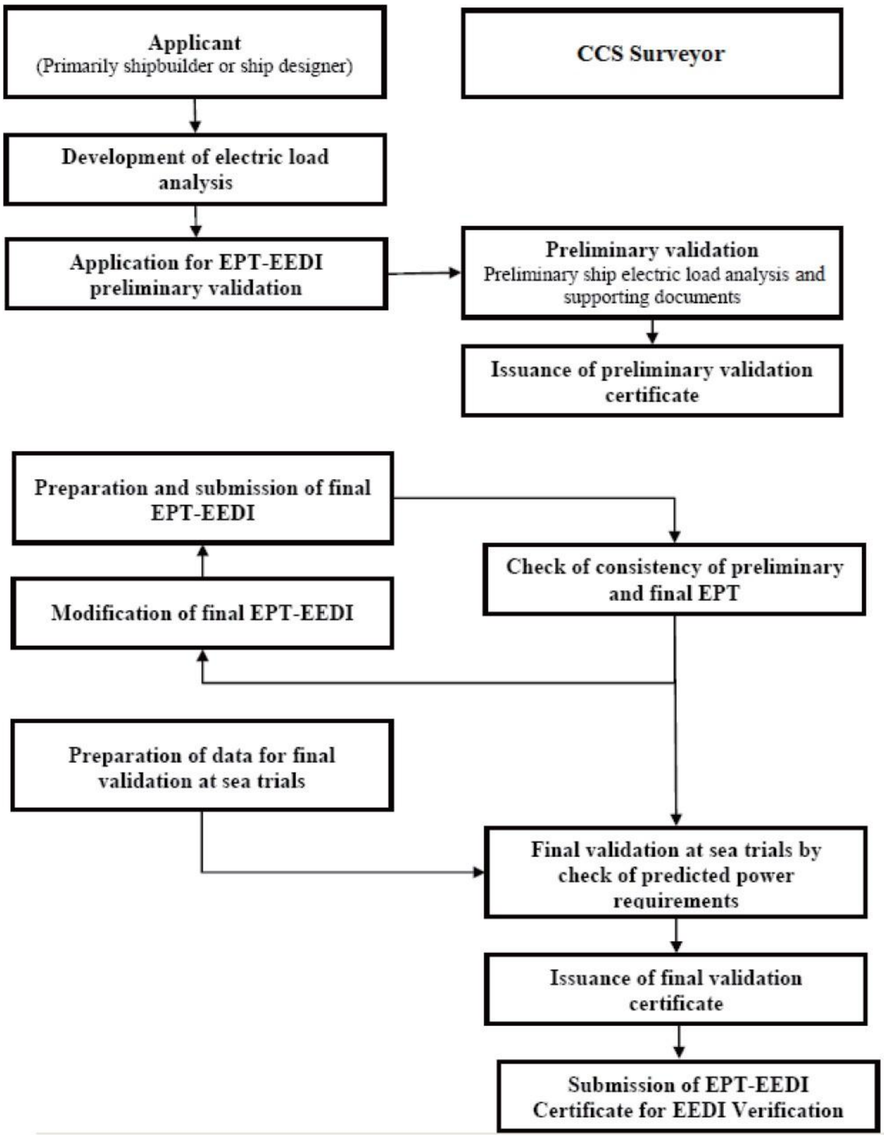


Figure 5.1.1 Basic Flow of EPT-EEDI Validation Process

5.2 Preliminary validation

5.2.1 For the preliminary validation at the design stage, the applicant is to submit to ISC an application for the validation of EPT-EEDI together with the application of EEDI verification, inclusive of EPT-EEDI Form and all the relevant and necessary information for the validation as supporting documents.

5.2.2 The Surveyor may request from the applicant additional information on top of those contained in these Guidelines, as necessary, to enable the Surveyor to examine the calculation process of the EPT-EEDI. The estimation of the ship's EPT-EEDI at the design stage depends on each applicant's experiences, and it may not be practicable to fully examine the technical aspects and details of each machinery component. Therefore, the preliminary validation is to focus on the calculation process of the EPT-EEDI.

5.3 Final validation

5.3.1 The final validation process as a minimum is to include the check of ship electric load analysis to ensure that all electric consumers are listed; their specific data and the calculations in the power table itself are correct and are supported by sea trial results. If necessary, additional information has to be requested.

5.3.2 For final validation the applicant is to revise the EPT-EEDI Form and supporting documents as necessary, by taking into account the characteristics of the machinery and other electrical loads actually installed on board the ship. The EEDI condition at sea trials is to be defined and the expected power requirements in these conditions documented in the EPT. Any change within the EPT from design stage to construction stage is to be highlighted by the shipyard or ship designer.

5.3.3 The preparation for the final validation includes a desk top check comprising:

.1 consistency of preliminary and final EPT;

.2 changes of service factors (compared to the preliminary validation);

.3 all electric consumers are listed;

.4 their specific data and the calculations in the power table itself are correct; and

.5 in case of doubt, component specification data is checked in addition.

5.3.4 A sampling check prior to sea trials is performed to ensure that machinery characteristics and data as well as other electric loads comply with those recorded in the supporting documents.

5.3.5 During the sea trial, the Surveyor will check the data of selected systems and/or components given in the special column added to the EPT as specified in 4.3 and the predicted overall value of electric load by means of practicable measurements with the installed measurement devices.

6 Issuance of the EPT-EEDI statement of validation

6.1 The plan approval surveyor is to stamp the EPT-EEDI Form (as Noted) after he validated the EPT-EEDI in the preliminary validation stage in accordance with these Guidelines.

6.2 The site surveyor is to stamp the EPT-EEDI Form (as Endorsed) after he validated the final EPT-EEDI in the final validation stage in accordance with these Guidelines.

Annex 7-A Electric Power Table Form for Energy Efficiency Design Index (EPT-EEDI Form) and Statement of Validation

Ship ID:
IMO No.:
Ship's name:
Shipyard:
Shipyard No.:
Applicant:
Name:
Address:

Validation stage:
Preliminary validation □
Final validation □

Summary results of EPT-EEDI

Load group	Seagoing condition		Remarks
	Continuous load (kW)	Intermittent load (kW)	
Ship service and engine-room loads			
Accommodation (and cargo) loads			
Total installed load			
Diversity factor			
Normal seagoing load			
Weighted average efficiency of generators			
P_{AE}			

Supporting documents

Title	ID or remarks

Validator details:
Organization:
Address:
This is to certify that the above-mentioned electrical loads and supporting documents have been reviewed in accordance with the EPT-EEDI Guidelines and the review shows a reasonable confidence for use of the above P_{AE} in EEDI calculations.

The date of review: ________________   Statement of validation No. ________________

This statement is valid on condition that the electric power characteristics of the ship do not change.

Signature of Surveyor

____

Appendix 8 Guidelines for Determining Minimum Propulsion Power to Maintain the Manoeuvrability of Ships in Adverse Conditions

Purpose

The purpose of these Guidelines is to assist in verifying that sea-going ships engaged on international voyages, complying with Energy Efficiency Design Index (EEDI) requirements set out in regulations on energy efficiency for ships as specified in chapter 4 of MARPOL Annex VI and CO_2 emission requirements as specified in 2.3.2 and 2.3.3 of the Rules for Green-Eco Ships, have sufficient installed propulsion power to maintain the manoeuvrability in adverse conditions. .

1 Definition

1.1 "Adverse conditions" mean sea conditions with the following parameters:

Significant wave height h_s, m	Peak wave period T_p, s	Mean wind speed V_w, m/s
6.0	7.0 to 15.0	22.6

JONSWAP sea spectrum with the peak parameter of 3.3 is to be considered for coastal waters.

1.2 The following adverse condition should be applied to ships defined as the following threshold value of ship size:

Ship length L_{pp}, m	Significant wave height h_s, m	Peak wave period T_p, s	Mean wind speed V_w, m/s
Less than 200	4.5	7.0 to 15.0	19.0
$200 \le L_{pp} \le 250$	Parameters linearly interpolated depending on ship's length		
More than 250	Refer to paragraph 1.1		

2 Applicability

2.1 These Guidelines should be applied in the case of all new ships of types as listed in table 1 of annex 8-A of this Appendix required to comply with regulations on energy efficiency for ships according to Chapter 4 of MARPOL Annex VI and the Rules for Green-Eco Ships.

2.2 Notwithstanding the above, these Guidelines should not be applied to ships with non-conventional propulsion systems, such as pod propulsion.

2.3 These Guidelines are intended for ships in unrestricted navigation.

2.4 These Guidelines are applied in maximum summer load condition.

3 Assessment procedure

3.1 The assessment can be carried out at two different levels as listed below:

.1 minimum power lines assessment; and

.2 minimum power assessment.

3.2 The ship should be considered to have sufficient power to maintain the manoeuvrability in adverse conditions if it fulfils one of these assessment levels.

4 Assessment level 1 – minimum power lines assessment

4.1 If the ship under consideration has installed power not less than the power defined by the minimum power line for the specific ship type, the ship should be considered to have sufficient power to maintain the manoeuvrability in adverse conditions.

4.2 The minimum power lines for the different types of ships are provided in annex 8-A.

5 Assessment level 2 – minimum power assessment

5.1 The methodology for the minimum power assessment is provided in annex 8-B.

5.2 If the ship under consideration fulfils the requirements as defined in the minimum power assessment, the ship should be considered to have sufficient power to maintain the manoeuvrability in adverse conditions.

6 Documentation

6.1 Test documentation should include at least, but not be limited to, a

.1 description of the ship's main particulars;

.2 description of the ship's relevant manoeuvring and propulsion systems;

.3 description of the assessment level used and results; and

.4 description of the test method(s) used with references, if applicable.

Annex 8-A The Methodology for the Minimum Power Lines Assessment

1 The minimum power line values of total installed MCR, in kW, for different types of ships should be calculated as follows:

$$\text{Minimum Power Line Value} = a \times (DWT) + b$$

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.

Parameters a and b for determination of the minimum power line values for the different ship types **Table 1**

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	

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.

Annex 8-B The Methodology for the Minimum Power Assessment

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.

2 The maximum total resistance is defined as sum of the resistance in calm-water at the 2.0 knots forward speed U and the maximum added resistance in seaway X_a over wind and wave directions from head to 30 degrees off-bow.

Requirement

3 To satisfy the requirements of Minimum Power Assessment, the required brake power 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 P_B^{av} in the same conditions:

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

4 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.

5 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.

Definition of propulsion point

6 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, ρ =1025 kg/m^3;
u_a(m/s) is the propeller advance speed; and
D_p(m) is the propeller diameter.

7 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.

8 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.

Definition of required propeller thrust

9 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 factor taking into account suction force on the ship hull due to propeller thrust.

Definition of calm water characteristics

10 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 thrust deduction factor t and wake fraction w at the forward speed and relative rotative efficiency η_R. Default conservative estimate may also be used for thrust deduction factor and wave fraction; t = 0.1 and w = 0.15 respectively; and

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

Definition of added resistance

11 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.

Definition of wind resistance

12 The maximum added resistance due to wind X_w is calculated as:

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

where: $X'_w(\varepsilon)$ is the non-dimensional aerodynamic resistance coefficient;
ε(degree) is the apparent wind angle;
ρ_a(kg/m^3) is the air density, ρ_a =1.2 kg/m^3;
v_{wr} (m/s) is the relative wind speed, $v_{wr} = U + v_w \cos\mu$;
v_w (m/s) is the absolute wind speed, defined by the adverse conditions in paragraph 1 of these guidelines; and
A_F (m^2) is the frontal windage area of the hull and superstructure.

13 The maximum added resistance due to wind X_w is defined as maximum over wind directions from head ε = 0 to 30 degrees off-bow ε = 30.

14 The non-dimensional aerodynamic resistance coefficient X'_w is defined from wind tunnel tests or equivalent methods verified by the Administrations or the Recognized Organizations. Alternatively, it can be assumed with 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, X'_w = 1.4 should be assumed instead of X'_w = 1.1.

Definition of added resistance due to waves

15 The maximum added resistance due to waves X_d is defined in accordance with either

.1 expression

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

where: 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
h_s (m) is the significant wave height, defined according to paragraph 1 of these guidelines.

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

.2 or spectral method

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

where: X_d/A^2(N/m^2) is the quadratic transfer function of the added resistance in regular waves and A is the wave amplitude;
$S_{\zeta\zeta}(\omega')$ 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.

16 The maximum added resistance due to waves X_d is defined as maximum over wave directions from head μ=0 to 30 degrees off-bow μ=30. 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 s, with the step of peak wave period not exceeding 0.5 s.

17 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.

18 The spreading function $D(\mu-\mu')$ is defined as cos^2 -directional spreading。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.

19 The quadratic transfer functions of added resistance in regular waves X_d/A^2 are defined from seakeeping tests or equivalent methods verified by the Administrations or the Recognized Organizations. Alternatively, the semi-empirical method specified in annex 8-C of this document can be used.

Definition of added rudder resistance due to manoeuvring in seaway

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

$X_r = 0.03 \cdot T_{er}$, where T_{er} is the propeller thrust excluding X_r from T.

Annex 8-C 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 give in this annex 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 $X'_d = X_d/A^2$, in N/m^2, can be calculated as a sum

$$X'_d = X'_{dM} + X'_{dR}$$

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

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

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

where:

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

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

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

for $C_B > 0.75$

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

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

for $C_B \leq 0.75$

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

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

where: $\beta = \pi - \mu$ 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 X'_{dR} is given as follows:

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

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

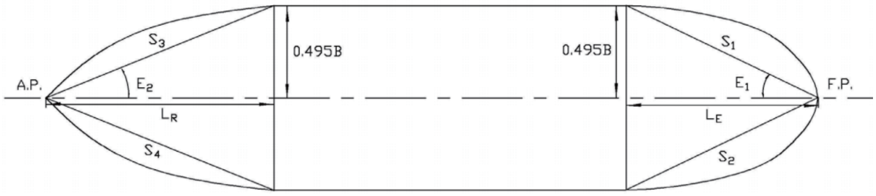


Figure 1 Sketch of the waterline profile of a ship and related definitions

when $E_1 \le \beta \le \pi$

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

when $\pi - E_1 \le \beta \le \pi$

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

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

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

when $0 \le \beta \le E_2$

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

where: ω_0 is the frequency of the incident wave;
α_{d^*} is the draft coefficient, calculated as

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

where for S_1 and S_2 segments

$$d^* = d$$

and for S_3 and S_4 segments

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

$$f(\beta) = \begin{cases} -\cos\beta & \text{for } \pi - E_1 \le \beta \le \pi \\ 0 & \text{for } \beta < \pi - E_1 \end{cases}$$