GUIDANCE NOTES
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CHINA CLASSIFICATION SOCIETY

GUIDELINES FOR SURVEY OF MARINE WIND-ROTOR ASSISTED PROPULSION SYSTEM

2023

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Beijing

CONTENTS

CHAPTER 1 GENERAL

1.1 General provisions

1.1.1 The Guidelines is applicable to sea-going ships installed with wind-rotor assisted propulsion system.

1.1.2 The marine wind-rotor assisted propulsion system is a system that makes use of wind Magnus effects to generate force to assist propulsion of ships, generally including the foundation, inner tower structure, flettner-rotor structure, drive system, power supply system, monitoring alarm and control system, etc., as shown in Figure 1.1.2.

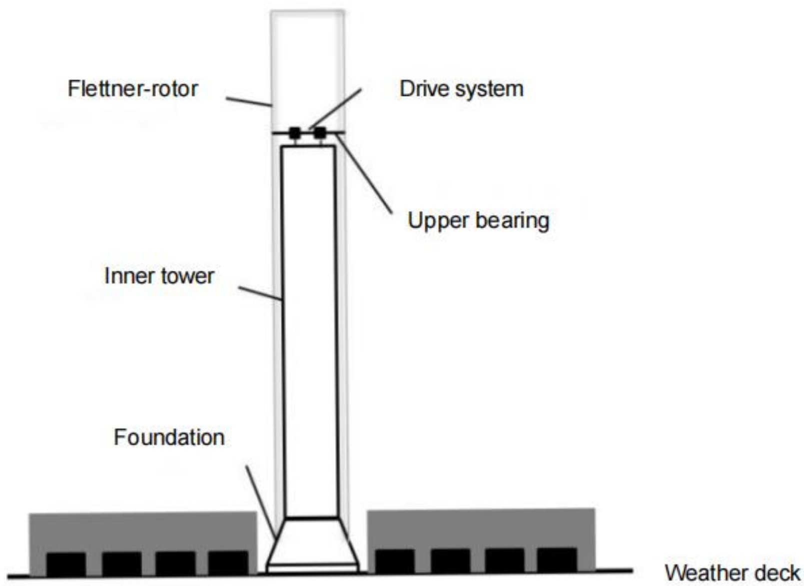

Figure 1.1.2 Diagram of wind-rotor assisted propulsion system

1.1.3 The Guidelines specifies the technical requirements for the arrangement and design of the marine wind-rotor assisted propulsion system, power supply and electrical system, monitoring and control system, strength and stability of the ship, noise, etc., defines the survey requirements for relevant equipment, and proposes the EEDI calculation methods and verification requirements for ships installed with the wind-rotor assisted propulsion system.

1.1.4 In addition to the requirements of the Guidelines, the sea-going ships installed the wind-rotor assisted propulsion system defined in the Guidelines are to meet the applicable requirements of CCS Rules for Classification of Sea-going Steel ships and Rules for Materials and Welding.

1.1.5 The Guidelines is applicable to the wind-rotor assisted propulsion system described in 1.1.2 of this Chapter. Considering that the wind-rotor propulsion technology is still at a development stage, the corresponding test, theoretical basis, service experience or effective recognized standards of the calculation methods, evaluation criteria, survey and testing methods for the other type systems, if any, may be accepted as equivalent methods with the consent of CCS.

1.2 Definitions

1.2.1 The applicable definitions of the Guidelines are as followings:

(1) Magnus effect means a phenomenon that when a fluid (gas or liquid) flows through the surface of a rotating object, it will change the streamline of the fluid to produce lift.

(2) Wind-rotor assisted propulsion technology means a wind energy utilization technology that make use of Magnus effect to drive the cylinder installed on weather deck to rotate by motor, and transfers Magnus force to the hull to generate force to assist the propulsion of the ship, so as to reduce the energy consumption of the propulsion system.

(3) Flettner-rotor means the external cylindrical structure in the wind-rotor assisted propulsion system, which is arranged on weather deck, directly affected by the wind, driven by the motor to rotate, and transfers the generated force to the inner tower of the wind-rotor assisted propulsion system.

(4) Inner tower and foundation mean the internal structures in the wind-rotor assisted propulsion system, which provide a supporting structure for the installation, inspection and maintenance of the flettner-rotor and the motor, and transfer the force generated by the rotors to the hull of the ship

1.3 Class notations

1.3.1 If the ship applies the wind-rotor assisted propulsion technology, the requirements in Chapter 1, 2, 3, 4 and 5 of the Guidelines are to be met. Upon application, the WAP (ROTOR) class notation may be assigned to the ship.

1.3.2 The newbuildings applicable to 2.3.2 and 4.3.2 of CCS Rules for Green Eco-Ships, if the wind-rotor assisted propulsion system is installed, the energy-saving effect of the wind-rotor assisted propulsion system may be calculated and verified according to the requirements of Chapter 6 of the Guidelines, and is to be included in the Attained EEDI value of the ship and assigned with the CDx class notation.

1.3.3 The ships in-service applicable to 2.3.3 of CCS Rules for Green Eco-Ships, if the wind-rotor assisted propulsion system is installed, the energy-saving effect of the wind-rotor assisted propulsion system may be calculated and verified according to the requirements of Chapter 6 of the Guidelines, and is to be included in the Attained EEXI value of the ship and assigned with the CDEx class notation.

1.4 Plans and information

1.4.1 The following plans and information are to be submitted for approval, if they have been included in the drawings and data required to be submitted by the ship, it is unnecessary to resubmit them:

(1) Arrangement of wind-rotor assisted propulsion system;

(2) Structure of flettner-rotor of the wind-rotor assisted propulsion system;

(3) Structure of inner tower of the wind- rotor assisted propulsion system;

(4) Structure of foundation;

(5) Structural strengthening of hull within the rotor area;

(6) Electrical system related to wind-rotor assisted propulsion system and its arrangement;

(7) Mooring test program of wind-rotor assisted propulsion system;

(8) Navigation test program of wind-rotor assisted propulsion system (including ship emergency

braking test);
(9) EEDI technical files (if applicable);
(10) Other drawings and data deemed necessary by CCS.
1.4.2 For the conversion ships, at least the following plans and information are to be submitted for approval:
(1) General arrangement;
(2) Navigation bridge visibility plan;
(3) Signal equipment layout;
(4) Inclination test program (if applicable);
(5) Inclination test report (if applicable);
(6) Loading manual, damage stability calculations, loading computer (if applicable);
(7) Power load calculations;
(8) Additional electrical system related to wind-rotor assisted propulsion system and its arrangement;
(9) Antenna layout (if applicable);
(10) Noise control diagram (if applicable);
(11) Arrangement of electrical equipment within hazardous zones (if applicable);
(12) EEDI technical files (if applicable);
(13) EEXI technical files (if applicable);
(14) Other statutory drawings and information affected by the change of ship tonnage (if applicable);
(15) Other drawings and data deemed necessary by CCS.
1.4.3 The following drawings and data are to be submitted for information:
(1)The design specifications of wind-rotor assisted propulsion system is at least to include description of system, functions of critical components, system principles, system control functions and descriptions of external interfaces of the system;
(2) Alteration specifications of wind-rotor assisted propulsion system (applicable to the conversion ships);
(3) Specifications of system equipment;
(4) Estimation of light weight and center of gravity changes and assessment of stability impact (applicable to the conversion ships);
(5) Tonnage calculations;
(6) Structural strength calculations of the flettner-rotor;
(7) Structural strength calculations of the inner tower (including foundation);
(8) Local strength calculations of hull structure within rotor area;
(9) Test report of rotor materials;
(10) Operating manual of wind-rotor assisted propulsion system;
(11) Other drawings and data deemed necessary by CCS.

CHAPTER 2　SHIP DESIGN REQUIREMENTS

2.1　General provisions

2.1.1　Basic requirements

2.1.1.1　The arrangement and design, longitudinal strength, local strength, stability, noise, electrical installations of the ships installed with the wind-rotor assisted propulsion system are to meet the design requirements of this Chapter.

2.1.1.2　The wind-rotor assisted propulsion system is to be capable of normal working under the design environmental conditions.

2.2　Arrangement and design

2.2.1　Navigational bridge visibility

2.2.1.1　The size and installation position of the wind-rotor assisted propulsion system are to meet the navigational bridge visibility requirements, and comply with the relevant provisions of SOLAS Reg. V/22 and flag State regulations under all operating conditions.

2.2.2　Navigation light

2.2.2.1　The size and installation position of the wind-rotor assisted propulsion system are not to affect the navigation safety, and the navigation lights are to be so arranged to comply with the latest International Regulations for Preventing Collisions at Sea and the relevant provisions of the flag State regulations.

2.2.3　Tonnage

2.2.3.1　For conversion ships, the impact of the change of ship tonnage on the statutory applicable requirements after the installation of the wind-rotor assisted propulsion system is to be taken into consideration.

2.2.4　Fire safety

2.2.4.1　At least one approved portable fire extinguisher or other equivalent fire extinguishing device is to be provided in or adjacent to the inner tower.

2.2.4.2　Proper ventilation device is to be provided in the inner tower, and proper ventilation is to be conducted before personnel enter the space. When the wind-rotor assisted propulsion system is located in a hazardous zone, sufficient power ventilation is to be provided to the inner tower from a safe place. For permanent installations the capacity of eight air changes per hour are to be provided and for portable systems the capacity of 16 air changes per hour. Fans or blowers are to be clear of personnel access openings.

2.2.4.3　Fixed fire detection and alarm system are to be so installed and arranged at the position of motor in the inner tower to quickly detect the fire signs and initiate the audible and visual alarms in sufficient places onboard the ship under the normal working condition of the wind-rotor assisted propulsion system and the required ventilation changes within the possible ambient temperature range. Fire detection system using only thermal detectors is not to be permitted. The number of detectors is to meet the requirements of 2.4.2.2 and 2.4.2.3 in Chapter 9 of International Code for Fire Safety Systems issued by IMO.

2.2.5　Handrails

2.2.5.1　Where the arrangement of wind-rotor assisted propulsion system has an impact on the safe accesses of the crew, any one of the measures is to be taken according to the relevant requirements of Regulation 25-1 of ICLL. Where the arrangement of handrails needs to be changed, the protection requirements for crew members in Regulation 25 of ICLL is to be met.

2.2.6 Radar system

2.2.6.1 The radar system is to be so arranged to take consideration of the impact of the wind-rotor assisted propulsion system and comply with the relevant provisions of the Convention and flag State regulations.

2.2.7 Maneuverability

2.2.7.1 The wind-rotor assisted propulsion system is to be so operated to ensure that the ship meets the maneuverability requirements.

2.2.7.2 During the sea trial, the steering equipment and main propulsion system of the ship are to be demonstrated additionally that they can eliminate the adverse impact on the ship maneuverability caused by the operation of the wind-rotor assisted propulsion system within the ship's service range.

2.2.7.3 The operating manual is to record whether the ship applies the wind-rotor assisted propulsion system under various typical working conditions and the ship's maneuverability, including the operation limits and measures under extreme conditions.

2.2.8 Explosion-proof

2.2.8.1 In principle, electrical equipment and cables are not be installed and laid in hazardous zones specified in Table 1.3.3.3, Chapter 1, PART FOUR of CCS Rules for Classification of Sea-going Steel Ships, Sections 16 and 18 of Chapter 2 in CCS Guidelines for Hazardous Area Classification and Electrical Installations of Tankers. Where the electrical equipment and cables related to the wind-rotor assisted propulsion system need to be installed and laid in hazardous areas due to operational requirements, the relevant explosion-proof requirements of the above-mentioned rules and guidelines are to be met.

2.2.9 Lightning protection

2.2.9.1 The wind-rotor assisted propulsion system is to be so installed to be capable of reducing the indirect damage effect on the electrical system caused by lightning stroke. The metal shell of the equipment is to be reliably grounded, and meet the relevant requirements of Section 13, Chapter 2, PART FOUR of CCS Rules for Classification of Sea-going Steel Ships.

2.3 Longitudinal strength

2.3.1 Basic requirements

2.3.1.1 The longitudinal strength of newbuildings is to be calculated in accordance with the requirements of Section 2, Chapter 2, PART TWO in CCS Rules for Classification of Sea-going Steel Ships.

2.3.1.2 The longitudinal strength of conversion ships is to be determined for recalculation according to the evaluation results of impact on the light weight center of gravity and loading conditions after the installation of wind-rotor assisted propulsion system.

2.4 Local strength

2.4.1 Calculation model

2.4.1.1 The scope of the model is generally the local three-dimensional structure model (hereinafter referred to as the local model), centered on the rectangular (a×b) centroid of the effective acted plane of the foundation, extends to the surroundings at least once the corresponding length and width of the rectangular (3a×3b), respectively and vertically extends from the foundation surface to the first platform below the deck or at least D/4 (D is the molded depth). If the main supporting structural members are not provided on the boundary of model obtained according to the above-mentioned method, the model is to be re-extended until the boundary falls on the main supporting structural members. In order to take into account the interaction between the inner tower of rotor and the supporting structure, a section of the inner tower of the rotor extending above the deck is to be considered in the model. The principles of element selection, characteristics and modeling mesh division for the model are to be in accordance with the requirements of 1.5.6, Chapter 1, PART TWO in CCS Rules for Classification of Sea-going Steel Ships. In order to better observe the impact of the opening at the high stress part, it is recommended to refine the mesh of the local area at the edge of the opening.

2.4.1.2 The boundary conditions are to be assumed on the basis of principle not affecting the calculation results of the observed elements in the model center. In general, free support or fixed support may be provided.

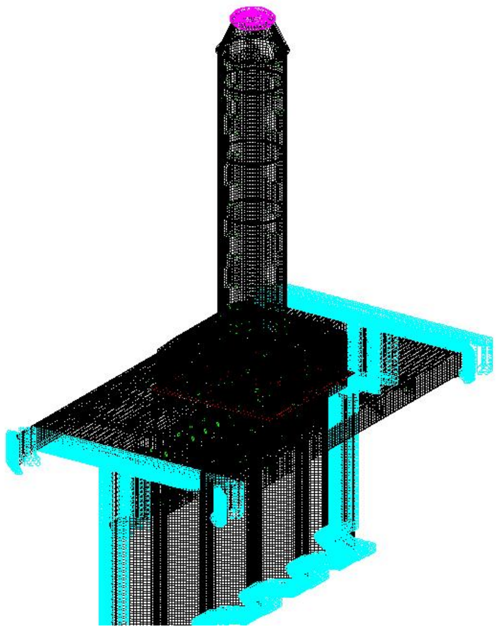

Figure 2.4.1.1 Boundary conditions

2.4.2 Selection of design loads and conditions

2.4.2.1 The design loads are generally to be based on the flettner-rotor and inner tower calculation conditions and combinations, at least including the following loads:

(1) Wind loads (including Magnus force);

(2) Inertial force load due to ship motion;

(3) Gyroscopic torque generated by rotation of flettner-rotor;

(4) Weights of flettner-rotor and inner tower;

(5) Greenseas load on deck (when the rotor is arranged within 1/4L of the bow).

2.4.2.2 The design working conditions are to include the most unfavorable forced conditions of the rotor hull supporting structure, and several typical working conditions in longitudinal, transverse and different oblique directions can also be selected according to experience and actual operation conditions (each working condition for every 45°within the deck operating plane).

2.4.3 Evaluation criteria

2.4.3.1 At each working condition, the calculating stress of rotor hull supporting structure is not to be greater than the allowable value in Table 2.4.3.1.

Allowable stress Table 2.4.3.1

Type of element	Allowable stress
Cross girder system	Normal stress: $[\sigma]=0.67R_{eH}$ Shear stress: $[\tau]=0.39R_{eH}$
Plate element	Equivalent stress: $[\sigma]=0.80R_{eH}$

Note: R_{eH} — yield stress of material, in N/mm^2.

2.4.3.2 For the longitudinal support structural members within 0.4L (L is the ship's rule length) of the amidship taking account of calculation of the longitudinal strength for the hull girders, in addition to the local strength requirements specified in 2.4.3.1, the strength under the combined action of local loads and the longitudinal bending moment of the hull girders is also to be checked, and the safety factor of the superimposed equivalent stress is not to be less than 1.1.

2.5 Stability

2.5.1 Operating condition

2.5.1.1 For ships installed with wind-rotor assisted propulsion system, the unfavorable effects on stability under off-working and normal working conditions are to be considered.

2.5.2 Wind area

2.5.2.1 The impact of the wind-rotor assisted propulsion system is to be considered for the wind area. The wind area of the system is to be its side projection area multiplied by the height correction factor C_H. The height correction factor C_H is to be obtained by the vertical distance Z_H measured from the center of the side projection area to the waterline in Table 2.5.2.1.

Height correction factor C_H Table 2.5.2.1

Z_H (m)	$0\le Z_H<15$	$15\le Z_H<30$	$30\le Z_H<45$	$45\le Z_H<60$	$60\le Z_H<75$	$75\le Z_H<90$	$90\le Z_H<105$	$105\le Z_H<120$
C_H	1	1.16	1.32	1.44	1.53	1.61	1.68	1.74

2.5.3 Icing accretion

2.5.3.1 For ships with ice class notation or navigating in areas where ice may accumulate, the unfavorable effects caused by the icing accretion of the wind-rotor assisted propulsion system are to be considered for stability of the ships.

2.5.4 Additional heeling moment effect

2.5.4.1 In the intact stability calculation, the unfavorable effects of the additional heeling moment that may be generated due to aerodynamic influency at the maximum operating speed are to be considered based on the characteristics of the wind-rotor assisted propulsion system, and the following requirements are to be complied:

(1) The static heeling angle is not to be greater than 2 °, or;

(2) If the static heeling angle is greater than 2 °, the impact of static heeling angle is to be taken into account in the criteria regarding righting arm curve properties.

2.5.5 Other requirements

2.5.5.1 The stability manual is to include additional guidance for the operation of the wind-rotor assisted propulsion system, including considerations for operational envelops or weather window.

2.5.5.2 For the conversion ships, the impacts of the installed wind-rotor assisted propulsion system on the detail weights and center of gravity calculation to adjust the lightship properties and stability information are to be evaluated, and the evaluation results are used to determine whether the ship need to be re-inclined and the loading manual, damage stability calculations and loading computer need to be re-submitted for approval.

2.6 Noise

2.6.1 Basic requirements

2.6.1.1 Ships that MSC.337 (91) is applicable are to be considered the impacts of operation of rotors on the noise in the superstructure compartments, and meet the requirements of compartment noise limits specified in the Code on Noise Levels on Board Ships.

2.7 Electrical installations

2.7.1 Power load

2.7.1.1 The power load of the wind-rotor assisted propulsion system is to be calculated in the power load estimation of the global ship, which may be included in "the power load estimation of main power supply and emergency power supply" required to be submitted for approval in 1.1.3.1, Chapter 1, PART FOUR of CCS Rules for Classification of Sea-going Steel Ships.

2.7.2 Shell protection of electrical equipment

2.7.2.1 The shell protection type of electrical equipment related to the wind-rotor assisted propulsion system is to be so selected to be appropriate to the installation space, and its minimum protection level is to meet the requirements of Table 1.3.2.2, Chapter 1, PART FOUR of CCS Rules for Classification of Sea-going Steel Ships.

2.7.3 Overload and short circuit protection

2.7.3.1 Each feeder circuit of wind-rotor assisted propulsion system is to be protected against overload and short circuits by a multi-pole circuit breaker arranged to interrupt simultaneously all insulated poles, or a multi-pole switch with fuses, and meet the requirements of 2.5.9, Chapter 2, PART FOUR of CCS Rules for Classification of Sea-going Steel Ships.

2.7.4 Lighting

2.7.4.1 Lighting is to be provided in the inner tower so as to facilitate inspection and maintenance.

2.7.5 Other requirements

2.7.5.1 In addition to the provisions of 2.7.1 to 2.7.4 mentioned above, the electrical system and electrical installations of wind-rotor assisted propulsion system are to meet the applicable requirements of Chapter 2, PART FOUR in CCS Rules for Classification of Sea-going Steel Ships.

CHAPTER 3　CONSTRUCTUION REQUIREMNTS OF ROTORS

3.1　General provisions

3.1.1　Basic requirements

3.1.1.1　The rotors are to be so constructed to ensure safety under design environmental conditions and continuous normal working under operating conditions.

3.2　Materials

3.2.1　Basic requirements

3.2.1.1　The materials used for manufacturing the rotors are to meet the environmental conditions during the service.

3.2.1.2　The metal materials and welding process used for manufacturing the rotors are to meet the relevant requirements in PART ONE and PART THREE of CCS Rules for Materials and Welding. The fiber, resin, core material and other non-metallic materials used to manufacture the rotors are to meet the relevant requirements in Chapter 2, PART TWO of CCS Rules for Materials and Welding and the construction technology may refer to the relevant provisions in Chapter 3, PART TWO.

3.2.1.3　Effective measures are to be taken to prevent water vapor from entering the internal and external surfaces of the flettner-rotors.

3.2.1.4　If the flettner-rotor is made of carbon fiber materials, corrosion of the metal materials in contact with carbon fiber is to be considered.

3.3　Design conditions

3.3.1　General description

3.3.1.1　This section gives the design conditions and minimum design loads for the structural safety assessment of wind-rotor assisted propulsion system.

3.3.2　Environmental conditions

3.3.2.1　In structural design, weather conditions, humidity, temperature, corrosion and other relevant environmental conditions are to be considered.

3.3.2.2　The rotors (including auxiliary mechanical and electrical equipment) are to be so designed to meet the following temperature and humidity requirements:

(1) Internal spaces:

Air temperature: -25℃~ +70℃

Relative humidity: 80%

(2) Weather areas:

Air temperature: -25℃~ +45℃

Relative humidity: 80%, and taking into account of the effects of salt spray and greenseas.

3.3.3　Operating conditions

3.3.3.1　Normal operating condition

The manufacturers are to determine the normal working condition and submit detailed calculation data to CCS for approval. The calculation data submitted include but are not limited to the maximum operating wind speed based on the ship's heading and the ship motion under the corresponding sea conditions. Under normal operating conditions, the following loads and their worst combinations are to be considered when analyzing the structure of the wind-rotor assisted propulsion system and the foundation structure:

(1) Inertial force load caused by dead weight and ship motion;

(2) Wind loads due to the wind;

(3) Gyroscopic torque generated by rotation of flettner-rotor;

(4) Ice and snow loads due to ice and snow (if applicable);

(5) Hull girder loads of the ship (for the foundation structure, and the structure is arranged on the longitudinal structural member taking account of calculation of the longitudinal strength).

3.3.3.2 Self-storage operating condition

For the self-storage operating condition, it represents the most severe environmental conditions that may be encountered by ships installed with wind-rotor assisted propulsion system. Under the self-storage operating condition, the environmental conditions are beyond the allowable operation range, and the wind-rotor assisted propulsion system stops running. The manufacturers are to determine the self-storage condition and submit detailed calculation data to CCS for approval. Calculation data submitted include but are not limited to wind conditions and corresponding sea state data. At the same time, in the structural analysis, the impacts of gust and the vertical distance from the water surface to the position of the wind-rotor assisted propulsion system are to be considered. Under the self-storage condition, the following loads and their worst combinations are to be considered when analyzing the wind-rotor assisted propulsion system structure and foundation structure:

(1) Inertial force load caused by dead weight and ship motion;

(2) Wind loads due to the wind;

(3) Greenseas load caused by green water;

(4) Ice and snow loads due to freezing and snowing (if applicable);

(5) Hull girder loads of the ship (for the foundation structure, and the structure is arranged on the longitudinal structural member taking account of calculation of the longitudinal strength).

3.4 Design loads

3.4.1 Basic requirements

3.4.1.1 This Section includes the design loads acting on the wind-rotor assist propulsion system and the foundation structure. All load calculation data are to be submitted to CCS for approval.

3.4.2 Wind load

3.4.2.1 The submitter is to submit the maximum wind load and corresponding wind direction under normal operating conditions and self-storage conditions.

3.4.2.2 The wind load under normal operating conditions is to be defined according to the force generating unit of the wind-rotor assisted propulsion system, including lift and resistance. The calculation method is to be submitted to CCS for approval. When the wind load is calculated, Magnus force, gust factor and vertical distance from the water surface are to be properly considered.

3.4.2.3 Under the normal operating condition, the design wind speed is generally not to be less than:

$$V_D = V_{max} \times G_f$$

Where:

V_D — design wind speed under normal operating condition;

V_{max} — maximum operating wind speed under normal operating condition;

G_f — gust coefficient, provided by the designer, generally to be taken as $1.25 \le G_f \le 1.45$.

3.4.2.4 The wind load under self-storage conditions is to consider the most unfavorable angle of wind direction and the resistance under projected area, etc. of the wind-rotor assisted propulsion system simultaneously. The calculation method is to be submitted to CCS for approval. In the absence of specific calculation methods, at least the following calculations are to be carried out:

(1) Wind speed

The wind loads under various design conditions are to be obtained based on measured data and provided by the owners / designers. Normally, the return period of design wind speed is not to be less than 100 years, and generally not to be less than 51.5 m/s.

(2) Wind pressure

The wind P is to be calculated by the following formula:

$$P = 0.613 \cdot V_S^2 \cdot 10^{-3} \quad \text{kPa}$$

Where:

V_S — design wind speed under self-storage condition, in m/s. When calculating the steady wind, taking the average wind speed at 10m above the average sea level with an interval of 1 minute.

(3) The wind force F acting on the structural member is to be calculated by the following formula, and the vertical height of resultant force acting point is to be determined:

$$F = C_H \cdot C_s \cdot S \cdot P$$

Where:

P — wind pressure, in kPa;

S — when the flettner-rotor structure is in the positive floating or inclined state, the positive projected area of the wind structural member, in m^2;

C_H — height correction factor of wind structural member, which may be obtained from Table 3.4.2.4 according to the height of wind structural member Z_H (the vertical distance from core of structural member to design water surface);

Height correction factor C_H Table 3.4.2.4

Z_H (m)	$0 \le Z_H < 15$	$15 \le Z_H < 30$	$30 \le Z_H < 45$	$45 \le Z_H < 60$	$60 \le Z_H < 75$	$75 \le Z_H < 90$	$90 \le Z_H < 105$	$105 \le Z_H < 120$
C_H	1	1.16	1.32	1.44	1.53	1.61	1.68	1.74

C_s — shape factor of wind structural members, taken as 1.0, and may be determined according to the wind tunnel test.

3.4.2.5 The data of representative model wind tunnel test conducted by a recognized laboratory may be used as the basis for determining the wind pressure and its resultant force.

3.4.3 Inertial force load

3.4.3.1 Inertial force load caused by ship motion means the load caused by ship motion and the self weight of the wind-rotor assisted propulsion system. These loads are to be submitted to CCS for approval, including but not limited to the ship acceleration considered.

(1) The acceleration for bulk carriers and oil tankers is not to be less than the calculated value

specified in 3.3, Chapter 4, PART NINE of CCS Rules for Classification of Sea-going Steel Ships.
(2) The acceleration for container ships is not to be less than the calculated value specified in 3.3, Chapter 4 of CCS Structural Rules for Container Ships.
(3) The acceleration for other ship types other than the above-mentioned (1) and (2) is not to be less than the calculated value specified in 1.5.2.2, Chapter 1, PART TWO of CCS Rules for Classification of Sea-going Steel Ships.
(4) In addition, the ship acceleration value directly calculated or obtained from model test may also be considered. In this case, when determining the acceleration for the ships navigating in unrestricted areas, the design life of the ship used is not to be less than 20 years, and wave dispersion diagram in IACS Rec.34 is to be used.
3.4.3.2 The combination coefficient of each acceleration under the conditions of head sea, beam sea and diagonal sea is shown in Table 3.4.3.2.

Acceleration coefficients Table 3.4.3.2

Load combination	a_x	a_y	a_z
Head sea 1	a_{x-env}	0	a_{z-env}
Head sea 2(1)	a_{x-env}	0	$-a_{z-env}$
Beam sea 1	0	a_{y-env}	a_{z-env}
Beam sea 2(1)	0	a_{y-env}	$-a_{z-env}$
Diagonal sea 1	0.6 a_{x-env}	0.6 a_{y-env}	a_{z-env}
Diagonal sea 2 (1)	0.6 a_{x-env}	0.6 a_{y-env}	$-a_{z-env}$
Note: (1) Under the hogging state			

3.4.4 Ice and snow loads
3.4.4.1 Where a ship is navigating in an iced sea area, the ice and snow loads are to be considered. If the accumulation of ice is to be taken account without empirical value or specified value, it is to be assumed that the ice accumulation thickness of all construction parts exposed to weather conditions is generally to be 3cm with the weight per unit volume of ice is 700kg/m^3, and the weight per unit volume of snow is 200kg/m^3.
3.4.5 Greenseas load
3.4.5.1 Under the self-storage condition, greenseas load is to be taken into consideration:
(1) The greenseas load for bulk carriers and oil tankers is not to be less than the calculated value specified in 5.4.3 and 5.4.4 of Chapter 4, PART NINE of the CCS Rules for Classification of Sea-going Steel Ships.
(2) The greenseas load for container ships is not to be less than the calculated value specified in 5.4.3 and 5.4.4 of Chapter 4 of the CCS Structural Rules for Container Ships.
(3) The greenseas load for other ship types other than the above-mentioned (1) and (2) is not to be less than the calculated value specified in 2.17.2, Chapter 2, PART TWO of CCS Rules for Classification of Sea-going Steel Ships.

3.5 Structural calculation of flettner-rotor

3.5.1 Local strength
3.5.1.1 The calculated load is to be selected according to the worst combination of loads required in 3.4 of this Chapter.

3.5.1.2 The calculated working condition is to be selected according to the worst combination of loads required by various working conditions in 3.3.3 of this Chapter.

3.5.1.3 The allowable stress $[\sigma]$ of steel flettner-rotor structure is to be calculated by the following formula:

$$[\sigma] = \frac{\sigma_s}{\beta \cdot n}$$

Where:

σ_s — yield strength of flettner-rotor material, in MPa;

n — safety coefficient，taken as 1.21 under normal operating conditions; and taken as 1.05 for self-storage conditions;

β — coefficient, selected from Table 3.5.1.3 according to the steel yield ratio.

Coefficient β Table 3.5.1.3

Yield ratio	≤0.7	0.75	0.80	0.85	0.90
β	1.0	1.045	1.084	1.120	1.155

Note: Yield ratio means the ratio of yield strength to tensile strength.

3.5.2 Buckling strength

3.5.2.1 The buckling strength of flettner-rotor is to be taken into consideration, including the global and local buckling. The global buckling check is to be carried out in accordance with 3.2.19 and 3.2.21 of CCS Rules for Lifting Appliances of Ships and Offshore Installations and the local buckling check is to be carried out in accordance with 3.2.20 of CCS Rules for Lifting Appliances of Ships and Offshore Installations.

3.6 Structural calculation for inner tower

3.6.1 Local strength

3.6.1.1 The calculated load is to be selected according to the worst combination of loads required in 3.4 of this Chapter.

3.6.1.2 The calculated working condition is to be selected according to the worst combination of loads required by various working conditions in 3.3.3 of this Chapter.

3.6.1.3 The allowable stress $[\sigma]$ of inner tower and its foundation is to be calculated by reference to the requirement of 3.5.1.3 in this Chapter.

3.6.1.4 The buckling strength of inner tower is to be calculated by reference to the requirement of 3.5.2 in this Chapter.

3.6.2 Vibration

3.6.2.1 The main excitation sources of the inner tower structure vibration include the main engine, propeller, as well as the vibration caused by the ship total vibration, ship motion and Karman-vortex-street phenomenon, etc.

3.6.2.2 The inner tower structure is to be avoid resonance with each excitation as far as possible to prevent harmful vibration.

3.6.3 Fatigue

3.6.3.1 The possibility of fatigue damage caused by cyclic load is to be considered at the design stage of the rotor supporting structures / foundation. For the requirements of fatigue strength calculation, refer to CCS Guidelines for Fatigue Strength of Hull Structures or other recognized standards.

3.6.3.2 The fatigue strength of the connection between the foundation of rotor and the deck is to be considered as a minimum.

3.6.3.3 At least the following fatigue loads are to be taken into account:

(1) Wind load;

(2) Inertial force load due to ship motion;

(3) Gyroscopic torque.

3.6.3.4 Where the rotor structure is subject to a larger vibration load, the impact of vibration load is also to be considered in the fatigue strength analysis.

3.6.4 Corrosion protection

3.6.4.1 For the steel supporting structures of inner tower, a certain corrosion increment is to be considered in the design according to the service life.

3.6.4.2 Anti-corrosion measures are to be taken for the supporting structure of inner tower, such as epoxy coating or aluminum thermal spraying, etc.

3.6.4.3 Insulation measures are to be taken for connection between different materials to avoid galvanic corrosion.

3.6.4.4 Anti-corrosion measures such as zinc coating protection, etc. are to be taken for bolts, nuts, gaskets and other fasteners connecting the flettner-rotor and the foundation to avoid crevice corrosion.

3.6.4.5 Anit-corrosion measures, such as coating are to be taken for the foundation.

3.7 Miscellaneous

3.7.1 Climbing protection

3.7.1.1 The ladders provided in inner tower are to be equipped with safety railings for climbing from the tower foundation to the maintenance platform. For work at height, appropriate safety measures are to be taken to set up connection points for safety belts.

CHAPTER 4 SYSTEM DESIGN REQUIREMENTS

4.1 General provisions

4.1.1 The wind-rotor assisted propulsion system is to be able to ensure continuous normal working under operating conditions and ensure operation safety.

4.2 Drive system

4.2.1 The drive motor and its control equipment are to meet the relevant requirements of Section 2 and Section 4, Chapter 3, PART FOUR of CCS Rules for Classification of Sea-going Steel Ships.

4.2.2 The drive system including power semiconductor converter, if equipped, is to meet the relevant requirements of Section 8, Chapter 3, PART FOUR of CCS Rules for Classification of Sea-going Steel Ships.

4.3 Safety measures

4.3.1 In a case of emergency, the drive system is to be shutdown and the rotation of the flettner-rotor is to be stopped.

4.3.2 A locking device is to be provided at the local position to prevent the wind-rotor assisted propulsion system from being unauthorized started and stopping the rotation of flettner-rotor.

4.3.3 The electrical system of the wind-rotor assisted propulsion system is to be so design to be able to inhibit or consume the rotation energy of the flettner-rotor, at meanwhile, avoid damage to the drive motor due to excessive pump voltage, and the pump rise voltage suppression circuit is not to be started when the drive motor is in a normal operation and electric state.

4.4 Control and monitoring alarm system

4.4.1 The wind-rotor assisted propulsion system is to have monitoring and automatic and manual control functions to maintain the system running within the predetermined parameter range under different operating conditions.

4.4.2 The control system and monitoring and alarm system are to be so designed that a failure in the operation process will not lead to other failures, and the risk generated will be reduced as low as possible.

4.4.3 The automatic control and remote control system are to ensure continuous, effective and reliable operation.

4.4.4 Each wind-rotor assisted propulsion system is to be equipped with an individual control device and protection device. Where multiple wind-rotor assisted propulsion systems are designed to operate simultaneously, they can be synchronously controlled by one system.

4.4.5 Where multiple control positions are provided, control conversion is to be capable of implementing between control positions when the equipment under common control operates normally or fails. Such conversion is not to lead to serious changes of operation status for the equipment. The control conversion may be carried out only after receiving the response. All control positions are to indicate which position is under control.

4.4.6 In case of severe failure (such as motor overspeed, system crash, etc.) of the wind-rotor assisted propulsion system, it is to be able to give an alarm. The manual emergency shutdown devices independent of the ship control system are to be provided in the navigation bridge, other remote control positions (if any) and local positions. The arrangement is to be able to prevent being accidentally initiated.

4.4.7 The following displays of wind-rotor assisted propulsion system are to be provided in the navigation bridge and other control positions (if provided):

(1) Normal operation of drive motor;

(2) Voltage, current, frequency and power of drive motor;

(3) Speed and direction of rotor;

(4) Wind direction and speed (except for local positions);

(5) System control mode;

(6) Status indication of the locking device.

4.4.8 The following audible and visual alarms are to be provided in the navigation bridge and other control positions (if any) for the wind-rotor assisted propulsion system:

(1) Failure of control, monitoring and alarm system;

(2) Power supply failure of power system;

(3) Power supply failure of control, monitoring and alarm system;

(4) Failure of drive motor;

(5) Conversion of stand-by motor (if provided);

(6) High temperature of motor cold medium (if provided);

(7) Motor overspeed;

(8) System emergency shutdown;

(9) High pump rise voltage (if applicable).

4.4.9 As a Category I system, the computer control system used for wind-rotor assisted propulsion is to meet the relevant requirements of Section 6, Chapter 2, PART SEVEN of CCS Rules for Classification of Sea-going Steel Ships.

4.4.10 In addition to the above-mentioned, requirements, the control and monitoring alarm system of wind-rotor assisted propulsion system is also to meet the requirements of Section 1, 2, 4 and 7, Chapter 2, PART SEVEN of CCS Rules for Classification of Sea-going Steel Ships.

CHAPTER 5　SURVEY

5.1　General provisions

5.1.1　Survey process and basic requirements

5.1.1.1　The requirements for wind-rotor assisted propulsion system in this Chapter are a supplement to the applicable survey provisions of PART ONE of the CCS Rules for Classification of Sea-going Steel Ships. The system is to be surveyed according to the requirements of this Chapter after installation.

5.1.1.2　CCS surveyor is to participate in and witness the workshop test, survey during construction and survey after construction of the system. The system is to be tested and inspected by personnel authorized by the manufacturer before it is installed onboard the ship.

5.1.1.3　Upon the onshore commissioning of the wind-rotor assisted propulsion system is completed, product certificate is to be issued by CCS.

5.1.1.4　The list of certificates for main components of wind-rotor assisted propulsion system is shown in Table 5.1.4.

List of certificates for main components　Table 5.1.4

No.	Name of product	Category of certificate		Approval mode				Plan approval	Remark
		C/E	W	DA	TA-B	TA-A	WA	PA	
1	Motor (50kW and above)	X	—	—	X	O	—	X	
2	Motor (below 50kW)	—	X	—	X	—	—	X	
3	Electrical control box	X	—	—	—	—	-	X	
4	Power, control and communication cables and wires	X	—	—	—	—	X	X	Including optical fiber and network cables in control and communication cables
5	Monitoring alarm system	X	—	—	X	O	—	X	
6	Frequency converter	X	—	—	X	O	—	X	Frequency converter with the power of 50kW and above
7	Small weather station (wind direction anemometer)	—	X	—	X	—	—	X	

8	Gear box	X	—	—	X	O	—	X	Applicable to the gear transmission device of the main propulsion machinery transmitting the maximum continuous power of 220kW or more and the important auxiliary engine of 110kW or more
9	Gear box	X	—	—	—	—	—	X	Applicable to the gear transmission device of the main propulsion machinery transmitting the maximum continuous power less than 220kW and the important auxiliary engine less than 110kW
10	Slewing bearing	X	—	—	—	—	—	X^1	C/E is to be provided for forging material

Symbol description:

1) C— marine product certificate; E—equivalent document; W— manufacturer document; X—applicable; O— optional;
2) DA—design approval; TA-B—type approval B; TA-A—type approval A； WA—works approval; PA—plan approval;
3) X^1: The survey is to be carried out according to the approved drawings of integrity product / system (ship, product).

5.1.1.5 Other equipment is to be designed and tested according to recognized standards. For the requirements of certificates, refer to Chapter 3, PART ONE of CCS Rules for Classification of Sea-going Steel Ships.

5.1.1.6 The wind-rotor assisted propulsion system is to be commissioned on shore in accordance with the test procedures approved by CCS before being installed onboard the ship.

5.2 Survey during construction

5.2.1 Function test

5.2.1.1 Before the wind-rotor assisted propulsion system is tested onboard the ship, necessary testing is to be carried out at workshop.

5.2.1.2 The following items are to be confirmed by surveyor:

(1) The wind-rotor assisted propulsion system has been installed in accordance with the approved drawings, and the followings are to be confirmed:

① Visual inspection of supporting structures and deck connections;

② Inspection of installation for mechanical devices, piping and electrical equipment;

③ Check of lightning protection measures (if applicable);

④ Check whether the operation and maintenance manual is available onboard the ship;

⑤ NDT (if applicable), refer to Table 5.2.1.2.

NDT for structural welds Table 5.2.1.2

Position of welds	NDT scope and method
Circumferential welds of the foundation and supporting structural members; Transition structural members between the foundation and supporting structure members;	For the plate thickness of 8mm or greater, 100% UT (RT) is to be carried out in full penetration area, and meanwhile, 100% PT or MT is to be carried out; For the fillet welds with plate thickness of 8mm or greater, 100% MT is to be carried out.
Critical welds of supporting structural members and the structural members generating force	For the plate thickness of 8mm or greater, 20% UT (RT) is to be carried out in full penetration area, and meanwhile, 100% PT or MT is to be carried out; For the fillet welds with plate thickness of 8mm or greater, 10% PT or MT is to be carried out.
Other welds	During construction, random NDT may be carried out if it is deemed necessary by the surveyor.

5.2.1.3 For the wind-rotor assisted propulsion system with slewing bearing, the followings are to be confirmed by the surveyor:

(1) Planeness;

(2) Surface condition;

(3) Contact surface of slewing bearing;

(4) Rolling test.

5.2.1.4 The functional test of wind-rotor assisted propulsion system is to be carried out according to the procedure approved by the surveyor, including at least the following items:

(1) Test for all alarm points and safety points;

(2) Automatic safe shutdown testing;

(3) Emergency shutdown testing;

(4) Functional test of mechanical devices, electrical units and control systems;

(5) Test of fire detection and extinguishing systems (if applicable).

5.2.2 Sea trail

5.2.2.1 According to the approved sea trial and commissioning procedures, sea trial is to be carried out for the wind-rotor assisted propulsion system, and the wind conditions is to be so converted to be corresponding to the design wind speed.

5.2.2.2 The followings are to be confirmed through the sea trial:

(1) The wind-rotor assisted propulsion system is to be capable of responding in accordance with the actual wind conditions, including emergency cases. During the sea trial, the surveyor is to confirm that the wind-rotor assisted propulsion system operates reliably, meets the functional requirements, and has no dangerous vibration within the entire design range. Based on the results of sea trial, the following information is to be updated and available on board the ship:

① Ship stopping time;

② Ship heading and stopping distance;

③ For ships with multiple propellers, the test results of navigation and maneuverability when one or several propellers fail.

(2) The unfavorable effects of wind-rotor assisted propulsion system on the normal operation of the ship, including maneuverability and stability, are to be considered. For specific information to be recorded, refer to the Provisions and Display of Maneuvering Information on Board Ships (IMO Resolution A.601 (15)).

(3) The response between the wind-rotor assisted propulsion system and the main propulsion system, steering system and control system is to be confirmed according to the test procedure submitted by the manufacturer and approved by CCS.

5.3 Survey after construction

5.3.1 Annual survey

5.3.1.1 In the annual survey, the followings are to be confirmed:

(1) Visual inspection is to be carried out for the foundation and supporting structural members of the wind-rotor assisted propulsion system so as to avoid the defects, such as excessive deformation, excessive wear, corrosion, cracks, etc.;

(2) The safety system of wind-rotor assisted propulsion system, including emergency shutdown, alarm, fire alarm and locking or release system in extreme cases is to be tested;

(3) The wind-rotor assisted propulsion system and its control system is to operate;

(4) If slewing bearing is provided, the crew is to inspect according to the checklist and cycle recommended by the manufacturer, and the surveyor is to confirm the self-inspection records onboard the ship.

5.3.2 Special survey

5.3.2.1 In addition to the applicable items specified in 5.3.1 of this Chapter, the special survey is also to include the contents of 5.3.2.2 and 5.3.2.3.

5.3.2.2 NDT verification may be carried out if any doubts on the foundation structural condition.

5.3.2.3 Where the wind-rotor assisted propulsion system is equipped with slewing bearing, the followings are to be inspected and tested:

(1) The surveyor is to carefully check the swivel device, including the bolts, foundation, bearing surface, etc., to check the defects, such as deformation, crack, etc.;

(2) Confirming the pretightening force of slewing bearing bolts according to the manufacturer's documents;

(3) All slewing bearing bolts are to be tested (such as hammering test or torque verification) to

determine their firmness and tightness;
(4) The slewing bearing bolts are to be inspected without disassembly and pull-out, unless it is deemed necessary by surveyor;
(5) Necessary NDT may be carried out for the slewing bearing bolts if surveyor has any doubts;
(6) The surveyor is to witness the rolling test according to the manufacturer's procedure. If the test results and / or grease samples show excessive wear, the bearing is to be opened for inspection or replacement.

CHAPTER 6 EEDI/EEXI CALCULATION AND VERIFICATION

6.1 General provisions

6.1.1 Application

6.1.1.1 This Chapter intends to provide relevant calculation methods and verification guidance for ships applying to include the energy-saving effect generated by the wind-rotor assisted propulsion system into the calculated value of Attained EEDI/EEXI.

6.1.1.2 The Guidelines ignores the additional resistance caused by the yawing, rudder angle and heeling of the ship, or the reduction of propeller efficiency caused by the light load operation of the ship when the wind-rotor assisted propulsion system is applied.

6.1.1.3 This Chapter is a supplement to ships installed with wind-rotor assisted propulsion system based on the CCS Rules for Green Eco-Ships, Guidelines for Calculation and Verification of Energy Efficiency Design Index (EEDI) for Ships Engaged on International Voyages, Guidelines for Calculation and Verification of Energy Efficiency Design Index (EEDI) for Ships Engaged on Domestic Voyages and Guidelines for Calculation and Verification of Energy Efficiency Index (EEXI) for Existing Ships, so as to provide the basis for assigning the CO_2 emission design index (CD_X) class notation to the newbuildings and the CO_2 emission design index (CDE_X) class notation to the ships in-service.

6.1.1.4 This Chapter only provides the stipulations to the EEDI calculation and verification of international sea-going ships installed with wind-rotor assisted propulsion system. The EEDI of ships engaged on domestic voyages is to be implemented by reference, and the EEXI of existing ships is to be implemented by comparison.

6.1.2 Scope of application

6.1.2.1 This Chapter is applicable to sea-going ships applying for the CO_2 emission design index (CD_X) class notation assigned to the newbuildings and the CO_2 emission design index (CDE_X) class notation assigned to ships in-service under the CCS Rules for Green Eco-Ships.

6.1.2.2 For the sea-going ships engaged on international voyages, the applicable ship types and definitions are referred to the provisions of Chapter 2, PART ONE in CCS Rules for Green Eco-Ships.

6.1.2.3 For the sea-going ships engaged on domestic voyages, the applicable ship types and definitions are referred to the provisions of Chapter 4, PART TWO in CCS Rules for Green Eco-Ships.

6.2 EEDI calculation methods for wind-rotor assisted propulsion ships

6.2.1 Attained EEDI formula

6.2.1.1 For ships installed with wind-rotor assisted propulsion system, the general Attained EEDI calculation formula is used, i.e.:

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

* 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 $0.75 * \sum_{i=1}^{nPTO} P_{PTO(i)} \leq P_{AE}$, $P_{AE}.C_{FAE}.SFC_{AE}$ 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}.

6.2.2 Definition and selection of parameters in Attained EEDI calculation formula

6.2.2.1 For ships installed with wind-rotor assisted propulsion system, except for the calculation of the contribution of the system to EEDI, other calculations are to be carried out in accordance with Chapter 2 of CCS Guidelines for Calculation and Verification of Energy Efficiency Design Index (EEDI) for Ships Engaged on International Voyages.

6.2.2.2 Main engine propulsion power（$P_{ME(i)}$）, main engine carbon conversion factor ($C_{FME(i)}$), Main engine specific fuel consumption ($SFC_{ME(i)}$), auxiliary engine power（P_{AE}）, auxiliary engine carbon conversion factor (C_{FAE}), auxiliary engine specific fuel consumption (SFC_{AE}), capacity, correction factor to account for ship specific design elements (f_j), capacity correction factor（f_i）, cubic capacity correction factor（f_c）, correction factor of speed loss in waves（f_w）, shaft motor power（$P_{PTI(i)}$）are to be selected in accordance with Appendix 1 of CCS Rules for Green Eco-Ships.

6.2.2.3 The speed (V_{ref}) means the ship speed, in knot, on deep water when the wind-rotor assisted propulsion system is shutdown at the main engine propulsion power（$P_{ME(i)}$）and capacity as defined in 6.2.2.2 and assuming the weather is calm with no wind and no waves.

6.2.2.4 The energy-saving effects of wind-rotor assisted propulsion system are expressed as P_{eff}, which is multiplied by innovative energy technology availability factor f_{eff}, and multiplied by C_{FME} and SFC_{ME}（if $P_{PTI(i)}>0$, the average weighted value of ($SFC_{ME} \cdot C_{FME}$) and ($SFC_{AE} \cdot C_{FAE}$)) and then be deducted from EEDI formula.

6.2.2.5 Among them, the available effective factors (i.e.: $f_{eff} \cdot P_{eff}$) of the wind-rotor assisted propulsion system may be converted to calculate by the following formula:

$$(f_{eff} \cdot P_{eff}) = \left(\frac{1}{\sum_{k=1}^{q} W_k}\right) \cdot \left(\left(\frac{0.5144 \cdot V_{ref}}{\eta_D} \sum_{k=1}^{q} F(V_{ref})_k \cdot W_k\right) - \left(\sum_{k=1}^{q} P(V_{ref})_k \cdot W_k\right)\right)$$

$$F_1 - F_k \geq 0 \wedge F_{k-1} - F_k \geq 0$$

and,

$$\sum_{k=1}^{q-1} W_k < \frac{1}{2} \wedge \sum_{k=1}^{q} W_k \geq \frac{1}{2}$$

Where:

(1) ($f_{eff} \cdot P_{eff}$) means the available effective output power of the wind-rotor assisted propulsion

system, in kW. Since the probability of each wind field and the force generated by the sail assisted propulsion system under various wind fields are different, the combination of f_{eff} and P_{eff} is to be used for calculation. The product of availability and power is the calculation result of the wind field probability matrix and propulsion force matrix deducting the power required for the operation of the wind-rotor assisted propulsion system.

(2) Reference speed V_{ref} is the same specified in 6.2.2.3.

(3) η_D is the total efficiency of the main drive(s) at 75% of the rated installed power (MCR) of the main engine(s). η_D is to be set to 0.7, if no other value is specified and verified by the verifier.

(4) $F(V_{ref})_k$ is the force matrix of the respective wind-rotor assisted propulsion system for a given ship speed $V_{ref.}$ Each matrix element represents the propulsion force, in kN for the respective wind speed and angle. The wind angle is given in relative bearings (with 0° on the bow).

(5) W_k is the wind field probability matrix. Each matrix element represents the probability of wind speed and wind angle relative to the ships heading. The sum over all matrix elements equals 1 and is non-dimensional.

(6) The power matrix needed by wind-rotor assisted propulsion system, $P(V_{ref})_k$, in kW, is to be with the same dimensions as $F(V_{ref})_k$ and W_k.

(7) The power for the operation of the specific wind-rotor assisted propulsion system is to be subtracted from the gained additional propulsion power.

6.2.3 Force matrix $F(V_{ref})_k$

6.2.3.1 Each wind-rotor assisted propulsion system generates different force with different ship speed, wind speed and wind direction angle relative to the heading, which is represented by a two-dimensional matrix $F(V_{ref})_{k.}$ The matrix contains any combination elements of wind speed under the reference speed V_{ref} and wind direction angle relative to the heading.

6.2.3.2 Each matrix element represents the propulsion force, in kN for the respective wind speed and angle. The wind angle is given in relative bearings (with 0° on the bow). The force matrix $F(V_{ref})_k$ for the wind-rotor assisted propulsion system may be formulated by reference of Table 6.2.3.2.

Force matrix of wind-rotor assisted propulsion system (kN) Table 6.2.3.2

Wind direction angle（°） Wind speed（m/s）	0	5	10	…	355
0.5	$f_{1,1}$	$f_{1,2}$	$f_{1,3}$	…	$f_{1,72}$
1.5	$f_{2,1}$	$f_{2,2}$	$f_{2,3}$	…	$f_{2,72}$
2.5	$f_{3,1}$	$f_{3,2}$	$f_{3,3}$	…	$f_{3,72}$
…	…	…	…	…	…
23.5	$f_{24,1}$	$f_{24,2}$	$f_{24,3}$	…	$f_{24,72}$
24.5	$f_{25,1}$	$f_{25,2}$	$f_{25,3}$	…	$f_{25,72}$
25.5	$f_{26,1}$	$f_{26,2}$	$f_{26,3}$	…	$f_{26,72}$

6.2.4 Wind field probability matrix W_k

6.2.4.1 The wind field probability is represented by a two-dimensional matrix $W_{k.}$

6.2.4.2 The wind field probability matrix W_k may be formulated by reference of Table 6.2.4.2.

Wind field probability matrix Table 6.2.4.2

Wind speed（m/s） \ Wind direction angle（°）	[0,5)	[5,10)	[10,15)	…	[355,360)
[0,1）	$w_{1,1}$	$w_{1,2}$	$w_{1,3}$	…	$w_{1,72}$
[1,2）	$w_{2,1}$	$w_{2,2}$	$w_{2,3}$	…	$w_{2,72}$
[2,3）	$w_{3,1}$	$w_{3,2}$	$w_{3,3}$	…	$w_{3,72}$
…	…	…	…	…	…
[23,24）	$w_{24,1}$	$w_{24,2}$	$w_{24,3}$	…	$w_{24,72}$
[24,25）	$w_{25,1}$	$w_{25,2}$	$w_{25,3}$	…	$w_{25,72}$
[25, +∞）	$w_{26,1}$	$w_{26,2}$	$w_{26,3}$	…	$w_{26,72}$

6.2.4.3 The wind field probability matrix is to be obtained from the wind field probability data on the global main shipping routes. In general, ships engaged on international voyages are to apply the global wind field probability distribution matrix in Appendix 1 of the Guidelines.

6.3 Verification method for contribution of wind-rotor assisted propulsion system to EEDI

6.3.1 Verification procedures

6.3.1.1 For ships installed with the wind-rotor assisted propulsion system, the EEDI verification is to be carried out in accordance with CCS Guidelines for Calculation and Verification of Energy Efficiency Design Index (EEDI) for Sea-going Ships Engaged on International Voyages at first.

6.3.1.2 The wind-rotor assisted propulsion system is to be verified according to the additional requirements of 6.3.2 and 6.3.3.

6.3.1.3 The force matrix $F(V_{ref})_k$ used to determine the final contribution of the wind-rotor assisted propulsion system to EEDI is to be verified by the experienced verifier.

6.3.2 Preliminary verification at the design stage

6.3.2.1 In addition to the requirements of Chapter 4 in CCS Guidelines for Calculation and Verification of Energy Efficiency Design Index (EEDI) for Sea-going Ships Engaged on International Voyages, the EEDI technical file submitted by the applicants is to include:

(1) Arrangement of wind-rotor assisted propulsion system;

(2) Schematic diagram of wind-rotor assisted propulsion system;

(3) Application of scope for wind-rotor assisted propulsion system;

(4) Control / operating manual for wind-rotor assisted propulsion system;

(5) Detailed process and results of performance test or simulation calculation of force matrix $F(V_{ref})_k$ of wind-rotor assisted propulsion system;

(6) Attained EEDI calculation process and preliminary results of a ship installed with a wind-rotor assisted propulsion system.

6.3.2.2 For ships installed with wind-rotor assisted propulsion system, the rapidity pool test is to be carried out according to the requirements of conventional ships at first.

6.3.2.3 In the design stage, the wind force factor is to be firstly measured in order to obtain the force matrix $F(V_{ref})_k$ of wind-rotor assisted propulsion system shown in Table 6.2.3.2.

6.3.2.4 Either of the following methods may be used to determine the aerodynamic characteristics of a wind-rotor assisted propulsion system:

(1) Wind tunnel model test;
(2) CFD / numerical calculations;
(3) Full scale test.

6.3.2.5 The force factor is to be determined for the combination of wind-rotor assisted propulsion system and ship.

6.3.2.6 In the case of the installation of multiple wind wind-rotor assisted propulsion systems, the force factor may be determined for the devices in isolation and by the summing the coefficients of each units comprising the system, provided that a validated method is in place to account for interaction effects between rotors and between the ship and rotors.

6.3.2.7 The wind tunnel model test is a major method for measuring the aerodynamic force of a wind-rotor assisted ship propulsion system under typical states. If the wind propulsion coefficients are measured by the wind tunnel model test, testing and calculation are to be conducted in accordance with Appendix 2 of the Guidelines.

6.3.2.8 For some types of wind-rotor assisted propulsion system wind tunnel model tests are not appropriate for measuring the wind propulsion coefficients. Therefore, numerical calculations, such as CFD-computation, may be accepted for estimating the wind propulsion coefficients with the consent of CCS, but the condition and the model of the numerical calculation are to be referred to wind tunnel model test, and in accordance with the latest revisions or equivalent versions of ITTC technical standards.

6.3.2.9 The test procedure to determine the wind propulsion coefficients is to be submitted to CCS in advance of conducting the test. The test is to be witnessed by CCS surveyor. In addition, the detail report of the test and calculation procedure is also to be submitted to CCS after the test. CCS may request the submitter to provide additional documents / information as necessary to verify the wind propulsion coefficients.

6.3.2.10 A single wind tunnel test may be accepted for several identical wind-rotor assisted propulsion systems and identical ship if the applicant provide the acceptable supporting documentation.

6.3.3 Final verification during sea trial

6.3.3.1 In addition to the requirements of Chapter 5 in CCS Guidelines for Calculation and Verification of Energy Efficiency Design Index (EEDI) for Sea-going Ships Engaged on International Voyages, the EEDI technical file submitted by the submitter is to include:
(1) Arrangement of wind-rotor assisted propulsion system (as-built);
(2) Configuration of wind-rotor assisted propulsion equipment (as-built);
(3) Application of scope for wind-rotor assisted propulsion system (as-built);
(4) Control / operating manual of wind-rotor assisted propulsion system (as-built);
(5) The revised Attained EEDI calculation process and final results for ships installed with wind-rotor assisted propulsion system.

6.3.3.2 The power consumption of the wind-rotor assisted propulsion system is to be measured by the direct measurement method to measure the power matrix $P(V_{ref})_k$ required for the operation of the wind-rotor assisted propulsion system under different wind speeds and wind directions, and then obtained by multiplying it with the wind field probability matrix W_k.

APPENDIX 1 GLOBAL WIND PROBABILITY MATRIX W_k

Normalized global wind chart showing the probability of wind conditions relative to the ship′s heading along the main global trading routes

Wind direction angle(°) / Wind speed (m/s)	0	5	10	15	20	25	30	35	40	45	50	55
<1	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
<2	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
<3	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
<4	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
<5	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
<6	0.002	0.002	0.002	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
<7	0.002	0.002	0.002	0.002	0.002	0.001	0.001	0.001	0.001	0.001	0.001	0.001
<8	0.002	0.002	0.002	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
<9	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
<10	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
<11	0.001	0.001	0.001	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
<12	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
<13	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
<14	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
<15	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
<16	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
<17	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
<18	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
<19	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
<20	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
<21	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
<22	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
<23	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
<24	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
<25	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
≥25	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Wind direction angle(°) / Wind speed（m/s）	60	65	70	75	80	85	90	95	100	105	110	115
<1	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
<2	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
<3	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
<4	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
<5	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
<6	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
<7	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
<8	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
<9	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
<10	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
<11	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
<12	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
<13	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
<14	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
<15	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
<16	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
<17	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
<18	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
<19	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
<20	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
<21	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
<22	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
<23	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
<24	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
<25	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
≥25	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Wind direction angle(°) / Wind speed（m/s）	120	125	130	135	140	145	150	155	160	165	170	175
<1	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
<2	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
<3	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
<4	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
<5	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
<6	0.001	0.001	0.001	0.001	0.001	0.001	0.002	0.002	0.002	0.002	0.002	0.002
<7	0.001	0.001	0.001	0.001	0.001	0.002	0.002	0.002	0.002	0.002	0.002	0.002
<8	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.002	0.002	0.002	0.002	0.002
<9	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
<10	0.000	0.000	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
<11	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001
<12	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
<13	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
<14	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
<15	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
<16	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
<17	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
<18	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
<19	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
<20	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
<21	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
<22	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
<23	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
<24	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
<25	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
≥25	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Wind direction angle(°) / Wind speed （m/s）	180	185	190	195	200	205	210	215	220	225	230	235
<1	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
<2	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
<3	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
<4	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
<5	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
<6	0.002	0.002	0.002	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
<7	0.002	0.002	0.002	0.002	0.002	0.001	0.001	0.001	0.001	0.001	0.001	0.001
<8	0.002	0.002	0.002	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
<9	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
<10	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
<11	0.001	0.001	0.001	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
<12	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
<13	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
<14	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
<15	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
<16	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
<17	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
<18	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
<19	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
<20	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
<21	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
<22	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
<23	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
<24	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
<25	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
≥25	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Wind direction angle(°) / Wind speed (m/s)	240	245	250	255	260	265	270	275	280	285	290	295
<1	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
<2	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
<3	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
<4	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
<5	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
<6	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
<7	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
<8	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
<9	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
<10	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
<11	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
<12	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
<13	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
<14	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
<15	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
<16	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
<17	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
<18	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
<19	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
<20	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
<21	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
<22	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
<23	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
<24	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
<25	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
≥25	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Wind direction angle(°) / Wind speed（m/s）	300	305	310	315	320	325	330	335	340	345	350	355
<1	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
<2	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
<3	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
<4	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
<5	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
<6	0.001	0.001	0.001	0.001	0.001	0.001	0.002	0.002	0.002	0.002	0.002	0.002
<7	0.001	0.001	0.001	0.001	0.001	0.002	0.002	0.002	0.002	0.002	0.002	0.002
<8	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.002	0.002	0.002	0.002	0.002
<9	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
<10	0.000	0.000	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
<11	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001
<12	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
<13	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
<14	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
<15	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
<16	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
<17	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
<18	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
<19	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
<20	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
<21	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
<22	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
<23	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
<24	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
<25	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
≥25	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

APPENDIX 2 WIND TUNNEL TEST AND FORCE MATRIX CALCULATION

1 Qualification of an organization to carry out wind tunnel test

1.1 Quality system

1.1.1 The test procedures and quality control system of the wind tunnel test organization are to be verified. If previous experience is not sufficient, the verifier is to audit the quality management system of the organization carrying out the wind tunnel test.

1.1.2 If the quality control system of the organization carrying out wind tunnel test is not certified by effective documents (such as ISO 9001), the following additional information on the organization of wind tunnel laboratory is to be submitted to the verifier:

(1) Description of facilities and equipment of wind tunnel laboratory, including names of facilities, details of equipment and calibration records of each monitoring device;

(2) The main facilities and equipment for wind tunnel test include large low-speed wind tunnel, strain type box balances for ship aerodynamic measurement, dynamic strain testing systems for strain balance signal acquisition and processing, and temperature, humidity and atmospheric pressure sensors for test environment measurement, etc.

2 Wind tunnel test criteria

2.1 Similarity criteria

2.1.1 The wind model test is to be in compliance with the geometric similarity, kinematic similarity and dynamic similarity criteria.

(1) Geometric similarity: the model of flettner-rotor made according to the unified scale meets the geometric similarity conditions.

(2) Kinematic similarity: the relative motion of the air medium simulates the uniform linear motion of the ship, and the angle of attitude and sail angle of the hull model are to be equivalent to those of the full-scale ship.

(3) Dynamic similarity: the test wind speed is to be higher than the critical wind speed and meet the dynamic similarity criterion. The measured model wind load coefficient may be directly extrapolated to predict the wind load coefficient for full-scale ship.

2.2 Model requirements

2.2.1 On the basis of meeting the above-mentioned similarity criteria at the same time, a reasonable scale ratio of the test model is to be set as far as possible, and the processing accuracy of the test model is to meet the requirements of the test procedures.

3 Wind tunnel test

3.1 Test methods

3.1.1 In general, two methods may be used to carry out wind tunnel test.

(1) Option 1: test on a ship model fitted with full wind-rotor assisted propulsion system;

(2) Option 2: test on a complete model of a single wind-rotor propulsion unit.

3.2 Method of test on a ship model fitted with the full wind-rotor assisted propulsion system

3.2.1 Model

3.2.1.1 The wind-rotor assisted propulsion system model and the hull model are to be made similarly to the real form, but appendages which do not affect the aerodynamic characteristics can be omitted from the model (e.g. handrails, windlass, etc.).

3.2.1.2 The draught condition of the hull model is to be corresponding to the capacity defined in the EEDI/EEXI calculation guidelines.

3.2.1.3 The hull model is connected with the turntable by force balance, and the wind direction angle of the ship model is changed by changing the angle of the turntable.

3.2.2 Test conditions

3.2.2.1 The wind tunnel model test of the wind-rotor assisted propulsion ship is to meet the geometric similarity criteria.

3.2.2.2 The dynamic similarity criterion is to be satisfied in the wind tunnel model test of a ship's wind-rotor assisted propulsion system. That is, when the test wind speed is higher than a certain critical wind speed, the dimensionless wind coefficient tends to be stable, and the flow around the model is similar to the real ship. The measured wind coefficient can be directly extrapolated to the real ship. During the test, the critical wind speed is determined by a variable wind speed test.

3.2.2.3 In the wind tunnel model test, Reynolds number of the test is to be more than 1.0×10^6. The Reynolds number, *Re*, is expressed by the following formula:

$$R_e = \frac{\rho \cdot U \cdot L_{PP}}{\mu}$$

Where: ρ and μ are the density and viscosity of the air, respectively, U is the wind speed, L_{pp} is the length between perpendiculars of the model ship.

3.2.2.4 The blockage ratio is not to be more than 5%. The ratio is calculated by the transverse projected area of the model divided by the cross-sectional area of wind tunnel.

3.2.3 Test methods

3.2.3.1 In order to obtain the maximum wind propulsion coefficients of the wind-rotor assisted propulsion system at each hull wind direction angle, the test scheme is to include:

(1) measurements of the aerodynamic force characteristics of the ship model without wind-rotor assisted propulsion system at a series of wind angles ranging from 0° to 360°, spaced by an interval of 5°, potentially extended to 10° .

(2) measurements of the aerodynamic force characteristics of the ship model with wind-rotor assisted propulsion system at a series of wind angles ranging from 0° to 360° (spaced by an interval of 5° or 10°).

(3) in the case where the measurements are carried out with spaced by an interval of 10°, each intermediate force characteristic (i.e. FX at 5°, 15°, 25°…) is to be interpolated by using the measurement results.

3.2.3.2 In the case where the shape of the ship and wind-rotor assisted propulsion system are symmetrical on starboard side and port side, the wind propulsion coefficients are also symmetrical and thus, the measurements at a series of wind angles ranging from 0° to 180° or 180° to 360° can be omitted.

3.2.3.3 If the wind-rotor assisted propulsion system has a changeable and controllable structure, the model of the wind-rotor assisted propulsion system can be arranged as the wind angle, the rotor speed, or other controllable structure to maximize the gained wind force or to minimize the wind resistance.

3.2.4 Calculation of wind propulsion coefficient

3.2.4.1 The formula of the wind propulsion coefficient acting on ship model is as followings:

$$C_{Fx} = F_x / (0.5\ \rho\ V^2 A)$$

3.2.4.2 The propulsion coefficient generated by the wind-rotor assisted propulsion system is to be determined by the following formula:

$$\triangle C_{Fx} = C_{Fx\text{-}with\ WPS} - C_{Fx\text{-}without\ WPS}$$

Where：

C_{Fx} — wind force coefficient of the model pointing to the bow;

F_x — wind force of the model pointing to the bow;

$\triangle C_{Fx}$ — wind propulsion coefficient generated by wind-rotor assisted propulsion system;

ρ — air density of the model test;

V — wind velocity of the model test;

A — total projected area included in the wind-rotor assisted propulsion system.

Note: The subscript "with WAPS" means the state with wind-rotor assisted propulsion system of the ship model, while "without WAPS" means the state without wind-rotor assisted propulsion system of the ship.

3.3 Test on a complete model of a single wind propulsion unit

3.3.1 Model

3.3.1.1 The effects of the hull and superstructures are to be taken into account by corrective actions taking into account the masked area and distance. If several wind propulsion units are installed onboard the ship, the aerodynamic interactions between them are to be taken into account by corrective actions. The applicant may request documentation to verify that these effects have been taken into account.

3.3.1.2 The model of wind-rotor propulsion system is to be connected to the turntable by means of a force balance.

3.3.2 Test conditions

3.3.2.1 The wind tunnel model test of the wind-rotor assisted propulsion system is to meet the geometric similarity criteria.

3.3.2.2 The dynamic similarity criterion is to be satisfied in the wind tunnel model test of a wind-rotor assisted propulsion system. That is, when the test wind speed is higher than a certain critical wind speed, the dimensionless wind coefficient tends to be stable, and the flow around the model is similar to the real ship. The measured wind coefficient can be directly extrapolated to the real ship. During the test, the critical wind speed is determined by a variable wind speed test.

3.3.2.3 In the wind tunnel model test, Reynolds number of the test is to be more than 1.0×10^5. The Reynolds number, Re, is expressed by the following formula:

$$R_e = \frac{\rho \cdot U \cdot L_{PP}}{\mu}$$

Where: ρ and μ are the density and viscosity of the air, respectively, U is the wind speed, C is the mean diameter of the wind-rotor assisted propulsion system.

3.3.2.4 The blockage ratio is not to be more than 5%. The ratio is calculated by the transverse projected area of the model divided by the cross-sectional area of wind tunnel.

3.3.3 Test methods

3.3.3.1 In order to obtain the maximum wind propulsion coefficients of the wind-rotor assisted propulsion system, the test scheme is to include measurements of the aerodynamic force characteristics for:

(1) a range of permissible angles of attack on the wind-rotor assisted propulsion system; and

(2) a range of permissible rotation speed of the wind-rotor assisted propulsion system.

3.3.3.2 The propulsive force on the ship is the aerodynamic force measured on the wind-rotor assisted propulsion system pointing to the bow.

3.3.4 Calculation of wind propulsion coefficient

3.3.4.1 When the wind tunnel test is carried out with a single model of wind-rotor assisted propulsion system, the wind propulsion coefficient of the model can be determined as:

$$C_{Fx} = F_x / (0.5\rho V^2 A)$$

Where:

C_{Fx}— wind force coefficient of the model pointing to the bow;

F_x— wind force of the model pointing to the bow;

ρ — air density of the model test;

V— wind velocity of the model test; and

A— projected area of the wind-rotor assisted propulsion system.

3.3.4.2 The wind-rotor propulsion coefficients C_{Fx} of a multi-unit wind-rotor assisted propulsion system can be calculated by summing the coefficients of the units comprising the system, weighted by the effects of interaction and masking by superstructures.

4 Calculation of force matrix

4.1 Calculation steps and methods

4.1.1 The wind propulsion coefficients of the ship's wind-rotor assisted propulsion system can be used to predict the wind-rotor assisted propulsion system force matrix. Apparent wind is defined as the combination of wind relative to the ground and wind created by the ship's velocity. The steps to calculate the wind propulsion system force matrix are as follows:

(1) Determine the velocity of the ship V_{ref};

(2) Select the average wind speed corresponding to terms in W_k, the global wind probability matrix at 10 m height. For example, the average wind speed corresponding to the first wind speed range (0-1 m/s) of the wind probability matrix is selected as 0.5 m/s, the average wind speed corresponding to the second wind speed range (1-2 m/s) is selected as 1.5 m/s, etc.; by analogy, the average wind speed corresponding to the 26th wind speed range (≥ 25m/s) is selected as 25.5m/s;

(3) Extrapolate the wind speed to the reference height of the wind-rotor assisted propulsion systems taken as the aerodynamic centre of effort height or half height from the waterline:

$$v_{Zref} = v_{10m} \ (z_{ref}/10)^{\alpha} \quad for \ z_{ref} < 300m$$

$$v_{Zref} = v_{10m} \ (300/10) \quad for \ z_{ref} \geq 300m$$

Where:

z_{ref}— the reference height above the water line, to be equal to the point of mid-height of each wind-rotor assisted propulsion system;

v_{10m}— the wind velocity at 10 m above sea level;

v_{Zref}— the resulting wind velocity at the reference height; and

α — taken as 1/9 conforming to ITTC recommendations.

(4) According to the corresponding average wind speed, wind direction angle and the velocity of the ship, calculate the relative wind speed V_k and the relative wind direction angle of the ship;

(5) According to the relative wind direction angle, and the corresponding relationship between the relative wind direction angle and the wind propulsion coefficient C_{Fx}, calculate the average wind propulsion coefficients (C_{Fx}) of the wind-rotor assisted propulsion system corresponding to W_k;

(6) According to the average wind propulsion coefficient of the wind-rotor assisted propulsion system, calculate the terms of the wind propulsion system force matrix $F(V_{ref})_k$ of the full-scale ship corresponding to W_k by following formula:

$$F(V_{ref})_k = \Delta C_{Fx} \bullet (0.5\ \rho\ V_k^2\ A)$$

Where:

ΔC_{Fx}— the average wind propulsion coefficients corresponding to W_k;

ρ— the average air density in shipping environment, taken as 1.225 kg/m^3;

V_k— the relative wind velocity of the full-scale ship corresponding to W_k;

A— the total projected area of the wind-rotor assisted propulsion system.

4.2 Supplement

4.2.1 The settings of the wind-rotor assisted propulsion system may be varied in order to find the best $(\Delta C_{Fx})_k$; this may be done using interpolation provided that increments in settings are sufficiently small.

4.2.2 The settings and deployment of the wind-rotor assisted propulsion system must adhere to the operational constraints as defined for the system (e.g. a maximum operational wind speed, if lower than provided by the global wind probability matrix).

4.2.3 The potential wind drag induced by the system is to be accounted for, such as in unusable wind directions close to head wind and when the systems is not operational due to exceedance of operational limits.

4.2.4 If $F(V_{ref})_k$ exceeds the resistance of the ship, such that the propeller thrust would be negative, $F(V_{ref})_k$ is to be limited at the resistance value.

5 Power consumption of wind-rotor assisted propulsion system

5.1 Calculation steps and methods

5.1.1 For options 1 and 2 of the wind tunnel test scheme, the average power consumption coefficients of the active wind assisted propulsion system are to be calculated during the wind tunnel test.

5.1.2 The power consumption of the wind-rotor assisted propulsion system is to be measured and the power consumption matrix is to be prepared based on the measured values and the systems control plan.

6 Operational limits, lateral forces and yawing moments

6.1 Value range of $F(V_{ref})_k$

6.1.1 $F(V_{ref})_k$ must be calculated only when it is within the operational domain applicable to the wind-rotor assisted propulsion system.

6.1.2 $F(V_{ref})_k$ must be zero for any pair (wind direction; wind force) not in conformity with the operational domain of the wind-rotor assisted propulsion system.

6.2 Lateral forces and yawing moment

6.2.1 The lateral forces on the ship and the yawing moments applied by the wind-rotor assisted propulsion system to the ship are to be documented by the shipyard and / or propulsion system manufacturer and observed by CCS.

6.2.2 Where the lateral forces and yawing moment are particularly significant, the verifier may request course keeping and rudder angle demonstrations to validate conformity with the operational domain.