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FURTHER CONSIDERATION OF THE DRAFT GUIDELINES SUPPORTING THE UNIFORM AND EFFECTIVE IMPLEMENTATION OF IMO'S MID-TERM MEASURES

Draft guidance on how to monitor, report and verify the energy derived from wind propulsion systems (WPS)

Submitted by Norway

SUMMARY	
Executive summary:	This document contains a revised draft of the guidance on wind propulsion systems (WPS) for consideration by the Group. It is proposed to adopt the draft WPS guidance for voluntary application, to gain experience on using the methods and models prior to any mandatory application, such as through the GHG fuel intensity (GFI) calculation.
Strategic direction, if applicable:	3
Output:	3.2
Action to be taken:	Paragraph 12
Related documents:	MEPC 84/WP.5; ISWG-GHG 21/2/1, ISWG-GHG 21/2/7 and ISWG-GHG 23/INF.3

Introduction

1 ISWG-GHG 21 considered and agreed to use the draft WPS guidance contained in document MEPC 84/WP.5 as the base document. To advance discussions on this matter, Norway, other Member States and international organizations have worked together informally to further develop the draft WPS guidance. Based on this informal cooperation, Norway submits a revised draft WPS guidance for the consideration of the Group.

2 The following provides an overview of the main updates and the rationale for key decisions.

Reliability factors

3 The WPS guidance defines four tiers for monitoring energy from WPS. Each of the tiers utilizes a different set of operational data with varying levels of refinement, and each tier has different data monitoring requirements. A reliability factor is intended to be included for each tier based on the accuracy of the measurement method and other relevant variables, resulting in a more conservative (i.e. lower) estimate of the energy derived from WPS for tiers with lower accuracy. However, the possibility of setting multiple reliability factors may be considered if errors arising from different methods, models and monitoring equipment within a tier are found to differ significantly.

4 For the first version of the guidance, which is intended for voluntary application, specific reliability factors are not necessary to be included, as they are only required for mandatory application of the GHG fuel intensity (GFI). The development of precise reliability factors for each tier should be undertaken during the experience building period, during which a body of accurate comparative operational data can be collated.

Accepted models and methods

5 Depending on the tier, the WPS guidance requires the use of recognized performance prediction methods, publicly available wind probability matrices, and hindcast metocean data from recognized meteorological offices. In the first version, the appendix contains only a limited list of examples. For later versions, prior to mandatory application of the GFI, the methods may be limited to models and data sources accepted by the Committee and listed in the appendix. This would ensure consistent application of the monitoring of energy from WPS.

Method for Tier 4 (Direct thrust measurements) added

6 A method for measuring the energy derived from WPS using direct thrust measurements has been added to Tier 4. Under Tier 4, the thrust provided by the WPS is measured directly and continuously during operation. The conversion from thrust to power contribution is performed using a pre-computed model, which is verified through sea trials.

7 Unlike Tiers 1 to 3, which rely on a pre-computed power model combined with ship speed and wind data, Tier 4 derives the aerodynamic contribution of the WPS from onboard force measurements. This reduces dependence on meteorological/anemometer input and detects deviations in WPS performance, for instance due to changes in the atmospheric boundary layer, loading conditions or cargo arrangements, mechanical integrity of the sail, or other operational changes.

8 It should be noted that Tier 4 requires the measured forces to be converted to energy derived from WPS using a conversion model. Uncertainties in this conversion, such as those related to the increase in resistance due to side force and yaw moment, also affect the accuracy of the result. The uncertainty associated with the effect of the WPS on hydrodynamic performance and propulsion efficiency still needs to be accounted for through modelling.

Review and future updates

9 The WPS guidance should be kept under continuous review, taking into account experience gained through its application. To accommodate future updates to the WPS guidance and avoid the need to repeat sea trials and model verifications, a paragraph has been added stating that power and conversion models and sea-trial results accepted in accordance with the version of the guidance in force at the time of approval should remain valid following subsequent revisions of the guidance, unless significant deficiencies are identified or revalidation is specifically required under revised provisions.

Example methods and case studies

10 Reference is made to document ISWG-GHG 23/INF.3 (IWSA), which provides example methods for estimating the wind propulsion contribution to the attained GFI, together with supporting case studies.

Proposal

11 Norway proposes that, following consideration by the Group, the Committee is invited to adopt the draft WPS guidance for voluntary application in order to gain experience with the methods and models prior to any mandatory application, such as through the GFI calculation. The WPS guidance should be kept under review in light of the experience gained through its implementation.

Action requested of the Working Group

12 The Group is invited to consider the draft WPS guidance set out in the annex to this document and the proposal in paragraph 11, and to take action as appropriate.

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ANNEX

DRAFT GUIDANCE ON HOW TO MONITOR, REPORT AND VERIFY THE ENERGY DERIVED FROM WIND PROPULSION SYSTEMS (WPS)

1 Introduction

1.1 This document provides guidance on how to monitor, report and verify the energy derived from wind propulsion systems (WPS).

1.2 The WPS Guidance should be kept under continuous review and updated in light of experience gained through its application in order to make it more robust and effective. Power and conversion models and sea-trial results accepted in accordance with the version of the Guidance in force at the time of approval should remain valid following subsequent revisions of the Guidance, unless significant deficiencies are identified or revalidation is specifically required under revised provisions.

1.3 The purpose of the method is to calculate the energy derived from WPS. Four tiers of methods can be applied as shown in table 1:

.1 Tier 1: Simplified analytic power model combined with statistical weather data;

.2 Tier 2: Ship-specific power model validated by sea trial, combined with hindcast weather data;

.3 Tier 3: Ship-specific power model validated by sea trial, with measured wind-field data under operational conditions; and

.4 Tier 4: Direct thrust measurement (to be developed).

Table 1: Overview of methods for each Tier

	TIER 1	TIER 2	TIER 3	TIER 4
Purpose	Simplified analytic power model combined with statistical weather data	Ship-specific power model validated by sea trial, combined with hindcast weather data.	Ship-specific power model validated by sea trial, with measured wind-field data under operational conditions.	Direct thrust measurement combined with a force to power hydrodynamic and machinery model
Reliability factor	Not defined	Not defined	Not defined	Not defined
Power model	ITTC 7.5-02-03-01.9 Level I or higher. Alternative methods may be accepted.	ITTC 7.5-02-03-01.9 Level II or higher, verified and correlated based on a short sea trial, for example as per ITTC 7.5-04-01-02. Alternative methods may be accepted.	ITTC 7.5-02-03-01.9 Level II or higher, verified and correlated based on a short sea trial, for example as per ITTC 7.5-04-01-02. Alternative methods may be accepted.	Hydrodynamic and machinery effects according to ITTC 7.5-02-03-01.9 Level II or higher, verified and correlated based on a short sea trial, for example as per ITTC 7.5-04-01-02. Alternative methods may be accepted.
Data resolution	Departure and arrival	One hour	One hour	One minute average
Position and speed data	Onboard data acquisition system	Onboard data acquisition system	Onboard data acquisition system	Onboard data acquisition system
Weather data	Statistical	Hindcast	Onboard monitoring	N/A

2 Definitions

2.1 *Apparent Wind Speed (AWS)* is the speed of the wind, in m/s, as measured on board a (moving) ship.

2.2 *Apparent Wind Angle (AWA)* is the angle of the wind, in degrees relative to the ship's heading, as measured on board a (moving) ship.

2.3 *Brake power equivalent* means the means the portion of the ship's propulsion power provided by the WPS, expressed as the equivalent brake power that would otherwise need to be delivered by the engine(s). This does not include the power needed to operate the system.

2.4 *Data Collection Plan* means the methodology and processes that will be used to collect and report the data required to derive the energy from WPS, and can form part of the ship's SEEMP.[1]

[1] Refer to the 2024 Guidelines for the development of a Ship Energy Efficiency Management Plan (SEEMP) (resolution MEPC.395(82), as amended).

2.5 *True Wind Speed (TWS)* is the speed over ground of the wind, in m/s, referenced to a height of 10 metres above sea level.

2.6 *True Wind Direction (TWD)* is the angle of the wind direction, in degrees relative to true North, referenced to a height of 10 metres above sea level.

2.7 *True Wind Angle (TWA)* is the angle of the wind, in degrees relative to the ship's course over ground, independent from the ship's motion, referenced to a height of 10 metres above sea level.

2.8 *Voyage segment* is a sailing segment with a duration limited by the required resolution associated with the relevant Tier.

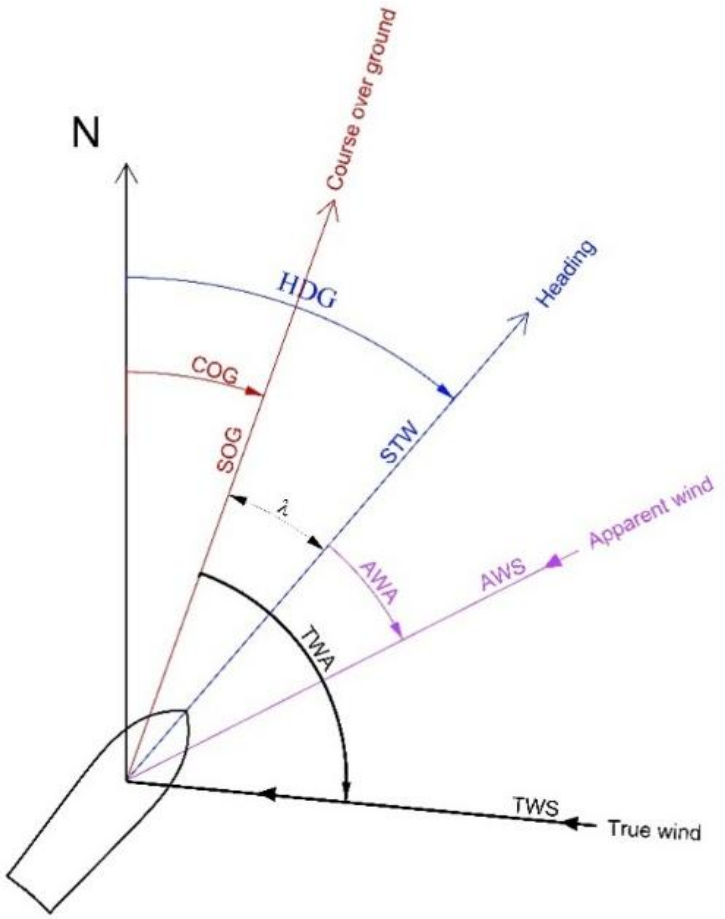


Figure 1: Illustration of the relationships between apparent/true wind, course/heading and speed overground/through water

3 Reliability factors

3.1 Each of the tiers defined in section 1 utilises a different and more/less refined set of operational data and each tier will have differing data monitoring requirements. A reliability factor is intended to be included for each tier based on the accuracy of the measurement method and other variables, resulting in a more conservative (i.e. lower) energy derived from WPS estimate for the tiers with lower accuracy.

3.2 The development of precise reliability factors for each of the tiers will be determined during an experience building period prior to any mandatory application such as through the GFI calculation, during which a body of accurate, comparative operational data can be collated.

3.3 Although a single default factor may be assigned to each tier to ensure simplicity, the possibility of setting multiple reliability factors may be considered if errors arising from different methods, models and monitoring equipment within a tier are found to differ significantly. More detailed, differentiated reliability factors may be revisited once sufficient operational data and validation experience has been collected.

3.4 Once assigned, the default factors will still be subject to review and may be refined as further experience is gained.

3.5 The following elements could, inter alia, be considered when assessing reliability factors:

.1 confidence in performance prediction models;

.2 quality of model validation;

.3 measurement quality and uncertainty;

.4 accuracy of wind-field characterization;

.5 representativeness of operational data;

.6 data quality management and traceability; and

.7 robustness under operational conditions.

3.6 These elements may be assessed using quantitative metrics, including associated uncertainties, fidelity levels, data completeness and resolution, reproducibility, and auditability. For each element, a typical conservative estimate of the associated error or bias should be determined and weighted according to its impact on overall reliability.

3.7 The methodology for determining reliability factors should recognize improvements in areas that can be directly influenced by equipment manufacturers, including, but not limited to, wind speed and direction measurements, thrust measurements, and high-frequency data acquisition.

4 Tiers 1, 2 and 3: power model combined with ship speed and wind data

4.1 General approach

4.1.1 Tiers 1, 2, and 3 share a common general approach to estimate the energy derived from WPS using a power model based on ship and WPS characteristics. The model estimates the brake power equivalent provided by the WPS for different ship speeds, wind speeds and angles, and may be validated by a sea trial.

4.1.2 The ship's position, time sailed, speed and whether the WPS is in use are monitored with a certain resolution as required by the Tier and used to derive wind data. The wind data can either be based on statistical data (Tier 1), hindcast metocean data (Tier 2) or monitored onboard (Tier 3).

4.1.3 The power model, validation, source of weather data and onboard data collection determine the Tier and which reliability factor should be applied.

4.2 Calculation or energy derived from WPS

4.2.1 The energy derived from WPS, $Energy_{WPS}$, expressed in MJ, is generally calculated according to the following equation:

$$Energy_{WPS} = f_R \times 3.6 \times \sum_s P(x) \times t_s$$

Where:

f_R is the reliability factor as given in table 1 for the respective Tier;

s is a voyage segment with a given AWA, AWS and ship speed;

t_s, expressed in hours, is the duration of the voyage segment;

v_s, expressed in nautical miles per hour (knots), is the ship's speed during the voyage segment s;

$P(x)$, expressed in kW, is the contribution to the ship's propulsion power, in equivalent brake power, of the respective WPS as a function of the ship's speed and wind conditions; and

the factor 3.6 is the conversion factor from kilowatt-hours (kWh) to megajoule (MJ).

4.2.2 The ship speed should be measured as the speed over ground for Tier 1, and the speed through water for Tiers 2 and 3.

4.3 Power function

4.3.1 For Tier 1, the power function should be determined using recognized performance prediction methods such as ITTC 7.5-02-03-01.9, Level I or more (see the appendix for examples).

4.3.2 For Tiers 2 and 3, the power function should be determined using recognized performance prediction methods such as ITTC 7.5-02-03-01.9, Level II or more (see the appendix for examples). The power function should be defined for all relevant wind directions, wind speeds as well as ship speeds at 0.5 knot intervals within the operational domain of the WPS, using a representative loading condition (draft). For ship speeds outside this range, the power provided should be considered as zero. The power function should be verified by a sea trial.

NOTE: Specification of the loading condition to be used may be added at a later stage.

4.3.3 When the WPS can be stowed, intermediately deployed, deployed, or have its motion stopped depending on wind conditions, the power function should be calculated based on the expected WPS operating(s) state for each combination of wind direction, wind speed, and ship speed.

4.3.4 The power should not include the electric power needed to operate WPS which is taken into account in the total fuel consumption of the ship.

4.4 Wind data

4.4.1 For Tier 1, TWS and TWD are derived from a publicly available wind probability matrix constructed from hindcast weather data[2], based on the ship's average speed when sailing in predefined geographic zones. Depending on the power model used, TWS and TWD or AWS and AWA may be used to represent wind conditions.

4.4.2 For Tier 2, TWS and TWD are derived from hindcast metocean data from recognized meteorological offices[3] based on the ship's position. The hindcast data spatial resolution should be no more than 1 degree (approx. 60 nm), at maximum 1-hour intervals. The data should be calculated into AWS and AWA and corrected to the same reference height for which the power function was derived (usually 10m above water surface).[4]

4.4.3 For Tier 3, AWA and AWS are measured under operation using LIDAR or anemometer(s). AWA and AWS should be corrected to the same reference height for which the power function was derived (usually 10m above water surface).

LIDAR

4.4.4 The LIDAR system should measure the undisturbed AWA and AWS at the reference height for which the power function was derived. LIDAR measurements are recommended to be done between 0.5 to 1 ship lengths from the ship, and should be done pointing directly into the apparent wind, if possible, or otherwise facing forward. A scanning 2D LIDAR should be used, while a 1D LIDAR may be used if the measurement points align as closely as possible with the reference height using in the power model.

4.4.5 LIDAR data should be processed to derive horizontal wind speed and direction, and the effects of ship motions should be assessed in terms of variability of height of the measurement and the variation of averages. Until dedicated correction methods are available average values may be used.

Anemometers

4.4.6 Multiple anemometers at different positions may be used to select the least disturbed wind measurement at different wind angles. Still, the measurements obtained from the anemometer are typically influenced by flow disturbances caused by the ship's freeboard, superstructure and wind propulsion devices. Therefore, the anemometer readings must be corrected, using one or a combination of the following:

.1 correction derived using CFD simulations;

.2 correction derived using temporarily fitted LIDAR; and

.3 correction using hind-cast wind data collected over longer time period.

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2 See sources stated in ITTC 7.5-02-03-01.9

3 For example ERA5 from ECMWF (access to the data may require registration and an account): https://www.ecmwf.int/en/forecasts/dataset/ecmwf-reanalysis-v5

4 The method for deriving AWA and AWS and the correction for height will be included in the 2027 version of ITTC 7.5-04-01-02.

4.4.7 In all cases, the corrected wind measurements should be compared with an independent hindcast wind dataset and should demonstrate agreement on average over a sufficiently long period.

4.5 Data collection

4.5.1 Data should be recorded as required for the relevant Tier. Each voyage, between departure from berth to arrival at berth, is split into segments. For Tier 1, the segments are based on predefined geographical zones in the wind probability matrix. The ship should record the time and position at departure and arrival. The route and traversing of geographical zones should then be calculated assuming the shortest route between departure and arrival, avoiding land, but consider canals if used by the ship. The ship may also report at entry/exit of each geographical zone and consider the shortest route across each zone as a voyage segment. For Tiers 2 and 3, the duration of each segment should be no longer than 1 hour.

4.5.2 For each voyage segment, the data should be monitored, calculated or derived as indicated for Tiers 1, 2 and 3 in Table 2. The data may be needed for calculating the energy from WPS, for verification purposes, or to gather experience in the application of this guidance. Data elements to be monitored, calculated or derived for Tier 4 are covered in section 5.

Table 2: **Data elements to be monitored, calculated or derived per segment for Tiers 1, 2 and 3 (M: Monitored by the ship; C: Calculated based on other data; D: Derived from weather data))**

	Tier 1	Tier 2	Tier 3
Timestamp at the start and end of the segment	M (voyage) C (segment)	M	M
Location, in coordinates, at the start and end of the segment;	M (voyage) C (segment)	M	M
Duration, in hours;	C	C	C
Speed over ground, SOG, in knots (nautical miles per hour);	C	M	M
Speed through water, STW, in knots (nautical miles per hour);	-	M	M
Course over ground, COG, in degrees relative to true north;	-	M	M
Heading, in degrees relative to true north;	-	M	M
True wind speed, TWS, in metres per second, and angle, TWA, in degrees	D	D	-
Apparent wind speed, AWS, in metres per second, and angle, AWA, in degrees	C/D (depending on model)	C	M
Duration(s), in hours, that the WPS was in the operational state(s) corresponding to the power function	M (voyage) C (segment)	M	M
Fore and aft drafts, in metres	M	M	M

4.5.3 All data elements, except the timestamps and locations, should be calculated as an average for the duration of the voyage segment.

4.5.4 The ship's Data Collection Plan, to be verified by the Administration, should include procedures for identification and addressing data gaps. In case any data required to be monitored is unavailable, incomplete, or determined to be invalid due to, for example, sensor malfunction, communication failure, calibration issues, or other reasons, the cause and

duration of the data gap should be recorded. Where feasible, missing and erroneous values should be replaced using a documented estimation method. The extent of estimated data should be minimized and should not materially affect the accuracy or integrity of the estimated energy derived from WPS.

4.5.5 In case monitoring speed through water is not possible, for example due to a failure of the measuring equipment, speed over ground can be used until the speed through water monitoring can be resumed.

4.5.6 Where a reliable estimation is not possible, the ship may revert to a lower Tier for which the data is sufficient, or the relevant segments should be excluded from the calculation of energy derived from WPS.

4.6 Documentation and verification

4.6.1 The power function should be described and documented in the WPS Technical File to be verified by the Administration. Additional information from the shipbuilder or manufacturer may be requested by the verifier, documenting the detailed calculation process of the wind propulsion system force matrix and results of performance tests. The power function is defined once, and is valid until any major change is made to the WPS or the ship which could impact the performance of the WPS.

4.6.2 For Tiers 2 and 3, the power function should be verified and correlated (spot-check) based on sea trials as described in ITTC 7.5-04-01-02. The basic principles of this procedure are as follows:

.1 the power at a limited number of wind conditions (at least 5) are measured using short consecutive runs with the WPS device on and off; and

.2 if the found power do not match the predicted power model, then the prediction modelling must be adjusted. The changes should reflect all wind conditions in a reasonable way, not just the conditions tested in the sea trial.

4.6.3 Sea trials can be conduction during operation, but should be completed prior to reporting of data. Sea trials for sister ships with a similar WPS system and arrangement may be accepted.

4.6.4 The method for recording the data with the required resolution and procedures for identification and addressing data gaps should be stated in the Data Collection Plan to be approved by the Administration. The recorded data should be submitted to verifier as part of the verification of the annual reported data.

4.6.5 The verification of the annual energy derived from the WPS should include a review of the performance prediction calculations, the sea trial result, the data collection, the data processing and, if relevant, the following power function adjustment.

5 Tier 4: direct thrust measurement

5.1 General approach

5.1.1 Tier 4 derives the aerodynamic contribution of the WPS from onboard force measurements which is calculated into energy derived from WPS using a force to power conversion model.

5.1.2 The method consists of two steps:

.1 Establishment and verification of a force to power conversion model: The model should convert the measured forces to equivalent brake power accounting for both the primary aerodynamic benefit and the secondary hydrodynamic effects (such as leeway resistance, yaw moment). The conversion model should be established prior to operation and verified against sea trial ON-OFF test results; and

.2 Onboard force measurements: the longitudinal thrust force and the lateral side force are measured continuously at each WPS unit and converted to equivalent brake power using the established model.

5.2 Conversion from force to power model

5.2.1 The conversion from force to power model should be established using either Method A or B as described below and verified by a sea trial prior to reporting of data. The verification of the conversion model is conducted through comparison with sea-trial data and assessment of the associated measurement uncertainty using validation acceptance criteria in accordance with ISO/WD 26204:2026 and ITTC 7.5-04-01-02.

NOTE: ISO/WD 26204:2026 is under development and not published yet.

Method A

5.2.2 The power is predicted using a Performance Prediction Programme (PPP). Based on the simulation results, a conversion table is constructed that relates ship speed, the total sum WPS thrust forces, yaw moment, and WPS side forces to the resulting equivalent brake power. The conversion table should be defined for all relevant aerodynamic forces as well as ship speeds at 0.5 knot intervals within the operational domain of the WPS.

5.2.3 For each segment, the filtered and averaged ship speed and force measurements are used to look up the corresponding brake power saving P from the verified conversion table.

Method B

5.2.4 As an alternative to Method A, the conversion may be performed by explicit step-wise processing. The following should be determined by model tests or CFD, for example as part of the design verification using a PPP according to ITTC 7.5-02-03-01.9 Level 3:

.1 the added resistance R_i on hull and appendages induced by the WPS side force, as a function of ship speed, the WPS side force, and the WPS yaw moment;

.2 the (propeller) propulsive efficiency η_D as a function of propeller torque and propeller rotation rate (and propeller pitch, if a controllable pitch propeller is used); and

.3 during operation, the following processing is performed for each time step of measured data:

$$P_{WPS} = V_S \times \sum_k F_{x,k}$$

$$P_{E,WPS} = P_{WPS} - V_S \times R_i\left(V_S, F_y, M_z\right)$$

$$P = \frac{P_{E,WPS}}{\eta_D(Q_{PROP}, n_{PROP}\ [, PD_{PROP}])}$$

Where:

V_S is the ship speed through water

$F_{x,k}$ is the thrust measured at wind propulsion unit k, directed forward along the centreline;

R_i is the pre-processed induced resistance due to the total WPS side force and yaw moment;

η_D is the overall propulsive efficiency;

n_{PROP} is the propeller rotation rate;

Q_{PROP} is the propeller shaft torque; and

PD_{PROP} is the propeller pitch setting (only with controllable pitch propellers).

5.3 Onboard force measurements

5.3.1 Two main methods are available to measure the thrust and side force delivered by each WPS unit.

Measurement of structural deformation (including but not limited to strain gauge, optical measurement, ultrasonic)

5.3.2 Strain gauges or optical fibre sensors are installed at structural points in the base, mast, or support structure of the WPS unit. The correlation between measured strain levels and forward and lateral forces should be determined and verified through calibration.

5.3.3 Tension of a kite system can similarly be measured, for example, with strain-based measurement system. In case of kite-system, the force components need to be resolved in longitudinal and lateral directions.

5.3.4 Corrections should be applied for inertial loads arising from ship motions (heave, pitch, and roll), and accelerations (translational and angular), where applicable. Where the steady trim or heel of the ship is not negligible, a corresponding correction to the resolved force components should be applied.

5.3.5 Temperature correction should be applied to all deformation-based measurement approaches.

Pressure-based measurement

5.3.6 Pressure sensors are positioned across the outer surface of the WPS device. Number of sensors used needs to be high enough for a full surface pressure field reconstruction. Integrating the pressure field over the device surface yields the resultant thrust and side force vectors.

NOTE: The requirements for sensor accuracy, correction methods (inertia, temperature, wind application point, sheer where applicable) applied and further guidance on number of sensors used are to be developed.

5.4 Signal processing and data handling

5.4.1 Raw sensor signals should be processed as follows before being used in the power saving computation.

5.4.2 Time averaging: signals should be averaged over 1-minute intervals. Time alignment between force signals and ship motion signals should be verified to avoid phase errors in the inertia correction.

5.4.3 Inertia correction: the measured forces and moments should be corrected for at least the averaged heel and trim using the mass distribution of the WPU above the sensor location. The correction method should be documented and validated**.**

NOTE: Requirements preventing errors from signal misalignment are to be developed (time synchronization).

5.4.4 The processed one-minute averages of thrust, side force, and yaw moment, together with the associated ship speed, propeller operating point, should be passed to the conversion model described in section 5.2 to compute the one-minute brake power saving. These are accumulated over the reporting period to yield the energy from WPS.

5.5 Calibration and measurement integrity

Initial calibration

5.5.1 After sail installation and prior to entering service, the force measurement system based on structural deformation should be calibrated using reference loads of known magnitude applied to the WPS structure. Calibration should be conducted in longitudinal and lateral directions. Calibration should be documented and made available for the verifier.

5.5.2 For pressure-based systems, the calibration should include calibration of the pressure sensors and determination of the zero-position of the angular/orientation measurement.

Maintaining continued validity

5.5.3 Following the initial calibration, the continued validity of the force measurement system should be maintained through a documented measurement-integrity programme. This applies irrespective of the sensing technology employed. The programme should be capable of detecting drift, offset, or a change in the relationship between the measured quantity and the applied forces of a magnitude that would materially affect the reported energy saving.

NOTE: The detailed requirements for the measurement-integrity program are to be developed. See also example content is given in ISWG-GHG 23/INF.3.

Data quality and failure management

5.5.4 The data acquisition system should include plausibility checks to flag or reject erroneous data points, such as signals outside physically expected ranges or sudden step changes indicative of sensor failure.

NOTE: Standardised data quality acceptance criteria, flagging thresholds, and fallback procedures are to be developed.

5.6 Documentation and verification

5.6.1 The scope of verification for Tier 4 should include

.1 review and approval of the force measurement system design, sensor placement, FEM or pressure-integration model, and initial calibration records and calibration method description;

.2 review and approval of the signal processing and inertia correction methodology;

.3 review and approval of the conversion model;

.4 verification of the conversion model against the sea trial ON-OFF test results, confirming that the comparison error E is within the specified acceptance criterion;

.5 review of the Data Collection Plan, including data architecture, storage, quality control procedures, failure management, and fallback provisions; and

.6 annual review of recorded data, including calibration and zero-check logs, flagged and fallback periods, and the accumulated computation of energy from WPS.

5.6.2 Annual verification should include a review of any changes to the force measurement system or conversion model, recalibration records, and a plausibility check of the accumulated energy results, including comparison against Tier 2 or Tier 3 estimates**.**

NOTE: Detailed guidance on verifier qualifications, the scope of annual verification, and audit trail requirements for force measurement data are to be developed.

APPENDIX

EXAMPLES OF METHODS AND MODELS

Recognized performance prediction methods, Tier 1

Force matrix obtained according to section 2.4 of the *2021 Guidance on treatment of innovative energy efficiency technologies for calculation and verification of the attained EEDI and EEXI* (MEPC.1/Circ.896)

"P2310-11-A - Wind Propulsion Power Formula – Documentation.pdf", OPERVENT Project, CRAIN, 2024 – https://www.craintechnologies.com/simwaps/files/P2310-11-A-Wind_Propulsion_Power_Formula-Documentation.pdf

Recognized performance prediction methods, Tier 2 and 3

To be developed