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Analysis of Speed/Power Trial Data

1. PURPOSE

This procedure concerns the method of analysis of the results obtained from the speed trials.

This method follows a methodology similar to the one recommended by ISO 15016.

The primary purpose of speed trials is to determine ship performance in terms of speed, power and propeller revolutions under prescribed ship conditions, and thereby verify the satisfactory attainment of the contractually stipulated ship speed.

The purpose of this procedure is to define procedures for the evaluation and correction of speed trials covering all influences which may be relevant for the individual trial runs.

The applicability of this procedure is limited to commercial ships of the displacement type.

2. TERMS AND DEFINITIONS

For the purposes of this procedure, the following terms and definitions apply:

- **Ship Speed** is that realized under the contractually stipulated conditions. Ideal conditions to which the speed should be corrected are
  - no wind (or maximum wind speed according to Beaufort 2)
  - no waves (or waves with maximum wave heights and wave periods according to Beaufort 1)
  - no current
  - deep water
  - smooth hull and propeller surfaces
- **Docking Report**: Report that documents the condition of the ship hull and propulsors (available from the most recent dry-docking).
- **Trial Agenda**: Document outlining the scope of a particular Speed/Power trial. This document contains the procedures on how to conduct the trial and table(s) portraying the runs to be conducted.
- **Trial Log**: For each run, the log contains the run number, type of maneuver, approach speed by log, approach shaft speed, times when the maneuvers start and stop, and any comments about the run.
- **Propeller Pitch**: This would be the design pitch for controllable pitch propellers.
- **Running Pitch:** the operating pitch of a CPP
- **Brake Power**: Power delivered at the output coupling of the propulsion machinery before passing through any speed reducing and transmission devices and with all continuously operating engine auxiliaries in use.
- **Shaft Power**: Net power supplied by the propulsion machinery to the propulsion shafting after passing through all speed-

reducing and other transmission devices and after power for all attached auxiliaries has been taken off. This is the power usually measured during trials.

- **Delivered Power**: Power delivered to the propeller.

3. RESPONSIBILITIES

The trial team is responsible for carrying out the trials and for correcting the data received. Preferably before the sea trials start, but at the latest when the trial area is reached and the environmental conditions can be studied, agreement between the trial team, shipyard and ship-owner should be obtained concerning the limits of wind forces, wave heights and water depths up to which the trials should be performed. Agreement should be obtained concerning the methods used to correct the trial data.

4. ANALYSIS PROCEDURE

4.1 Measured and observed data prior to the trials

Prior to the trial, the data specified below shall be recorded, based on measurements where relevant:

- Date
- Trial area
- Weather conditions
- Mean water depth in the trial area
- Water temperature and density
- Draughts
- Corresponding displacements
- Propeller pitch in the case of a CPP

It is recommended to retain a record of the following factors, which should prove useful for verifying the condition of the ship at the time of the speed trial:

- Time elapsed since last hull and propeller cleaning
- Surface condition of hull and propeller.

4.2 Data on each run

The following data should be monitored and recorded on each run:

- Clock time at commencement
- Time elapsed over the measured distance
- Ship heading
- Ship's speed over ground
- Propeller rate of revolutions
- Propeller shaft torque and/or brake power
- Relative wind velocity and direction
- Air temperature
- Observed wave height (or: wave height corresponding to observed and/or agreed wind conditions)
- Wave period (or length) and direction
- Rudder angle
- Drift angle
- Ship position and track

Data such as ship's speed, frequency of revolutions of the propeller, torque, rudder angle and drift angle to be used for the analyses shall be the average values derived on the measured distance. The conditions such as wind speed and direction, wave height and direction, water depth and rudder angle should not change considerably during a single run, and average value should be utilised in the corrections.

4.3 Analysis procedure

4.3.1 General Remarks

The recommended procedure for the analysis of speed trials (see flow chart in the annex, Fig.2) is based on thrust identity and requires thrust deduction factors, the wake fractions and the relative rotative efficiencies as input values. Further, reliable propeller open water characteristics of the full scale propeller in use should be available. Such propeller open water characteristics may be derived either from model tests or from calculations received from the propeller manufacturer *[1])

4.3.2 Description of the Analysis Procedure

The analysis of speed-power-trials should follow the flow chart given in the annex (Fig 2) and should consist of

- the evaluation of the acquired data
- the correction of the resistance data derived from the acquired data
- the correction of the speeds at each run for the effect of shallow water
- the calculation of the brake power required for each run corrected for environmental influences
- the presentation of the trial results

1 In case no propeller open water characteristics are available the influence of varying propeller loads on the propulsive coefficients cannot be allowed for; however the proposed correction methods may be applied to the resistance values which have to be calculated assuming statistical values for the quasi-propulsive efficiency of the ship under investigation.

$$\Delta P = \Delta R/\eta_D \qquad (1)$$

4.3.2.1. Evaluation of the acquired data

The evaluation of the acquired data consists of the calculation of the resistance values associated with the measured power values separately for each run of the speed-power-trials.

The reasons the associated resistance should be calculated is that a careful evaluation should consider the effects of varying hydrodynamic coefficients with varying propeller loads. The recommended correction methods except for the one used for shallow water effects are applicable to resistance values only.

The method proposed by Lackenby to correct for shallow water effects is applicable to the ship's speed measured during each run.

As the propeller thrust normally is not measured during speed-power-trials the thrust value associated with the measured torque should be determined by use of the propeller open water characteristics of the actual full scale propeller. To estimate K_T related to the K_Q – value derived from the trial measurements, either the knowledge of η_R is necessary, which can be obtained either from model tests or from statistics, or $\eta_R = 1$ has to be assumed to calculate K_Q' according to (3). With K_Q' as an input to the propeller open water characteristics K_T can be determined and the respective thrust value can be calculated; the required resistance value follows from the calculated thrust by use of the thrust deduction factor which can be derived either from model tests or from statistics.

The formulae to be used are as follows:

$$K_Q = Q/(\rho n^2 D^5) \qquad (2)$$

with

Q: measured torque at each run

n: measured rate of revolution at each run

ρ: density of the sea water
D: diameter of the actual full scale propeller

$$K_Q' = K_Q/\eta_R \quad (3)$$

with
η_R : relative rotative efficiency by use of the thrust identity derived either from model tests or from statistics at set 1 by use of torque identity.

$$K_T = T/(\rho n^2 D^4) \quad (4)$$
$$T = K_T(\rho n^2 D^4) \quad (4a)$$

with
T: thrust, derived from the propeller open water characteristics by use of thrust- or torque identity
n: measured rate of revolution at each run
ρ: density of the sea water
D: diameter of the actual full scale propeller

$$R = T(1 - t) \quad (5)$$

with
R: resistance
t: thrust deduction fraction derived either from model tests or from statistics; the thrust deduction factor may vary as a function of different propeller loads.

4.3.2.2. Correction of the resistance data derived from the acquired data

The resistance values of each run should be corrected for environmental influences and effects such as

- wind
- waves
- water temperature and water density
- steering (R_δ)
- drift (R_β)
- displacement and trim

4.3.2.3. Correction of the measured ship's speed of each run for possible shallow water effects

In case corrections for shallow water effects have to be applied they should be done according to the method proposed by Lackenby (see item 4.3.3.7) for each run. The corrected ship's speeds are then used in the calculation of the propeller load factor.

4.3.2.4. Calculation of the corrected brake power

Based on the resistance value corrected for environmental effects, the associated thrust value has to be calculated according to (4a). With K_T/J^2 as an input value to the propeller open water characteristics the associated values of K_Q' and J should be determined; by use of η_R the relevant K_Q can be obtained according to (3).

From J the corrected value for the propeller revolution can be calculated assuming the knowledge of the effective wake fraction w; w can be derived either from model tests or from statistics.

The brake power P_B can be calculated from the shaft power P_S considering the mechanical losses in the gear box(es), which might be obtained from manufacturers data. The delivered power P_D can be obtained from the shaft power by considering mechanical losses in the intermediate bearings. These losses are normally at least 0,5% per bearing.

The formulae to be used are as follows:

$$T_{corr} = R_{Tcorr} /(1 - t) \quad (6)$$

with
T_{corr}: corrected thrust value for each run

R_{Tcorr}: corrected resistance value for each run
t: thrust deduction factor, either derived from model tests or statistics;

$$(K_T/J^2)_{corr} = T(\rho V_e^2 D^2) \qquad (7)$$

with
T_{corr}: corrected thrust
ρ: mass density of the sea water
V_e: speed of advance:

$$V_e = V_S(1 - w)$$

with
V_S : speed of the ship measured at each run
w : effective wake fraction, to be derived either from model tests or from statistics;

$$J_{corr} = V_e/(n_{corr} D) \qquad (8)$$
$$n_{corr} = V_e/(J_{corr} D) \qquad (8a)$$

with
V_e: speed of advance
J: advance coefficient
D: propeller diameter

$$P_D = 2\pi\rho . n^3_{corr} D^5 K_{Qcorr} \qquad (9)$$

with
P_D: shaft power
ρ: mass density of the sea water
n_{corr}: corrected propeller revolution [1/s]
D: propeller diameter [m]
K_{Qcorr}: corrected K_Q' [-]

$$P_B = P_D/\eta_m \qquad (10)$$

with
P_B: brake power
η_m: mechanical efficiency; considers mechanical losses´in the shafting(s) and gear box(es)

4.3.2.5. Presentation of the trial results

The corrected shaft power values, together with the associated, corrected speed values of runs at almost identical power level, but in opposite directions, should be combined and the means of speed, power and rates of revolutions should be used to fair the final results.

4.3.3 Correction Methods

4.3.3.1 Correction of the ship's performance due to the effects of wind

The resistance increase due to wind is calculated from

$$R_{AA} = \rho_A/2\ V_{WR}^2\ C_{AA}(\psi_{WR})\ A_{XV}$$

using

$$C_{AA}(\psi_{WR}) = C_{AA0}\ K(\psi_{WR})$$

where
A_{XV}: area of maximum transverse section exposed to the wind
$C_{AA}(\psi_{WR})$: wind resistance coefficient
C_{AA0}: wind resistance coefficient in head wind
$K(\psi_{WR})$: directional coefficient of the wind resistance
V_{WR}: relative wind velocity
ρ_A: mass density of air

The wind resistance coefficient in head wind and the directional coefficient of wind resistance shall be based on data derived from model tests in a wind tunnel.

In cases where data are available covering ships of similar type, such data may be used instead of carrying out model tests.

A wide range of statistical data concerning wind resistance coefficients of various ships are given by Blendermann (22). A good initial estimate for such a coefficient for head- and following wind is 0,9.

4.3.3.2. Correction of the ship's performance due to the effects of waves

The most reliable way to determine the loss of speed of a ship in waves is to carry out sea keeping tests in regular head seas of constant wave height and different wave lengths at various speeds. Overlapping the response function of the resistance increase (or thrust increase) in waves and the energy spectrum of the sea state during sea trials leads to the resistance (or thrust-) increase due to the effect of waves.

An analysis method calculating the resistance increase based on these measurements is given in the ISO 15016.

A very simple but nevertheless very useful formula to estimate the resistance increase in waves of heights up to 1,5 to 2m from the bow only is given by Kreitner:

$$\Delta R_T = 0{,}64\ \xi_W^2\ B^2\ C_B\ \rho\ 1/L$$

with

ξ_W: wave height [m]

ρ: specific weight of the water [N/m³]

L: Length of the ship [m]

4.3.3.3. Water temperature and salt content

Both, water temperature and salt content, affect the density of the sea water and so the ship's resistance; usually trial prediction calculations are based on a temperature of the sea water of 15°C and a density of 1,025 t/m³.

A method to correct for the effects of water temperature and salt content is given in the ISO 15016, annex D.

4.3.3.4. Correction of the ship's performance due to the effects of shallow water.

It is recommended to use the method given by Lackenby (Fig. 1).

Using Lackenby for the correction of shallow water effects results in a correction to the ships speed.

$$\Delta V_S/V_S = 0{,}1242(A_M/h^2 - 0{,}05) + 1 - (\tanh(gh/V_S^2))^{1/2}$$

where

A_M: midship section area under water in [m²]

g: acceleration due to gravity in [m/s²]

h: water depth [m]

V_S: ship's speed [m/s]

ΔV_S: loss of speed due to shallow water [m/s]

4.3.3.5. Correction of the ship's performance due to the effects of current.

The effects of current on the ship's performance should be minimised by performing respective runs in opposite directions close together in time. If differences in speed between runs in opposite directions are large, a current correction is recommended following the method outlined in ISO 15016.

4.3.3.6. Effects of steering and drifting

Although methods are proposed to correct steering-and drifting effects during speed trials such corrections may not be accepted by the ship's owner and also are not really appropriate as they may indicate a lack of course stability of the vessel.

The methods, however, are not scientific and the resulting performance should not be utilized for any purpose beyond general guidance.

A method to correct for the effects of steering and drifting is given in the ISO 15016, annex C.

4.3.3.7. Effects of hull and propeller surface roughness

If the trial is performed within a reasonable period of time after final hull painting and propeller polishing, changes in the surface roughness should be minimal and their effect on ship performance negligible.

For particular cases, where the trial takes place after a lapse of a considerable period following final docking, and the effect of surface roughness can no longer be neglected, it may be necessary to correct for such effects using the best available techniques.

Such methods, however, should only be used with caution.

4.3.3.8. Correction of the ship's performance due to the effects of displacement and trim

Displacement and trim are, in general, factors that can be adjusted to stipulated values at the time of the trial but there may be substantial reasons for discrepancies.

Ideally the difference of the actual displacement during the individual trial from the specified value should not exceed 2% and trim shall be maintained within very narrow limits, i.e. the deviation from the specified trim shall be less than 1% of the midship draught. Often this is not possible.

Where the impact of displacement variations is larger, it is recommended to use the correction method given in the ISO 15016, Annex E.

A very simple formula which can be applied either to resistance- or power figures is the Admiral-formula, the use of which is recommended in case the displacement changes within narrow limits.

$$P_1 / (V_1^3 D_1^{2/3}) = P_2 / (V_2^3 D_2^{2/3})$$

where

P_1: power corresponding to displacement D_1

P_2: power corresponding to displacement D_2

V_1: speed corresponding to displacement D_1

V_2: speed corresponding to displacement D_2

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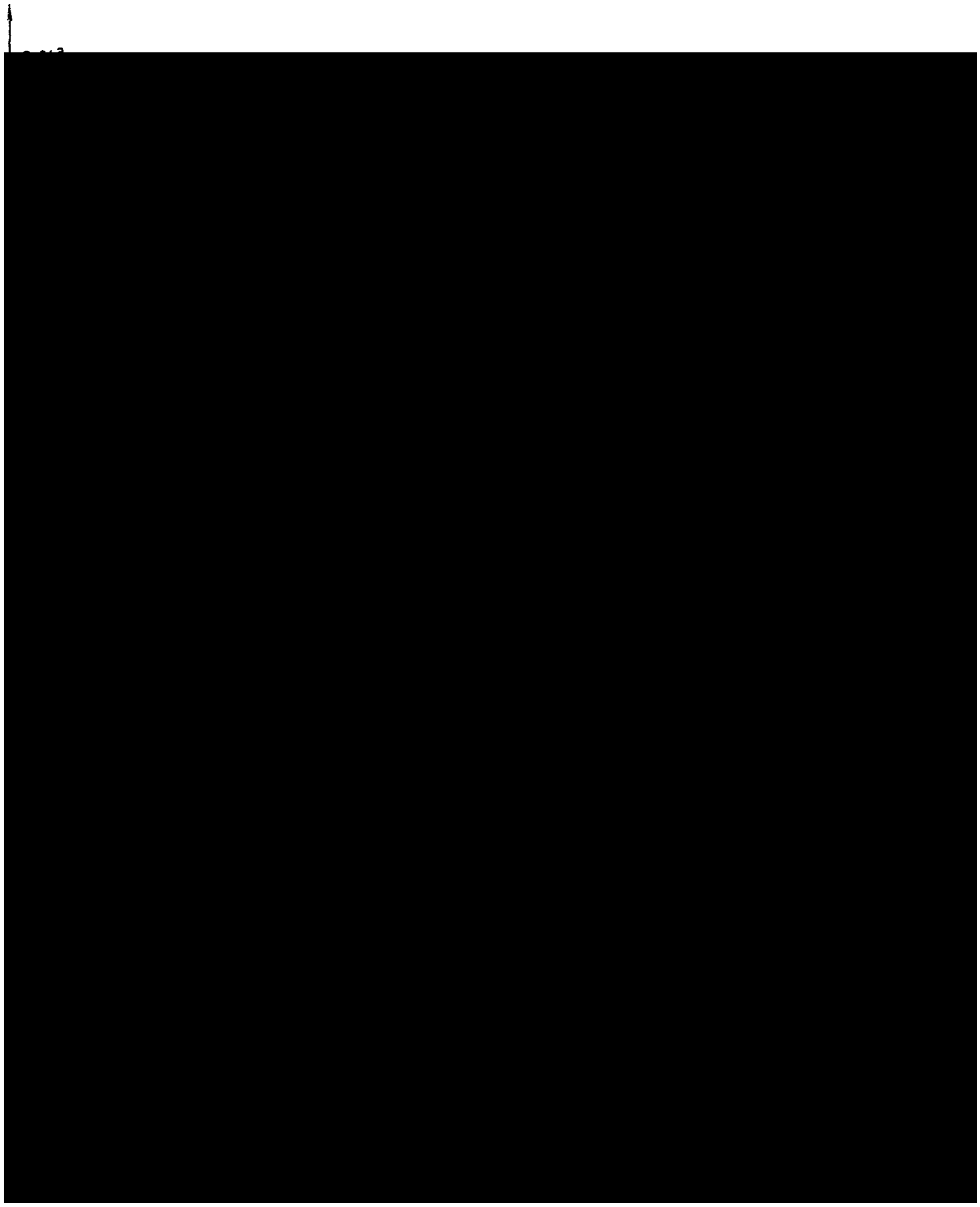

Percentage loss in speed

Figure F.1 - Speed loss due to shaliow water effect

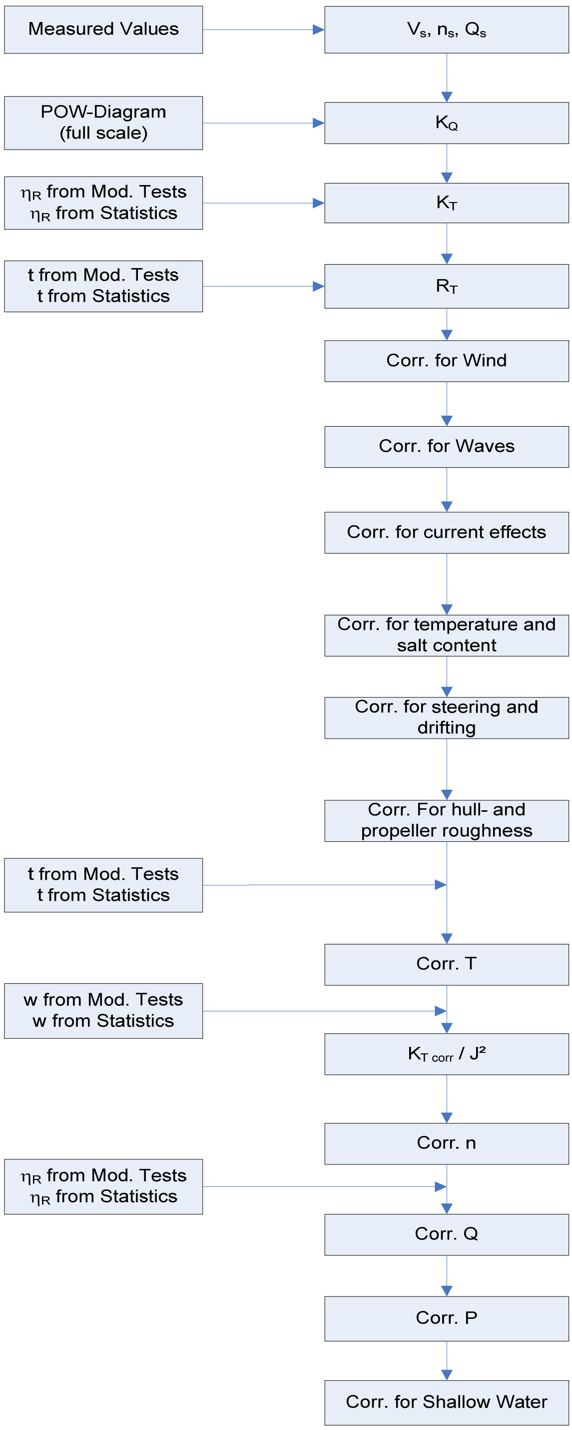
Measured Values
Vs, ns, Qs
POW-Diagram (full scale)
KQ
ηR from Mod. Tests
ηR from Statistics
KT
t from Mod. Tests
t from Statistics
RT
Corr. for Wind
Corr. for Waves
Corr. for current effects
Corr. for temperature and salt content
Corr. for steering and drifting
Corr. For hull- and propeller roughness
t from Mod. Tests
t from Statistics
Corr. T
w from Mod. Tests
w from Statistics
KT corr / J²
Corr. n
ηR from Mod. Tests
ηR from Statistics
Corr. Q
Corr. P
Corr. for Shallow Water

Figure 2