The Specialist Committee on Speed and Powering Trials

Final Report and Recommendations to the 23rd ITTC

1. MEMBERSHIP AND MEETINGS

The 22nd International Towing Tank Conference (ITTC) appointed the following members to the Speed & Powering Trials Specialist Committee:

Dr. Pierre Perdon (Chairman), BEC (FR)

Mr. Everett Woo (Secretary), NSWCCD (USA)

Dr. Roberto Fazzeri, CETENA (IT)

Dr. Yukio Koshiba, IHI (JPN)

Dr. Lech Murawski, CTO (PL)

Dr. Deuk-JoonYum, HHI (ROK)

Technical Committee meetings were held as follows:

DGA/DCE/BEC,Val de Reuil (FR), November 1999

IHI, Yokohama (JPN), April 2000

CTO, Gdansk (POL), September 2000

CETENA, Genova (IT), April 2001

DGA/DCE/BEC, Val de Reuil (FR), December 2001

2. TASKS OF THE SPECIALIST COMMITTEE

Tasks of the 23rd ITTC Technical Committees were given in Appendix 2 of the 22nd ITTC Proceedings and are as follows:

1. Review and update the Guide for Speed/Powering Trials ITTC Procedure 4.9-03-03-01.3 based on the recommendations of the 22nd ITTC trials and Monitoring Committee.
2. The revised procedure must be in the format defined in the ITTC Quality Manual and it should be included in the Committee report as a separate appendix.
3. Take into account the recommendations of ISO TC8/SC9/WG2 Committee Draft 15016.

3. INTRODUCTION

The Specialist Committee (SC) determined, at their first meeting, that Section 4 entitled Speed/Power Trials and Analysis and Appendix 1 entitled Suggested Procedure for Speed/Power Trials of the 22nd ITTC Trials & Monitoring SC final report was well received by the ITTC members. Hence this could be used as the basis for the modification of the Speed/Powering Trials ITTC Procedure 4.9-03-03-01.3. As was evident at the last triennial meeting from the many comments and suggestions, a more in-depth set of inputs was required to complete the assigned SC task. The following approach was devised:

1. Invite shipbuilders and owners to attend the scheduled SC meetings in order to include their insights on how to conduct speed/power trials and to analyze the data obtained from those trials.
2. Expand the uncertainty analysis section to include DGPS and optical torsionmeters.

3. Research and summarize the various data analysis procedures currently in use with emphasis on:
   (a) BSRA Standard Method of Speed Trial Analysis (1978)
   (b) ISO TC8/SC9/WG2 Committee ISO/FDIS 15016 Guidelines for the assessment of speed trial and power performance by analysis of speed trial data.
   (c) Jinnaka, T., On a method of analysis of ship speed trial results of ships, WSNAJ, N°. 64, 1982
   (d) Kracht/VWS et al., Evaluation of trial tests, Proceedings of IWSH '99, Wuhan, China, 1999
   (e) SNAME Guide for Sea Trials, SNAME (1989) (Chapter 4.0 addresses the speed/power trials, known as "Standardization Trials").
   (f) Taniguchi/Tamura: On a new method of correction for wind resistance relative to the analysis of speed trial results, Proceeding of 11th ITTC (1966), ITTC Guide for Measured-Mile Trials, 12th ITTC (1969).
4. Revise the Speed/Powering Trials ITTC Procedure to reflect the knowledge learned.

A clear distinction between the shipyard practice (mainly devoted to delivering the ship within budget and schedule limitations and ship/owner requirements) and the scientific purpose of sea trials was evident.

This newly revised guideline was developed to include the many additional suggestions from shipbuilders, ship owners and research & development personnel. Both contractual and scientific needs and concerns were considered.

4. SECTION 1: PERFORMANCE OF TRIALS FROM THE 22ND ITTC/ISO PROCEDURES

Within the past few years, the most recent guidance in the conduct of ship trials has been concentrated in the area of newly available measuring techniques and in providing guidelines to ITTC members in developing a procedure that demonstrates compliance to ISO 9000 International Standards for Quality Management (1993).

As a result of the work from the previous 22nd ITTC Trials & Monitoring Specialist Committee, suggestions from ITTC members and further discussions with shipbuilders, the SC has developed a number of ISO based procedures that when utilised together may serve as a revised guideline for the conduct of speed/power trials. This guideline attempted to address both the practical and scientific purpose for conducting speed/power trials. A discussion dealing with the analysis of the data obtained from these trials is also presented after the SC reviewed many of the data reduction methods currently in use.

Instead of gathering all aspects of speed powering trials preparation and conduct in a single ITTC recommended procedure, the SC felt it was more appropriate to split the different phases of speed powering trials into different procedures for ease of use and reference as would normally be found in a quality manual.

Six recommended procedures have therefore been derived for approval by the conference.

- "Speed/Power Trial Preparation" 7.5-04-01-01.1
- "Speed/Power Trial Ship Inspection" 7.5-04-01-01.2
- "Speed/Power Trial Hull and Propulsor Survey" 7.5-04-01-01.3
- "Speed/Power Trial Instrumentation Installation and Calibration" 7.5-04-01-01.4
- "Speed/Power Trial Conditions" 7.5-04-01-01.5
- "Speed/Power Trial Conduct" 7.5-04-01-01.6

The two first procedures (Trial Preparation and Ship Inspection) may appear to be slightly outside the scope of ITTC preoccupations but it must not be forgotten that most of the success of a sea trial period lies in the preparation.

"Hull and Propulsor Survey" is an operation, which by itself may not be necessarily related to speed/power trials nor accomplished by the staff in charge of the trial. A separate procedure is clearly justified.

As determined by the 22nd ITTC Trials & Monitoring Specialist Committee, the following measurements shown in Table 4.1 were identified as being required for the successful conduct of speed/power trials:

Table 4.1 List of Measurements and Measurement Equipment.

Physical Quantity	**Measurement Equipment**
ship track	DGPS, Raydist, Other radio-location systems
speed over the ground	DGPS, Raydist, Other radio-location systems
shaft torque	torsionmeter with strain gauges
shaft rpm	pick-up, laser counter, ship revs counter
time	computer clock
water depth	ship echo sounder, nautical charts
rudder angle	angular potentiometer, ship rudder repeater
ship heading	external gyrocompass, ship gyrocompass
relative wind	ship anemometer, external anemometer
wave height (or sea state)	master evaluation, wave meter buoy, weather forecast
roll/pitch	external inclinometer (for fast ships)
shaft thrust	strain gauges, dynamometric load cells

5. SECTION 2: REVISED UNCERTAINTY ANALYSIS

5.1. Introduction

The absolute certainty of a measurement is an abstract concept. Each physical measurement has a certain accuracy level; with the degree of accuracy mostly depending on the intrinsic characteristics of the experimental set-up and the physical quantities involved. This leads to an inherent uncertainty that even the most skilled scientist must consider.

The full-scale speed/power tests imply the acquisition of data relevant to a large amount of physical quantities, each one measured with a given degree of accuracy. To neglect the errors in measurements may cause a complete misunderstanding of the phenomenon and therefore jeopardize any remedial actions.

The Uncertainty Analysis (U.A.) represents the scientific method to evaluate the accuracy of a measurement. In the case of the speed/power tests, U.A. mainly concerns ship speed, shaft torque and shaft revolutions.

The importance of U.A. for sea trials is twofold; relevance to the technical aspects of the full-scale measurements and relevance to the contractual aspects, which are proprietary for commercial sea trial measurements.

The first aspect does not require any comment: since sea trial measurements are a specific kind of measurement and are subjected to the same validation criteria as any experimental measurement.

The second aspect is specific to commercial sea trials, and has a twofold implication. The assessment of the degree of accuracy of the speed-power measurements may represent a guarantee for both shipyards and ship owners on the quality of the results. Additionally in case of dispute, the shipyard could make use of the U.A. to ensure the accuracy of the performed measurements thus avoiding the repetition of the trials.

U.A. may provide the shipyard with an opportunity to perform a quality assurance of the sea trials instrumentation and to support the selection of that instrumentation. The U.A. should not be considered as a part of the sea trials measurements but as a quality procedure to certify the degree of accuracy of the measurements. The determination of the degree of accuracy is performed once for each measurement chain and for each component of the chain. It does not need to be carried out for each individual sea trial. The results of U.A. should constitute an internal document, i.e. a part of the Quality Manual of the company.

The SC recommends the use of the American National Standards Institute (ANSI) and the American Society of Mechanical Engineering (ASME) (1986), standard on Measurement Uncertainty and the approach described by Coleman and Steele (1989) when conducting an uncertainty analysis.

The following sections present additional examples of U.A.

5.2. Determination of Torque Measurements Uncertainty

The torque measurements are performed with the use of an extensometric measurement method. The uncertainty of this measurement consists of three basic components based on:

- gauge
- calibration
- installation on a ship
- recalculation of torque

Gauge uncertainty

The torque measurement is performed with the following systems:

The HBM system consists of components supplied by Hottinger Baldwin Messtechnik (HBM). The system set-up is presented in Figure 5.1.

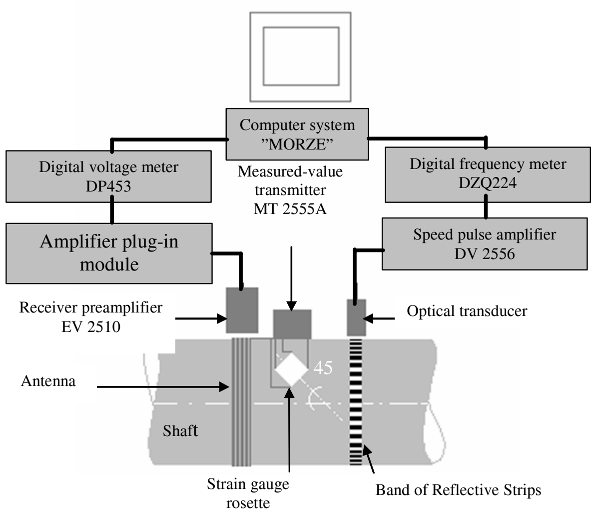


Figure 5.1 Power Measurement System's (Based on Hottinger Baldwin Messtechnik Equipment).

The part of the HBM system responsible for the torque measurement consists of:

1. Strain gauge bridge

Gauge type: CEA-06-25μs-350 Ω

Resistance: R_g=350.0 ± 0.4% Ω

Gauge factor at 24°C 2.045±0.4%

as determined by Micro Measurements, Measurements Group Raleigh, North Carolina.

Hence, the standard uncertainty of the gauge:

$$u(R_g) = \frac{0.4\%}{\sqrt{3}} = 0.2309\%$$

2. Measured-value transmitter and receiver preamplifier

Transmitter type: MT 2555A

Receiver type: EV 2510

Bridge supply voltage: 9V

Nominal input signal: ±2 mV/V

Sensitivity, output frequency: Δf = 5 kHz ±25 Hz (±0.5%)

Effect of ambient temperature on sensitivity: ±0.1%

Effect of operating voltage per 1V: ±0.5% - not required for the system as the voltage is stabilized by UPS.

The standard uncertainty of the transmitter and receiver

$$u^2(\Delta f)=\frac{(0.5\%)^2}{3}+\frac{(0.1\%)^2}{3}=0.08667$$

$$u(\Delta f) = 0.2944\%$$

3. Amplifier plug-in module

Amplifier type:	MD60C
Measurement range:	±5 kHz
Measured value nominal voltage:	$V_{amp} = \pm 10$ V
Linearity deviation:	0.02%
Residual ripple and disturbing peaks:	±0.3%
Effect of temperature on sensitivity:	±0.1%
Effect of change in supply voltage:	0.01% - not required for the system as the voltage is stabilized by UPS.

The standard uncertainty of the Amplifier plug-in module:

$$u^2(V_{amp}) = \frac{(0.02\%)^2}{3}+\frac{(0.3\%)^2}{3}+\frac{(0.1\%)^2}{3} = 0.0335$$

$$u(V_{amp})=0.1829\%$$

4. Digital voltage meter described in the Tesar Electronics catalogne

Meter type: DP453

Made by: Tesar Electronics

Computer port plug: RS485

Output limiting error: V_{out}±0.346%

The standard uncertainty of the digital voltage meter

$$u(V_{out})=\frac{0.346\%}{\sqrt{3}}=0.1998\%$$

5. Computer system "MORZE"

Description: Recording and analyzing of data: ship position, torque and revolutions, rudder action, ship heading (gyro) as a function of time (sample) using software. Performs all necessary recalculations of shaft torque, revolutions and power. Allows data storage in computer files and quick presentation in graphical and tabular formats. System consists of computer, printer, and converters.

The computer system does not generate significant gauge errors.

The uncertainty of measurements for all components of the system has been calculated on the basis of possible errors according to the equipment's documentation. This source generally specifies only the measured value tolerance and does not provide any level of confidence information or probability distribution. It is assumed that the probability of the result is uniformly distributed in the interval specified by the tolerance.

It is also assumed, that uncertainty of all components of the system has equal influence on the combined uncertainty of the whole system.

The combined standard uncertainty of the shaft torque measurement part of the HBM system is:

$$u(Q_{HBM})=\sqrt{c_1\cdot u^2(R_g)+c_2\cdot u^2(\Delta f)+c_3\cdot u^2(V_{amp})+c_4\cdot u^2(V_{out})}$$

assuming equal influence of uncertainty of all gauges ($c_1=c_2=c_3=c_4$):

$$u(Q_{HBM})=\sqrt{(0.2309)^2+(0.2944)^2+(0.1829)^2+(0.1998)^2}$$

$$u_c(Q_{HBM})=0.4619\ \%$$

<u>Uncertainty due to calibration</u>

The information in this section is based on data concerning gauge calibration uncertainty in CTO Technical Report No. RK-99/T-039, Section 8, page 22 Ship Design and Research Center, (1998).

A standard resistor is used for the calibration of the HBM system. It is plugged into the system instead of the strain gage. The standard calibrating resistor of type S-87150 is made by Micro Measurements' Measurements Group and has a limiting error no larger than 0.01%.

The shaft relative strain ε is obtained from the following formula:

$$\varepsilon = \left(\frac{R_t}{R_t + R_{CAL}} \right) \cdot \frac{1}{4k_t} \quad \text{or:} \quad \varepsilon = \frac{R_t}{4k_t R_2}$$

where: $R_2 = R_t + R_{CAL}$

Where:
R_t – strain gauge effective resistance
R_t = 350 ±0.4 %
k_t – gauge factor at 75°F
k_t = 2.045Ω ±0.5 %
R_{CAL} – Resistance of standard resistor
R_{CAL} = 87150Ω±0.01 %
$R_2 = R_t + R_{CAL}$ = 350Ω + 87150Ω = 87500Ω

$$\left(\frac{u(\varepsilon)}{\varepsilon} \right)^2 = \left(\frac{\partial\varepsilon}{\varepsilon \partial R_t} u(R_t) \right)^2 + \left(\frac{\partial\varepsilon}{\varepsilon \partial R_t} u(R_t) \right)^2 + \left(\frac{\partial\varepsilon}{\varepsilon \partial R_t} u(R_t) \right)^2$$

$$\frac{\partial\varepsilon}{\varepsilon \partial R_t} = \frac{1}{R_t}; \quad \frac{\partial\varepsilon}{\varepsilon \partial k_t} = -\frac{1}{k_t}; \quad \frac{\partial\varepsilon}{\varepsilon \partial R_2} = -\frac{1}{R_2}$$

Thus:

$$\left(\frac{u(\varepsilon)}{\varepsilon} \right)^2 = \left(\frac{u(R_t)}{R_t} \right)^2 + \left(\frac{-u(k_t)}{k_t} \right)^2 + \left(\frac{-u(R_2)}{R_2} \right)^2$$

$$u(R_t) = \frac{0.004 \cdot 350}{\sqrt{3}} \cong 0.8083\Omega;$$

$$u(R_{CAL}) = \frac{0.0001 \cdot 87150}{\sqrt{3}} \cong 5.0316\Omega;$$

$$u(R_2) = \sqrt{u^2(R_t) + u^2(R_{CAL})} = 5.09611\Omega;$$

$$\frac{u(R_t)}{R_t} = \frac{0.4}{\sqrt{3}} \cong 0.2309\%;$$

$$\frac{u(k_t)}{k_t} = \frac{0.5}{\sqrt{3}} \cong 0.2887\%;$$

$$\frac{u(R_2)}{R_2} = \frac{5.09611}{87500} \cong 5.8241 \cdot 10^{-5}\%;$$

$$\left(\frac{u(\varepsilon)}{\varepsilon} \right)^2 = 0.2309^2 + 0.2887^2 + \left(5.8241 \cdot 10^{-5}\right)^2$$

$$\text{thus:} \left(\frac{u(\varepsilon)}{\varepsilon} \right)^2 = 0.1367$$

The combined uncertainty due to calibration:

$$u(\varepsilon) = 0.3697\%$$

Uncertainty due to installation on a ship

The measurement equipment is installed on the shaft prior to the ship's departure from the shipyard. The effects of different conditions before, during transit to the trial site, or at the trial site are eliminated by calibrations performed during the transit, or included in the section entitled "Gauge Uncertainty". The possibility of errors resulting from the mounting of the equipment on the shaft line must also be considered.

For the torque measurement the only equipment element that needs to be mounted precisely is the strain gauge bridge. The bridge is glued to the shaft line. It is crucial to maintain the proper angle between the axis of symmetry of the gage and the shaft. For the torque measurements this angle must be 45° as it is shown in Figure 5.1.

Other errors, such as an improperly glued gauge (i.e. air bubbles) or incorrectly connected cables would result in gross errors clearly visible for an experienced measurement operator.

The relationship between angle and the strain of the gauge for the plain torsion (torque load) is as follows:

$$\varepsilon_\alpha = \varepsilon \cos 2\alpha$$

where:

ε_α - strain in direction 45°±α

ε - strain in direction exactly 45°

α - direction (angle) error $\alpha = \pm 3°$

Thus the error:

$$\frac{\varepsilon - \varepsilon_\alpha}{\varepsilon} = 1 - \cos 2\alpha = 1 - 0.9945 = 0.5478\%$$

The standard uncertainty due to gauge installation on the ship equals:

$$\mathrm{u}(\alpha) = \frac{0.5478}{\sqrt{3}} = 0.3163\%$$

Uncertainty due to recalculation of the torque

The torque is calculated from the measured strain of the strain gages with the following formula:

$$Q = \alpha_Q\, \varepsilon \text{ [Nm]}$$

where:

ε [-]: relative strain of the strain gage

$\alpha_Q = \dfrac{4GJ}{D}$ [Nm]: constant for the particular shaft

$J = \dfrac{\pi D^4}{32}$ [m^4]: moment of inertia for solid shafts

G [Nm]: shear modulus

D [m]: shaft diameter

Thus: $\alpha_Q = \dfrac{\pi G D^3}{8}$ and: $Q = \dfrac{\pi G D^3 \varepsilon}{8}$

The standard uncertainties of the components are as follows:

- for G: $\dfrac{\mathrm{u}(G)}{G} = 1.15\%$ as $3S$=3.45%
  (according to CETENA research)

- for D: ±0.1mm for D > 200mm:

$$\frac{\mathrm{u}(D)}{D} = \frac{0.1}{200} \cdot \frac{100\%}{\sqrt{3}} = 0.029\%$$

- for ε: $\dfrac{\mathrm{u}(\varepsilon)}{\varepsilon} = 0.3697\ \%$

The combined uncertainty of the torque recalculation is calculated as follows:

$$\left(\frac{\mathrm{u}_C(Q)}{Q}\right)^2 = \left(\frac{\partial Q}{Q \partial G} \cdot \mathrm{u}(G)\right)^2 + \left(\frac{\partial Q}{Q \partial D} \cdot \mathrm{u}(D)\right)^2 + \left(\frac{\partial Q}{Q \partial \varepsilon} \cdot \mathrm{u}(\varepsilon)\right)^2$$

$$\frac{\partial Q}{Q\, \partial G} = \frac{1}{G};\ \frac{\partial Q}{Q\, \partial D} = \frac{3}{D};\ \frac{\partial Q}{Q\, \partial \varepsilon} = \frac{1}{\varepsilon}$$

$$\left(\frac{\mathrm{u}_C(\mathrm{Q})}{\mathrm{Q}}\right)^2 = \left(\frac{\mathrm{u}(\mathrm{G})}{\mathrm{G}}\right)^2 + 9 \cdot \left(\frac{\mathrm{u}(\mathrm{D})}{\mathrm{D}}\right)^2 + \left(\frac{\mathrm{u}(\varepsilon)}{\varepsilon}\right)^2$$

$$\left(\frac{\mathrm{u}_C(Q)}{Q}\right)^2 = 1.15^2 + 9 \cdot 0.029^2 + 0.3697^2 = 1.4667$$

The combined uncertainty due to torque recalculation:

$$\frac{\mathrm{u}_C(Q)}{Q} = 1.2110\%$$

Total uncertainty of the torque measurement system

The uncertainty of torque measurements consists of the following components as determined above:

gauge uncertainty	$\mathrm{u_c}(Q_{HBM})$=0.4619 %
uncertainty due to calibration	$\mathrm{u}(\varepsilon)$ = 0.3697 %
uncertainty due to installation	$\mathrm{u}(\alpha)$ = 0.3163 %
uncertainty due to recalculation	$\mathrm{u_c}(Q)$ =1.2110 %

The total combined uncertainty of the torque measurement system equals:

$$u_C(\text{Total}\,Q) = \sqrt{u^2(\text{gauge}) + u^2(\varepsilon) + u^2(\alpha) + u^2(Q)}$$

$$u(\text{gauge}) = u_c(Q_{\text{HBM}}),$$

$$u_c(\text{Total}\,Q) = 1.3844\ \%$$

The expanded uncertainty of the torque measurement system is as follows:

$$U = 2u_c = 2.7688\ \%$$

As an example, for a torque of Q = 1520 kNm for example the total combined uncertainty equals:

$$u_c(\text{Total}\,Q) = 21.04\ \text{kNm}$$

The expanded uncertainty for this value of torque is:

$$U = 42.08\ \text{kNm}$$

Thus the torque of Q = 1520 kNm may be presented as:

$$Q = 1520 \pm 42.08\ \text{kNm}$$

Determination of shaft speed uncertainty

The shaft speed is determined using the Hottinger Baldwin Messtechnik (HBM) measurement system described in HBM literature. Torque and shaft speed measurements are derived using the same measurement system.

The uncertainty of this measurement consists of two basic components based on:

- gauges
- calibration and installation on a ship

Gauge uncertainty

The shaft speed measurement is performed in the same manner as the torque measurement:

The HBM system consists of components supplied by Hottinger Baldwin Messtechnik. The scheme of this system has been presented in Figure 5.1.

The part of the HBM system responsible for the shaft speed measurement consists of:

- Band of Reflective Strips

A band consisting of 60 strips of reflective tape is glued around the shaft. The strips reflect the light signal, which is counted by the optical transducer. All possible errors connected with this measurement are described in the section entitled “Uncertainty due to calibration”.

- Optical Transducer OA1 described in HBM literature.

The optical transducer OA1 receives light signals reflected by the strips placed on a band, which was placed around the shaft. It causes no error and introduces no uncertainty.

- Speed Pulse Amplifier DV 2556 described in HBM literature.

The Speed Pulse Amplifier transfers the signals from the optical transducer to the digital frequency meter. Digital output causes no error and introduces no uncertainty.

- Digital frequency meter DZQ224 described in Tesar Electronics catalogue.

The digital frequency meter counts signals from the speed pulse amplifier. It sends those results to a computer system via a RS485 plug. The meter introduces no error or uncertainty.

- Computer system “MORZE”.

Description: Saving and analyzing data using software. Performs all necessary recalculations of shaft torque, revolutions and power. Allows for data storage in computer files and quick presentation in graphical and tabular formats.

- Hardware: Computer, printer, converters.

The computer system is not generating significant gauge errors. Uncertainty of recalculations is described in the section entitled “Total uncertainty of shaft speed measurement”.

The gauge itself is a simple system, which introduces no errors or uncertainty: u(HBM)=0%.

Uncertainty due to calibration and installation on a ship

The resolution of the shaft speed is:

$$\frac{1\text{ strip}}{1\text{ rotation}}100\% = \frac{1\text{ strip}}{60\text{ strips}}100\%$$
$$= \frac{1\text{ rotation}}{60\text{ rotation}}100\% = \frac{1}{60}100\%$$
$$= 1.67\%$$

as there are 60 strips around the shaft.

The sum of possible error of the striped band installation on the shaft including diameter uncertainty and the error caused by the resolution is not bigger than one strip per rotation. As the shaft rotates, the error will appear only at the last shaft rotation. In simpler terms, the error appears once per measurement at the last rotation.

For a 5 minute measurement of shaft speed at 90 rpm, the shaft performs 450 rotations. This causes an error of:

$$\sigma = \frac{1\text{ strip}}{450\text{ rotations}}100\% = \frac{1\text{ strip}}{450\cdot 60\text{ strips}}100\% = 0.0037\%$$

which gives the standard uncertainty of:

$$\text{u(inst)} = \frac{0.0037}{\sqrt{3}} = 0.0021\%$$

which in practice, is negligible.

Total uncertainty of shaft speed measurement

The total uncertainty of the standard shaft speed measurement is equal to the uncertainty due to the gauge installation:

u(Total N) = u(inst) = 0.0021%

The expanded uncertainty for the standard shaft speed measurement is:

U= 2·u(Total n) = 0.0042%

Therefore, the shaft speed, n, can be presented as:

n = n ± U [rpm]

An example of a typical measurement is:

n = 90 ± 0.0042% rpm

5.3. Determination of Power Measurement Uncertainty

A system used by the CTO measurement team for the power measurement measures both shaft speed and shaft torque. The determination of the output power uncertainty for the HBM system is as follows:

$$P = \frac{\pi}{30}\cdot Q\cdot N$$

where:

Q [kNm]: torque

N [rpm]: shaft speed

The standard uncertainties of torque and shaft speed calculated above have the following values:

Torque total combined uncertainty:

$$\frac{\text{u}_\text{c}(\text{Total } Q)}{Q} = 1.3844\%$$

Shaft speed standard uncertainty:

$$\frac{\text{u}(\text{Total } N)}{N} = 0.0021\%$$

The combined uncertainty of the shaft power is:

$$\left(\frac{\text{u}_\text{c}(P)}{P}\right)^2 = \left(\frac{\partial P}{P\,\partial Q}\cdot\text{u}(\text{Total } Q)\right)^2 + \left(\frac{\partial P}{P\,\partial N}\cdot\text{u}(\text{Total } N)\right)^2$$

$$\frac{\partial P}{P\cdot\partial Q} = \frac{1}{Q};\ \frac{\partial P}{P\cdot\partial N} = \frac{1}{N}$$

$$\left(\frac{\text{u}_\text{c}(P)}{P}\right)^2 = \left(\frac{\text{u}(\text{Total } Q)}{Q}\right)^2 + \left(\frac{\text{u}(\text{Total } N)}{N}\right)^2$$

Thus the combined uncertainty of shaft power is:

$$\frac{\text{u}_\text{c}(P)}{P} = \sqrt{1.3844^2 + 0.0021^2} = 1.3844\%$$

5.4. Uncertainty in Ship Speed Measurement Using DGPS

The ship speed is calculated by position and time information obtained from the DGPS (Differential Global Positional System) using the following formula.

$$V_S = \frac{S}{\Delta t}$$

where

$S = \sqrt{\Delta x^2 + \Delta y^2}$: speed trial run length

$\Delta x = x - x_0$, $\Delta y = y - y_0$, $\Delta t = t - t_0$

x_0, y_0 : coordinates of the start point

x, y : coordinates of the end point

t_0 : time of the start point

t : time of the end point

The uncertainty of coordinates can be evaluated by:

$$\mathrm{u}(\Delta x) = \mathrm{u}(\Delta y) = \sqrt{\mathrm{u}^2(x) + \mathrm{u}^2(x_0)} = \sqrt{2\mathrm{u}^2(x)} = \mathrm{u}(x)\sqrt{2}$$

$$\mathrm{u}(\Delta t) = \sqrt{\mathrm{u}^2(t) - \mathrm{u}^2(t_0)} = \sqrt{2\mathrm{u}^2(t)} = \mathrm{u}(t)\sqrt{2}$$

Thus, the square of the uncertainty in the run length becomes

$$\mathrm{u}^2(S) = \left(\frac{\partial S}{\partial \Delta x} \cdot \mathrm{u}(\Delta x)\right)^2 + \left(\frac{\partial S}{\partial \Delta y} \cdot \mathrm{u}(\Delta y)\right)^2$$

$$\frac{\partial S}{\partial \Delta x} = \frac{\Delta x}{\sqrt{(\Delta x)^2 + (\Delta y)^2}} = \frac{\Delta x}{S};$$

$$\frac{\partial S}{\partial \Delta y} = \frac{\Delta y}{\sqrt{(\Delta x)^2 + (\Delta y)^2}} = \frac{\Delta y}{S}$$

$$\mathrm{u}^2(S) = \left(\frac{\Delta x}{S} u(\Delta x)\right)^2 + \left(\frac{\Delta y}{S} u(\Delta y)\right)^2$$

For $\mathrm{u}(\Delta x) = \mathrm{u}(\Delta y) = \mathrm{u}$

$$\mathrm{u}^2(S) = \left(\frac{\Delta x}{S}\mathrm{u}\right)^2 + \left(\frac{\Delta y}{S}\mathrm{u}\right)^2 = \mathrm{u}^2\left(\frac{(\Delta x)^2 + (\Delta y)^2}{S^2}\right)$$

$$\mathrm{u}(S) = \mathrm{u}\sqrt{\frac{(\Delta x)^2 + (\Delta y)^2}{S^2}} = \mathrm{u}$$

Therefore,

$$\mathrm{u}(S) = \mathrm{u}(\Delta x) = \mathrm{u}(\Delta y)$$

The uncertainty of ship speed measurement can be obtained by the following formula

$$\mathrm{u}^2(V_S) = \left(\frac{\partial V_S}{\partial S} \cdot \mathrm{u}(S)\right)^2 + \left(\frac{\partial V_S}{\partial \Delta t} \cdot \mathrm{u}(\Delta t)\right)^2$$

with

$$\frac{\partial V_S}{\partial S} = \frac{1}{\Delta t}\ ;\ \frac{\partial V_S}{\partial \Delta t} = -\frac{S}{(\Delta t)^2}$$

The uncertainty in time is assumed negligible in its magnitude compared to the uncertainty in position measurement.

The absolute uncertainty is

$$\mathrm{u}(V_S) = \frac{1}{\Delta t} \cdot \mathrm{u}(S)$$

and the relative uncertainty is

$$\mathrm{u}_r(V_S) = \frac{\mathrm{u}(V_S)}{V_S} \cdot 100 = \frac{\mathrm{u}(S)}{S} \cdot 100\ (\%)$$

The 95% confidence interval of ship speed can be presented as:

$$V_S = V_S \pm 2 \cdot \mathrm{u}(V_S)$$

Table 5.1 shows the absolute and relative uncertainties and 95% confidence interval with two run lengths of 1 mile and 2 miles and two ship speeds of 15 kn and 25 kn. The positional uncertainty of DGPS with 95% coverage is assumed to be 2 meters as provided in the Trimble DGPS DSM12/212 leaflet.

This table shows that the absolute uncertainties of ship speed depend both on run length and ship speed. On the other hand, the relative uncertainties depend only on run length.

Table 5.2 is an example of typical bias and precision limit values for surface ship trial data.

Table 5.1 Uncertainties in Ship Speed Measurement Using DGPS (Trimble's DMS12/212 System).

Ship Speed	**Items**	**Run Length**	
		1 mile	2 miles
15 kn	S (m)	1852	3704
	Δt (sec)	240	480
	u(S) (m)	1.4142	1.4142
	u(V_s) (m/s) (kn)	0.0059 0.0115	0.0029 0.0057
	$u_r(V_s)$ (%)	0.076	0.038
	95% confidence interval of V_s	15.0±0.023 (kn) (±0.152%)	15.0±0.0114 (kn) (±0.076%)
25 kn	S (m)	1852	3704
	Δt (s)	144	288
	u(S) (m)	1.4142	1.4142
	u(V_s) (m/s) (kn)	0.0098 0.0191	0.0049 0.0095
	$u_r(V_s)$ (%)	0.076	0.038
	95% confidence interval of V_s	25.0±0.0382 (kn) (±0.152%)	25.0±0.019 (kn) (±0.076%)

Table 5.2 Example of Bias and Precision Limit Values for Surface Ship Trial Data (17900 kW and 100 rpm).

Quantity	**Units**	**Bias Limit**	**Precision Limit**	**Uncertainty**
Ship Speed	kn	±0.05	±0.10	±0.11
Shaft Torque	Nm	±17,195	±40,145	±43,670
Optical Torque	Nm			
Shaft Revolutions	rpm	±0.392	±1.854	±1.895
EM Log	kn	±0.37	±0.74	±0.83
Shaft Power	kW	±193	±536	±569
Rudder Angle	deg	±0.562	±4.43	±0.531
Heading Angle	deg	±0.531	±1.336	±1.437
Wind Relative Speed	kn	±0.46	±1.24	±1.32
Wind Relative Dir.	deg	±5.02	±3.26	±5.98

6. ANALYSIS AND CORRECTION METHODS

6.1. Evaluation of ship speed using DGPS

Four different methods of evaluating ship speed over ground from DGPS measurements are examined and a comparison of speed results resulting from the adoption of each method is presented.

The four different methods utilized are as follows:

- Average of Actual Speeds;
- Starting-Ending Point;
- Step-by-step Speed;
- U.S. Navy.

The "Average of Actual Speeds Method" concerns the evaluation of the speed as the average of the actual ship speed during the run. This method implies the use of equipment able to supply the actual or instantaneous speed value, i.e., DGPS. From a statistical point of view, the greater the number of instantaneous speed samples, the greater the statistical confidence level of the speed calculated along the ship's path. However, it does not take into account the coursekeeping ability of the ship.

The "Starting-Ending Point Method" concerns the evaluation of ship speed by calculating the minimum distance covered at a constant heading. It derives directly from the traditional "Measured Mile" method. The covered distance is calculated without any consideration to the ship track, even if the ship covered a longer distance. The ship speed is calculated considering the rectilinear track from the starting point to the ending point. Generally speaking, this method is conservative since; it gives a speed smaller than the speed calculated using the distance travelled along the ship's path.

The "Step-by-Step Method" is a derivation of the previous method. This method represents the iterative application of the "Starting-Ending Point Method" along the ship's path. The mean speed is derived as the average of successive speed calculations. These successive speed calculations are obtained by dividing the total number of samples in half and using the distances and times between successive paired samples to calculate speed values. This method takes into account the variation of speed, seen in the incremental speed calculations, over the course of the entire run in the final calculation of the average speed. The results of this method are probably the most realistic.

The "U.S. Navy Method" is a further derivation of "Starting-Ending Point Method". It considers the projected distance of the "Step-by-Step" contributions on the final direction of the run. It utilizes iterative applications, so the mean speed is evaluated as the average of the speeds calculated according to the projection of the "Step-by-Step Method".

The equations for the different methods are presented in the Table 6.1.

Table 6.2 shows the comparison of the results for the described methods applied to different ship types, at different speeds and different ship sizes. In Table 6.3 the patterns of track and actual speed for each presented result are shown.

Comparing the results given by the three methods based on the covered distance – elapsed time ratio (Starting-ending point method, Step-by-step method, U.S. Navy method) it appears that these three methods are substantially equivalent.

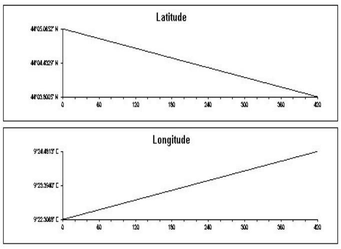
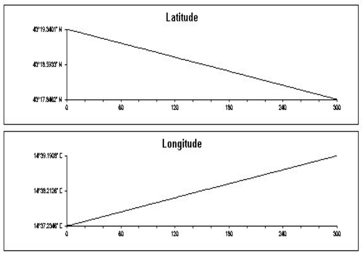
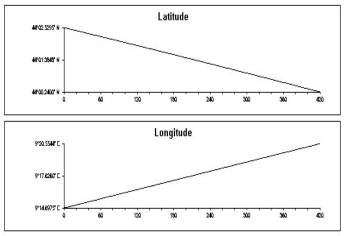
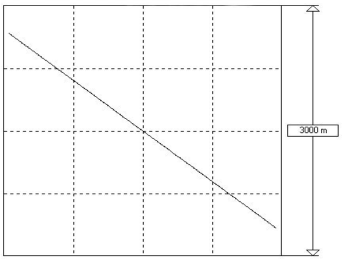
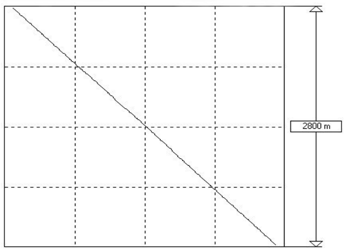
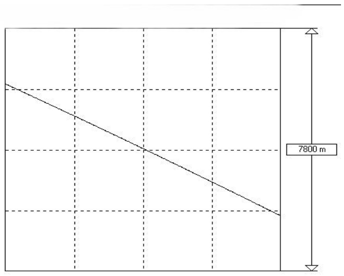
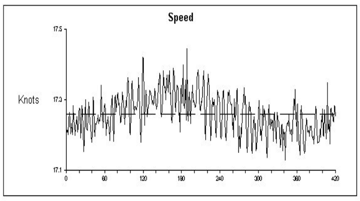
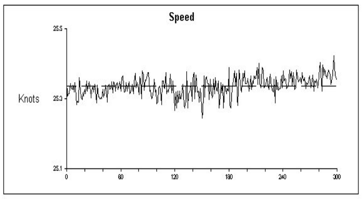
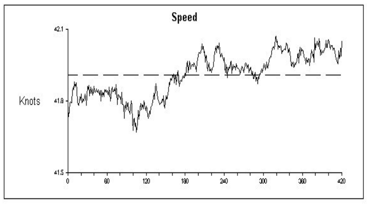
Table 6.1 Formulas involved for each method for mean speed calculation.

	Average of Actual Speeds	**Starting-Ending Point**	**Step-by-step speed**	**U.S. Navy speed**
"Mean" speed	$V = \frac{\sum_{i=1}^{n} Vi}{n}$	$V = \frac{S}{t}$	$V = \frac{\sum_{i=1}^{n/2} V_i}{n/2}$	$V = \frac{\sum_{i=1}^{n/2} V_i}{n/2}$
V_i	Actual speed from DGPS	-	$V_i = \frac{S_i}{t/2}$	$V_i = \frac{S_i}{t/2}$
S	-	$S = \sqrt{(X_e - X_s)^2 + (Y_e - Y_s)^2}$	$S_i = \sum_{i=1}^{n/2} \sqrt{\left(X_{\frac{n}{2}+i} - X_i\right)^2 + \left(Y_{\frac{n}{2}+i} - Y_i\right)^2}$	$S_i = \sum_{i=1}^{n/2} \sqrt{\left(X_{\frac{n}{2}+i} - X_i\right)^2 + \left(Y_{\frac{n}{2}+i} - Y_i\right)^2} \cos\alpha_i$
t		$t = T_e - T_s$	$t = T_e - T_s$	$t = T_e - T_s$
s, e		starting, ending points	starting, ending points	starting, ending points
α_i	-	-	-	actual angle between *S* and *Si*

Table 6.2 Comparison of speed determination methods for 3 Different Kinds of Ships.

	Chemical Tanker	**Cruise Vessel**	**Fast Ferry**
a - Average of Actual Speeds	17.259	25.336	41.907
b - Starting-Ending Point	17.228	24.736	41.089
c - Step-by-step speed	17.232	24.792	41.093
d - U.S. Navy speed	17.233	24.794	41.092
Average of the three speeds (b, c, d)	*17.231*	*24.774*	*41.091*
Diff % of Starting-Ending Point	-0.0002	-0.0015	-0.0001
Diff % of Step-by-step speed	0.0001	0.0007	0.0000
Diff % of U.S. Navy speed	0.0001	0.0008	0.0000

Table 6.3 Example of Speed Measurement Obtained with DGPS for 3 Different Kinds of Ships.

	Chemical Tanker	**Cruise Vessel**	**Fast Ferry**
Latitude Longitude			
	Time	Time	Time
Track			
	Time	Time	Time
Actual Speed time trace			
Duration (h, m, s)	00,07,00	00,05,00	00,07,00
Distance (m)	3722.4	3821.8	8877.9
Maximum speed (kn)	17.433	25.422	42.069
Mean speed (kn)	17.259	25.336	41.907
Minimum speed (kn)	17.129	25.245	41.670
Standard deviation	0.055	0.028	0.091

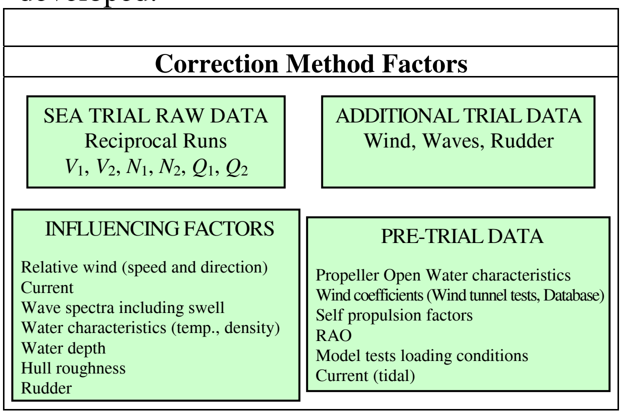
6.2. Correction methods

Aim

Ship performance from a contractual basis concerns ship speed through the water obtained in calm weather conditions. Unfortunately, the most accurate means of measuring ship speed deliver a value of speed relative to the ground. Since sea trials are almost never performed in ideal environmental conditions, corrections have to be performed to extrapolate the sea trials results to an ideal condition.

General content of the methods

The SC and shipbuilders from Japan, Korea and Poland met to compile a set of criteria that all felt were important in order to have a complete picture of what was needed to analyze speed/power trial data. The following general "Correction Method" flow chart was developed.



Schematically, correction methods can all be studied using the following approach:

- General philosophy,
- Correction items
- Data required
- Individual correction methods

It was decided to divide the methods on this sheet into 2 different categories:

(a) Methods actively used by shipyards and referenced (SNAME, BSRA, Taniguchi-Tamura, ISO TC8/SC9)

(b) Other publicly noted methods (Jinnaka, Kracht/VWS, Schmiechen)

General Philosophy Behind Each Method

(a) SNAME Method (SNAME 1989)

The basis behind the SNAME method is a correction of speed based on the effective horsepower curve where resistance is added using a derivative of the power curve. Corrections are limited to wind and current.

Current is corrected using the mean of means method, which is only correct for a linear variation of current over a short period of time.

(b) BSRA Method (BSRA 1978)

The shaft power curve is the basis for correction where resistance is added using a derivative of the power curve.

The assumption is made that the quasi-propulsive coefficient does not change with propeller loading.

(c) Taniguchi-Tamura Method (Taniguchi & Tamura 1966)

This method uses the propeller loading condition and propeller open water characteristics as the basis for corrections. The propeller loading coefficient is used for the balance of forces.

(d) ISO TC8/SC9 Method

This method is essentially the same as the Taniguchi-Tamura's method and is based on the propeller working point.

(e) Jinnaka (Jinnaka 1982) Method

This method uses the propeller open water characteristics as the basis for corrections. The balance of forces is derived from the Taylor expansion.

(f) Kracht (Kracht 1999) Method

Propeller open water characteristics are the basis for correction.

(g) Schmiechen Method (Schmiechen 1991)

The Schmiechen "Rational Method" is really in a category by itself. It does not really follow the same format as all of the other methods and hence was not used in the comparison of factors reviewed in each method. This method can be used in conjunction with system identification methods.

Correction Items

Table 6.4 summarizes the different influencing factors accounted for in each of the methods discussed in the report. In relation with those items, additional information required for corrections are presented.

It can be observed that the ISO TC8/SC9 was the most comprehensive of the methods reviewed in analyzing speed/power data. However, the manner in which the method used to handle each factor dealing with corrections for environmental and ship conditions might not have been the most complete or comprehensive. Hence the SC decided to look at each factor indicated by the ISO TC8/SC9 method and compare how other methods dealt with it. SC member comments are in the attached file in tabular format.

Table 6.4 Correction Items Considered by Different Methods.

	Methods Actively Used by Shipyards and Referenced				**Other Public Methods**	
	SNAME	**BSRA**	**Taniguchi-Tamura**	**ISO TC8/SC9**	**Jinnaka**	**Kracht/ VWS**
Correction Item						
Wind	×	×	×	×	×	×
Current	×	×	×	×	×	×
Wave				×		×
Steering				×		×
Water Temperature				×		
Vessel Condition				×		
Shallow Water		×		×		×
Related Model Test/Analysis/Database Compilation						
Resistance	×	×			×	
Propulsion		×	×	×	×	
Propeller Open Water			×	×	×	×
Wind Resistance	×	×	×	×	×	×
Resistance Increase in Waves				×		×

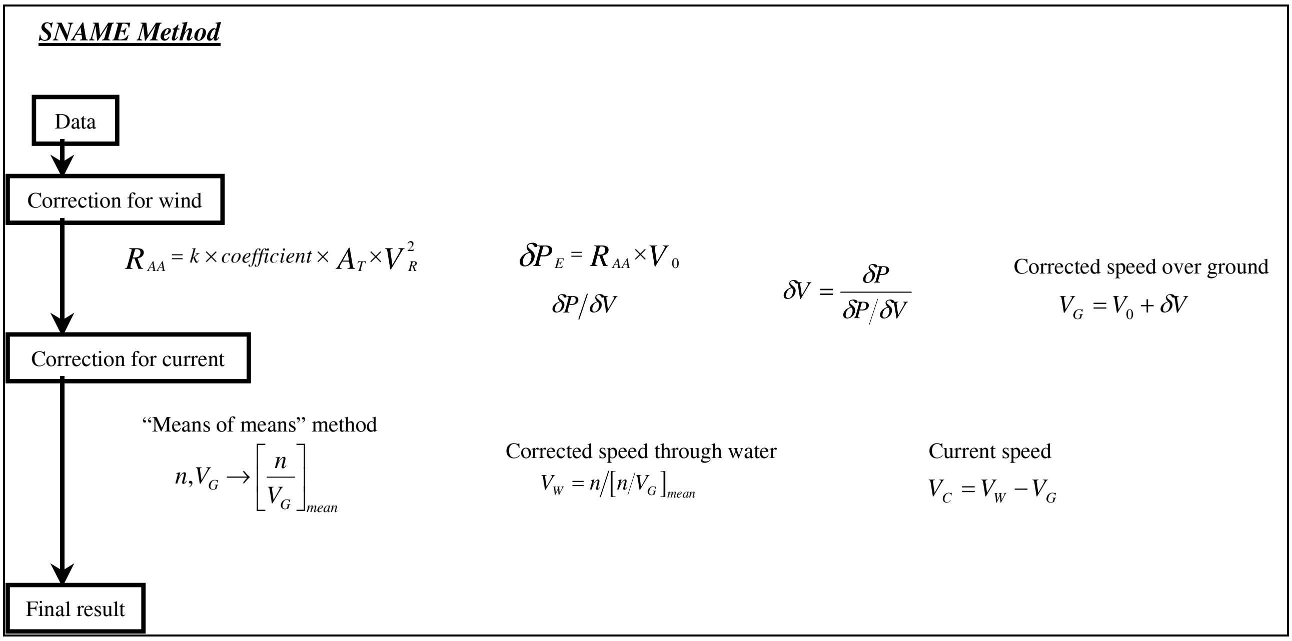


Figure 6.1 SNAME Method.

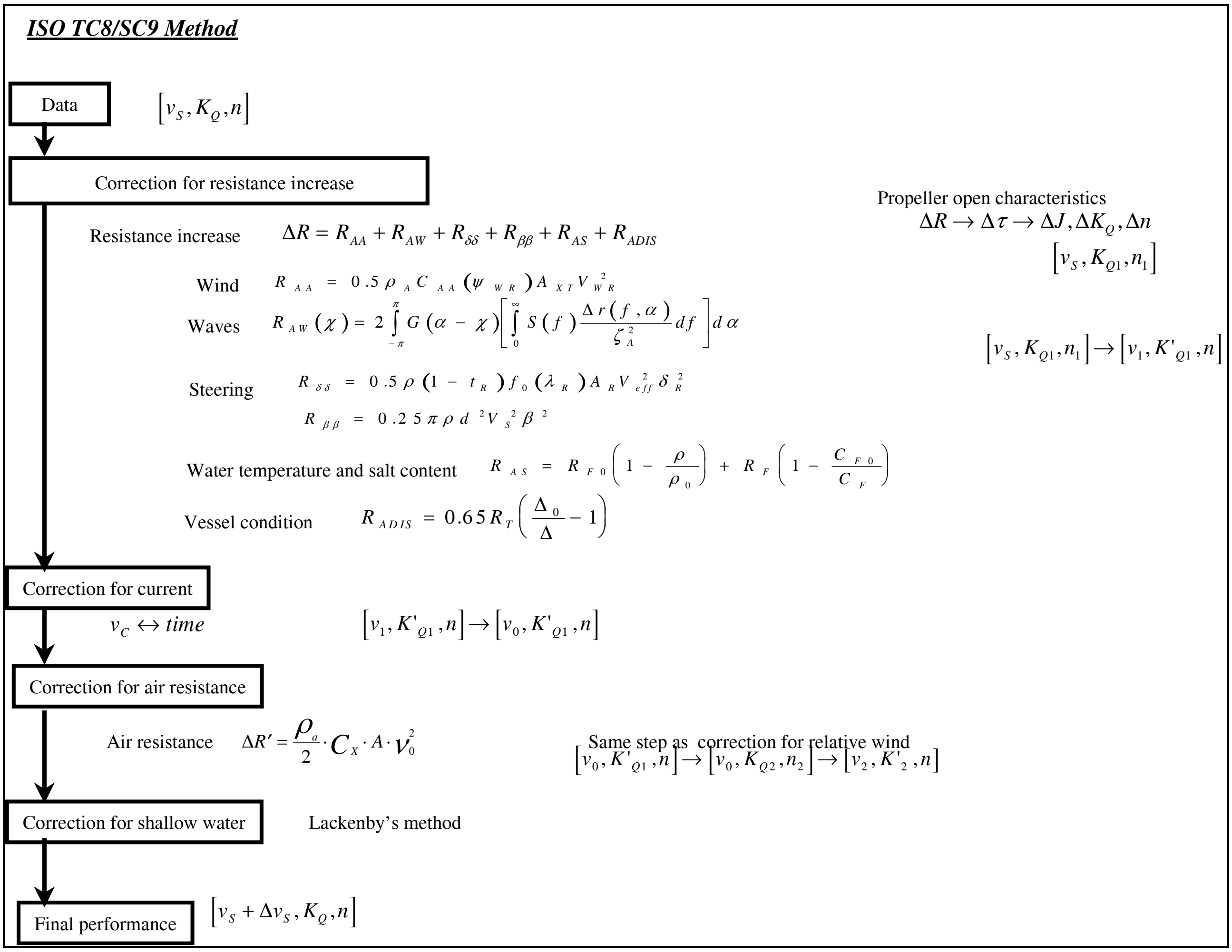


Figure 6.2 ISO TC8/SC9 Method.

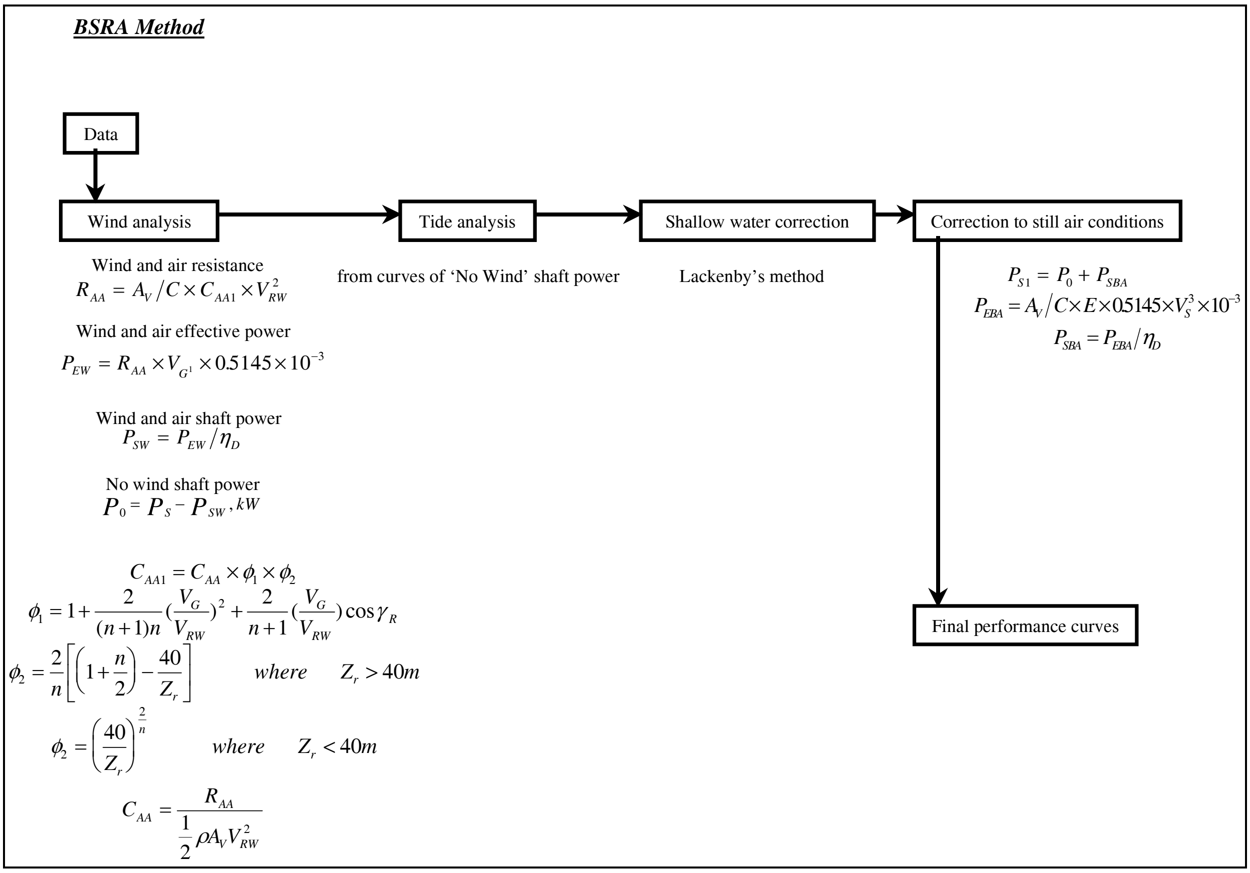


Figure 6.3 BSRA Method.

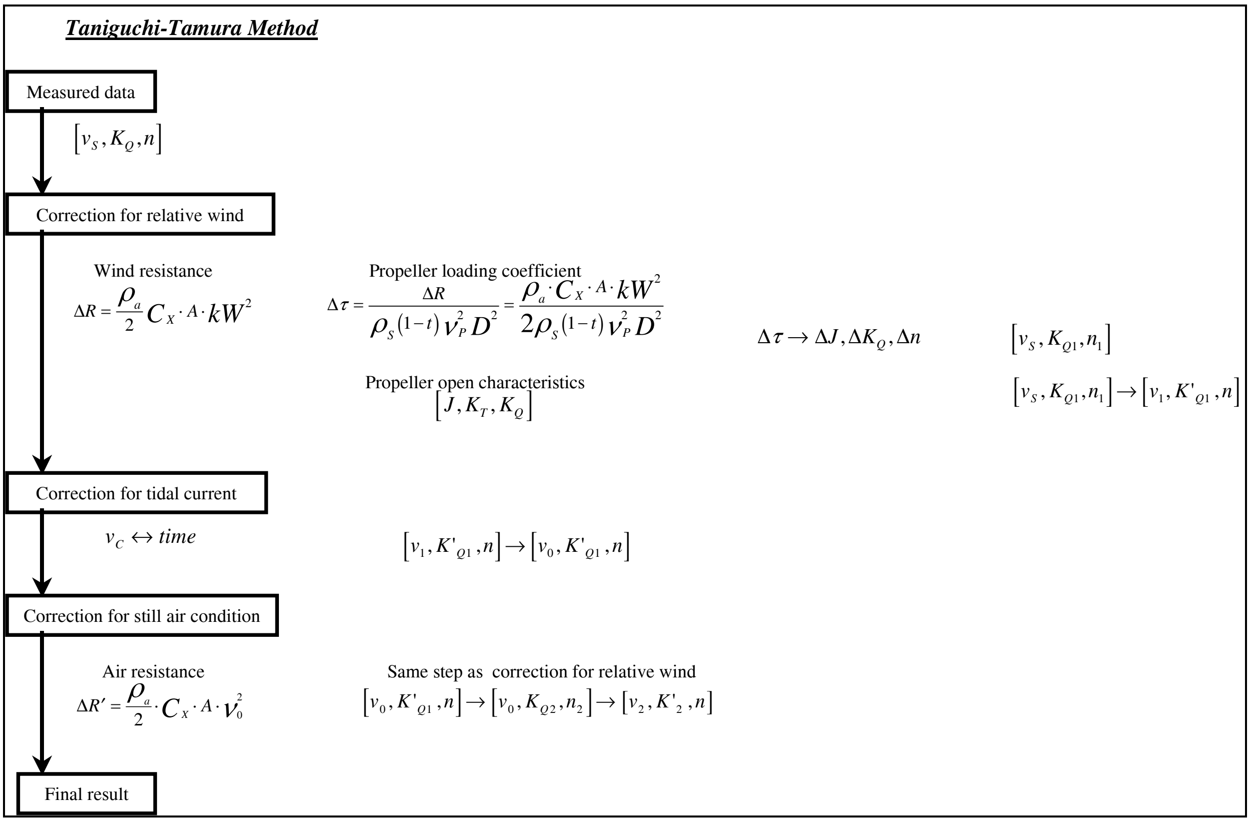


Figure 6.4 Taniguchi - Tamura Method.

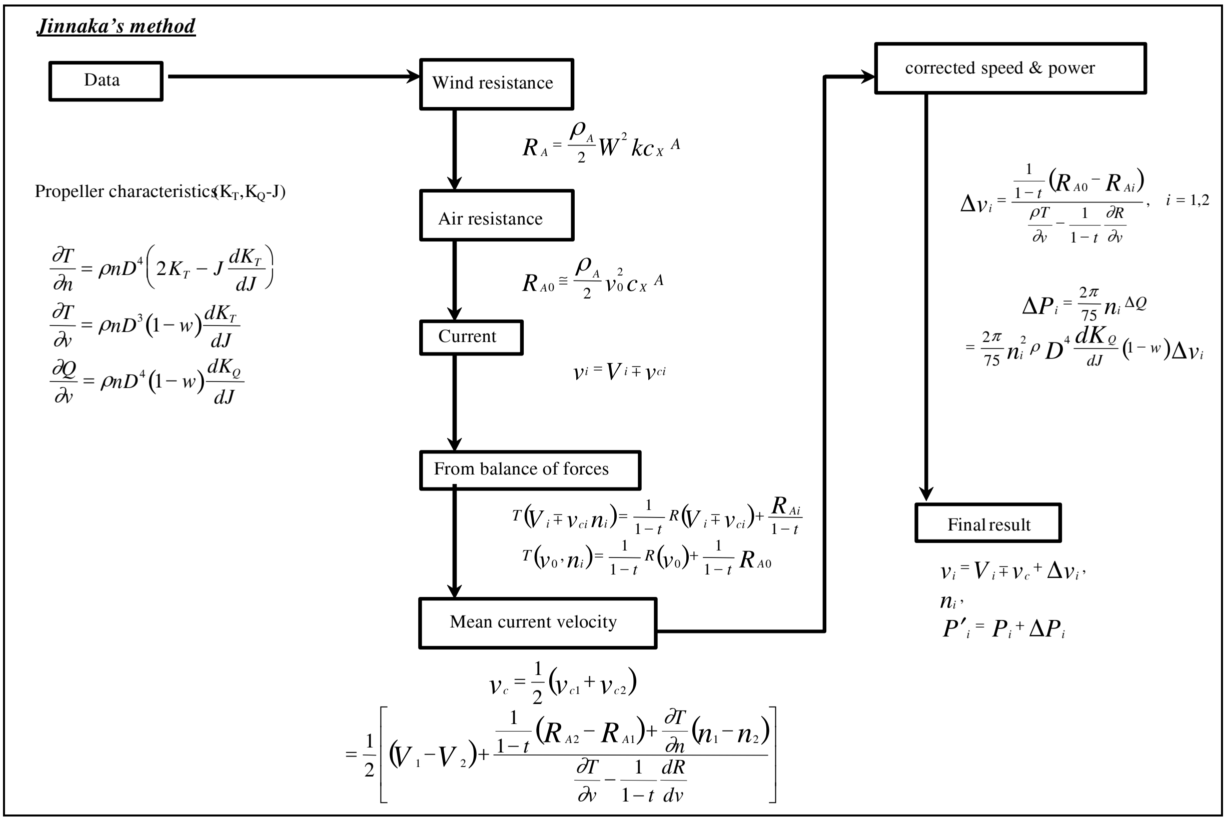


Figure 6.5 Jinnaka Method.

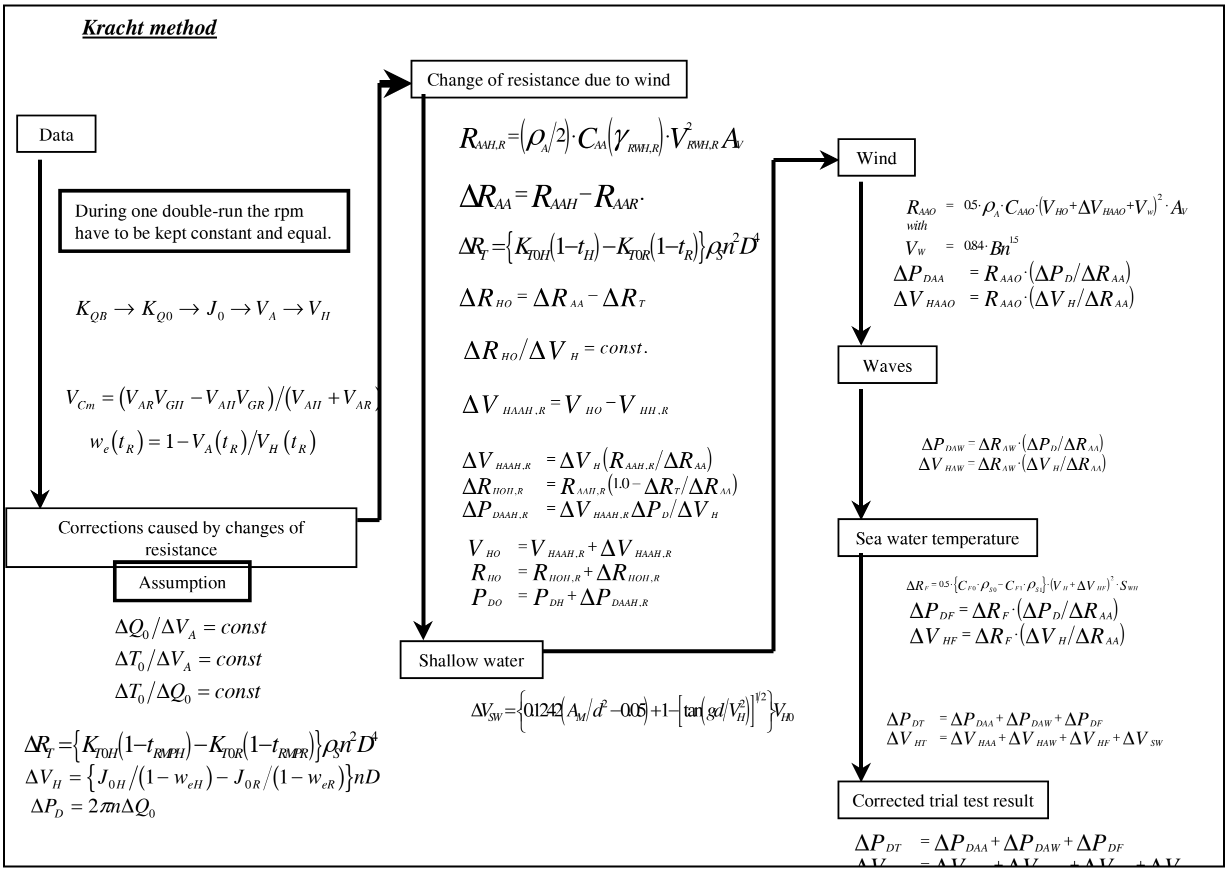


Figure 6.6 Kracht Method.

Table 6.5 Comparison of Analysis Methods.

Necessary data for analysis		Sea Trial Raw Data	Measurement to be done Influencing Factors	Pre-Conditions Needed before Trial
Data prepared before trial				
Propeller diameter	General			×
Propeller open water characteristics	General			×
Resistance curve	General			×
Self-propulsion factors	General			×
Quasi-propulsive coefficient	General			×
Wetted surface area	General			×
Wind resistance coefficient	Wind			×
Wind direction coefficient	Wind			×
Above-water cross-sectional area of ship	Wind			×
Height of anemometer	Wind			×
Response function of resistance increase	Wave			×
Wave spectrum	Wave		×	×
Direction distribution of incidence wave	Wave		×	×
Real slip ratio	Steering			×
Aspect ratio of rudder	Steering			×
Rudder area	Steering			×
Rudder height	Steering			×
Resistance deduction fraction due to steering	Steering			×
Effective inflow velocity to rudder	Steering		×	×
Drift angle	Steering	×		
Midship section area under water	Shallow			×
Basic data measured on trial				
Displacement and trim	General	×		
Sea water temperature and density	General	×	×	
Run No. and direction	General	×		
Time	General	×		
Elapsed time on each course	General	×		
Ship speed over ground	General	×		
Shaft torque	General	×		
Propeller revolution	General	×		
Air temperature	Wind	×		
Atmospheric pressure	Wind	×		
Relative wind velocity	Wind	×	×	
Relative wind direction	Wind	×	×	
Magnitude and direction of sea waves	Wave	×		
Rudder angle	Steering	×		
Drift angle	Steering	×		
Depth of water on course	Shallow	×		

Table 6.6 Basis for Method Corrections.

Method	Feature	Notation
SNAME	* Speed correction is based on effective horse-power curve. * Mean of means method is adopted for current correction.	* Mean of means method is correct only for linear change of current. * Effect on propeller isn't considered. * Correction is considered only for relative wind.
BSRA	* Shaft power curve is the base of correction. * Position of anemometer is considered for wind resistance. * Various wind resistance coefficient data are prepared.	* Effect on propeller isn't considered.
Taniguchi-Tamura	* Propeller open water characteristics are the basis of correction. * Propeller loading coefficient is used for the balance of forces. (self-propelling condition)	
ISO TC8/SC9	* Principle is same as Taniguchi-Tamura method. * Propeller open water characteristics are the basis of correction. * Propeller loading coefficient is used for the balance of forces. (self-propelling condition)	
Jinnaka	* Propeller open water characteristics and resistance curve are basis of correction. * Base equation is Taylor expansion of balance of forces.	
Kracht	* Propeller open water characteristics are the basis of correction.	* During one double-run the rpm have to be kept constant and equal. * It is assumed that torque, thrust and speed are proportional to each other.

Principles

- Propeller open water characteristics

The use of propeller open water characteristics is the basis for four of the correction methods studied by the SC.

For controllable pitch propellers, the difficulty in accurately measuring the pitch during full-scale trials may introduce unacceptable uncertainty in the correction method.

Correction Items:

- Wind Correction

The basic inputs for wind correction are relative wind speed and direction and aerodynamic coefficient. Aerodynamic coefficient can be obtained from databases e.g. Blendermann (1996), estimations based on regression analysis e.g. Isherwood (1973) or more desirably, from wind tunnel measurements.

Wind speed and relative direction can be measured using conventional anemometers.

The BSRA method corrects the wind speed measurement to account for the height of the anemometer. In principle, this correction is useful but in practice most anemometers installed on board ships are affected by the surrounding mast equipment. In practice, limited to no calibration is performed with the anemometer in place on the ship (wind tunnel tests could be used for a proper calibration of anemometers). Moreover, during the different interviews the committee held with shipbuilders, it was consistently mentioned that for correction purposes, the wind speed and direction were simply obtained from visual observation (Beaufort scale). Actual wind measurements should be used to monitor the wind evolution during the run as a check for consistency and/or a source of error in the data. For that purpose absolute (relative to ground) wind speed and direction are calculated using ship anemometer measurements, ship speed (DGPS), and heading.

- Waves

Ship performance is affected by sea state and therefore several methods are proposed to account for the resistance increase due to waves. It is beyond the scope of this report to enter into the seakeeping theory involved in each correction method but it must be noted that all proposed methods make the assumption that ship motions remain linear and do not significantly affect the self-propulsion factors. The maximum sea state in which speed and powering trials can reasonably be performed is therefore related to the level of ship motions. A limitation of sea state based on wave height/ship length ratio seems to be more consistent. A figure of 2% is proposed in the Kracht method while ISO TC8/SC9 proposed 1.5% and in any case less than 3 m. The main criticism that needs to be addressed in the correction method for waves is that the main additional input required (i.e., wave height, direction and period) is not measured.

- Rudder and Drift

In the ISO TC8/SC9 correction method, a correction is proposed for both steering and drift. In both cases added resistance formulae refer to empirical coefficients, which may introduce additional uncertainty. In any case those corrections only consider “constant” drift and rudder deflection (caused by wind) and should not be applied to rudder cyclic activity and course deviation caused by sea state or the poor course keeping ability of the ship. The drift angle to be considered is the drift angle of the ship relatively to the water and can therefore not be measured directly. ISO TC8/SC9 does not indicate how to obtain this drift angle using onboard measurements and only suggests the use of “theoretical or alternative methods”.

- Shallow Water Correction

All methods that consider correction for shallow water effect are based on Lackenby’s formula (Lackenby 1963). The two parameters considered in the formula are related to ship sectional area and the Froude Number based on water depth. These two parameters are related to two different hydrodynamic phenomena and should therefore be considered separately.

$$\frac{\Delta V}{V} = 0.1242\left(\frac{A_m}{h^2} - 0.05\right) + 1 - \left(\tanh\left(\frac{gh}{V^2}\right)\right)^{0.5}$$

According to the original paper, this formula was verified for 6 ships up to the following limits:

$$h > 2\sqrt{A_m} \text{ and } h > 0.3V^2$$

This limitation is implicitly taken into account in the ISO/TC8/SC9 draft, which, indicates that water depth should be such that the percentage speed loss calculated using Lackenby’s formula should be less than 2%.

On the other hand, the speed loss was found to be negligible when:

$$h > 6.0\sqrt{A_m} \text{ and } h > 0.5V^2$$

which could constitute an absolute limitation for trial site depth when no correction is to be applied.

Other formulae for trial site depth are proposed in the literature. They are less restrictive than the one above and, depending on ship type, have a variable severity when compared to each other:

- SNAME 1973/21st ITTC Powering Performance Committee

$$h > 10\frac{TV}{\sqrt{L}}$$

$d \geq 10TV/(L)^{0.5}$ (2)

d = water depth, ft

V = speed, kn

L = length between perpendiculars, ft

- SNAME 1989 from Det Norske Veritas Nautical Safety- Additional Classes NAUT-A, NAUT-B AND NAUT-C, July 1986

$$h > 5.0\sqrt{Am} \text{ and } h > 0.4V^2$$

h = water depth, m

A_m = midship section area, m^2

V = ship speed, m/s

$h > 5\ (T)$ (4)

T = Mean draft, m

- 22nd ITTC Trials & Monitoring Specialist Committee/12th ITTC based on ship section and Froude Number

$$h > 3.0\sqrt{BT} \text{ and } h > 2.75\frac{V^2}{g}$$

h = depth in appropriate length units

B = beam in appropriate length units

T = draft in appropriate length units

V = speed in system of units consistent with the above dimension

g = acceleration due to gravity in units consistent with the above dimension

h = water depth, m

A_m = midship section area under water, m^2

V = ship speed, m/s

ΔV = speed loss due to shallow water effect, m/s

g = acceleration due to gravity, m/s^2

Another limitation the correction proposes is a global factor, which makes no differentiation between resistance increase and alteration of propulsion works.

Table 6.7 Comments on Analysis Method Handling of Various Correction Factors.

ISO TC8/SC9	Wind	Waves	Steering	Drift	Water Temperature & Salt Content	Vessel Condition	Shallow Water	Correction for Current	Correction for Still Air Resistance
SC Comments on ISO TC8/SC9 references refer to Draft Internatl Std ISO/DIS 15016		limitation of actual sea state to perform the test are SS 5 for ship > 100 m and SS 4 for ship < 100 m limitation is ship motion propulsion factor assumed constant 1. thrust deduction 2. Wake fraction	additional data needed from regression eqns or data base (not much data available) not really a stand alone correction but part of a global ship system resistance mean value of rudder, rudder angle coeff related to rudder is needed need lift of rudder Appendix C p.35 - formula is noted in Appendix & not in main body as available information	assumption is 0.25 is constant coefficient for drift. how drift is measured is not addressed by ISO TC8/SC9	salt content forrmula based on: 1. Change in density of water 2. Change in frictional resistance ISO considered using 1. Salt content formula 2. Temperature formula	draft formula used if difference between actual & specified displacement < 2% see Annex E, p. 39, formula E1 ISO TC8/SC9 needs to define when this formula should be used	correction based on Lackenby - Annex F, p.40	tidal current is considered after disturbance SC indicates need to separate current & still air conditions, ISO assumes tidal current	coefficient related to rudder needed, not really a stand-alone correction, part of a global ship system resistance correction really deals with superstructure resistance & not with the resistance of just the hull (w/o superstructure)
SNAME	SNAME Global Coeff is approx same as ISO TC8/SC9	N/A	N/A	N/A	N/A	N/A	N/A	reciprocal run, similar to BSRA	N/A
BSRA	wind speed corrected $C_{AA1} = C_{AA} \times \phi_1 \times \phi_2$	N/A	N/A	N/A	N/A	N/A	N/A	tidal current, correction on power using power curve, similar to SNAME	N/A
Taniguchi/ Tamura	same as ISO TC8/SC9 with exception of use of different notation	N/A	N/A	N/A	N/A	N/A	N/A	same as ISO TC8/SC9	N/A
Jinnaka	same as ISO TC8/SC9	N/A	N/A	N/A	N/A	N/A	N/A	disturbance is removed current in still air condition identified at the same time more reasonable than ISO TC8/SC9 method	N/A
Kracht/VWS	same as ISO TC8/SC9 with exception of use of different notation $\gamma_{RWH,R} = \varphi_{WR}$	limitations are: 1. wave height, $\zeta < 2\%$ of L_{PP} 2. No ship motion	N/A	difference between viscous coeff at actual temperature vs reference temperature	formula based on difference between viscous coeff at actual temperature vs reference temperature no consideration to changes in wetted surface related to contractual conditions as well as wind and wave conditions	N/A	N/A	current is considered before disturbances Q and V are constant in two reciprocal runs is a big assumption	N/A
	need for additional coefficients to account for: 1. Boundary layer 2. Anemometer location								

7. CONCLUSIONS

1. A revised guideline for conducting speed/power trials has been established by the Specialist Committee to account for the concerns of shipbuilders, ship owners and the scientific community.
2. Uncertainty analysis is a useful tool in developing an increased confidence in the trial data obtained.
3. DGPS has become the universal standard for obtaining ship position.
4. The Specialist Committee evaluated different data analysis methods to derive ship speed (over ground) from DGPS information and has determined that all of the data analysis methods are substantially equivalent.
5. There is no definitive standard for the analysis of trials data, though Final Draft International Standard ISO ISO/FDIS 15016 (E), ISO/TC 8/SC 9WG 2 of 2001 guidelines is the most comprehensive.
6. Some data analysis procedures now include a correction for sea state. Therefore, greater emphasis should be placed on the acquisition and evaluation of sea state trial data when developing or revising data analysis procedures.
7. Current data analysis procedures assume that ship motions are limited.
8. Uncertainty Analysis should be performed for each measurement chain according to the example provided in the report. (HBM system and DGPS in the text).
9. Sea state should be directly measured or obtained from hindcasting as opposed to the current practice of estimation based upon long time sea experience.
10. A time history with appropriate time sampling of each trial measurement is necessary to increase confidence in the trial data and to evaluate it's level of quality.

8. RECOMMENDATIONS TO THE CONFERENCE

1. Adopt the Procedure "Speed/Power Trial Preparation" 7.5-04-01-01.1
2. Adopt the Procedure "Speed/Power Trial Ship Inspection" 7.5-04-01-01.2
3. Adopt the Procedure "Speed/Power Trial Hull and Propulsor Survey" 7.5-04-01-01.3
4. Adopt the Procedure "Speed/Power Trial Instrumentation Installation and Calibration" 7.5-04-01-01.4
5. Adopt the Procedure "Speed/Power Trial Conditions" 7.5-04-01-01.5
6. Adopt the Procedure "Speed/Power Trial Conduct" 7.5-04-01-01.6

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The Specialist Committee on Speed and Powering Trials

Committee Chair: Dr. Pierre Perdon (Bassin d'Essais des Carènes)
Session Chair: Dr. Seung-Il Yang (KRISO)

I. DISCUSSIONS

I.1. Discussion on the Report of the 23rd ITTC Secialist Committee on Speed and Powering Trials: Rational method for evaluating traditional and quasusteady trials

By: Michael Schmiechen, Germany

The Committee Report deals with traditional methods for evaluating traditional trials in great depth, essentially without drawing any conclusions. But the Report hardly mentions other methods, referring only to the Proceedings of the 2nd INTERACTION Berlin '91 devoted to the METEOR project, far beyond the scope of the SC work. Therefore I would like to draw the attention of the Conference to rational procedures for evaluating trials.

At first I mention the development of a rational method for evaluating traditional trials, which has been triggered by the Japanese proposal for an ISO standard five years ago and has since reached a state of maturity. During the same time ISO Committee Draft 15016 became a standard proper, although since the early stages of discussion the procedure proposed has been shown to lead to inconsistent results.

Secondly I like to draw the attention of the Conference to the rational method for evaluating 'rational' quasisteady trials already applied in the METEOR project. This method has finally reached a state of maturity only during the last half year, triggered by a seminar I gave at the Gdansk Ship Model Basin in January 2002 taking into account all the lessons learned during the past fifteen years.

For those interested in the development I brought a short leaflet with references to all the related material on my website http://www.t-online.de/home/m.schm. For those who do not like to surf the Internet and to download files I brought a longer version with all the details of the evaluations printed on paper.

The essential point of the rational procedures is to get away from the ever more detailed models generating more problems than solving them and to move towards highly aggregate models with only few parameters to be identified from the few data available. This permits to evaluate trials without reference to model test results and other prior information, as it should be. Unless we start evaluating trials as objectively as possible we cannot reasonably talk about scaling.

This contribution does evidently not only relate to the Report of the SC on Speed and Powering Trials but to Reports of the Committees on Propulsion, on Resistance, on Procedures for Models Tests and on Test Procedures for Waterjets.

I.2. Discussion on the Report of the 23rd ITTC Secialist Committee on Speed and Powering Trials: Comments on Procedures

By: G.G.J. Mennen, MARIN, The Netherlands

Comments on Procedures:
ITTC Standard Procedure 4.9-03-03-01.7 Chapter 5.6, and

ITTC Standard Procedure 4.9-03-03-01.8 Chapter 5.1

In these procedures wave heights are indicated either as Sea state (procedure 01.7) or as wave height in m and relative wave direction (procedure 01.8) without further information.

In Standard Procedure 4.9-03-03-01.6 on page 6, item 2.c, however, a distinction is made between wave and swell height together with other wave characteristics.

Often during speed trials waves due to wind are present together with swell from another direction. Because the origin of both wave systems is different they influence the performance of the ship in a different way. Therefore, it can be of importance to:

a. select the ship's heading by taking into account effects due to the most dominant wave system, but taking into account other sources of drift as well.

b. Collect the following wave data of both wave systems separately for each run:
   Waves due to wind:
   - wave height (m)
   - wave period (s)
   - relative wave direction (deg)

   Swell:
   - wave height (m)
   - wave period (s)
   - relative wave direction (deg)

The wave height should be the significant wave height $H_{1/3}$.

I.3. Discussion on the Report of the 23rd ITTC Secialist Committee on Speed and Powering Trials: Foul Release Coating Surface Characteristics and their Measurements

By: M. Atlar and M. Candries, University of Newcastle-upon-Tyne, United Kingdom

In fighting against to ship fouling in conventional way, for years the most widely applied marine antifoulings have been Tributyl-Tin Self-Polishing Co-Polymers (TBT-SPC). However, due to environmental side effects related with TBT, the International Maritime Organisation (IMO) has decided in October 2001 to prohibit the application of TBT-SPCs from 2003 and hence completely phase out their use by 2008.

There are currently two alternatives on the market that can also offer satisfactory antifouling performance. The first alternative, Tin-free SPC, uses the same chemical principle but instead of TBT uses other chemically bound moieties, based on copper, silyl or zinc compounds which have much less impact on the marine environment. The second alternative, Foul Release coatings, acts as a physical rather than a chemical defence against fouling. Instead of killing marine organisms that have attached to the hull, they try to prevent the attachment of the organisms altogether by virtue of their surface properties. Most of the Foul Release coatings currently on the market are silicone elastomers based on polydimethylsiloxane (PDMS). PDMS has an extremely flexible backbone, which allows the polymer chain to readily adapt to the lowest surface energy configuration.

Recent research carried out at the University of Newcastle by Candries (2001) indicated that Foul Release coatings can offer attractive reduced drag characteristics compared to Tin free SPC coatings. The attraction of Foul Release coatings is being further exploited by some major shipping companies by coating their propellers to keep them clean and hence to save fuel.

The latter aspect of these coatings is being currently investigated at Newcastle University as reported by Atlar et al. (2002).

However an important practical implication of using Foul Release surfaces is that, the procedure adopted by the International Towing Tank Conference (ITTC) to correlate roughness with ship resistance only accounts for a single roughness amplitude parameter. This procedure will not work for Foul Release surfaces, unless a texture parameter is included in the roughness characterisation as proposed by Candries and Atlar (2003). Even then, full-scale data should be gathered in order to adjust and validate the prediction of added drag from measured roughness characteristics. It is also recommended that more roughness profiles will be collected from dry-dockings since this study has only analysed newly applied coatings.

It may be noted that the measurement of the Foul Release surface, using stylus type devices (e.g. BMT Roughness Analyser) requires special care in that the coated surface has to be moistened slightly with a cloth in order to get meaningful readings. If the surface is too dry, the stylus will stutter, and if the surface is too wet, the drive wheels will slip very easily; both practices will give erroneous readings. In the case of propeller surfaces these measurements get even more difficult due to high curvature of the propeller surfaces requiring sophisticated roughness and texture analysers.

One practical solution for the measurement of relatively flat hull surfaces could be, if a relatively simple modification of the stylus type instrument (e.g. BMT Hull Roughness Analyser) is carried out to record the entire profiles digitally, rather than only the average extreme amplitude, to extract necessary texture parameters. However, the measurement of the propeller surfaces still requires other solutions.

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II. COMMITTEE REPLIES

II.1. Reply of the 23rd ITTC Specialist Committee on Speed and Powering Trials to M. Schmiechen

The committee recognises that no emphasis has been placed on "new" methods for evaluating ship performance at sea such as the rational method promoted by Dr. Schmiechen. The reason for this is that as far as the committee knows, no shipyard or organisation actually uses such a method in its daily work. Therefore it is not justified to debate such a method with the final objective of establishing a standard.

Concerning the method itself, the committee feels that system identification methods in general may suffer from robustness, i.e., that different series of tests performed on the same ship may lead to significant differences in the values of parameters identified.

II.2. Reply of the 23rd ITTC Specialist Committee on Speed and Powering Trials to G.G.J. Mennen

The committee fully agrees with Mr. Mennen on the necessity of obtaining more complete information on waves characteristics. This is an essential part of ship trials where it is important to define the conditions of the ship being tested and the environment/trial site conditions where that ship is being evaluated.

The use of instruments such as wave rider buoys or bow-mounted wave sensors was recommended by the 22nd ITTC Trials and Monitoring Specialist Committee and is endorsed by our committee. Our committee indicates in our final report that this essential information required for the correction of the trials data is commonly not available as an actual measurement. Typically this information, if available, is visually acquired and filtered by the experience of the observer.

The committee does indicate in the final report, the use of global drift as a mean for the trial team to obtain reliable information. The global drift will include the wave information as part of its overall make-up but does not allow for the separation of all the individual factors making up this useful tool. Information is required by many data analysis procedures to correct the speed/power data for environmental effects. This information should be acquired by direct measurement.

In conclusion, the committee strongly recommends the acquisition of all the measurements identified in the final report using calibrated instrumentation, and in recording that information with a computer. This enables the conduct of a meaningful uncertainty analysis and a more realistic correction of the speed/power data for ship conditions and trial site environmental conditions.

II.3. Reply of the 23rd ITTC Specialist Committee on Speed and Powering Trials to M. Atlar and M. Candries

The committee would like to thank Dr. Atlar for his comments regarding the measurement of roughness of the ship hull and propellers. Dr. Atlar is correct in reminding the committee about some of the deficiencies regarding the BSRA/BMT roughness gage. The stylus-type gage is not suitable for rough surfaces. Hence only measurements done on fairly smooth surfaces can be considered reliable. However, this is the standard instrument in use for this kind of measurement.

The committee agrees with Dr. Atlar that the BSRA/BMT roughness gage is not suitable for all situations. It is hoped that some organisation will develop a gage suitable for the measurement of all kinds of surfaces with a high degree of accuracy and reliability.

The committee knows of only one comprehensive attempt to determine the effect of hull roughness on ship speed. This was a US Navy study conducted in the early 1980s where it was determined that small differences in paint and paint thicknesses in combination with different cleaned areas produced significant fuel cost savings.

Therefore it would be of interest to the ship community that a comprehensive study of the relationship between hull and propeller surface roughness and ship speed/power be investigated.