Evaluating Ship Speed Trials
A memorandum

Further steps towards a rational standard

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Abstract

Recent lectures and discussions on the rational procedure for evaluating ship speed trials developed by the author over the last thirteen years have triggered further developments and steps towards a rational standard. The author has not updated his own early drafts of such a standard, but strongly supports and promotes early updates in order to have them ready for consideration at the forthcoming update of the present ISO 15016: 2002-06.

In this short memorandum concerned with new fundamental insights and solutions, only the minimum background necessary is provided, more detailed elaborations are to be found in earlier papers and worked examples, all to be found on the website of the author.

1 Introduction

The work of the author on evaluating ship speed trials has been triggered by the Japanese proposal of an ISO standard of 1993, which has in the meantime become ISO 15016: 2002-06, despite serious counter-arguments presented to the Japan Marine Standards Association and other bodies involved. The following is a quotation from the letter of April 15, 1998 to the Convener, Prof. M. Ikehata, Yokohama National University:

> "Since one year I am retired now and I am studying various fundamental problems, which I could not finally solve while still at the model basin due to the daily workload, mostly non-scientific of course. Among these problems is full scale testing of ships, which I had the opportunity to study in great depth based on my rational theory of hull-propeller interaction not only in connection with the METEOR project, but further in connection with the SES CORSAIR project.
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> Immediately when I saw the first draft of the Standard, prepared by the SRAJ Panel SR-208 in March 1993, I sat down and drafted my own version much along the lines of my thoughts and my experience, which I have explained in detail in my workshop on the rational theory of hull-propeller interaction, the 2nd INTERACTION Berlin '91. I recall that the workshop was attended by all members of the 20th ITTC Powering Performance Committee with their Chairman Professor Nakatake.
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> My draft was discussed quite extensively in our German ad hoc Trials Group at DIN/NSMT, but the decision was that the time was not yet ripe for the drastic change of the approach, which I am advocating and promoting. The position of the group is known to you and has evidently led to the new proposal now under discussion. From the style you may guess that the annex of the German position on 'Corrections of shaft power and propeller speed' is based on input I have drafted.

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When I saw this new proposal my old reservations concerning the whole procedure, as it is followed traditionally, and concerning the standardisation of special theories, became virulent again and I felt that the members of the ISO Working Group 2 should at least know my proposal, which I attach in an up-dated version, and consider it themselves, before taking decisions on a standard, which is quite fundamental and with considerable impact on industry.

Of particular interest in this context is the extensive discussion of the Report of the 21st ITTC/PPC, by Japanese colleagues in particular, and a note of Dr. Kitagawa to Prof. Huse, mentioning that most of the shipbuilders in Japan were complaining about the proposed guidelines and felt it to be dangerous for shipbuilders. To my knowledge the same feeling prevails at European shipbuilders concerning the new standard proposed. Dr. Kitagawa rightly concludes with the remark, that we need to be much more careful with our reports, and I add: with our proposals of standards as well.

My approach is based on the theory of conflict resolution, on a simple model of hull-propeller interaction and the basic facts of systems identification in the presence of noise, even feed back of noise in closed loops. It is the approach systems engineers, knowing little or nothing about ship theory, would take. And you may find it difficult to tell, where this approach is wrong or inadequate. It is not only much more convincing and trustworthy than the traditional approach, but may even be proved to be correct, avoiding unnecessary and maybe even irrelevant diversions."

Based on a half-sentence in the Report on the METEOR project (Schmiechen, 1991) the author in 1993 immediately began work on the problem and proved that the proposed method much along the lines of the traditional approach was not meeting present-day conceptual and methodical standards, and, even worse, that the results of the example provided with the proposal and later with the standard are 'wrong' by any 'standard'.

The rational method proposed together with results has been published on many occasions since 1998, and the whole development, including worked examples and the correspondence with the convener and many other bodies involved has been documented on the website of the author. Recent presentations and discussions have triggered further developments and steps towards a rational standard and essentially only these are subject of the present memorandum, providing only the minimum background necessary.

Evaluation of speed trials is in any case identification of parameters of powering models (Schmiechen, 2001). The rational procedure proposed permits to deal separately and sequentially with the power supplied and the power required, respectively. In the first step the parameters of the propeller powering performance in the behind condition and the parameters of the current velocity, and thus the speed of the ship through the water, are identified by solving a first system of linear equations. In the second step the parameters of the powers required due to the motion in water, wind and waves, and thus the power required at the condition of no wind and no waves, are identified by solving a second system of linear equations.

In both cases the problems, well defined in terms of simple mathematical models to be discussed in due course, are ill-conditioned, nearly singular or even 'practically' singular, this problem as well to be discussed in due course. Ill-conditioned problems cannot be solved with paper and pencil or with home-made algorithms, as Japanese colleagues have tried, but require the most advanced algorithms based on singular value decomposition.

The situation is even aggravated, if the problem is not well-defined as in the traditional procedure underlying the ISO standard adopted in June 2002. In view of the conceptual simplicity and the mathematical and numerical sophistication necessary and to be discussed in detail the author has no idea how anybody can seriously believe to provide reliable solutions of ill-defined, ill-conditioned problems by more, mostly less educated guess work as is done in the standard ISO 15016: 2002-06.

2 Power supplied, current velocity

2.1 Basic laws

For ready reference the following quotation is provided (Schmiechen, 2001):

"The propeller performance in the behind condition, in the full scale wake, and the current velocity can be identified simultaneously by solving one set of linear equations.

For screw propellers the shaft power

$$P_P = 2\,\pi\, n\, Q_P$$

can be derived from measured values of the rate of revolutions and of the torque. In case the latter are averages of periodically or stochastically oscillating values already this simple formula is a convention. Further conventions are necessary, if instead of the power in the shaft the power at the propeller is being considered as is the case in the traditional method based on model propeller open water characteristics.

Further the speed of the ship over ground, with reference to an earth fixed observation space, can be measured using the global positioning system GPS, which is readily available today, now even without the previously limited resolution. But the speed of the ship's hull through the water cannot be measured directly due to the unknown current velocity.

This problem can be resolved, if the data observed in a series of steady runs on opposite courses at given times are described by the power law

$$P_P = p_0\, n^3 + p_1\, n^2\, v_H$$

and the hull speed

$$v_H = v_G + v_C$$

expressed as the sum of the speed over ground and the current velocity, and by a model for the current velocity as function of time, maybe harmonic with the tides or just polynomial

$$v_C = \Sigma\, c_i\, t^i\,, \quad i = 0, \ldots 3\,,$$

preferably linear in the unknown parameters. Both laws are 'local' in the sense that they apply only in the 'vicinity' of the operational conditions met and can be extrapolated only with great care."

The power law looks like a 'Newtonian' law for the hydrodynamics of pumps. But as has been shown at the recent international conference MAHY 2006 even this rudimentary reference to hydrodynamic theory is not necessary.

2.2 Buckingham's Π -Theorem

The following quotation provides the arguments (Schmiechen, 2006):

"We are solving our problems by more or less involved models. Before talking about special models I will mention some general conditions these models must meet. In order to be useful for the description of objective relationships the models must be invariant with respect to changes of units. Buckingham's Π-Theorem is the expression of this meta-principle (Birkhoff, G.: Hydrodynamics. A study in logic, fact and similitude. New York: Dover, 1955; pages 77-90). Colloquially it is referred to as dimensional analysis.

An important, often forgotten observation is that the theorem says nothing about the number and type of parameters to be chosen and the format of the function. This information is a matter of *experience*, past or present, not necessarily of hydrodynamics. The parameters can be changed to others, amounting to a change to oblique coordinates in logarithmic scales. Although everybody learns this at school, hardly anybody draws the conclusions.

The reduction in the number of parameters by three appears to be large, but the number of mostly geometrical parameters, necessary to describe a hydromechanical system, is usually very large. As a consequence aggregate or global parameters, typically 'characteristic' lengths are of interest, usually a matter of more, mostly less educated guess work trying to anticipate the results of the tests to be performed."

2.3 Simplest example: Speed trials

The application to speed trials has been stated as follows:

"Often the situation is even simpler and the problem at hand can be solved pragmatically. Let us consider as a simple, but most fundamental example, the powering performance of a ship at given loading condition and speed.

In this case the power ratio

$$K_P \equiv P / (\rho\, D^5\, N^3)$$

is assumed to be a function

$$K_P = f_P\,(J_H)$$

of the hull advance ratio

$$J_H \equiv V / (D\, N)\ .$$

Due to the very small variability of the data the most general function that can be identified with confidence is [some two parameter function, if nothing else is suggested by some theory,] a linear function

$$K_P = K_{P\,0} + K_{P\,H}\, J_H\ .$$

With the ship speed over ground, to be measured by GPS, and the unknown current speed over ground the hull advance ratio is

$$J_H = J_G - J_C\ ."$$

The linear law is equivalent to the power law stated earlier. Thus, contrary to the earlier instinctive belief the model is indeed strictly based on formal arguments and not at all on physical, hydrodynamical arguments. Anything else is plain professional superstition, unnecessary complication of a problem difficult enough. And this is not a naughty exaggeration, but the result of the most basic ship theory, as the author understands it. It is important to note that in identifying the parameters the law in terms of physical magnitudes is being used, in order to avoid inadequate weighting due to normalising.

In the traditional approach reference is being made to the theory of hull-propeller interaction, unnecessarily introducing a number of problems, which cannot be solved rationally and very often result in erroneous estimates of the current velocity. In view of the basic rule in hydromechanical experiments: 'If you have not estimated the velocity correctly, you can safely forget everything else', the reliable identification of the current velocity is absolutely crucial.

The argument that the current velocity at a given location and time is not of interest as such, does not imply that only nominal values of the current velocities are required. The assumption, frequently met in traditional evaluations, that the current velocity remains constant for runs up and down wind, clearly contradicts the goal of the exercise, to determine changes of the current velocity.

The analysis can be greatly improved if it is not based on often obscure averages, but on the quasi-instantaneous values preferably of quasi-steady tests, providing for variability and not suppressing all relevant information as is done in traditional 'steady' speed tests. In view of the very large masses of ships monitoring of the remaining spurious, maybe very small accelerations is absolutely mandatory. The resulting inertial forces may easily upset the momentum and energy balances.

As experience has shown the quality of the measurements has greatly improved over the last few years. The standard deviation of the residua in solving the set of linear equations is less than 100 kW, particularly if the data are carefully scrutinised and outlyers are individually taken care of.

3 Power required due to wind and waves

3.1 Simple 'power laws'

Exactly the same approach taken in the first step can be applied in the second step. Simple local laws maybe assumed for the power required due to the motion in water, wind and waves. The following quotation has been slightly modified for the purpose at hand (Schmiechen, 2001):

"Identifying parameters of models from observed data, even visually observed wave data, has the advantage that systematic errors in the observations are 'to a great extent' automatically accounted for by identifying the appropriate correlation factors instead of relying on a priori physical data not accounting for systematic errors in the observations. In case of the proposed, very involved ISO method this is not the case, although it is based on the same wind measurements and the same crude wave observations available. This fact is one major reason for the concerns about the ISO method expressed unisonously by experts in ship yards and model basins.

The shaft power required is due to the motions of the vessel through water, waves and wind. As in the case of the power supplied the parameters of simple 'local' overall models … can be identified and used to determine the speed-power relationship at conditions different from the trials conditions, typically at the no wave and no wind condition.

The power due to motion through the water is 'locally', 'in the vicinity' of the operating conditions, sufficiently modelled by the parabola

$$P_{\text{Water}} = \Sigma\, c_{\text{Water } i}\, v^{i}, \quad i = 2, 3, 4 .$$

All attempts to use only two parameters have finally been shown to fail.

The power due to motion through the wind is as usual sufficiently modelled by the law

$$P_{\text{A.Wind}} = c_{\text{A.Wind}}\, C_{\text{A.Wind}}$$

using the short hand notation

$$C_{\text{A.Wind}} = [\rho_{\text{Air}}\, A_{\text{Wind}}\, v_{\text{Wind.R}}\, |v_{\text{Wind.R}}|/2]\, v$$

for the aggregate 'cause' of the power due to wind with the relative wind speed, if the wind direction is basically from ahead or behind. In general an additional law needs to be introduced to account for the 'directional' coefficient of wind resistance. …

Slightly more involved is the added power due to the operation in waves. The simple law

$$P_{\text{A.Wave}} = c_{\text{A.Wave}}\, C_{\text{A.Wave}}$$

using the short hand notation

$$C_{\text{A.Wave}} = [\rho\, h_{\text{Wave}}^{2}\, v_{\text{Wave.R}}\, |v_{\text{Wave.R}}|/2]\, v$$

for the aggregate 'cause' of the power due to waves with the observed wave height and the relative wave speed derived from the observed wave period, similar to the law of the shaft power due to wind, is being suggested and has been used in the re-evaluation of the ISO/DIS example. An addi-

> tional law for the transverse waves may be necessary. As in the case of the supplied power and of the current the models proposed are open for discussion and for improvement. They are the conventions to be agreed upon!"

The 'coefficients' or *parameters of added power* due to wind and waves introduced are *not* identical with the coefficients of the wind and wave resistance used in the traditional procedures!

3.2 Singularity

In the usual case of nearly perfect linear correlation of the aggregate wind and wave causes the problem becomes singular, implying that infinitely many, mathematically correct solutions exist. A straightforward solution is obtained if the value of the parameter of added power due to wind is arbitrarily assumed.

Accordingly all the subsequent results depend on the value assumed for the wind power parameter. Among the results is the standard deviation of the residua in solving the set of linear equations. Due to the very crude 'observations' of the waves this standard deviation is much larger than that in the first step. The result of interest is of course the power required at the contract condition, at the service speed and the no wind and no wave condition.

In an example the standard deviation of the residuum remained essentially unchanged for different values of the wind parameter, while the values of the contract power at the contract condition exhibited only relatively small changes depending on the value of the wind power parameter. Thus the value chosen for the wind power parameter does not really matter, it does not significantly affect the result of interest.

The problem to select a satisfactory, a meaningful, solution, to provide a rationale for deciding on the value of the wind power parameter, can only be solved by convention. Formal 'solutions' suggested in an earlier expositions are hardly meaningful in physical terms. In the given engineering context of evaluating trials the convention

$$c_{A.\ Wind} = 1$$

is suggested and may be generally acceptable.

This convention is indeed plausible as it implies that the value of the coefficient of wind resistance is assumed to equal the value of the propulsive efficiency. And looking at the values of the coefficient of wind resistance published in the standard ISO 15016 this assumption appears to be quite acceptable in general. And as stated earlier small deviations from this assumption have only a very small effect on the final result of interest, the power at the service speed and the no wind and wave condition.

If the down wind condition very nearly equals the no wind and no waves condition, the so called 'vacuum condition', this fact may provide the only solution in cases where only crude estimates or even only vague guesses of wind and wave data are available and where other procedures break down. In these cases the 'windy' wind and wave data can be safely 'forgotten'. For the purposes of power prediction only the added power due to motion through the air needs to be estimated using the above convention. In these cases detailed analyses of the propulsive performance are 'of course' not possible. An example of this type was to be published on the website of the author but on close inspection the data turned out to be corrupt.

4 Conclusions

To repeat: In view of the conceptual simplicity and the mathematical and numerical sophistication necessary and discussed in detail the author has no idea how anybody can seriously believe to provide reliable solutions of ill-defined, ill-conditioned problems by more, mostly less educated guess work based on unnecessary assumptions as in the standard ISO 15016: 2002-06.

Contrary to the opinion of English colleagues the evaluation of trials can be standardized and needs to be standardized by introducing conventions. As the traditional method the rational method is a conventional method, it is based on conventions to be agreed upon. Though the simple conventions proposed have been tested successfully in many cases they need to be further developed and finally to be agreed upon by the community in a generally acceptable standard.

The international agreement on ISO 15016: 2002-06 has been reached although most of the foregoing considerations and results have been communicated in time to all organisations and bodies involved. Only the Korean colleagues have opposed the new standard, but for the wrong reason. They wanted to introduce more hydrodynamics, an even more fancy seakeeping theory 'based' on shaky grounds, the crude estimates or rather guesses of the sea state.

During the period of the 23rd ITTC apart of the Propulsion Committee three Specialist Committees have been dealing with matters of propulsion: Speed and Powering Trials, Procedures for Resistance, Propulsion and Open Water Tests, Validation of Waterjet Test Procedures. The report of the Specialist Committee on Speed and Powering Trials provides a comparison of all trials codes currently in use.

The rational method proposed has been considered as "a category by itself. It does not really follow the same format as all the other methods and hence was not used in the comparison of factors reviewed in each method." *Purposely the method proposed does not follow the same format!* According to the experience of the author and according to the ISO example the problem is not so much to analyse random errors, but the dominant problem is still to avoid conceptual and systematic errors.

To the big surprise of the author the Specialist Committee on Speed and Powering Trials has been discontinued. Evidently the governing bodies of ITTC 'felt' that all problems have been solved, at the same moment member organisations and other bodies concerned finally started to be concerned. On the other hand a Specialist Committee on Powering Performance Prediction has been established, charged with the task which traditionally has been the essential task of the Propulsion Committee.

The following quotation is taken from the most recent paper of the author (2006):

> "Only after the acceptance of ISO 15016: 2002-06 ship theoreticians and model basins appear to realise that they have for incredibly long time completely neglected the most fundamental problem of ship theory, the evaluation of the performance of ships under service conditions. Besides a paper on the 'Evaluation of the Service Performance of Ships' by Poul Andersen, Anne Sophie-Borrod and Hervé Blanchot (Marine Technology 42 (2005) 4, 177-183), evidently driven by Kappel's 'enthusiasm', MARIN at Wageningen has started a new Joint Industry Project 'to bring sea trials up to speed' (Report, Sept. 2005, no. 86, 16)."

In exercises for the German Fachausschuss für Marine Hydrodynamik and in connection with the MARIN's Joint Industry Project ISO 15016: 2002-06 has been shown to be error prone. A problem in communicating details of exercises is, that not only the groups mentioned are reluctant to have their cases published, even if anonymous. This commercial policy is delaying necessary innovations but will not stop them.

As the title of this memorandum states the present exposition is providing further steps and clarifications towards a rational standard for evaluating ship speed trials. The author has not updated his early drafts of such a standard, but strongly supports and promotes early updates in order to have them ready for consideration at the forthcoming update of the present ISO 15016: 2002-06.

The argument that such drastic changes of the conventions and standards meets with psychological problems on the side of the clients is not valid. The fact is that the problems are those of the 'experts'! Clients have for a long time been asking for a more transparent procedure in evaluating speed trials and are willing to pay for it, as the project at Wageningen shows.

As a result of that project "the best practice is documented in the 'Recommended Standard of Speed Trials' which is available from MARIN for use by owners and yards worldwide" (Press Bulletin released September 25, 2006). Despite an urgent request the author has not yet received this 'standard'.

The procedure suggested for the identification of the speed through the water has already been used by HSVA and will be utilised by MARIN in the subsequent Joint Industry Project on 'Ship Service performance Analysis': "We have used your approach for Trial analysis as a starting point from which we are developing a method for Performance Analysis. Improvements we hope to make are in the added wave resistance and the wind resistance." (e-mail of September 1, 2006).

5 References

A complete list of references is to be found on his website www.m-schmiechen.homepage.t-online.de under 'Bibliography: Propulsion'. All papers and their presentations, worked examples and correspondence since about 1991 are to be found under 'Recent papers: Propulsion' and under 'What's new?' in the pertinent contexts. Further information and discussion are obtained on request via E-mail: m.schm@t-online.de .

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