International Symposium on Ship Propulsion

Evaluating Ship Speed Trials
Identifying Parameters of Powering Models

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Status: 2001.06.10

Rational theory of ships

It is a great privilege and honour being invited for the **fourth time to present a piece of my work** aiming at a rational theory of ship propulsion here **at St. Petersburg, where Euler published** among other works on hydrodynamics **his Scientia Navalis in 1749**, two volumes of a general theory of rest and **motion of floating bodies**, and where he found his own rest at the St. Lazarus cemetery 1783.

Contents, plan

- Problems, need for standards
- Conventions, principles
- Parameter identifications
- Power supplied, current models
- Testing: traditional, quasi-steady
- Powers required: correlations
- Detailed analysis, generalisations
- Non-traditional configurations
- Propellers conceived as pumps

Traditional method: problems

Many problems in the traditional **performance and evaluation** of trials are **due to:**

- **waiting for steady conditions,**
- **ignoring a great deal of useful information,**
- **using ill-defined average values**

and, **worst of all,**

- **using <u>incoherent models and ill-defined procedures</u>** resulting in ‘uncertainties’ of the results.

Need for standards

Despite serious discomfort of industry with the traditional procedure of ship speed trials a Japanese **proposal, refining past practice, has become draft standard ISO/DIS 15016**.

In any case the <u>sensitivity of the results</u> on models, data and procedures <u>requires standardisation</u> not of past practice, but **rationalisation <u>based on adequate and acceptable theories and methods</u>!**

Conflicts: conventions

In the interest of the profession an in-depth discussion of the fundamentals and an **alternative standard** has been suggested and is being promoted **based on the theory of rational resolution of conflicts:**

<u>Agree on minimal sets of measurable concepts and plausible propositions</u>, as well as simple rules of deduction and clear-cut procedures, <u>and accept results derived</u>.

Principles

Accordingly the author has developed, originally as a by-product of the METEOR project, a **consistent systems identification method**

- with **few simple explicit models** and
- with **few parameters to be identified**,
- requiring **no reference to model test results**
- **and to any other prior information**, **as it should be**.

Parameter identification

- Parameters of **propeller performance in the behind condition and current velocity** are being identified simultaneously solving **one set of linear equations.**
- Subsequently parameters of the **shaft powers required due to water, wind and wave resistance** are being identified simultaneously solving a **second set of linear equations.**

Examples, test cases

A large number of trials data have been analysed prior to the comprehensive test cases provided by the ISO/DIS 15016 example and the EVEREST data constructed by Tamura.

Some differences remaining in the results of rational and traditional evaluations can be **ascribed to inconsistencies in the traditional,** typically the ISO **procedure and in the inverse procedure** of constructing test data.

Verification, validation

The **correctness** of analysis procedures is being **proved with 'simulated' data** generated by the corresponding inverse synthesis procedures.

Very clearly **simulated data,** even provided they had been generated correctly and according to the rules set forth, **are not useful to prove the adequacy of a particular analysis procedure nor of any alternative procedure.**

Only real data can serve the purpose.

What needs to be done?

Not 'acceptable' numerical differences between results of various methods, but **acceptable conventions have to be agreed upon!**

Forget about the differences and try to understand the essence of the difficult problem to be solved and try to understand the very simple clear-cut solution proposed.

Testing: traditional

The **typical samples** of six, at best eight or ten ‘doubtful’ averages from ‘steady’ runs are ‘of course’ **too small for ‘serious’ applications of ‘purely’ statistical methods**. Additionally the **results depend on the models and procedures adopted**.

In the ISO/DIS 15016 example to be discussed ten runs provide for a detailed analysis.

Testing: quasi-steady

Sufficient data for the identification of the parameters **can be obtained if data acquisition is not limited to a few steady double runs, but extended to the unsteady changes between runs.**

In the METEOR and CORSAIR trials **quasi-steady test manoeuvres** have been performed and shown to provide not only more, but **in shorter time more reliable information.**

‘Time histories’

These manoeuvres provide at the same time **references necessary for the suppression of systematic errors** due to feedback of the omnipresent noise, **even at service conditions in heavy weather.**

The Recommendation of the Specialist Committee on Trials to the ITTC concerning the necessity to record and to analyse ‘time histories’ are fully endorsed.

SVD, normalising results

In view of the **ill-conditioned problems arising** there is **no chance to solve the equations with do-it-yourself algorithms,** singular value decomposition is an absolute requirement.

After the identification results are normalised for purposes of scrutiny. Due to the ‘weighting’ **systematic effects become evident.**

Powering model

The ‘local’ model

$$\mathbf{P = p_0\, n^3 + p_1\, n^2\, V}$$

relating shaft power P, rate of revolutions n and speed through the water V, can be visualized as a surface in a three dimensional space.

Only the rate of revolutions and the torque, and consequently the power, can be measured directly.

Current models

The speed through the water

$$\mathbf{V = V_{Grd} + V_{Curr}},$$

cannot to be measured directly, but speed over ground. The current is unknown!

In the simplest cases **harmonic tidal currents prevail, often a polynomial law**

$$\mathbf{V_{Curr} = \Sigma\, v_j\, t^j}$$

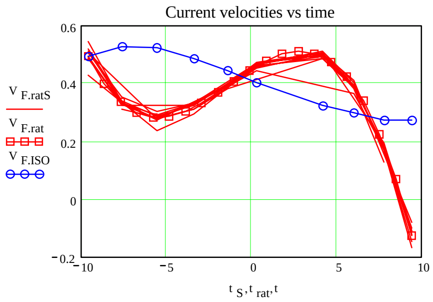
will do. Attention! Components in ship direction! Vectorial subtraction of velocities!

Statistical analysis

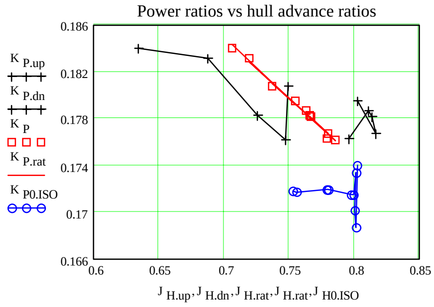
The following figure of the currrents versus time in the ISO/DIS case for scrutiny shows not only the results including all ten runs, but also the results of the ten possible sets including only nine runs. This scrutiny revealed a misprint in one of the power data.

After appropriate correction, which has been confirmed, the subsequent figures show only the results including all ten runs.

ISO/DIS: Current velocities



ISO/DIS: Power ratios



Contract conditions

Contracted power P_{contr} at speed V_{contr} and rate of revolutions n_{contr} , **derived from** or at least confirmed by **model test results.**

For given power P_{contr} and speed V_{contr} rate of revolutions is the solution of the equation

$$P_{contr} = p_0\, \mathbf{n_{req}}^3 - p_1\, \mathbf{n_{req}}^2\, V_{contr}\ .$$

Consequently compliance with contracted conditions can be established **without the usual reference to resistance data.**

Further evaluation

Usually a **speed power relation at a given weather condition,** typically moderate or no wind and no waves, **is being contracted.**

If one wants to do that, one opens **Pandora's box of problems.** The assumptions underlying the traditional procedure are simply too shaky.

The only way to escape is to **adhere to the principles stated, and this is possible!**

Correlation of changes

The approach is to **correlate changes of power with the changes of wind and waves as observed.** The advantage of **this procedure** is that it **accounts for systematic errors** in the measurement of the wind data and in the estimation of the wave data!

In the ISO procedure the very crude wave observations serve as input for very fancy Japanese and Korean **seakeeping theories.**

Power required

Simple 'local' models for powers required due to water resistance

$$\mathbf{P_{Water} = a_1\, V + a_2\, V^2 + a_3\, V^3}$$

and due to wind resistance

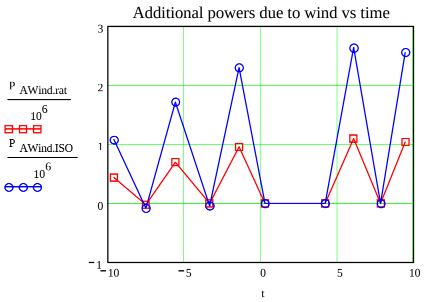
$$\mathbf{P_{Wind} = b\, |\, V_{Wind,\, rel}\, |\, V_{Wind,\, rel}\, V.}$$

The power required at the no wind condition is

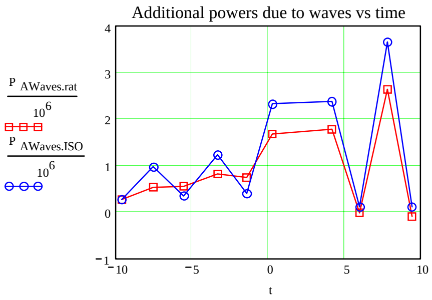
$$\mathbf{P_{Air} = b\, V^3\ .}$$

Similarly the added power due to waves can be accounted for.

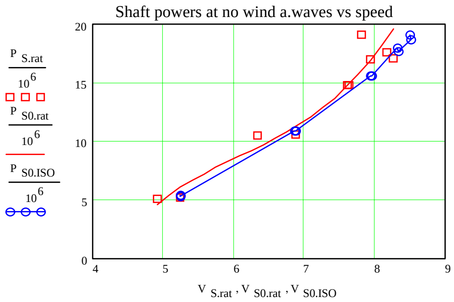
ISO/DIS: Powers required due to wind



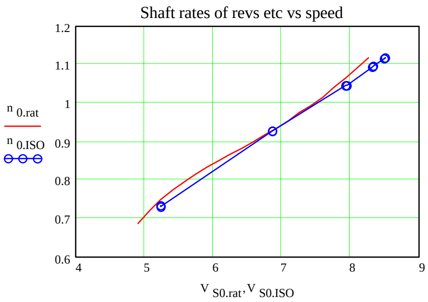
ISO/DIS: Powers required due to waves



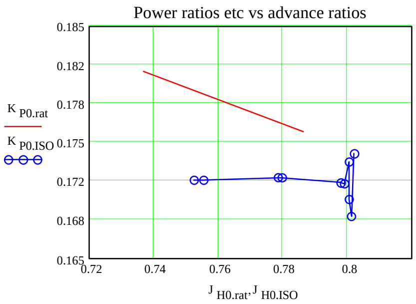
ISO/DIS: Powers at no wind and waves



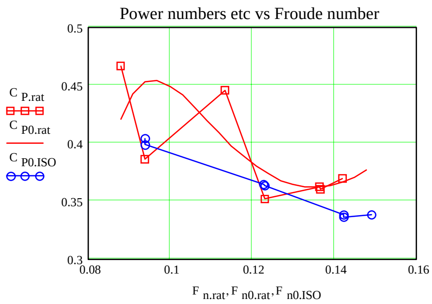
ISO/DIS: Rates of revolution at ...



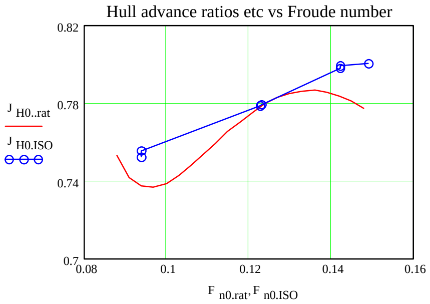
ISO/DIS: Power ratios at ...



ISO/DIS: Power numbers at ...



ISO/DIS: Hull advance ratios at ...



Thrust deduction axiom

In the METEOR project the thrust has also been measured precisely and it has been shown that a **<u>complete analysis</u> of the powering can be based on data from quasi-steady tests.**

One basis is the **thrust deduction axiom**

$$\mathbf{t = t_H\, J_H} \quad \text{with } \mathbf{t_H = const}\ .$$

The **plausibility** has been shown and the resulting values of the resistance are very close to the values determined in towing tests.

Lost power / wake axioms

The **lost power axiom** formerly introduced and resulting in a very involved and sensitive method for the determination of the wake fraction **has long been found to be unreliable in applications and felt to be inadequate**.

Much simpler and robust are the wake axiom

$$\mathbf{w = w_H\, J_H} \quad \text{with } \mathbf{w_H = const}$$

and the hydraulic efficiency axiom

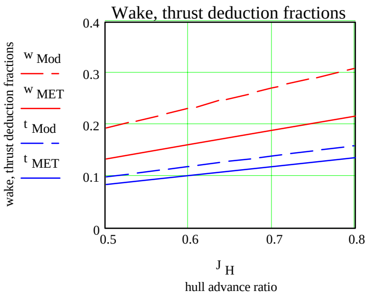
$$\mathbf{\eta_{JP} = const}\ .$$

Powering prediction, scale effects

For powering prediction based on model tests **corresponding methods will have to be developed**.

The re-evaluation of the METEOR prototype and model data including thrust deduction as well as wake fractions permits for the first time ever the **<u>reliable direct determination of scale effects in the wake and thrust deduction fractions</u>.**

METEOR: Scale effects



Generalisations

The procedure of parameter identification may be generalized to identify **effects of load conditions**. **Up to now <u>data available</u>** for the identification of relevant parameters **are <u>simply being ignored</u>!**

<u>The ISO/DIS 15016 does not even address this problem</u> usually solved by referring to model test results at various load conditions.

Need for cooperation

The rational method proposed, being still in its infancy, **needs the joint effort and, being a conventional method, the agreement of all experts** before it can be established as a reference and a standard.

The promissing **results avoid the inconsistencies of the traditional methods, but those concerned are not yet concerned!**

Non-traditional configurations

In case of traditional single screw configurations the question may be raised: **Why should the traditional method of evaluation be replaced as long as it provides the 'right' answers, despite its internal inconsistencies?**

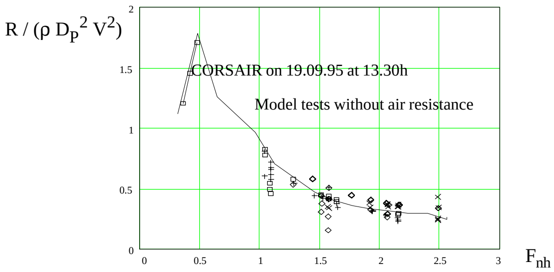
In cases of non-traditional configurations the method proposed adapted to the particular problems **is the only 'alternative', the only possible method. Example SES CORSAIR.**

SES CORSAIR: mass, resistance

In the CORSAIR project, where the **traditional methods of performance analysis fail** due to the **lack of adequate open water tests** with the semi-submerged propellers, it has been shown that **even the inertia of the ship and the resistance in shallow water can be identified reliably.**

SES CORSAIR: resistance

Normalised as function of Froude depth number



Propulsor design

As has been shown in a paper presented here at St. Petersburg on occasion of the Centenary of the Krylov Institute in 1994 **the concepts underlying the evaluation of the powering performance can also be used for the design of unconventional propulsors.**

The advantage of the overall models is that **all hull propeller interactions are being treated implicitly and taken care of correctly.**

Conclusions

It has been shown, that **the rational evaluation** of ship speed trials without reference to model data and others **is possible**.

If necessary the models and procedures, axioms or conventions proposed can be improved according to the principles stated. Only, this has to be done now!

There is no way and no need to go back to the traditional conventions and procedures.