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To whom it may concern

Berlin, September 04, 1999

Sub: **New ISO/CD 15016 Example**
here: **Re-evaluation according to the proposed rational method**
Ref.: Evaluations of August 10, 24, 29, 1999,
Discussion by the German Trials Group at DIN/NSMT on September 01. 1999

including the reduction to the no-wind and no-waves condition based on the **added resistance due to waves computed according to the ISO method**

The present re-evaluation of the new example published in the ISO/CD 15016, circulated 1999.07.29, is including the reduction to the no wind condition.

Concerning the resistance due to waves the author has not yet seriously thought about an adequate, sufficiently simple model, the parameters of which can be identified from the data simultaneously with the parameters of the wind and water resistance models. Consequently, in order to avoid lengthly discussions at this stage, he is taking the crude values provided in the ISO example. The first tests with various, even accepted models of added resistance in waves provided mostly unplausible results, the problems still to be studied.

The change to the one-file organisation without intermediate storage of the data in 'standard format and the change to the symbols of ISO/CD 15016 have been made to improve the readability and direct comparability, respectively, and thus hopefully the acceptability.
The values taken from ISO/CD 15016 are plotted in blue and denoted by o's, while the values computed according to the rational procedure are plotted in red and denoted by +'s.

Units $kN := 10^3 \cdot newton$ $N := newton$ $W := watt$

Test identification TID := "23010" New ISO/CD 15016 example

Constants

Length of ship

$L := 318 \cdot m$

$L := \frac{L}{m}$

Diameter of propeller

$D := 9.5 \cdot m$

$D := \frac{D}{m}$

Density of sea water

$\rho := 1.024 \cdot 10^{3} \cdot kg \cdot m^{-3}$

$\rho := \dfrac{\rho}{kg \cdot m^{-3}}$

Density of air

$\rho_A := 1.225 \cdot kg \cdot m^{-3}$

$\rho_A := \dfrac{\rho_A}{kg \cdot m^{-3}}$

Data reported from traditional trial measurements

time: row 48

$$t := \begin{bmatrix} 16.792 \\ 18.830 \\ 20.826 \\ 23.053 \\ 24.986 \\ 26.682 \\ 30.597 \\ 32.433 \\ 34.231 \\ 35.849 \end{bmatrix} \cdot hr$$

course: row 3

$$\psi_0 := \begin{bmatrix} 5.901 \\ 2.909 \\ 5.901 \\ 2.909 \\ 5.901 \\ 2.909 \\ 2.909 \\ 5.901 \\ 2.909 \\ 5.901 \end{bmatrix} \cdot rad$$

speed over ground: row 4

$$V_G := \begin{bmatrix} 4.409 \\ 5.561 \\ 6.050 \\ 7.182 \\ 7.218 \\ 8.082 \\ 8.416 \\ 7.773 \\ 8.437 \\ 7.922 \end{bmatrix} \cdot \frac{m}{sec}$$

frequency of revolution: row 5

$$n := \begin{bmatrix} 0.7317 \\ 0.7300 \\ 0.9267 \\ 0.9267 \\ 1.0467 \\ 1.0467 \\ 1.0933 \\ 1.0950 \\ 1.1167 \\ 1.1133 \end{bmatrix} \cdot Hz$$

brake power measured: row 6

$$P_B := \begin{bmatrix} 5711 \\ 5533 \\ 11349 \\ 11140 \\ 16200 \\ 16190 \\ 18500 \\ 18330 \\ 19450 \\ 19756 \end{bmatrix} \cdot kW$$

Data non-dimensionalized in view of further use in some mathematical subroutines, which by definition cannot handle arguments with (different) dimensions

$t := \dfrac{t}{hr}$ $\quad \psi_0 := \dfrac{\psi_0}{rad}$ $\quad V_G := \dfrac{V_G}{m \cdot sec^{-1}}$ $\quad n := \dfrac{n}{Hz}$ $\quad P_B := \dfrac{P_B}{W}$

Data normalized for check of consistency

$i := 0 .. \text{last}(t)$

$J_{H_i} := \frac{V_{G_i}}{D \cdot n_i}$

$K_{P_i} := \frac{P_{B_i}}{\rho \cdot D^5 \cdot (n_i)^3}$

$J_{H.0} := \text{Sort}(J_H, K_P, \psi_0)^{\langle 0 \rangle}$

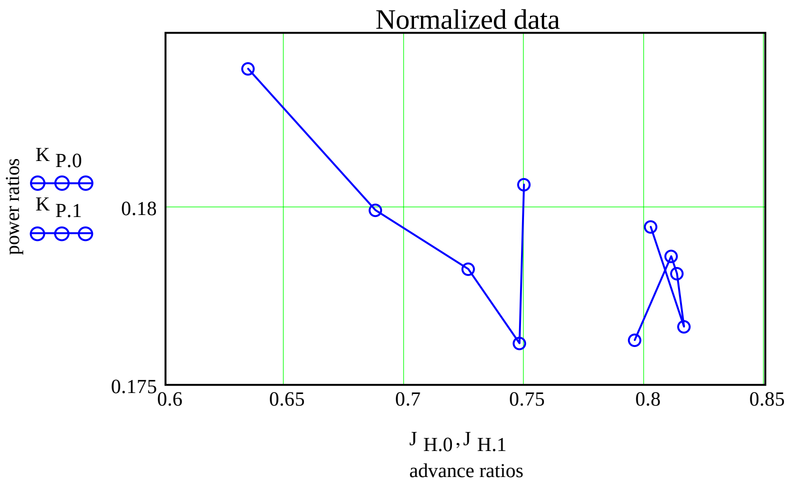
$K_{P.0} := \text{Sort}(J_H, K_P, \psi_0)^{\langle 1 \rangle}$

$J_{H.1} := \text{Sort}(J_H, K_P, \psi_0)^{\langle 2 \rangle}$

$K_{P.1} := \text{Sort}(J_H, K_P, \psi_0)^{\langle 3 \rangle}$

Sort

```
Sort(J_H, K_P, ψ) := | j_0 ← 0
                     | j_1 ← 0
                     | for i ∈ 0 .. last(J_H)
                     |   | if ψ_i > π
                     |   |   | S_(j_0,0) ← J_H_i
                     |   |   | S_(j_0,1) ← K_P_i
                     |   |   | j_0 ← j_0 + 1
                     |   | otherwise
                     |   |   | S_(j_1,2) ← J_H_i
                     |   |   | S_(j_1,3) ← K_P_i
                     |   |   | j_1 ← j_1 + 1
                     | S
```



$J_{H.0} = \begin{bmatrix} 0.634 \\ 0.687 \\ 0.726 \\ 0.747 \\ 0.749 \end{bmatrix}$

$J_{H.1} = \begin{bmatrix} 0.802 \\ 0.816 \\ 0.813 \\ 0.81 \\ 0.795 \end{bmatrix}$

Data reduced in view of inconsistencies at runs 9 and 10

$i := 0 .. \text{last}(t) - 2$

$temp1_i := t_i$ $\quad t := temp1$

$temp1_i := \psi_{0_i}$ $\quad \psi_0 := temp1$

$temp1_i := V_{G_i}$ $\quad V_G := temp1$

$temp1_i := n_i$ $\quad n := temp1$

$temp1_i := P_{B_i}$ $\quad P_B := temp1$

$i := 0 .. \mathrm{last}\left(J_{H.0}\right) - 1$ $j := 0 .. \mathrm{last}\left(J_{H.1}\right) - 1$

$temp2_i := J_{H.0_i}$ $J_{H.0} := temp2$ $temp3_j := J_{H.1_j}$ $J_{H.1} := temp3$

$temp2_i := K_{P.0_i}$ $K_{P.0} := temp2$ $temp3_j := K_{P.1_j}$ $K_{P.1} := temp3$

Reduced data set evaluated for current velocity and powering characteristic in behind at the trials conditions.

Power supplied

$i := 0 .. \mathrm{last}(t)$

$A_{sup_{i,0}} := \left(n_i\right)^3$ $A_{sup_{i,1}} := -\left(n_i\right)^2 \cdot V_{G_i}$

Current velocity

$T_T := 12 \cdot hr + 25 \cdot min$ Average cycle of tides

$\omega := \dfrac{2 \cdot \pi}{T_T}$ $\omega := \omega \cdot hr$ $\omega = 0.506$

$d_{FM_i} := \mathrm{if}\left(\psi_{0_i} < \pi, 1, -1\right)$ Direction of current

$A_{sup_{i,2}} := \left(n_i\right)^2 \cdot d_{FM_i}$

$A_{sup_{i,3}} := A_{sup_{i,2}} \cdot t_i$

$A_{sup_{i,4}} := A_{sup_{i,2}} \cdot \cos\left(\omega \cdot t_i\right)$

$A_{sup_{i,5}} := A_{sup_{i,2}} \cdot \sin\left(\omega \cdot t_i\right)$

$A_{sup_{i,4}} := A_{sup_{i,2}} \cdot \left(t_i\right)^2$ ■ Disabled!

$A_{sup_{i,5}} := A_{sup_{i,2}} \cdot \left(t_i\right)^3$ ■ Disabled!

Left-inverse

$$
LI(A) := \left|
\begin{array}{l}
r \leftarrow \mathrm{rows}(A) \\
c \leftarrow \mathrm{cols}(A) \\
s \leftarrow \mathrm{svds}(A) \\
\text{for } i \in 0 .. c - 1 \\
\quad ISV_{i,i} \leftarrow \left(s_i\right)^{-1} \\
UV \leftarrow \mathrm{svd}(A) \\
U \leftarrow \mathrm{submatrix}(UV, 0, r - 1, 0, c - 1) \\
V \leftarrow \mathrm{submatrix}(UV, r, r + c - 1, 0, c - 1) \\
A_{inv.left} \leftarrow V \cdot ISV \cdot U^T \\
A_{inv.left}
\end{array}
\right.
$$

Least square fit

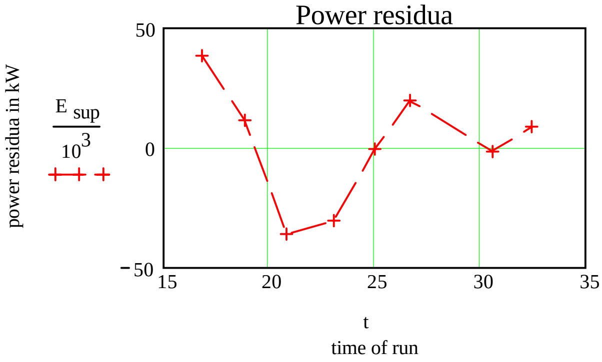
$X_{sup} := LI\left(A_{sup}\right) \cdot P_B$

Residua in terms of power

$E_{sup} := P_B - A_{sup} \cdot X_{sup}$

Quality of approximation

$\dfrac{\left|E_{sup}\right|}{\left|P_B\right|} = 0.169 \circ \%$



These residua do not look quite random, but they are so small that changes of the models are not warranted.

$$\mathrm{Stdev}\left(\frac{E_{sup}}{10^3}\right) = 24.8$$

Current velocity

Rational evaluation

$j := 0 .. 3$

$$v_j := \frac{X_{sup_{2+j}}}{X_{sup_1}} \qquad \sqrt{\left(v_2\right)^2 + \left(v_3\right)^2} = 0.08$$

Tidal current amplitude in m/sec

$$V_{F.rat_i} := v_0 + v_1 \cdot t_i + v_2 \cdot \cos\left(\omega \cdot t_i\right) + v_3 \cdot \sin\left(\omega \cdot t_i\right)$$

$$V_{F.rat_i} := \sum_j v_j \cdot \left(t_i\right)^j$$ Disabled!

Interpolation

$m := 100 \qquad k := 0 .. m \qquad T_k := t_0 - 1 + \frac{t_{last(t)} - t_0 + 2}{m} \cdot k$

$$V_{F.rat.int_k} := v_0 + v_1 \cdot T_k + v_2 \cdot \cos\left(\omega \cdot T_k\right) + v_3 \cdot \sin\left(\omega \cdot T_k\right)$$

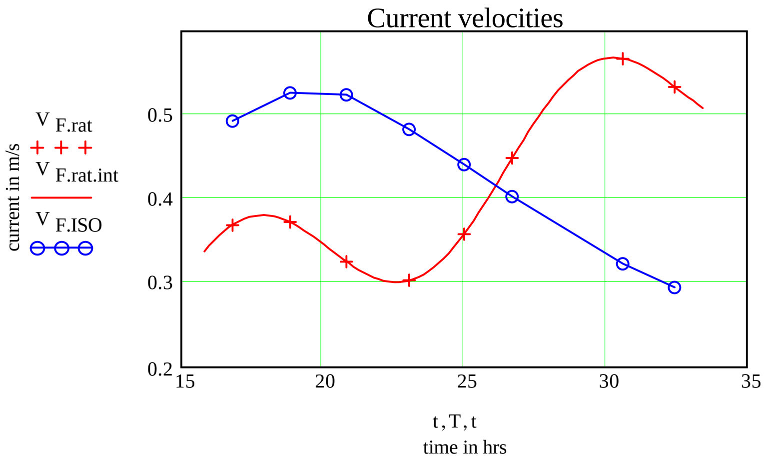
$$V_{F.int_k} := \sum_j v_j \cdot \left(T_k\right)^j$$ Disabled!

ISO/CD evaluation:

current at each run:
row 52

$$V_{F.ISO} := \begin{bmatrix} 0.494 \\ 0.527 \\ 0.525 \\ 0.484 \\ 0.442 \\ 0.404 \\ 0.324 \\ 0.296 \end{bmatrix} \cdot \frac{m}{sec}$$

$$V_{F.ISO} := \frac{V_{F.ISO}}{m \cdot sec^{-1}}$$



Ship speed relative to water

$$V_{S0.rat_i} := V_{G_i} - V_{F.rat_i} \cdot d_{FM_i}$$

Power parameters, rational

$$p_{rat_0} := X_{sup_0} \qquad p_{rat_1} := X_{sup_1}$$

$$P_{B.rat_i} := p_{rat_0} \cdot \left(n_i\right)^3 - p_{rat_1} \cdot \left(n_i\right)^2 \cdot V_{S0.rat_i}$$

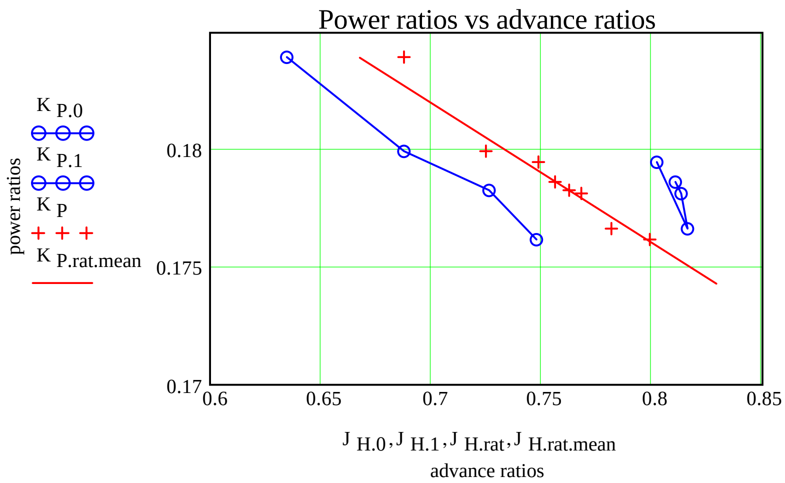
Normalised values

$$J_{H.rat_i} := \frac{V_{S0.rat_i}}{D \cdot n_i} \qquad k_{P.rat_0} := \frac{p_{rat_0}}{\rho \cdot D^5} \qquad k_{P.rat_1} := \frac{p_{rat_1}}{\rho \cdot D^4}$$

$$k := 0 .. 1$$

$$J_{H.rat.mean_k} := J_{H.rat_0} - 0.02 + \left(J_{H.rat_{last(t)}} - J_{H.rat_0} + 0.05\right) \cdot k$$

$$K_{P.rat.mean_k} := k_{P.rat_0} - k_{P.rat_1} \cdot J_{H.rat.mean_k}$$



Power required

Power required due to water resistance

$p := 2$ $\qquad$ $q := 2$

$k := 0 .. p$ $\qquad$ $A_{req_{i,k}} := \left(V_{S0.rat_i}\right)^{k+q}$

Additional power required due to wind resistance

Relative wind measured

relative wind velocity: row 7

relative wind direction: row 8

$$V_{WindR} := \begin{bmatrix} 13.5 \\ 4.0 \\ 15.0 \\ 2.8 \\ 16.0 \\ 0.7 \\ 0.4 \\ 16.5 \end{bmatrix} \cdot \frac{m}{sec} \qquad \psi_{WindR} := \begin{bmatrix} -0.1745 \\ 2.5307 \\ -0.1745 \\ 2.3562 \\ 0.0873 \\ 2.6180 \\ 2.3562 \\ 0.0873 \end{bmatrix} \cdot rad$$

Non-dimensional values, not normalized(!), in coherent units

$$V_{WindR} := \frac{V_{WindR}}{m \cdot sec^{-1}} \qquad \psi_{WindR} := \frac{\psi_{WindR}}{rad}$$

$$V_{WindR.x_i} := V_{WindR_i} \cdot \cos\left(\psi_{WindR_i}\right)$$

$$A_{req_{i,3}} := V_{WindR.x_i} \cdot \left| V_{WindR.x_i} \right| \cdot V_{S0.rat_i}$$

Additional power required due to wave resistance

The author has not yet seriously thought about **an adequate, sufficiently simple model, the parameters can be identified** from the data simultaneously with the parameters of the wind and water resistance models. **Consequently**, in order to avoid lengthly discussions at this stage, the **he is taking the crude values provided in the ISO example**.

resistance increase due to waves:
row 30

$$R_{AWaves} := \begin{bmatrix} 31.4 \\ 111.8 \\ 31.4 \\ 106.9 \\ 31.4 \\ 182.6 \\ 180.1 \\ 7.9 \end{bmatrix} \cdot 10^3 \cdot N$$

$$\eta_D := 0.6$$

Propulsive efficiency, crude estimate for plausibility checks only!

$$R_{AWaves} := \frac{R_{AWaves}}{N}$$

$$P_{AWaves_i} := \frac{R_{AWaves_i} \cdot V_{S0.rat_i}}{\eta_D}$$

Least square fit

$$X_{req} := LI(A_{req}) \cdot (P_B - P_{AWaves})$$

Residua

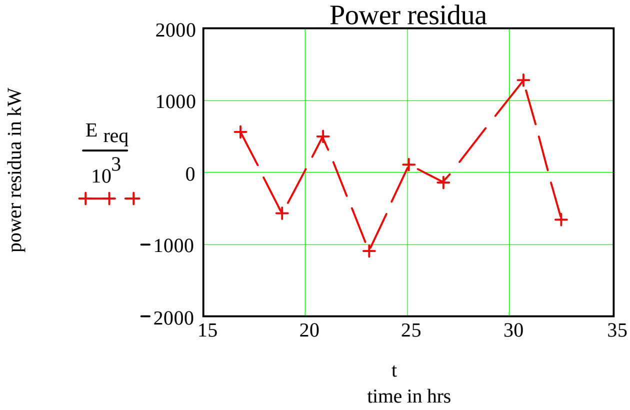
$$E_{req} := (P_B - P_{AWaves}) - A_{req} \cdot X_{req}$$

relative residua

$$E_{req} := \begin{bmatrix} 5.614 \cdot 10^5 \\ -5.649 \cdot 10^5 \\ 5.057 \cdot 10^5 \\ -1.087 \cdot 10^6 \\ 1.147 \cdot 10^5 \\ -1.339 \cdot 10^5 \\ 1.288 \cdot 10^6 \\ -6.5 \cdot 10^5 \end{bmatrix}$$

Quality of approximation

$$\frac{|E_{req}|}{|P_B|} = 5.248 \circ \%$$



In view of the fact that the scatter of the power values around the propeller power line is very small these large residua indicate that the wave resistance is not correctly assessed by the proposed ISO procedure.

$$\mathrm{Stdev}\left(\frac{E_{req}}{10^3}\right) = 773.1$$

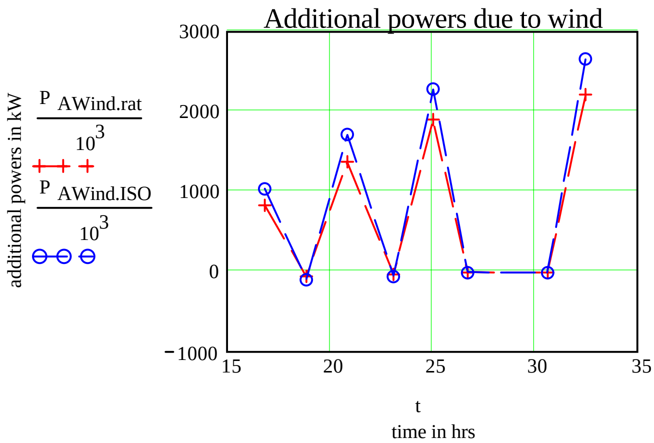
Additional power and resistance due to wind according to rational evaluation

$$P_{AWind.rat} := A_{req}^{\langle 3 \rangle} \cdot X_{req_3}$$

according to ISO/CD evaluation

$$R_{AWind.ISO} := \begin{bmatrix} 131.5 \\ -10.9 \\ 162.3 \\ -4.5 \\ 181.2 \\ -0.3 \\ -0.1 \\ 192.7 \end{bmatrix} \cdot 10^3 \cdot N \qquad R_{AWind.ISO} := \frac{R_{AWind.ISO}}{N}$$

$$P_{AWind.ISO_i} := \frac{R_{AWind.ISO_i} \cdot V_{S0.rat_i}}{\eta_D}$$



$$\frac{|P_{AWind.rat}|}{|P_{AWind.ISO}|} = 0.825$$

Final performance data according to rational evaluation

Reduction to the no-wind condition

$$V_{S3_i} := \left(V_{S0.rat_i}\right)^3$$

$$P_{B0.rat} := A_{req} \cdot X_{req} - P_{AWind.rat} + V_{S3} \cdot X_{req_3}$$

Rates of revolutions

Solve cubic equations

$$\mathrm{Revs}(p, V, P, N) := \left| \begin{array}{l} n_i \leftarrow \mathrm{last}(V) \\ \text{for } i \in 0 .. n_i \\ \quad \left| \begin{array}{l} q_0 \leftarrow P_i \\ q_1 \leftarrow V_i \\ n \leftarrow N_i \\ N_{rat_i} \leftarrow \mathrm{root}\left(q_0 - p_0 \cdot n^3 + p_1 \cdot n^2 \cdot q_1, n\right) \end{array} \right. \\ N_{rat} \end{array} \right.$$

$$n_{0.rat} := \mathrm{Revs}\left(p_{rat}, V_{S0.rat}, P_{B0.rat}, n\right)$$

Final performance data according to rational evaluation

frequency of revolution: ship speed: brake power:

$$n_{0.rat} = \begin{bmatrix} 0.6654 \\ 0.7219 \\ 0.8733 \\ 0.9313 \\ 1.0055 \\ 1.0111 \\ 1.0322 \\ 1.0744 \end{bmatrix} \quad V_{S0.rat} = \begin{bmatrix} 4.779 \\ 5.188 \\ 6.376 \\ 6.878 \\ 7.577 \\ 7.633 \\ 7.848 \\ 8.307 \end{bmatrix} \quad \frac{P_{B0.rat}}{10^3} = \begin{bmatrix} 4171 \\ 5325 \\ 9388 \\ 11351 \\ 14213 \\ 14444 \\ 15336 \\ 17215 \end{bmatrix}$$

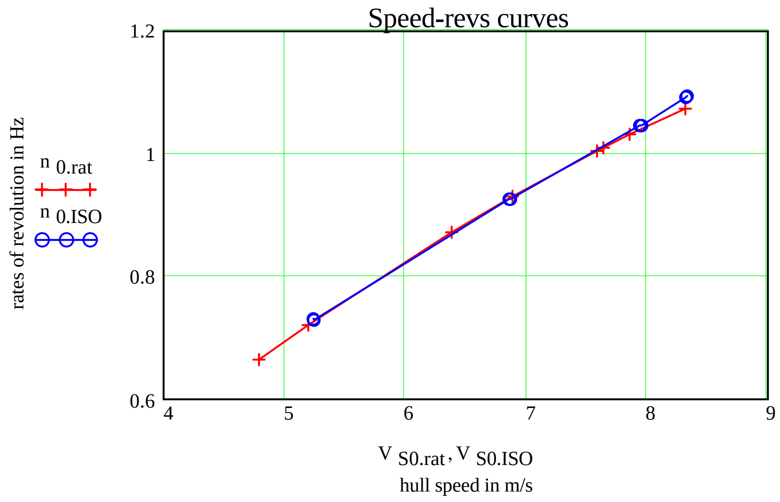
Final performance data according to ISO evaluation

frequency of revolution: row 61 (5) ship speed: row 65 brake power: row 63

$$n_{0.ISO} := \begin{bmatrix} 0.7317 \\ 0.7300 \\ 0.9267 \\ 0.9267 \\ 1.0467 \\ 1.0467 \\ 1.0933 \\ 1.0950 \end{bmatrix} \cdot \mathrm{Hz} \quad V_{S0.ISO} := \begin{bmatrix} 5.230 \\ 5.238 \\ 6.852 \\ 6.861 \\ 7.932 \\ 7.946 \\ 8.315 \\ 8.327 \end{bmatrix} \cdot \frac{m}{sec} \quad P_{B0.ISO} := \begin{bmatrix} 5331 \\ 5293 \\ 10839 \\ 10838 \\ 15582 \\ 15578 \\ 17945 \\ 17696 \end{bmatrix} \cdot \mathrm{kW}$$

Non-dimensional values, not normalized(!), in coherent units

$$n_{0.ISO} := \frac{n_{0.ISO}}{\mathrm{Hz}} \quad V_{S0.ISO} := \frac{V_{S0.ISO}}{m \cdot sec^{-1}} \quad P_{B0.ISO} := \frac{P_{B0.ISO}}{W}$$



Normalized values

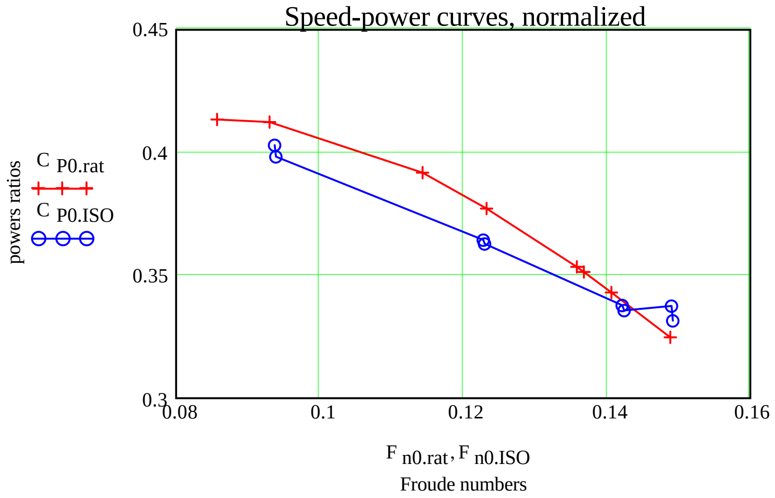
Froude numbers, power ratios

$g := 9.81$

$$F_{n0.rat_i} := \frac{V_{S0.rat_i}}{\sqrt{g \cdot L}} \qquad C_{P0.rat_i} := \frac{P_{B0.rat_i}}{\rho \cdot D^2 \cdot \left(V_{S0.rat_i}\right)^3}$$

$$F_{n0.ISO_i} := \frac{V_{S0.ISO_i}}{\sqrt{g \cdot L}} \qquad C_{P0.ISO_i} := \frac{P_{B0.ISO_i}}{\rho \cdot D^2 \cdot \left(V_{S0.ISO_i}\right)^3}$$

$$J_{H0.rat_i} := \frac{V_{S0.rat_i}}{D \cdot n_{0.rat_i}} \qquad K_{P0.rat_i} := \frac{P_{B0.rat_i}}{\rho \cdot D^5 \cdot \left(n_{0.rat_i}\right)^3}$$



Correct(ed) rates of revolution in view of the following comparison.

$n_{0.ISO.corr} := \mathrm{Revs}\left(p_{rat}, V_{S0.ISO}, P_{B0.ISO}, n\right)$

Due to the large effect of the rate of revolutions
the differences are of course very small.

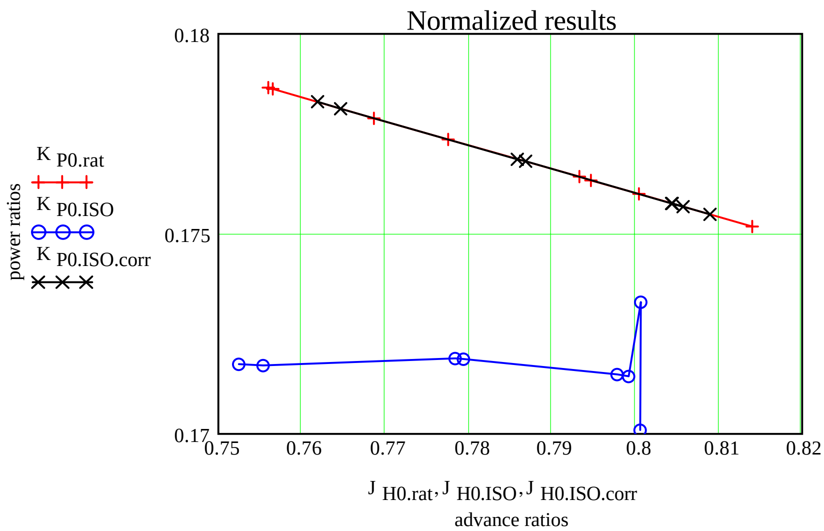
$\Delta n_{0.ISO} := \left(n_{0.ISO} - n_{0.ISO.corr}\right) \cdot \mathrm{Hz}$

$$\Delta n_{0.ISO} = \begin{bmatrix} 0.545 \\ 0.533 \\ 0.527 \\ 0.523 \\ 0.514 \\ 0.51 \\ 0.308 \\ 0.68 \end{bmatrix} \circ \mathrm{min}^{-1}$$

Normalized values, cont'd

$J_{H0.ISO_i} := \dfrac{V_{S0.ISO_i}}{D \cdot n_{0.ISO_i}}$ $\qquad K_{P0.ISO_i} := \dfrac{P_{B0.ISO_i}}{\rho \cdot D^5 \cdot \left(n_{0.ISO_i}\right)^3}$

$J_{H0.ISO.corr_i} := \dfrac{V_{S0.ISO_i}}{D \cdot n_{0.ISO.corr_i}}$ $\qquad K_{P0.ISO.corr_i} := \dfrac{P_{B0.ISO_i}}{\rho \cdot D^5 \cdot \left(n_{0.ISO.corr_i}\right)^3}$



The differences in magnitude and, **particularly, in trend** of the normalized results between the proposed rational and the proposed ISO evaluations are **due to inconsistencies in the ISO procedure**. **To cope with them by changing the rates of revolution according to the rational power characteristic is certainly not rational.**

Conclusions

The new ISO/CD 15016 example provides another test case for the rational evaluation of trials proposed. **There remain differences in the evaluations still to be analysed.**

Of course **the rational method proposed does not yet cope with all the problems and details being still in its infancy and needing the joint effort and agreement of all experts before it can be established as a standard.**

The advantages of the rational procedure are a minimum number of conventions and the consistent application of systems identification methods requiring no reference to model test results, as it should be.

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. In case of the proposed, very involved ISO method this does not apply, although it is based on the same crude wave data. This fact is the reason for the concerns about the method expressed nearly unisono by experts in shipyards and institutions.

It is important to note here that 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. In a great number of examples, based on actual data from industry, it has been shown that this procedure is superior to the traditional procedures of solving eight or ten simultaneous equations iteratively. The author has no idea how this can be done reliably!

In his contribution to the discussion of the Report of the Specialist Committee on Trials and Monitoring to the 22nd ITTC in Seoul and Shanghai September 05/11, 1999 the author fully endorses Recommendation 5 to the Conference concerning the recording of 'time histories'. Even if runs are considered stationary sound performance and confidence analyses have to be based on instantaneous values of the data.

Many problems in the evaluation of trials are due to waiting for steady conditions and using ill-defined average values. In the METEOR and CORSAIR trials quasisteady test manoeuvres have been shown to be much superior to steady testing, providing not only much more information, but at the same time the necessary references for the suppression of the omnipresent noise, even at service conditions in heavy weather.

END Rational re-evaluation of new ISO/CD 15016 example

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