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To whom it may concern

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 correlations with the added resistances due to wind and waves computed according to the ISO method!**

This is not proposed as a method, but just for checking the data!

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	Diameter of propeller
$L := 318 \cdot m$	$D := 9.5 \cdot m$
$L := \frac{L}{m}$	$D := \frac{D}{m}$

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

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

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

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

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

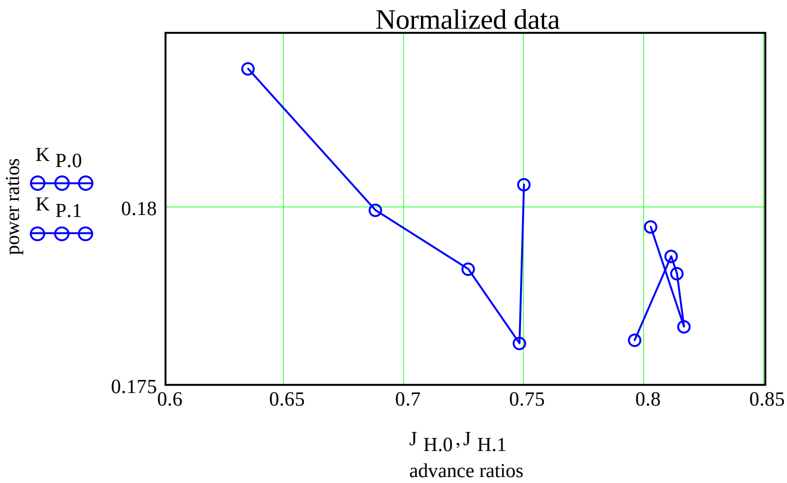
$K_{P.0} := \text{Sort}(J_H, K_P, \psi_0)^{\langle 1 \rangle}$

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

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

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

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

$temp1_i := t_i$	$t := temp1$
$temp1_i := \psi_{0_i}$	$\psi_0 := temp1$
$temp1_i := V_{G_i}$	$V_G := temp1$
$temp1_i := n_i$	$n := temp1$
$temp1_i := P_{B_i}$	$P_B := temp1$

$i := 0 .. \text{last}(J_{H.0}) - 1$ $\quad$ $j := 0 .. \text{last}(J_{H.1}) - 1$

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

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

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

Power supplied

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

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

Current velocity

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

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

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

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

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

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

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

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

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

Left-inverse

```
LI(A) := | r ← rows(A)
         | c ← cols(A)
         | s ← svds(A)
         | for i ∈ 0 .. c − 1
         |    ISV_(i,i) ← (s_i)^-1
         | UV ← svd(A)
         | U ← submatrix(UV, 0, r − 1, 0, c − 1)
         | V ← submatrix(UV, r, r + c − 1, 0, c − 1)
         | A_inv.left ← V·ISV·U^T
         | A_inv.left
```

Least square fit

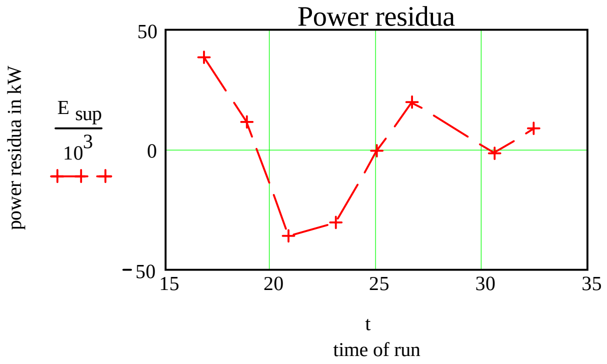
$X_{sup} := LI(A_{sup}) \cdot P_B$

Residua in terms of power

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

Quality of approximation

$\dfrac{|E_{sup}|}{|P_B|} = 0.169 \cdot \%$



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

$j := 0 .. 3$

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

Tidal current amplitude in m/sec

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

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

Interpolation

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

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

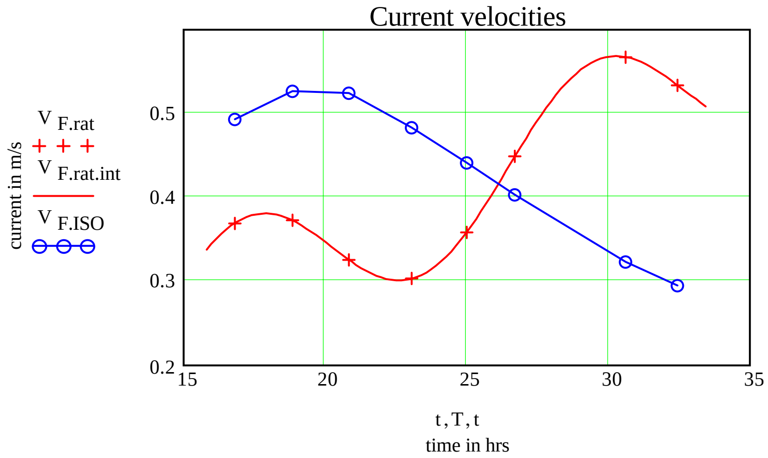
$$V_{F.int_k} := \sum_j v_j \cdot (T_k)^j$$ Disabled!

ISO/CD evaluation:

current at each run:
row 52

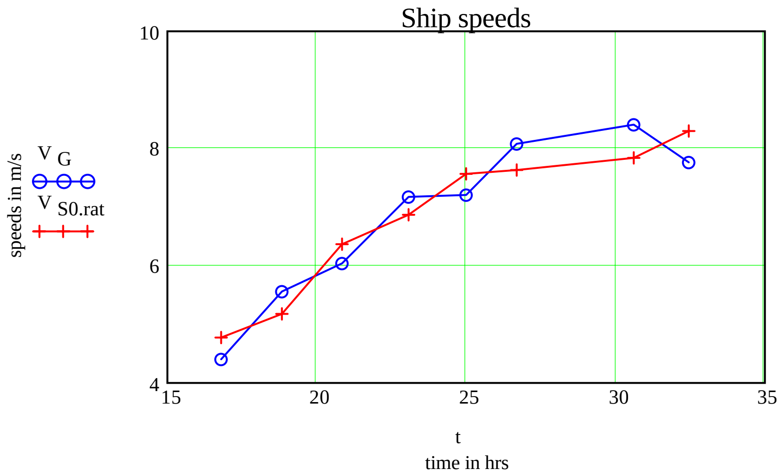
$$V_{F.ISO} := \begin{bmatrix} 0.494 \\ 0.527 \\ 0.525 \\ 0.484 \\ 0.442 \\ 0.404 \\ 0.324 \\ 0.296 \end{bmatrix} \cdot \frac{m}{sec}$$

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



Ship speed relative to water

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



Power parameters, rational

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

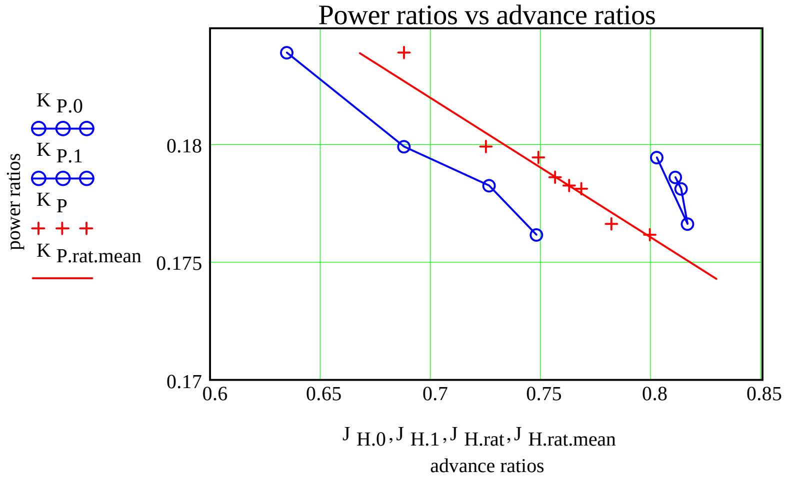
$P_{B.rat_i} := p_{rat_0} \cdot \left(n_i\right)^3 - p_{rat_1} \cdot \left(n_i\right)^2 \cdot V_{S0.rat_i}$

Normalised values

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

$k := 0 .. 1$ $\quad J_{H.rat.mean_k} := J_{H.rat_0} - 0.02 + \left(J_{H.rat_{last(t)}} - J_{H.rat_0} + 0.05\right) \cdot k$

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



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

according to ISO/CD evaluation

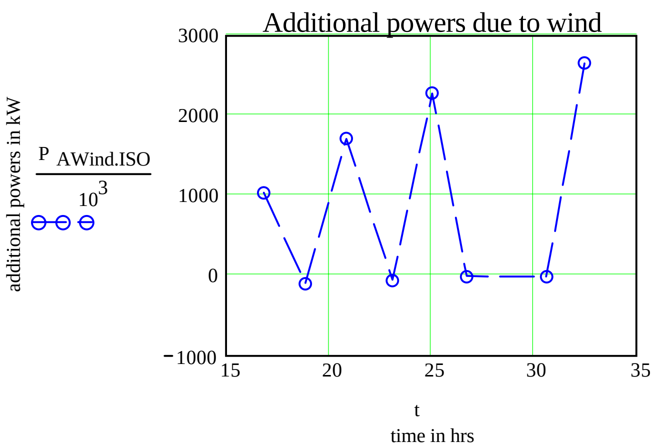
$$R_{AWind.ISO} := \begin{bmatrix} 131.5 \\ -10.9 \\ 162.3 \\ -4.5 \\ 181.2 \\ -0.3 \\ -0.1 \\ 192.7 \end{bmatrix} \cdot 10^3 \cdot N$$

$\eta_D := 0.6$

Propulsive efficiency, crude estimate for plausibility checks only!

$$R_{AWind.ISO} := \frac{R_{AWind.ISO}}{N}$$

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



The following reduction to the no-wind and no-waves condition is **based on correlations with the values of added resistance due to wind and waves computed according to the ISO method!** **This is not proposed as a method, but just for checking the data!**

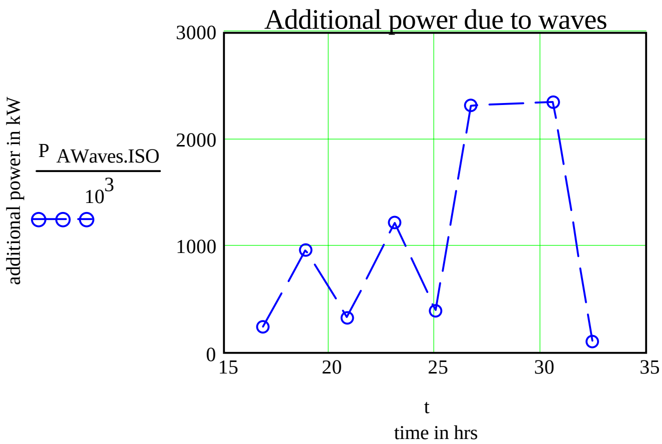
$A_{req_{i,3}} := P_{AWind.ISO_i}$

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

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

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



$A_{req_{i,4}} := P_{AWaves.ISO_i}$

Least square fit

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

$$X_{req} = \begin{bmatrix} -2.223 \cdot 10^5 \\ 9.161 \cdot 10^4 \\ -5.42 \cdot 10^3 \\ 2.518 \\ 3.262 \end{bmatrix}$$

Residua

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

Quality of approximation

$$\frac{|E_{req}|}{|P_B|} = 3.002 \circ \%$$

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

Discussion of results

The most important observation is that the added resistance values due to wind and waves computed according to the proposed ISO method correlate 'considerably' with the brake power. **The results indicate that the added resistance due to wind is 2.5 times as large as computed and the added resistance due to waves is 3.3 times as large as computed**!

Further the results are less satisfactory than those obtained with the fully rational method as shown by the following analysis.

Scatter analysis

The scatter analysis is the only way to decide on the adequacy of the models.
The sample standard deviation according to this 'method'

$$\mathrm{Stdev}\left(\frac{E_{req}}{10^3}\right) = 442.2$$

If the excessive values are excluded

$E_{red} := E_{req} \qquad E_{red_{6-1}} := 0 \qquad E_{red_{7-1}} := 0$

the sample standard deviations reduce to

$$\mathrm{Stdev}\left(\frac{E_{red}}{10^3}\right) = 148.9$$

and the quality of approximation to

$$\frac{|E_{red}|}{|P_B|} = 1.011 \cdot \%$$

These values are twice as large as those according to the fully rational method!

Conclusions

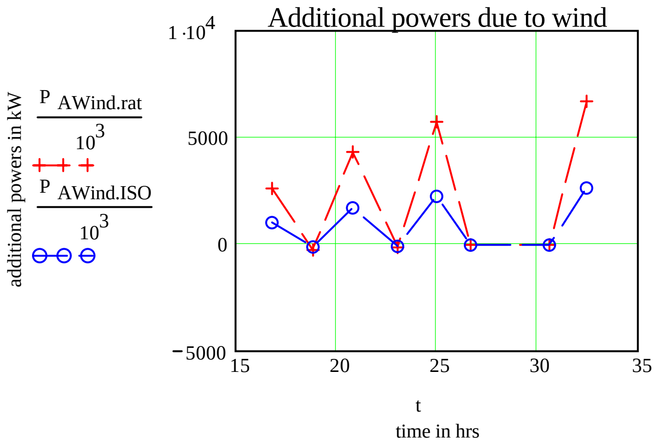
The only possible conclusion from all these observations is that **the proposed ISO procedure is not correctly modelling the added powers due to wind and waves.**

Additional powers

Additional power due to wind

according to rational evaluation

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

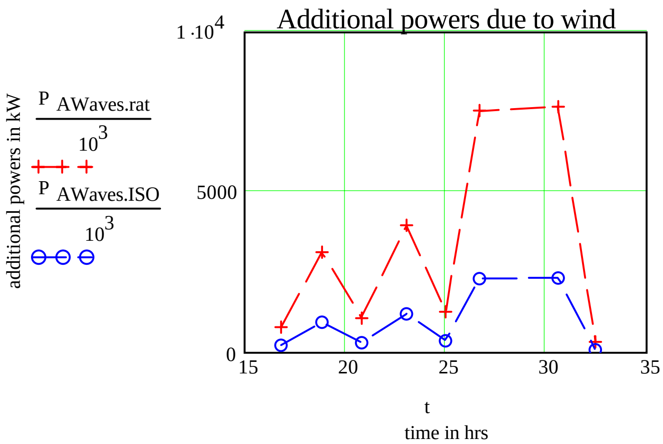


$$\frac{|P_{AWind.rat}|}{|P_{AWind.ISO}|} = 2.518$$

Additional power due to waves

according to rational evaluation

$P_{AWaves.rat} := A_{req}^{\langle 4 \rangle} \cdot X_{req_4}$



$$\frac{|P_{AWaves.rat}|}{|P_{AWaves.ISO}|} = 3.262$$

The rest of the results is very unsatisfactory and will not be discussed.
The final conclusions have been updated according to the results of the fully rational evaluation iso_fin5, but does not include this particular result!

Final performance data according to rational evaluation

Reduction to the no-wind and waves condition

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

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

Rates of revolutions **Solve cubic equations**

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

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

Final performance data according to rational evaluation

frequency of revolution: ship speed: brake power:

$$n_{0.rat} = \begin{bmatrix} 0.5397 \\ 0.5989 \\ 0.7523 \\ 0.8096 \\ 0.8818 \\ 0.8872 \\ 0.9074 \\ 0.9475 \end{bmatrix} \quad V_{S0.rat} = \begin{bmatrix} 4.779 \\ 5.188 \\ 6.376 \\ 6.878 \\ 7.577 \\ 7.633 \\ 7.848 \\ 8.307 \end{bmatrix} \quad \frac{P_{B0.rat}}{10^3} = \begin{bmatrix} 2095 \\ 2883 \\ 5753 \\ 7164 \\ 9226 \\ 9392 \\ 10031 \\ 11368 \end{bmatrix}$$

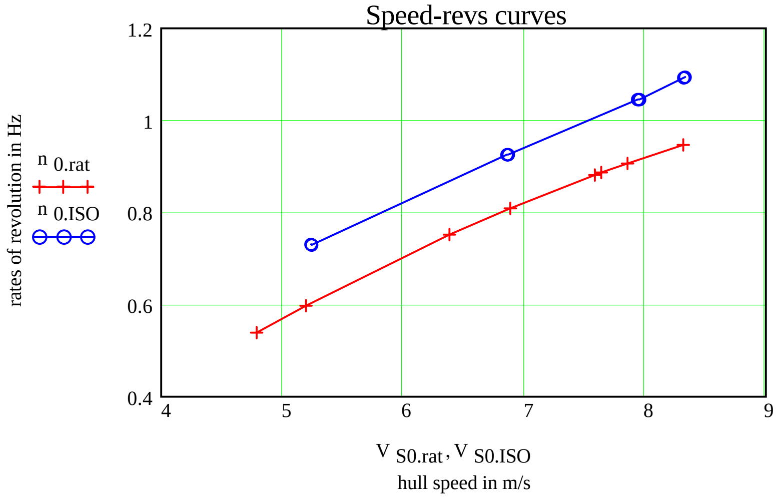
Final performance data according to ISO evaluation

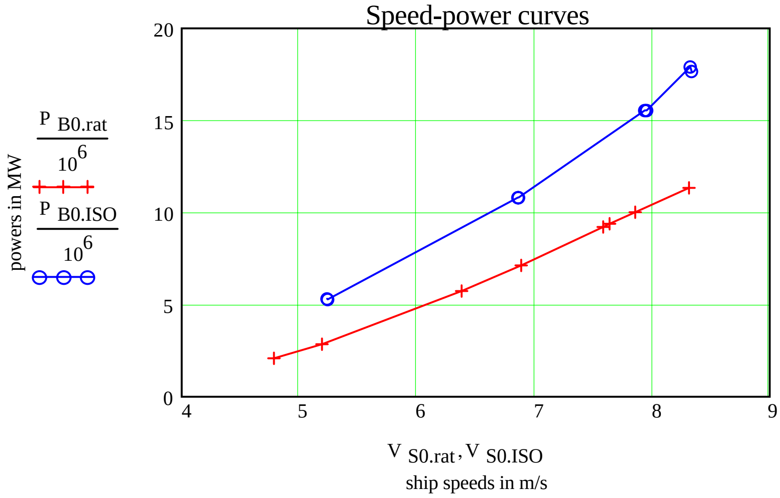
frequency of revolution: row 61 (5) ship speed: row 65 brake power: row 63

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

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

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





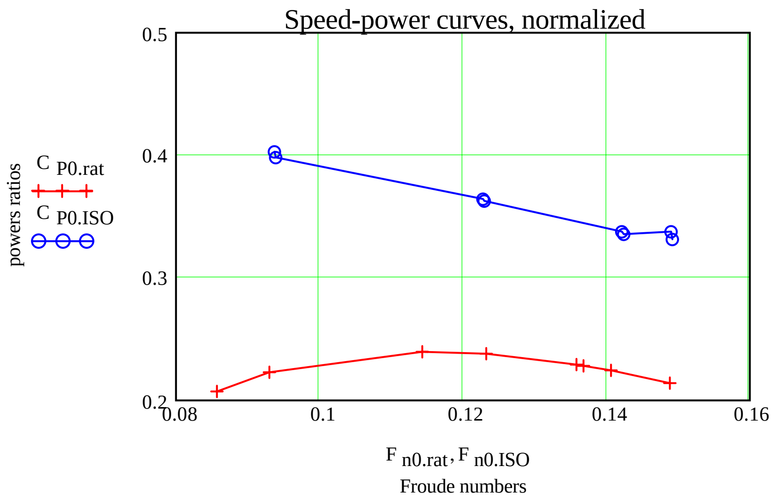
Normalized values

Froude numbers, power ratios $g := 9.81$

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

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

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



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

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

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

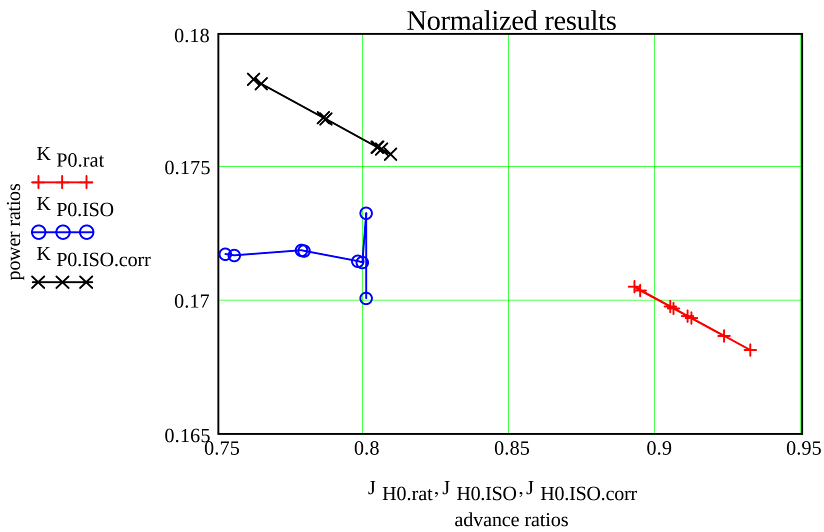
$\Delta n_{0.ISO} := \left(n_{0.ISO} - n_{0.ISO.corr}\right)\cdot Hz$

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

Normalized values, cont'd

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

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



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. Independent of this analysis **the differences** in magnitude and, particularly, in trend of the normalized results between the proposed rational and the proposed ISO evaluations **can be ascribed to inconsistencies in the ISO procedure.**

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 <u>requiring no reference to model test results and other prior data, as it should be.</u>**

The propeller performance in the behind condition, i.e. in the full scale wake (!), and the current velocity can be identified simultaneously by solving one set of linear equations. After the 'calibration' the propeller power characteristic in the behind condition can be used for monitoring purposes, e.g. to determine the value of current velocity from measured values of the rate of revolution and the torque, or to determine the value of resistance after additional calibrations or even crude assumptions.

Further the power required due to the resistance in water, in wind and in waves can be identified simultaneously by solving another set of linear equations. Identifying parameters of models from observed data, even visually observed wave data, has the advantage that **<u>systematic errors in the observations are to a great extent automatically accounted for.</u> 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 one major reason for the concerns about the method expressed nearly unisono by experts in shipyards and institutions.**

From the data at hand the values of the added power due to waves being identified according to the rational method are more than twice as large as the 'nominal' values computed according to the proposed ISO method. And the latter was particularly designed to deal with this problem, just with reference to the very crude data of wave observation, but without any reference to the observed data of brake power!

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. The present samples of at best eight 'doubtful' averages are just too small in size for serious applications of statistical methods.**

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 <u>the necessary references for the suppression of the omnipresent noise</u>, even at service conditions in heavy weather.**

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