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Sub:	**Ship Powering Performance Prediction**	MS 0805191800
here:	**Up-date of the procedure of March 14, 2002**	MS 0805281600
	on Model Powering Performance Evaluation	MS 0806111400
	An explanation added on page 13	**MS 0810201430**
	Output added and layout adapted	MS 1308202000
	Further output added for comparison with results of quasi-steady 'model' trial, ignoring measured thrust values (mod_trial.mcd)	MS 1404211700

Ref.: Second appendix of a paper by Michael Schmiechen, formerly Versuchsanstalt für Wasserbau und Schiffbau, VWS: the Berlin Model Basin, 'On eval uating the propulsive performance of ship models, predicting the propulsive performance of and evaluating traditional steady speed trials with full scale ships' prepared after discussions at a seminar on 'Evaluating ship and model powering performance' held at Gdansk Ship Model Basin in January, 16-18, 2002. and published on occasion of the 23rd ITTC held at Venice in September 08-14, 2002.

Preface

The basis of the 'rational' full scale ship powering performance prediction based on model tests to be developed are 'rational' procedures of model testing and of evaluating the model powering performance. Such procedures based on quasi-steady propulsion tests with ship models have been described and demonstrated to be feasible using VWS ship model 2491.0 and propeller model 1340 in the final report VWS Bericht Nr. 1105/88 on the project and in the preliminary report:

Schmiechen, M.: Wake and Thrust Deduction from Quasi-steady Ship Model Propulsion Tests Alone. VWS Report No. 1100/87. Published on occasion of a visit to Korean and Japanese ship research institutes and the 18th ITTC at Kobe in October 1987 and in commemoration of the 4th ITTC at Berlin in May 1937.

The essential parts of this report, including body plan and the contours of stem and stern, will constitute the first appendix of the paper. They are to be found on the website of the author as well. Warning: the file is large, nearly 1 MB!

The subject of this document is to re-re-evaluate the sample model data in that report based on the insight and experience gained over the past fifteen years and during the months of April and May 2008. In particular the local axioms or constitutive laws of wake and thrust deduction have been scrutinised again, triggered by questions of Dr.-Ing. habil. Klaus Wagner of Rostock.

The following exercise shows that nearly all the unsolved problems have finally been solved, the solution of the energy wake problem still open. The test case shows that the model powering performance in a wide range of hull advance ratios can be derived from the data of only one run down the model basin, may be using freely moving models, not requiring a towing carriage. Evidently the same technique can be applied on full scale. Thus in both cases a dramatic gain in reliability and cost effectivity can be obtained.

The Mathcad document and the data file will be made available on request. Despite extreme care in every detail the evaluation may still contain inconsistencies and/or errors. The author will be most grateful for any communication, not only concerning such mistakes, but maybe concerning lack of clarity in the exposition, questions arising and experience gained in applications.

'Unneccesary' to mention that in routine applications the programming will be quite different, typically in terms of subroutines, which have been used only occasionally in this document. But in view of the sensitivty of the problem at hand colleagues are warned: there will be 'no plug and play' program. In any case careful scrutiny of data and intermediate results is absolutely mandatory.

And to repeat: The method proposed offers dramatic technological and commercial advantages. No propeller open water and hull towing tests are necessary and the extremely short propulsion tests provide a wealth of consistent data and results.

Preliminaries

**Mathcad permits to handle physical quantities,
but all data are being used without their SI units**
in view of further use in mathematical subroutines,
which by definition cannot handle arguments with units.

Constants

Gravity field $g := 9.81 \cdot m \cdot sec^{-2}$ $g := g \cdot m^{-1} \cdot sec^{2}$

Units

Force $N := newton$

$kp := g \cdot N$

Torque $Nm := newton \cdot m$

Power $W := watt$

Routines

Left inverse

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

Filter

$$\mathrm{Filter}(t, x, ord_{max}) := \left| \begin{array}{l} n \leftarrow \mathrm{last}(t) \\ \text{for } i \in 0..n \\ \quad \text{for } j \in 0..3 \\ \quad\quad A_{i,j} \leftarrow (t_i)^j \\ X \leftarrow \mathrm{LeftInv}(A) \cdot x \\ x_{0.trend} \leftarrow A \cdot X \\ x_{0.red} \leftarrow x - x_{0.trend} \\ \Delta t \leftarrow t_n - t_0 \\ \Delta x_{0.red} \leftarrow x_{0.red_n} - x_{0.red_0} \\ \text{for } i \in 0..n \\ \quad x_{0.red_i} \leftarrow x_{0.red_i} - i \cdot \dfrac{\Delta x_{0.red}}{n} \\ x_{0.red.F} \leftarrow \mathrm{cfft}(x_{0.red}) \\ \text{for } k \in ord_{max}+1..n-ord_{max} \end{array} \right.$$

$$x_{0.red.F_k} \leftarrow 0$$

$$\omega \leftarrow \frac{2\cdot\pi}{\Delta t}$$

for $k \in 1 .. ord_{max}$

$$x_{1.red.F_k} \leftarrow x_{0.red.F_k} \cdot (-k\cdot\omega\cdot i)$$

$$x_{1.red.F_{n+1-k}} \leftarrow x_{0.red.F_{n+1-k}} \cdot (k\cdot\omega\cdot i)$$

$$x_{2.red.F_k} \leftarrow x_{0.red.F_k} \cdot (-k\cdot\omega\cdot i)^2$$

$$x_{2.red.F_{n+1-k}} \leftarrow x_{0.red.F_{n+1-k}} \cdot (k\cdot\omega\cdot i)^2$$

$$x_{0.red} \leftarrow Re(icfft(x_{0.red.F}))$$

$$x_{1.red} \leftarrow Re(icfft(x_{1.red.F}))$$

$$x_{2.red} \leftarrow Re(icfft(x_{2.red.F}))$$

for $i \in 0 .. n$

$$x_{0_i} \leftarrow x_{0.red_i} + i\cdot\frac{\Delta x_{0.red}}{n} + x_{0.trend_i}$$

$$x_{1.trend} \leftarrow \sum_{k=1}^{3} k\cdot X_k\cdot A^{\langle k-1\rangle}$$

$$x_1 \leftarrow x_{1.red} + \frac{\Delta x_{0.red}}{\Delta t} + x_{1.trend}$$

$$x_{2.trend} \leftarrow \sum_{k=2}^{3} k!\cdot X_k\cdot A^{\langle k-2\rangle}$$

$$x_2 \leftarrow x_{2.red} + x_{2.trend}$$

$$\begin{bmatrix} x_0 & x_1 & x_2 \end{bmatrix}$$

Evaluation of model data VWS 2491/1340
according to rational method proposed

Test identification	TID := "VWS 2491 /1340"
Date of test	Date := 860909
Test No.	Test := 8

Basic data

Ship model VWS Mod. 2491.0

Barge Carrier, which has not been built, body plan and contours of stem and stern to found in the first appendix.

Length	$L := 6.5 \cdot m$	$L := L \cdot m^{-1}$
Breadth	$B := 1.00 \cdot m$	$B := B \cdot m^{-1}$
Draught	$Tg := 0.255 \cdot m$	$Tg := Tg \cdot m^{-1}$
Displacement	$V := 1.431 \cdot m^3$	$V := V \cdot m^{-3}$
Block coefficient	$\phi := \frac{V}{L \cdot B \cdot Tg}$	$\phi = 0.8633$
Density of tank water	$\rho := 1.00 \cdot 10^3 \cdot kg \cdot m^{-3}$	$\rho := \rho \cdot kg^{-1} \cdot m^3$
Mass, model	$M_{nom} := \rho \cdot V$	$M_{nom} = 1431.0000$
Mass, added	$V_{half\_ellips} := \frac{2 \cdot \pi}{3} \cdot \frac{L}{2} \cdot \frac{B}{2} \cdot Tg$	$V_{half\_ellips} = 0.8679$
	$\phi_{half\_ellips} := \frac{V_{half\_ellips}}{L \cdot B \cdot Tg}$	$\phi_{half\_ellips} = 0.5236$

Thus the ship is much fuller than the equivalent half-ellisoid
and added mass data of ellipsoids provide only very crude estimates. The following value has been 'read' from figure 67 on pages 244-245 in the monograph of W.G. Price and R.E.D. Bishop: Probabilistic Theory of Ship Dynamics. London: Chapman and Hall, 1974.

$m_x := \frac{0.5}{58} \cdot 3$ $\qquad m_x = 0.0259$

$M_{hyd} := M_{nom} \cdot m_x$

$M_{hyd.S} := \rho \cdot 0.15 \cdot \pi \cdot B \cdot Tg^2$ $\qquad$ According to Sainsbury (Ship and Boat Builder 1963/12)

$m_{x.nom} := \frac{M_{hyd.S}}{M_{hyd}} \cdot m_x$ $\quad m_{x.nom} = 0.0214$

Model scale $\lambda := 37.23$

Location of trip wire $x_{wire} := 19.25$

Surface $S := 8.967 \cdot m^2$ $\quad S := S \cdot m^{-2}$

Propeller model VWS Prop. 1340

CP propeller, right handed

Diameter of propeller $D := 0.195 \cdot m$ $\quad D := D \cdot m^{-1}$

Disc area $A_D := \frac{\pi}{4} \cdot D^2$ $\quad A_D = 0.0299$

Pitch ratio, design $P_{D.des} := 0.825$

Pich ratio, actual $P_{D.act} := 0.813$

Number of blades $Z := 4$

Rate of revolutions at open water test $n_{open} := 12 \cdot Hz$

Model test conditions

Carriage velocity $F_n := 0.168$

$v_{carr} := F_n \cdot \sqrt{g \cdot L}$ $\quad v_{carr} = 1.3415$

Frictional deduction $C_F := 0.183$

$F_F := C_F \cdot \rho \cdot D^2 \cdot v_{carr}^{\,2}$ $\quad F_F = 12.5234$

Input: Digitized .jpg files

Fig's 6, 7, 8, 9 in VWS Report No. 1100/87 to found in the first appendix.

Data := READPRN("mod_data.dat")

$nr := last\left(Data^{\langle 0 \rangle}\right)$ $\quad ns := 0$ $\quad r := 0 .. nr - ns$

time

$t_r := Data_{ns+r,0} \cdot sec$

$t := t \cdot sec^{-1}$

rate of revolutions

$n_{raw_r} := Data_{ns+r,1} \cdot Hz$

$n_{raw} := n_{raw} \cdot Hz^{-1}$

Data are taken over four full periods.

relative shift of model

$s_{raw_r} := Data_{ns+r,4} \cdot m$

$s_{raw} := s_{raw} \cdot m^{-1}$

thrust

$T_{raw_r} := Data_{ns+r,3} \cdot N$

$T_{raw} := T_{raw} \cdot N^{-1}$

torque

$Q_{raw_r} := Data_{ns+r,2} \cdot Nm$

$Q_{raw} := Q_{raw} \cdot Nm^{-1}$

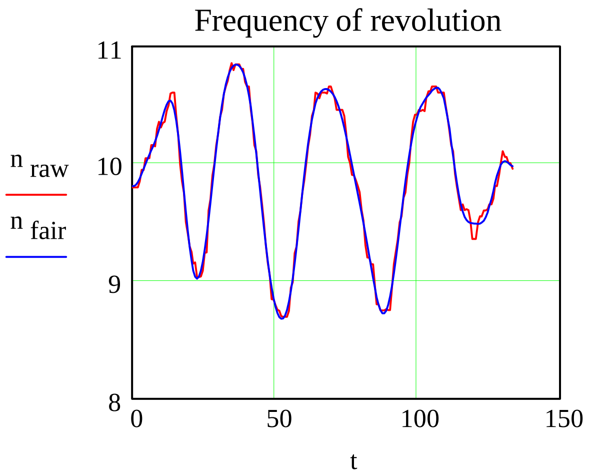
Rate of revolution faired

This value has been chosen as 'optimal', closest to the steady conditions.

$ord_{max} := 15$

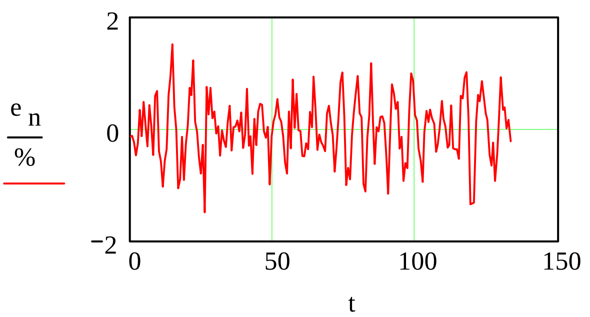
$\left[n_{fair} \;\; n_1 \;\; n_2 \right] := Filter\left(t, n_{raw}, ord_{max}\right)$

$E_n := n_{raw} - n_{fair}$ $\qquad e_n := \dfrac{E_n}{mean\left(n_{fair}\right)}$ $\qquad stdev\left(E_n\right) = 0.0541$



$n_m := mean\left(n_{raw}\right)$

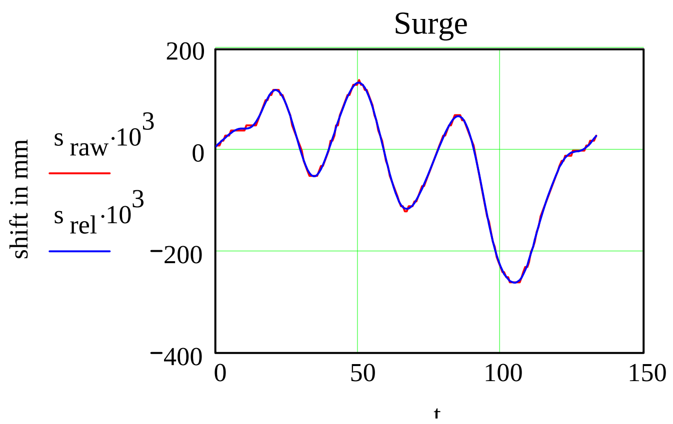
$n_m = 9.8880$

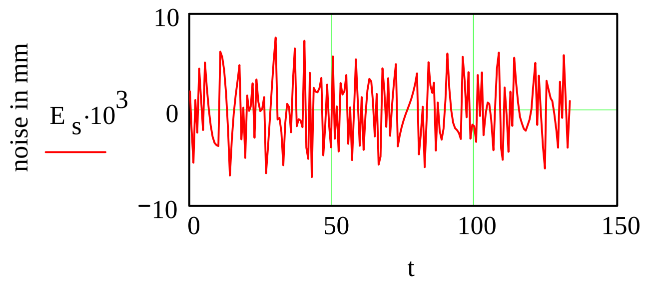


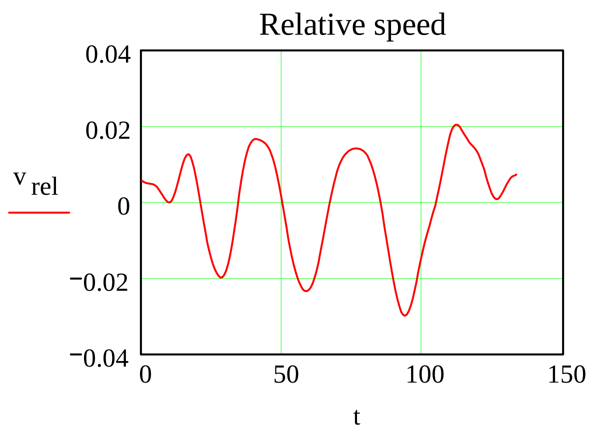
Velocity and acceleration

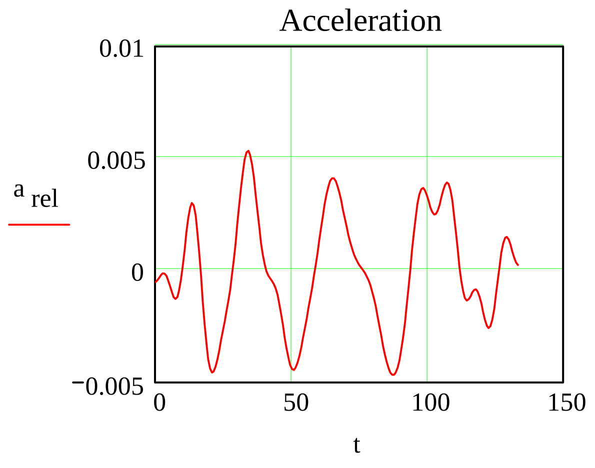
$\left[s_{rel} \;\; v_{rel} \;\; a_{rel} \right] := Filter\left(t, s_{raw}, ord_{max}\right)$

$E_s := s_{raw} - s_{rel}$ $\qquad stdev\left(E_s\right) = 0.0032$


Surge
200
0
−200
−400
0
50
100
150
t
shift in mm
s raw·10^3
s rel·10^3


10
0
−10
0
50
100
150
t
noise in mm
E s·10^3


Relative speed
0.04
0.02
0
−0.02
−0.04
0
50
100
150
t
v rel

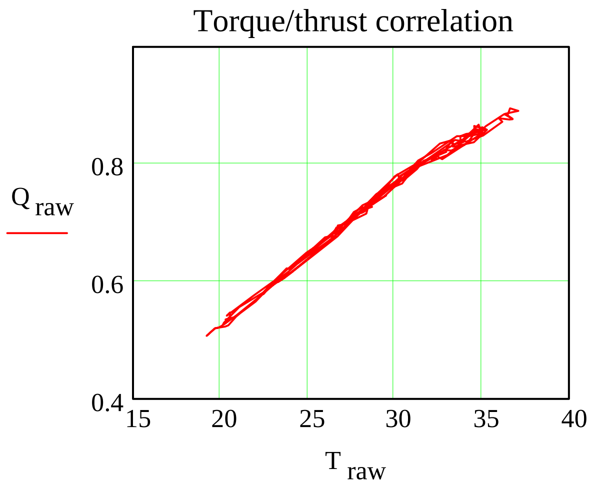

Acceleration
0.01
0.005
0
−0.005
0
50
100
150
t
a rel

'Final' values

$v_{fair} := v_{carr} + v_{rel}$ $a_{fair} := a_{rel}$

Scrutinize data

Correlate torque and thrust



Something has happened in the measurements of the higher torque values? Was there a problem with the dynamometer or did the flow pattern at the model propeller suddenly change?

The **systematic problems** above T = 32 N, Q = 0.8 Nm have been observed earlier and have already been mentioned explicitly in the basic VWS report No. 1100/87. There may have been many reasons for this behaviour, which has not been observed in the other runs. After much deliberation torque data are being corrected according to 'initial' linear correlation.

'Correct' torque values

```
Red(T, Q, T_lim) :=  | j ← 0
                     | k ← 0
                     | for i ∈ 0 .. last(T)
                     |    | T_red_j ← T_i  if T_i < T_lim
                     |    | Q_red_j ← Q_i  if T_i < T_lim
                     |    | j ← j + 1  if T_i < T_lim
                     |    | T_res_k ← T_i  if T_i ≥ T_lim
                     |    | Q_res_k ← Q_i  if T_i ≥ T_lim
                     |    | k ← k + 1  if T_i ≥ T_lim
                     | [ T_red  Q_red  T_res  Q_res ]
```

$T_{lim} := 32$

$\left[T_{red}\ \ Q_{red}\ \ T_{res}\ \ Q_{res}\right] := \mathrm{Red}\left(T_{raw}, Q_{raw}, T_{lim}\right)$

Correlation of reduced sets

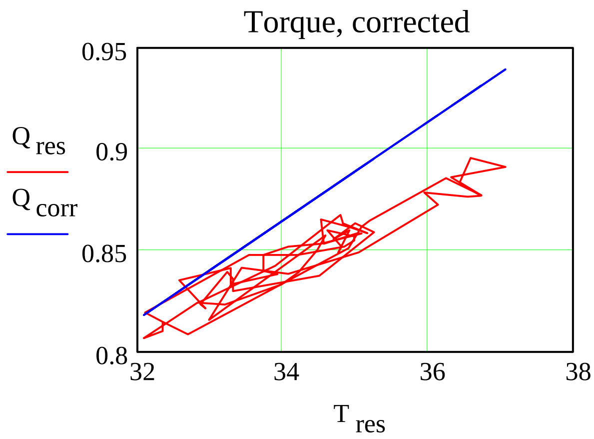
$j := 0 .. \mathrm{last}\left(T_{red}\right) \qquad A_{red_{j,0}} := 1 \qquad A_{red_{j,1}} := T_{red_j}$

$X_{red} := \mathrm{LeftInv}\left(A_{red}\right) \cdot Q_{red}$

'Correct' torque values

$k := 0 .. \mathrm{last}\left(T_{res}\right) \qquad A_{res_{k,0}} := 1 \qquad A_{res_{k,1}} := T_{res_k}$

$Q_{corr} := A_{res} \cdot X_{red}$



'Correct' torque values replaced

$$\mathrm{Rep}\left(T, Q, Q_{corr}, T_{lim}\right) := \begin{array}{|l} k \leftarrow 0 \\ \text{for } i \in 0 .. \mathrm{last}(T) \\ \quad \begin{array}{|l} Q_i \leftarrow Q_{corr_k} \ \text{ if } T_i \geq T_{lim} \\ k \leftarrow k + 1 \ \text{ if } T_i \geq T_{lim} \end{array} \\ Q \end{array}$$

$Q_{corr} := \mathrm{Rep}\left(T_{raw}, Q_{raw}, Q_{corr}, T_{lim}\right)$

Fair torque, thrust and force values

$A_{fair_{r,0}} := \left(n_{fair_r}\right)^2$ $\quad A_{fair_{r,1}} := n_{fair_r} \cdot v_{fair_r}$ $\quad A_{fair_{r,2}} := \left(v_{fair_r}\right)^2$

$X_T := \text{LeftInv}\left(A_{fair}\right) \cdot T_{raw}$ $\quad X_Q := \text{LeftInv}\left(A_{fair}\right) \cdot Q_{corr}$

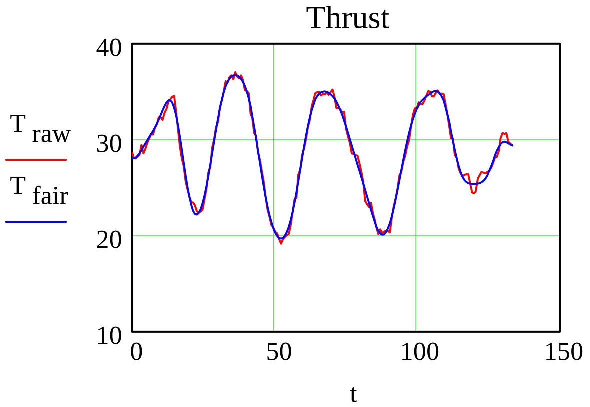
$T_{fair} := A_{fair} \cdot X_T$ $\quad Q_{fair} := A_{fair} \cdot X_Q$

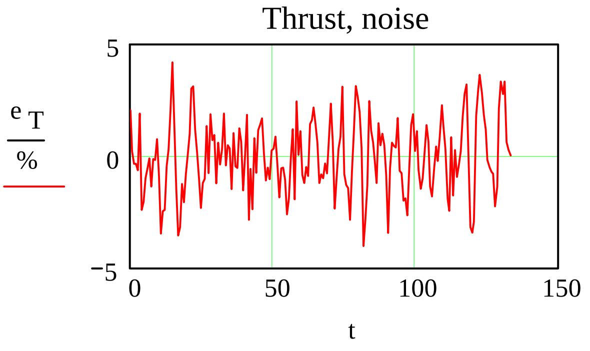
$E_T := T_{raw} - T_{fair}$ $\quad E_Q := Q_{corr} - Q_{fair}$

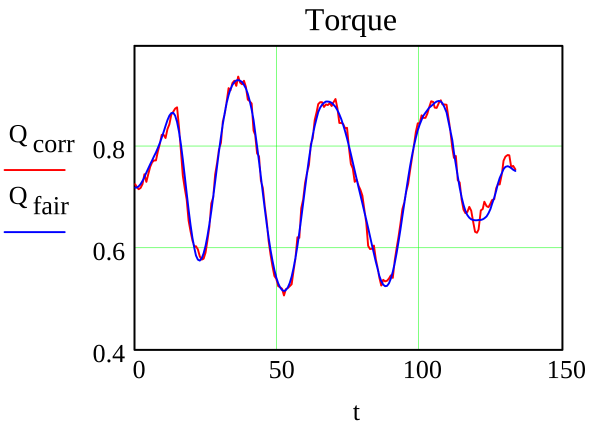
$\text{stdev}\left(E_T\right) = 0.4704$ $\quad \text{stdev}\left(E_Q\right) = 0.0117$

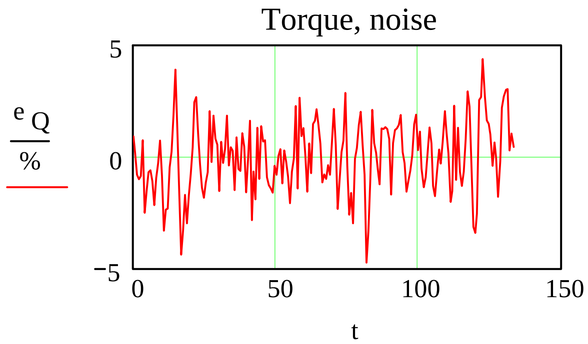
$e_T := \dfrac{E_T}{\text{mean}\left(T_{raw}\right)}$ $\quad e_Q := \dfrac{E_Q}{\text{mean}\left(Q_{corr}\right)}$

Faired thrust and torque data









Normalize polynomial

$j := 0 .. 2$

$$X_{KTH_j} := \frac{X_{T_j}}{\rho \cdot D^{4-j}} \qquad X_{KPH_j} := \frac{2 \cdot \pi \cdot X_{Q_j}}{\rho \cdot D^{5-j}}$$

Thrust and power ratios as functions of hull advance ratio

$$k_{TH}(j_H) := \sum_j X_{KTH_j} \cdot j_H{}^j \qquad k_{PH}(j_H) := \sum_j X_{KPH_j} \cdot j_H{}^j$$

Recording of raw and faired values **MS 201308**

$Dat_{raw}^{\langle 0 \rangle} := t$

$Dat_{raw}^{\langle 1 \rangle} := n_{raw}$ $Dat_{raw}^{\langle 2 \rangle} := v_{fair}$ $Dat_{raw}^{\langle 3 \rangle} := a_{fair}$ $Dat_{raw}^{\langle 4 \rangle} := Q_{raw}$

WRITEPRN("dat_raw.dat") := Dat_{raw}

$Dat_{fair}^{\langle 0 \rangle} := t$

$Dat_{fair}^{\langle 1 \rangle} := n_{fair}$ $Dat_{fair}^{\langle 2 \rangle} := v_{fair}$ $Dat_{fair}^{\langle 3 \rangle} := a_{fair}$ $Dat_{fair}^{\langle 4 \rangle} := Q_{corr}$

WRITEPRN("dat_fair.dat") := Dat_{fair}

Identify nominal wake fraction

MS 0805112230

Problem solved

As the detailed numerical exercises have shown the problem of the performance evaluation solely based on the results of quasi-steady propulsion tests is singular.
The only way to solve the problem is to provide an additional axiom or convention permitting to identify the nominal wake fraction, the phenomenological parameter in the wake axiom.
The additional axiom postulated before is that the hydraulic or pump efficiency of the propeller has a maximum at the centre of the range of interest.
In earlier evaluations this axiom has been applied without appropriate scrutiny to randomly available samples. The following procedure the 'range of interest' is changed until the postulate is met.

MS 0810201430

Explanation added

The axiom, a condition limiting the complexity of the model, has been adopted to get along with only two parameters to be identified in a robust procedure. Consequently this condition has to be provided for by appropriate selection f the range investigated. After all the procedure is meeting the standards originally envisaged.
The detailed analysis reveals that the excellent results obtained earlier have been strictly accidental. The hydraulic efficiency happened to be stationary in the sample randomly selected!
According to the above explanation all attempts to identify the two parameters from randomly chosen propulsion data, may be at only two conditions, are doomed to fail 'by definition', due to the model purposely simplified.

Determine range of data

$$J_{H.fair_r} := \frac{v_{fair_r}}{D \cdot n_{fair_r}}$$

$J_{H.fair.mean} := \mathrm{mean}(J_{H.fair})$ $\qquad J_{H.fair.mean} = 0.6984$

$J_{H.fair.min} := \min(J_{H.fair})$ $\qquad J_{H.fair.min} = 0.6370$

$J_{H.fair.max} := \max(J_{H.fair})$ $\qquad J_{H.fair.max} = 0.7871$

Determine jet efficiency

Based on axiom of jet efficiency and on thrust identity!

$j_H := J_{H.fair.mean}$

$\omega_{TJ} := 0.5$

$h_{TJ} := 0.7$

Given

$$\frac{2 \cdot k_{TH}(j_H)}{\pi \cdot j_H^{2} \cdot (1 - \omega_{TJ} \cdot h_{TJ})^2} = \frac{1}{h_{TJ}^{2}} - \frac{1}{h_{TJ}}$$

$H_T(\omega_{TJ}, j_H) := \mathrm{Find}(h_{TJ})$

$$H_{TJ.T}(\omega_{TJ}, j_H) := \left| \begin{array}{l} \text{for } i \in 0 .. \mathrm{last}(j_H) \\ \quad \eta_{TJ_i} \leftarrow H_T(\omega_{TJ}, j_{H_i}) \\ \eta_{TJ} \end{array} \right.$$

Based on axiom of constant hydraulic efficiency!

$h_{TP} := 0.8$

Given

$$h_{TJ} = \frac{h_{TP}}{\eta_{JP}} \cdot \left(1 - \omega_{TJ} \cdot h_{TJ}\right)$$

$H_P\left(\omega_{TJ}, \eta_{JP}, h_{TP}\right) := \text{Find}\left(h_{TJ}\right)$

$$H_{TJ.P}\left(\omega_{TJ}, h_{JP.m}, h_{TPH}, j_H\right) := \left| \begin{array}{l} \text{for } i \in 0 .. \text{last}\left(j_H\right) \\ \quad \eta_{TJ_i} \leftarrow H_P\left(\omega_{TJ}, h_{JP.m}, h_{TPH_i}\right) \\ \eta_{TJ} \end{array} \right.$$

Solve for nominal wake
and mean hydraulic efficiency

$\omega_{TJ} := 0.57$ $\qquad h_{JP.m} := 0.76$

Given

$H_{TJ.P}\left(\omega_{TJ}, h_{JP.m}, h_{TPH}, j_H\right) = H_{TJ.T}\left(\omega_{TJ}, j_H\right)$

$\text{JetEff}\left(\omega_{TJ}, h_{JP.m}, h_{TPH}, j_H\right) := \text{MinErr}\left(\omega_{TJ}, h_{JP.m}\right)$

Determine maximum hydraulic efficiency

$n := 5$

$\Delta j := 0.001$

$j_{H.c} := J_{H.fair.min}$

$$\text{Index}\left(v, v_m\right) := \left| \begin{array}{l} j \leftarrow 0 \\ \text{while } v_j \neq v_m \\ \quad j \leftarrow j + 1 \\ j \end{array} \right.$$

$$\Delta J(j_{H.c}, \Delta j) := \left| \begin{array}{l} \text{for } i \in 0..2 \cdot n \\ \quad \left| \begin{array}{l} j_{H_i} \leftarrow j_{H.c} + \Delta j \cdot (i - n) \\ k_{T_i} \leftarrow k_{TH}(j_{H_i}) \\ k_{P_i} \leftarrow k_{PH}(j_{H_i}) \\ h_{TPH_i} \leftarrow \dfrac{k_{T_i} \cdot j_{H_i}}{k_{P_i}} \end{array} \right. \\ \Omega \leftarrow \mathrm{JetEff}(\omega_{TJ}, h_{JP.m}, h_{TPH}, j_H) \\ \omega_{TJ} \leftarrow \Omega_0 \\ h_{TJ} \leftarrow H_{TJ.T}(\omega_{TJ}, j_H) \\ \text{for } i \in 0..2 \cdot n \\ \quad \left| \begin{array}{l} \omega_i \leftarrow \omega_{TJ} \cdot h_{TJ_i} \\ h_{JP_i} \leftarrow h_{TPH_i} \cdot \dfrac{(1 - \omega_i)}{h_{TJ_i}} \end{array} \right. \\ h_{JP.max} \leftarrow \max(h_{JP}) \\ m \leftarrow \mathrm{Index}(h_{JP}, h_{JP.max}) \\ \Delta j_H \leftarrow j_{H_m} - j_{H.c} \\ \Delta j_H \end{array} \right.$$

$$J_{H.c} := \mathrm{root}(\Delta J(j_H, \Delta j), j_H)$$

$J_{H.c} = 0.6984$

This result 'explains' why the former evalution with the value 0.7 has been *accidentally* correct!

$$\text{SampRange}(j_{H.c}, \Delta j) := \left| \begin{array}{l} \text{for } i \in 0..2 \cdot n \\ \quad \left| \begin{array}{l} j_{H_i} \leftarrow j_{H.c} + \Delta j \cdot (i - n) \\ k_{T_i} \leftarrow k_{TH}(j_{H_i}) \\ k_{P_i} \leftarrow k_{PH}(j_{H_i}) \\ h_{TPH_i} \leftarrow \dfrac{k_{T_i} \cdot j_{H_i}}{k_{P_i}} \end{array} \right. \\ \Omega \leftarrow \text{JetEff}(\omega_{TJ}, h_{JP.m}, h_{TPH}, j_H) \\ \begin{bmatrix} j_H \\ k_T \\ k_P \\ h_{TPH} \\ \Omega \end{bmatrix} \end{array} \right.$$

$S := \text{SampRange}(J_{H.c}, \Delta j)$

$w_{TJ} := (S_4)_0$ $\qquad w_{TJ} = 0.5913$

$\eta_{JP.m} := (S_4)_1$ $\qquad \eta_{JP.m} = 0.7590$

Evaluate over a wide range

$$J_{H.c} := \frac{\text{round}(10 \cdot J_{H.fair.mean})}{10} \qquad J_{H.c} = 0.7000$$

$$\Delta j := \frac{\text{round}\left[10 \cdot (J_{H.fair.max} - J_{H.fair.min})\right]}{10 \cdot n} \qquad \Delta j = 0.0400$$

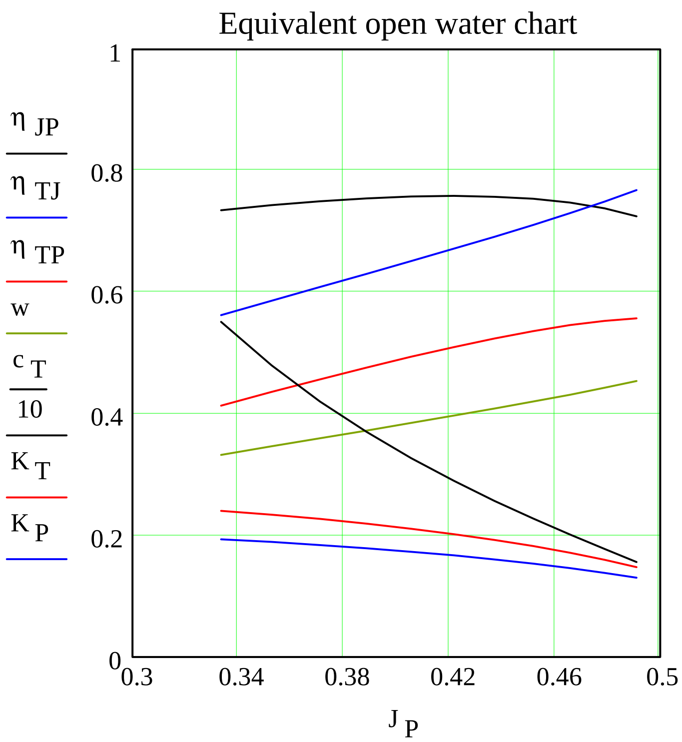
$$\begin{bmatrix} J_H \\ K_T \\ K_P \\ \eta_{TPH} \\ \Omega \end{bmatrix} := \mathrm{SampRange}\left(J_{H.c}, \Delta j\right)$$

Determine derived magnitudes

$i := 0 .. \mathrm{last}\left(J_H\right)$

$\eta_{TJ} := H_{TJ.T}\left(w_{TJ}, J_H\right)$ $\quad w_i := w_{TJ} \cdot \eta_{TJ_i}$ $\quad J_{P_i} := J_{H_i} \cdot \left(1 - w_i\right)$

$\eta_{TP_i} := \dfrac{K_{T_i} \cdot J_{P_i}}{K_{P_i}}$ $\quad \eta_{JP_i} := \dfrac{\eta_{TP_i}}{\eta_{TJ_i}}$ $\quad c_{T_i} := \dfrac{8 \cdot K_{T_i}}{\pi \cdot \left(J_{P_i}\right)^2}$



'Equivalent' open water chart of CP propeller model in the behind condition according to rational procedure proposed.

Compare with traditional evaluation based on propeller open water test results

Data

$$\text{Data}_{prop} := \begin{bmatrix} 0.35 & 48.0 & 63.5 \\ 0.40 & 43.0 & 59.5 \\ 0.45 & 38.0 & 53.0 \\ 0.50 & 33.0 & 48.0 \\ 0.55 & 28.0 & 43.0 \\ 0.60 & 22.5 & 37.5 \\ 0.65 & 17.5 & 32.0 \end{bmatrix}$$

KT and 10 KQ values read in mm from Fig. 0.2 in VWS Bericht Nr. 1126/88

$scale := 200$

$$J_{P.open} := \text{Data}_{prop}^{\langle 0 \rangle}$$

$$K_{T.raw} := \frac{\text{Data}_{prop}^{\langle 1 \rangle}}{scale}$$

$$K_{P.raw} := \frac{2 \cdot \pi \cdot \text{Data}_{prop}^{\langle 2 \rangle}}{10 \cdot scale}$$

$$k := 0 .. \text{last}\left(J_{P.open}\right)$$

$$A_{JP.open_{k,j}} := \left(J_{P.open_k}\right)^j$$

$$X_{KT.open} := \text{LeftInv}\left(A_{JP.open}\right) \cdot K_{T.raw} \qquad X_{KPo} := \text{LeftInv}\left(A_{JP.open}\right) \cdot K_{P.raw}$$

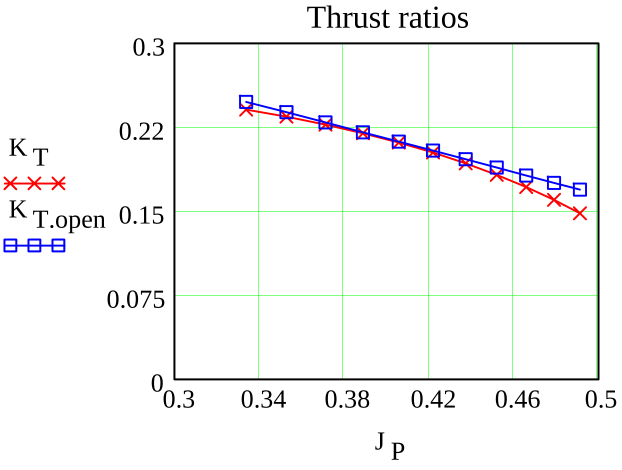
$$K_{TP} := A_{JP.open} \cdot X_{KT.open} \qquad K_{PP} := A_{JP.open} \cdot X_{KPo}$$

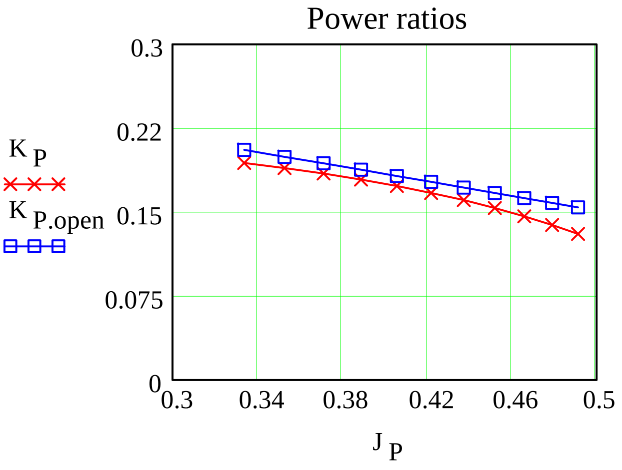
Thrust and power ratios as functions of propeller open water advance ratio

$$k_{T.open}\left(j_P\right) := \sum_j X_{KT.open_j} \cdot j_P^{\,j} \qquad k_{P.open}\left(j_P\right) := \sum_j X_{KPo_j} \cdot j_P^{\,j}$$

$$K_{T.open_i} := k_{T.open}\left(J_{P_i}\right) \qquad K_{P.open_i} := k_{P.open}\left(J_{P_i}\right)$$

Compare with open water values





Wake fractions based the model propeller open water performance

Thrust identity

$j_{PT} := 1$

Given

$k_{T.open}(j_{PT}) = \kappa_{TH}$

$\iota_{PT}(\kappa_{TH}) := \text{Find}(j_{PT})$

$J_{PT_i} := \iota_{PT}(K_{T_i})$

$w_{T_i} := 1 - \frac{J_{PT_i}}{J_{H_i}}$ $\qquad$ $w_{trad} := w_T$

$j := 0 .. 1$

$A_{JH_{i,j}} := \left(J_{H_i}\right)^j$

$X_{WT} := \mathrm{LeftInv}\left(A_{JH}\right) \cdot w_T$

$k_{WT}\left(j_H\right) := \sum_j X_{WT_j} \cdot j_H^{\,j}$

Power identity

$j_{PP} := 1$

Given

$k_{P.open}\left(j_{PP}\right) = \kappa_{PH}$

$\iota_{PP}\left(\kappa_{PH}\right) := \mathrm{Find}\left(j_{PP}\right)$

$J_{PP_i} := \iota_{PP}\left(K_{P_i}\right)$

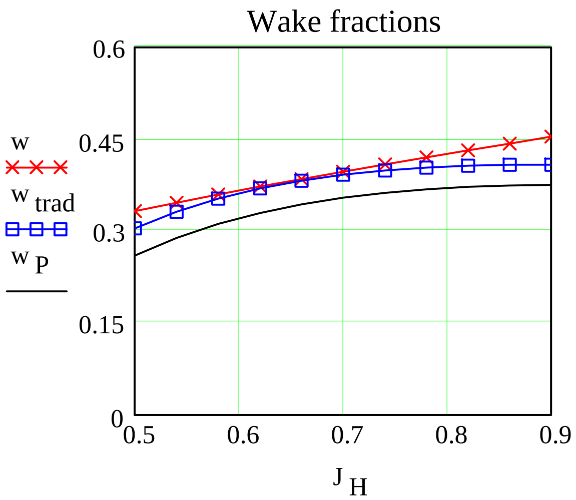
$w_{P_i} := 1 - \frac{J_{PP_i}}{J_{H_i}}$

$j := 0 .. 1$

$A_{JH_{i,j}} := \left(J_{H_i}\right)^j$

$X_{WT} := \mathrm{LeftInv}\left(A_{JH}\right) \cdot w_T$

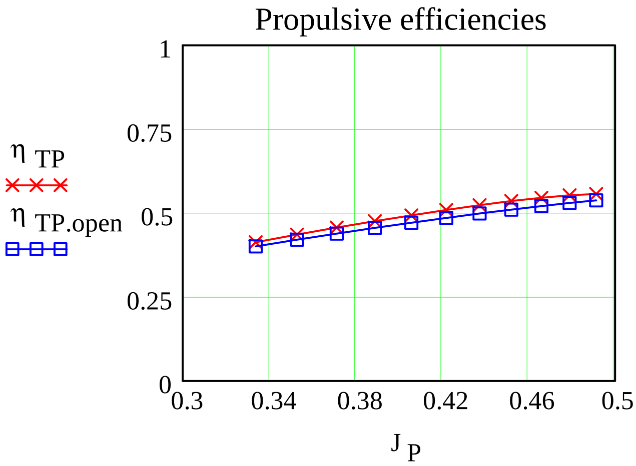
$k_{WT}\left(j_H\right) := \sum_j X_{WT_j} \cdot j_H^{\,j}$

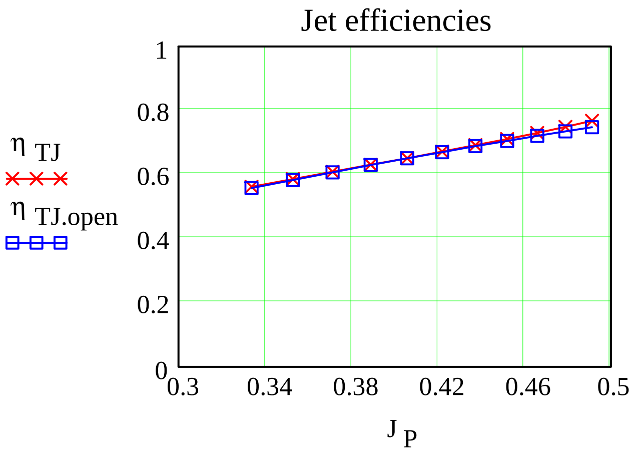


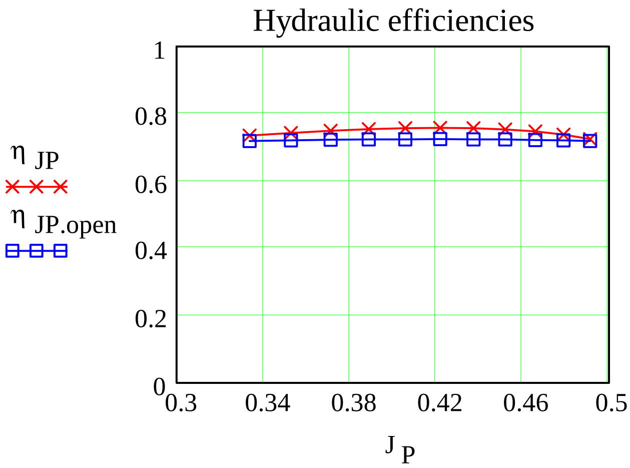
Determine propeller effiencies: open condition

$$\eta_{TP.open_i} := \frac{K_{T.open_i} \cdot J_{P_i}}{K_{P.open_i}} \qquad c_{T.open_i} := \frac{8 \cdot K_{T.open_i}}{\pi \cdot \left(J_{P_i}\right)^2} \qquad \eta_{TJ.open_i} := \frac{2}{1 + \sqrt{1 + c_{T.open_i}}}$$

$$\eta_{JP.open_i} := \frac{\eta_{TP.open_i}}{\eta_{TJ.open_i}}$$







Determine resistance and thrust deduction fraction

MS0805181630

Problem solved

As has been observed earlier the thrust deduction axiom in accordance with the global approximation of the thrust deduction theorem is too crude to permit the identification of reasonable energy wake fractions.

Accordingly further attempts have been made to replace that axiom but without success. By the way it has been noticed that the value of the longitudinal hydrodynamic inertia is crucially affecting the momentum balance and the final results.

Further it has been observed that the maximum order of the filter selected has considerable impact on the inertia identified. Accordingly a procedure has been developed to extrapolate from quasi-steady to steady conditions.

Determine time range

$t_m := \mathrm{mean}(t)$ $\quad t_m = 66.5759$ $\quad \Delta t_r := t_r - t_m$

Determine velocity range

$v_m := \mathrm{mean}(v_{fair})$ $\quad v_m = 1.3417$ $\quad \Delta v_{fair_r} := v_{fair_r} - v_m$

$\min(v_{fair}) = 1.3118$ $\quad \max(v_{fair}) = 1.3621$

Determine thrust deduction fraction based on simple axiom in accordance with global approximation of thrust deduction theorem

$$J_{H.fair_r} := \frac{v_{fair_r}}{D \cdot n_{fair_r}}$$

$$\eta_{TJ.fair_r} := H_T\left(w_{TJ}, J_{H.fair_r}\right)$$

$$w_{fair_r} := w_{TJ} \cdot \eta_{TJ.fair_r}$$

$$F_{fairR_r} := F_F \cdot \left(1 - \frac{a_{fair_r}}{g}\right) - M_{nom} \cdot \left(1 + m_{x.nom}\right) \cdot a_{fair_r}$$

$$A_{MR_{r,0}} := \eta_{TJ.fair_r} \cdot T_{fair_r}$$

$k := 0 .. 1$

$A_{MR_{r,k+1}} := \left(\Delta v_{fair_r}\right)^k$

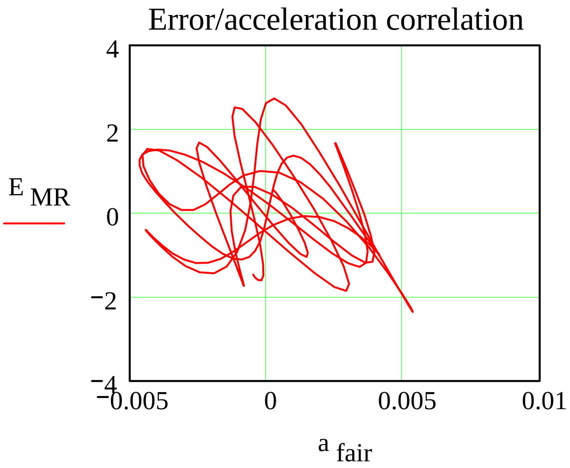
$A_{MR_{r,3}} := \Delta t_r$

$B_{MR_r} := T_{fair_r} + F_{fairR_r}$

$X_{MR} := \text{LeftInv}\left(A_{MR}\right) \cdot B_{MR}$

$E_{MR} := B_{MR} - A_{MR} \cdot X_{MR}$

$$X_{MR} = \begin{bmatrix} 0.399 \\ 33.715 \\ 74.445 \\ -0.016 \end{bmatrix}$$



$$\frac{\left|E_{MR}\right|}{\left|B_{MR}\right|} = 0.0272$$

$$M_{hyd.id} := \frac{E_{MR} \cdot a_{fair}}{a_{fair} \cdot a_{fair}}$$

$M_{hyd.id} = -129.6873$

$t_{TJ} := X_{MR_0}$

$thd := t_{TJ} \cdot \eta_{TJ}$

$$R_r := \sum_k \left(\Delta v_{fair_r}\right)^k \cdot X_{MR_{k+1}}$$

Determine total inertia

$$F_{fairI_r} := F_F \cdot \left(1 - \frac{a_{fair_r}}{g}\right) - R_r$$

$A_{MI_{r,0}} := \eta_{TJ.fair_r} \cdot T_{fair_r}$

$A_{MI_{r,1}} := a_{fair_r}$

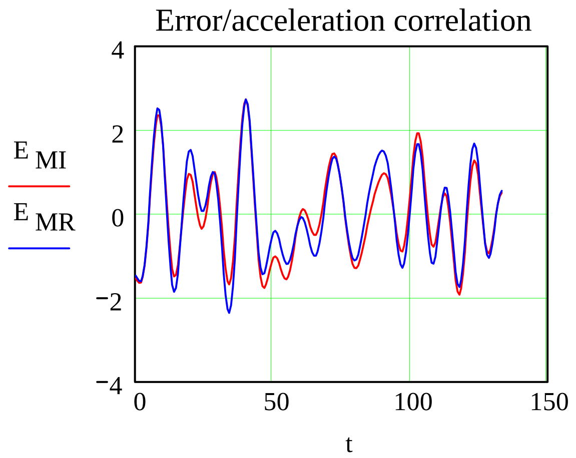
$A_{MI_{r,2}} := \Delta t_r$

$B_{MI_r} := T_{fair_r} + F_{fairI_r}$

$$X_{MI} := \mathrm{LeftInv}\left(A_{MI}\right) \cdot B_{MI}$$

$$E_{MI} := B_{MI} - A_{MI} \cdot X_{MI}$$

$$X_{MI} = \begin{bmatrix} 0.4015 \\ 1329.2432 \\ -0.0158 \end{bmatrix}$$



$$t_{TJ} := X_{MI_0}$$

$$thd := t_{TJ} \cdot \eta_{TJ}$$

$$\Delta M := M_{nom} \cdot \left(1 + m_{x.nom}\right) - X_{MI_1} \qquad \Delta M = 132.3991$$

$$m_{x.meas} := \frac{X_{MI_1}}{M_{nom}} - 1 \qquad m_{x.meas} = -0.0711$$

Extrapolation from quasi-steady to steady conditions

$$inertia := \begin{bmatrix} 16 & 1300.70 & -0.091 \\ 12 & 1376.69 & -0.03795 \\ 10 & 1385.36 & -0.03189 \\ 8 & 1393.59 & -0.02614 \\ 7 & 1423.06 & -0.00555 \\ 6 & 1432.24 & 0.00087 \\ 5 & 1437.10 & 0.00426 \\ 4 & 1435.18 & 0.00292 \end{bmatrix}$$

k.max, M.tot.meas, m.x.meas
determined by repeated computations with
varying maximum order of the filter

$$ord_{max} := inertia^{\langle 0 \rangle} \qquad M_{tot.meas} := inertia^{\langle 1 \rangle} \qquad m_{x.meas} := inertia^{\langle 2 \rangle}$$

$j_{max} := \mathrm{last}(ord_{max})$

$j := 0..j_{max}$

$A_{O_{j,0}} := 1$

$A_{O_{j,1}} := \left(ord_{max_j}\right)^2$

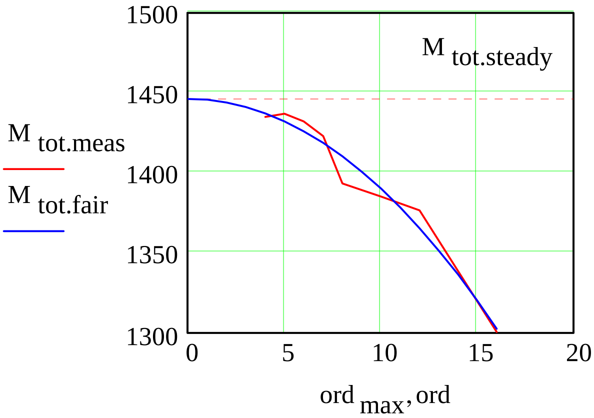
$X_M := \mathrm{LeftInv}(A_O) \cdot M_{tot.meas}$

$M_{tot.steady} := X_{M_0}$ $M_{tot.steady} = 1446.3679$

Plot of extrapolation

$\mathrm{inert}(ord) := X_{M_0} + X_{M_1} \cdot ord^2$

$jj := 0..16$ $ord_{jj} := jj$ $M_{tot.fair_{jj}} := \mathrm{inert}(ord_{jj})$



Scrutinise result

$M_{steady} := \dfrac{M_{tot.steady}}{1 + m_x}$ $M_{steady} = 1409.9049$ $M_{nom} = 1431.0000$

Difference in 'observed' and nominal model mass

$\Delta M := M_{steady} - M_{nom}$ $\Delta M = -21.0951$

Of course this result is strictly accidental. But it may also be speculated that the model was not fully ballasted, two 10 kg 'weight pieces' missing for whatever reason. In view of the uncertainty there is no chance to identify the coefficient of the hydrodynamic inertia.

'Ship efficiencies'

$$\eta_{RT_i} := \frac{1 - thd_i}{1 - w_i}$$

Hull efficiency,
'Rumpfeinflussgrad'

$$\eta_{RJ_i} := \eta_{RT_i} \cdot \eta_{TJ_i}$$

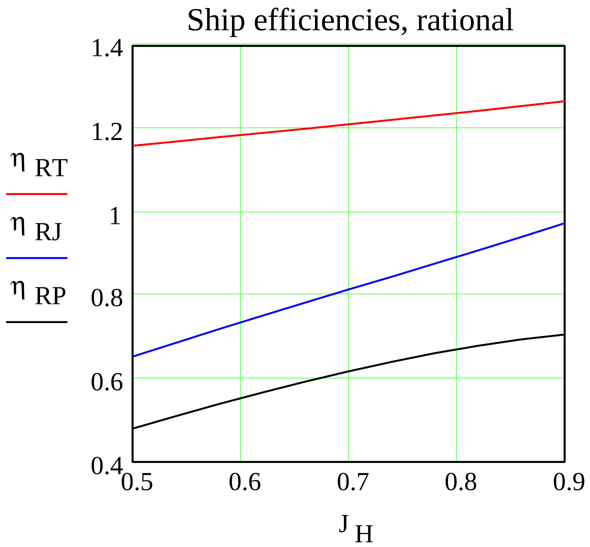
Configuration efficiency,
'Konfigurationsgütegrad'

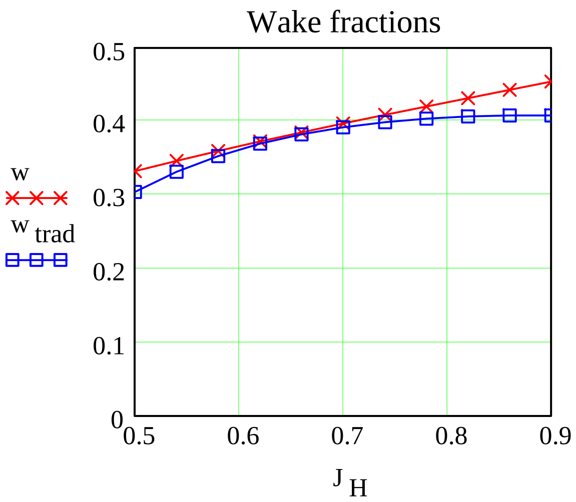
$$\eta_{RP_i} := \eta_{RJ_i} \cdot \eta_{JP_i}$$

Propulsive efficiency,
'Gesamtgütegrad'

$$\eta_{rot_i} := 1$$

Rotative efficiency,
equals 1 by definition
in the rational theory!





Compare with traditional evaluation based on hull towing test

Resistance, traditional: hull towing

Scrutiny of data

$$\mathrm{Data}_{tow} := \begin{bmatrix} 0.90 & 13.6 \\ 1.00 & 16.8 \\ 1.10 & 20.7 \\ 1.20 & 25.2 \\ 1.30 & 30.4 \\ 1.35 & 33.2 \end{bmatrix}$$

Values v in m/s, of R in N read from Fig. 3.4 in VWS Bericht Nr. 1126/88. They conicide with those in VWS Report No. 1100/87.

$v_{tow} := \mathrm{Data}_{tow}^{\langle 0 \rangle} \cdot m \cdot sec^{-1}$ $\qquad v_{tow} := v_{tow} \cdot m^{-1} \cdot sec$

$R_{tow} := \mathrm{Data}_{tow}^{\langle 1 \rangle} \cdot N$ $\qquad R_{tow} := R_{tow} \cdot N^{-1}$

Fair data

$j := 0 .. \mathrm{last}(v_{tow})$ $\qquad k := 0 .. 3$ $\qquad A_{R.trad_{j,k}} := \left(v_{tow_j}\right)^k$

$X_{R.trad} := \mathrm{LeftInv}(A_{R.trad}) \cdot R_{tow}$

$v_{plt_j} := 1.31 + j \cdot 0.01$

$A_{R.plt_{j,k}} := \left(v_{plt_j}\right)^k$

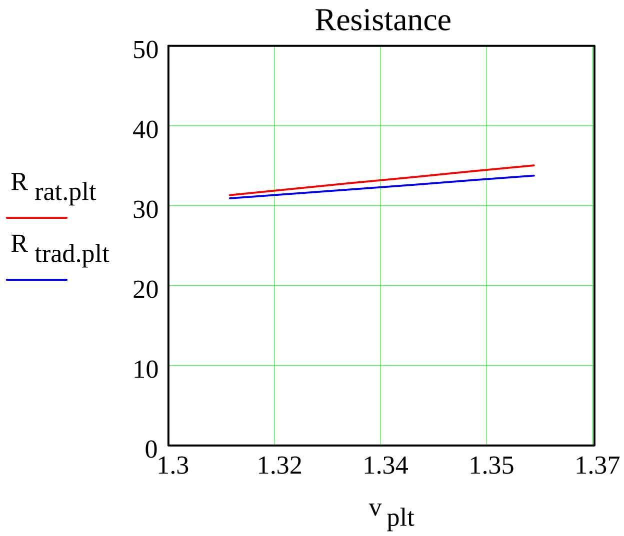
$R_{trad.plt} := A_{R.plt} \cdot X_{R.trad}$

Resistance, rational

$j := 0 .. \mathrm{last}(v_{fair})$ $\qquad k := 0 .. 3$ $\qquad A_{R.rat_{j,k}} := \left(v_{fair_j}\right)^k$

$X_{R.rat} := \mathrm{LeftInv}(A_{R.rat}) \cdot R$

$R_{rat.plt} := A_{R.plt} \cdot X_{R.rat}$



$$A_{R.tow_{r,k}} := \left(v_{fair_r}\right)^k$$

$$R_{tow} := A_{R.tow} \cdot X_{R.trad}$$

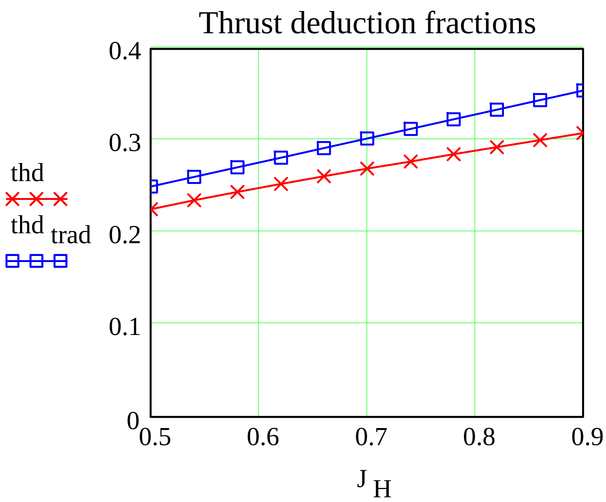
Thrust deduction fraction, traditional

$k := 0 .. 1$ $\qquad A_{thd_{r,k}} := \left(J_{H.fair_r}\right)^k \cdot T_{fair_r}$

$B_{thd} := T_{fair} + F_{fairR} - R_{tow}$

$X_{thd} := \mathrm{LeftInv}\left(A_{thd}\right) \cdot B_{thd}$ $\qquad X_{thd} = \begin{bmatrix} 0.1200 \\ 0.2612 \end{bmatrix}$

$$thd_{trad_i} := \sum_k \left(J_{H_i}\right)^k \cdot X_{thd_k}$$



'Ship efficiencies', traditional

$$\eta_{RP.trad_i} := \left(1 - thd_{trad_i}\right) \cdot \frac{K_{T_i} \cdot J_{H_i}}{K_{P_i}}$$ Propulsive efficiency, 'Gesamtgütegrad'

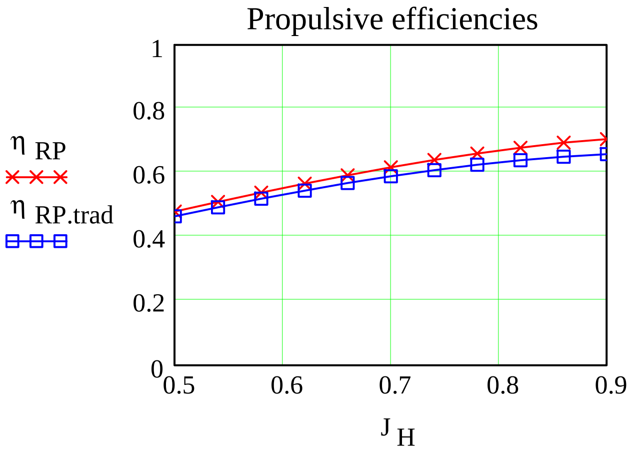
$$\eta_{RT.trad_i} := \frac{1 - thd_{trad_i}}{1 - w_{trad_i}}$$ Hull efficiency, 'Rumpfeinflussgrad'

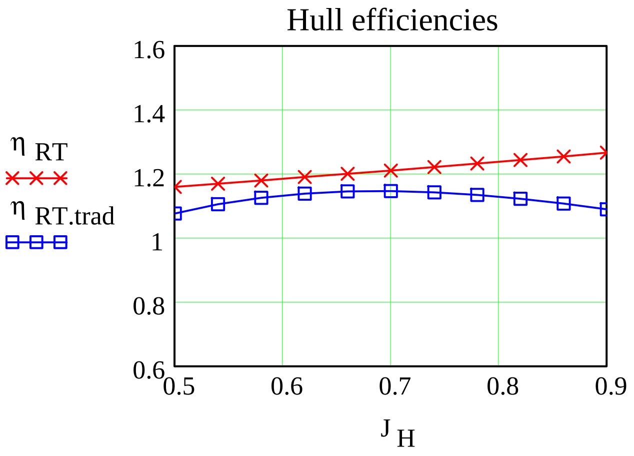
$$\eta_{TP.trad_i} := \frac{\eta_{RP.trad_i}}{\eta_{RT.trad_i}}$$ Behind efficiency

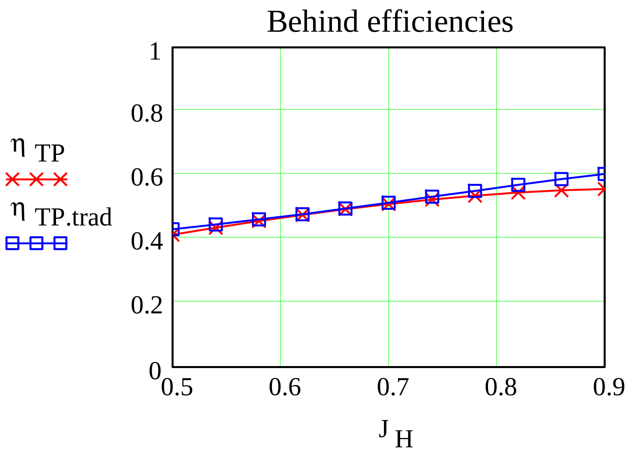
$$\eta_{rot.trad_i} := \frac{\eta_{TP.trad_i}}{\eta_{TP.open_i}}$$ Rotative efficiency, Anordnungsgütegrad

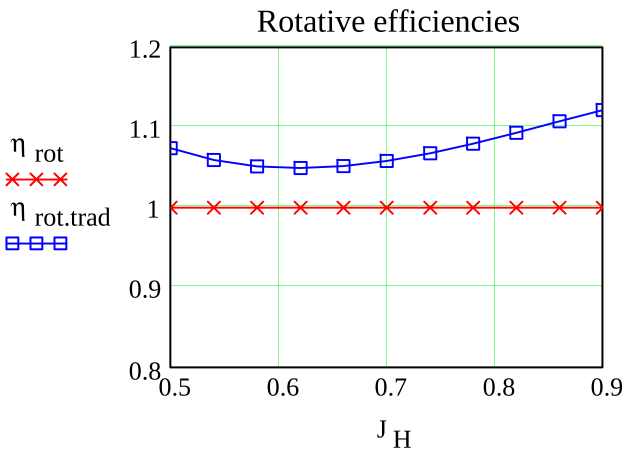
$$\eta_{RJ.trad_i} := \eta_{RT.trad_i} \cdot \eta_{TJ.open_i}$$ Configuration efficiency, 'Konfigurationsgütegrad'

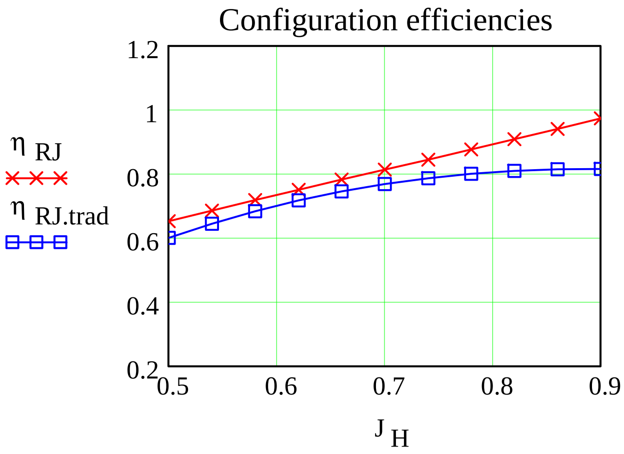
Compare with results of rational evaluation











Output of results for comparison with the results of quasi-steady 'model' trial (mod_trial.mcd)

$$res\_mod\_eval := \begin{bmatrix} v_{plt} & R_{rat.plt} & R_{trad.plt} \\ J_H & \eta_{RP} & \eta_{RP.trad} \end{bmatrix}$$

WRITEPRN("Res_mod_eval") := res_mod_eval

Some conclusions

This rigorous re-evaluation of the model test has confirmed the results of the former re-evaluation
and shown why that evaluation accidentally happened to be correct concerning the determination of the nominal wake fraction etc.

Concerning the determination of the resistance and thrust deduction fraction numerical studies have shown that the momentum balance is crucially affected by the value of the hydrodynamic inertia assumed and thus the final values of the resistance and the thrust deduction fraction.

Further the analysis has shown that the values of the inertia identified strongly depend on the maximum order of the filter applied to the raw data. Accordingly a procedure has been developed to extrapolate from quasi-steady conditions to the steady condition.

In view of the remaining uncertainties the small value of the hydrodynamic inertia cannot be identified. A nominal value has been assumed according to Sainsbury.

Concerning the determination of the energy wake fraction the problems observed earlier have not yet been resolved, maybe they cannot be resolved in the context developed so far.

For the time being further analysis has to be delayed.

(The file had to be reprinted due to problems with the pdf-writer. MS 090626)

END
Model data VWS 2491/1340 re-evaluated