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'Model' test of quasi-steady ship powering trials and monitoring

Ref: The basic 'model' test and this 'model' trial are directly accessible via the following links:
http://www.m-schmiechen.homepage.t-online.de/HomepageClassic01/**mod_evaf.pdf**
http://www.m-schmiechen.homepage.t-online.de/HomepageClassic01/**mod_trial.pdf**

Preamble

The latter file replaces the unsatisfactory, subsequently found to be flawed preliminary version documented in the 'Festschrift' published on this website and distributed at the 108th Annual Meeting of STG at Berlin in 2013 to commemorate the quasisteady propulsion tests with the research vessel METEOR in the Greenland Sea in November 1988.

Preface

The following 'model' test of quasi-steady ship powering trials and monitoring is intended to demonstrate, that quasi-steady trials full scale, *nota bene* without thrust measurements!, of about one hour duration, at service conditions without anybody noticing that such tests are being performed, permit to monitor the resistance and the propulsive efficiency in the range of interest at the conditions prevailing during the trials.

This paradigmatic test is based on the data of the 'model' test of only two minutes duration with models VWS 2491/1340 performed on 09.09.1986 to demonstrate the feasibility of the more ambitious quasi-steady tests including thrust measurements performed with the research vessel METEOR in the Greenland Sea in November 1988. The same data have since extensively been used further to develop the rational technique proposed, details to be found in the file directly accessible via the link quoted in the Reference.

Exposition improved by plots of data MS 201308281200

Text and layout marginally changed MS 201308311630

Evaluation corrected following the detection of an error in data transmission and subsequently rigorously rationalised
MS 201404182000

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

Field strength	$g := 9.81 \cdot m \cdot sec^{-2}$	$g := g \cdot m^{-1} \cdot sec^{2}$
Units		
Force	$N := newton$	$kp := g \cdot N$
Torque	$Nm := newton \cdot m$	
Power	$W := watt$	

Model data VWS 2491/1340

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 be found in the first appendix.

Model scale	$\lambda := 37.23$	
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	$\phi := \dfrac{V}{L \cdot B \cdot Tg}$	$\phi = 0.8633$
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	$m_{mod} := \rho \cdot V$	$m_{mod} = 1431.0000$
Added inertia	$m_{x} := 0.024$	
Total inertia	$M_{x} := m_{mod} \cdot (1 + m_{x})$	$M_{x} = 1465.3440$
Surface	$S := 8.967 \cdot m^{2}$	$S := S \cdot m^{-2}$

Propeller model VWS Prop. 1340

CP propeller, right handed

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

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

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 $F_n := 0.168$

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

Frictional deduction $C_F := 0.183$

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

Tank dimensions $h := 4.2$

$l := 240$

Data input

Digitized .jpg files

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

In the fundamental 'model' test mod_eval.mcd the raw data have been scutinzed, faired and recorded for ready reference.

$Dat_{fair} := READPRN("dat\_fair.dat")$

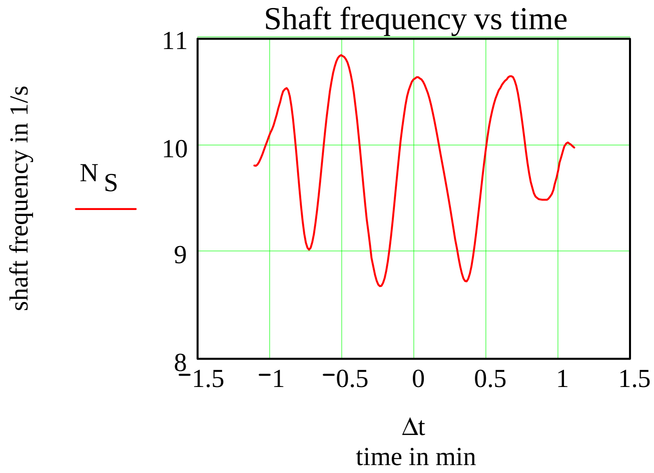
$t := Dat_{fair}{}^{\langle 0 \rangle}$ $ni := last(t)$ $i := 0 .. ni$ $t := t \cdot \frac{sec}{min}$

$t_m := mean(t)$

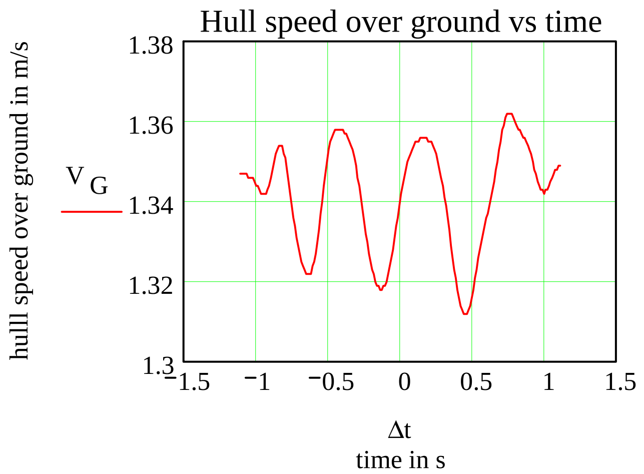
$\Delta t := t - t_m$

$N_S := Dat_{fair}{}^{\langle 1 \rangle}$ $V_G := Dat_{fair}{}^{\langle 2 \rangle}$ $A := Dat_{fair}{}^{\langle 3 \rangle}$ $Q_S := Dat_{fair}{}^{\langle 4 \rangle}$

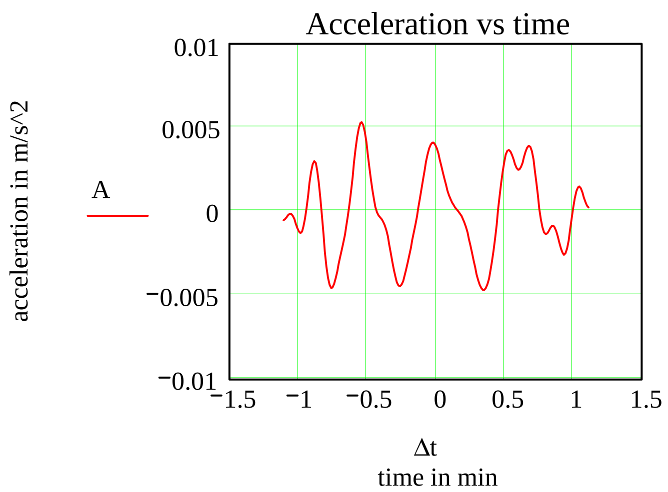
Shaft frequency



Hull speed over ground

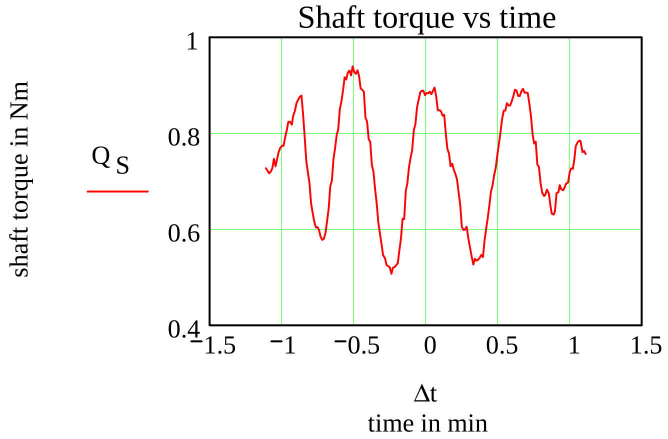


Hull acceleration



Shaft torque

$Q_P := Q_S$



Parameters identified

Hull speed

$V_{C_i} := 0.0$

Mean current in the tank
assumed for lack of more precise information

$V_H := V_G - V_C$

$V_{H.mean} := \mathrm{mean}(V_H)$ $\quad V_{H.mean} = 1.3417$

$\Delta V_{H_i} := V_{H_i} - V_{H.mean}$

Hull advance ratio

$$J_{H_i} := \frac{V_{H_i}}{D \cdot N_{S_i}}$$

$J_{H.mean} := \mathrm{mean}(J_H)$ $\quad J_{H.mean} = 0.6984$

$\Delta J_{H_i} := J_{H_i} - J_{H.mean}$

Shaft power

$P_{P_i} := 2 \cdot \pi \cdot N_{S_i} \cdot Q_{P_i}$

$P_{P_i} := P_{P_i}$

$P_{P.mean} := \mathrm{mean}(P_P)$ $\quad \Delta P_{P_i} := P_{P_i} - P_{P.mean}$

$P_{P.mean} = 46.4870$

Set up energy balance

$A_{P_{i,0}} := -V_{H_i}$

$A_{P_{i,1}} := A_{P_{i,0}} \cdot \Delta V_{H_i}$

Partial linearised towing power
with unknown total resistance parameters

$A_{P_{i,2}} := P_{P_i}$

$A_{P_{i,3}} := A_{P_{i,2}} \cdot \Delta J_{H_i}$

Partial linearised propulsive power
with unknown propulsive efficiency parameters

$B_{P_i} := \left(M_x \cdot A_i - F_F\right) \cdot V_{H_i}$

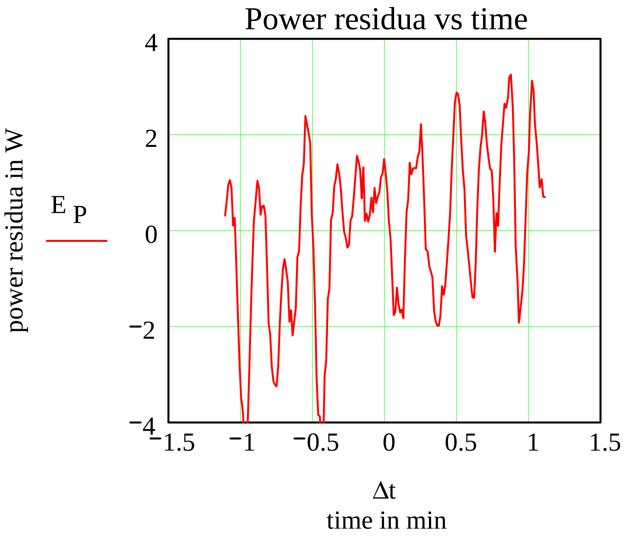
Towing power due to known 'forces'

Solve equations

$X_P := \mathrm{geninv}\left(A_P\right) \cdot B_P$

$$X_P = \begin{bmatrix} 29.2225 \\ 59.2086 \\ 0.4821 \\ -0.0603 \end{bmatrix}$$

$E_P := B_P - A_P \cdot X_P$



The power residua are exhibiting
a pronounced linear tendency.

Results of evaluations including measured thrust values

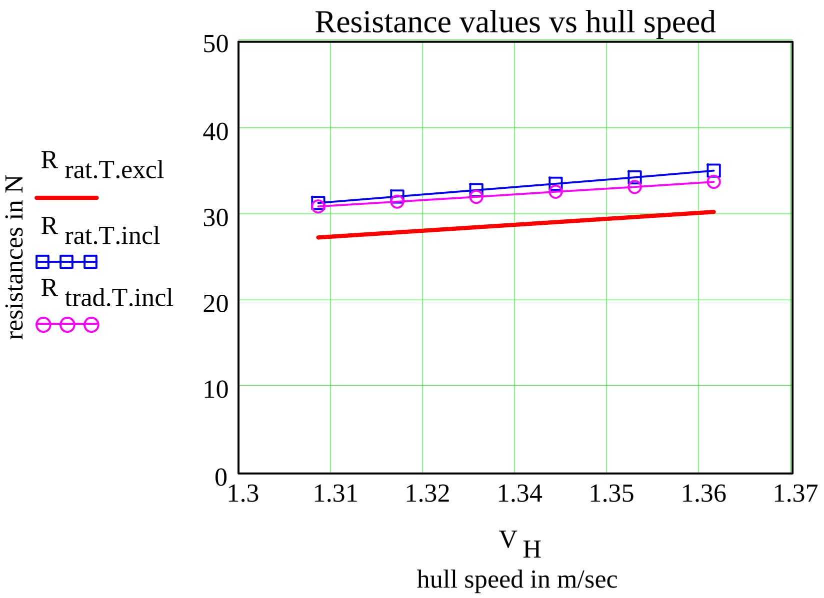
$$\begin{bmatrix} V_H & R_{rat.T.incl} & R_{trad.T.incl} \\ J_H & \eta_{TEP.rat.T.incl} & \eta_{TEP.trad.T.incl} \end{bmatrix} := \mathrm{READPRN}(\text{"Res\_mod\_eval"})$$

Resistance values
identified excluding measured thrust values

$j := 0 .. \mathrm{last}(V_H)$

$\Delta V_{H.plt_j} := V_{H_j} - V_{H.mean}$

$R_{rat.T.excl_j} := X_{P_0} + X_{P_1} \cdot \Delta V_{H.plt_j}$

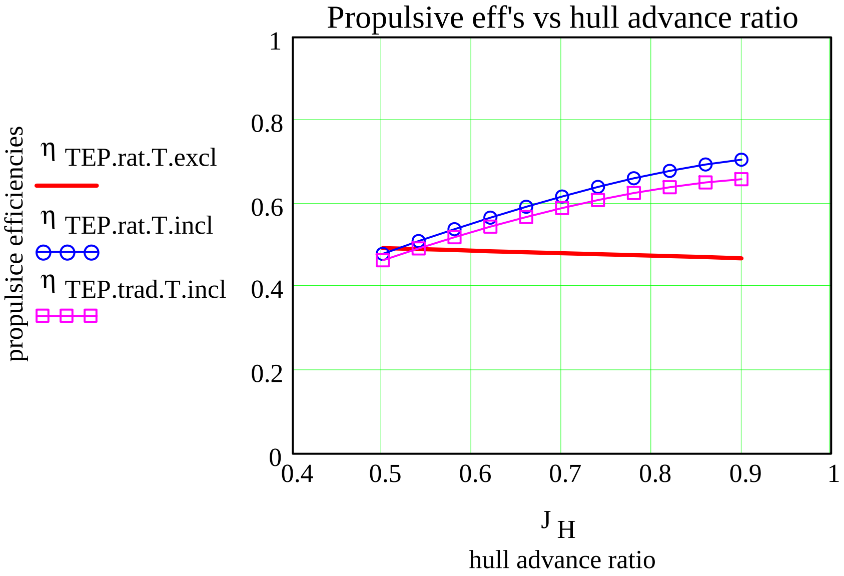


Propulsive efficiency values
identified excluding measured thrust values

$j := 0 .. \mathrm{last}(J_H)$

$\Delta J_{H.plt_j} := J_{H_j} - J_{H.mean}$

$\eta_{TEP.rat.T.excl_j} := X_{P_2} + X_{P_3} \cdot \Delta J_{H.plt_j}$



Evidently the results are quite unsatisfactory,
the energy balance not accounting
for unknown effects of the towing tank environment,
e.g. drift due to previous tests and tidal waves.

Identify trend of power residua

$t_m := \mathrm{mean}(t)$ $\qquad \Delta t := t - t_m$

$A_{E_{i,0}} := 1$

$A_{E_{i,1}} := \Delta t_i$.

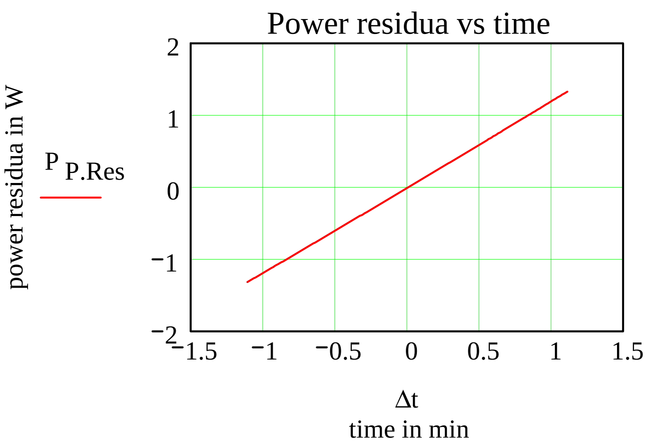
$A_{E_{i,2}} := \left(\Delta t_i\right)^2$

$X_E := \mathrm{geninv}\left(A_E\right) \cdot E_P$

$$X_E = \begin{bmatrix} -0.004483 \\ 1.192338 \\ 0.010865 \end{bmatrix}$$

The analysis shows that the trend is in fact linear.

$P_{P.Res} := A_E \cdot X_E$



Modify power balance

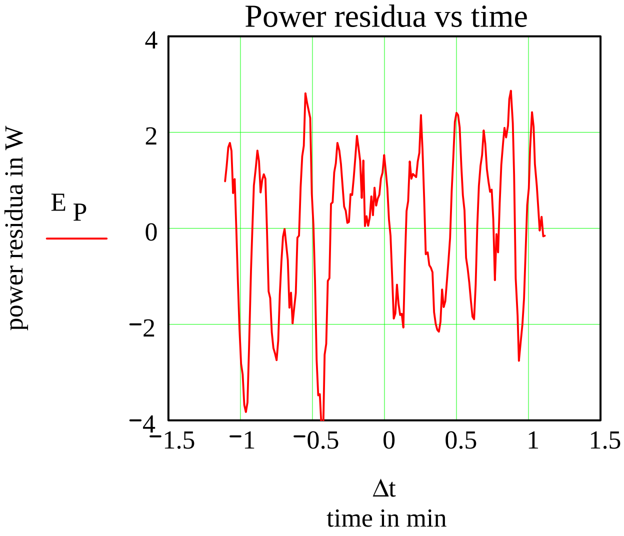
$$A_{P_{i,2}} := P_{P_i} + P_{P.Res_i}$$

Solve modified equations

$$X_P := \mathrm{geninv}\left(A_P\right)\cdot B_P$$

$$X_P = \begin{bmatrix} 32.4629 \\ 66.7494 \\ 0.5800 \\ 0.4202 \end{bmatrix}$$

$$E_P := B_P - A_P \cdot X_P$$

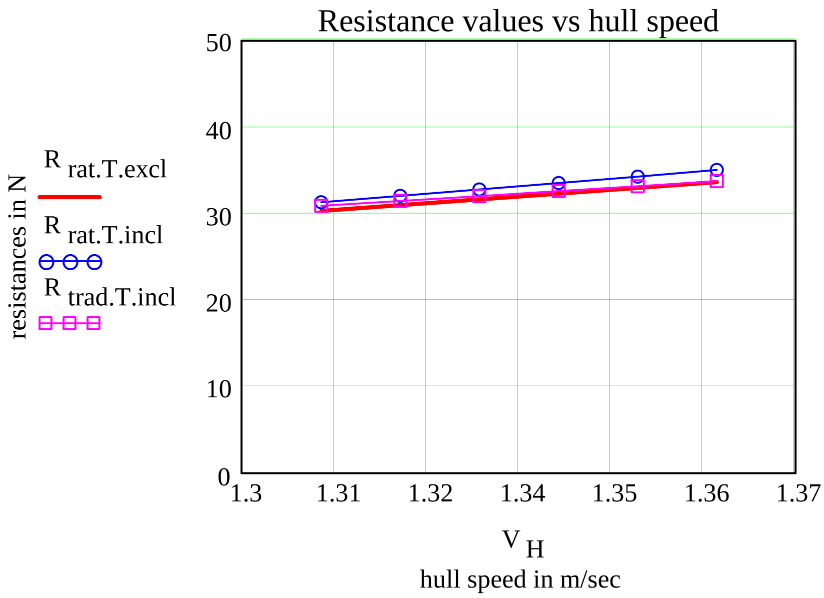


Resistance values
identified excluding measured thrust values

$$j := 0 .. \mathrm{last}(V_H)$$

$$\Delta V_{H.plt_j} := V_{H_j} - V_{H.mean}$$

$$R_{rat.T.excl_j} := X_{P_0} + X_{P_1} \cdot \Delta V_{H.plt_j}$$



The model resistance identified excluding the measured thrust values is thus nearly identical to the towing resistance.

$$V_H = \begin{bmatrix} 1.3100 \\ 1.3200 \\ 1.3300 \\ 1.3400 \\ 1.3500 \\ 1.3600 \end{bmatrix} \qquad R_{rat.T.excl} = \begin{bmatrix} 30.3466 \\ 31.0141 \\ 31.6816 \\ 32.3491 \\ 33.0166 \\ 33.6841 \end{bmatrix} \qquad R_{trad.T.incl} = \begin{bmatrix} 30.9400 \\ 31.5000 \\ 32.0600 \\ 32.6300 \\ 33.2100 \\ 33.7900 \end{bmatrix}$$

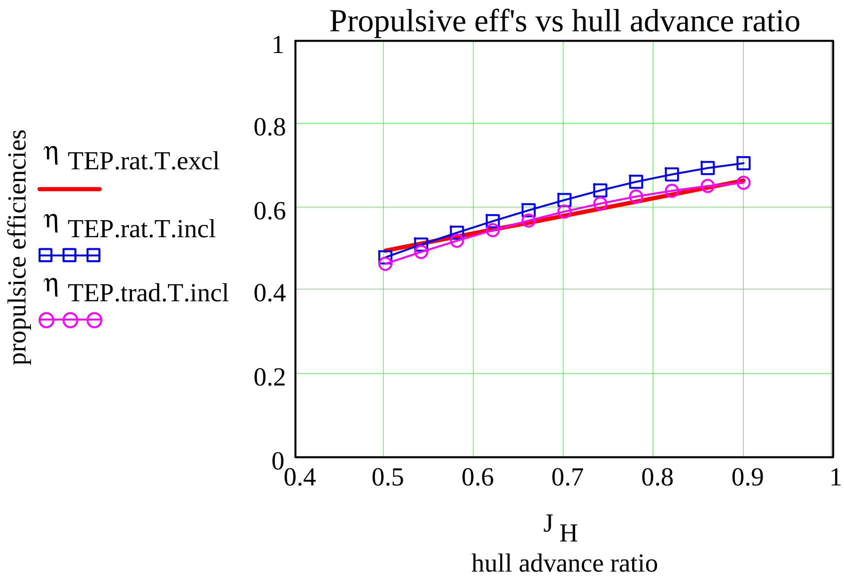
Similarly the values of the model propulsive efficiency identified excluding the measured thrust values are nearly identical to the values based on the model propeller open water performance.

Propulsive efficiency values identified excluding measured thrust values

$j := 0 .. \text{last}(J_H)$

$\Delta J_{H.plt_j} := J_{H_j} - J_{H.mean}$

$\eta_{TEP.rat.T.excl_j} := X_{P_2} + X_{P_3} \cdot \Delta J_{H.plt_j}$



$$J_H = \begin{bmatrix} 0.5000 \\ 0.5400 \\ 0.5800 \\ 0.6200 \\ 0.6600 \\ 0.7000 \\ 0.7400 \\ 0.7800 \\ 0.8200 \\ 0.8600 \\ 0.9000 \end{bmatrix} \quad \eta_{TEP.rat.T.incl} = \begin{bmatrix} 0.4804 \\ 0.5108 \\ 0.5398 \\ 0.5676 \\ 0.5938 \\ 0.6184 \\ 0.6411 \\ 0.6617 \\ 0.6799 \\ 0.6951 \\ 0.7069 \end{bmatrix} \quad \eta_{TEP.trad.T.incl} = \begin{bmatrix} 0.4652 \\ 0.4937 \\ 0.5206 \\ 0.5458 \\ 0.5691 \\ 0.5905 \\ 0.6096 \\ 0.6264 \\ 0.6405 \\ 0.6517 \\ 0.6593 \end{bmatrix}$$

Conclusions

After correction of the mistake in the data transmission from the preceding basic programme mod_eval.mcd to the present progrmme all the earlier subsequent speculations concerning the reasons of the discrepancies observed in the propulsive efficiencies are obsolete.

Accounting for the trend of the observed power residua, without caring for their possible reasons, results in perfect agreement with the traditionl results not only in case of the resistance, but also in case of the propulsive efficiency.

Thus, from the preceding **basic exercise**, the evaluation of data acquired at a quasi-steady 'model' test of only two minutes duration, ignoring the thrust data (!), it is concluded that quasi-steady trials of about an hour full scale will be possible for detailed monitoring of the powering performance of ships at the conditons prevailing during the test.

Towing tanks can easily test this procedure, as they did in 1936/37 with Horn's proposal, and can ask for such tests at the next trials they are involved in. Of course in evaluating full scale data others of my procedures developed to identify current and environmental parameters have to be accounted for. The pertinent development may be subject of a master's or even a doctoral thesis.

'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 sensitivity of the problem at hand colleagues are warned: there may 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 hull towing tests and propeller open water are necessary and the extremely short propulsion tests provide a wealth of consistent data and results.

END
'Model' test of quasi-steady
ship powering trials and monitoring