Prof. Dr.-Ing. M. Schmiechen

To whom it may concern

Powering performance
of a bulk carrier
during speed trials
in ballast condition
at two trim settings
reduced to the nominal no
wind and waves condition

As first evaluated data at the second,
at the larger trim, i.e. at the larger
nominal propeller submergence

Units, constants, routines

Reference: C:\ANONYMA\_5\routines.mcd

Trials identification

<table>
<thead>
<tr>
<th>TID = &quot;ANONYMA&quot;</th>
</tr>
</thead>
</table>

Trials condition

trim := 2

The data of the second, the later trials at the larger trim have been evaluated first, after the preliminary evaluation of the data of the first trials resulted in an unrealistic propeller power characteristic, indicating that something was 'wrong' with the data. Reasons to be revealed subsequently, when the data of the first, the earlier trials at the smaller trim are being evaluated next.

Constants

<table>
<thead>
<tr>
<th>Trim at trials</th>
<th>( \Delta T_{\text{nom}} := 3.64 , \text{m} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>T_aft := 7.15 , \text{m}</td>
<td></td>
</tr>
<tr>
<td>( \Delta T_{\text{Tip}} := 1.35 , \text{m} )</td>
<td></td>
</tr>
</tbody>
</table>

Input of mean data

means := READPRN("Means_2.prn")

rstdevs := READPRN("rSdvM_2.prn")

nr := rows(means) \quad run := 0..nr - 1 \quad nr = 6.000

nc := cols(means) \quad mag := 0..nc - 1 \quad nc = 17.000
### Assign data

<table>
<thead>
<tr>
<th>Data Type</th>
<th>Formula</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time</td>
<td>( t := \text{mean}^{02} \cdot \text{hr} )</td>
</tr>
<tr>
<td>Shaft frequency</td>
<td>( N_S := \text{mean}^{22} \cdot \text{Hz} )</td>
</tr>
<tr>
<td>Shaft power</td>
<td>( P_S := \text{mean}^{1} \cdot \text{W} )</td>
</tr>
<tr>
<td>Speed over ground</td>
<td>( V_G := \text{mean}^{33} \cdot \frac{\text{m}}{\text{s}} )</td>
</tr>
<tr>
<td>Wind speed</td>
<td>( V_W := \text{mean}^{77} \cdot \frac{\text{m}}{\text{s}} )</td>
</tr>
<tr>
<td>Wind direction</td>
<td>( \psi_W := \text{mean}^{66} \cdot \frac{\text{deg}}{\text{rad}} )</td>
</tr>
<tr>
<td>Trim</td>
<td>( \Delta T := \text{mean}^{55} \cdot \text{m} )</td>
</tr>
<tr>
<td>Ship speed in water</td>
<td>( V_{H,\text{rep}} := \text{mean}^{15} \cdot \frac{\text{m}}{\text{s}} )</td>
</tr>
</tbody>
</table>

Data in SI-Units non-dimensionalized in view of further use in some mathematical subroutines, which by definition cannot handle arguments with (different) physical dimensions!
Mean values, intermediate results

For ready reference the matrices of the mean values of the measured magnitudes, alias 'quantities', are printed here. Further down intermediate results are printed as well to permit checks of plausibility.

\[
\begin{bmatrix}
-1.004 \\
-0.638 \\
-0.142 \\
0.227 \\
0.571 \\
0.986 \\
\end{bmatrix}
\begin{bmatrix}
1.748 \\
1.900 \\
1.587 \\
1.587 \\
1.898 \\
\end{bmatrix}
\begin{bmatrix}
4.824 \\
6.924 \\
4.143 \\
3.621 \\
6.281 \\
\end{bmatrix}
\begin{bmatrix}
7.203 \\
5.725 \\
4.970 \\
6.675 \\
7.796 \\
\end{bmatrix}
\]

\[
\begin{bmatrix}
7.742 \\
21.690 \\
20.870 \\
20.550 \\
7.871 \\
6.565 \\
\end{bmatrix}
\begin{bmatrix}
3.759 \\
0.617 \\
0.250 \\
0.244 \\
3.808 \\
3.852 \\
\end{bmatrix}
\begin{bmatrix}
4.020 \\
3.850 \\
3.845 \\
3.791 \\
3.839 \\
\end{bmatrix}
\begin{bmatrix}
7.203 \\
5.725 \\
4.970 \\
6.675 \\
7.796 \\
\end{bmatrix}
\]

\[
\begin{bmatrix}
\psi \quad W \quad \frac{\psi_{W}}{1} = 0.256
\end{bmatrix}
\]

The value reported does not fit into the pattern

Relative (!) standard deviations of mean (!) values

For ready reference the matrices of the relative (!) standard deviations of mean values of the measured magnitudes are also printed here, conveniently in %. Multiplied by the factor 2 these values are estimates of the relative 95% confidence radii of the mean values.

\[
\begin{bmatrix}
N_{S,rsdm} \\
P_{S,rsdm} \\
V_{G,rsdm} \\
V_{W,rsdm} \\
\end{bmatrix} = \begin{bmatrix}
0.019 \\
0.016 \\
0.016 \\
0.019 \\
0.016 \\
0.016 \\
0.019 \\
0.016 \\
\end{bmatrix}
\begin{bmatrix}
0.099 \\
0.077 \\
0.071 \\
0.102 \\
0.110 \\
0.110 \\
0.110 \\
0.110 \\
\end{bmatrix}
\begin{bmatrix}
0.030 \\
0.058 \\
0.061 \\
0.160 \\
0.034 \\
0.032 \\
\end{bmatrix}
\]

\[
\begin{bmatrix}
V_{W,rsdm} \\
\psi_{W,rsdm} \\
\Delta T_{rsdm} \\
V_{H,rep,rsdm} \\
\end{bmatrix} = \begin{bmatrix}
0.604 \\
0.249 \\
0.233 \\
0.366 \\
0.565 \\
0.687 \\
\end{bmatrix}
\begin{bmatrix}
0.145 \\
5.662 \\
7.374 \\
11.270 \\
0.136 \\
0.181 \\
\end{bmatrix}
\begin{bmatrix}
0.381 \\
0.732 \\
0.695 \\
1.888 \\
0.413 \\
0.318 \\
\end{bmatrix}
\begin{bmatrix}
0.030 \\
0.058 \\
0.061 \\
0.160 \\
0.034 \\
0.032 \\
\end{bmatrix}
\]

At the up-wind conditions, runs 2, 3, 4 (indices 1, 2, 3), the wind direction is varying considerably. The variations in the trim are also noteworthy.
**Normalise data**

for preliminary check of consistency only!

\[ i := 0 \ldots n_i \]

\[ J_G_i := \langle D, V_G \cdot N_{S_i} \rangle \]

\[ K_P_i := \langle \rho, D, P_S \cdot N_{S_i} \rangle \]

\[
J_G = \begin{bmatrix}
0.710 \\
0.565 \\
0.602 \\
0.540 \\
0.725 \\
0.708
\end{bmatrix}
\]

\[
K_P = \begin{bmatrix}
0.134 \\
0.154 \\
0.150 \\
0.154 \\
0.135 \\
0.137
\end{bmatrix}
\]

**Sort data in down and up-wind**

\[ S := \text{Sort\_runs}\langle J_G, K_P, \psi, H \rangle \]

\[ J_G.do := S^{<0>} \]

\[ J_G.do = \begin{bmatrix}
0.710 \\
0.725 \\
0.708
\end{bmatrix} \]

\[ K_P.do.or := S^{<1>} \]

\[ K_P.do.or = \begin{bmatrix}
0.134 \\
0.135 \\
0.137
\end{bmatrix} \]

\[ J_G.up := S^{<2>} \]

\[ J_G.up = \begin{bmatrix}
0.565 \\
0.602 \\
0.540
\end{bmatrix} \]

\[ K_P.up.or := S^{<3>} \]

\[ K_P.up.or = \begin{bmatrix}
0.154 \\
0.150 \\
0.154
\end{bmatrix} \]
Analyse power supplied

Confidence range of mean powers

\[ i := 0.. \text{last}(P_S) \]

\[ P_{S.sdv_i} := P_{S.rsdm_i} \cdot P_i \]

\[ P_{S.Conf_i} := 2 \cdot \text{mean}(P_{S.sdv}) \]

Identify current

Linear current convention

\[ o := 1 \]

\[ \text{Res}_{\text{sup.o1}} := \text{Polyn.current}(o, \rho, D, t, \psi, V_G, N_S, P_S) \]

\[ \begin{bmatrix} P.S.E.o1 & V.o1 & V.C.o1 & P.o1 & V.H.o1 & P.S.o1 & P.nor.o1 & J.H.o1 & K_P.o1 \end{bmatrix} := \text{Res}_{\text{sup.o1}} \]

Current velocity
Power residua

Supplied power residua $\text{o1}$ vs time

\[ \text{Power residua in MW} \]

Supplied power residua $\text{o1}$ vs time

Quadratic current convention

\[ \text{Res}_{\text{sup, o2}} := \text{Polyn. current} (\omega, \rho, D, t, \psi, H, V, G, N, S, P, S) \]

\[ \left[ P, S.E.o2, V, C.o2, P, o2, V, H, 2, P, S.o2, P, \text{nor.n2}, J, H, 2, K, P, o2 \right] := \text{Res}_{\text{sup, o2}} \]

Power ratios $\text{o2}$ vs hull advance ratios

\[ \text{Power ratios o2 vs hull advance ratios} \]

Current velocity

Current velocities $\text{o1}$ and $\text{o2}$ vs time

\[ \text{Current velocities o1 and o2 vs time} \]
According to this detailed analysis the linear law for the current may be considered as optimal, as most acceptable in the range of observations, as the quadratic law does not improve the quality of the approximation. This criterion has been used earlier for optimal estimates of spectra as described e.g. in the paper: Schmiechen, M.: Estimation of Spectra of Truncated Transient Functions. Schiffstechnik/Ship Technology Research 46 (1999) No. 2, pp. 111/127.

And as shown in the following it happens accidentally (!) that the linear law results in nearly exactly the same current as a simple tidal law, a constant current super-imposed by a harmonic tidal current, the latter permitting extrapolation to the earlier trial at smaller trim.

An interesting observation concerning the propeller characteristic

According to the above evaluations the propeller characteristic does not change significantly with changing order of approximation, but the small differences matter.
Identification of current at the larger trim

\[ \text{Res}_{\text{sup}} := \text{Tidal}\_\text{current}(\theta, T, t, T_2, m, \rho, D, t, \psi, H, V, N, S, P) \]

\[ \begin{bmatrix} P_{\text{S,E,sup}} & V_{C,2} & P_{2} & V_{H,2} & P_{\text{S,sup,2}} & P_{n,2} & J_{H,2} & K_{P,2} \end{bmatrix} := \text{Res}_{\text{sup}} \]

Accounting for the 'universal' tidal period and the tidal phase, known from the table of tides, the constant current velocity and the tidal current amplitude are identified.

![Current velocities vs 'local' time](image)

![Supplied power residua vs time](image)

\[ V_{C,2} = \begin{bmatrix} -0.681 \\ -0.640 \\ -0.565 \\ -0.499 \\ -0.430 \\ -0.343 \end{bmatrix} \]

\[ V_{C,2,\text{mean}} := V_{0} \]

\[ V_{C,2,\text{ampl}} := V_{1} \]

The mean northerly current is 0.58 kn

The tidal current amplitude is 0.83 kn

Results stored

\text{WRITEPRN}"Res\_\text{sup}\_2.prn" := \text{Res}_{\text{sup}}
**Extrapolate to current at the smaller trim**

As has been mentioned earlier the identification of the current at the first trials with the smaller trim is not possible. Thus its values are determined by extrapolation based on the current and tide identified from data recorded at the second trials.

Due to the very high length of the tidal wave crudely estimated from a source readily at hand* there is no need to account for tidal phases due to the different locations of the runs in the two sets of trials, but only for a mean phase shift between the two sets of runs.


The location of the first set of runs was north of second set, the rotating tide in the North Atlantic is also moving north at the location of the trials. Thus the tide at the first trials was later than that at the first trials.

\[
\Delta t := \frac{\Delta s}{c T} \\
\Delta t = 0.125
\]

\[
k := 0.21
\]

\[
V_{C.2.m} := v_0
\]

\[
t_{exp_k} := -9.0 + 0.5k
\]

\[
V_{C.2.exp_k} := VC(v_2, t_{exp_k} + t_{2.m}, \omega T, t T)
\]

**Time at first trials**

\[
\text{means}_1 := \text{READPRN}("Means_1.prn")
\]

\[
\Delta t := \text{means}_1 <0>
\]

\[
t_1 := t_{1.m} + \Delta t_1
\]

\[
V_{C.1} := VC(v_2, t_1 - \Delta t_1, \omega T, t T)
\]

\[
\text{WRITEPRN}("V.C.1.prn") := V_{C.1}
\]

\[
t_{exp} := t_{exp} + t_{2.m}
\]

'Evidently the global phase correction is quite small.'

'Global' or day time at the second trial

'Store for the analysis of the data at the smaller trim.'

'Local' time at second trim
Plot current velocities at both locations

![Graph showing current velocities vs day time with different markers and labels: V_C.2, V_C.2.exp, V_C.1, V_C.2.m, t_2.exp, t_1.exp, day time in hrs.]

Ship speed thru water

![Graph showing hull speed thru water vs 'local' time with different markers and labels: V_H.2, V_G, time in hrs.]

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MS 17.06.2013 17:02 h
**Analyse power required**

**Identify power (!) 'coefficients' of environment convention**

\[
\text{Res}_{\text{req.2}} = \text{Required} \left( V_{H,2}, V_{C,2}, P_{S}, V_{W}, W \right) \\
\begin{bmatrix}
P_{S,\text{E.req.2}} & P_{S,\text{req.2}} & P_{S,\text{req.2.0}} & P_{S,\text{req.2.1}}
\end{bmatrix} = \text{Res}_{\text{req.2}}
\]

**Required power residua**

As usual the required power residua are much larger than the supplied power residua due to the uncertainties of the wind measurements and the crude wave observations.

The residua can be considered as a measure of changes of the inviroment

**Power required**

![Power required and supplied vs time](image-url)
First partial power required

This concept has formerly, misleadingly been called 'water' power.

Second partial power required

This concept has formerly, misleadingly been called 'wind and wave' power. Both concepts include additional power due to the seastate.

Power vs hull speed

at the nominal no wind and waves condition

\[
P_{S,2} := C_{PV,2} V_{H,2}^3
\]

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Powering performance

at the nominal no wind and waves condition

Power coefficient normalised

\[ C_{PV.2,n} = \frac{C_{PV.2} \cdot 10^6}{\rho \cdot D^2} \]

Identify equilibrium

\[ J := 1 \quad K := 1 \]

Given

\[ K = p_{n.20} + p_{n.21} \cdot J \]

\[ K = C_{PV.2,n} \cdot J^3 \]

Solve

\[
\begin{bmatrix}
J_{H.equil.2} \\
K_{P.equil.2}
\end{bmatrix} = \text{Find}(J, K)
\]

\[ J_{H.equil.2} = 0.695 \]

\[ K_{P.equil.2} = 0.140 \]

Results plotted

\[ k := 0 \ldots 20 \]

\[ J_{H.plt_k} := 0.45 + 0.02 \cdot k \]

\[ K_{P.sup.plt_k} := p_{n.20} + p_{n.21} \cdot J_{H.plt_k} \]

\[ K_{P.req.plt_k} := C_{PV.2,n} \cdot \left( J_{H.plt_k} \right)^3 \]

Due to the model adopted in this case the propeller is permanently operating at the same normalised condition.
Check of consistency

Frequency of shaft rev's vs hull speed
at the nominal no wind and waves condition

\[ N_{S,2} : = 1 \quad \text{initial values} \]

\[ N_{S,2} : = \text{Identify_freq}(p_{2}, V_{H,2}, P_{S,2}, N_{S,2}) \]

\[
\begin{array}{rcccccc}
\text{V}_{H,2} \text{ in m/s} & 4 & 5 & 6 & 7 & 8 & 9 \\
N_{S,2} & 1.109 & 1.262 & 1.506 & 1.763 & 1.956 & 2.019 \\
\end{array}
\]

Linear approximation

\[ A_{N,2,1} : = 1 \quad A_{N,2,1} : = V_{H,2} \]

\[ X_{N,2} : = \text{geninv}(A_{N,2}) \cdot N_{S,2} \]

\[ N_{S,E,2} : = N_{S,2} - A_{N,2} \cdot X_{N,2} \quad N_{S,E,2} \text{Conf} : = 2 \cdot \text{stdev}(N_{S,E,2}) \]

\[ X_{N,2} = \begin{bmatrix} -3.1677 \cdot 10^{-5} \\ 0.2481 \end{bmatrix} \]

\[ N_{S,E,2} \text{Conf} = 7.225 \cdot 10^{-5} \]

Per definition this result is in accordance with the nominal no wind and waves condition derived: the frequency of shaft rotation is directly proportional to the hull advance speed.

\[ C_{NV,2} : = \frac{1}{D \cdot J_{H,\text{equil},2}} \quad C_{NV,2} = 0.2481 \quad N_{S,2} : = C_{NV,2} \cdot V_{H,2} \]

\[ N_{S,2} = \begin{bmatrix} 1.109 \\ 1.262 \\ 1.506 \\ 1.763 \\ 1.956 \\ 2.019 \end{bmatrix} \]

Required power results

\[ \text{Res}_{\text{req}} : = \begin{bmatrix} P_{S,\text{req},2.0} & V_{H,2} & P_{S,\text{req},2.1} & P_{S,2} & N_{S,2} \end{bmatrix} \]

Store results

\[ \text{WRITEPRN}("\text{Res}\_\text{req}.prn") : = \text{Res}_{\text{req}} \]
Appendix

Check correlation of relative speeds of wind and hypothetical waves

\[
V_{\text{Wind.rel}} = -V_{W_i} \cos(\psi_{W_i} - \psi_{H_i}) \cdot \text{dir}(\psi_{H_i})
\]

\[
V_{\text{Sea.rel}} = V_{S} \cdot \text{dir}(\psi_{H_i}) - V_{G_i}
\]

<table>
<thead>
<tr>
<th>$V_{\text{Wind.rel}}$</th>
<th>$V_{\text{Sea.rel}}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>-7.717</td>
<td>-4.195</td>
</tr>
<tr>
<td>19.606</td>
<td>17.123</td>
</tr>
<tr>
<td>18.815</td>
<td>18.035</td>
</tr>
<tr>
<td>18.470</td>
<td>16.368</td>
</tr>
<tr>
<td>-7.867</td>
<td>-4.723</td>
</tr>
<tr>
<td>-6.565</td>
<td>-3.602</td>
</tr>
</tbody>
</table>

![Correlation of wind and wave speeds](image)

END

As first evaluated data at the second, at the larger trim, i.e. at the larger propeller submergence