Software Developing in a Distributed Environment
Exemplified for a Propeller Damping Tool

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Abstract
This paper explains on the basis of a propeller damping tool, a way of developing software within small and distributed teams of engineers. An overview will be given about the technical problem, the theoretical background and the technical need of the developed tool. Furthermore, there will be an introduction of the ship design framework E4. A focus is on the coordination between different teams of developers. There are special requirements to maintain a software framework on cross border basis of different organisations. It will be discussed, how a teamwork is possible although the involved organisations have to protect their own intellectually property.

1. Introduction

Ship design needs complex software. But in the same way as other technical products, software design requires a special knowhow. Commercial software is built by companies with big IT departments and a clear structured development strategy. An Organisation can concentrate themselves on questions of the own naval architect core competence by using such software. But the disadvantage is a limitation in flexibility. Commercial software has limitations in adapting it to special features of the own organisation. Sometimes it is very useful to implement an own physical model to analyse special technical problems which are relevant for a project.

But it is not easy to handle software projects in-house with limited resources for software engineering. Beside the physical and numerical problems, software design has to handle many pure IT tasks. Topics about data handling, communication and user interfaces are important. A concept is needed for the distribution, bug fixing and documentation of different software versions. These topics are important for a software product. But a company, which only want to use software for solving a special technical problem, has mostly not enough financial and technical resources to handle all these aspects of software engineering.

In contrast to commercial software, the ship design software E4 is a product which is developed by a group of independent partners from the maritime industry. The E4 framework is no monolithic software. It is a software system which contains many tools for different topics of ship design. Depending on the technical problem a single tool is more or less complex. Each partner is able to develop and support own tools and adopted them to their specific problems.

Propeller damping is such a problem, which shows the advantage of own software. An important question is in which way propeller damping affects propeller shaft vibrations. Prof. Schwanecke solved the interaction of hydrodynamic mass of a propeller with the blades by an analytic description of the propeller and water interaction. Beside the sophisticated physical and mathematical background, the developed model is small and easy to use. Coding in the computer language FORTRAN needs no explicit IT knowhow. The implementation has been done within the ship design framework E4 and could be realized in a short time. This was possible because all main functionality like data handling and user interface were already part of the framework and could be used by the developer.

The E4 framework is supported by a group of organisations who share their resources for software developing. In addition to someone’s own interests and situations of completion, each partner has the benefit to be able to use a software framework to realise own software projects. The main resources can be focused to solve technical problems. The necessary work for supporting the basic system is shared with the partners and reduces the effort for each partner.
2. The E4 framework and partner group

The ship design software E4, Bühr (1988), Krüger (1999), has been developed over a period of 30 years. The focus was to build a software framework for ship design. Therefore, many different types of numerical methods have been developed and integrated into this system. The framework has the task to support the design engineer, especially during the early design as described in Krüger (2003). It is a set of many different tools, which are working on the same database. This concept allows different engineers and scientists to integrate their own knowledge to the framework by developing special methods. As symbolized in Fig.1, there are different types of “first-principle methods” available. The framework has a strong modular structure. All methods can be used as single programs. For each method, permissions for sharing can be defined individually. This allows a good control over the own knowhow and an individual distribution of the own software.

![Fig.1: Principle structure of E4 ship design framework](image)

2.1 The developer structure

Within the E4 group there are partners with different requirements. Sometimes methods should be used by others people who are not the developer. Sometimes a development in cooperation is wanted. In this case source code has to be shared. For such purpose, it is necessary to exchange own developed tools. Therefore, the E4 framework needs a permission system, which allows every partner to control the distribution of the own software. Two aspects have to be taken into account:

- Software tools and/or software libraries have to be distributed as a precompiled binary package.
- Source code should be developed together with other partners.

In contrast to classical software, there is no single organisation which handles the whole developing. This means, the developing process needs a decentralized procedure. Engineers have to develop their own tools without having access to the whole framework. Consequently, it is not possible to store the complete E4 framework on a single source code control system.

Corresponding to the decentralized approach, every partner has the ability to use an own subversion server for the source code of their tools. Fig.2 shows the structure of the E4 marketplace and developing environment. Although the framework operates totally decentralized, the TUHH offers some services for the community. Not every partner has the resources and/or knowhow to run an own server. In such a case, it can be hosted by the TUHH. Additionally, a central build and testing server has been implemented. Sometimes a partner has an agreement with another partner for using the software without having access to the source code. In such a case, it is necessary to distribute parts of the E4 framework as a binary package. Every partner is free to exchange own software with each other as one like. Consequently, the needed binary packages are different for every partner. The TUHH as a neutral non-commercial partner has access to all source code of tools which should be exchanged within the E4 community. The process of configuring and compiling has been automatized.
by server called “Build-Bot”. This Build-Bot has the task to control every change within the source code, whether it is correct or not. Now two compilers are used for checking the source code. First the open source GNU-Fortran compiler is used. This compiler has the advantage of being very critical. It can be configured to control many aspects of modern FORTRAN and to give warnings about discrepancies to the standardization. As a second compiler we use a commercial compiler for packaging. The optimization features are much better. The combination of both compilers has the advantage to have a good control about the quality of the source code in combination with a highly optimized method for the user of the distributed tool.

Beside the advantage of having control over the own developments, the decentralized approach has the disadvantage of a more complex environment. Every partner has different access to source code and binary files. Fig.3 shows a typical structure. An engineer needs to check out a set of different source code repositories. Additionally, often binary libraries are needed. The source code will be synchronized by subversion and the libraries have to be downloaded from the Update Server of TUHH.

The configuration of permissions is handled by text files stored in the config-directory of each subversion server. Each partner can define which libraries and methods are distributed to which other partners. The permission system is based on a simple set of rules. Every source code directory can be characterized by four flags.
• The “read” flag allows to get read access to the source code directory.
• The “write” flag allows to get write access to the source code directory.
• The “binary” flag allows to get a precompiled binary file of the specified library or method.
• The “documentation” flag allows to get access to the documentation of the specified library or method.

This mechanism of permission files allows an infrastructure where different partners can cooperate in an individual way. Each partner can focus on their own task. Basic functionality of the E4 framework is stored in a special repository, which is open for the community. This repository contains the primary functionality. Libraries for reading and writing data, GUI and basic naval architect functionality are in this open pool. This pool is supported in cooperation by the group. In this way, restricted resources can be used more efficient for such a task which is not part of the core business. The main resources can be investigated in the not public parts of special naval architect tools. If and under which conditions an own development should be shared, can be decided later on.

3. Method of propeller damping calculation

Now it should be explained in which way such a framework can be used for special developments. The actual trend to operate vessels in the so-called slow-steaming mode has posed a lot of complex problems to the naval architects, as the ships operate far away from their design condition. This is of most importance for the operation of the engine and the propeller. When the propulsion system is operated at low revolutions, it is at the same time operated closer to the torsional vibration resonance, because the drive train is designed with a resonance frequency at low revolutions. During run up or slow down, a so called barred speed range is passed to avoid permanent operation close to the resonance. As a consequence, the layout of the drive train with respect to torsional vibrations must be carried out taking this operational boundary condition into account. With respect to torsional vibrations, the propeller – besides the engine – is the main source of excitation as well as the most important damper of the drive train. Furthermore, the mass moment of inertia of propeller – including the so called added mass moment of inertia (MOI) due to forces of the entrained water – dominates the resonance frequency of the drive train. To compute hydrodynamic damping, there are some semi-empirical theories available, where the most advanced method was developed by Schwanecke and Grim. Even though there was a significant development in both numerical and experimental techniques, there are no such applications used for the calculation of propeller damping. Steen (2015) has reported that RANS applications can presently not be used to predict propeller damping due to numerical difficulties, and also model tests failed to properly predict propeller damping. Consequently, there are only a very few publications which deal with this problem. Additionally, only a few full-scale measurements are available for this problem. For these reasons, the authors have chosen to investigate the Grim/Schwanecke method.

The theory of Schwanecke and Grim is based on the established theory of the oscillating airfoil. As the practical application of the theory published by Schwanecke and Grim resulted in complex and time consuming computations, Grim and Schwanecke had introduced some simplifications into the theory. This resulted in quite simple formulae which allowed the computation of hydrodynamic damping and added mass or MOI in an easy way for all six degrees of freedom. However, since these developments screw propellers have been subject to a continuous development, where the aim was mainly to reduce pressure pulses and to increase the efficiency. The most important developments were the introduction of the propeller skew and the application of radially nonuniform pitch distributions. Both measures were intended to increase the comfort level of modern propellers, posing the difficulty to the propeller designers to keep the efficiency at least constant. This resulted in more cambered propeller profiles and lower blade area ratios. All these developments have not been foreseen by the simplified formulae published by Schwanecke and Grim.

Due to the new operational challenges of the ships, propeller damping and added MOI have to be computed more accurately, while at the same time it is not clear whether the simplified formulae
published in 1963, 1973 and 1983, respectively, are still able to cope with modern screw propellers. As computational power is not a problem anymore, it was found useful by the authors to reformulate the original theory by Schwanecke and Grim in the context of an updated lifting line model for modern screw propellers. If this has once been done, it is also possible to analyze the propeller in the wake field of a modern ship design in any propulsion condition. It is then further possible to analyze controllable pitch propellers in off-design pitch conditions, too.

3.1. Harmonic forces acting on an oscillating hydrofoil of infinite span

An airfoil of infinite span in a parallel inflow $U$ is exposed to harmonic lateral or rotational oscillations of the amplitudes $\varepsilon_A$ or $\varphi_a$. The motion equations read:

$$
\varepsilon = \varepsilon_A \cdot e^{i\omega t} \quad \text{resp.} \quad \varphi = \varphi_a \cdot e^{i\omega t} \tag{1}
$$

Assuming the transversal velocities to be small compared to the inflow velocity $U$, the problem becomes independent from the mean angle of attack of the airfoil as well as from the thickness of the airfoil. The harmonic hydrodynamic forces $L$ rectangular to the parallel inflow can be obtained from the theory of conformal mapping as follows Grim (1983), Karman (1938), Küssner (1936):

$$
L_\varepsilon = -\frac{c_A'}{2} \rho l U \varepsilon \left( \frac{k}{2} + C(k) \right) \quad \text{resp.} \quad L_\varphi = -\frac{c_A'}{2} \rho l U^2 \varphi \left( \frac{k}{2} + \left(1 + \frac{ik}{2} \cdot C(k)\right) \right) \tag{2}
$$

In Eqn. 2, $L_\varepsilon$ denotes the harmonic lift forces due to the lateral motion, $L_\varphi$ due to the rotational motion. In Eqn. (2) $c$ denotes the chord length of the airfoil, $U$ the inflow velocity and $\rho$ the density of the fluid. $c_A'$ denotes the gradient of the lift coefficient, which theoretically amounts to $2\pi$. In practice, values between $(0.87 \ldots 0.93) \cdot 2\pi$ are obtained. $k$ is the nondimensional frequency of the oscillation and it is defined as

$$
k = \frac{\omega c}{2U} \tag{3}
$$

$C(k)$ is a complex function which is shown in Fig.4, right. From Fig.4 and Eqn. (2) the fact can be derived that the magnitude of the harmonic hydrodynamic forces actually depends on the frequency of the oscillation. From Fig.4 it can also be seen that the imaginary part $C(k)$ becomes zero if $k$ equals either zero or infinite. If $k = 0$, the problem becomes stationary, and with $C(k = 0) = 1$ the stationary solution for the profile lift is obtained, Grim (1983). If on the other hand the reduced frequency $k$ becomes large enough, the oscillating lift forces do also become independent from $k$ as the imaginary part vanishes and $C(k = \infty) = 0.5$. For the screw propeller this means that the frequency of the oscillation $\omega$ must be sufficiently large against the inflow velocity $U$. If we assume an aspect ratio of $c/D = 0.25$ for a modern screw propeller blade, where $c$ is the mean chord length of the propeller blade and $D$ the propeller diameter, and if we introduce the advance ratio $J = \nu/(nD)$ into Eqn. (3), we obtain $c/D = 0.25 K = 0.785 N/J$, where $N$ is the order of the oscillation with respect to the number of revolutions. We can therefore conclude that for a screw propeller, the harmonic forces due to torsional vibrations are practically independent from the vibration frequency.
If we assume a four-bladed propeller operating at an advance ratio \( J \) of about 0.8, \( k \) becomes about 4, and from Fig.4(right), the fact can be derived that this condition is close to the vanishing of the imaginary part of \( C(k) \), which is equivalent to the fact that the harmonic forces become independent from the frequency of the oscillation.

### 3.2. Harmonic forces acting on a propeller blade

Fig.5 (left) shows the inflow condition to the blade of a screw propeller. The direction of the flow with the velocity \( U_I \) is given by the hydrodynamic pitch angle \( \beta_I \). \( U_I \) is the vector sum of the rotational speed of the blade section \( \omega_r \), the (local) inflow velocity \( V_A \) and the sum of the propeller induced velocities, here denoted by \( U_N \). The angle of attack of the blade is given by the difference of the blade angle (\( \delta \)) and the hydrodynamic pitch angle \( \beta_I \). For the moment, it is assumed that the flow around the propeller blade is 2d, so that the formulae for the foil of infinite span (Eqns. (1) and (2)) can be applied. The propeller blade now performs a harmonic torsional oscillation. For the resulting hydrodynamic force element, the component rectangular to the inflow velocity \( U_I \) is relevant, which means that all translational force elements have to be multiplied with \( \cos(\beta_I) \), and all rotational elements with \( -\sin(\beta_I) \). From Eqn. (2), we obtain for the torsional harmonic moment due to a torsional oscillation by integration over the propeller radius:

\[
M_{\psi \phi} = -\frac{c'_a}{2} \rho N \int_{r=R_N}^{R_a} r^2 \left( \frac{\dot{\varphi}}{2} + c_u U \right) \sin^2(\beta_I) \cdot dr
\]

(4)

In Eqn. (4), \( N \) denotes the number of blades of the Propeller. Eqn. (4) now includes terms which depend on the first time derivative of \( \varphi \); they can be interpreted as damping terms. Terms depending on the second time derivative of \( \varphi \) can be interpreted as inertia terms. If we use the notation introduced by Schwanecke (1973, 1963), then we obtain the hydrodynamic damping \( b_{\psi \phi} \) and the hydrodynamic MOI of the propeller \( a_{\psi \phi} \) from the radial integration of all force elements, 

\[
a_{\psi \phi} = -c_{stat} \cdot c_{AR} \cdot \frac{c'_a}{4} \rho N \int_{r=R_N}^{R_a} r^2 \frac{c^2}{2} \sin^2(\beta_I) \cdot dr
\]

(5)

\[
b_{\psi \phi} = -c_{stat} \cdot c_{AR} \cdot \frac{c'_a}{4} \rho N \int_{r=R_N}^{R_a} r^2 c_u \sin^2(\beta_I) \cdot dr
\]

(6)

In Eqns. (5) and (6) \( R_N \) denotes the hub radius and \( R_a \) the half of the propeller diameter. Eqn. (4) has been developed assuming a purely 2d flow around the propeller blade. Therefore, corrections have to be made for the foil of finite span in Eqns. (5) and (6). This has been accounted for by introducing the correction factors \( C_{stat} \) and \( C_{AR} \). \( C_{stat} \) takes into account the fact that the 3d flow around the propeller blade leads to a reduction of the effective angle of attack and therefore to a reduction of the stationary propeller thrust and torque. \( C_{stat} \) can be computed for each propeller e.g. by using the lifting line method (see below). As a rough approximation, Schwanecke has proposed a \( C_{stat} \) value of...
0.85 Schwanecke (1973,1963). \( C_{AR} \) takes into account that also the harmonic oscillatory forces of the propeller are subject to a reduction by 3d flow effects. This has been computed by Breslin (1970), and values for \( C_{AR} \) can be taken from Fig.6(right), Grim (1983). In this diagram, \( Z \) denotes the number of blades, and \( A_e/A_0 \) is the expanded area ratio of the propeller. \( r_0 \) denotes the hub radius of the propeller and \( n \) is the order of vibration. Except for the correction of \( c_1^k \); viscous effects have not been included in the theory so far, because the viscous influence is known to be small. However, Isay (1963) showed that the influence of the viscosity on the torque of a screw propeller can be included by multiplying the radial torque coefficient with \( (1 + \epsilon \cot(\beta)) \), where \( \epsilon \) is the lift/drag ratio of the profile at the given (mean) angle of attack. In this sense, Eqns. (5) and (6) can be corrected accordingly.

After some simplifications and some assumptions for the propeller blade geometry, the inflow velocity and the hydrodynamic pitch angle, the following simple formulae have been obtained for \( a^\psi \phi \) and \( b^\psi \phi \) by Schwanecke and Grim:

\[
\begin{align*}
  a^\psi \phi &= -c_a \cdot \frac{\rho D^5}{N \pi} \left( \frac{P}{D} \right)^2 \left( \frac{A_e}{A_0} \right)^2 \\
  b^\psi \phi &= -c_b \cdot \frac{\rho D^5}{\pi} \left( \frac{P}{D} \right)^2 \frac{A_e}{A_0}
\end{align*}
\]

Schwanecke (1973) has proposed values for \( c_a \) and \( c_b \) of 0.0703 and 0.0231, respectively. In a later publication, Grim (1983) revised these values to 0.052 and 0.017, and also later publications by Schwanecke mention these revised values. In Eqns. (7) and (8), \( P/D \) means the pitch/diameter ratio of the propeller. This is often given at 0.7R, and this value is at the same time the maximum \( P/D \) of the propeller. In the sense of Eqn. (7) and (8), the correct mean pitch of the propeller could be used instead of the maximum pitch at about 0.7R. It must further be understood that these formulae are not applicable for controllable pitch propellers in off-design pitch conditions.

Nevertheless, it is of course possible to directly solve the Eqns. (5) and (6) for any screw propeller. This requires the exact computation of the (local) inflow velocity of the propeller and the hydrodynamic pitch angle. Both require the calculation of the propeller induced velocities denoted by \( U_q \). \( U_q \) is the vector sum of the axial induced velocity \( U_0 \) and the circumferential velocity \( V_q \). Both can be computed by means of the lifting line theory with sufficient accuracy. This is at first done for the stationary propeller inflow, Isay (1963), Karman (1938), Krüger (1998).

### 3.3. Stationary lifting line theory

From Biot-Savart’s law, the vortex induced velocities can be computed for any propeller assuming that the free vortex sheets are located on regular helices of constant pitch \( k_0 \) by the following integral-differential equations, expressed in cylindrical coordinates \((x,r)\):

\[
\begin{align*}
  u_q(x,r) &= \frac{1}{4\pi} \sum_{n=0}^{N-1} \int_{s=R} \frac{d\Gamma(s)}{ds} \left. \frac{d\psi}{ds} \right|_{s=0} \left( r \cos(\phi-\phi_0-\frac{2\pi n}{N}) - s \right) d\psi ds \\
  v_q(x,r) &= \frac{1}{4\pi} \sum_{n=0}^{N-1} \int_{s=R} \frac{d\Gamma(s)}{ds} \left. \frac{d\psi}{ds} \right|_{s=0} \left( s \cos(\phi-\phi_0-\frac{2\pi n}{N}) - r \psi \sin(\phi-\phi_0-\frac{2\pi n}{N}) \right) k_0 d\psi ds
\end{align*}
\]

In Eqns. (9) and (10), \( N \) denotes the number of propeller blades where \( \phi_0 \) is the phase angle of the key blade. \( \Gamma(s) \) denotes the radial distribution of the bounded vortex circulation representing the propeller blade, and according to Helmholtz’ law of vortex conservation, \( d\Gamma(s)/ds \) is the vortex strength of a free vortex thread starting at the radial position \( s \) at the bounded vortex. It should be
noted that the integrand becomes singular if the collocation point coincides with a vortex point, which means that the velocity is to be computed exactly in the free vortex surface. A detailed mathematical discussion of these singularities was treated by Isay (1963) and Lerbs (1955).

For the computation of the propeller damping and added MOI, it is sufficient to compute the circular average of the propeller induced velocities. Further it is sufficient to compute these averaged velocities on the key blade at the position of the bounded vortex. In this case, Eqns. (9) and (10) simplify to:

\[
\begin{align*}
    u_Q &= \frac{r \cdot N \Gamma}{k_0} \frac{1}{4\pi r \kappa} \\
    v_Q &= -\frac{N \Gamma}{4\pi r \kappa} \frac{1}{k_0}
\end{align*}
\]  

In Eqns. (11) and (12), \( \kappa \) is the Goldstein Factor which can be taken from Isay (1963) or from Lerbs (1955). Now it is possible to compute the hydrodynamic pitch angle \( \beta_1 \) and the inflow velocity \( U_1 \) if the radial distribution of the circulation distribution of the bounded vortex \( \Gamma(r) \) is known. According to the law of Kutta-Joukowski, we obtain for the radial circulation distribution:

\[
\Gamma(r) = c'_a \frac{c}{2} U \sin(\delta_0 - \beta_1)
\] 

From Fig.5 (left), we obtain for the composition of the inflow velocities:

\[
\begin{align*}
    U \cos(\beta_1) &= \omega r + v_Q \\
    U \sin(\beta_1) &= u_0 + u_Q
\end{align*}
\]

Introducing Eqns. (14) and (15) in (13) using Eqns. (11) and (12) at the same time, we obtain for the radial circulation distribution \( \Gamma(r) \):

\[
\Gamma(r) = \frac{\omega r \tan(\delta_0) - u_0}{2 \left( c'_a c \cos(\delta_0) \right) + \frac{1}{4\pi \kappa} \left( \tan(\delta_0) + \frac{r}{k_0} \right)}
\] 

The pitch of the free vortex sheets \( k_0 \) can be computed from the hydrodynamic pitch angle as follows, see also. Fig.5, left:

\[
k_0 = r \tan(\beta_1) = r \frac{u_0 + u_Q}{\omega r + v_Q}
\]

Using Eqn. (17), Eqn. (16) can be solved iteratively. For the 1st iteration, \( u_Q \) and \( v_Q \) are set to zero. This allows to compute the Goldstein factor \( \kappa \) and the circulation distribution \( \Gamma(r) \). With \( \Gamma(r) \) the induced velocities \( u_Q \) and \( v_Q \) are determined. Using these values for the induced velocities, the next iteration for \( k_0 \) is obtained. The computation usually converges after about 20 iterations. Although the theory requires that the free vortices are located on regular helices having a constant pitch \( k_0 = r \cdot \tan(\beta_1) \) which requires light propeller loading, it was found by many authors that the results are also acceptable when the free vortex sheets are significantly deformed, which coincides with a heavy loading of the propeller. From the results of Eqns. (16) and (17) it is now possible to compute the hydrodynamic propeller damping and the added MOI according to Eqns. (5) and (6).
3.4. corrections for modern propeller designs

So far, no corrections for the 3d flow have been made in the lifting line theory. These need to be considered now, as damping and added MOI for modern propeller designs shall be computed. Two major corrections should be made to the theory to better cope with modern propeller designs:

- A correction which considers the propeller skew.
- A correction which considers the reduction of the angle of attack due to the three-dimensional flow around the propeller blade.

Weissinger (1949) and Gersten (1961) have developed a nonlinear lifting line theory for airfoils. As many practical airfoils are inclined by the so-called sweep angle $\theta$, Weissinger has found that the lift of an airfoil is decreased when the foil is inclined by a sweep angle. This is because, due to the inclination of the foil in direction of the flow, longitudinal vortices occur, inducing velocities which decrease the effective angle of attack of the foil. The lower the aspect ratio of the foil, the larger is the lift reduction. From the complex theory, Weissinger has developed the following simplified formula to account for the sweep angle of the foil:

$$
\frac{c_{a,\theta}'}{c_a'} = \frac{\Lambda + 2}{\Lambda \cos(\theta) + 2}
$$

In Eqn. (18), $\Lambda$ denotes the aspect ratio of the foil, the ratio on the left side of Eqn. (18) expresses the lift gradient of a foil with nonzero sweep angle and the lift gradient of a foil with a sweep angle. Eqn. (18) can be applied now to a screw propeller if the sweep angle is computed from the difference of the maximum skew angle (usually at the blade tip) and the minimum skew angle (usually at the hub). The aspect ratio of the blade can be obtained from the averaged chord length $c$ of the blade and the difference between $R_A$ and $R_{Hub}$. The reduction ratio according to Eqn. (18) is computed once in our method and then applied to the $ca'$-values of all radii.

Lerbs (1955) pointed out that the 3d flow around the propeller blade reduces the effective profile camber. Consequently, the geometrical profile camber needs to be reduced. This artificial correction of the effective camber would result in a corrected zero lift angle of each profile. As the blade angle $\delta_0$ is measured against the zero lift axis of each profile, it is equivalent to correct the local blade angle $\delta_0$ accordingly. This correction must be considered during the application of Eqn. (16) to obtain the corrected circulation distribution. At the same time, the hydrodynamic pitch angle $\beta_I$ needs to be increased accordingly in Eqns. (5) and (6). Lerbs (1955) has suggested the following relationship for the effective angle of attack in 3d flow $\alpha_{3D}$, where $\alpha = \delta_0 - \beta_I$:

$$
\frac{\alpha_{2D}}{\alpha_{3D}} = F_1 \left( \frac{r}{R_a} \right) \cdot F_2 \left( \frac{r}{A_a}, \frac{A_e}{A_0} \right) \cdot F_3 \left( \frac{A_e}{A_0}, J \right)
$$

F1 and F2 can immediately be taken from the original publication from Lerbs (1955). F3 was recalculated for the purpose of the present analysis. The calculation procedure was such that for a series of selected propellers of the Wageningen B-Series, the value of F3 was adjusted in such a way that the measured propeller thrust was exactly met. This was done to better compare the values we have obtained with the results of Lerbs. During the computation of F3, a correction for the propeller skew according to Eqn. (18) was also not made to keep the results comparable. The resulting values of F3 are shown in Fig.6, left. Like in the original publication by Lerbs, we have made the values of F3 dimensionless with those obtained for $J=0.4$. In addition, we have extended the computations for the $J$-values 0.0 and 1.0. The comparison of Fig.6, left, with the original data published by Lerbs (1955) shows a good agreement.
3.5. The screw propeller behind the ship

Hydrodynamic propeller damping and added MOI can be computed using Eqns. (5) and (6) if beforehand the propeller inflow conditions have been computed, using Eqns. (16) and (17). However, these computations require the propeller rpm and the propeller inflow condition as an input. These can only be computed if the propulsion condition of the ship is known. At a given floating condition and ship speed, the ship has a specific resistance $R_T$, which also may include additional resistances due to environmental conditions. The revolutions of the propeller must now fulfill the propulsion equilibrium condition, which means that the propeller thrust $T$ must equal the sum of ship resistance $R_T$ and thrust deduction, $T \cdot (1 - t) = R_T$. The inflow condition to the propeller for the stationary case is defined as $V_A = V_S \cdot (1 - w)$, where $w$ is the effective wake fraction, typically obtained from a model test. It will later be shown that the wake distribution has a small effect on the damping only and can therefore be taken into account by the relative rotative efficiency. The calculation procedure for each calculation speed is as follows:

- Determine the ship resistance $R_T$ for the actual floating condition and environmental conditions
- Determine thrust deduction fraction $t$ and effective wake fraction $w$
- Find the rpm of the propeller which fulfills the propulsion equilibrium $T \cdot (1 - t) = R_T$
- For the computed combination of ship speed and propeller revolutions, solve Eqn. (16) iteratively.
- Then solve Eqns. (5) and (6) to obtain the propeller damping and added MOI.

If the propeller is a controllable pitch propeller (CPP), the propulsion equilibrium must be obtained from the correct combination of pitch setting and rpm, which must be taken from the ship’s propulsion control system settings.

For the screw propeller behind the ship, the values obtained for damping and added MOI should theoretically be corrected for the relative rotative efficiency ($\eta_R$) of the ship, as $\eta_R$ expresses the relationship of the propeller torque behind the ship compared to the J-equivalent open water condition. However, as $\eta_R$ is typically close to 1 for the cases examined below, this effect was neglected.

3.6. Validation

Full-scale Measurements of propeller damping are difficult to conduct and they are therefore very rare. Additionally, many of the data are confidential and therefore difficult to obtain. For the purpose of the present analysis, measured data are fortunately available from sea trial measurements. The
validation has been published in Krüger S. (2017). The propeller is a fixed pitch propeller with four blades, diameter 6m, area ratio 0.5, pitch ratio (at 0.7R) 0.7. The measurements by Orthmann (2017) and the computations are shown in Fig. 7. The black curves show the results for the presented method, for reasons of comparison the results obtained from the GRIM method are shown.

4. Conclusion

The development of software tools is often necessary, if special technical problems have to be solved. The presented lifting line model allows the computation of hydrodynamic damping and added MOI for any type of screw propeller. The proposed method is based on the theory on propeller damping published by Schwanecke and Grim, who have applied well established methods from the airfoil theory to the screw propeller. Both authors also have developed simplified formulae to avoid the complex computation of the propeller inflow conditions.

Besides the complex physical modelling, the implementation of software needs special knowhow and a lot of human resources. For many organizations, it is not possible to provide such resources alone. A sharing of resources for pure IT tasks is useful, because a cooperation in this topic means no loss of own intellectual property. The E4 framework bases on a grid of individual source code servers. The access to these servers can be configured by every partner self. Standard functionality is stored in a special repository and is supported in cooperation for the whole group of partners. Further a central server exists for checking the software and for assembling binary software packages. This approach of a distributed software development allow sharing resources by still keeping control about the own intellectual property.

References


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