Design guidelines and empirical evaluation tools for inland ships

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ABSTRACT

For inland ships, state-of-the-art hull form design is to a large extent based on experience, common sense, or adjusting previous designs. The idea therefore arises that further optimization is possible if the right knowledge is available. This knowledge is insufficiently available due to two main reasons. First, research into inland ship optimization is usually omitted from the design process due to the high cost compared to the design budget. This has led to a lack of fundamental knowledge about the complex hydrodynamics around the hull of an inland ship. Second, as a consequence of omitting optimization research, adequate empirical power prediction methods have not been developed for inland ships due to the lack of data.

In the Top Ships project, effort is put in the development of an empirical method for inland ship power estimation as well as the derivation of design guidelines. Both should aid designers in the process of a new ship's design. The present paper gives an overview of available information from literature that aids to design of inland ships. Design guidelines and power prediction methods that relate to the design of a new inland ship are presented and discussed. The conclusions emerging from this review lead to the choice of focus in the Top Ships project. Therefore an introduction, the approach and intended results of this project are briefly presented as well.

Keywords: inland ships, literature review, shallow water, ship resistance, inland ship improvements

1. INTRODUCTION

In several European countries, inland ships play an important role in overall cargo transport [Vries, 2013, pp. 18]. Improving these ships therefore can have a significant impact on fuel consumption and emission of pollutants. Also, it gives them a better competitive position against other transport modalities.

The present paper addresses the improvement of the hull form of inland ships. To do this, sufficient knowledge as well as adequate tools are required, especially given the fact that inland ships frequently encounter shallow water with its complex hydrodynamics. To aid in the design of a good inland vessel, designers can make use of (empirical) ship evaluation tools, power prediction tools, design guidelines, model tests and software packages regarding computational fluid dynamics. However, as the design budget for inland ships is relatively low (especially when compared to that for sea-going ships), designers mostly use design guidelines or empirical methods, apart from their own experience, to design an inland ship.

Unfortunately, these design guidelines are not widely available or simply hard to find. Reasons for this are that research on inland ships is usually published in the native language of the author [Hekkenberg, 2013, pp. 198], and some works are not digitally available. The present paper therefore gives an overview of available design guidelines, (empirical) analysis and power prediction tools that can be used in designing an optimized inland ship. The work also provides a frame of focus for a further research project on inland ship optimization, to which an introduction is presented as well.

The next section provides an overview of design guidelines for the design of the ship bow, stern and selection of a sufficient set of main dimensions. Section three presents various methods to estimate resistance and required power for propulsion, including the effects of shallow water. The fourth section summarizes the observations made in the review of literature and gives an introduction to the Top Ships project, which has been initiated to improve tools and methods for inland ship design. Last, the fifth section concludes with the most important findings in this work.

2. Design Guidelines

Design guidelines available from literature consist of schematic drawings, notes on specific design aspects and proposed limits for certain ship-related parameters. This section gives an overview of available information on design guidelines and is split in three parts. These parts respectively describe design guidelines considering the ship's main dimensions, bow shape design and finally stern shape design.

2.1. Main dimensions

From analysis of inland ship main dimensions, Hekkenberg found that roughly 42 percent of European inland ships built over the last 20 years have a length and width of 110 and 11.45 meters respectively, which correspond to the upper limits of European class Va waterways [Hekkenberg, 2013, p. 16]. This shows that the main dimensions of inland ships are strongly influenced by their navigable area. That maximizing the main dimensions up to a certain fairway's dimensional limits is not always the best solution from an economical point of view, is further pointed out in the work of Hekkenberg.

From an hydrodynamic point of view, it is commonly concluded that a longer vessel is more efficient. In research reports on the development of an efficient inland vessel for the Danube River, a long vessel ($10 < L/B < 12$) is mentioned to be up to 20 percent more efficient than a beamy vessel ($7 < L/B < 9$) [DPC, 2004, p. 20]. Heuser also shows that increasing the L/B ratio leads to lower specific resistance (R_T/Δ) [Heuser, 1986, p.63], up to L/B values of 18 above which the specific resistance remains nearly constant. Although the graph presented by Heuser is derived on basis of shallow-water tests as well, Luthra states the opposite. According to Luthra, a wider ship is preferable over a long and slender ship if the ship is designed for navigation in shallow water. Similar statements are made by Hofman and Kozarski [Hofman and Kozarski, 2000], who show that a decrease of the h/L ratio (increase of length at fixed water depth) could result in the ship sailing in a critical region with high resistance. Still, the idea of increasing length to obtain a more efficient ship is correct from physical point of view as well. If the bow and stern region mostly contribute to wave and viscous pressure resistance, increasing the length (by enlarging the midship region) only leads to an significant increase of frictional resistance (as a consequence of almost linearly increasing the wetted surface S), without seriously affecting other resistance components. As long as frictional resistance does not have a 100 percent share of total resistance, increasing the ship's length will decrease the specific resistance R_T/Δ.

2.2. Bow region

Considering the design of the ship bow, the designer can choose between several bow shape types. Over the years, a variety of bow forms have been applied to inland ships [Heuser, 1987]. The pontoon-shaped (or shovel) bow, mostly used before 1970 thanks to its simple construction and hence low building cost, is less frequently applied now due to significantly higher resistance in shallow water [Zöllner, 1991, Nussbaum,

1979]. For deep water, the choice of bow shape type is less important as differences in resistance are usually small [Latorre and Ashcroft, 1981]. According to Heuser, the U-shaped bow form is best to use as long as the required bow block coefficient is not too large. In most cases, the V-shaped bow is the best solution for inland ships [Heuser, 1994].

Heuser presents a set of guidelines to design the bow in more detail as well. These guidelines correspond to the bow region length (L_B) as well as the bow region block coefficient ($C_{B\text{-}B}$). These guidelines are presented in [Heuser, 1986].

For the V-shaped bow, Landgraf shows that the application of a bulbous bow leads to a propulsion power decrease up to 20 percent at a speed of 12 km/h for a Class Va ship (L x B x T = 110 x 11.40 x 3.5) [Landgraf, 1990]. However, he notes that the advantage of the bulbous bow quickly diminishes at a draught different from the design draught. Apart from the ship's draught, the water depth (especially keel clearance) also has a significant effect on the usefulness of the bulb. For inland ships, which often sail with different draughts and cope with a wide variety of water depths, the bulbous bow therefore appears to be less useful.

2.3. Stern region

Compared to the bow region, the stern region hull design is far more complex. This is due to the propellers and the tunnel geometry, the last of which is commonly applied in order to improve the bow towards the propeller (thereby preventing from vibrations, ventilation or providing room for a larger propeller). Considering the overall stern shape, there exist a wide variation of designs. Several new ship designs are outfitted with the pram-shaped stern without tunnels, but the pram-shaped stern is also used in combination with tunnels. Most inland ships have a V-shaped stern, usually in combination with a tunnel geometry. This V-shaped stern is mostly combined with a single or double propeller configuration, but in some cases three or even four propellers are applied [Zöllner, 2006].

Specifically for the classical V-shaped stern with one or two propellers, Heuser proposed a set of design guidelines [Heuser, 1994, 1986]. As a decisive guideline for the choice between one and two propellers, Heuser states that a ship with a width exceeding 12 meters should be equipped with at least two propellers [Heuser, 1986, p. 21]. In case of a two-propeller ship, Heuser advises to design the stern such that the propeller shafts converge towards the transom [Heuser, 1986, p. 21]. This results in the flow at the propeller plane being better aligned with the propeller outflow, so that less energy is lost in redirecting the flow. Furthermore, the application of converging propeller shafts offers some advantages regarding ship manoeuvring. Similar to the guidelines for the bow shape, Heuser presents a set of design guidelines regarding the stern block coefficient ($C_{B\text{-}S}$), propeller longitudinal position and the length of the stern (L_S) [Heuser, 1986].

The pram-shaped stern is applied less often to self-propelled inland ships. Although it is less complex to construct and provides significant freedom for propeller and rudder configuration, the choice for a pram-shaped stern is less favorable in shallow water according to Von der Stein [Stein, 1986, p. 108].

When considering a classical V-shaped stern, the tunnel geometry is of significant importance to the overall ship performance. According to a document from between 1960 and 1980 (of which the source is not identified) [Unspecified Author, 1980], the tunnel is required to ensure the ship is sufficiently capable of manoeuvring in unloaded conditions. When in loaded condition, the tunnel may improve the propeller inflow but also increases the ship's resistance and demand for propulsion power. Therefore, a good

design of the tunnel geometry is important [Unspecified Author, 1980]. A few guidelines on tunnel construction have been proposed by Heuser. He mentions that at the propeller position, the tunnel radius (assuming the tunnel is circular) should equal the propeller diameter, while the tunnel circle center is located at the propeller plane bottom. Together with the advised block coefficient for the stern ($C_{B\text{-}S}$), a rough design guideline is proposed for the tunnel geometry. Few more detailed guidelines have been published in the document mentioned above, including the note of preventing a change of flow direction just before the propeller, as well as the minimum draught of the tunnel border at the propeller position as well as the increase of minimum draught of the tunnel towards the bow. In this publication, the tunnel radius at propeller position is advised to be equal the propeller diameter, similar to the advice of Heuser [Heuser, 1986].

For pram-shaped sterns, tunnels can be applied as well. Guidelines regarding the tunnel design of pram-shaped sterns are mostly developed for use with pushers, which have regularly been outfitted with a pram-shaped stern. An extensive overview of design guidelines available for the tunnels at pushers is given by van Terwisga in [Terwisga, 1989]. The guidelines are fairly detailed and based on experience. For the pram-shaped stern, the addition of the skeg may be important regarding course stability as well as providing extra support when docking. Various skeg types have been investigated by Lee and Kim [Lee and Kim, 2004]. According to their results the mariner-type skeg performs best in most cases, except for higher velocities. Then, an asymmetrical skeg (double skeg configuration) type becomes superior. Similar results are shown by Latorre and Ashcroft in their study on barge resistance [Latorre and Ashcroft, 1981]. The importance of a good skeg design is underlined by Holtrop, who states that the addition skeg leads to a significant increase of overall ship resistance [Holtrop, 1990].

2.4. Conclusions on design guidelines

This chapter discussed various design guidelines regarding the design of an efficient inland ship, aiming at resistance and propulsion. Design guidelines on ship manoeuvring are not included. The guidelines available from literature are mostly aimed at pushers (of which a variety is discussed in [Terwisga, 1989]). For self-propelled inland cargo vessels, design guidelines are scarce. Adding to that, design guidelines meant for self-propelled vessels are very rough as well, and do not provide much detail.

The design guidelines for self-propelled cargo vessels can be used to choose between a single-propeller or a double-propeller ship, and they provide guidance on certain design aspects of the ship hull. However, even if a designer would follow the guidelines strictly, he can still design anything from a very bad ship to a good, well performing ship. In order to ensure that designers have adequate guidelines to design a well performing ship, the design guidelines should be extended with further detail on various design aspects.

3. Methods for analysis and prediction of performance

Whereas the previous chapter discussed various design guidelines that can be applied in ship design, this chapter discusses methods that can be used to evaluate the inland ship's performance. Evaluation methods or power prediction methods can be used to test the performance of the ship in an initial design stage. In this way, the designer can make a trade-off between cargo capacity or efficiency, for example.

One method to evaluate a ship's performance is to estimate its resistance for deep water, then correct this for the effects of shallow water (if any). The propulsion factors can be obtained from the resistance estimation or from a separate method, and these factors can then be used in combination with a set of propeller series polynomials to obtain the required power P_D being delivered to the propeller shaft. From this, the hydrodynamic transport efficiency factor can be computed. In order to exclude the influence of the engine's fuel efficiency this factor, $(CC \times V_S) / P_D$ is used, in which CC is the cargo capacity, V_S is the speed and P_D is the power delivered to the propeller shafts [Heuser, 1994].

Apart from the method described above, which is a fairly traditional method for performance evaluation, an alternative method to evaluate the ship's propulsive performance is developed by Simíc [Simíc and Radojčić, 2013]. He set up a mathematical model which determines the required propulsion power for a self-propelled inland ship based on model and real-world test results. The model inputs are main dimensions, ship speed and fairway restrictions (width and depth). The goal of this model is to determine the EEDI (Energy Efficiency Design Index) for a new inland ship.

3.1. Prediction of resistance

There exists a wide variety of methods to predict a ship's resistance, each of them having it's specific range of application. Probably the most widely used method is that of Holtrop and Mennen [Holtrop, 1977]. It has been revised several times through new publications, and also includes methods to evaluate the performance of ships equipped with a pram shaped stern [Holtrop, 1984]. In the 1977 publication, the method is mentioned to include results from ships with L/B ratios 6.0 up to 9.5, of which the maximum value is common for inland ships. However, this range applies to the container ships included in the method only, and their prismatic coefficients did not exceed 0.67, while this value for inland ships exceeds 0.8 in most cases. Still, the method is used by Geerts in his research on improvement of small inland vessels [Geerts et al., 2010], and Pompée states the method is sufficient for inland ships as well [Pompée, 2013]. The authors published a similar method as well, aimed at the estimation of barge resistance [Holtrop, 1990]. This method is used by Hekkenberg [Hekkenberg, 2013] to simulate the ships resistance in an overall model for evaluation of an inland ship concept. The method includes higher values for prismatic coefficients as well as for block coefficients, however the L/B ratio is significantly smaller than commonly encountered at inland ships. Also other methods for estimation of barge resistance (The method of Dai, The method from Latorre and Ashcroft) are based on a dataset with L/B ratios lower than observed among inland ships [Terwisga, 1989]. Also, a barge hull shape is significantly different from that of self-propelled inland ships.

The method of Guldhammer and Harvald [Guldhammer and Harvald, 1974] provides a relatively wide range of application, which also includes the $L/\Delta^{(1/3)}$ ratio encountered at inland ships. The range for prismatic coefficient has a maximum value of 0.8, which is too low compared to inland ships. However, the method of Guldhammer and Harvald gives reasonably good results according to Pompée [Pompée, 2013], as long as the block coefficient does not become too high.

A last method for estimation of inland ship resistance is given by Verheij [Verheij et al., 2008]. The method requires an input for the return flow which can be determined by an empirical method such as Kreitner's method [Kreitner, 1934]. For the pressure and frictional coefficients, Verheij presents a small set of values depending on whether the ship is loaded or unloaded. Verheij thus presents an easy to use method, however the

lack of detail makes it impossible to benchmark or evaluate a ship design using this method. Although not mentioned by Verheij, the formula considered is that from Gebers, as presented by Graewe [Graewe, 1966].

3.2. Resistance in shallow water

The estimation of resistance is discussed above. Most of these methods, however, do not include the effects of shallow water. Especially for inland ships, these effects have a significant impact on their performance since these ships continuously encounter shallow water during their operation (effects starting from $h/T < 4$ [Heuser, 1986]). This section therefore gives an overview of various methods available to estimate the effects of shallow water on ship resistance.

Lackenby's method [Lackenby, 1963], being an extension of the work of Schlichting, is one of the most widely known methods to estimate the effects of shallow water (the effect of restricted width is not taken into account). The method provides a speed correction in shallow water if power input is kept constant, and does this using a simple formula. The method is validated by Müller [Müller, 1983] for a coaster (which significantly deviates from the warships used to gain experimental data). Müller showed that Lackenby's method gives good results for a depth-to-draught ratio down to 2.0. More recently however, Raven questions the accuracy of Lackenby's method [Raven, 2012], especially because of its small basis (experimental data from tests with three warship hull forms) and because of paradoxical results for ships with an unusual composition of total resistance.

A relatively new method is that proposed by Jiang [Jiang, 2001]. The method provides an equation to compute the effective speed in shallow water. This new effective speed can then be used to obtain the resistance curve using methods mentioned above. In his publication, Jiang shows that his method works well for an inland ship, also in a more extreme case of shallow water. However, the method also relies on an estimation of ship sinkage, which then also aspects the accuracy of Jiang's method. Also, the method is not used often and not widely validated [Raven, 2012].

The method of Karpov was chosen by Hekkenberg [Hekkenberg, 2013] for implementing the effect of shallow water on ship resistance. This method is discussed by van Terwisga [Terwisga, 1989]. The method of Karpov corrects for the effects of shallow water by providing two corrected velocities; one velocity to correct for wave resistance, the other velocity to correct for backflow, mainly affecting viscous resistance. The importance for separately correcting resistance components was underlined by Raven [Raven, 2012].

The previous three methods discussed do not take the effect of limited waterway width into account (the method of Jiang does so depending on the sinkage estimation chosen). However, the increase of resistance due to limited waterway width can be significant, as is shown by Simíc [Simíc and Radojčić, 2013]. The method of Kreitner provides a method to include the effect of channel width by focusing on the ratio between the channel cross-section and the midship cross-section for the determination of return flow [Kreitner, 1934]. This can, however, lead to a very small resistance increase for an extremely shallow but very wide river. A more detailed but similar method is that from Schijf, which is discussed by Verheij in [Verheij et al., 2008]. Schijf includes a parameter for the non-uniformity of the return flow.

The methods described above all model the effects of shallow water using a single velocity correction. Raven [Raven, 2012] stated that each of the resistance components should be corrected separately. Millward's method actually gives a correction for one of the resistance components, namely the viscous resistance. Using the formula of

Millward, a correction for the form factor can be computed [Millward, 1989]. According to Raven, the method is in good agreement with computational results. A correction specific for wave resistance can be obtained using the Srettensky integral, as shown by Hofman and Kozarski [Hofman and Kozarski, 2000].

3.3. Propulsion of inland ships

In the previous two sections, methods to estimate the ship resistance, for deep as well as for shallow water have been presented. This section presents various empirical methods that can be used to compute the propulsion factors; thrust deduction (t) and wake fraction (w). Using these parameters, propeller series theory can be applied to finally arrive at the required propulsion power for a certain ship in a certain situation.

The method presented by Holtrop and Mennen [Holtrop and Mennen, 1982] also provides a set of formulas to estimate w and t. The method of Holtrop and Mennen thereby provides a complete method to estimate the inland ship power requirement, in which the estimation of resistance as well as that of the propulsion factors is based on the same set of experimental data. Still, one should note that inland ships are significantly different from most ships in the dataset of Holtrop and Mennen, as was stated earlier in this work.

Another method to estimate the wake fraction and thrust deduction is presented by Basin and Miniovich [Basin and Miniovich, 1982]. They discuss the formulas of Papmel, which have been used with good agreement. The formulas from Papmel are also presented by van Terwisga [Terwisga, 1989] and applied in the work of Hekkenberg [Hekkenberg, 2013] as well.

A more detailed (and hence more complicated as well) method is presented by Kulczyk [Kulczyk, 1981]. Kulczyk's method also takes into account the effect of limited water depth, which has a significant effect on the propulsive performance according to experimental results obtained by Harvald [Harvald, 1976]. The shallow water effect on inland ship propulsion is also shown by Raven using results from real-world tests with a Campine river vessel. [Raven, 1981].

Heuser [Heuser, 1986] estimates the propulsive efficiency directly without using the propulsion factors w and t. The reasons for this are the complexities with the determination of an average wake fraction or thrust deduction. The complexities of shallow water effects increase the uncertainty in the estimation of propulsive efficiency even more. Heuser therefore presents a figure from which the propulsive efficiency can be estimated from applied shaft power P_D and ship speed.

Using the aforementioned methods, the propulsion factors for an inland ship can be estimated. The relative rotative efficiency (η_R), which accounts for the swirl left behind by the propeller in the flow, is not discussed in detail. The propulsion factors can be used to determine thrust and torque produced and required by the propeller from propeller series (Wageningen B-series [Oosterveld and Oossanen, 1975], Kaplan series [Oosterveld, 1972] or Meyne VBD-series [VBD, 2002]) theory in order to arrive at an estimation of power requirement.

3.4. Discussion on empirical power prediction

The previous section discussed the prediction of inland ship resistance, the corresponding correction for shallow water and the estimation of propulsion factors. Together, this leads to a classical method of power prediction for inland ships. Also, an alternative approach by Simíc [Simíc and Radojčić, 2013] is described.

For the estimation of ship resistance, various methods are available, each of them having its own basis and range of application. Unfortunately, inland ships partly fall out

of a method's range of application because most methods are derived on basis of test results for sea-going ships. Especially block coefficients, B/T ratios or L/B ratios are significantly different for inland vessels. Methods for sea-going ships thus have to be applied with care. The method presented by Verheij (The formula of Gebers) is specifically aimed at inland ships, and so is the method of Heuser.

Apart from the insufficient range of application (in case of sea-going ship methods), the parameters involved in methods for sea-going ships are not always useful. For example, the block coefficient (C_B) is not an effective parameter for inland ships, since the mid-ship region takes up nearly 70 percent of the ship [Stein, 1986, Heuser, 1986]. The same applies for the waterplane coefficient or the prismatic coefficient. For inland ships, parameters can be more effective if they are defined more locally. Unfortunately, the methods directly aimed at inland ships also only use global parameters (displacement, wetted surface) to estimate ship resistance.

Another disadvantage of most methods available is the lack of detail implemented in the methods. Both a very good and a very bad ship design can be assigned the same performance using a non-detailed empirical method. Stein [Stein, 1986] proposed a set of parameters related to an inland ship stern which can be used in an empirical method and should provide more detail. These parameters can serve as a basis for the development of a new empirical method.

Methods for estimation of propulsion performance (which is usually done through estimation of the wake fraction and thrust deduction, and then applying the propeller series theory) are not widely available. Papmel's formulas are used with good results [Basin and Miniovich, 1982] but lack the inclusion of shallow water effects. The method of Kulczyk is more extensive and also includes shallow water and provides accurate results for a pusher [Kulczyk, 1981]. For a self-propelled cargo vessel however, results are less accurate. According to Heuser, it is better to empirically estimate the propulsive efficiency directly, since the flow beneath an inland ship's stern is too complicated to simply approximate it using several empirical methods.

A proposition is made by Stein [Stein and Zöllner, 2007] to define a parameter in which the total performance of the ship's stern is presented, rather than using classical propulsion theory consisting of separate estimation methods for resistance and propulsion.

4. Review and improvement of the state-of-the-art

The previous two sections discussed design guidelines for inland ships as well as power prediction methods (or evaluation tools) respectively. The observations made are summarized in this chapter, along with a description of a research project that aims at filling certain gaps in the design knowledge of inland ships.

4.1. Summary of the state-of-the-art

In this work, various methods on inland ship evaluation as well as information on design guidelines for inland ships have been discussed. The following summarizes the main findings:

- Design guidelines for self-propelled inland ships are rough and not sufficiently detailed.
- Most of the work on inland ship design guidelines is published in the author’s native language only, making it difficult to use by designers that are not familiar with the language.

- The range of application of popular and widely known power prediction methods (to be used in the evaluation of inland ships) is not adequate for inland ships.
- Parameters used at inputs for empirical methods are not always effective for inland ships
- Power prediction methods do not include important (for inland ships) details such as the tunnel geometry.
- The prediction of propulsion performance for inland ships is limited in availability. Also, the amount of validation data is limited.

Given the above, design guidelines are useful (as also underlined by Radjocic in [Radojčić, 2009]), but lack specific detail. Also the empirical methods do not include sufficient details in order to provide inland ship designers with the possibility of evaluating their ship design sufficiently accurate.

4.2. Further research

In order to improve design knowledge, guidelines, empirical power prediction and estimation of shallow water effects for self-propelled inland ships, the Top Ships project is initiated. The project focus is chosen to be the inland ship's stern, as the bow design is less complex.

- An empirical method to estimate the performance of an inland ship by altering the stern hull shape. The empirical method relies on a dataset of results obtained by computational fluid dynamics (CFD) exercises, which are conducted for a series of inland ship geometries for which the stern hull shape is systematically varied.
- Design guidelines to aid the designer in his ship stern design. These guidelines should not only help the designer obtaining a better hull form, they should also provide more insight in inland ship hydrodynamics. Whereas the empirical method helps the designer choosing the global stern hull shape (as the amount of input parameters should remain limited), the design guidelines should aid the designer with detailed improvements on the hull form.

By investigation of literature, the most important gaps have been identified. Thereby, the focus in the Top Ships project is set on the goals mentioned.

In a parameter study, the most important and effective variations at the stern hull shape of an inland ship are investigated. This is done by analysis of existing inland ship hull forms and based on earlier research on inland ship optimization. Furthermore, input parameters need to be defined for the empirical method. The work of Stein [Stein, 1986] may be used as a basis for this.

The dataset form which the empirical method is derived is mainly created out of results from CFD. Ship models for the computations are generated by a 3D design tool and varied based on the defined parameters. The design guidelines to be developed do also rely on this data but in order to provide designers with more detailed design guidelines, additional computations are conducted for variations and specific design aspects that cannot be included in the empirical method.

Effects of shallow water on inland ships are also to be included in the empirical method as well as in the design guidelines. The influence of certain design aspects on the shallow water effect is investigated and the effects are included in the empirical method for the design aspects that are of greatest influence.

An important note to make here is that the Top Ships project does not focus on designing the optimal ship itself. The main focus is to improve hydrodynamic design

knowledge for inland ships and providing designers with tools and guidelines so that they can improve their ship designs.

5. Conclusions

The present paper presents and discusses available design guidelines and empirical power prediction methods from literature to predict inland ship performance and evaluate the ship's efficiency. Overall, design guidelines and power prediction methods do not include sufficient detail. Thereby, designers can design anything between a good and a bad ship, following design guidelines, and still evaluate them with the same results. It is therefore concluded that design guidelines and power prediction methods for inland ships need to be improved.

For this, the Top Ships project is initiated and discussed in this work as well. In the Top Ships project, design guidelines as well as an empirical power prediction method for inland ships are developed. Both aim specifically at the ship's stern. The effects of shallow water are investigated as well. With the results from the Top Ships project, designers should have tools at hand using which they can design a better, more efficient inland cargo ship.

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7. Nomenclature

Δ	Vessel displacement	m^3	L_S	Stern region length	m
B	Vessel width	m	η_R	Relative rotative efficiency	
$C_{B\text{-}B}$	Bow region block coefficient		P_D	Propeller shaft power	W
$C_{B\text{-}S}$	Stern region block coefficient		R_T	Total ship resistance	N
CC	Cargo capacity	ton	T	Ship draught	M
h	Water depth	m	T	Thrust deduction factor	
L	Vessel length	m	V_S	Ship speed	m/s
L_B	Bow region length	m	w	Wake fraction number	

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