Bow Shape Optimization for Ice Loads

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Introduction

The bow shape area of a ship hull is of utmost importance in an icebreaking process and a well-shaped bow designed for handling ice loads should break the ice in an efficient way while obtaining low ice resistance values. The angles describing the bow shape are therefore seen as the most important parameters when evaluating the ice resistance.

Semi-empirical and numerical methods for ice resistance prediction are developed over the past decades in order to estimate the forces acting on the ship hull advancing in level ice, and thereby give an indication of the ship performance in certain ice conditions. The methods are applied in an early design phase to predict the ice resistance instead of performing model tests, which are more reliable, but costly. The non-homogeneous properties of ice makes it difficult to measure and predict the ice conditions and thus the methods of ice resistance prediction are under constant development in order to find the most reliable and applicable method. The existing methods are based on diverse assumptions and will therefore limit the applicabilities of the methods. In addition, the sensitivity for geomtric changes of the bow shape in the methods might be different and should thus be identified when analysing the ice resistance.

Objectives and Scope

The main objective of this thesis is to optimise icebreaking bow shape on case study vessels with regard to the bow shape angles by appyling reviewed methodologies. In order to generate desired bow shapes, a parametric 3D model has to be developed in MATLAB. The optimised bow shape angles will be found by applying an optimisation procedure to minimize the objective function, which in this case will be the breaking resistance. Only the ship bow will be considered in this thesis and the focus of the parametric model will be limited to the ice belt area where waterline entrace angle , α, buttock angle, φ, and flare angle, ψ, will be estimated. In addition, the achieved results of the applied methodologies will be analyzed and the sensitivity to changes in the bow shape angles will be identified.

Parametric 3D Model

The parametric model developed in MATLAB will generate 3D bow shapes based on the following input parameters: breadth of bow, B_{bow}, length of bow, L_{bow}, ice thickness, h_i, two waterline entrance angles, α_1 and α_2, two frame angles, β_1 and β_2, and the buttock angle at the stem, φ. The model consists of a "bow skeleton" which is built up by a 4-by-4 mesh grid with control points desiring the shape, and the considered area is assumed to be the ice belt region.

A non-uniform rational basis spline (NURBS) surface is added to the bow skeleton to obtain a 3D surface on the bow shape. In order to calculate the bow shape angles, normal vectors are generated out from the surface at the ice bottom surface and the ice top surface. Figure 1, Figure 2 and Figure 3 are respectively illustrating the top view, the 3D view and the port side view of a bow shape, and Figure 3 includes the normal vectors pointing out from the surface.

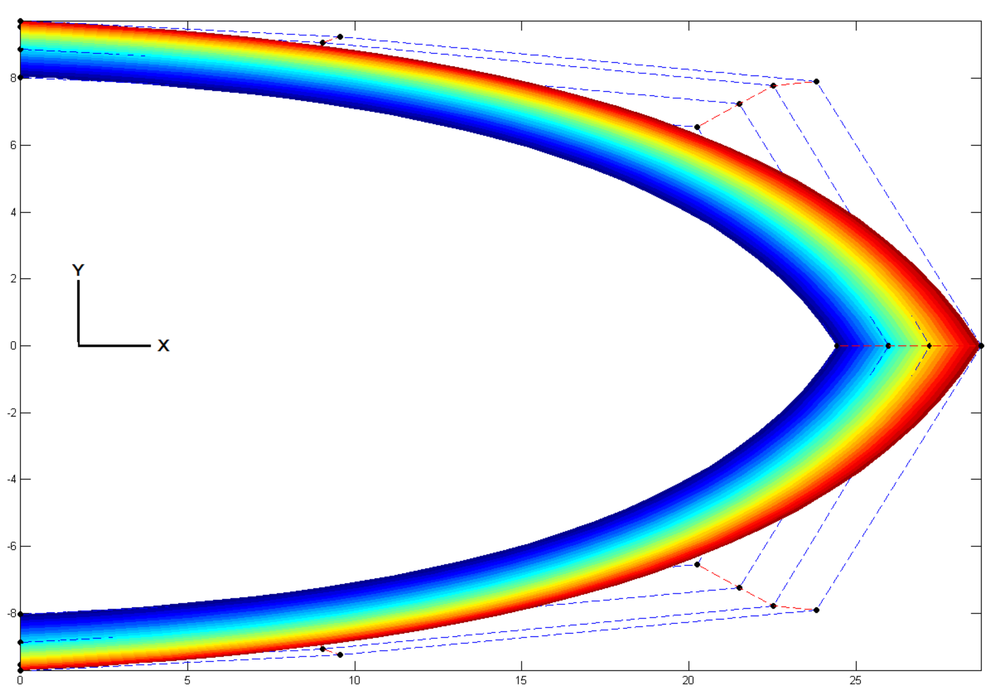

Figure 1: Top view of a bow shape.

Parametric 3D Model

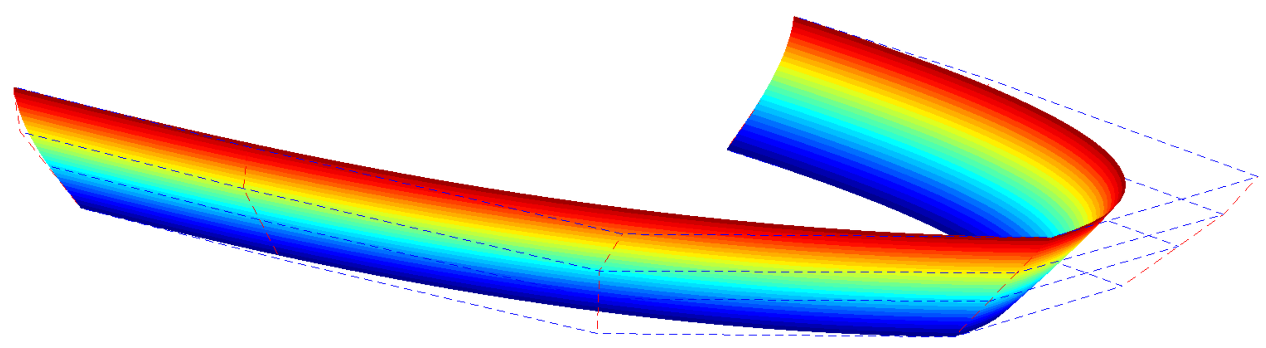

Figure 2: 3D view of a bow shape.

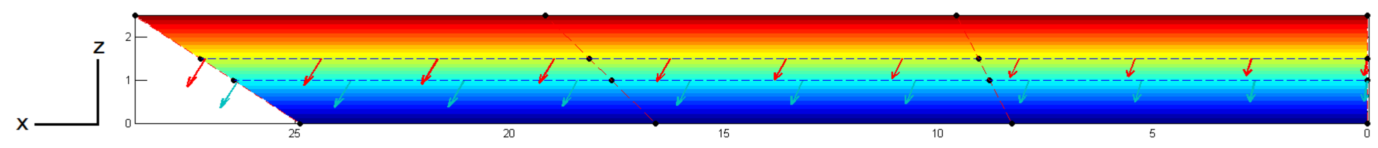

Figure 3: Port side view of a bow shape.

Optimisation Procedure

The optimised bow shape angels for case study vessels were found by using nonlinear programming on reviewed ice resistance prediction methods. The objective was given as an ice resistance function to be minimzed with regard to the bow shape angles, which are the decision variables in the problem. The constraints of the objective function were given as the upper and lower bounds of the decision variables in addition to nonlinear constraints.

The first method to apply, is the semi-empirical method of Lindqvist (1989), which considers three angles describing the bow shape; waterline entrance angle, buttock angle at the stem and flare angle. The input data for the main dimensions are from the coast guard vessel KV Svalbard retrieved from Lubbad and Løset (2011) and the ice properties are assumed values. The second method is the numerical method of Erceg et al. (2014), which is currently under developement, and therefore the results are not ready at the moment. This method models the initiation of icebreaking pattern in level ice and considers the predefinition of the ice cusp geometry.

Results

The optimal values found when applying the method of Lindqvist are α = 50.0 degrees, φ = 20.0 degrees and ψ = 25.4 degrees, and the resulting breaking resistance is $R_{ice,breaking}$ = 1188 kN. The results indicate that the optimal value of α will be as large as possible, while ϕ will be as low as possible in order to obtain low ice resistance. The results matches the characteristic icebreaking bows which are desired to have a small stem angle and a large waterline entrance angle. However, the method is not considering the physical effects of the icebreaking process, such as the geometry of the forming ice cusps. Other methods should be applied for further discussion and anaylsis, and to confirm te applicability of the methods and the identification of the sensitivty towards geometric changes.

References

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