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# Parametric modelling of marine structures for hydrodynamic calculations

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ABSTRACT

The paper describes a numerical 3D modelling method to develop quadrilateral meshes for panel method calculations with an integrated solution to obtaining the mass properties from the same grid. It aims to offer a more precise and versatile alternative to the spreadsheet type approach repeatedly used in early design stages of marine structures. The given formulae additionally serve to obtain the mass properties of an existing grid without additional software. The input format is in the form of matrices and can be altered within a script. First, the modelling approach is described, followed by the calculation of the mass properties of volume, weight, inertia, and the centre of gravity. After detailing the principles, various examples that encompass different geometric forms such as a torus, an offshore platform, and a ship are provided to demonstrate the usage. The results of the mass property calculations are validated through comparisons with ANSYS and Rhino3D. The hydrodynamic mesh is evaluated in WAMIT by comparing models made with the presented approach to MultiSurf and Rhinoceros3D with its PanelingTools plugin. A measure of performance is also included to provide a basis for loop-type design procedures that utilise the given method.

## 1. Introduction

Initial design stages contain a significant number of unknowns. In settled industries such as shipbuilding, the process begins with the cumulative knowledge from previous experiences and may progress into improving an existing geometric form (e.g., Papanikolaou, 2010; Ventura and Guedes Soares, 2011). Conversely, in novel applications such as floating offshore wind turbine platforms, the most favourable implementation is still under discussion (Bagbanci et al., 2015, 2012; Robertson et al., 2013). For instance, as of 2013, over 80 platform concepts were being evaluated globally (Bossler, 2013) with diverse approaches to the design problem. Considering the variety of forms to start from, the number of unknowns is equally high for a new concept.

In all cases, mathematical modelling of static and dynamic behaviour requires a correct representation of the mass and inertia. If the structure is afloat, underwater geometry related hydrodynamic coefficients become an additional requirement. These properties are closely linked with the geometry of the platform, hence, involving CAD software to get reliable estimates. The same reasons that make the use of these sophisticated tools and software favourable at later design stages present a complication at the earlier design stages. When the knowledge is limited to a concept, preparing a set of iterations of 3D models for parametric studies as in Tracy (2007) can become tedious. Another problem arises from the specialisation of tools. Some codes are made to perform a specific calculation well while expecting input from another source. For instance, WAMIT (Lee and Newman, 2005) is a verified code in hydrodynamic calculations, provided that the six by six mass matrix is correctly provided. Erred mass will lead to errors in estimated motion responses. Accordingly, this data needs to be prepared externally. The procedure needs to be repeated for each iteration of the concept.

To remedy this problem in new designs, researchers usually revert to avoiding sophisticated 3D modelling tools entirely and rely on spreadsheet calculations and simplifications as outlined in Chakrabarti (2005) and utilised in Bachynski and Moan (2012) and Leimeister et al. (2016). This case creates a substantial gap between the higher-complexity surface models such as NURBS and the simple hand calculations on a spreadsheet. The issue is not only present at initial stages but also repeats itself from another perspective for optimisation studies. Two interlinked sides need to be considered in this regard: mass properties and hydrodynamics.

Obtaining the mass and inertia on a spreadsheet is less problematic when a partial analytical solution exists. Accordingly, one approach is to introduce simplifications to describe the model, removing some of its parts, effectively reducing it to a form that is broken down into solvable components (e.g., cylinders) (Andersen et al., 2015; Hall et al., 2014; Roddier et al., 2010). This is not a generic solution, as it is inapplicable for a body that cannot be expressed as a set of basic shapes. Regarding

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hydrodynamics, a solution to the hydrodynamic coefficients can be obtained from tabular data for members (Clauss et al., 1992; Sarpkaya and Isaacson, 1981). However, if the platform requires a potential flow solution, they will be inaccurate as discussed in an experiment-to-code comparison by Adam et al. (2013). In that case, it is still necessary to build a 3D model despite the preliminary hand calculations. Furthermore, the entire breakdown and calculation process needs to be repeated if the structure is altered, as the solution is specific to a given body.

From the point of optimisation, another problem arises. A recently published work describing the evaluation of semisubmersible hulls for weight and heave motion (Park et al., 2015) states that one of its main contributions is including mass as an optimisation variable, unlike previous studies which took it as a constant (Clauss and Birk, 1996; Lee et al., 2007; Lee and Lim, 2008). Starting from Bezier & B-Spline curves, the study assumes that the mass equals a statistically obtained constant multiplied by the surface area of a simplified version of the 3D model. The reduced geometry is given as a set of rectangular prisms without the curvatures and other details of the hydrodynamic model. In essence, the approach is a reversal to the spreadsheet calculation inside a complex system. The inertia is not mentioned; therefore, the study is limited to the heave mode in a manner similar to Birk (2008). It should also be noted that a shortcoming of statistical data is that they do not exist for novel structures (e.g., wind turbine platforms, wave energy converters).

In another study that considers both mass and inertia, Venzon et al. (2014) assumes the mass and the radius of gyration to be based on percentages of the main dimensions, and takes a fixed position for the centre of gravity. The rationale behind this decision is not explained in the work. For tension leg platforms, using an assumption of mass as in Lee et al. (2007) is especially problematic considering the relation between the tendon tension and the structural weight. In the absence of proper inertia estimations, the pitching and rolling effects on tendon tension are also overlooked. In this regard, with a large number of dependencies, it is clear that the mass properties should preferably be calculated, as opposed to assumed. While this estimation may be more complicated for structures designed for significantly variable cargo (e.g., tankers, bulk carriers, oil-and-gas platforms), a mass matrix can be obtained for fixed-loading type structures with a higher precision (e.g., floating wind turbine platforms).

From a purely hydrodynamics point of view, once the mass properties are calculated, the estimation of responses will require evaluating a suitably prepared mesh as in Jafaryeganeh et al. (2015) and Rodrigues and Guedes Soares (2014). The coefficients of the equations of motion rely on the underwater geometry, and even smaller changes reflect in motion dynamics (Sutulo et al., 2010; Uzunoglu et al., 2016). Hence, simplifications also lead to consequences such as altering the natural frequencies (Uzunoglu and Guedes Soares, 2015a). In sum, it is beneficial to devise a consolidated approach to the problem. A solution would be to implement the estimations of mass properties into the 3D meshes used in hydrodynamics while keeping the file format compatible. Additionally, the calculation method should be mathematically simple so that it can be implemented by other researchers in any programming language and should avoid commercial CAD tools. It is also preferable to use a numerical input format as it has advantages regarding parameterisation for iterative design. In that regard, specialised approaches exist for parameterising bodies such as ships (Ko et al., 2011). However, with an increased number of unknowns in fields such as the design of floating wind turbine platforms, flexibility assumes a larger role. Hence, the solution should not be limited to an individual hull form.

This work outlines this type of a numerical solution to creating a quadrilateral mesh and obtaining its mass properties for a more precise solution at early design stages. While it is mainly intended as a replacement for the commonly used spreadsheet methods, the mass calculations apply to any grid mesh. Matrix data are utilised to input the geometry. Partial solutions of a section of the model provide the mass and volume distribution in space. Integration for the entirety of the structure delivers the model weight, volume, and inertia. The output is then fed to WAMIT to validate the model's use in hydrodynamic calculations. While the tool was initially developed for the numerical design of offshore platforms for wind turbines (Uzunoglu and Guedes Soares, 2016, 2015b), it allows modelling a wider range of structures. To illustrate this point and its usage, the examples throughout the text are diversified. The validation of the code is performed through comparisons with Rhino3D combined with its PanelingTools plug-in, ANSYS, and MultiSurf models for volume, mass, and hydrodynamic properties. It should be noted that the number of software packages needed for comparisons also emphasizes the current lack of a consolidated solution. The concluding section contains a measure of performance to evaluate the method's efficiency in providing the 3D model and mass properties to be used in a system that requires iterative model building.

## 2. Representation of a 3D geometry with quadrilaterals

The quadrilateral meshes utilised in panel method tools such as WAMIT are defined by the x, y, and z coordinates of each panel's four vertices (i.e., 12 values per panel). When two of the adjacent four vertices coincide, the polygon forms a triangle. The entirety of the structure is then represented as a combination of individual panels. The ordering of the vertices defines the surface normal direction using the right-hand rule. In Fig. 1, the coordinate system is presented. The darker shaded arrow demonstrates the normal facing the fluid domain as required by WAMIT, while the lighter shaded arrow is the inverted normal. The inverse normal will be used to simplify mass property calculations.

The modelling process described below is divided into radius based and face based approaches. Radius-based models encompass cylinders, cones, frustums, spheres and similar shapes that can be described as a function of their radii at a given height. Face-based models have a broader range of applications. A triangular prism with an open bottom uses three faces. A rectangular prism consists of six faces. Eventually, the idea may be extended to a sphere as a set of connected quadrilateral panels. In this context, radius-based models are a subset of face-based models. In practice, having the radius-based model option simplifies and speeds up the modelling. For this reason, both approaches are explained, starting with the radius-based approach.

### 2.1. Radius-based approach

Consider a quadrant of a disc, with the radius and the arc length divided as illustrated in Fig. 2. The polygon's z coordinates are identical, resulting in a flat disc on the xy-plane. The input data of this case are the radius ($r$), the number of segments between two consecutive edges (i.e., inner edge with a zero radius and the outer edge radius of $r$), the Z coordinate, and the reference angle (i.e., 90° for a quadrant, $\varphi_c$). The number of segments on the radius ($s_r$) and the arc ($s_p$) are utilized to define the increments of $r_{inc}$ and $\varphi_{inc}$ respectively:

$$\varphi_{inc} = \frac{\varphi_c}{s_p} \tag{1}$$

$$r_{inc} = \frac{r_i}{s_r} \tag{2}$$

The information above suffices to express the location of the four vertices in the Cartesian coordinate system as a function of Equations (1) and (2) and set the origin to $O(X_0, Y_0)$.

$$X_{i_1} = \cos(\varphi_i + \varphi_{inc})\cdot(r_i - r_{inc}) + X_0 \tag{3a}$$

$$Y_{i_1} = \sin(\varphi_i + \varphi_{inc})\cdot(r_i - r_{inc}) + Y_0 \tag{3b}$$

$$Z_{i_1} = Z_i + Z_{inc} \tag{3c}$$

$$X_{i_2} = \cos(\varphi_i)\cdot(r_i - r_{inc}) + X_0 \tag{4a}$$