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GERAÇÃO DE MALHAS PARA SIMULAÇÃO DE CORPOS TRIDIMENSIONAIS SUBMERSOS USANDO O *SOFTWARE* NEMOH

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Resumo. Na simulação de dispositivos de conversão de energia das ondas, é necessário o entendimento das interações fluido-sólido para a determinação das propriedades hidrostáticas e hidrodinâmicas dos corpos submersos. Diversos *softwares* estão disponíveis para a simulação destas interações, dentre eles o NEMOH. NEMOH é um código do tipo BEM (*Boundary Element Method*) dedicado à computação de cargas de ondas de primeira ordem em estruturas desenvolvido por pesquisadores da Escola Central de Nantes, na França. Este trabalho tem como objetivo apresentar um código inédito e escrito no ambiente computacional *Octave* capaz de facilmente gerar perfis de corpos submersos para criação de malhas necessárias para a obtenção das propriedades hidrostáticas e hidrodinâmicas, através do NEMOH. Trata-se de uma simulação computacional com estudos de casos. Como resultados tem-se uma *interface* amigável capaz de gerar malhas com o uso do *software* livre, a geração de perfis representativos da porção molhada (submersa) de um ou dois corpos modelados no NEMOH e a geração da superfície submersa completa do corpo.

Palavras-chave: *software* NEMOH; geração de malhas; *software* livre; corpos submersos; octave.

MESH GENERATION FOR SIMULATION OF SUBMERGED THREE-DIMENSIONAL BODIES USING NEMOH *SOFTWARE*

Abstract. In the simulation of wave energy conversion devices, it is necessary to understand fluid - solid interactions to determine the hydrostatic and hydrodynamic properties of submerged bodies. Several software is available for simulating these interactions, including NEMOH. NEMOH is a BEM-type (Boundary Element Method) code dedicated to computing first-order wave charges in structures developed by researchers at the Ecole Centrale de Nantes, in France. This work aims to present an unprecedented code written in the Octave computing environment capable of easily generating profiles of submerged bodies to create meshes necessary to obtain hydrostatic and hydrodynamic properties, through NEMOH. This work is a computer simulation with case studies. As a result, one has a friendly interface capable of generating meshes using free software, generating profiles representing the wet (submerged) portion of one or two bodies modeled in NEMOH and generating the complete submerged surface of the body.

Keywords: NEMOH; mesh generation; free software; submerged bodies; octave.

1 INTRODUCTION

Currently, the use of software is an effective alternative in reducing costs and simulating real physical models that has been extensively adopted in all phases of product development, from conception to decommissioning. Among this software, there are those used for the analysis of the action of external or internal loads that generate and use a mesh to represent specific regions of the object to be modeled and subsequently simulated. In the simulation of rigid bodies submerged in an aqueous medium, specifically in the case of vessels and buoys at sea, the theory of potential flow is generally used, which makes it possible to obtain the mathematical expressions that govern the interactions between

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the rigid body, the sea, and the air. The potential flow theory enables the description of the field of water velocities as the gradient of a scalar function, the velocity potential. Such mathematical expressions are strongly non-linear, coupled and entirely dependent on the boundary conditions adopted and for their resolution (and consequently for the obtaining of the hydrodynamic coefficients) mathematical solvers are used. Among these flow equation solvers there are those based on the boundary element method, which is a computational method for solving systems of differential equations in integral form.

In the simulation of wave energy conversion devices subjected to the action of ocean waves, it is necessary to understand these interactions to determine the hydrostatic and hydrodynamic properties. Briefly, it can be said that the simulation of these devices progresses from the study of static submerged bodies to the study of submerged bodies in motion due to the movement of the water surface. For the simulation of the interactions between submerged bodies and the aqueous medium several software are available, including Aquaplus, WAMIT, NEMOH, LAMP 1-2, Orcaflex, Deeplines, WEC-SIM, InWave, Proteus3D, AEGIR, OpenFoam, Fluent, ISIS-CFD, SPH-Flow and DNS. Among the open-source software (Free Software) there is NEMOH, a BEM (Boundary Element Method) type of code dedicated to computing first-order wave loads in offshore structures (added mass, damped radiation and diffraction forces). It has been developed by researchers at the École Centrale de Nantes for over 30 years and has been used in a variety of projects, typically in the estimation of the dynamic response of submerged structures or in the assessment of the performance of wave energy converters (Nemoh, 2024). The NEMOH developers also created an interface for its use in Matlab (MATLAB, 2023).

This work aims to present a code (script or program) written in the Octave computational environment (EATON et al., 2018) capable of generating the profile (silhouette) of symmetrical bodies necessary for the creation of meshes that represent the wet surface of these submerged three-dimensional bodies, to be used in obtaining the hydrostatic and hydrodynamics properties of the bodies, using the routines developed by the creators of NEMOH.

The rationale for the presentation of this code is centered on the importance of developing a friendly interface in Octave/Matlab code to generate meshes of submerged bodies, on the use of computer simulation to represent floating devices in the open sea, for carrying out tests on models of reduced scale and for teaching hydrodynamics, in addition to the importance of disseminating the use of open-source software in BEM. On the other hand, the creators of NEMOH have provided a discussion forum (GITLAB LHEEA, 2024) where you can find various questions and requests for help about creating profiles and meshes compatible with NEMOH. Therefore, this code to be presented here is an important contribution to the NEMOH's forum.

2 METHODOLOGY

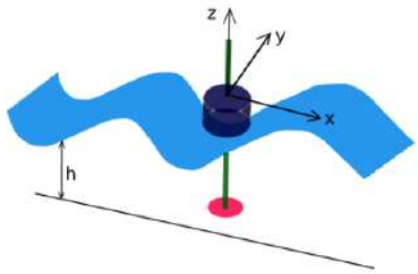
For the simulation, the methodology used to generate the profiles consisted of installing the free software Octave (EATON et al., 2018), developing the *revoldr1b.m* and *revoldr2b.m* codes and executing these codes. Then, to generate the mesh, the code *aximesh.m* (NEMOH, 2024) was executed. To understand this work, it is necessary to know that the codes proposed here for the generation of unrefined meshes, to be used as input in NEMOH, generate the profile of the submerged body to serve as input data for the *axiMesh.m* (for *axisymmetric* bodies) and *Mesh.m* (for symmetric bodies) codes, both developed by the creators of NEMOH. Originally, the NEMOH software was designed in Fortran and made available to run from the command line on Windows or Linux operating systems. The creators of NEMOH also developed a friendly interface in Matlab code (MATLAB, 2023) which can be found in Gitlab LHEEA (GITLAB LHEEA, 2024). In addition to this interface, tools for meshing symmetrical and asymmetrical bodies are also available. There are several alternatives for generating meshes for NEMOH, for example using CAD software. NEMOH software does not require installation, just the download of four executable files: Mesh.exe, preProcessor.exe, Solver.exe and postProcessor.exe.

All codes in Octave, Matlab and compiled routines from NEMOH were executed on a desktop computer Intel Core i3-3250 CPU 3.5 GHz with 8GB of RAM in the Windows 7 operating system in 64 bits. The results obtained are presented in this work as images.

3 POTENTIAL FLOW SOLVER NEMOH

NEMOH is the first open-source program in the world that uses a numerical technique to solve a system of partial differential equations defined in the form of boundary integrals or BEM - Boundary Element Method (Penalba et al., 2017), under the terms of the GNU General Public v3 (GNU, 2024). Unlike other BEM software, the technique used in NEMOH consists of applying the method of Green's functions to transform the flow problem into a potential distribution pro-

Figure 1: Representation of the notation and orientation of the Cartesian axes.



Source: Created by the author (2024).

blem on the surface of the body by decoupling the resolution of the BVP (Boundary Value Problem) on the linear free surface (Barbarit and Delhommeau, 2015). This feature makes it easy to work with flexible structures, hydroelasticity, generalized modes and unconventional degrees of freedom using NEMOH.

NEMOH consists of three main programs that must be operated successively. The Preprocessor reads and prepares the mesh and defines the types of calculations. The Solver solves the linear equation of the BVP for the potential field, depending on the condition of each body, and calculates the pressure field, the hydrodynamic coefficients, the far field coefficients, and the wave elevation. The post-processor provides results that can be used to calculate Response Amplitude Operators (RAO) and plot the free surface elevation of the wave. NEMOH also outputs the data necessary to simulate bodies subjected to the action of ocean waves, such as the hydrodynamic coefficients, excitation force, added mass, radiation and damping coefficients and the complex diffracted and disturbed wave field around the Body.

The units used in NEMOH are all from the International System of Units (SI): length in meters, mass in kilograms, time in seconds, angular frequency in rad/s, forces in newtons, among other measures. According to Babarit and Delhommeau (2015), the coordinate system considers the point 0(0,0,0) as the referential origin. The horizontal plane Z=0 defines the free surface at rest. The vertical Z axis is pointing up. The wave direction of 0 degrees means that the wave is propagating towards the positive X axis, as can be seen in Figure 1. The phase angle is represented at the origin of the inertial reference system 0(0,0,0) in radians and h is the water depth in meters.

The NEMOH software does not have its own screen. As stated earlier, the three blocks (preprocessor, processor, and postprocessor) are available as executable files on the command line and accessed in different ways on both Linux and Windows (x64) operating systems. Alternatively, one can compile NEMOH using CMake (Available on the NEMOH's website) on the command line. Recently, the NEMOH 3.0.1 version was made available with the inclusion of the treatment of irregular frequencies, extension of the post-processing module for first-order hydrodynamic results and the complete computation of second-order wave loads, expressed through the Quadratic Transfer Function (QTF) (Kurnia; Ducrozet; Gilloteaux, 2022).

In this work, NEMOH v.3.0.1 was adapted and executed in the free software Octave (EATON et al., 2018) through the interface with Matlab provided by the creators of NEMOH, having as input data the files with the properties and mesh of the submerged body to be simulated in NEMOH. Therefore, the profile generator software proposed in this work does not constitute an interface to execute NEMOH, but a necessary code for the coarse or refined mesh generator to execute NEMOH.

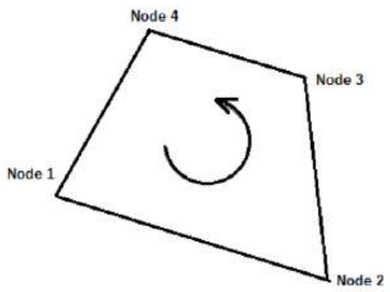
The raw input mesh can be generated manually, using Octave, Matlab, *Mesh.exe*, or by any other software capable of generating mesh files, as long as the generated file is compatible with the input standard required by NEMOH. NEMOH needs as input a file containing the tables of the mesh nodes and their connectivity and another file containing additional geometric information, such as the use or not of symmetry around the xOz plane, the number of nodes, the number of panels, the number of bodies, the panels by body, the geometric center of each panel, the vectors normal to the panel and the area of the panels. NEMOH uses rectangular panels, as shown in the representation in Figure 2 (NEMOH MESH, 2024).

Through the discretization of the entire wet surface by an initial mesh composed of panels, NEMOH performs the refinement of this initial mesh based on values provided by the user. The result of the simulation in NEMOH is a series of hydrostatic and hydrodynamic parameters and the number of panels used in the refined mesh.

The creators of NEMOH provide examples of meshes on their respective websites. An example available on the NEMOH website (NEMOH MESH, 2024) is of a submerged rectangular body, as shown in Figure 3b. This mesh was generated in Octave from the sequence of command lines shown in Figure 3a.

Another example available on the NEMOH website (NEMOH MESH, 2024) is of a submerged vertical cy-

Figure 2: Representation of a mesh panel used by NEMOH.



Source: NEMOH MESH (2024).

lindrical body, as shown in Figure 4b. This mesh was generated by the sequence of command lines shown in Figure 4a.

There is also a Forum for questions, comments, reporting bugs, contributing to the development of NEMOH or getting information about tools to support NEMOH (NEMOH FORUM, 2024). As shown in these examples available on the NEMOH website, the relationship between the coordinates of the points typed in the Octave command line and the desired geometric shape is not trivial. For example, Kalofotias (Kalofotias, 2017) has provided a manual for meshing and determining forces for a semi-submerged sphere, using the Salome cross-platform open-source scientific computing environment. In this work, the use of NEMOH software will not be addressed, nor the use of the interface with Matlab created by the NEMOH developers, only the profile generation software and unrefined mesh (coarse mesh) will be treated here, which is one of the main data of mandatory entry for simulation of submerged bodies in NEMOH.

4 PRESENTATION AND ANALYSIS OF RESULTS.

Within the philosophy of using free software, it was decided to use the free *software* Octave (EATON et al., 2018) to generate representative profiles of the wet (submerged) portion of the bodies to be modeled in NEMOH. After defining each profile, the mesh is generated by the *axiMesh.m* code, which is necessary for the preprocessing in NEMOH to occur in accordance with the expected input. It should be noted here that, due to its symmetry, NEMOH only presents half of the simulated submerged body. Non-symmetrical bodies can be modeled and simulated in NEMOH, but examples will not be contemplated in this work. The following are the *revoldr1b.m* and *revoldr2b.m* codes, both written in Octave.

4.1 Generating profiles and meshes of only one submerged body

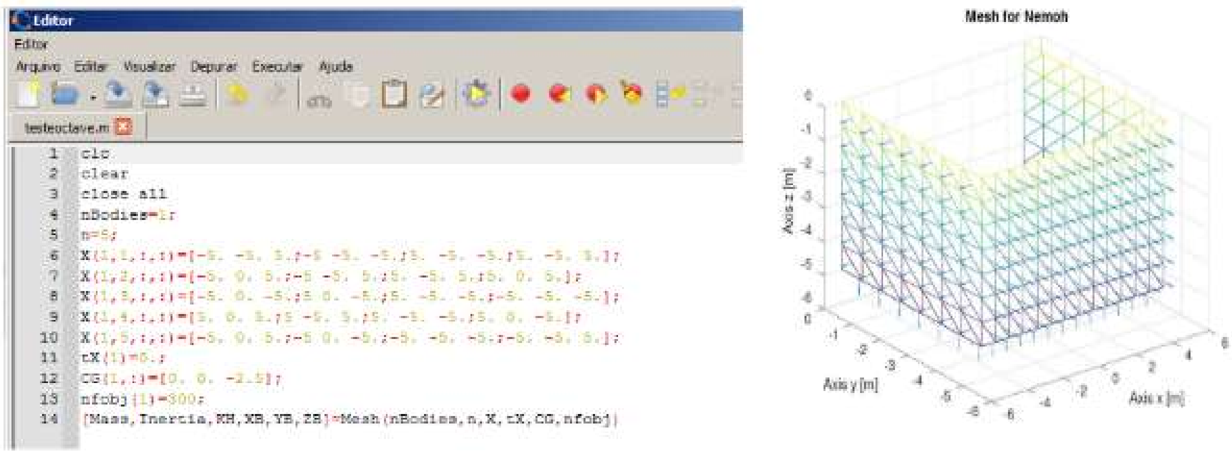
The *revoldr1b.m* code was developed with the objective of generating a solid of revolution around its vertical symmetry axis (Z Axis). The code is previously adjusted to a scale in centimeters, due to the initial use to simulate submerged bodies on a reduced scale to be tested in a didactic wave tank. The radial magnitudes of the submerged body are represented on the X axis. However, the code allows the user to adjust the scale to meters or millimeters, if desired. Figure 5 shows a copy of the Octave screen when executing the *revoldr1b.m* code.

When executing *revoldr1b.m* in the Octave environment, the user can choose to enter the X and Z coordinates of the points or generate the profile coordinates using the mouse by clicking on the work area of the figure created by the code. In both cases, the user just must choose in the initial menu between Points or Drawing and then inform the number of points to be typed or clicked. Figure 6 shows a schematic representation of the *revoldr1b.m* code flowchart.

Coordinate typing should only be used when the user wants to simulate a submerged body that already exists, so that its coordinates can be properly measured and then typed when executing the code. But in most cases the body does not yet exist physically and generating its profile with the computer mouse is the best solution. Generating the coordinates of the line representing the body profile with the mouse is simple. The user just needs to inform the number of points to be used to properly define the profile of the body and then click with the mouse inside the active area of the figure created by the code (Figure 7a), generating the profile. Figure 7 shows the option to generate the profile.

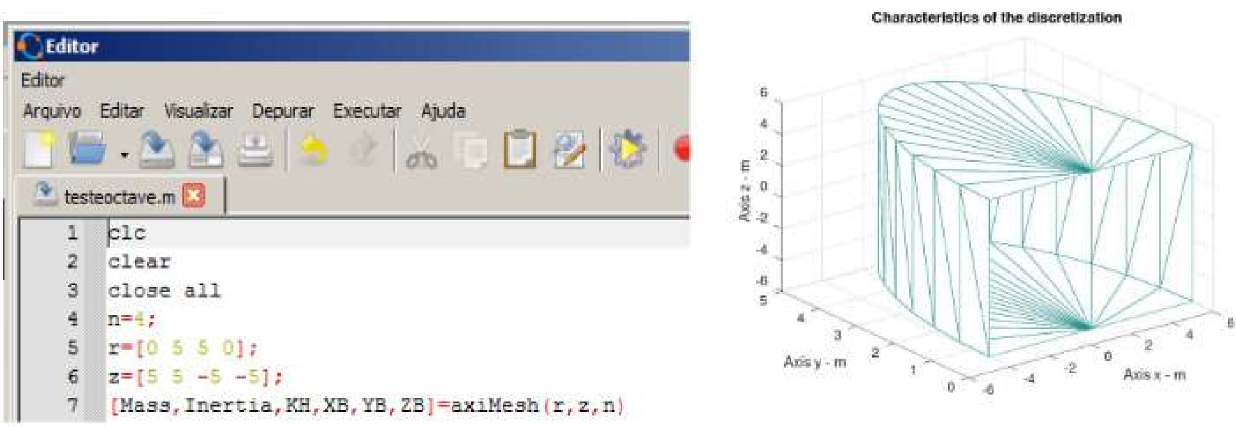
In addition to the number of points and to the coordinates of the points of the lines that define the profile of the submerged body obtained by the sequence of mouse clicks on the figure created by the code, the user must provide the vertical position (Z axis) of the center of mass of the body to be modeled. It should be noted that the Z axis is negative in the depth direction. After executing the *revoldr1b.m* code in Octave, the user can run the *axiMesh.m* code in Octave and get the input mesh refinement for NEMOH. To exemplify this sequence of results, in Figure 8 there is a new profile generated in the *revoldr1b.m* code from 5 points, to obtain the profile of a single submerged body. In Figure 8a the typed points that generated the submerged profile can be seen,

Figure 3: a) Command lines and b) Mesh representation of a rectangular body generated by NEMOH



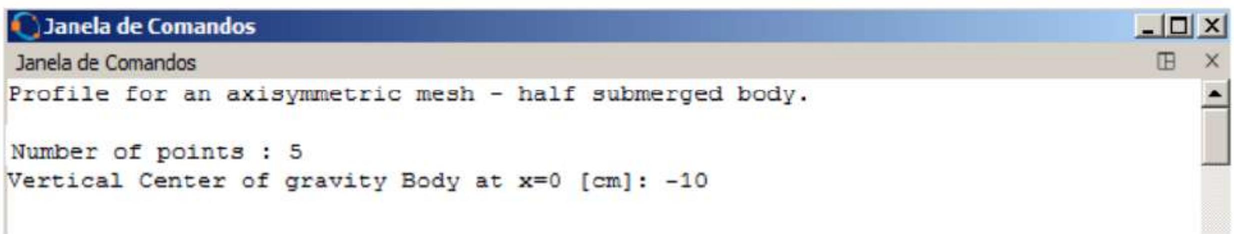
Source: NEMOH MESH (2024).

Figure 4: Representation of a mesh of a cylindrical body used by NEMOH



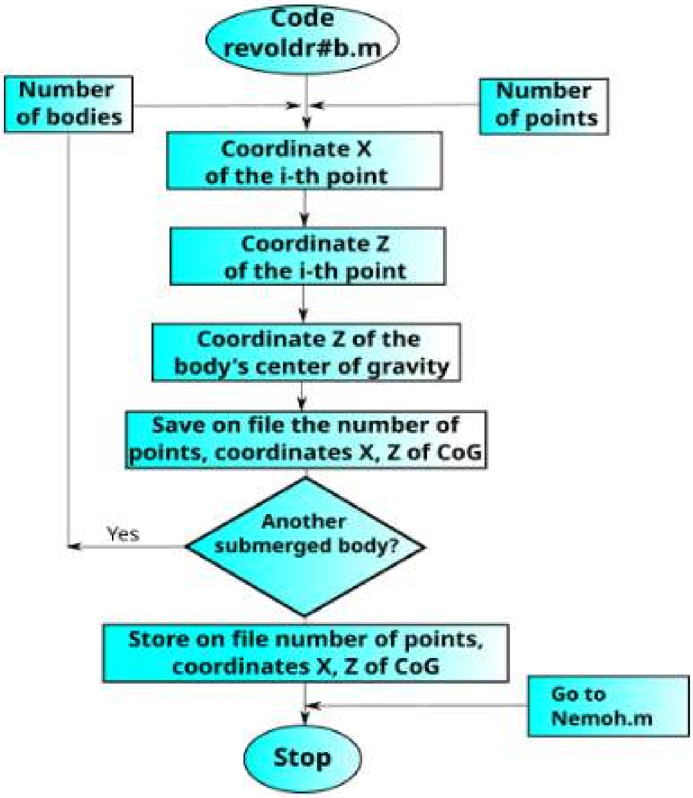
Source: NEMOH MESH (2024).

Figure 5: Octave screen referring to the *revoldr1b.m* code



Source: NEMOH MESH (2024).

Figure 6: shows a schematic representation of the *revoldr1b.m* code flowchart



Source: NEMOH MESH (2024).

while in Figure 8b the unrefined mesh generated by the *axiMesh.m* code is shown and Figure 8c exhibits the refined mesh generated after the execution of NEMOH.

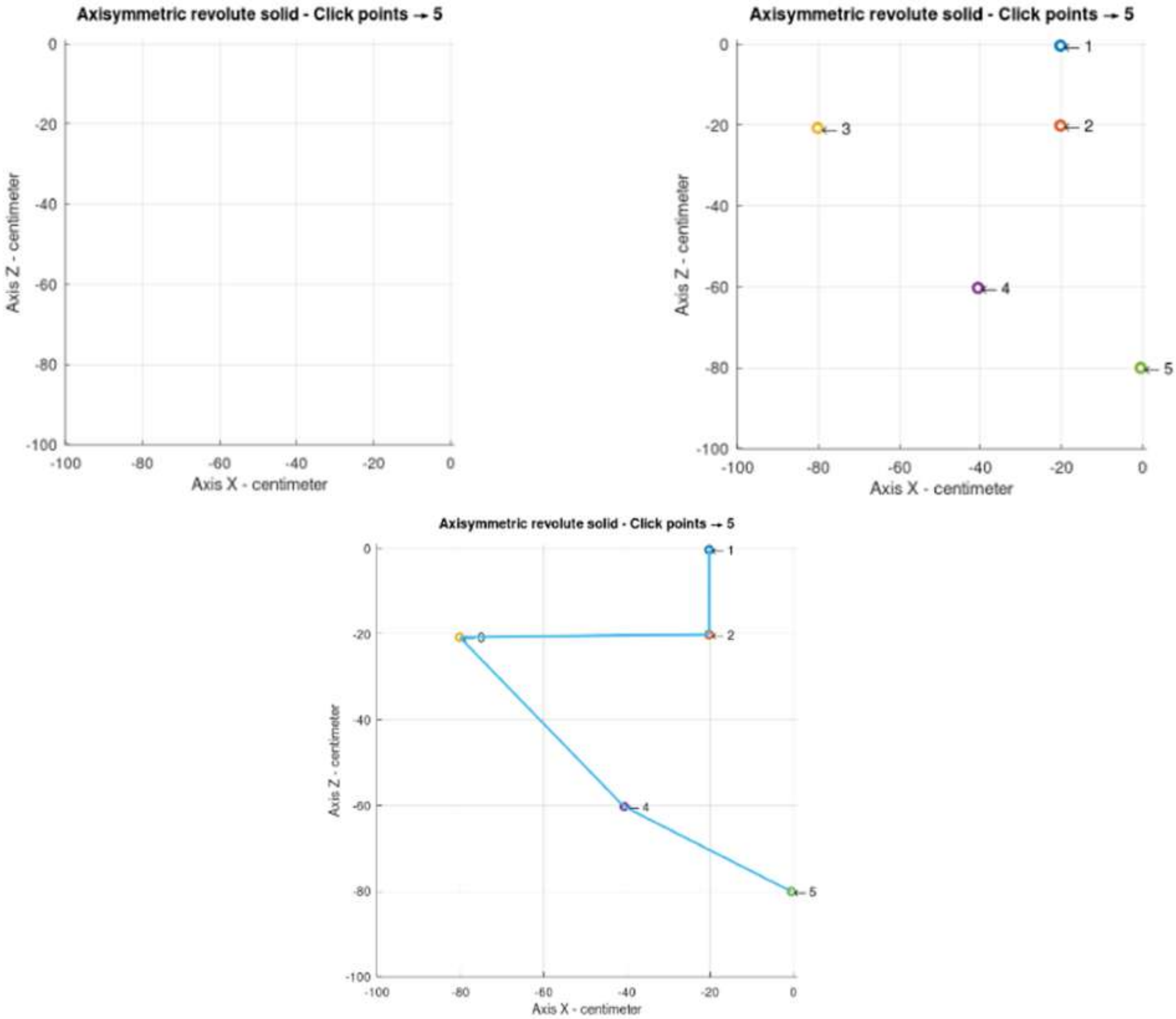
4.2 Generating profiles and meshes of two submerged bodies

The *revoldr2b.m* code was developed to generate two solids of revolution around their vertical symmetry axis (Z Axis) to then be simulated simultaneously in NEMOH. The code is also set to a centimeter scale. The radial magnitudes of the submerged body are represented on the X axis. The code allows the user to adjust the scale to meters if desired. Figure 9 shows a copy of the Octave screen obtained during the execution of the *revoldr2b.m* code. It is also possible to generate more than two solids of revolution (or submerged bodies) using the code *revoldr2b.m* and NEMOH, the user only needs to edit the number of bodies in both software.

As in previous code, when running *revoldr2b.m* in the Octave environment the user can choose to enter the X and Z coordinates of the points or generate such coordinates from the profile using the mouse. In both cases the user just has to choose in the initial menu between Points or Drawing and then inform the number of points to be typed or clicked. Just like in *revoldr1b.m* code, the user simply follows the same steps described previously for each body. It should be noted that the active area for defining the points with the mouse is the same for all bodies. Figure 10 shows the option of generating the profile, where it is possible to observe the numbering from 1 to 5 to define the profile of each body.

After executing the *revoldr2b.m* code in Octave, the user can run the *axiMesh.m* program in Octave and obtain the refinement of the input mesh for NEMOH. To exemplify the validity of the results obtained through the *revoldr2b.m* code and the sequence of these results in the NEMOH, in Figure 11a one has the unrefined mesh generated in the Mesh.m code and Figure 11b

Figure 7: The first three screens of the *revoldr1b.m* code generated in Octave



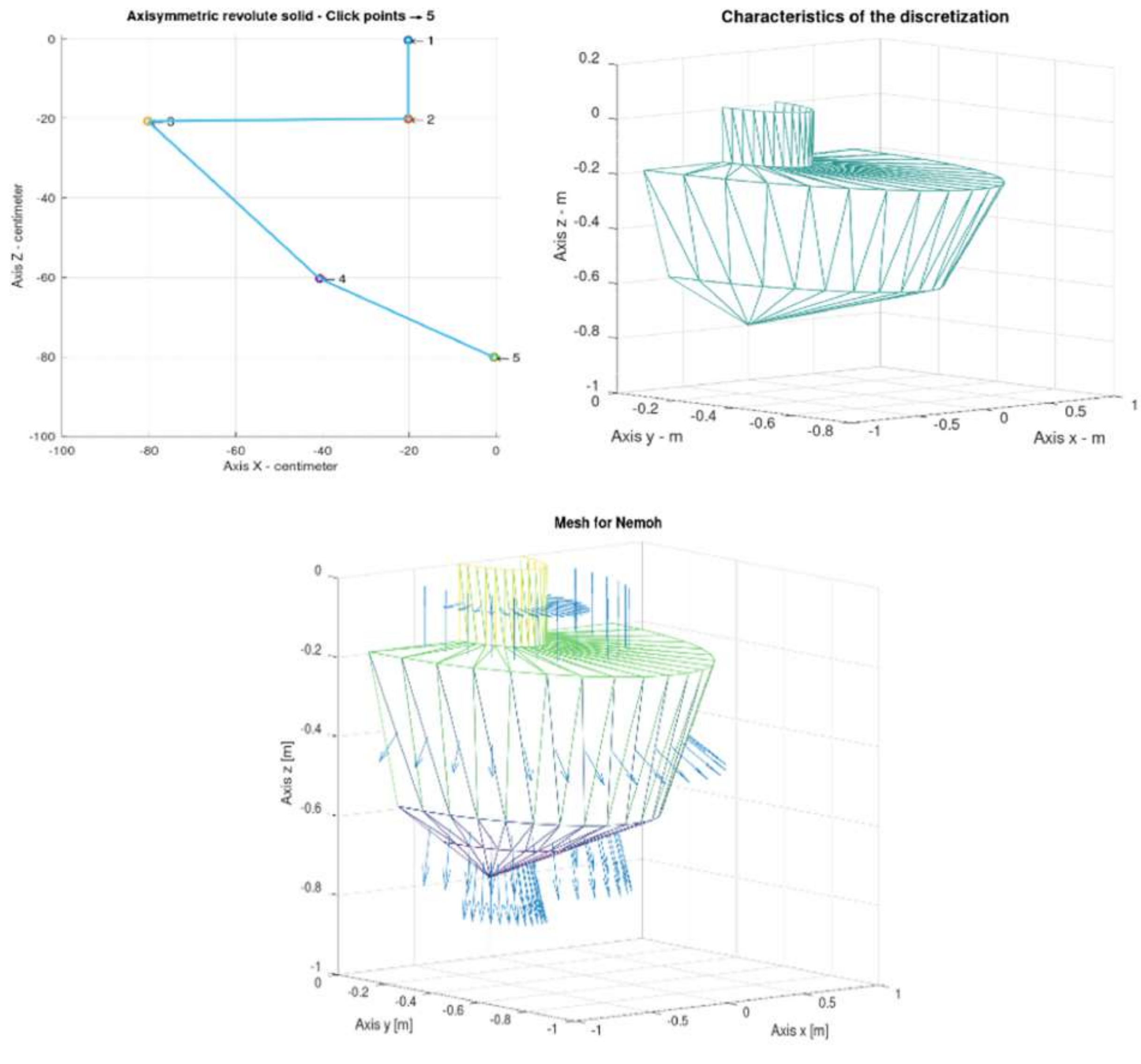
shows the refined mesh generated in the NEMOH representing the submerged bodies.

To compare the quality of the graphics and the compatibility of the *revol2dr.m* code, Figure 11 was generated again in the Matlab software, as can be seen in Figure 12.

4.3 Generating the entire surface of the submerged body

Vincent Arnal, one of the developers of NEMOH, created and made available a code capable of determining extra parameters from the results obtained in the simulation of NEMOH (Nemoh extra abilities) for one body. Among these extra parameters, it is possible to determine the values of the pressure P acting on each panel, considering, among other aspects, the direction of the incident wave (yellow region of Figure 12). Using meshes from *revoldr2b.m*, the refined mesh obtained in NEMOH, and the values obtained from these extra parameters, it was possible to create a routine in Octave to mirror the panels symmetrically, duplicating them one by one and then plotting them using the Matlab/Octave command trisurf(tri, x,y,z,P) to obtain the complete submerged surface of the body, where tri is a triangular mesh generated by the Delaunay triangulation, x and y are the indices of the vertices of each triangle of the mesh in the x-y plane, z is the height of each

Figure 8: a) Generation of the profile of revolution of the wet surface of the body in the code *revoldr1b.m.* b) Coarse mesh generated in NEMOH and c) Final refined mesh of the submerged surface generated in NEMOH



vertex above this plane, and the vector P (pressure) was used to define the color map. Figure 13a shows half of the submerged bodies generated from the NEMOH output parameters and the 3D representation of the entire submerged surface of these bodies on Figure 13b, all obtained from the simulation of the *revoldr2b.m* code.

5 CONCLUSIONS

Despite the existence of several software for drawing 2D and 3D projections used in the simulation of wave energy conversion devices subjected to the action of sea waves, both in proprietary and free software, the generation of the mesh that represents the specific regions of the object modeled still lacks contributions. In this work, two codes written in the Octave computational environment were presented, capable of generating the

Figure 9: Octave screen referring to the *revoldr2b.m* code

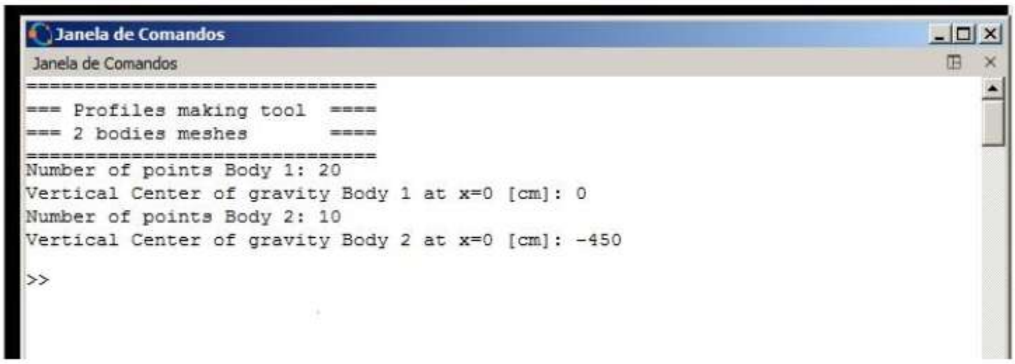
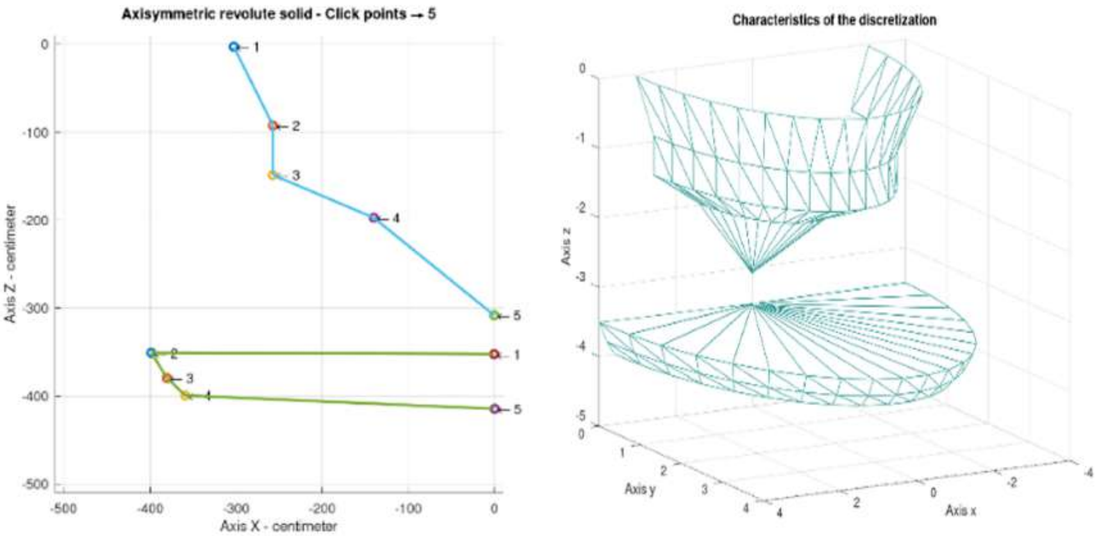


Figure 10: a) Workspace for generating profiles in the *revoldr2b.m* code and b) bodies generated in Octave.



profile (silhouette) of symmetrical submerged bodies, which is necessary for the creation of meshes that represent the wet surface of these three-dimensional submerged bodies. The generated meshes were fully compatible with the routines developed by the creators of NEMOH and necessary for the determination of hydrostatic and hydrodynamic properties through NEMOH.

NEMOH was chosen because it is the first open-source program in the world of the BEM (Boundary Element Method) type for solving the Boundary Value Problem (BVP) of the free linear surface of the body, considering the conditions of contour on the body (body condition). Octave, on the other hand, was chosen for being free software and compatible with Matlab.

The proposed codes *revoldr1b.m* and *revoldr2b.m* are compatible with the free software Octave and capable of generating representative profiles of the wet (submerged) portion of the bodies to be modeled in NEMOH. The proposed *revoldr1b.m* code was able to generate a profile of a solid of revolution around its vertical symmetry axis (Z axis) by typing the X and Z coordinates of the points that describe the body profile. The option of generating the profile coordinates using the mouse was also presented when clicking on the work area of the figure created by the code. The second developed *revoldr2b.m* code was able to generate two solids of revolution around its vertical symmetry axis (Z axis) to be then simulated simultaneously in NEMOH.

Figure 11: a) Unrefined mesh generated in NEMOH from the profile of revolution of the wet surface of the body in the code *revoldr2b.m* and b) Refined mesh

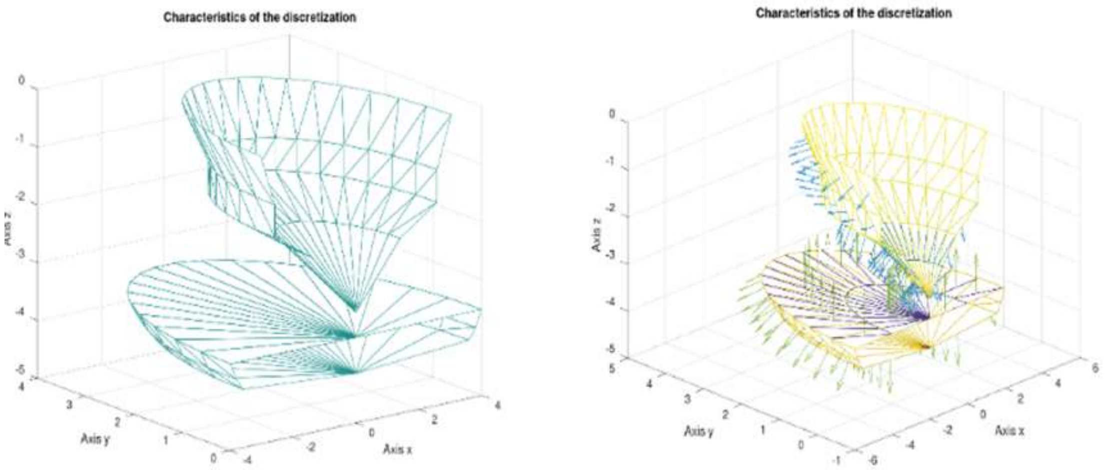
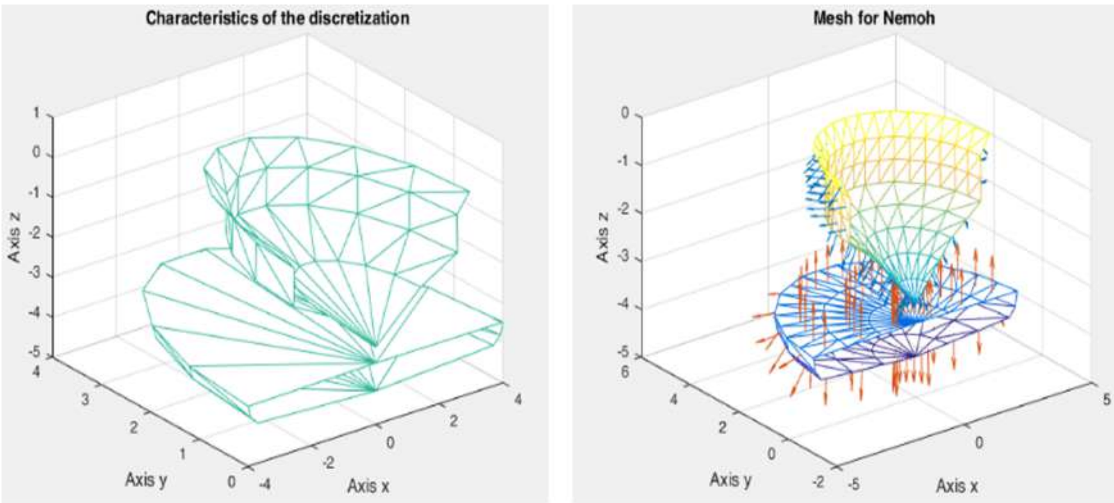


Figure 12: a) Unrefined mesh generated in Matlab from the revolution profile of the wet surface of the bodies and b) Refined mesh



As with *revoldr1b.m*, the user can choose to enter the X and Z coordinates of the points or generate such coordinates from the profile using the mouse.

To exemplify the validity of the results obtained through the codes, several figures were presented. A new routine was also created in Octave to mirror the panels symmetrically, duplicating them one by one, and then plotting them using the Matlab/Octave command trisurf(tri,x,y,z,P) to obtain the complete submerged surface of the body, according to Figure 12.

For future work, it is planned to develop a routine to generate profiles of non-symmetrical bodies.

6 Thanks

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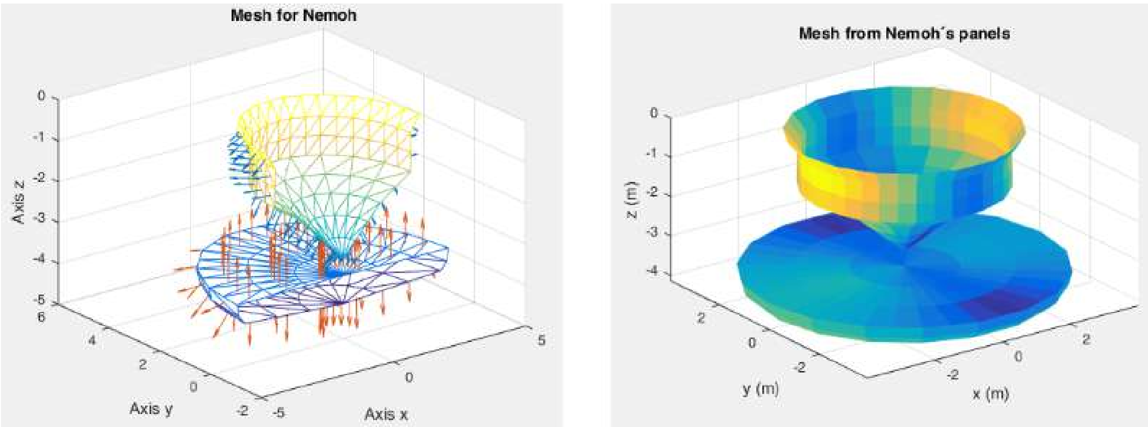
Figure 13: a) Half of the submerged bodies generated from the NEMOH output parameters, b) 3D body generated from the NEMOH output parameters and the *revoldr2b.m* code simulation.



onalism, and to engineer Toby Dewhurst for his patience, precious contributions, and invaluable help in developing the codes for more than one submerged body. Thank you very much to all of you.

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