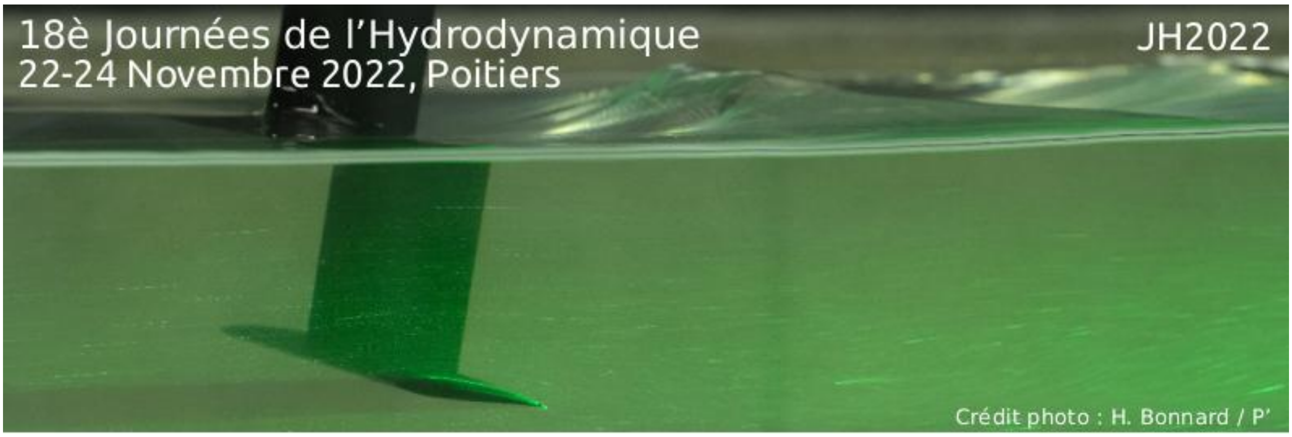

Numerical Model Development of the SEATURNS concept

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Summary

Seaturns is a French company based in Bordeaux which has been developing a new concept of terminator-type wave energy converter (WEC). As part of the engineering services provided by INNOSEA during this period, a numerical model of the system was developed. The objective of this work was to build a model capable of simulating the dynamic behaviour of the concept in order to conduct parametric studies and design variations with more flexibility and speed than with physical models tested in a laboratory.

The WEC concept consists in the following main parts: a cylindrical-shaped floater whose axis is parallel to the wave crest, an internal water volume that acts as a pendulum, a fixed ballast weight positioned below the floater, an innovative mooring line layout which couples the Pitch and Surge motion, and a longitudinal partition of the air chamber above the pendulum to create two independent air chambers. The power conversion system is based on air flowing through a turbine (PTO) located in the partition between the air chambers. The working principle is simple: as the hull rotates in Pitch under the action of the waves, the displacement of the water pendulum inside the floater creates an oscillating air flow between the air chambers. The kinetic energy of this air flow is captured by a turbine, which then converts this passing air flow into electrical energy.

The numerical model is built mainly using the Orcaflex software. It can perform realistic time domain simulations by means of Linear Potential Theory, taking inputs in the form of hydrodynamic databases (HDB) from other software such as Orcawave. However, Orcaflex is unable to calculate the internal forces in the Seaturns concept, related to the dynamic motion of the water pendulum and pressure differences in the internal chambers. Therefore, to consider these effects, a numerical code was developed in the Python programming language and coupled with the Orcaflex model. It acts as an external function to the model, and it feeds the time domain simulations at each time step with the internal force effects. This external function puts together the dynamic equation of the water pendulum motion and the pressure problem, forming an ODE (Ordinary Differential Equation). This ODE is solved, at each time step, with the help of a numerical solver that integrates the equations and derives the internal forces.

After the numerical model was built, a series of test cases and parametric studies were performed to validate its performance and further explore the Seaturns concept. The results of this work show that the numerical model is capable of capturing the physical behaviour of the system and it is a useful tool to provide insights into future designs of the WEC.

I – Introduction

The wave energy sector aims to provide a substantial part of the worldwide energy needs, with many parts of the world benefiting from significant resources [1]. It is in continuous development since the start of the 21^{st} century. Many actions were taken before, but the continuity in research programs, especially within the European Union, can be traced back to the early 2000s. While some programs are or were aimed at developing specific technologies, or to foster development of the sector through case studies linked to specific marine energy concepts, several programs have been financed with the principal goal of supporting the education of marine energy researchers (i.e. Wavetrain programs, Marie Curie EU research grant). These programs also enabled access to test facilities (MaRINET 1 and 2, EU grant Nº 262552 and 731084) and engineering opportunities. Within this context, the Marine Energy Alliance[1] (MEA) project, supported by Interreg North West Europe and national funding agencies, offers engineering services to developers of marine energy technologies with the overall goal of reducing the failure rates during prototype development and improving concept performance. Developers must apply to the scheme and, if selected, they get offered specialised services tailored to their needs.

During the course of the MEA project, the wave energy developer Seaturns[2] was selected. One of the services provided to Seaturns was an evolution of the existing numerical model of the concept which had been previously developed by INNOSEA. Under this service, the existing frequency-based only model would be used to define a new time-domain model of the Seaturns concept.

This study presents the time domain model of the Seaturns concept developed by INNOSEA. It focuses on the peculiarities of this model, i.e. the complex representation of the mooring. The following sections present the Seaturns WEC concept, the architecture and physical base of the numerical model, early validation work of the model, and finally some conclusion and perspective for future work.

II – The Seaturns wave energy converter

The Seaturns wave energy converter (WEC) concept is a cylindrical-shaped floater, with a water ballast inside, acting as a water pendulum. The air chamber above the water pendulum is separated in two by a partition hosting a pneumatic power take off (PTO) system. The working principle is relatively simple, as the hull rotates with the action of the waves, the movement of the water pendulum inside the floater creates an air flow between chambers. The kinetic energy of this air flow is captured by a turbine located on top of the floater inside the chamber and converted into electricity. The concept is equipped with an innovative mooring system, allowing to convert Surge motion into Pitch as the device rolls back and forth on its mooring (see section III-2). More details on the concept are available in [2].

The Seaturns WEC concept consists in the following main parts:

- A cylindrical-shaped floater and an internal coaxial cylinder;
- An internal water volume that acts as a pendulum;
- A fixed ballast weight located below the floater, opposite to the chamber partition;
- Mooring lines working as a station-keeping system;
- A power conversion system based on air flowing through a turbine.

Figure 1 shows the floater rolling with the water pendulum inside and connected to the mooring lines (green line). The degree of freedom in which the floater rolls around the y-axis is

[1] https://www.nweurope.eu/projects/project-search/nwe-mea-north-west-europe-marine-energy-alliance/
[2] https://seaturns.com/

referred to as Pitch, vertical displacements (z-axis) happen in Heave direction and horizontal displacements (x-axis) in Surge direction. The centre of the system is point P, with point O representing the origin of the system before movement started. Points G_w and G_b being the centres of gravity for the water pendulum and fixed ballast weights respectively. The convention is that positive rotations are clockwise, with angle θ representing the angular displacement of the hull in Pitch and angle α the displacement of the water pendulum.

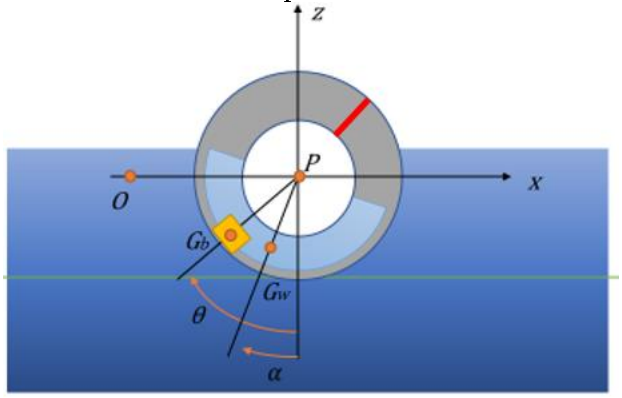

Figure 1: Schematics of the Seaturns concept

The PTO is installed in a partition located on top of the cylinder (highlighted in red in Figure 1, vertical when the system is at rest), that extends itself longitudinally along the y-axis to both extremes of the floater, therefore separating the internal chamber into two chambers, one on the positive side on the x-axis in Figure 1, the other on the negative side.

To this day, the Seaturns development has followed the recommendation of stage-by-stage approach codified in [3]. The technology was tested at increasing scale for validation and improved its performance from 2018 to 2021.

III – Numerical model

III – 1 Modelling challenge

To conduct parametric studies and design variations with more flexibility and speed than with physical models tested in a laboratory, Innosea was hired by Seaturns to build a numerical model of the WEC concept capable of simulating the dynamic behaviour of the system, and to provide design inputs for future prototypes of the concept.

The first approach proposed was to try to develop a numerical model based entirely on an open source programming language, using both analytical equations and a numerical solver. This code was not only going to represent the external hydrodynamics of the WEC, but also the internal forces. The mooring was to be represented by a combination of linearized mooring equations and stiffness matrix, calibrated against experimental data. This approach was proven not to be effective, mainly due to poor mooring behaviour representation. Due to the characteristics of the Seaturns concept [2], the mooring system is a critical part of its performance, and tank test analysis proved that it cannot be efficiently linearised. Thus, a new approach was proposed, in which a state-of-the-art commercial software would be used to carry out the hydrodynamics and mooring modelling.

The model is built mainly using the Orcaflex[3] software. It can perform realistic time domain simulations including mooring lines, wave-structure interaction, second-order effects, and multi-body interactions. The tool can model a variety of objects such as lines, vessels, buoys, shapes, constraints, winches, and others. Orcaflex uses Linear Potential Theory by taking inputs in the form of hydrodynamic databases (HDB) from external BEM software (i.e. Orcawave, Wamit, NEMOH , etc). However, Orcaflex is unable to calculate the internal forces in the Seaturns concept, related to

[3] https://www.orcina.com/orcaflex/, version 11.2d

the dynamic motion of the water pendulum and pressure differences in the internal chambers. For this purpose, a numerical code was developed in Python[4] and coupled with the Orcaflex model. It acts as an external function to the model and it feeds the time domain simulations, at each time step, with the internal force effects due to the water pendulum dynamics and pressure changes. This external function puts together the dynamic equation of the water pendulum motion and the pressure problem, forming an ODE (Ordinary Differential Equation). This ODE is solved, at each time step, with the help of a numerical solver that integrates the equations and derives the inertial forces of the water pendulum motion and the induced moment from the pressure difference in the chambers.

As the simulation evolves in OrcaFlex, the HDB provides OrcaFlex with excitation, radiation and hydrostatic restoring forces, OrcaFlex feeds the external function with instantaneous forces, motions and tensions and get the outputs from the external function. Figure 2 illustrates the data flow described for the numerical model.

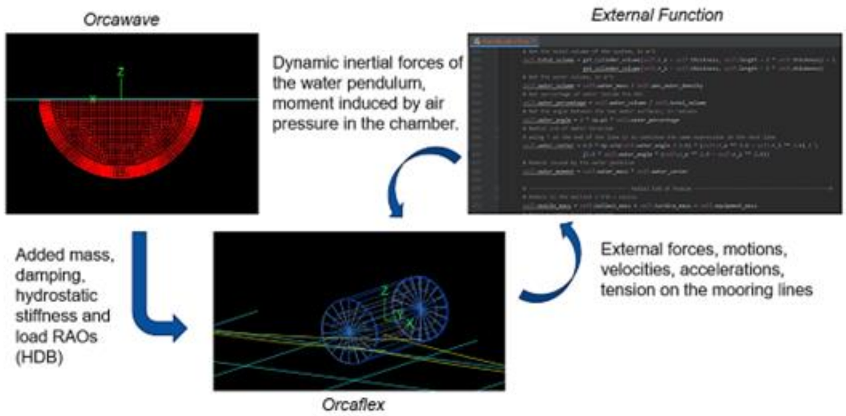

Figure 2: Schematics of the numerical model

The main forces acting on the system can be summarized as follows. At each time step, the first five forces are calculated by OrcaFlex, while the last two are estimated by the external function.. Table 1 presents the numerical model assumptions and limitations.

- Wave-induced forces
- Mooring line forces
- Hydrostatic force
- Inertial force of the floater
- Inertial force of the fixed ballast
- Inertial force of the water pendulum
- Pressure moment induced by the air flow

Table 1. Assumptions & Limitations for the numerical model

Item	Assumptions & Limitations
Environmental Loads	- Linear Potential Theory. - Empirical calibration of viscous damping based on decay tests.
Water Pendulum	- Friction with the internal wall of the floater neglected. - Pendulum represented as a rigid body in free rotation around the floater axis with its own degree of freedom.
Mooring Lines	- Neutral buoyancy mooring lines, like the ropes used in tank tests (during validation of the model).
PTO	- Passive PTO represented as an equivalent turbine drag applied in an orifice location inside the hull.
Internal Air Flow	- Law of Perfect Gases. - Isothermal and isovolumetric system.

[4] https://www.python.org/doc/, version 3

III – 2 Orcaflex Model

To build the Orcaflex model, the Seaturns team provided INNOSEA with data concerning tank scale models used in experimental campaigns. This way, the simulations could be validated against the tank test results. An HDB was prepared for the floater and then uploaded in Orcaflex, with the geometry and mesh being prepared using ANSYS[5], and hydrodynamics solved using Orcawave[6]. Figure 3 shows the mesh of the submerged part of the hull in Orcaflex, whilst Figure 4 and Figure 5 present the catenary mooring system made of chains and rope.

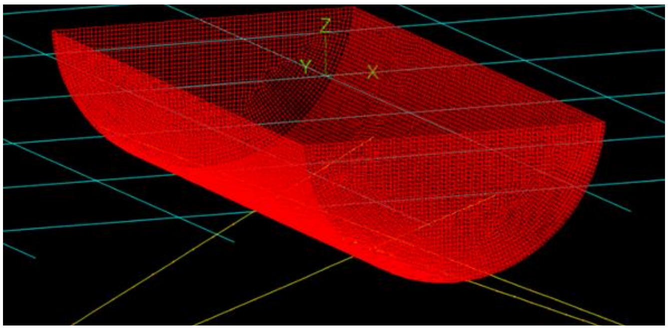

Figure 3: Mesh of the submerged part of the floater in Orcaflex

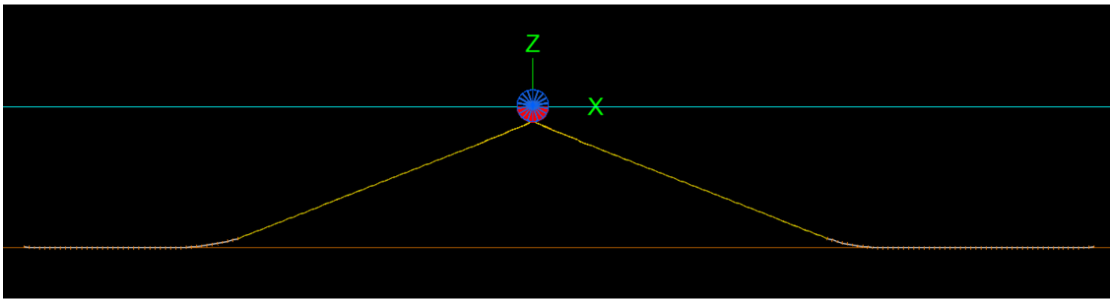

Figure 4: Mooring system configuration

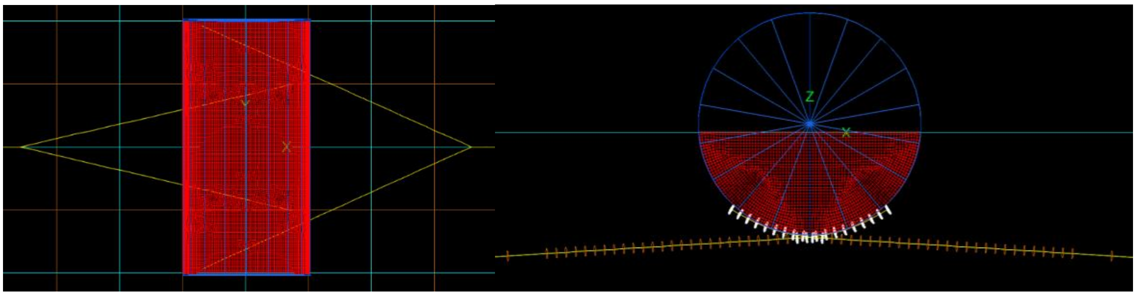

Figure 5: Mooring system details with top view (left) and front view (right)

The correct modelling of the contact area between the mooring lines and the floater is a detail that deserves attention due to the specificity of the Seaturns concept. Usually, offshore structures haver their mooring lines with a small point of contact with the floater, limited to the fairlead position. However, the Seaturns floater must roll around the mooring lines constantly, which increases the area of contact and interaction between lines and floater.

In the Orcaflex model, the discretization of the mooring lines close to the floater was increased with a sensitivity study focused on the stability of the simulation, this can be noticed in Figure 5 by looking at the highlighted orange sections in the line, where each of these sections

[5] https://www.ansys.com/, version 15

[6] https://www.orcina.com/webhelp/OrcaWave/Default.htm, version 11.2d

represents a line node delimiting different segments. This is important because the nodes of the mooring lines are the actual contact points between the lines and other floating bodies in Orcaflex, so having a more discretized line increases the quality of the contact modelling. The nodes highlighted in white represent the nodes which are in contact with the floater in its static position. Moreover, the shape form used to represent the floater (in dark blue in Figure 5) was modelled as an elastic solid material with a high normal stiffness value.

Further details about the theory behind the software can be found in the Orcaflex manual[7]

III – 3 Analytical Model of the External Function

The analytical model presents the equations allowing to describe the dynamic behaviour of the water pendulum and pressure inside the hull. This section will present details on how these equations are derived and used within the external function.

III – 3 – 1 Dynamic equations of pressure variation

The main objective of the resolution of the pneumatic problem is to estimate the rate of change of the pressure in each chamber at each time step.

The pneumatic problem is modelled assuming the perfect gas law, $PV = mR_ST$, and an isotherm compression hypothesis is made. The pressure and volume variable for each chamber are noted P_1, V_1 and P_2, V_2 (see Figure 6). The air masses in each chamber are m_1, m_2, with R_S being the mass-specific gas constant, and $T = T_0$ is the absolute air temperature, constant throughout the system and in time. The PTO air turbine is assumed as a simple orifice.

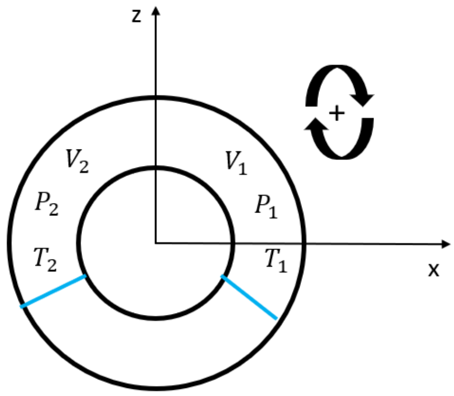

Figure 6: Identification of each of the air chambers and signal convention

At each instant *t*, the flow Q through the modelled orifice is given by the orifice law [4]:

$$Q = A_{pto}C_d\sqrt{\frac{2|P_2 - P_1|}{\rho_{air}}} \cdot sgn(P_2 - P_1) \Rightarrow \dot{m} = Q\rho_{air} = A_{pto}C_d\sqrt{2|P_2 - P_1|\rho_{air}} \cdot sgn(P_2 - P_1)$$

with:

C_d: orifice discharge coefficient, estimated by Seaturns equal to 0.67 from previous tests;

$sgn(\,)$: is an operator that represents the signal of the calculation between ( );

A_{pto}: equivalent orifice area between the chambers;

ρ_{air}: density of air;

$\dot{m}$: the mass flow rate.

For each chamber, the derivation of the perfect gas equation gives:

$$\dot{P}_1V_1 + P_1\dot{V}_1 = \dot{m}R_ST_0 \text{ and } \dot{P}_2V_2 + P_2\dot{V}_2 = -\dot{m}R_ST_0, \text{ with } \dot{m} = \dot{m}_1 = -\dot{m}_2$$

[7] https://www.orcina.com/orcaflex/, version 11.2d

The known state of the system at each time step is $\left[\dot{\theta}, \dot{\alpha}, P_1, P_2, \theta, \alpha\right]$, with α the angular position of the pendulum, and θ the Pitch angle of the hull. From the state vector elements, the volume V_1, V_2 and the volumes rate of change $\dot{V}_1, \dot{V}_2$ can be directly estimated, as well as $\dot{m}$.
The rate of change of the pressure can then be directly estimated at each time step:

$$\dot{P}_1 = \frac{1}{V_1}\left(\dot{m}RT_0 - P_1\dot{V}_1\right)$$

$$\dot{P}_2 = \frac{1}{V_2}\left(-\dot{m}RT_0 - P_2\dot{V}_2\right)$$

The dynamic moment induced in the water pendulum by the change in air pressure between the chambers is given by equation (1), likewise the equivalent moment induced in the floater's hull is defined in (2):

$$M_{pw} = -A_w(P_2 - P_1)\,\frac{r_e + r_i}{2} \tag{1}$$

$$M_{ph} = A_h(P_2 - P_1)\,\frac{r_e + r_i}{2} \tag{2}$$

Where:
A_w: free surface area of the water pendulum inside one chamber.
A_h: effective area of application for the pressure moment transmitting force to the hull.

$$A_h = A_w - A_{pto}$$

III – 3 – 2 Dynamic equations of the water pendulum

Figure 7 presents the position vector of centre of gravity of the water pendulum. To derive its expression, the angle between the free surfaces of the water pendulum on each side of the floater needs to be considered.

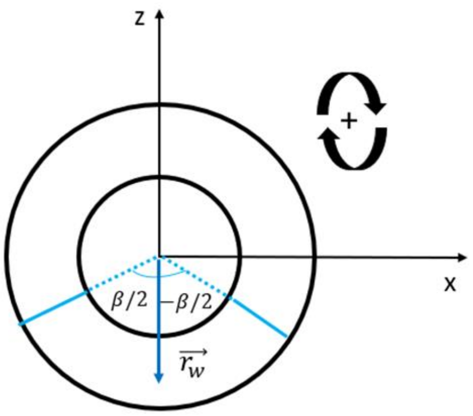

Figure 7: Position vector for the water pendulum

$$r_w = \frac{\int z\,dm}{\int\,dm} = \frac{\int_{r_i}^{r_e}\int_{-\frac{\beta}{2}}^{\frac{\beta}{2}}(r cos\theta)\,\rho_w r d\theta dr}{\int_{r_i}^{r_e}\int_{-\frac{\beta}{2}}^{\frac{\beta}{2}}\rho_w r d\theta dr} = \frac{\rho_w\beta(r_e^2 - r_i^2)}{2} \tag{3}$$

Where:
dm: infinitesimal mass of water pendulum, with $dm = \rho_w r d\theta dr$;
ρ_w: density of water used as water pendulum;
β: angle between free surfaces of the water pendulum;
V_w: volume of water pendulum;
m_w: mass of the water pendulum;

V_{total}: total volume inside both chambers of the floater;
L: length of the floater along the y-axis.

To find the acceleration of the water pendulum, we develop an expression for $\overrightarrow{r_w}$ in the global coordinate system, as a function of (x, z).

$$\overrightarrow{r_w} = (-r_w \sin \alpha\,, -r_w \cos \alpha) \tag{4}$$

$$\begin{aligned} x_w &= x - r_w \sin \alpha \\ z_w &= z - r_w \cos \alpha \end{aligned} \tag{5}$$

Where:
α: angular displacement of the water pendulum. It is the angle between the position vector and the z-axis in a local coordinate system, as illustrated in Figure 1;
x: floater displacement in Surge;
z: floater displacement in Heave.

To find the corresponding acceleration vector of the water pendulum $\vec{a}_w$ in the global coordinate system, we derive $\overrightarrow{r_w}$ and its components twice with respect to time. Considering the water pendulum as a point-mass, the inertial dynamic moment τ_w for the water pendulum is:

$$\tau_w = m_w \vec{r}_w \wedge \vec{a}_w = m_w r_w (\ddot{\alpha} r_w + \ddot{z} \sin \alpha - \ddot{x} \cos \alpha) \tag{6}$$

The operator $\wedge$ represents a vectorial product. The water pendulum has also a gravitational dynamic moment $\tau_{w,g}$, which can be deduced as:

$$\tau_{w,g} = m_w \vec{r}_w \wedge \vec{g} = -g m_w r_w \sin \alpha \tag{7}$$

The different forces acting on the system can be described based on Newton's Second Law for the water pendulum degree of freedom:

$$\tau_w = M_{pw} + \tau_{w,g} \tag{8}$$

Substituting equations (1), (6) and (7) into (8) and re-arranging we have:

$$\ddot{\alpha}(m_w r_w^2) + \ddot{z}(m_w r_w\, sin\, \alpha) - \ddot{x}(m_w r_w\, cos\, \alpha) = -A_w (P_2 - P_1)\, \frac{r_e + r_i}{2} - g m_w r_w\, sin\, \alpha \tag{9}$$

III – 3 – 2 Numerical implementations

Finally, the external function must solve the following system of equations:

$$\begin{cases} \ddot{\alpha}(m_w r_w^2) + \ddot{z}(m_w r_w\, sin\, \alpha) - \ddot{x}(m_w r_w\, cos\, \alpha) = -A_w (P_2 - P_1)\, \dfrac{r_e + r_i}{2} - g m_w r_w\, sin\, \alpha \\ \dot{P}_2 = \dfrac{1}{V_2}\left(-\dot{m} R T_0 - P_2 \dot{V}_2\right) \\ \dot{P}_1 = \dfrac{1}{V_1}\left(\dot{m} R T_0 - P_1 \dot{V}_1\right) \\ \dot{m} = A_{pto} \rho_{air} v = A_{pto} C_d \sqrt{2|P_2 - P_1| \rho_{air}} * sgn(P_1 - P_2) \end{cases}$$

The OrcaFlex model feeds the external function with the external force and the state vector components. Initial values correspond to the static equilibrium position of the Orcaflex model. For P_1 and P_2, initial values correspond to standard air pressure of 1 atm = 101325 Pa.

In the Python code, first it is necessary to create a function that analytically derives the expressions of the equations that need to be solved, this is the deriv() function. Later, a native function from the SciPy[8] package in Python is used to numerically solve the analytical expressions defined by deriv(), at each time step, with the data provided by the OrcaFlex model.

The purpose of deriv() is to analytically develop the expressions to derivate the initial state vector containing velocities, pressures and displacements to a new state vector containing accelerations, rate of change of pressure and velocities (see Figure 8).

To do so, it makes use of a state vector $X(t)$, containing the variables $\left[\dot{\theta}, \dot{\alpha}, P_1, P_2, \theta, \alpha\right]$. The system of equations is written as a function of these variables, which allows the expression of first and second order derivatives of these variables. The deriv() function can then provide the derivative of the state vector $\dot{X} = \left[\ddot{\theta}, \ddot{\alpha}, \dot{P}_1, \dot{P}_2, \dot{\theta}, \dot{\alpha},\right]$.

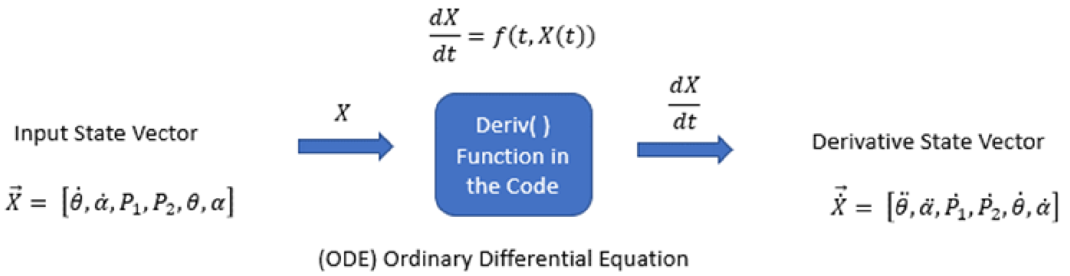

Figure 8. Schematics of the deriv() function

In the end, what we are really interested in are the values for pressure in the chambers (P_1 and P_2) and water pendulum motions (α). As the analytical expression of the derivative state vector contains accelerations, rate of change of pressure and velocities, the next task is to solve this ODE problem by means of a numerical solver, the solve_ivp() function. This function numerically integrates a system of ODE given an initial value and the analytical expression of the state vector derivative. In our case, the initial value is the input state vector containing the values from the previous time step, and the limits of integration are the current and previous moments in time of the simulation.

At each time step *t*, the state vector must be defined from known quantities to be passed as input to the deriv() function. While the variables P_1, P_2, θ, α and $\dot{\theta}$ are known at time t, the derivative $\dot{\alpha}$ is not, and therefore the estimate from the previous time steps is used. This means that, at each time step, we have limited information about the past states of the system, since there is no memory function. This prevents the implementation of complex PTO control strategies, which usually requires to have information of the state of the system from a significant number of previous time-steps. At this stage of the Seaturns technological development, this has not been an issue, however it is a clear point of improvement for future works.

It is important to mention that the numerical solver uses an adaptative sub time step to solve the equations. This means that the numerical integration within the ODE can be solved with a shorter time step than the hydrodynamic problem in Orcaflex. This allows the problem solved by the external function to be potentially stiffer than the hydrodynamic problem solved by Orcaflex, therefore having different time step schemes allows the resolution of the overall problem to be faster and stable, otherwise Orcaflex would have to unnecessarily take the same time step resolution of the numerical solver in the external function.

After completing the numerical integration, we obtain a new input state vector, with updated values in the current time step for pressures in the chamber, water pendulum motion and velocity. The updated state vector is stored to serve as input state vector in the next time step. In the end of each time step, the external function transfers to the OrcaFlex model three forces, the horizontal inertial force of the water pendulum F_x, the vertical inertial force of the water pendulum F_z and the pressure moment induced by the moving air flow between the chambers M_y. These are applied to the system, in combination with the external forces already calculated by Orcaflex.

[8] https://docs.scipy.org/doc/scipy/reference/generated/scipy.integrate.solve_ivp.html

IV – Validation

The current state of the model and the definition of the mooring system were checked against the experimental results obtained in the CCOB[9] wave tank. At this stage, the objective was fundamentally to validate the main modelling options and a complete agreement with the tank data is not thought after. While care has been taken to replicate the device characteristics as well as possible in the numerical model, significant differences remain:

- The numerical model assumes a perfect orifice between the chambers, whereas the tank model was fitted with a representative pneumatic PTO system based on an air turbine. This would induce significant differences in the expected flow, especially for small values of pressure differential. The overall damping provided to the pendulum is likely to be different.
- To obtain the right mooring pretension, the length of the mooring lines had to be adjusted. This results in small but significant differences in the mooring geometry between the numerical and experimental model, which are likely to have an impact on the mooring characteristics. These necessary adjustments are likely due to the difficulty of measuring accurately the mooring line lengths and to take into account the tightening of knots and the creep of the lines after several tension cycles.

The initial checks are focused on the static properties of the mooring system as the mooring characteristics proved to have a strong influence on the model behaviour in previous test campaign [2]. Pull-out tests were carried out in the tank to evaluate the mooring stiffness and are reproduced with the model. Figure 8 presents the comparison between the experimental and numerical model for one of the runs. Overall, a good agreement is achieved, especially for the small displacement, whilst for the larger the model presents a slightly lower stiffness than the actual tank model.

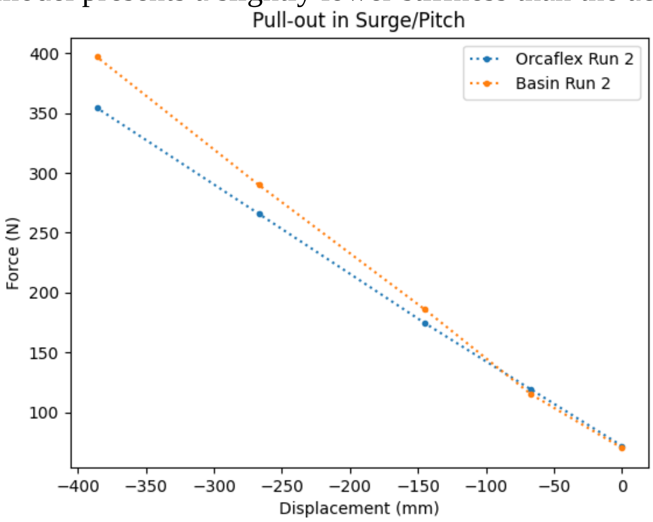

Figure 8: Comparison of pull-out tests for Run 2

The decay tests carried out provided a good opportunity to check the adequate behaviour of the relation between Pitch and Surge of the model, and of the dynamics of the pendulum. Due to the nature of the system, it appears to be impossible to force the numerical model position from the static equilibrium to the offset fixed position in the tank without creating numerical instability. Instead, a method consisting of applying subsequent threshold of Surge force was devised to gradually bring the model to the desired position, and then the virtual force can be stopped to simulate the release of the device as in the tank. The detail of this load is presented in Figure 9. It should be noted that at the time of the release (45s) the numerical model was not completely still, and further decay tests simulation should contemplate longer threshold before the release.

[9] https://ihcantabria.com/instalaciones-experimentales/laboratorio-de-hidraulica-costas-y-offshore/

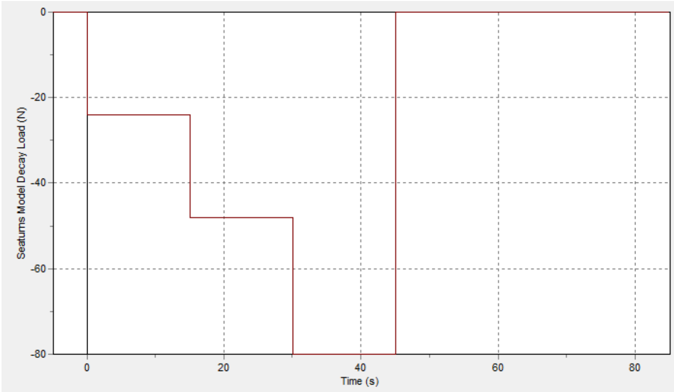

Figure 9: Decay load applied in the numerical model in steps, to ensure numerical stability

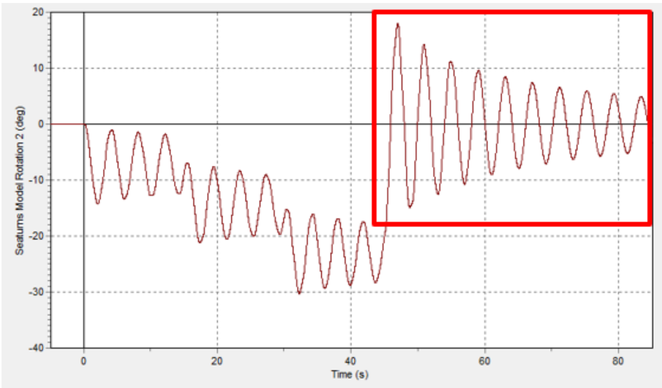

Figure 10: Decay motion data in Pitch, red square highlights the actual decay test data considered

The natural decay period in Pitch of both models was evaluated (see Figure 10) . For the tank model, values of Pitch pseudo-periods were measured around 6.8 seconds, whereas it was estimated at 4.05 seconds for the numerical model. The rate of decrease of the oscillations was also higher in the tank model experiments. This points towards a higher damping in general in the tank experiment, probably due to the difference in the pneumatic PTO system and the perfect orifice of the numerical model, as well as different levels of hydrodynamic damping.

The comparison of the pressure differential in the chambers against the relative position between the pendulum angular position and the device Pitch is a good method to evaluate the behaviour of the external function. Figure 11 presents this evolution for the tank model on the left plot, and the numerical model simulation on the right plot.

The pressure differential evolves similarly in both case, which is reinsuring regarding the good work of the external function, the phase between both quantities is correct. However, it can be seen that the pressure differential values is decreasing much faster in the tank model.

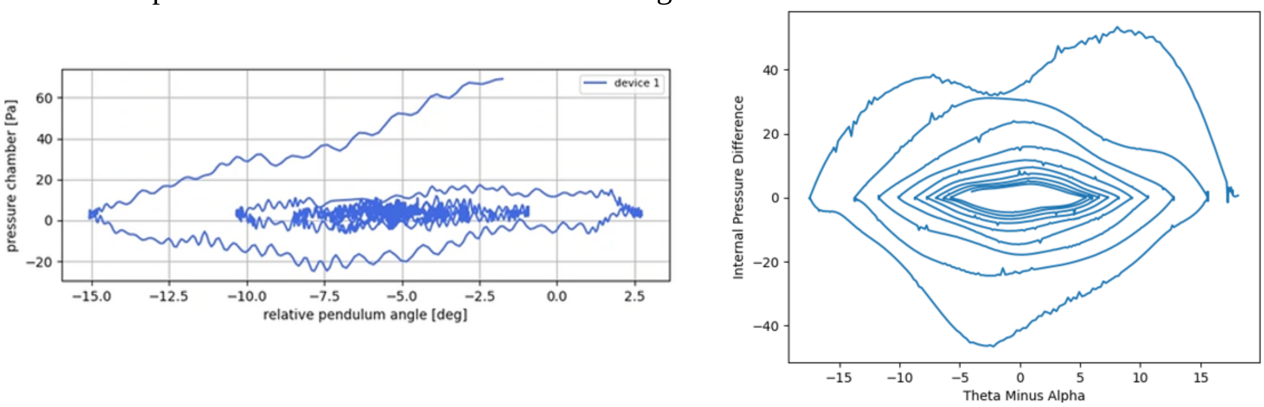

Figure 11: Comparison of internal pressure versus relative angle of floater and water pendulum

Comparison of the numerical model with results in regular wave could not be completed due to the mooring geometry implemented in the tank, which created significant issue for the Orcaflex mooring model in these conditions. The frequent contact of the section connecting the rope and the chain with the seabed created numerical instabilities, since the stiffness of both material is very different. As the mooring geometry of the concept is evolving, it was not seen necessary to focus more resource on resolving these issues in the numerical model at this stage.

V – Conclusions and perspectives

This study presents the integration of an external function used to model the dynamics of internal body within a hull with a complex Orcaflex model. This allows the representation of complex mechanical systems with their own dynamics and to benefit from the capabilities of Orcaflex to represent complex moorings and wave-structure interactions.

The validation works on the model show that the model is fundamentally able to reproduce the concept behaviour, even if further improvement is required to obtain a good agreement in terms of absolute values of internal pressure and motions. Future works on the model will focus on evaluating the sensitivity of the numerical model to several parameters in order to better understand and interpret the differences observed between experimental and numerical results. Once calibrated, future model evolution will concentrate on the integration of a realistic turbine model, and the integration of further hydrodynamics effect into the actual Orcaflex model, and the possibility to model multiple Seaturns device on a single mooring as it is expected to be deployed in future commercial arrays.

VI – Acknowledgments

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