# EXPERIMENTAL AND NUMERICAL DETERMINATION OF THE HYDRODYNAMIC CHARACTERISTICS FOR A SMALL-SCALE MODEL OF A SUBMERSED VEHICLE

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*The acoustic prospecting systems of the marine environment having water as their working environment can be placed on shore installations, on the seabed or on a carrier object in immersion, on the water surface or in the air. In this paper, an experimental and numerical study for the determination of the hydrodynamic coefficients for a scale model of a submersed vehicle is presented. The 1:14 scale model was towed into a water pool, in order to measure the hydrodynamic forces exerted on it. A numerical modeling of the vehicle movement in the water using a deformable discretization is also performed.*

**Keywords**: underwater towed vehicle, CFD, modeling, simulation, scale model.

## 1. Introduction

The prospecting of the marine environment is a field with wide applications in economics and science. The exploitation of sea resources, the geological - geophysical research of the ocean floor, the discovery and location of objects located on the seabed, in immersion or on the surface represent only some of these applications. The marine acoustic prospecting systems mounted on surface ships have the greatest popularity. In this last case, the ship's own noises created by the mechanisms, the propulsion system, namely the hydrodynamic noise represents a serious impediment in achieving a good prospecting.

Lately, the towed systems for the prospecting of the marine environment, where the main element of the system (the one that converts acoustic pressure in electrical signal and/or vice versa) can be immersed at the optimal depth in terms of the propagation of acoustic waves, are imposing themselves on the market.

These systems are increasingly used in the geological - geophysical research of the bottom of the planetary ocean in order to discover the areas with hydrocarbon resources and mineral deposits, in the seismographic prospecting of the submarine soil, in the exploitation of the large submarine oil and gas pipelines, in "scanning" the seabed to locate shipwrecks or other objects, in detecting fish groups and also in the military field of submarine detection [1].

The study of the dynamics and stability of towed submarine vehicles is based on the determination of hydrodynamic coefficients that allow the measurement of hydrodynamic forces and moments.

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Laboratory experiments on scaled models allow the observation of important phenomena with financial savings, as they facilitate the prediction of model behavior in real conditions. The drag force has the expression:

$$F_D = \frac{1}{2}\rho v^2 \cdot S \cdot C_D \tag{1}$$

where $C_D$ is the drag coefficient, $\rho$ is the density of the fluid, $v$ is the relative velocity of the immersed body in the fluid, and $S$ is the characteristic area of the vehicle (the projected area of the vehicle on a normal plane to the direction of motion) [2].

The use of the experimental method for directly obtaining results regarding the solution of a specific problem of fluid mechanics or hydraulics is done on physical models on a small scale in laboratory conditions.

Paper [3] introduces a technique for determining characteristic areas by capturing images of the vehicle from various angles, covering a wide range of movement scenarios.

A specific procedure was proposed in order to estimate the hydrodynamic parameters of a basic small-scale model of a submarine in [4].

The similarity criteria *Re* (Reynolds) and *Fr* (Froude) are the basis of the laboratory simulation process, on a reduced scale model of the natural phenomenon. Because the two criteria are being incompatible, the most important criterion in the development of the phenomenon must be chosen [5].

To model the displacement of a body immersed in water at a depth where the influence of the free surface can be neglected, the criterion *Re* is chosen as determinant in the modelling process [6-7]. In this case, the underwater vehicle drag force has only friction and form (pressure) type components which has to be modeled at the transposition from full scale to reduced scale model by Reynolds similarity criteria [8].

Experimental research can be carried out in water pools by towing the model, or in water tunnel and the wind tunnel for fixed models [10].

Papers [11-12] present the determination of lift and drag coefficients, both numerically using CFD simulation, but also experimentally by towing a 1:32 scale model in a water tank.

In the work [7], the determination of the drag coefficient by testing the scale model in the towing tank, is presented. The experimental parameters are expressed in terms of the Reynolds criterion.

This paper aims to present an experimental and numerical study in order to determinate the hydrodynamic coefficients for a 1:14 scale model of a submersed vehicle.

## 2. Numerical modeling

The most accessible numerical method and algorithm to investigate problems that involve fluid flows based on the principles of fluid mechanics is Computational fluid dynamics modeling (CFD) [13]. For this CFD modeling, we performed a simulation using a deformable discretization for the moving vehicle wall area and a stationary fluid.

Considering the same number of cells, a new discretization and a mapping of the results for the new configuration must be permanently determined. The Ansys CFX software was used for the numerical calculation [14].

The presented simulation corresponds to the reduce-scale model (1:14), at trim angle of 0 degrees, the velocity being 0.47 m/s.

The dimensions of the scaled model are presented in Fig. 1.

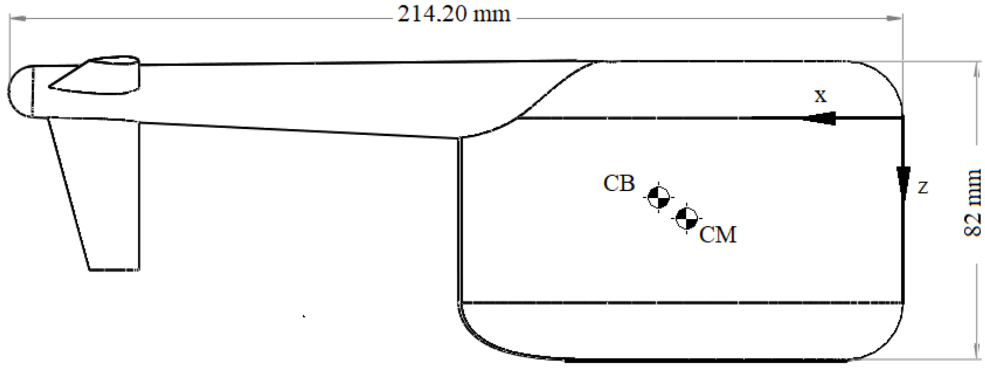


Fig. 1 Geometry of the scaled model, with the position of the center of mass

Regarding to the system depicted in Fig. 1, the center of buoyancy coordinates are (millimeters): $x_{CB} = 58.50$, $y_{CB} = 0.00$, $z_{CB} = 19.09$ and the coordinates of center of mass are (millimeters): $x_{CM} = 60.59$, $y_{CM} = 0.00$, $z_{CM} = 18.77$.

The volume of the scale model is 210601.24 $mm^3$ and the cross-sectional area is 4937.3 $mm^2$.

The Reynolds number corresponding to the drag velocity is $1.002 \cdot 10^7$. The turbulence model used is $k - \varepsilon$ [15].

In modeling, the mechanical system that produces the movement of the model is neglected (namely, the presence of the model holding rod is neglected).

Fig. 2 presents the distribution of the dynamic pressures in the vertical longitudinal plane and on the moving walls of the vehicle, for different moments of time: 0.25 s, 0.5 s, 0.75 s and 1 s. An increase in manometric pressure in the frontal area of the vehicle is noted, immediately followed by an area with negative manometric pressure variations on the stabilization surfaces of the tail. During the movement, the manometric pressure values increase.

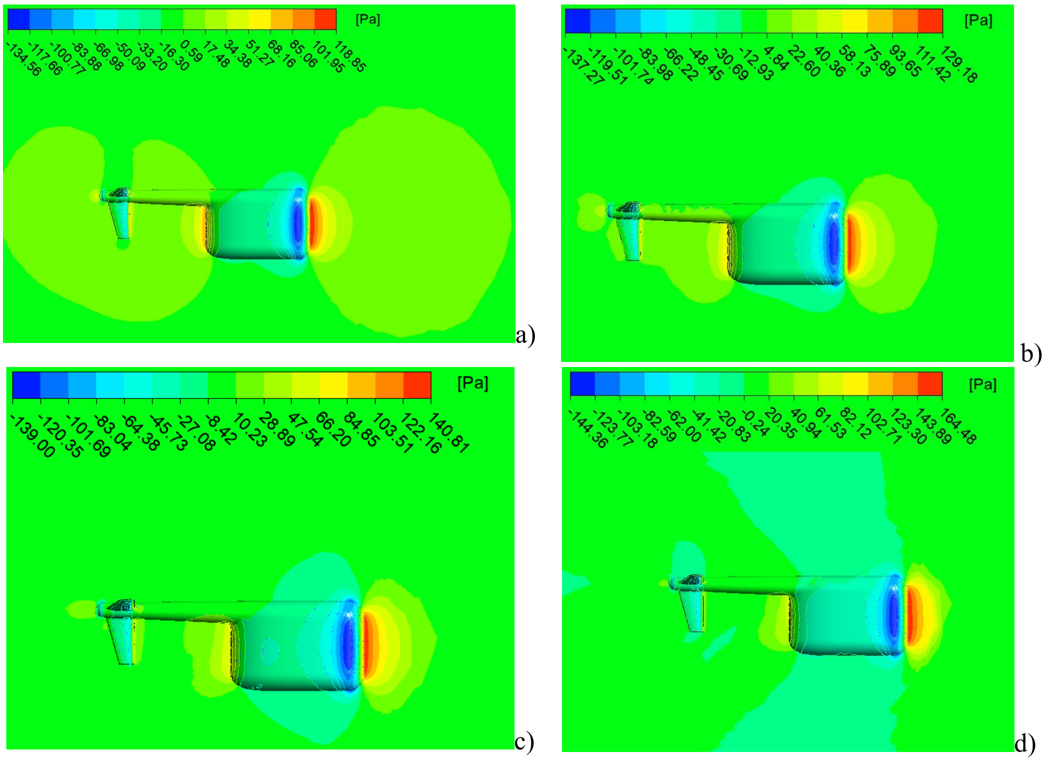


Fig. 2. The dynamic pressure distribution around the vehicle at:
a) 0.25 s, b) 0.5 s, c) 0.75 s, d) 1 s

Fig. 3 presents the distribution of velocities in the vertical longitudinal plane, for the same moments of time: 0.25 s, 0.5 s, 0.75 s and 1 s.

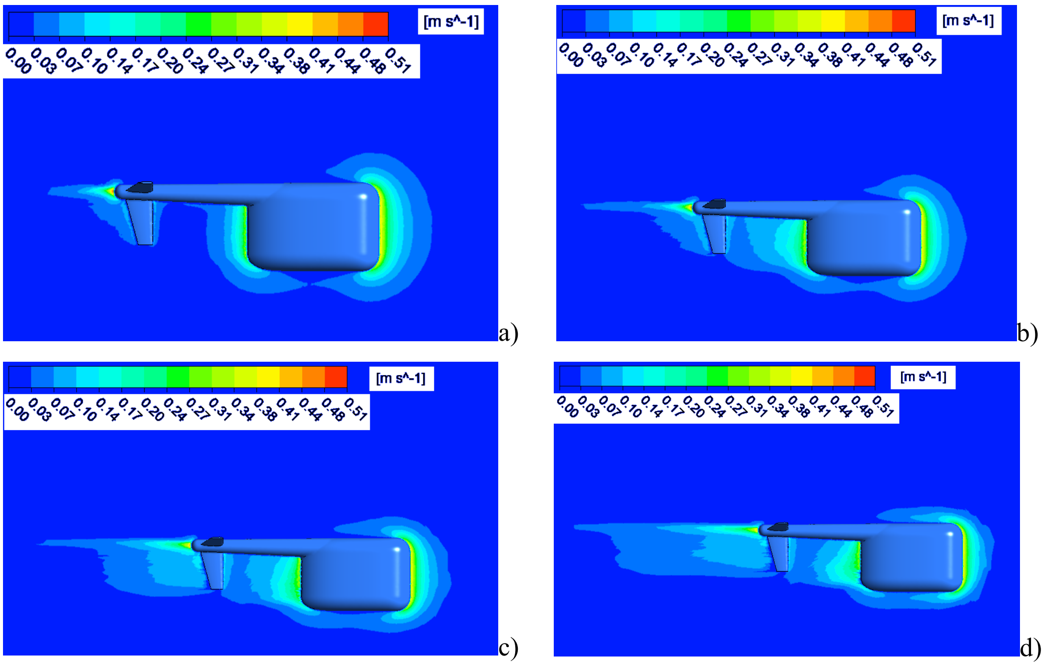


Fig. 3. The velocity distribution around the vehicle at: a) 0.25 s, b) 0.5 s, c) 0.75 s, d) 1 s

An evolution of the flow over time is observed along the vehicle wall area, the maximum velocity having a constant value of 0.51 m/s.

Additionally, to the pressure and velocity fields, from the numerical simulation, drag forces were extracted by integrating the pressure and viscosity shear stress on the surface of the body.

## 3. Experimental determination of hydrodynamic coefficients with a mobile scale - model

For the experimental determination of the hydrodynamic coefficients in the case of the mobile model, a 1:14 scale model was used, which was towed through a parallelepipedic pool with the dimensions 2 m x 0.4 m x 0.3 m.

The model was immersed in the pool and positioned under a certain trim angle that ranging from five-to-five degrees between $-20°, +20°$ (Fig. 4). The angular position was determined using a protractor joint.

The model is attached through the force sensor to a mobile platform that can translate along the pool, being driven by a stepper motor (Fig. 5).

The model was fixed by a cylindrical steel rod with a diameter of 4 mm. The assembly, model together with the positioning system and the force sensor were translated at constant velocity.

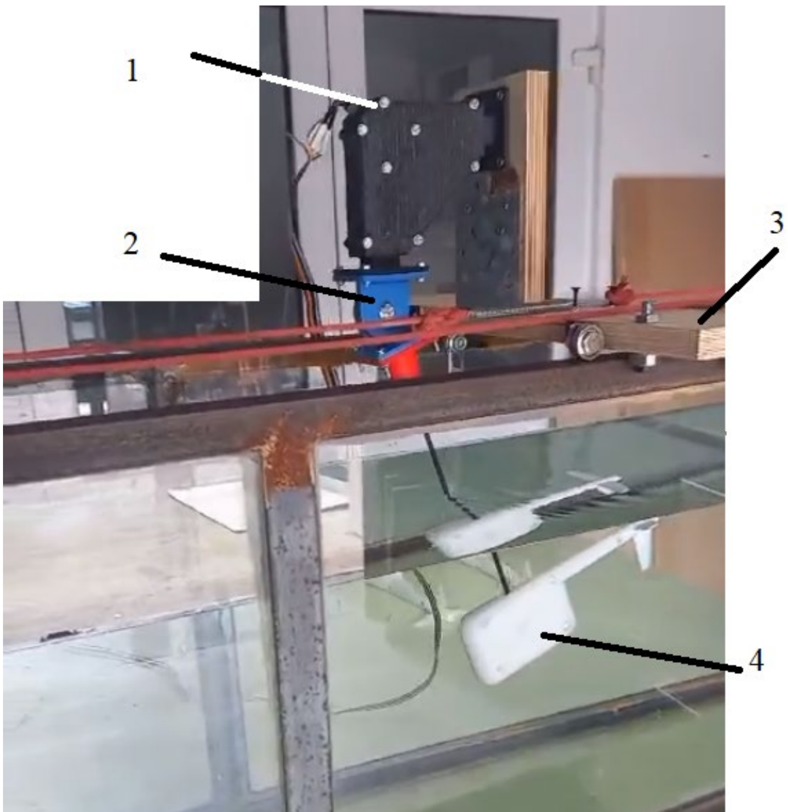


Fig. 4. The model submersed in the pool: 1 – force sensor;
2 – protractor (allows setting the trim angle); 3 – mobile platform; 4 – scaled model

The engine command and implicitly the translation velocity of the platform, were initiated by pulses given by the Arduino type controller, the motor driver.

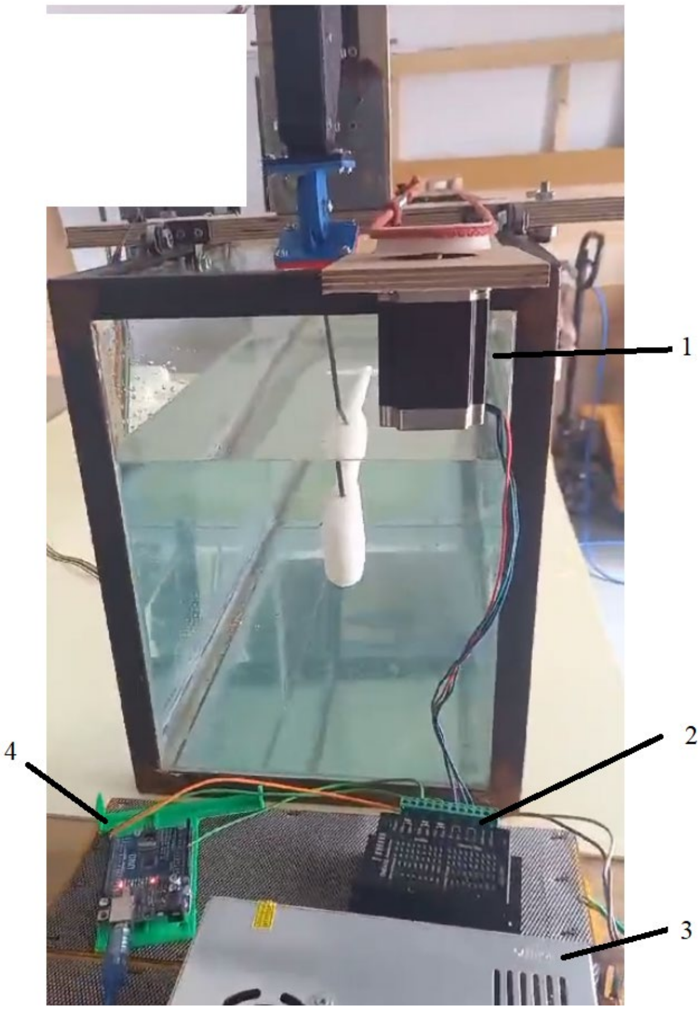


Fig. 5. Mobile platform operation:1 – stepper motor; 2 – driver motor; 3 – power source; 4 – controller

The 1:14 scale model illustrated in Fig. 6 was made on a 3D printer, from polylactic acid (PLA), from two symmetrical parts. After assembling the two 3D printed parts with screws (the screw head and the nut are inside the structure), the remaining holes were covered with putty and the surface of the model was sanded.

Data acquisition is performed using a specific QuantumX MX1615B instrument. The device is used to acquire data from resistive, inductive or piezoresistive strain gauges in full bridge, half bridge and quarter bridge configurations. The data acquisition from the QuantumX module is made by a Catman interface. This program allows the storage, analysis and visualization of data during and after the completion of the investigation [16].

Data acquisition for the proposed configuration was done with a frequency of 300 Hz.

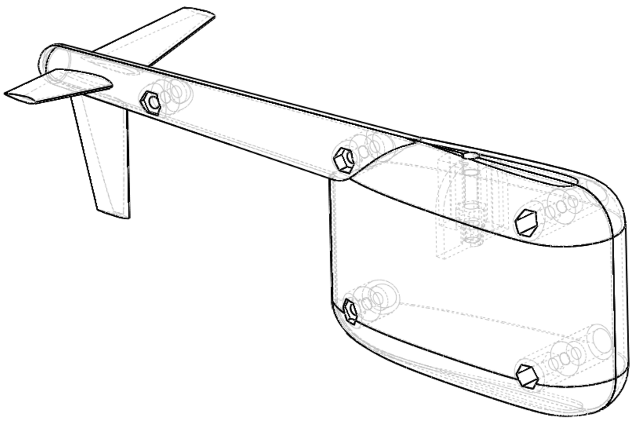

Fig. 6. The geometry of the 1:14 scale model made with the 3D printer

In Fig. 7 is presented the drag force evolution determined experimentally and numerically, in a comparative manner for 0 to 1 second interval and for −20° trim angle.

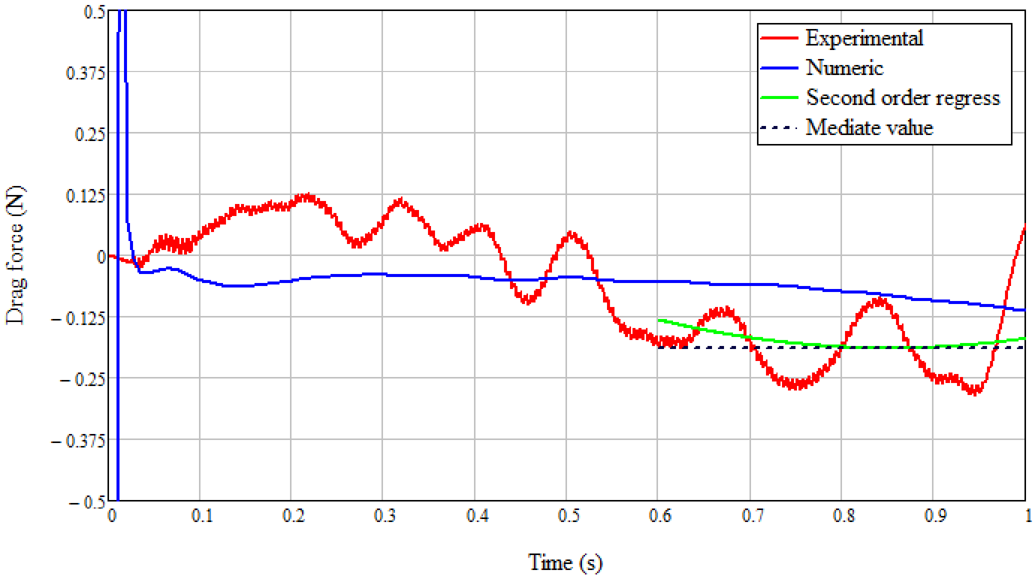


Fig. 7. The drag force evolution determined experimentally and numerically

The FFT analysis of the recorded signal is presented in Fig. 8. From the undamped free vibration analysis through finite element method, for the system composed of: scaled model, rod, clamping elements and force sensor, the natural frequencies with values of 3.97 Hz, 10.6 Hz and 66.9 Hz in the model's plane of movement are observed. For the first two frequencies, the deformation mode is bending, with large relative displacements of the clamping rod and model assembly, in the force sensor the relative displacements being very small.

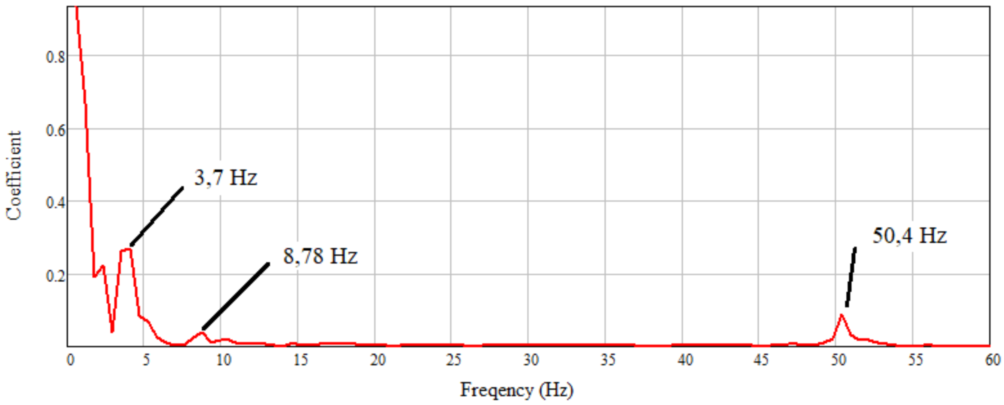


Fig. 8. The Fourier transform of the resistance force determined experimentally

To determine the value of the hydrodynamic forces, the signal recorded by the force sensor is averaged over the time interval of $(0.6,1)$ seconds.

Fig. 9 and Fig. 10 present the drag coefficient and lift coefficients variations, corresponding to the towing velocity of 0.47 m/s, depending on the trim angle.


Fig. 9. Variation of drag coefficient according to the trim angle

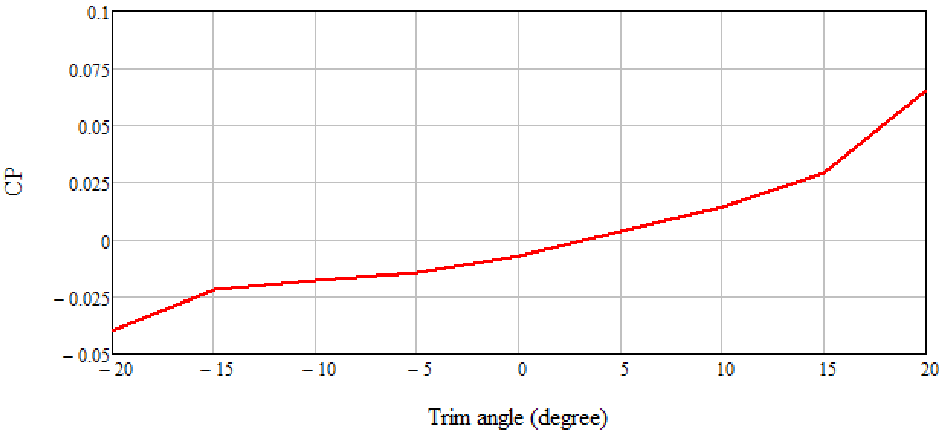


Fig. 10. The variation of the lift coefficient according to the trim angle

## 4. Conclusions

The performed study highlights the fact that the obtained results, both in the numerical simulation and the experimental testing are in good correlation.

In the case of the numerical simulation, a jump in the drag force is observed at the beginning of the movement, which is caused by the absence of an acceleration period from zero velocity to the nominal velocity.

In the case of the experiment with the towed model, an influence of the elasticity of the system on the signal recorded by the force sensor is observed. It is recommended to use precise linear rails for the platform to be translated.

The towing velocity (0.47 m/s) was chosen to be presented since it is the most representative from the point of view of the analysis considered.

If the velocity were lower, the hydrodynamic forces would be very small and measurement errors would appear (due to the sensor sensitivity). Also, if the velocity were higher, the pool length and the size of the scaled model do not allow the execution of an active run which would yield reliable results, and in addition the model can hit the pool edges.

A pool with larger dimensions, both in length and in cross-sectional area, is also required. The large cross-section allows the model to be tilted at greater angles, so as to ensure a sufficiently large distance between the model and the free surface of the water in the pool, or between the model and the bottom of the pool.

A large length of the test pool leads to an uniformization of the flow around the submerged body, also allowing a high towing velocity to be achieved.

For the future, we have in plan to use an initial period of acceleration followed by a constant velocity movement to reduce oscillations in the motion plane. Also is considered the use of a support rod of the elliptical section or symmetrical NACA model, which stiffens the system in the plane of motion.

Experimental determinations using the wind tunnel is difficult because of the high air velocities that must be used. Achieving such speeds would require a small test section, leading to small-scale models.

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