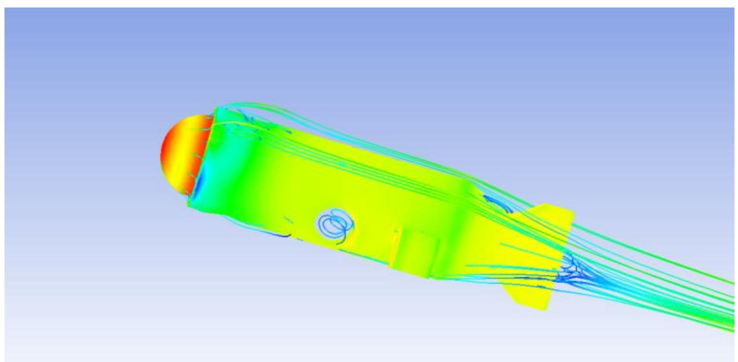
**CONSTANTA MARITIME UNIVERSITY**
**DOCTORAL SCHOOL OF MECHANICAL ENGINEERING**
DOCTORAL THESIS

# DOCTORAL THESIS

# STUDIES AND RESEARCHES REGARDING THE CONTROL AND STABILIZATION OF AN UNCONVENTIONAL VEHICLE FOR UNDERWATER RESEARCH

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The validation of the results obtained using numerical modelling would not have been complete and possible without the help of the EOD Combat Divers Division of the 175th Combat Divers Squadrom of Romanian Diver Center for handling the vehicle, as well as for the information they made available to me through the kidness of the Captain Gherghinescu Cătălin.

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I dedicate this work to my family, my parents and my husband, who have always supported me, totally and unconditionally with infinite patience.

## CONTENTS OF THE DOCTORAL THESIS ABSTRACT

***A SYNTHESIS OF THE CHAPTERS IN THE PRESENT DOCTORAL DISSERTATION***

# Contents

# CHAPTER I INTRODUCTION

***Motivation for choosing the theme***

One of the most spectacular achievements from a scientific point of view was the conquest of outer space by launching the first artificial satellite, followed by the conquest of the ocean abysses, by exploiting the Marianas Trench with the help of underwater vehicles.

This rise of science and technology was aimed not only at the desire for knowledge and scientific exploitation, but also at economic, military or political interests. It is almost impossible to build a satellite used for telecommunications or a bathyscaphe without the help of a team of specialists in mechanics, electrical engineering, electronics, aerospace or shipbuilding. The multidisciplinary nature of the domains is also valid in the case of the technologies used for the exploitation of the marine environment and underwater work.

Remote controlled underwater vehicles are, therefore, a valuable tool, sometimes even difficult to replace in terms of Romanian oceanographic research, used in the marine drilling industry or for other areas of activity related to the marine underwater environment, such as monitoring medium.

The aim of the study is to analyze recent progress in stabilizing unconventional underwater vehicles.

***General description***

The main purpose is to establish the time required for unconventional underwater vehicles to dive to a set depth, taking this into account to ensure their safe operation and operation.

Using the specialized programs, in the thesis, I performed simulations on the influence of hydrometrological factors on the movement, respectively the stabilization of vehicles at a required depth. In order to determine the hydrometeorological factors, I performed experimental simulations using the VALENPORT Model 108 current meter, in the custody of the “Mircea cel Bătrân” Naval Academy. These measurements can be found in the Scientific Research - Development Project no. 129 of the Sectoral Plan for Research and Development of the Ministry of National Defense, 2019. The data obtained were further implemented in specialized simulation programs (ANSYS CFD, ANSYS AQWA, MATLAB SIMULINK) to determine the stabilization of the vehicle. For the experimental realization regarding the reaction of underwater vehicles, I use the prototype of the remote-controlled underwater vehicle ARROW-1, from the Naval Academy “Mircea cel Batran”, as well as the autonomous underwater vehicle ECA A9M belonging to the EOD Diving Section. Taking these data into account, they can be entered into the VMAX PerrySlingsby simulator belonging to the GSP Training Center Company.

***Thesis structure and contributions***

In order to cover the proposed objectives, the doctoral thesis "**STUDIES AND RESEARCHES REGARDING THE CONTROL AND STABILIZATION OF AN UNCONVENTIONAL VEHICLE FOR UNDERWATER RESEARCH** " is carried out as follows: documentary stage, numerical modeling and experimental research. To achieve the proposed objectives, the thesis was structured on eight chapters to highlight the value of the scientific approach.

# CHAPTER II. STATE-OF-ART AND DEVELOPMENT TRENDS OF UNDERWATER VEHICLES

Chapter IInd presents the State-of-Art and development trends of underwater vehicles. ROVs capabilities are continuously expanding as the technology is constantly evolving. The introduction of improved specifications or the upgrading of existing ones aims to make ROV vehicles more efficient. In general, ROVs are used for a multitude of operations that take place underwater, of which we list:

- Underwater mining - on the bottom of the world's seas and oceans there are in some areas deposits of areas of interest such as: manganese nodules, various rare metals, even diamond mines;
- Submarine wiring and communication nodes - real-time 4D investigations and monitoring of crowded offshore oil fields
- Auxiliary industries to other industries - used to monitor the action of suction cells during extractions
- Investigations and supervision of Jack-up and Semi-Submersible installations - preparation and inspection of drilling and extraction platforms of this type (checking the feet for corrosion or mechanical defects, checking the piercing areas of the feet.)
- Support for drilling and well completion operations - monitoring of drilling operations, installation or uninstallation of underwater tank molds or preventers, removal of debris or stones and other objects, support for maintenance and repairs
- Geotechnical investigations - prospecting and inspections for routes followed by submarine pipelines, all operations related to the installation and repair of defects in the construction of submarine pipelines and wiring, passages and sub-passages of pipelines and cables, post-construction inspections, inspections of routine
- Underwater wiring - inspection of routes, laying of cables, monitoring the fall of cables during installation over the underwater landscape, burying cables
- Ocean research - sampling and inspections for underwater life and biodiversity
- Observation of underwater microhabitats - monitoring of nature reserves against pollution
- Nuclear industry - inspections, interventions and decommissioning of nuclear power plants located on the seafront or in the vicinity
- Commercial inspections - investigations regarding the insurance of goods and their recovery in case of sunken vessels, cargo and potentially dangerous equipment
- Inspections of ships and port harbour, strait monitoring, national security investigations and others

Chapter two also presents relevant and important benefits of using remote-controlled underwater vehicles:

- Monitoring and evaluation of industrial civilian underwater entities or of own or third party military capabilities
- Avoiding working in harsh conditions from a human perspective
- Relatively long working time regardless of environmental conditions
- Determining the underwater environmental characteristics of the maritime districts of interest
- Monitoring the maritime transport routes of the commercial fleets
- Ability to work in relatively narrow spaces, in embankments, on vertical walls, near the feet of offshore drilling rigs, inside wrecks or under ice
- High maneuverability due to small size
- Low cost of work performed, compared to the use of autonomous or heavy divers, or submarines with human crew on board

***Operating conditions and disposal of the product in operation***

The operating conditions take into account the underwater environment in which the vehicle operates. Taking into account the meteorological and hydrogeographic conditions in which it is used, we can conclude that even the environment imposes certain special constructive-functional requirements for operation. Some operating parameters for the underwater environment to ensure optimal functionality of the remote controlled underwater vehicle are:

– Hydrostatic pressure corresponding to working immersion
– Marine or river currents
– Water temperature
– Corrosive environment due to water salinity or due to the lynx in which it moves
– Low visibility
– Possibility of surface feeding
– Data exchange / reception of surface data

***Technical status and international trends***

The international development-research trend of remote-controlled underwater vehicles is directed towards the following characteristics:

- Robustness - the vehicle must be able to work in a hostile environment (large pressure differences, temperature variations, currents, etc.)
- Flexibility - the remote-controlled underwater vehicle together with the assembly with which it is interconnected, must be able to perform various underwater activities and operations, regardless of operating conditions
- Modularity - both the vehicle itself and the control system must ensure the operation in optimal conditions of the task to be performed
- Specialization - the construction of the vehicle must be carried out so that it can fulfill its mission in a specialized field of work

- Maneuverability - the remote-controlled underwater vehicle must be able to perform translation and rotation maneuvers in complete safety
- Stability - the vehicle movement parameters must be within a tolerance range allowed by the operator / user

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# CHAPTER III. ANALYTICAL FUNDAMENTALS OF VEHICLE MOVEMENT

The study carried out in the paper is based on the requirements imposed on an ROV to operate on the Romanian coast, taking into account its technical characteristics and use, the simulations being performed on the prototype ROV ARROW-1 vehicle in the custody of the Mircea cel Batran Naval Academy, Constance similar to the underwater robot PAP-Mk5, made by ECA Group.

Figure 3.1. illustrates the geometry of the vehicle, together with the limits of the calculation range. The body of the vehicle can be divided into 3 (three) sections: the section in the bow in the form of a hemisphere, the actual body of the vehicle in the form of a cylinder and the body in the stern represented by a conical cylinder. The 3D Cartesian coordinate system used in the study is implemented by initially placing the origin of the coordinates in the bow of the vehicle, then to be placed along the body of the vehicle to draw the thrusters, and finally in the stern for drawing the wings. The OX axis is taken along the length of the vehicle. Therefore, in the first stage, all axial distances along the vehicle body are calculated in relation to the vehicle bow.

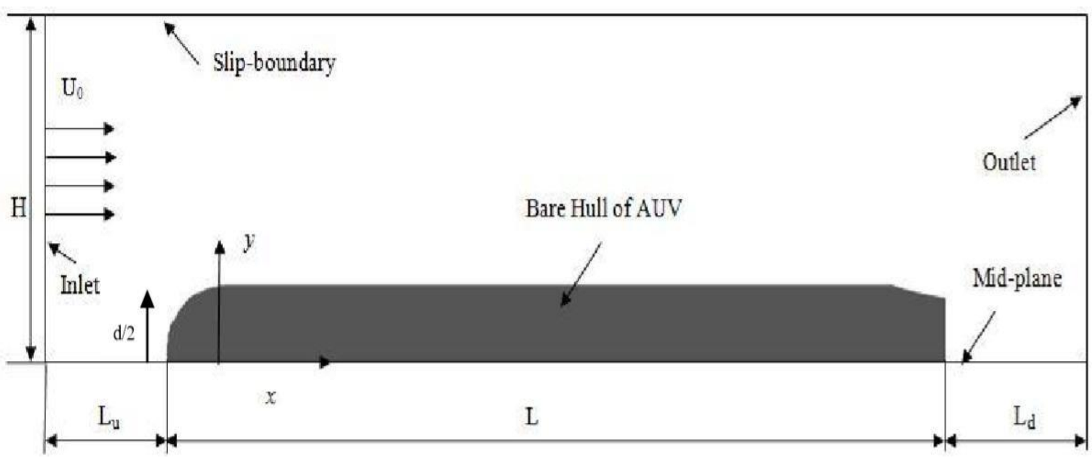


Figure 3.1. Vehicle geometry and range limits

# CHAPTER. IV. THEORETICAL RESULTS ON UNDERWATER MOVEMENT CONTROL SYSTEMS

The accuracy and feasibility of running and stabilizing maneuvers on the set trajectory are determined by the dynamic properties of the vehicle: maneuverability, stability and the ability to react immediately to steering controls. These dynamic properties are interdependent with the technical-tactical and hydrodynamic characteristics of the vehicle.

***ROV equations of motion***

General considerations for performing calculations

- It is considered that the influence of current does not act on the body of the vehicle, the vehicle performing activities in an operational underwater environment, this makes the vehicle act only the forces determined by its movement and interaction with water.
- The vehicle does not interact with waves, external structures or the seabed.
- The hydrodynamic coefficients of the model can change only due to its travel speed. They are influenced by salinity, pressure or water temperature.
- The center of gravity of the vehicle is considered in its center of buoyancy when it is not adrift.
- The vehicle has a positive buoyancy, which can be lost when it enters the dive.
- The body of the vehicle is a rigid body of constant mass. This makes its construction and length have a minimal impact on the behavior and movement of the vehicle.
- The propellers and fins of the vehicle do not bend at any angle, they remain fixed throughout the movement.
- The forces acting on the vehicle are the inertial, gravitational, hydrostatic, forward resistance and additional forces.

Tabel 4.1. Non-linear maneuvering coefficients :Force

| Parameter | Value | Units | Description |
|---|---|---|---|
| $X_{u\|u\|}$ | -1.62 | $Kg/m$ | Cross-flow drag |
| $X_{\dot{u}}$ | -0.930 | $kg$ | Added Mass |
| $X_{wq}$ | -35.5 | $Kg/rad$ | Added Mass Cross-term |
| $X_{qq}$ | -.193 | $Kg\ m/rad$ | Added Mass Cross-term |
| $X_{vr}$ | -35.5 | $Kg/rad$ | Added Mass Cross-term |
| $X_{rr}$ | -1.93 | $Kg\ m/rad$ | Added Mass Cross-term |
| $Y_{v\|v\|}$ | -131 | $Kg/m$ | Cross-flow Drag |
| $Y_{r\|r\|}$ | 0.632 | $Kg\ m/rad^2$ | Cross-flow Drag |
| $Y_{uv}$ | -28.6 | $Kg/m$ | Body Lift Force and Fin Lift |
| $Y_{\dot{v}}$ | -35.3 | $kg$ | Added Mass |
| $Y_{\dot{r}}$ | 1.93 | $Kg\ m/rad$ | Added Mass |

| | | | |
|---|---|---|---|
| $Y_{ur}$ | 5.22 | $Kg/m$ | Added Mass Cross-term |
| $Y_{\dot{w}p}$ | 35.5 | $Kg/m$ | Added Mass Cross-term |
| $Y_{pq}$ | 1.93 | $Kg\ m/rad$ | Added Mass Cross-term |
| $Z_{w\|w\|}$ | -131 | $Kg/m$ | Cross-flow Drag |
| $Z_{q\|q\|}$ | -0,632 | $Kg\ m/rad^2$ | Cross-flow Drag |
| $Z_{uw}$ | -28.6 | $Kg\ m/rad$ | Body Lift Force and Fin Lift |
| $Z_{w}$ | -35.5 | $kg$ | Added Mass |
| $Z_{\dot{q}}$ | -1.93 | $Kg\ m/rad$ | Added Mass |
| $Z_{uq}$ | -5.22 | $Kg/rad$ | Added Mass Cross-term |
| $Z_{vp}$ | -35.5 | $Kg/rad$ | Added Mass Cross-term |
| $Z_{rp}$ | 1.93 | $Kg/rad$ | Added Mass Cross-term |

Tabel 4.1. Non-linear maneuvering coefficients :Moments

| Parameter | Value | Units | Desription |
|---|---|---|---|
| $K_{p\|p\|}$ | -0.013 | $Kg\ m^2/rad^2$ | Rolling Resistance |
| $K_{p}$ | -0.0141 | $kg\ m^2/rad$ | Added Mass |
| $M_{w\|w\|}$ | 3.18 | $Kg$ | Cross-flow Drag |
| $M_{q\|q\|}$ | -9.4 | $Kg\ m^2/rad^2$ | Cross-flow Drag |
| $M_{\dot{w}}$ | -1.93 | $Kg\ m$ | Added Mass |
| $M_{\dot{q}}$ | -4.88 | $kg\ m^2/rad$ | Added Mass |
| $M_{uq}$ | -2 | $kg\ m/rad$ | Added Mass Cross-term |
| $M_{vp}$ | -1.93 | $kg\ m/rad$ | Added Mass Cross-term |
| $M_{rp}$ | 4.86 | $Kg\ m^2/rad^2$ | Added Mass Cross-term |
| $N_{v\|v\|}$ | -3.18 | $Kg$ | Cross-flow Drag |
| $N_{r\|r\|}$ | -9.4 | $kg\ m^2/rad^2$ | Cross-flow Drag |
| $N_{\dot{v}}$ | 1.93 | $Kg\ m$ | Added Mass |
| $N_{\dot{r}}$ | -4,88 | $kg\ m^2/rad$ | Added Mass |
| $N_{\dot{u}r}$ | -2 | $kg\ m/rad$ | Added Mass Cross-term |
| $N_{\dot{w}p}$ | -1.93 | $kg\ m/rad$ | Added Mass Cross-term |
| $N_{\dot{p}q}$ | -4.86 | $kg\ m^2/rad^2$ | Added Mass Cross-term |

# CHAPTER V. THEORETICAL RESULTS REGARDING THE HYDRODYNAMIC PROPERTIES OF THE UNDERWATER VEHICLE CABLE

Chapter V provides a presentation of umbilical cable that connects the vehicle to surface, the determining equations for this cable, as well as a simulation performed in ANSYS AQWA. The UC that connects the vehicle to the support vessel can be affected by many parameters, including the movements of the vehicle or support vessel, the current along the cable, and the total length of the cable itself. The UC configuration can be optimized by numerical simulations. However, most research on the numerical model for predicting underwater vehicle movement neglects the effect of UC on the vehicle. The main reason is that the inclusion of the UC effect will make the numerical model very complicated and difficult to solve.

Consider the action of current on a small area on an element of cable length, noted $dp$.

The resistance force has two components: the tangential resistance force ($R_n$) and the normal force on the surface of the element ($R_t$). These forces can be defined as:

$$R_n = \frac{1}{2}\rho t C_n V^2 \sin\psi|\sin\psi|\,, R_t = \frac{1}{2}\rho t C_f V^2 \cos\psi|\cos\psi| \tag{5.1}$$

Where $\rho$ represents the water density, $t$ is the cable diameter, $C_n$ is the coefficient of the normal resistance $C_f$ is the tangential coefficient of resistance, $V$ is the realative speed of the current along the cable, $\psi$ represents the angle formed between the direction of the current and the cable. $R_t$, $R_\varphi$ și $R_\vartheta$ represent the forces of the fluid per unit length in the direction $i_t$, $i_b$ și $i_n$ and the formulas can be considered:

$$R_t = \frac{1}{2}\rho t\pi C_f V^2 \cos\bar{\psi}\left|\cos\bar{\psi}\right|, R_\vartheta = R_{nx}\cos\left(\bar{\vartheta}+\frac{\pi}{2}\right) + R_{ny}\sin\left(\bar{\vartheta}+\frac{\pi}{2}\right) \tag{5.2}$$

$$R_\varphi = R_{nx}\cos\bar{\vartheta}\,cos\left(\bar{\varphi}+\frac{\pi}{2}\right) + R_{ny}\sin\bar{\vartheta}\,sin\left(\bar{\varphi}+\frac{\pi}{2}\right) + R_{nz}\,sin\left(\bar{\varphi}+\frac{\pi}{2}\right) \tag{5.3}$$

The force on an element of non-extended length can be written as:

$$\frac{d}{ds}\left(T_e\vec{t}\right)ds = \left[\frac{\partial T_e}{\partial s}\vec{t} + \frac{T_e}{\rho}\vec{n}\right]ds \tag{5.4}$$

***Introduction to the numerical simulation of the underwater vehicle response***

ANSYS AQWA offers a set of integrated engineering tools used for the development of hydrodynamic parameters, for the evaluation of complex movements and the analysis of the response. ANSYS AQWA is a set of specialized tools for the offshore field and the maritime domain, being able to work integrated or independently with the other modules belonging to the ANSYS Workbench platform. With the help of ANSYS AQWA software RAO response analyzes can be performed for simulations including semi-submersible devices, platforms or ships of any type.

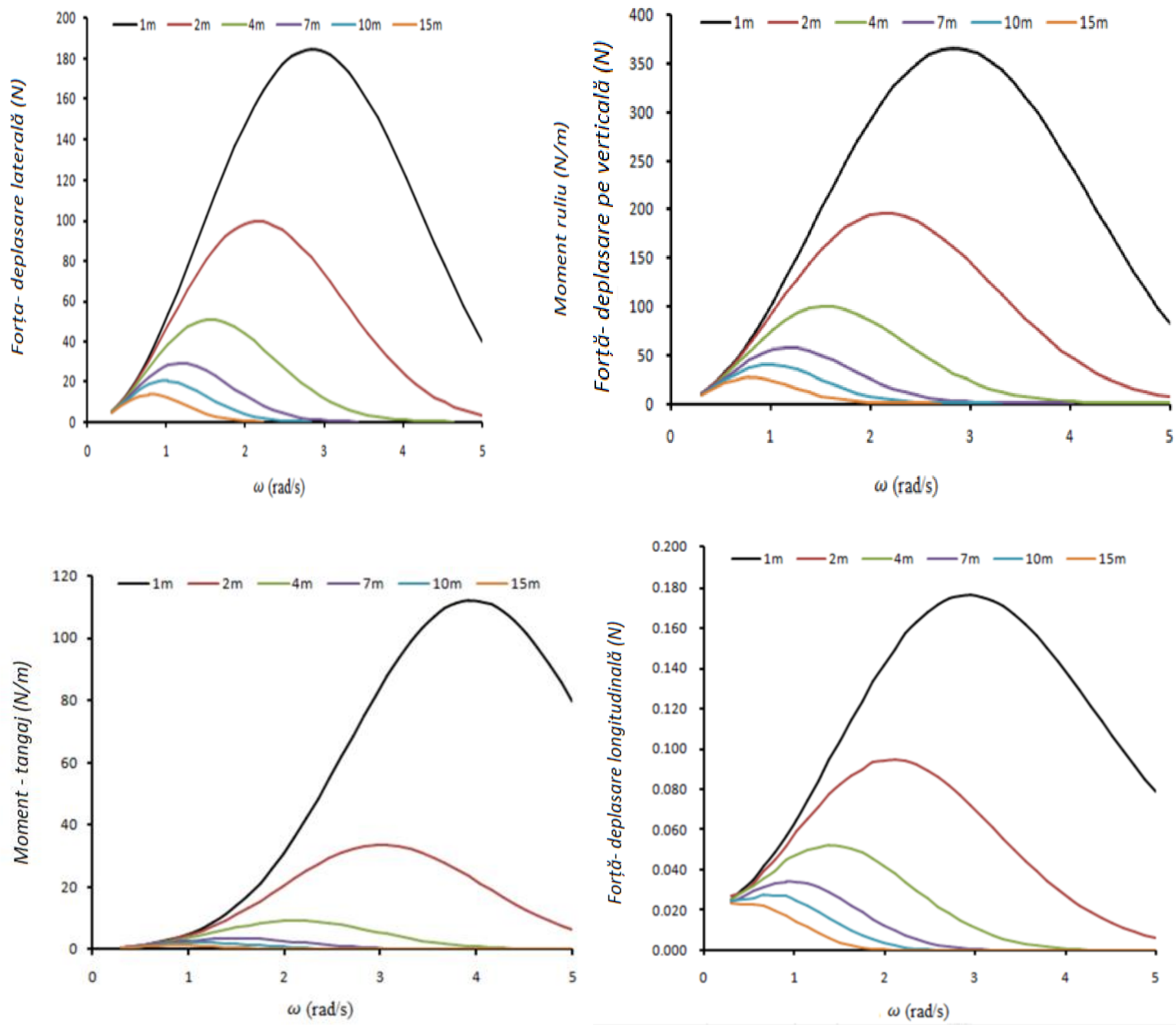


Figure 5.1. Curves determined by the force and moment of the shared wave with the operating frequencies of the underwater vehicle at different depths

The previous figures show the curves determined by the force and moment of the wave compared to the operating frequencies of the underwater vehicle at different depths. The tendency of the curves shows that the magnitude of the forces and moments decreases with increasing depth of the vehicle and finally defines insignificant at a depth of 15 m. This can be explained by the fact that the amplitude of the particles of water displacement decreases exponentially with its depth.

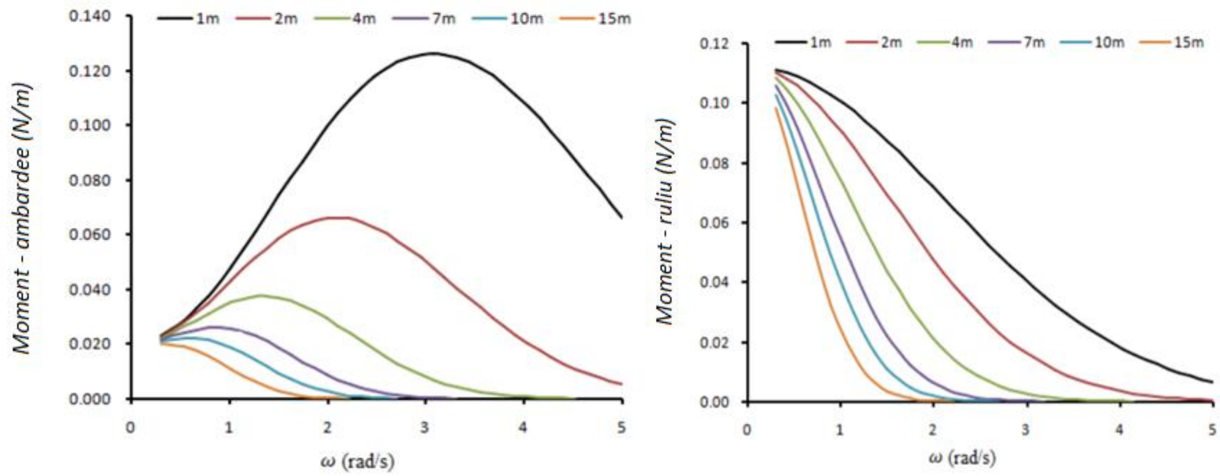


Figure 5.2. Moment roll and yam

***ANSYS AQWA results***

To solve the Parameters vs Frequency Hydrodynamic equation (Figure 11), as the RAO structure for the Global RX component, representing the tangent of the underwater vehicle, namely the displacement along the X axis, the abscissa value of the minimum position is 1.50514 Hz, the abscissa of the maximum position 0.01592 Hz, the minimum value on the wavelength is 0.0 ° / m, and the maximum value obtained is 365.39133 ° / m.

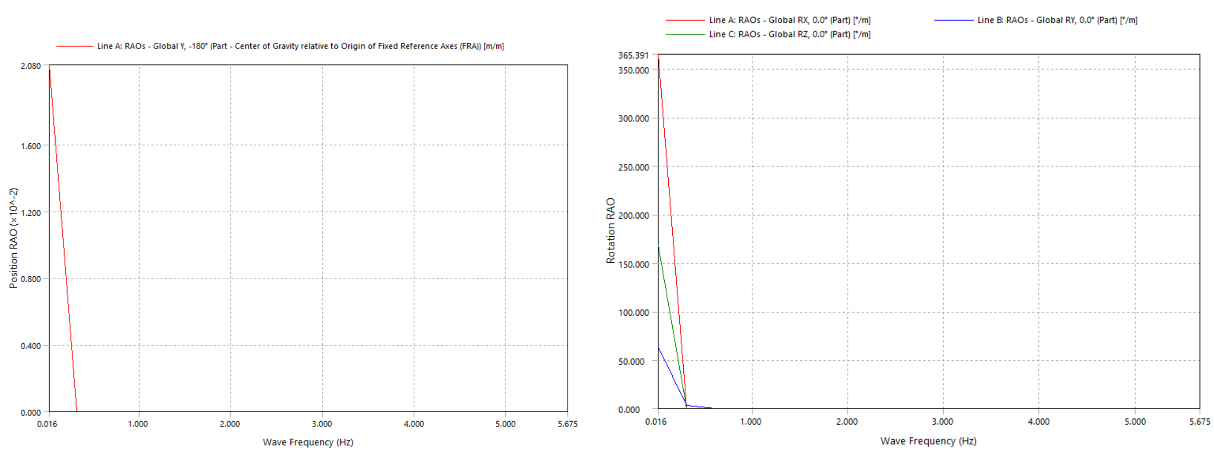


Figure 5.3. Model (B3, C3) > Hydrodynamic Response (C4) > Irregular Wave 1

The procedure is analogous for the Global RY component: the abscissa value of the minimum position 1.50514 Hz, the abscissa of the maximum position 0.01592 Hz, the minimum value on the wavelength is 0.0 ° / m, and the maximum value obtained is 63.27088 ° / m.

For the Global RZ component, the data obtained are: the abscissa value of the minimum position 1.50514 Hz, the abscissa of the maximum position 0.01592 Hz, the minimum value on the wavelength is 0.0 ° / m, and the maximum value obtained is 168.12218 ° / m.

For the Hydrodynamic Time Response analysis, we consider the Irregular Wave Response with Slow Drift analysis, in which the drift is not taken into account. The number of steps to perform the simulation is 600, the position of the starting point being based on the geometry of the vehicle body.

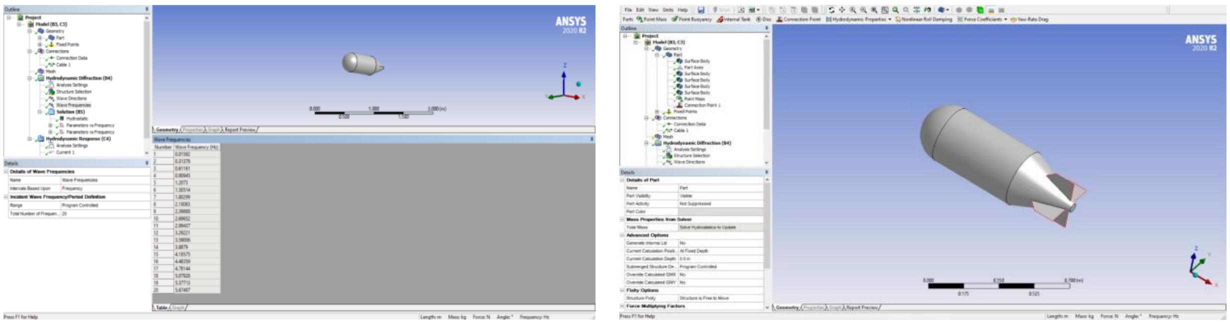

Figure 5.4. ANSYS AQWA Simulation

Regarding the influence of the current, it is Not Supressed, considering the maximum water depth 100m, the current speed is constant of 0.2m / s with a direction of 90 °.

The waves were also defined here. The height of the waves is made according to the frequency of this. During the simulation, JONSWAP (Alpha) waves were chosen, having a 90 ° spectrum direction.

The frequency of the wave spectrum starts at 2.9 Hz and ends at 25.5505 Hz, for an Alpha and Gamma value of 1.

# CHAPTER VI. NUMERICAL SIMULATION REGARDING THE DRAG OF THE UNDERWATER VEHICLE

CFD analysis aims to determine the forces, moments and displacements of the model subjected to the action of hydrodynamic forces, especially regular waves. With the help of the DesignModeler component we created the structure of the underwater vehicle for study, but also the field of work by using the Boolean / Subastract function. Initially, the vehicle body was made using Solidworks solfeaware, then modified and created using DesignModeler. The environment in which the underwater vehicle moves is known as the domain. To perform the simulation, a sufficiently wide range was created to avoid the range limits affecting the flow along the vehicle body.

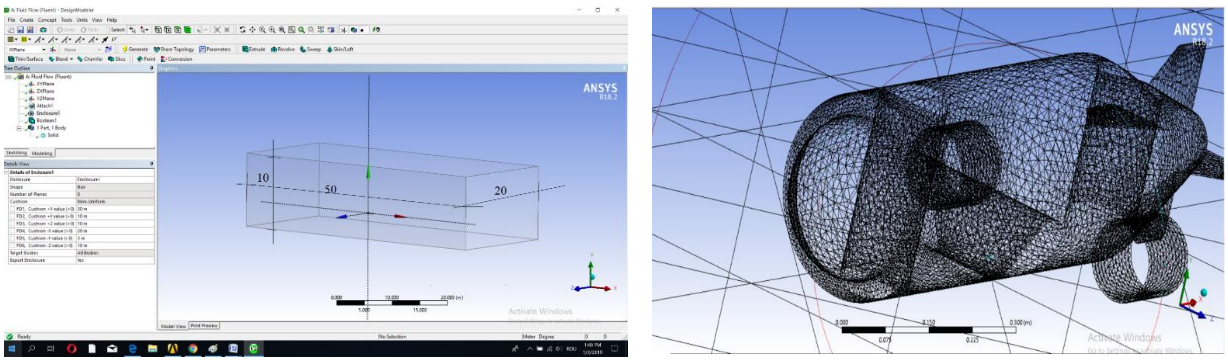

Figure 6.1. ANSYS CFD simulation

The simulations were run on the Intel (R) Core (TM) i7-7500 CPU configuration with 16 Gb of RAM.

The analytical solution of the Navier-Stokes equations is performed for simple flows subject to ideal conditions. In order to obtain exact solutions for real flows, an analytical solution must be used in which the equations and values can be replaced approximately, and can be solved by a numerical method. The CFX solver uses the finite volume method, which aims to discretize the field of analysis. The discretization presented above is used by the CFX solver to build finite volumes that have as properties the mass and the moment of inertia. This takes place in 3 working directions, discretization being a 3D process.

The following figures shows the total pressure exerted on the vehicle body. According to the simulation, the maximum value of the pressure is 50891.4 Pa, reached in the bow of the vehicle, according to the legend where the color is red. The minimum value is -92984.5 Pa touched in the immediate vicinity of the vehicle's truck, it is materialized in Figure 6.2 with the blue color.

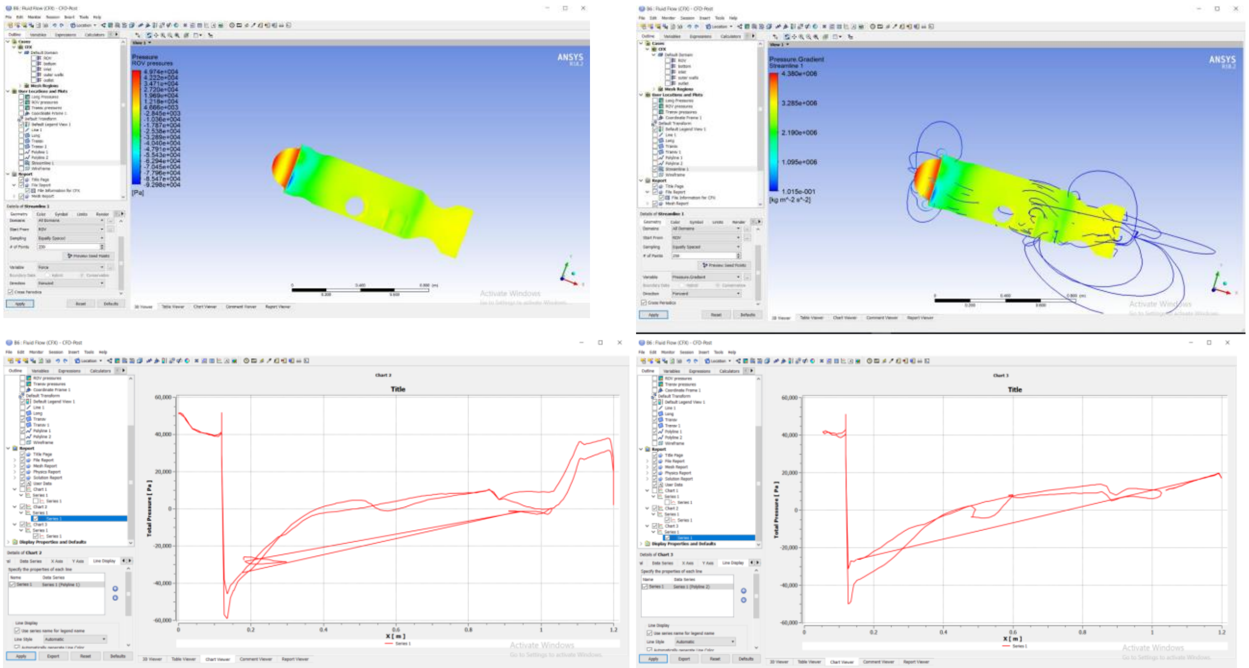

Figure 6.2. ANSYS simulation

## CHAPTER VII. STABILIZATION AND CONTROL OF UNCONVENTIONAL UNDERWATER VEHICLE FOR UNDERWATER RESEARCH

With the logistical support of the Naval Academy "Mircea cel Batran" I determined the study regarding the stabilization of the underwater vehicle. The basin within the “Mircea cel Bătrân” Naval Academy allows the application of applied research on small structures in order to offer new concepts to the development in the naval field. Experimental tests are a way to study the behavior of ships, submersible structures and underwater vehicles on a real or small scale with benefits in developing knowledge in the field of naval hydrodynamics, while providing identification solutions for future modern projects.

The prototype used for the experiment was used in the verification and experimental validation of the theoretical models used in the evaluation of the kinematic and hydrodynamic parameters that characterize its displacement and stabilization in water. Studying its behavior in the basin may interfere with the performance investigation as interference may occur when the vehicle is operated in the open sea.

The purpose of the experimental program was to measure mainly the time required to stabilize the vehicle, as well as the forward resistance of the underwater vehicle and the study on the umbilical cable of the vehicle for ARROW-1.

***Measurements performed with ARROW-1***

In order to perform the experimental simulations, photographs and footage were taken of the vehicle's travel speeds and the corresponding traction forces in order to stabilize it.

The measurement formed for the experimental validation contains the primary signal processing equipment, the laptop unit for data storage as a function of time and the graphical analysis of the obtained results.

Figure 7.1. Captures made during the experimental simulation with ARROW-1

The movement of the underwater vehicle on the underwater trajectory is composed of permanent changes of the kinematic parameters. The accuracy of these maneuvers is mainly determined by the dynamic properties of the vehicle body, the most important of which are maneuverability, stability and responsiveness to steering controls.

These properties are interdependent with the hydrodynamic characteristics of the vehicle.

Using the vehicle's remote control, an initial speed was printed on it, calculating the time required for the vehicle to reach the desired depth.

Initially the vehicle exceeds the depth of 1 meter (after 10 sec), cause of inertial forces. Stabilize it to the desired depth after 15 seconds. The depth reached by ARROW-1 was measured using the diving console in the diving equipment that assisted the vehicle's activity in the water. The procedure took place in compliance with all protection rules regarding work in the hyperbaric environment.

The maximum depth of the basin is 4 meters. Equivalent to the second simulation case, the depth of 2.5 meters reached by ARROW-1 is achieved after a period of 20 seconds from the initial moment. In both cases, the time required to move the vehicle in immersion was measured using the diving console in the diver's diving equipment. Information on the speed of the vehicle was transmitted to the control console via the umbilical cable.

***Measurements performed with ECA A9M***

To achieve stabilization, as well as the types of images that an underwater vehicle can provide to operators, we used the ECA A9M autonomous underwater vehicle (Figure 7.2). The vehicle is equipped with EOD military divers from the 175th Division of Diving Ships, EOD Diving Section.

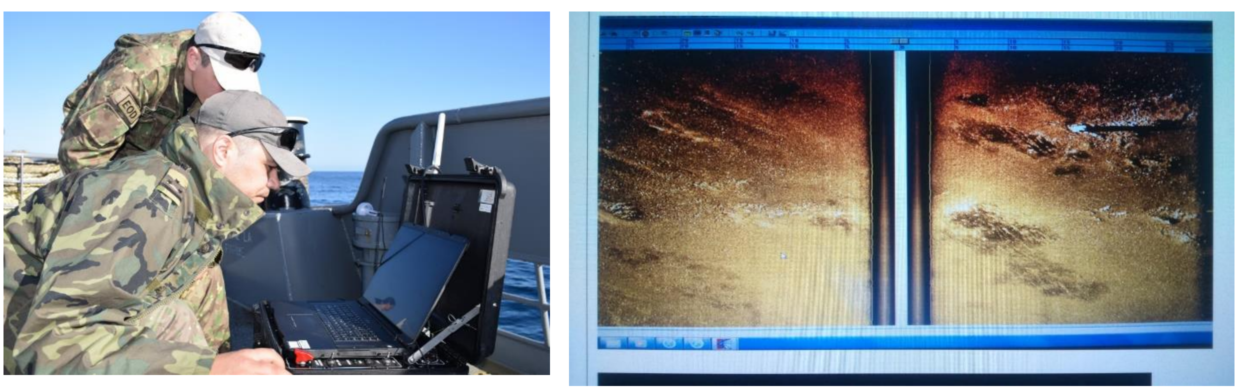

Figure 7.2. Captures made during the experimental simulation with ECA A9M

In the case of simulations performed with the ECA A9M autonomous vehicle, it is submerged to an immersion of 3 meters, with a horizontal visibility of 2 meters and a vertical visibility of 2 m. Its stabilization is done automatically, taking into account the depth at which its possibilities of autonomous adjustment for reaching the required depth are also immersed, drawing a descending helical trajectory. Proceeding in the same way as for the ARROW-1 vehicle, the time required for the ECA A9M to reach a depth of 1 m and to stabilize is 15 sec. The depth of 2.5 m is reached after a period of 35 sec.

# CHAPTER VIII. CONCLUSIONS

The world in which we evolve involves understanding and accumulating a huge amount of information, which then requires processing. Underwater vehicles are the infrastructure on which different applications can be used to monitor aquaculture, marine pollution, and the exploitation of offshore resources, navigation and data collection in the world's seas and oceans or even components of automated disaster prevention systems.

This paper, entitled "**STUDIES AND RESEARCHES REGARDING THE CONTROL AND STABILIZATION SYSTEMS OF AN UNCONVENTIONAL VEHICLE FOR UNDERWATER RESEARCHES"** shows that changes and contributions to the improvement of unconventional underwater vehicles can be made permanently, especially regarding the stabilization system of them.

Regarding the content of the paper, it presented both the theoretical study on the equations of motion and stabilization of underwater vehicles, but also the study of simulations by numerical methods, respectively real simulations using underwater vehicles at 1: 1 scale. The underwater vehicles used in the simulations were: the ARROW-1 remote-controlled underwater vehicle, a prototype belonging to the Mircea cel Batran Naval Academy and the ECA A9M autonomous underwater vehicle belonging to the EOD Combat Divers Division of the 175th Combat Divers Squadrom of Romanian Diver Center.

***Personal contributions***

Although this paper represent a continuation of an approach that is very effective, current and always in development, some of the contributions to the study of the stabilization of unconventional underwater vehicles can be briefly mentioned:

1. Synthesis of the current stage regarding the efficiency of the use of unconventional underwater vehicles, presenting the evolution of underwater vehicles, the existing models until now or at the design stage using the current bibliographic references presented in the paper;

2. Presentation of the influence of the umbilical cable of the remotely operated vehicle, the general structure of the umbilical cable, the hydrodynamic forces, of tension acting on the cable and the realization of its static analysis;

3. Carrying out the design of the vehicle body using SolidWorks- v student;

4. Simulation of the action of waves on the unconventional underwater vehicle cable by means of numerical simulation using ANSYS AQWA v.20, and the steps required to perform this analysis, as well as how to extract the necessary data, resulting in various simulations performed - RAO response for different situations and wave spectrum; the simulation was performed for the 3 main directions of travel: pitch, roll and yaw; following the simulation, the following were obtained:

- The abscissa of the position of the minimum value for the RAO value in case of the incidence angle of -180, has a constant value of 1.50514 Hz;

- The abscissa of the position of the maximum value for the RAO value in case of the incidence angle of -180, has a constant value of 0.01592 Hz;

5. Presentation of the methodology for performing the numerical simulation CFD (Computational Fluid Dynamics) in the conditions of simulating six degrees of freedom;

6. Evaluation of the influence of hydrodynamic parameters on underwater vehicles using ANSYS CFD v.20;

- The maximum value of the pressure is 50891.4 Pa, reached in the bow of the vehicle;
- The minimum value is -92984.5 Pa reached in the immediate vicinity of the vehicle's trunk, in the slot of its trunk;
- The uneven distribution of the pressure on the surface of the vehicle body, is in correspondence with the direction of movement of the vehicle body, respectively the speed of movement.

7. Appropriate use of methods and information necessary to perform CFD numerical simulation for the unconventional underwater vehicle

8. Field collection, processing and verification of data recorded using the current valve VALENPORT Model 106 necessary to determine the hydro-meteorological factors during on 2019;

9. Evaluation of the influence of coastal currents and waves on Romanian seaports, the data being subsequently integrated in the simulations regarding the stabilization of the underwater vehicle;

10. Determination by direct integration in MATCAD SOLIDWORKS of the characteristics of the underwater vehicle regarding the time necessary for its stabilization;

- The graphs regarding the trajectory of the underwater vehicle are presented: the position of the vehicle at a given moment when it is immersed;
- The vehicle has a downward trajectory up to the immersion of 1 m, following a stabilization of it at the value of 1,163 m; the time required is 2 seconds;
- Stabilizing the vehicle at a depth of 2.5158 m, it describes similarly to the previous case a downward trajectory to a depth of about 2.615 m., after a period of 10 sec.

11. Validation of results obtained from calculations and simulations using measurements made in the pool on the stabilization of the remote-controlled underwater vehicle ARROW-1;

- According to the results obtained, the vehicle is at a depth of 1 meter after about 10 sec, and after 15 sec is established at the desired depth;
- The vehicle is at a depth of 2.5m after about 20 sec;

12. Validation of the results obtained following the numerical simulations with measurements performed in the Black Sea regarding the stabilization of the autonomous underwater vehicle ECA A9M with the approval of the Division 175 EOD Divers;

- To reach the immersion of 1 meter, the time required is 15 sec, with a speed of 2.3 knots;
- The depth of 2.5 m is reached after a period of 35 sec.

13. Determining the time required for remote-controlled and autonomous scuba diving vehicles to enter a required depth, helps underwater vehicle operators to determine the time required for stabilization at a required depth in order to carry out specific missions.

14. Identification of optimization methodologies regarding the integration and optimization of the applicability of unconventional underwater vehicles within the special simulator intended within GSP Training;

15. Outlining medium and long-term research directions in the field of unconventional underwater vehicles;

***Further developments***

Entering all the data obtained in an integrated underwater vehicle driving simulator can facilitate the work of future vehicle operators in stabilizing them, in order to allow the necessary time when running different applications. For this, the GSP Training company has the Perry Slingsby VMAX ROV simulator. The operating mode of the simulator is similar to the actual operating mode. Following the visit made to GSP Training, Mr. Caraivan Mitruț, the director of the company, presented me the operation mode of the simulator for ROVs, as well as the vehicles they have in the equipment of the ships, and in the future we will establish a collaboration regarding the operation and certification of ROV Operators.

The unconventional underwater vehicle will continue to be one of the great challenges of the global research and engineering community. Taking into account the experience and knowledge gained during this research, we propose the following development directions:

- Continuation of experiments on the existing model;
- Performing the simulation of the underwater vehicle when it is equipped with a manipulator arm;
- Carrying out vehicle simulation using the Perry Slingsby VMAX ROV Simulator;
- Establish the feasibility of autonomous and remote-controlled underwater vehicles in an unconventional Multi-Control underwater vehicle.

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