

# TOWARDS A FIRST C.F.D. STUDY OF MODERN HORIZONTAL AXIS ARCHIMEDEAN WATER CURRENT TURBINES

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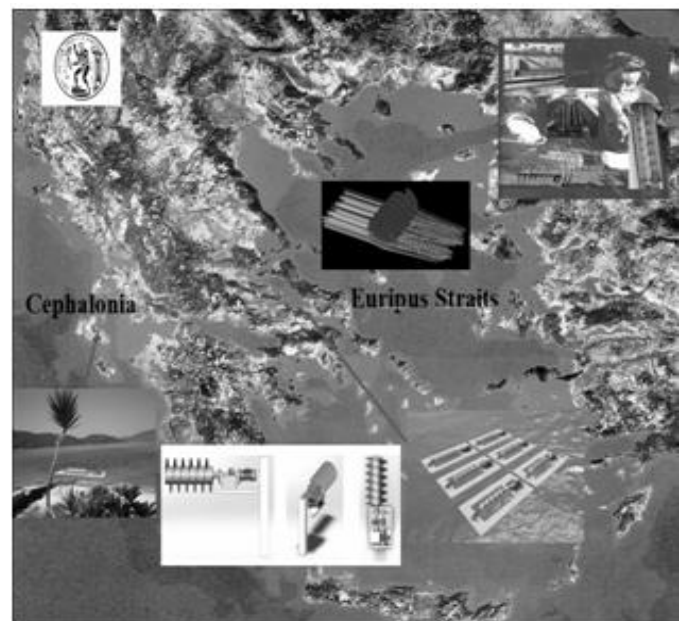
**Abstract** - *The possibility of exploiting kinetic hydraulic energy of watercourses, hydraulic networks, marine and tidal currents, for power generation, in Europe and Greece have both been given little attention, although such currents represent a large renewable energy resource which could be exploited by “modern Archimedean screw technologies”. Despite the age of the Archimedean screws, there is no consistent and appropriate theory for the rotor hydraulic design linking the screw’s geometry with their performances. This paper presents a short view of the first Archimedean Water Current Turbines C.F.D. modelling results, which were carried out within the program ARCHIMEDES III recent research entitled “Rebirth of Archimedes: contribution to the study of hydraulic mechanics and hydrodynamic behavior of Archimedean cochlear waterwheels, for recovering the hydraulic potential of natural and technical watercourses, of maritime and tidal currents”. The Computational Fluid Dynamics analysis concerns innovative Horizontal Axis Archimedean Water Current Turbines (HAAWCT) and shows some promising performances for such unconventional Archimedean cochlear hydraulic energy systems harnessing the hydraulic kinetic potential of a series of sites in natural and technical watercourses and the tidal potential of the Euripus Strait and of the very astonishing sea River of Cephalonia.*

**Key Words:** C.F.D., FLOW-3D, Archimedean Screw Turbines, Small hydropower, Kinetic Energy.

## 1. INTRODUCTION

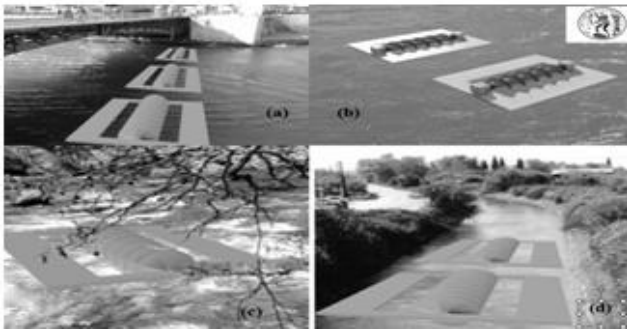
Pleiades of zero head sites in small and big watercourses, open water channels, as well as important sea and tidal currents, such as Cephalonian coastal paradox and Euripus Strait, are used for recovering kinetic hydraulic energy and marine power. Little attention has been given towards this exploitation in Europe, in Mediterranean countries

and in Greece, despite the fact that such currents represent a large renewable energy resource, that could be exploited by modern horizontal axis Archimedean hydropower technologies to provide impressive levels of electric power and give a significant contribution to fulfilling the energy demand (Figure 1) [1].



**Fig -1:** Modern Archimedean hydropower technologies for Cephalonia, Euripus Strait and whole Greece.

Although there is a trend towards “green” energy derived from renewable resources throughout the world, including kinetic energy of watercourses, sea waves, tidal and marine currents, with many countries offering important incentives and targets, the mysterious coastal river of Cephalonia and the strange tidal flow of the Euripus Strait, offer exciting technical propositions for the extraction of important amounts of energy, by using series of modern Horizontal Axis Archimedean Water Current Turbines (H,A,A.W.C.T.) [2, 3, 4]. Figure 2 represents our proposals for artificial floating HAAWCT’s in Euripus Strait (a, b), in a river (c) and in irrigation channel (d) [5, 6, 7].



**Fig -2:** Artificial Floating HAAWCT's in Euripus Strait (a,b), in a river (c) and in an irrigation channel (d).

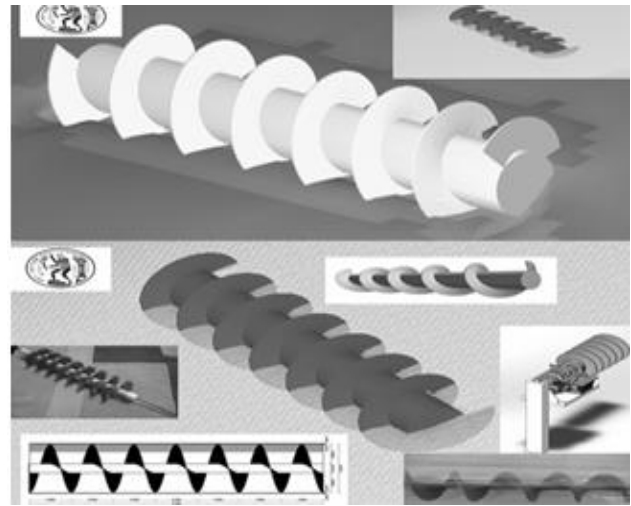
The beautiful island of Cephalonia is the site of one of the most astonishing hydrological phenomena in the world. A strange seawater massive current flows continuously into the karst substratum of the island through sinkholes, in the Livadi Gulf, near Argostoli. This seawater current disappearing in the water channel entrance in the Livadi Gulf, is reappearing on the opposite coast of the island at brackish springs, near the town of Sami. Besides Cephalonian important coastal current Euripus Strait is subject to strong tidal currents, with important unexploited hydropotential [1]. Figure 3 gives characteristic views of artificial HAAWCT's harnessing the local potential of the input and the output Cephalonia's coastal paradox.



**Fig -3:** Permanent Cephalonian sea water current entrance (a) and exit (b,c) in Livadi and Sami Gulf.

This paper presents preliminary Computational Fluid Dynamics (C.F.D.) analysis of new innovative Archimedean Water Current Turbines (HAAWCT's) having either

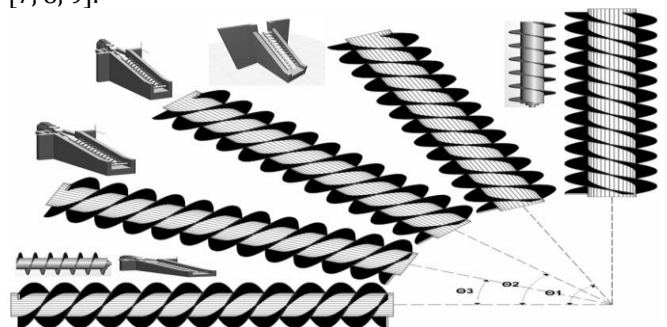
horizontal or vertical floating, or fixed cochlear rotors. A first "a priori" idea for such preliminary C.F.D. analysis of some innovative AWCT is given in Figure 4.



**Fig -4:** A first idea for such preliminary CFD analysis of some innovative HAAWCT's.

## 2. A FEW WORDS FOR HAAWCT'S C.F.D.

In the present work, we try to study, among all the inclination axis screw angle cases,  $\theta_1, \theta_2, \dots, \theta_n$ , from the zero angle ( $\theta=0^\circ$ ) to various inclined axis screws,  $0 < \theta < 90^\circ$ , including the special case of the vertical screws ( $\theta=90^\circ$ ) and the extreme cases concerning the horizontal and vertical axis screws, which are good for the recuperation of the kinetic hydraulic energy potential. It is obvious that the horizontal and the vertical axis screw rotors, are able to harness the zero head kinetic flowing potential of rivers, open channels, coastal and tidal currents. Figure 5 shows the spectrum of all screw axis orientation cases [7, 8, 9].

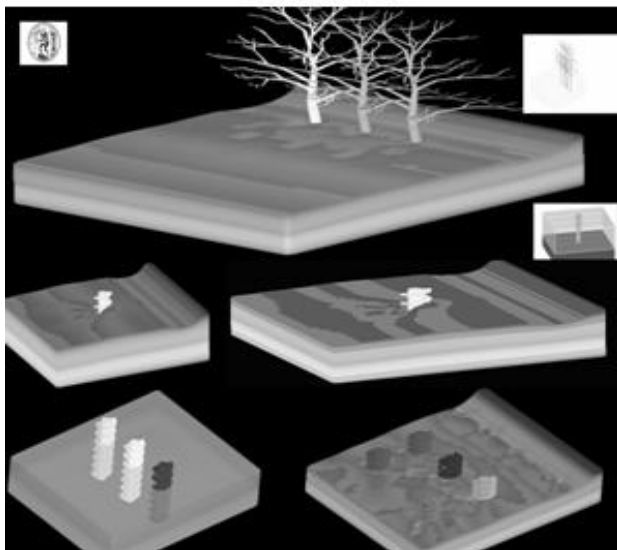


**Fig -5:** The spectrum of all the screw axis orientation cases.

The horizontal axis Archimedean screw rotors have been analyzed from fluid dynamics point of view by using modern C.F.D. techniques. By investigating the dynamic behavior of flowing water through the Archimedean rotors, C.F.D. provides flow simulation solutions for free-surface, steady-state problems in one, two and three dimensions and models. Such Archimedean C.F.D.

simulations were performed here, by using 3D views and an efficient Navier-Stokes Equations (NSE) solver, with structured rectangular mesh, when STL files of the CAD cochlear rotors drawings are imported into the mesh, in the flow simulation package. No special additional modules for meshing or post-processing are needed. An integrated graphical user interface ties everything together, from problem setup to post-processing [10, 11]. It gives good visualizations of the simulation results, including performances of the HAAWCT's cochlear rotors for various starting characteristics, rotational speeds and different flow conditions.

The presented here C.F.D. view of studying innovative Archimedean screw renewable hydraulic energy systems and the preliminary simulation results show very promising performances of all the unconventional Archimedean cochlear hydraulic energy systems, harnessing the unexploited flowing hydraulic potential of natural streams, of open channels hydraulic works and finally of coastal and tidal currents, as compared to the other conventional small hydropower turbines. Figure 6 gives a schematic first C.F.D. Archimedean vertical axis screw preview.

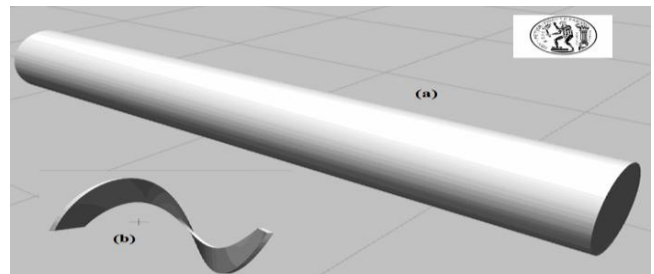


**Fig -6:** A first CFD "a priori" pre-view, for various vertical Archimedean rotors.

### 3. SHORT VIEW OF HORIZONTAL ARCHIMEDEAN SCREW DESIGN FOR C.F.D. STUDIES

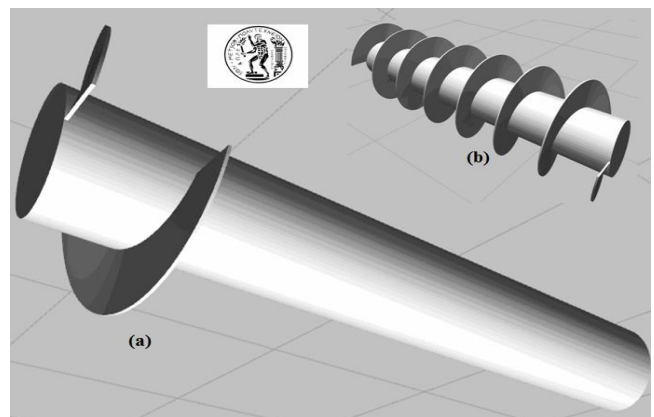
From a purely numerical perspective the geometric complexity of the Archimedean flow problem is such, that it demands the full power of modern computational fluid dynamics (C.F.D.) to solve the equations of motion and turbulence models in domains that involve multiple surfaces. Additional difficulties are associated with modelling free surface and secondary or vortex phenomena, the physics of which is not yet fully understood. In spite of the practical importance of the

problem, the literature on numerical modelling of Archimedean screw flows, is very limited. In the present work an attempt has been made to simulate and predict flow horizontal floating cochlear rotors. To configure the horizontal Archimedean screw was used the design software (CAD) which is able to perform a two-dimensional design and also a three-dimensional parametric geometry. Furthermore, specific objects were used, namely the cylinder and propeller which are some of the basic solid in the CAD program. These objects were changed in order to have the desired dimensions, as described below; initially, the cylinder with fixed length and diameter was constructed (Figure 7a). Then the screw blade was designed in such way that the internal radius coincides with the radius of the cylinder and its length is an integer multiple of the cylinder length (Figure 7b).



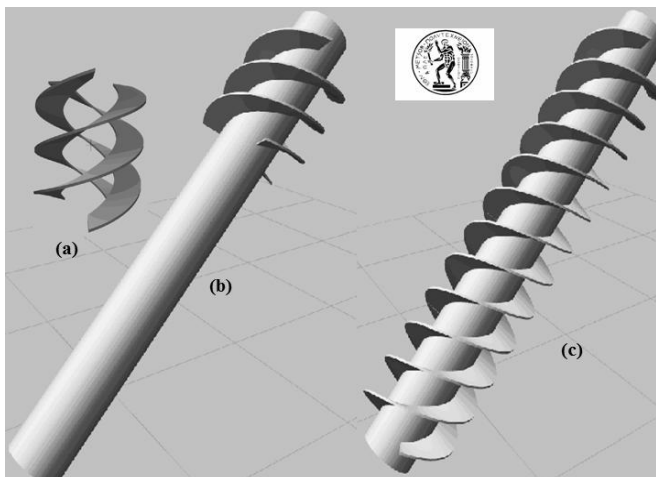
**Fig -7:** Perspective representations of the cylinder (a) and the helix (b) of an HAAWCT.

Then the inclined or horizontal helix was placed on the cylinder (Figure 8a) and finally, copies of the helix along the length of the cylinder were created (Figure 8b). Then the final form of the screw is easy to be shaped.



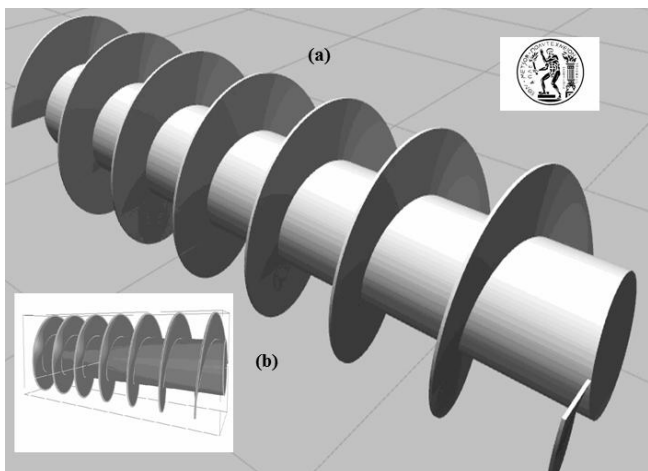
**Fig -8:** Placing the cylinder helix (a) and making copies of the helix along the length of the cylinder (b).

Furthermore a wide variety of number of helices (2, 3, 4,... n) can be used as shown below for the case of three blades. Constructing of three helices (Figure 9a), then placing these helices on the cylinder (Figure 9b) and finally making copies of the propellers along the cylinder (Figure 9c).



**Fig -9:** Placing screw blades on the inner screw cylinder (a, b, c).

The object library of a C.F.D. code did not include a screw, therefore the equivalent of drawing programs was used, as described above. The object form that receives the C.F.D. code is STL (stereolithography), thus a converter program to convert the CAD object into STL object was used (Figure 10a, 10b).

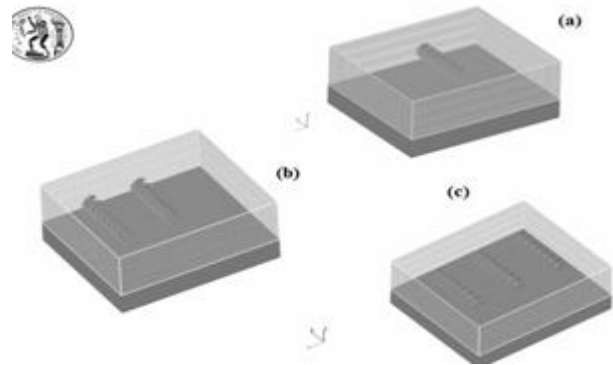


**Fig -10:** Placing Screw designed with CAD code (a) and object to STL format through converter program (b).

#### 4. HORIZONTAL AXIS ARCHIMEDEAN SCREW MESHING GEOMETRY AND BOUNDARY CONDITIONS

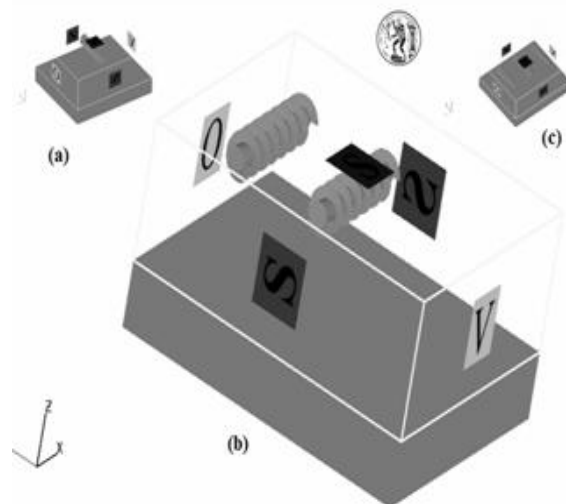
All C.F.D. problems are defined in terms of initial and boundary conditions. It is important that the user specifies these correctly and understands their role in the numerical algorithm. Horizontal screw rotors, with one or more blades, are the same rotors like the inclined screws, having the same blade number with a zero inclination angle. These HAAWCT screw turbines could be very promising for the efficient capturing of kinetic energy of watercourses, hydraulic works, sea and tidal currents.

Furthermore, the STL object, for 1, 2 and 3 rotors, was introduced to the C.F.D. program and created the grid, i.e. the section where the fluid exists but also the place where the computer program code is required to perform the calculations (Figure 11).



**Fig -11:** Introducing the STL object and the mesh generation (a, b, c).

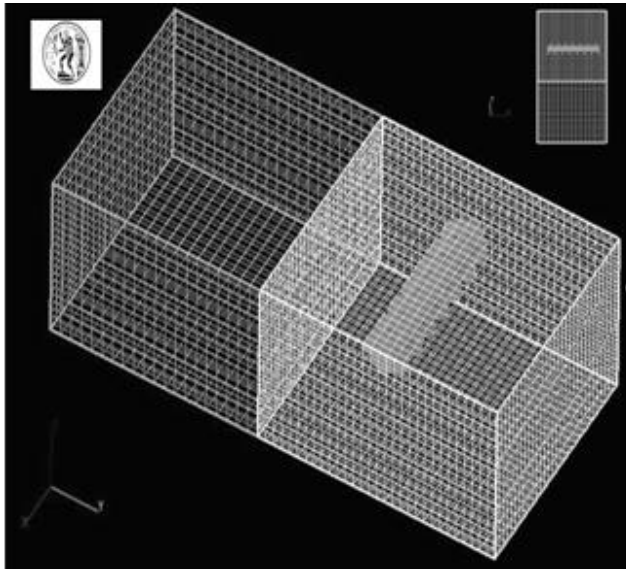
After choosing the fluid (water in this case), the physical conditions related to the problem should be defined, (namely gravity, viscosity, water speed etc) as well as the execution time of the numerical experiment. Moreover, there should be a selection of boundary conditions such as inlet and outlet of the water at a specific speed, existing symmetry and pressure. In Figure 12 below symmetry is illustrated by the symbol S, with V the entrance velocity, and O the outflow



**Fig -12:** Selection of boundary conditions for 1, 2 and 3 rotors (a, b, c).

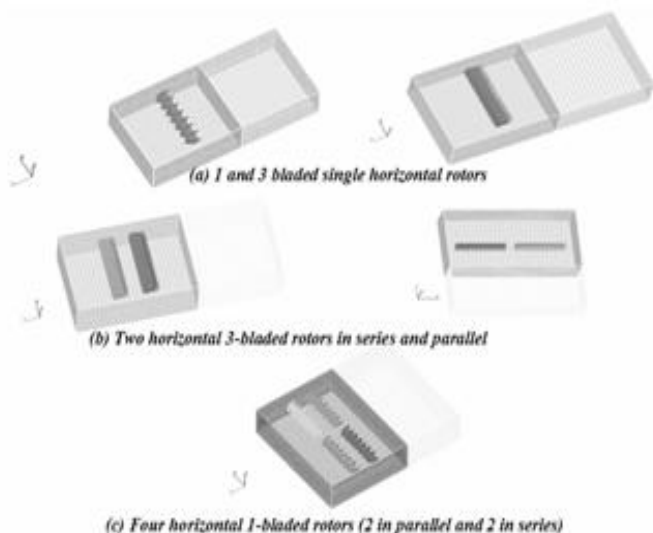
Then it becomes a preprocess of the program, in order to control the accuracy of the data, followed by the processing in which the program performs the necessary calculations. Figure 13 represents 2D and 3D views of the one bladed horizontal screw turbine, by using a more efficient "Multi-Block Gridding Technique" with a second

grid mesh, able to act as a numerical filter, when STL file of the CAD drawing is imported into the mesh in the C.F.D. software package.



**Fig -13:** One bladed horizontal STL object of screw turbine imported in the mesh block in a two mesh blocks approach.

The same technique with the second numerical filter grid mesh was followed in all simulation cases of Figure 14 with one 1-bladed and 3-bladed rotor, two 3-bladed horizontal rotors in parallel or in series, and four 1-bladed rotors (2 in parallel and 2 in series etc.).

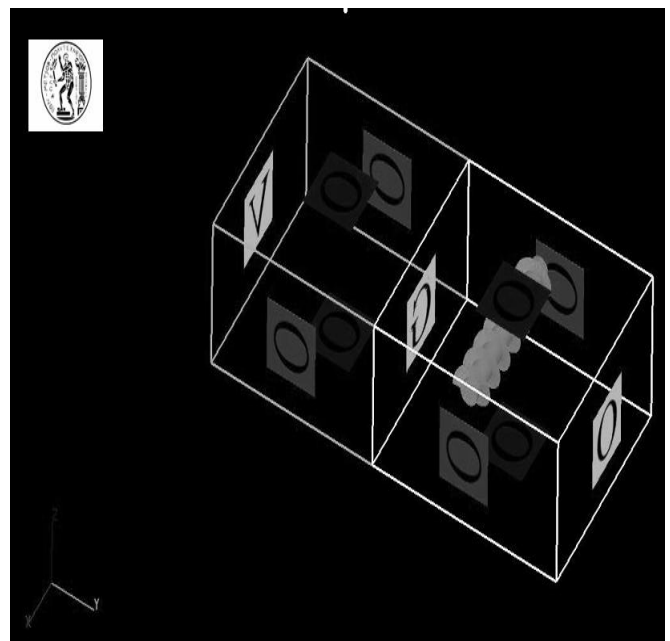


**Fig -14:** Various STL objects of horizontal screw turbines imported in the mesh block, with one single and 3-bladed, two 3-bladed and four 1-bladed rotors.

After choosing the fluid (water in this case), the physical conditions related to the problem should be defined (namely gravity, viscosity, moving and deforming object,

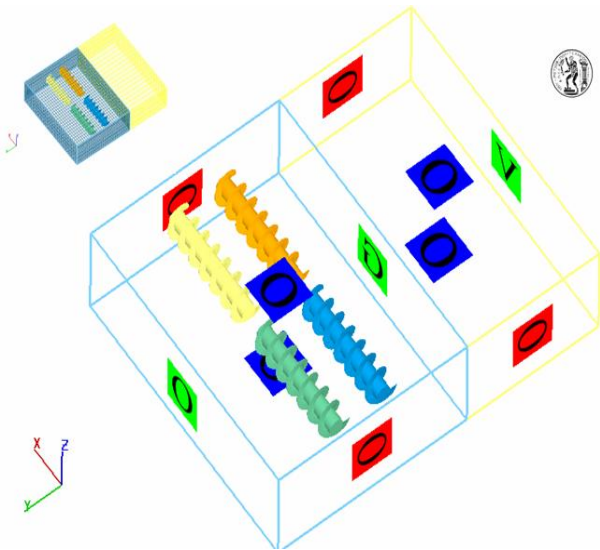
water speed etc) as well as the execution time of the experiment. Also there should be a selection of boundary conditions such as inlet and outlet of the water at a specific speed.

In Figure 15 below the symbols V and O illustrate the input and output conditions. The symbol G denotes the grid overlay condition. For the inlet a zero pressure-gradient (homogenous Neumann) is applied and all other variables are given Dirichlet conditions specified by the user. For the outlet, homogenous Neumann conditions are applied for all variables except the pressure where a homogenous Dirichlet value is set at one face. This is designed to recreate the upstream pressure distribution of the previous time-step at the boundary. At walls the pressure is set with a homogenous Neumann condition and the mass flow rate normal to the wall also set to be zero. A homogenous Dirichlet condition is applied to the tangential velocity. The values of scalars may be prescribed by either Dirichlet or Neumann conditions dependant on the actual flow geometry. For symmetry conditions the same conditions are applied as for walls except for the tangential velocity, which is homogenous Neumann. For cases concerning overlap of two mesh blocks, grid overlay conditions are used. The resolution of the mesh is adjusted by means of trial of error because of the hardware capability. A closer view to the boundary condition is shown in Figure 15. In the present simulation work two mesh blocks have been used. The overlap of the two mesh blocks is grid overlay. All other boundaries are assigned outflow. So, fluid comes from negative axis, hits the screw turbine and flows out.



**Fig -15:** Boundary Conditions of an AWCT.

Figure 16 gives boundary conditions information for the four 1-bladed rotors, 2 in series and 2 in parallel.

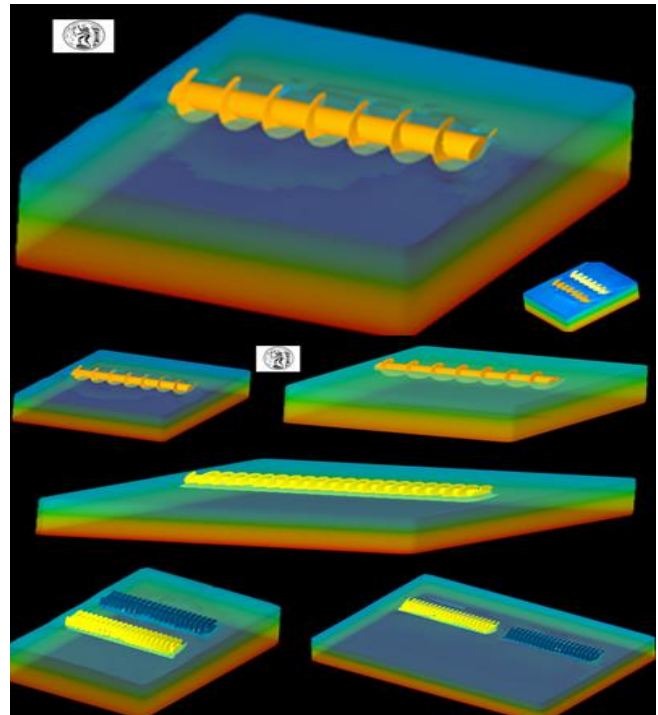


**Fig -16:** Boundary conditions for four 1-bladed rotors (2 in series and 2 in parallel).

Then it becomes a preprocess of the program, in order to control the accuracy of the data, followed by the processing in which the program performs the necessary calculations. Finally, the results of solution are exported to study and evaluate them.

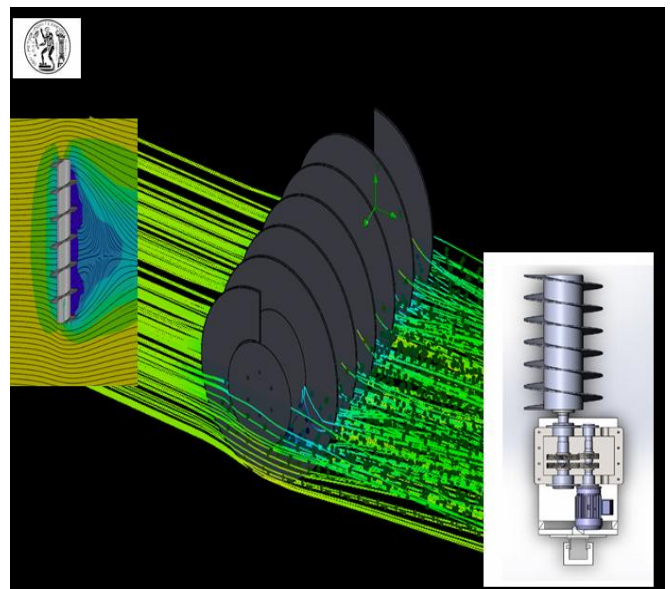
**5. SOME FIRST HAAWCT C.F.D. CONCLUSIONS**

The short C.F.D. view of studying innovative HAAWCTs and the preliminary simulation analysis show that to simulate complex 3D flow phenomena through rotating cochlear turbines, modern C.F.D. techniques are required. A screw designed by using CAD codes needs a converter program to obtain its STL (stereolithography) form admitted by C.F.D. codes. Then, the introduced STL object to the C.F.D. technique helped to create the mesh grid generation and resolve the Navier-Stokes equations for various inclined axis screws and for 1, 2 or more horizontal screws. Various C.F.D. codes (e.g. FLOW-3D, FINE-Turbo, OpenFoam, etc.) were used having important contribution to the study of hydrodynamic behavior of Archimedean screw turbines. These codes use interactive grid generation software and computation flow solver modules simulating continuity, Euler and Navier-Stokes equations, in all the cases of the flow regimes. The hydrodynamic performances of HAAWCT, with one or more blades, have been analyzed in various values of input flow. Figure 17 gives characteristic CFD simulation screens for one and two HAAWCT, in parallel and series.



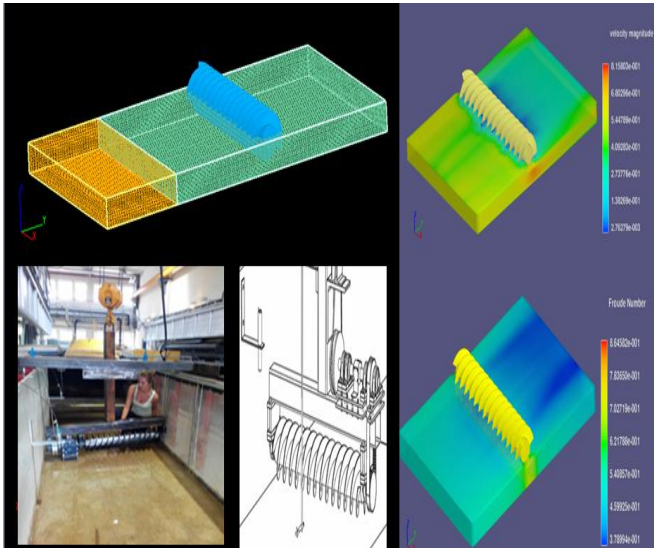
**Fig -17:** Preliminary CFD simulation screens for for one and two HAAWCTs, in parallel and series.

Figure 18 presents a preliminary C.F.D. simulation screen for a new innovative horizontal Archimedean screw designed in the framework of the present ARCHIMEDES III research.



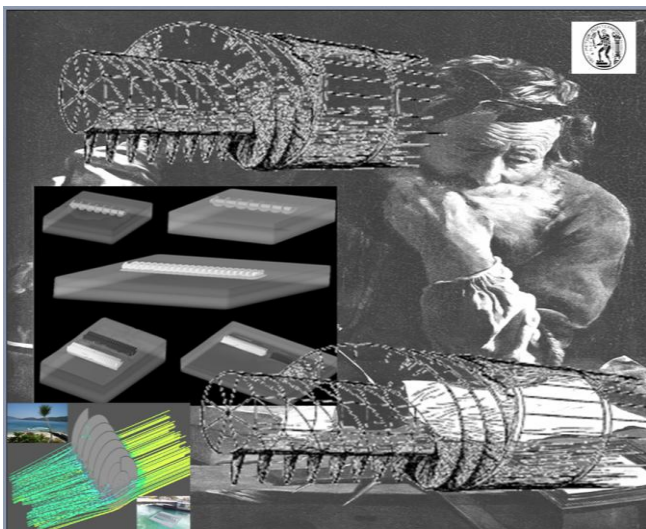
**Fig -18:** CFD screen for a new innovative HAAWCT.

Figure 19 gives some C.F.D. simulation views of a newly developed 3bladed HAAWCT by A.Stergiopoulou in BOKU University, Vienna [11].



**Fig -19:** C.F.D. views of one newly developed 3bladed HAAWCT

The presented below view and pre-view of Archimedean kinetic energy conversion systems preliminary HAAWCT simulation results, in the shadow of brilliant spirit of Archimedes show very promising performances of all HAAWCT cochlear systems, harnessing the important unexploited Greek flowing hydraulic potential of series of sites in natural and technical watercourses, in the Euripus Strait and the very astonishing sea river of Cephalonia (Figure 20).



**Fig -20:** C.F.D. and horizontal axis Archimedean rotors in the shadow of Archimedes

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