An eagle's CFD view of Studying Innovative Archimedean Screw Renewable Hydraulic Energy Systems

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Abstract
The Archimedean renewable energy systems are enjoying a renewed interest, since about one decade, and have become increasingly popular throughout Europe. It seems that this low head Archimedean technology is still a niche product. Despite the age of the Archimedean screws there is no consistent and appropriate theory for the screw hydraulic design linking the screw's geometry with their performances. This paper after giving a brief history of the Archimedean screw pumps and screw turbines presents an eagle's view of the recent NTUA and ASPETE C.F.D. modelling results of the 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".
Keywords: Archimedean Turbines; renewable energy sources; C.F.D.;small hydropower.

1. INTRODUCTION

Thousands of years after the original invention of the cochlear rotor, the best known of the early pumps, the Archimedean screw pump, also persists into modern times. During the last years, the inverse use of the Archimedean screw, as a kind of inverse screw pump-turbine, is under discussion within the hydropower scientific community [1-5]. Such low-head small hydropower plants were installed during the last decade in Central Europe by several industrial companies, which are based on the inversion of the energy flow in their pump operation and turning the old screw pumps into new Archimedean turbines [1, 5]. Recently, a series of various experimental and theoretical efforts had been made in the Hydraulic Laboratory of ASPETE, in collaboration with N.T.U.A., under the Research Program ARCHIMEDES III, concerning various Archimedean screw turbines configurations, by using small-scale models, in order to proceed in the exploitation of small hydropower potential in various river sites having small heads [4, 5]. For sites with greater heads, and greater water flows a cascade of two or more similar energy spiral rotors in series and in parallel could give an efficient Archimedean hydropower solution. Preliminary research efforts proved the useful exploitation of new screw techniques, under the form of innovative Archimedean Inclined Axis Cochlear Turbines (AIACT's) and innovative Archimedean Water Current Turbines (AWCT's) with horizontal floating cochlear rotors, harnessing the unexploited flowing hydraulic potential of natural streams, open channels hydraulic works, and coastal and tidal currents as well.
Figure 1 concerns photorealistic views in "virtual sites" of conventional and unconventional Archimedean Screw Small Hydropower Turbines, with 3-blade and 1-blade rotors, having inclined and horizontal axis, in series and parallel. Also, this figure shows an Archimedean Turbine Park, having 4 inclined and 4 horizontal Archimedean turbines.

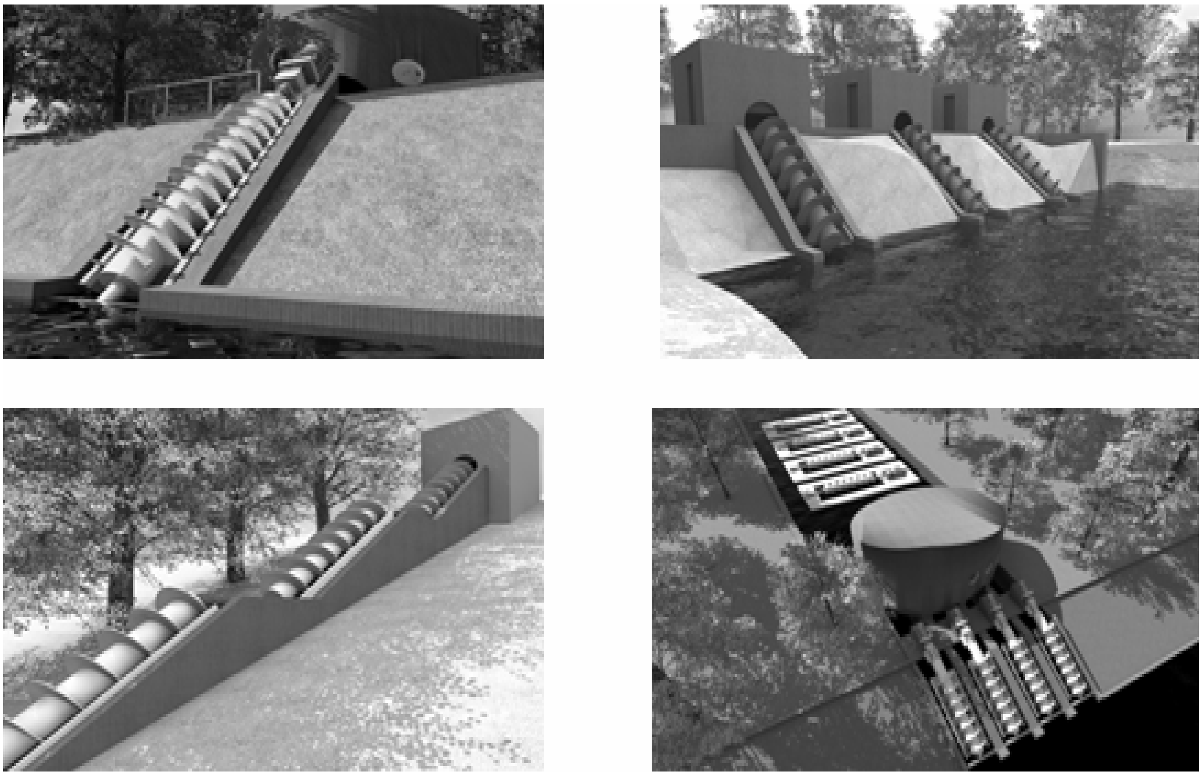

Figure 1. Four Archimedean artistic photorealistic views for "virtual sites" .

This research concerns a series of innovative conventional and unconventional inclined and horizontal axis floating Archimedean screw turbines to be installed in a multitude of very promising low head sites throughout Greece for recovering the unexploited Archimedean renewable hydraulic potential of watercourses, of open channel waterworks and the kinetic tidal energy potential of the Euripus Strait and the coastal paradox flow of Cephalonia. For such innovative Archimedean turbines, an ongoing Ph.D. work has developed having several theoretical, experimental, numerical methods and computational fluid dynamic simulations for the prediction of their hydrodynamic performances. This paper presents preliminary Computational Fluid Dynamics (CFD) analysis of new Archimedean Inclined Axis Cochlear Turbines (AIACT's) and innovative Archimedean Water Current Turbines (AWCT's) having horizontal or vertical floating cochlear rotors. These inclined, horizontal and vertical axis Archimedean screw rotors have been analyzed from fluid dynamics point of view by using modern Computational Fluid Dynamics (CFD) techniques By investigating the dynamic behaviour of flowing water through the Archimedean rotors CFD provides flow simulation solutions for free-surface, steady-state problems in one, two and three dimensions and models. Such Archimedean CFD 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 postprocessing are needed. An integrated graphical user interface ties everything together, from problem setup to postprocessing. It gives good visualizations of the simulation results, including performances of the AIACT's and AWCT's cochlear rotors for various starting characteristics, rotational speeds and different flow conditions. The presented here eagle's CFD 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 renewable hydraulic energy systems, harnessing the unexploited flowing hydraulic potential of natural streams, of open channels hydraulic works, and of coastal and tidal currents as well, as compared to the other conventional small hydropower turbines. Figure 2 gives a schematic first eagle's CFD Archimedean screw pre-view.

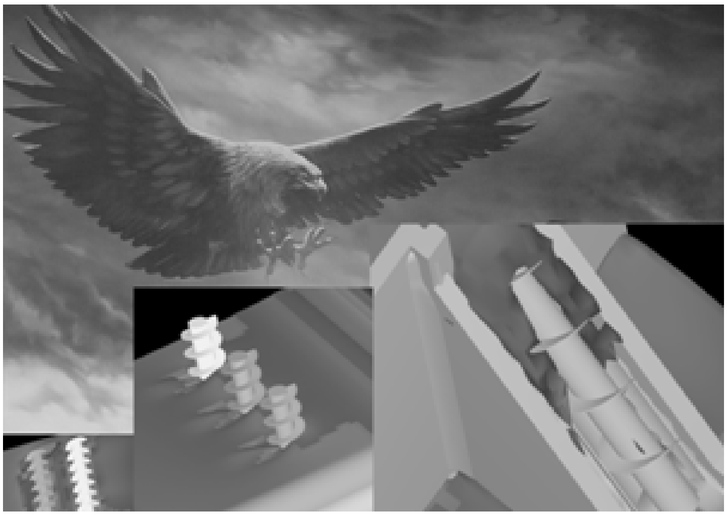

Figure 2. A first eagle's CFD Archimedean rotors pre-view.

2. SHORT VIEW OF DESIGN AND INNOVATIVE ARCHIMEDEAN SCREW

To configure the inclined or 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, were used specific objects, 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 follows. Initially, was constructed the cylinder with fixed length and diameter (Figure 3a). Then the screw blade constructed so that the internal radius coincides with the radius of the cylinder and its length is an integer multiple of the cylinder length (Figure 3b).

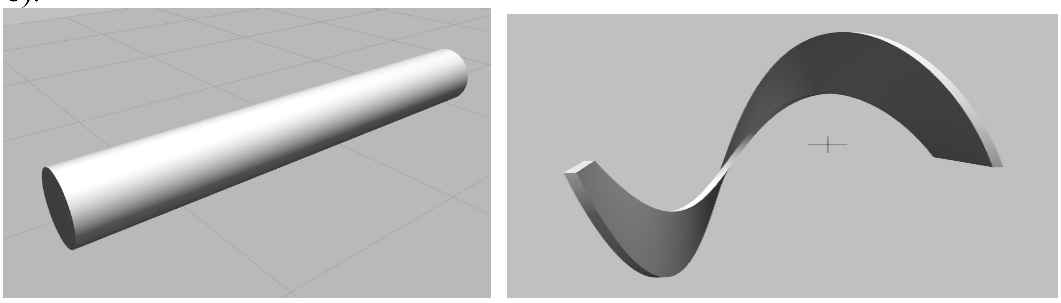

Figure 3. Perspective representations of the cylinder (3a) and the helix (3b)

Then the inclined or horizontal helix was placed on the cylinder (Figure 4a) and finally, was created copies of the helix along the length of the cylinder (Figure 4b). Then it is easy the final form of the screw.

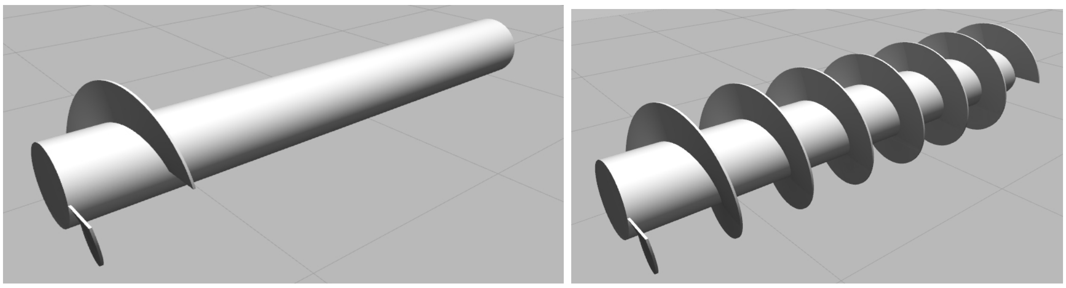

Figure 4. Placing the cylinder helix (2a) and making copies of the helix along the length of the cylinder (2b)

Furthermore may use 2, 3, 4,…. n helices, as shown below for the case of three blades. Constructing of three helices (Figure 5a), then placing the helices on the cylinder (Figure 5b) and finally making copies of the propellers along the cylinder (Figure 5c).

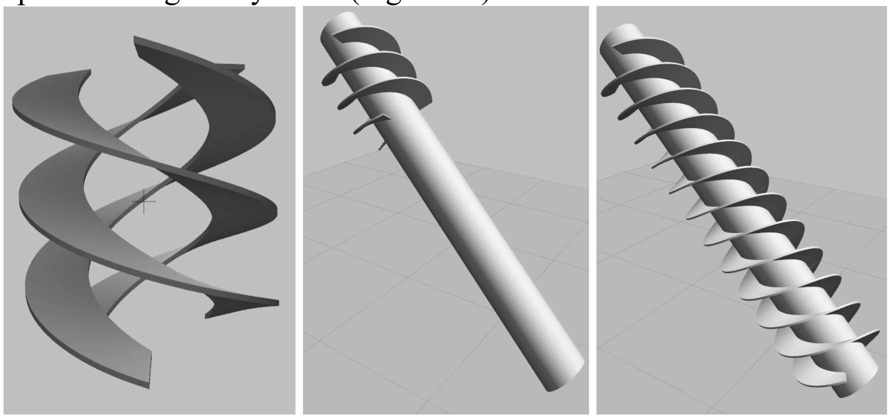

Figure 5. Placing screw blades on the inner screw cylinder 4a, 4b, 4c.

The object library of a CFD code did not include a screw, therefore it was used the equivalent of drawing programs as described above. The object form that receives the CFD code is STL (stereolithography), thus it was used a converter program to convert the CAD object into STL object (Figure 6a, 6b).

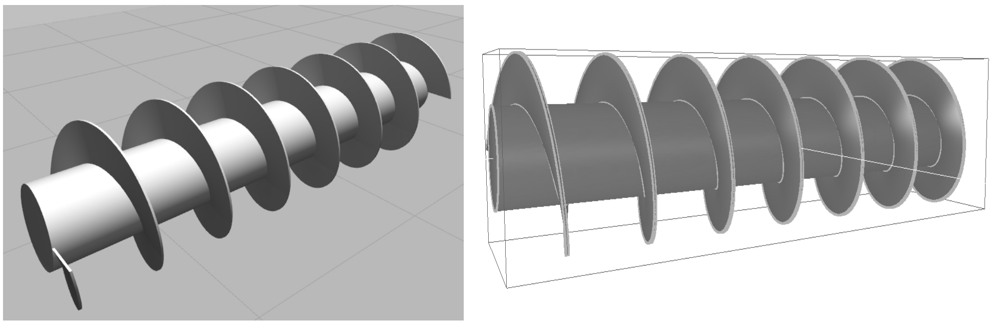

Figure 6. Screw designed with CAD program code (5a) and object to STL format through converter program (5b).

3. MESHING GEOMETRY AND BOUNDARY CONDITIONS OF SCREWS

All CFD 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. Basically these screw turbines are responsible for the efficient capturing of kinetic energy of watercourses, hydraulic works and sea as well tidal currents. Figure 7 represents 2D and 3D views of the one bladed horizontal screw turbine when STL file of the CAD drawing is imported into the mesh in Flow-3D software package.

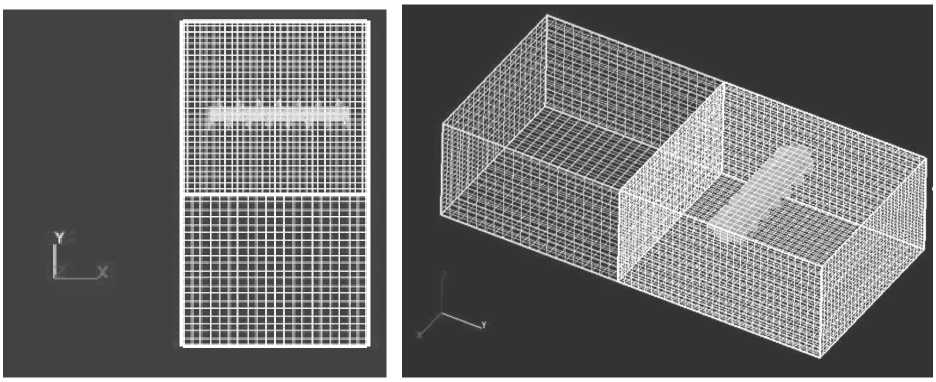

Figure 7. One bladed horizontal STL object of screw turbine imported in the mesh block.

After choosing the fluid (water in this case), should be defined the physical conditions related to the problem, (namely gravity, viscosity, moving and deforming object, water speed etc) and 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 the figure below is illustrated by the symbols V and O the input and the output conditions.In this figure 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 homegenous 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 is used grid overlay conditions. 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 8. In this work two mesh blocks have been used. Flow has been given from negative y axis. 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.

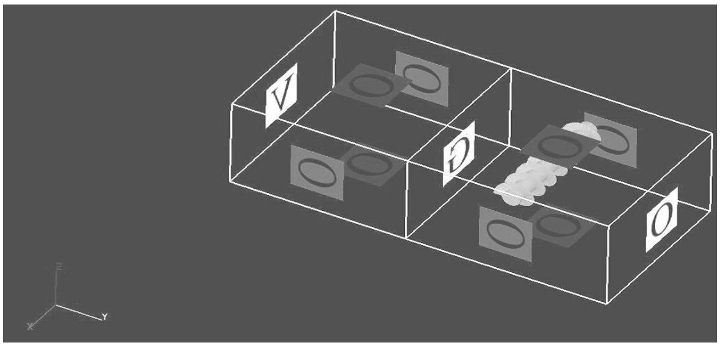

Figure 8. Boundary Conditions

Then it becomes a preprocess of the program, in order to the 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.

4. TOWARDS A PRELIMARY CFD STUDY OF AIACT's & AWCT's

The eagle's CFD view of studying innovative Archimedean screw and the preliminary simulation analysis show that to simulate complex 3D flow phenomena through rotating cochlear turbines, modern CFD techniques are required. A screw designed by using CAD codes needs a converter program to obtain its STL (stereolithography) form admitted by CFD codes. Then, the introduced STL object to the CFD 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. CFD codes (e.g. FINE-Turbo, OpenFoam, FLOW-3D etc.) were used having important contributions to the study of hydrodynamic behaviour 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.

$$\frac{\partial \rho}{\partial t} + \vec{\nabla}\cdot\left(\rho \vec{V}\right) = 0 \;, \quad \rho\frac{D\vec{V}}{Dt} = \rho\left[\left(\vec{V}\cdot\vec{\nabla}\right)\vec{V} + \frac{\partial \vec{V}}{\partial t} + \right] = -\vec{\nabla}p + \rho\vec{F}$$

$$\rho\frac{D\vec{V}}{Dt} = \rho\left[\left(\vec{V}\cdot\vec{\nabla}\right)\cdot\vec{V} + \frac{\partial \vec{V}}{\partial t}\right] = -\vec{\nabla}p + \rho g + \frac{\partial}{\partial x_j}\left[\mu\left\{\frac{\partial V_i}{\partial x_j} + \frac{\partial V_j}{\partial x_j}\right\} + \delta_{ij}\lambda\, div\vec{V}\right]$$

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. Figure 9 shows typical screws in various inclination angles, and one bladed inclined and horizontal STL screw turbines objects imported in the mesh blocks.

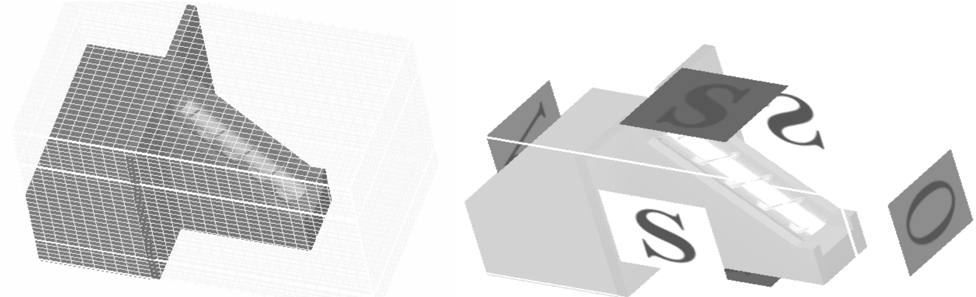

Figure 9. Inclined STL turbine object imported in the mesh blocks and boundary conditions.

The hydrodynamic performances of AIACT and AWCT have been analyzed in various values of input flow. Figure 9 gives two characteristic CFD simulation screens for a AIACT and a AWCT.

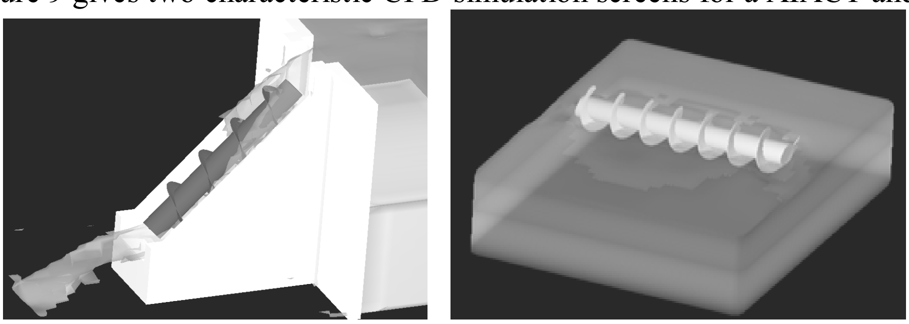

Figure 9. CFD simulation screens for a AIACT and a AWCT.

The presented here eagle's CFD view and pre-view of Archimedean Screw Turbines and some preliminary simulation results show very promising performances of all cochlear systems, harnessing the unexploited Greek flowing hydraulic potential.

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