



REVIEW ARTICLE

REVIEW OF THE APPLICATION OF BIDIRECTIONAL BLADES IN HORIZONTAL AXIS TIDAL TURBINES

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ABSTRACT

Currently, there are three main approaches to solving the problem of bidirectional power generation from ocean currents: utilizing variable pitch mechanisms, passive yaw systems and specially designed bidirectional rotors. Bidirectional rotors can directly harness bidirectional ocean currents. Although the performance of bidirectional blades is inferior to that of unidirectional blades, their simple structure, low cost, and high reliability confer unique advantages in certain scenarios. Numerous research team are dedicated to improving blade design and manufacturing processes to enhance their efficiency and performance. This article reviews their contributions and points out that bidirectional blades have unique applications in certain marine energy sectors and will become an important component of renewable energy technology.

KEYWORDS

Bidirectional Blades, Tidal Energy, Horizontal Axis, Turbine

1. INTRODUCTION

Energy is a critical driving force for social development and economic growth, playing an indispensable role in modern life (Chen and Lam, 2015). With the growing population and accelerated industrialization, the demand for energy is continuously increasing. However, the finite and non-renewable nature of traditional energy resources has become increasingly apparent, prompting a shift towards more sustainable and environmentally friendly energy forms (Ng et al., 2013). Traditional energy sources primarily include fossil fuels such as oil, natural gas, and coal, which have long been the mainstay of human energy consumption. However, the extraction and use of these traditional energy sources have led to numerous environmental issues, including air and water pollution and greenhouse gas emissions, exerting significant pressure on human society and ecosystems (Kang et al., 2023). Consequently, the search for alternative energy forms has become a major challenge faced by countries around the world today (Rehman et al., 2023).

The ocean is one of the most expansive natural resources on Earth, covering 71% of the planet's surface (Li et al., 2023). As a vast ecosystem, the ocean not only offers rich biodiversity but also plays a crucial role in climate regulation (Bazilevs et al., 2019). Additionally, the ocean harbors immense energy potential, including tidal energy, ocean current energy, wave energy, and ocean thermal energy, all quietly stored in the depths of the sea (Wang et al., 2015). Harnessing ocean energy can reduce reliance on traditional energy sources and lower greenhouse gas emissions, thus combating climate change. Consequently, the development and utilization of ocean energy have become hot topics in the global energy sector and a vital pathway towards sustainable energy development (Kai et al., 2021).

Ocean current energy, a form of renewable energy, refers to the technology that generates electricity by utilizing the kinetic energy of water currents in the ocean (Kulkarni et al., 2018). Ocean currents, driven by various factors including wind, Earth's rotation, and tidal forces,

possess enormous and consistently available energy (Finkl and Charlier, 2009). By installing specialized turbines or hydrokinetic devices, the kinetic energy of water flow can be converted into electrical power. Compared to other forms of ocean energy, ocean current energy offers higher predictability and stability, as ocean currents are less affected by seasonal and weather conditions. Moreover, ocean current energy has relatively high density, allowing substantial energy generation even at lower water flow speeds (Wang et al., 2015). The environmental impact of developing ocean current energy is relatively minimal, with no greenhouse gas emissions or other pollutants, making it a clean and environmentally friendly energy source. Although the technology for harnessing ocean current energy is still in its developmental stages, its vast potential suggests it could play a significant role in future energy transitions (Hammar et al., 2017).

Due to the periodic variation characteristics in the direction and flow speed of ocean currents, the design of horizontal axis ocean current energy conversion devices capable of bidirectional power generation has become a significant trend and holds considerable importance. Research institutions worldwide have been dedicated to addressing the challenge of bidirectional power generation in horizontal axis ocean current energy devices. Based on a comprehensive review, the main solutions currently employed include the following three approaches:

The principle of achieving bidirectional power generation using variable pitch mechanisms involves adjusting the blade angles through the variable pitch system when the direction of the ocean current changes. This adjustment allows the blades to follow the direction of the current, ensuring that the rotor continues to operate efficiently. The SeaGen system developed by Marine Current Turbines (MCT) in the United Kingdom, the HS300 by Norway's Andritz Hydro Hammerfest, the HaiNeng II by Harbin Engineering University, and the 120 kW unit by Zhejiang University all utilize this variable pitch mechanism to achieve bidirectional power generation (Fraenkel, 2006; Keysan et al., 2011; MacEnri et al., 2011). The

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actuating mechanism for the variable pitch system can be either motor-driven or hydraulically driven, both requiring additional structural design. For electric variable pitch systems, sufficient space is needed to accommodate the motor and gearbox. In contrast, hydraulic variable pitch systems use hydraulic cylinders to adjust the blade pitch angle, offering the advantage of quick response times. However, hydraulic systems also face issues such as oil leakage and sealing problems.

The passive yaw method, similar to that used in wind turbines, achieves alignment with the flow by rotating the entire nacelle. This is commonly accomplished using a tail vane. Systems such as Verdant Power's Free Flow System, Singapore's Atlantis Resources' AK100 and AR1000 utilize this passive yaw approach for alignment with the current. This method requires a large bearing to support the rotational movement of the entire nacelle, which imposes high demands on the bearing's sealing and corrosion protection.

Special designs for the turbine blades enable direct utilization of bidirectional ocean currents. The HyTide1000 developed by Voith Hydro in the United States employs bidirectional blades to harness bidirectional ocean currents directly. Similarly, the Clean Current Turbine designed by Clean Current Power Systems incorporates a streamlined shroud and specialized blade structure to achieve bidirectional power generation. Compared to the previous two approaches, this method does not require additional mechanisms, avoiding specific sealing issues. Its simple structure, high reliability, ease of maintenance, and high developmental value make it an attractive option.

Bidirectional blades can generally be divided into two categories: those

with central symmetry and those with full symmetry. The most common construction method for bidirectional airfoil profiles currently involves modifying existing wind turbine airfoils, including NACA airfoils, DVL airfoils, RAE airfoils, etc., using a method of truncating and reverse joining. Among these, the NACA series is the most widely used in airfoil modifications for tidal turbine systems. The advantage of this method lies in directly utilizing the leading edge of mature airfoil profiles that have been extensively validated through experiments, typically exhibiting ideal aerodynamic performance. The second method involves forming a new airfoil profile through simulation and optimization. Although airfoils produced using this method may demonstrate superior performance, the process of simulation and optimization requires significant time and computational resources investment. Whether the resulting airfoil profile exhibits central symmetry or full symmetry depends on whether the initial airfoil profile selected has curvature and the construction method employed.

2. BIDIRECTIONAL BLADES RESEARCH

Bin Guo has designed a bidirectional airfoil turbine and conducted a comparative study of its performance under single-pile installation conditions. They also evaluated the hydrodynamic performance of the bidirectional turbine. The results indicate that the bidirectional turbine has similar energy conversion capabilities in both tidal flow directions, but its performance is slightly inferior to turbines using NACA airfoils (Guo et al., 2019). Figure 1 and Figure 2 shows the model diagrams of the NACA airfoil and the bidirectional BDA airfoil and turbine designed by their team (Guo et al., 2019).

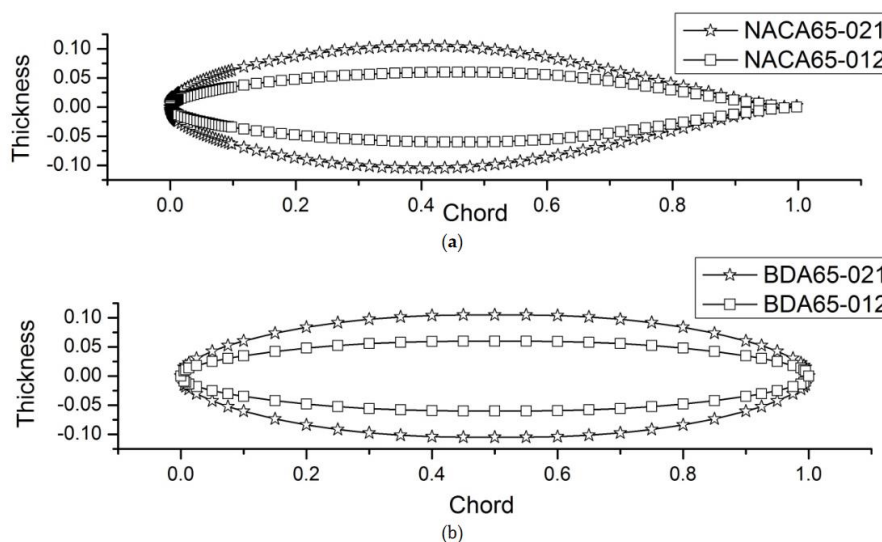


Figure 1: The section geometry of the foils, (a) NACA 65-021 and NACA 65-012 and (b) BDA 65-021 and BDA 65-012 (Guo et al., 2019).

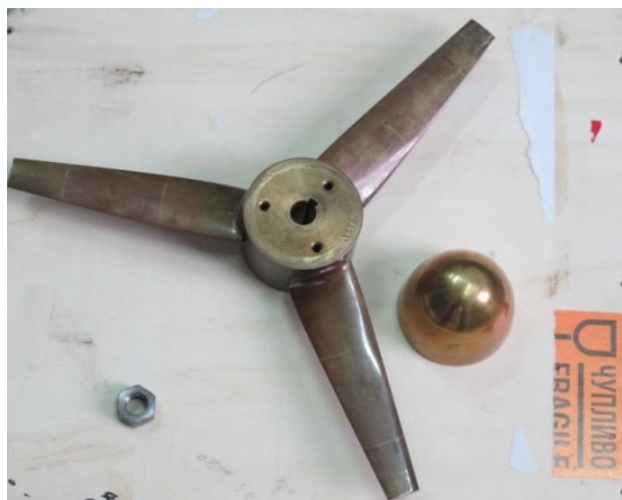


Figure 2: Photograph of the turbine model (Guo et al., 2019).

Although bidirectional blades may not match the performance of unidirectional blades, their simplicity in structure, absence of yaw mechanisms, low maintenance costs, and the advantage of efficiently harnessing bidirectional tidal energy make them uniquely attractive and

practical in certain scenarios. The simplicity in the design of bidirectional blades implies lower manufacturing and installation costs, while also reducing the number of mechanical components prone to failure, thus enhancing system reliability and stability. These advantages have garnered significant attention for bidirectional blades in some marine energy sectors, making them a noteworthy renewable energy technology.

Siyuan Liu systematically investigated the impact of different sweep angles of blades on the performance of bidirectional horizontal axis tidal turbines. They found that the effect of blade sweep on power and thrust varied with different operating conditions. Moreover, the blade tip clearance significantly affected the performance of upstream and downstream swept blades, while the curve exponent had a relatively minor impact (Liu et al., 2022). Figure 3 and Figure 4 shows the geometry of bidirectional hydrofoil and the four directions of the swept blade (Guo et al., 2019).

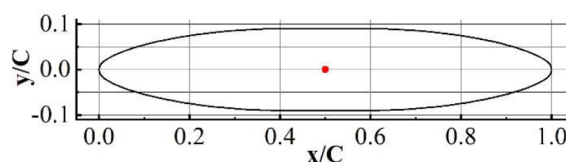


Figure 3: No-dimensional geometry of bidirectional hydrofoil, with the red point being the center-point of the hydrofoil (Liu et al., 2022).

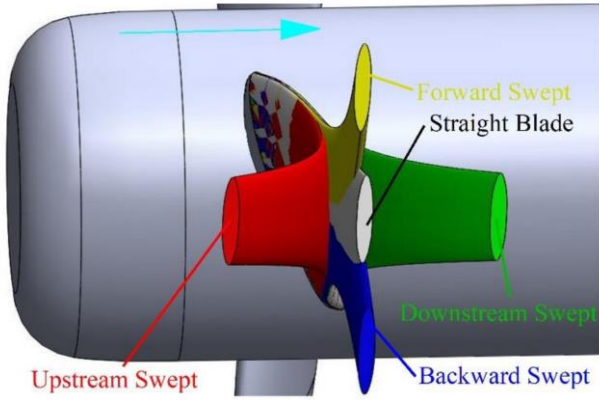


Figure 4: Sketch of four directions of the swept blade, with the cyan arrow being the direction of incoming flow (Liu et al., 2022).

Penfei Liu has researched and developed a series of prototype rotors for bidirectional horizontal axis tidal turbines. They optimized the rotor design using a tidal turbine program. The results showed a significant increase in the power coefficient of the optimized 20-meter bidirectional HATT rotor (Liu and Bose, 2012). Figure 5 and Figure 6 shows the profile of the bi-directional tidal turbine and meshing of the 20-m turbine (Liu and Bose, 2012). In August of the same year, the team also proposed a method for designing and optimizing rotor blades to address structural strength design issues (Liu and Veitch, 2012). Figure 7 shows thickness distribution for design y04 (Liu and Bose, 2012). In December 2013, the team developed a series of seven metal rotor models for bidirectional tidal turbines and studied the effects of Reynolds number, pitch-to-diameter ratio, pitch distribution, and solidity on the hydrodynamic performance of the helical propeller. The results indicated that the rotor with a solidity of 0.4 produced the highest power output (Liu et al., 2014). Figure 8 to Figure 10 shows different rotors and effect of solidity on drag and power coefficients (Liu and Bose, 2012).

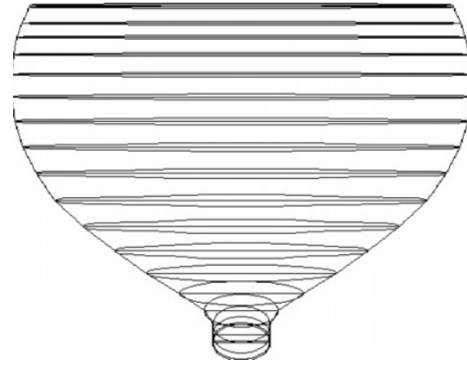


Figure 5: Typical blade sectional profile of the bi-directional tidal turbine (root to left) (Liu and Bose, 2012)

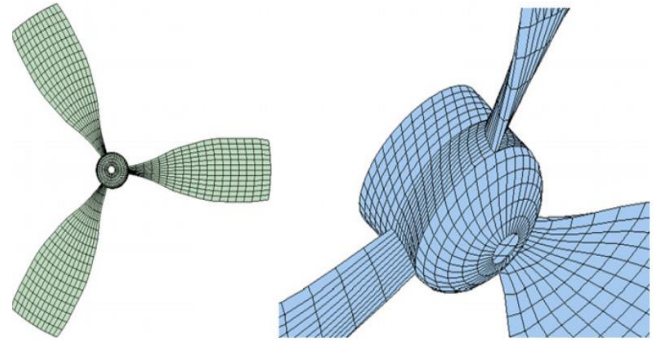


Figure 6: Surface meshing presentation of the 20-m turbine geometry and details at the intersections between the blade root and hub surfaces (Liu and Bose, 2012).

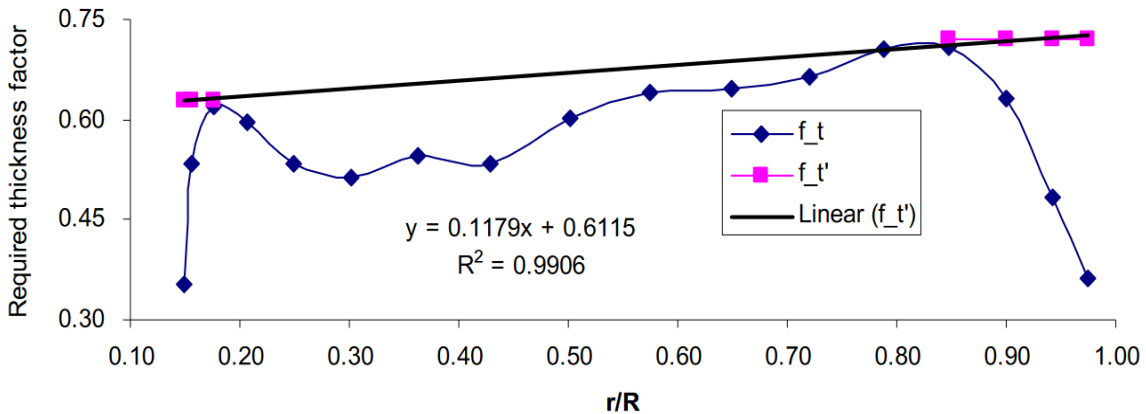
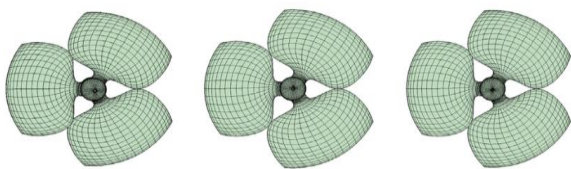


Figure 7: Minimum required sectional thickness factors at each radius and a smoothed blade thickness distribution for design y04 (Liu and Veitch, 2012).

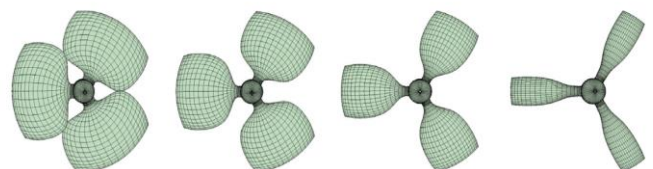


(a) Rotor No. 1 (b) Rotor No. 2 (c) Rotor No. 3



(d) Rotor No. 1 (e) Rotor No. 2 (f) Rotor No. 3

Figure 8: Rotor no.1-3 (Liu et al., 2014).



(a) Rotor No. 4 (b) Rotor No. 5 (c) Rotor No. 6 (d) Rotor No. 7



(e) Rotor No. 4 (f) Rotor No. 5 (g) Rotor No. 6 (h) Rotor No. 7

Figure 9: Rotor no. 4-7 (Liu et al., 2014).

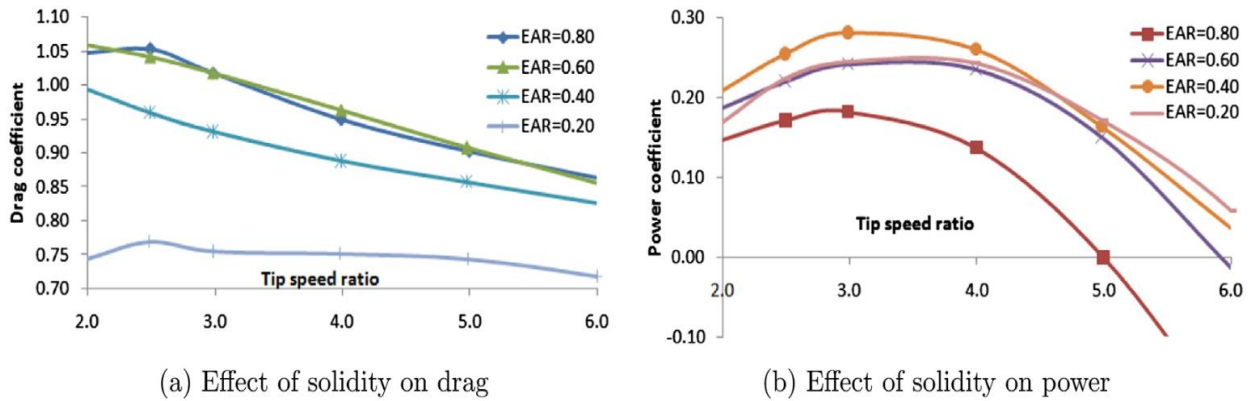


Figure 10: Effect of solidity on drag and power coefficients (Liu et al., 2014).

There are also teams focusing on optimizing the stall characteristics of bidirectional blades. Ivaylo Nedyalkov studied the NACA0015, NACA63-424, and their bidirectional versions, measuring lift and drag at different speeds, pressures, and angles of attack. They established a cavitation inception model for marine hydro turbines. The results showed that bidirectional airfoils tend to experience cavitation at lower cavitation numbers, making them more suitable for marine renewable energy conversion (Nedyalkov and Wosnik, 2013). Figure 11 shows the difference between NACA 0015, NACA 63-424 and bidirectional foil (Nedyalkov and Wosnik, 2013).

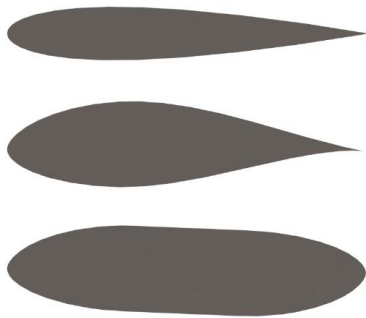


Figure 11: Hydrofoil sections. From top to bottom: NACA 0015; NACA 63-424; bidirectional foil (Nedyalkov and Wosnik, 2013).

Ivaylo Nedyalkov conducted a performance study of a series of bidirectional tidal turbine blade profiles, labeled as B3, using OpenFOAM

software. They also experimented with the cavitation inception characteristics of these profiles (Nedyalkov and Wosnik, 2014). Figure 12 shows difference kinds of B3 foils (Nedyalkov and Wosnik, 2013).

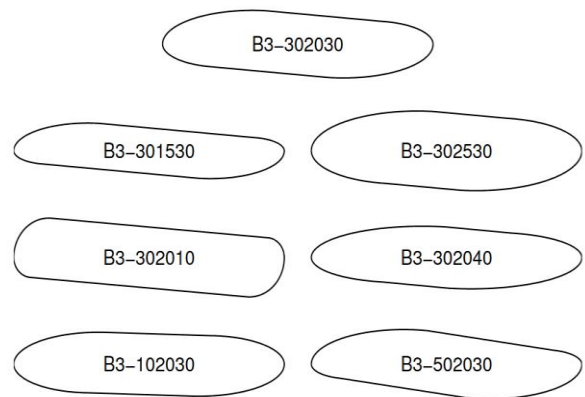


Figure 12: Sample B3 foils at 0° angle of attack (Nedyalkov and Wosnik, 2014).

Henry Shiu proposed two mechanisms to enhance the efficiency of bidirectional rotor tidal turbines: hydrofoil design and active flow control. Taking the yyb07cn hydrofoil family as an example, a series of variable-speed and constant-speed rotors were developed, resulting in a significant improvement in energy capture efficiency (Shiu and Van Dam, 2013). Figure 13 shows the 18% ellipse with a 1%c micro-tab at 98%c (Nedyalkov and Wosnik, 2013).

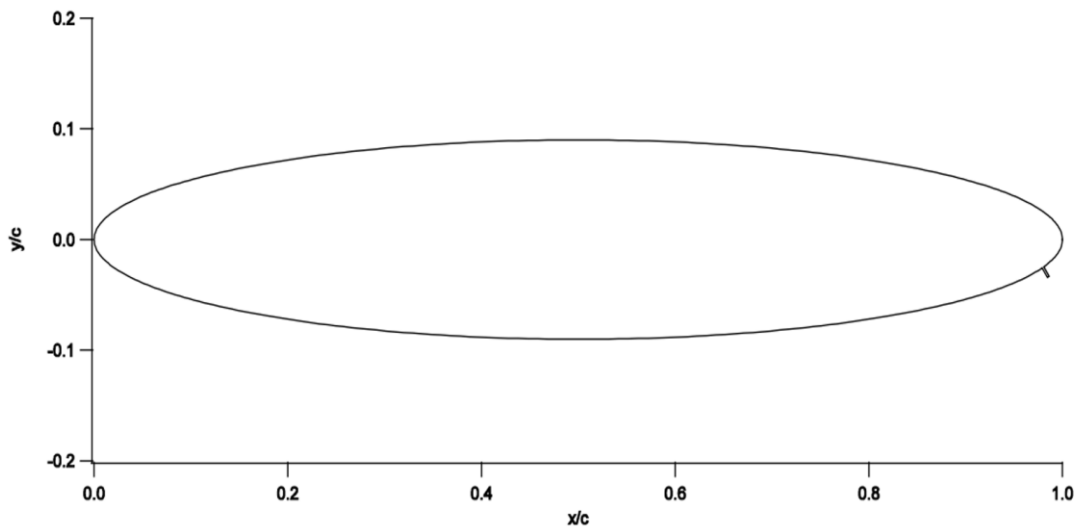


Figure 13: 18% ellipse with a 1%c microtab at 98%c (Shiu and Van Dam, 2013).

Micha presented a computational study on the flow characteristics of slender S-shaped hydrofoils and validated the findings using experimental data from the literature (Micha and Chatterjee, 2015). Figure 14 shows the

computational domain of a cascade of S-shaped hydrofoil (Nedyalkov and Wosnik, 2013).

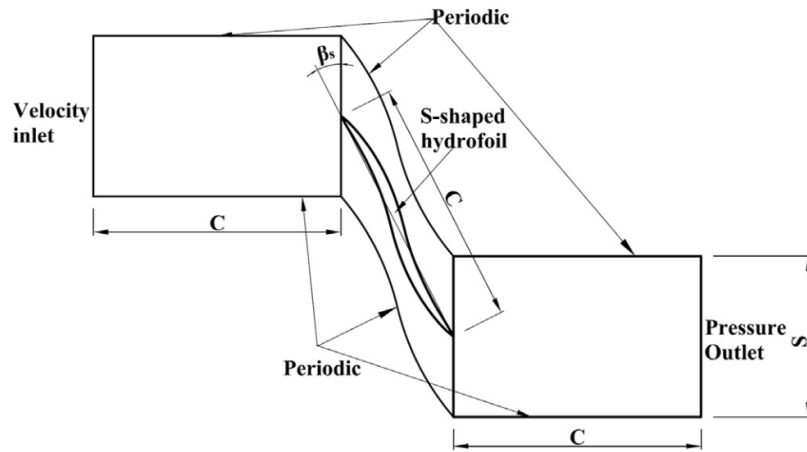


Figure 14: Computational domain of a cascade of S-shaped hydrofoil (Chatterjee, 2015).

3. CONCLUSIONS

Although there is extensive research on bidirectional blades both domestically and internationally, their application in real oceanic environments remains limited. Particularly, there is little attention paid domestically to the efficient utilization of bidirectional tidal energy. The advantages of bidirectional blades lie in their ability to maintain relatively high efficiency regardless of the direction of the tidal flow, thus avoiding the need for the entire device to adjust its orientation when the flow direction changes. Additionally, blades designed with symmetric airfoil profiles offer significant advantages in terms of manufacturing difficulty and precision.

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