DESIGN CLIMATE ACTION COMPETITION ENTRY

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TIDAL ENERGY TURBINE FORM REDESIGN WITH BIOMIMCRY

My name is Emilia Ziolek and I'm currently a third-year student in Product Design & Technology in the University of Limerick. I have become really passionate about sustainability since I went to Rosenheim, Germany last summer on a course for Sustainability and Circular Economy. Since then I have followed up this journey with educating myself on the pillars of sustainability. I think by far I really enjoy looking into different ways of harvesting energy from mundane activities, like using transducers in subway stations, or using kinetic-mechanical energy materials for stairs in densely populated areas etc.

As for this short project,, I would like to contribute to the advancement of sustainable energy solutions. I am undertaking the design of a novel tidal turbine inspired by principles of bio-inspired soft robotics. The central idea revolves around creating a turbine structure that mimics the fluidity and net-like characteristics found in nature, aiming to seamlessly integrate into its surrounding environment without disrupting wildlife. My focus is primarily on the form of the turbine, emphasizing a design that allows for a more harmonious interaction with marine ecosystems compared to traditional turbines. Although the technological intricacies are not fully laid out at this stage due to time constraints, the aspiration is to develop a concept that addresses environmental concerns

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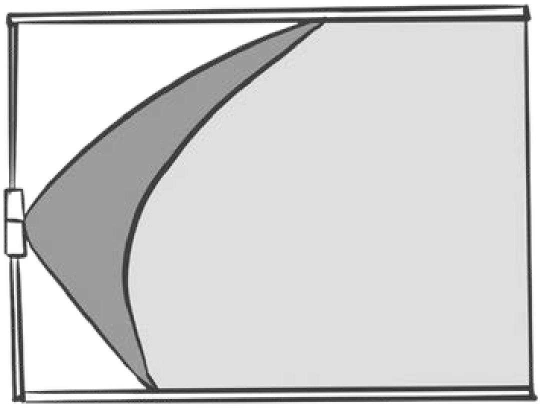
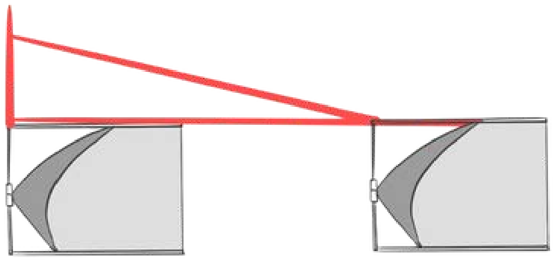
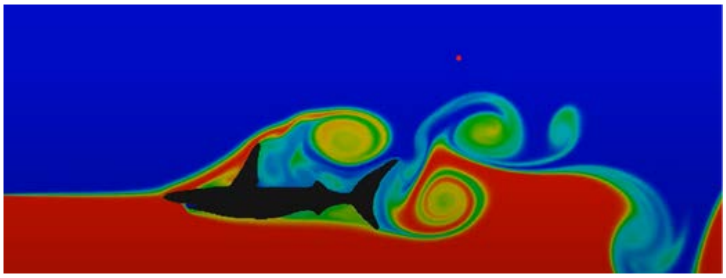
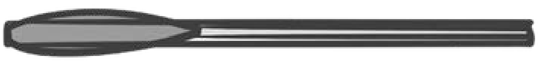
TIDAL

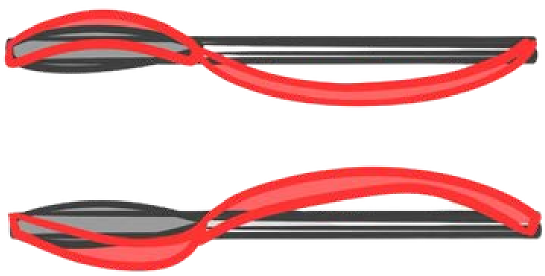
ENERGY TURBINE FORM REDESIGN WITH BIOMIMICRY

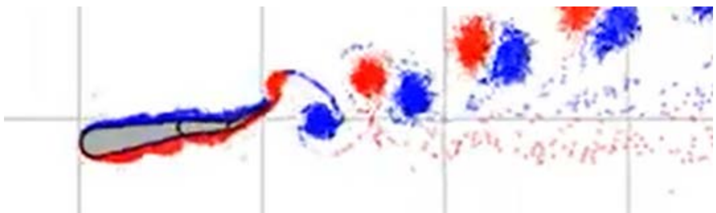


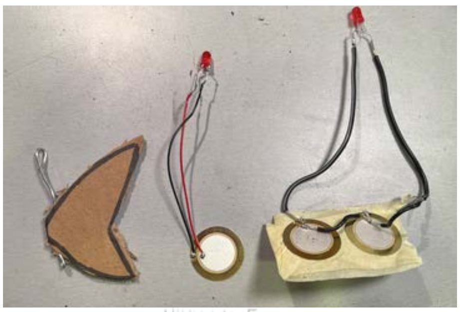


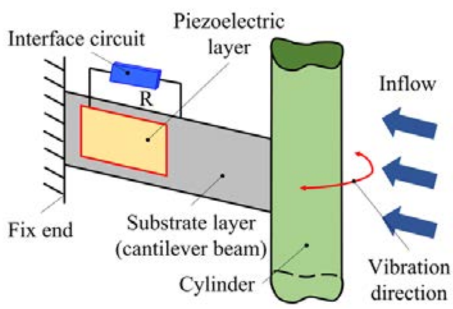


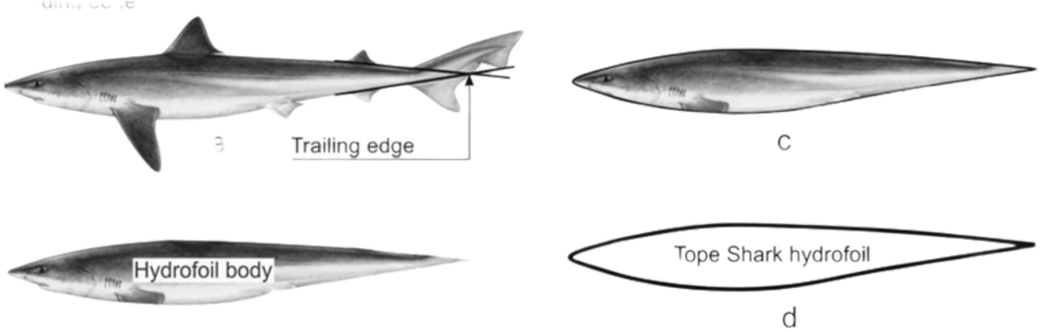








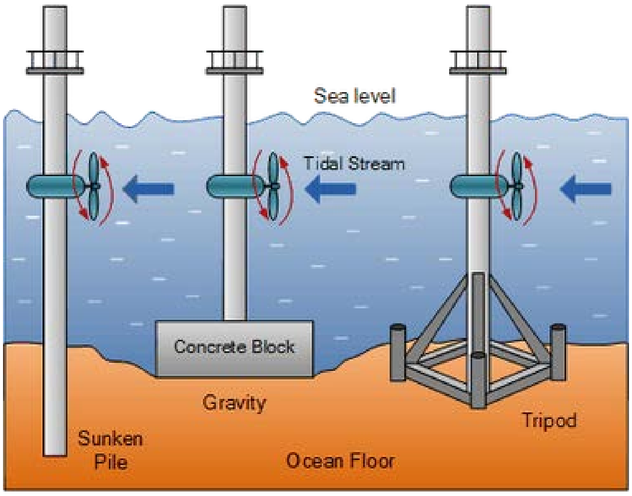




WHAT IS TIDAL ENERGY?

Tidal energy, a renewable energy source, is harnessed from the **flow of ocean waters caused by the rising and falling tides.** In the 20th century, engineers devised methods to utilize tidal movement for electricity generation in regions with substantial tidal ranges—the variation in water levels between high and low tides (Rutledge, 2023).

Tidal energy production is currently at an early stage of development. The generated power has been limited, and globally, there are only a handful of commercially sized tidal power plants currently in operation. **There are currently three different ways to make tidal energy: tidal streams, barrages, and lagoons.**

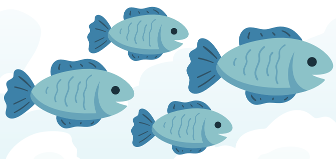


This project aims to discuss tidal streams, as they are the most common tidal energy generators (McDaniel, 2023). Turbines are positioned within tidal streams, which are swift currents formed by tides.

A turbine, a device designed to extract energy from the movement of fluid, can operate in both air (wind) and liquid (water). Due to the greater density of water compared to air, tidal energy surpasses wind energy in power. Notably, **tides are predictable and constant**. In locations where tidal generators are deployed, they **generate a consistent and dependable flow of electricity.**

So why hasn't tidal energy skyrocketed like it's solar and wind energy counterparts? The Sustainability Energy Ireland Report from 2004 stated that "...Benthic ecology, fishing grounds, marine mammals, visual impact and effect on recreational use of coastal waters were found to be the primary issues." – of tidal energy not being viable in a lot of situations. Beyond that tidal energy projects can also i**mpact sea shipment routes** and the environmental assessment process to identify suitable locations for tidal energy projects can be **expensive and time-consuming**. Additionally, the technology involved in tidal energy generation remains relatively expensive. The **high upfront costs** associated with the development and deployment of tidal energy infrastructure pose great financial challenges.

HOW DO TIDAL TURBINES CURRENTLY IMPACT MARINE LIFE?



Tidal turbines have the potential to cause physical injury to marine mammals through direct contact with moving structures or parts of the turbines (Wilson et al., 2007).

A 2021 study assessed whether harbor porpoises in Scotland were negatively impacted by tidal farms and turbines' rotating blades. The study found a 78% decline in porpoises when turbine flow speeds increased. Their avoidance of the tidal farm could derive from the loud noise it makes underwater. (Marsh, 2023)

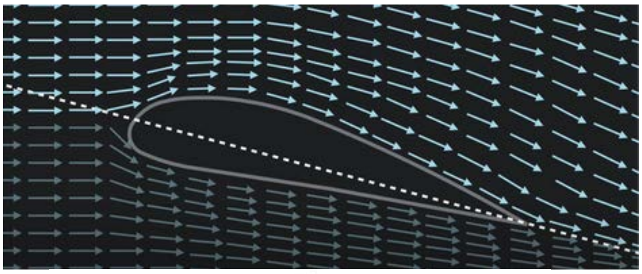
Estimated levels of risk for interactions of animals with marine energy devices, as described in the case studies in report on Biological Consequences of Marine Energy Development on Marine Animals by G.Hemery et al. in 2021.

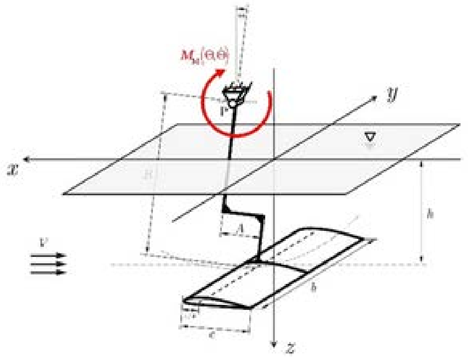
Low — Medium — High

Case studies	Early Life Stages	Changes in Competition	Food Availability	Predator Susceptibility	Death & Severe Injury	Reproductive Success
Seals	Collision				Collision & Underwater Noise	
Crab/Lobster	Underwater Noise	Habitat Change		Habitat Change		
Harbor Porpoise					Collision & Underwater Noise	
Salmon	Collision			Underwater Noise	Collision	
Skate		EMF & Habitat Change		Habitat Change		
Diving Seabirds					Collision	

A conscientious approach to marine conservation in the development of tidal energy is not only an ethical imperative but a fundamental requirement for a truly **sustainable source of energy that is clean and responsible.**

BLADELESS DESIGN - HYDROFOILS





WATERLUST - 2022 - Physics of a Hydrofoil

High pressure on the lower side, lower pressure on the high side result in upward force and reduce resistance, and allow the craft to accelerate. Commonly seen in modern boats. Their streamlined design not only reduces the environmental impact on marine life by **eliminating rotating blades** but also enhances **efficiency in energy conversion.** Hydrofoils operate by harnessing lift generated from water flow, allowing them to capture energy with reduced drag and increased effectiveness. Moreover, their adaptability to variable flow conditions enables optimal performance in fluctuating tidal environments.

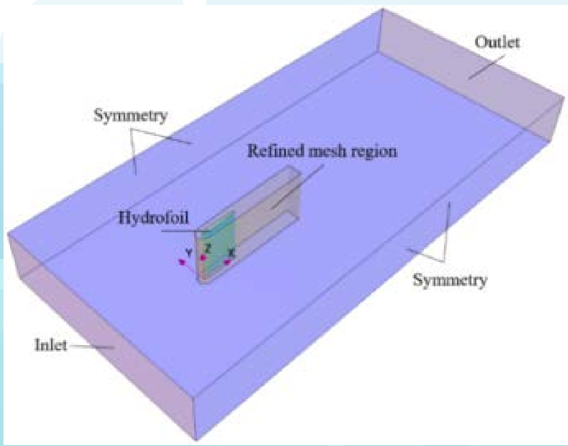
To further this hydrofoil design, a second one could be incorporated that oscillates in a lateral movement like a shark.

Mr teslonian (2019) video on twin oscillating hydrofoils to propel boat.

Mr teslonian on youtube - “This boat is being propelled by oscillating two hydrofoil blades through the water, similar to how a shark's tail works. By oscillating the hydrofoils in opposing directions I was able to stop a big energy loss I found when using a single foil, and that was stopping the boat from shifting back and forth.”

WHY LATERAL?

Lateral oscillating hydrofoils (side-to-side movement) can offer distinct advantages over horizontal hydrofoils. Unlike traditional horizontal hydrofoils, lateral oscillating designs leverage a more dynamic approach, mimicking the sideways movement of marine life like fish. This lateral motion enables these hydrofoils to **efficiently capture energy from tidal currents across a broader spectrum of flow directions**, optimizing energy extraction in environments where water currents exhibit lateral variability. (Gunnarson 2019) It also provides a more responsive and versatile energy capture system.

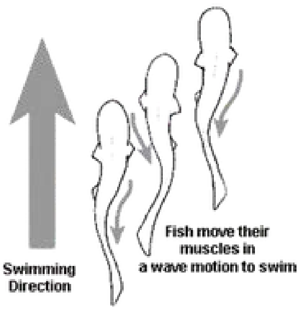


Hu, J. (2022) Analysis of lateral hydrofoils in three dimensional.

BIOMIMICRY - INSPIRATION FROM NATURE

Photograph:Mary Schwalm/Reuters

"starting with a whale that washed up on a New Jersey beach, Frank Fish thinks he knows their secret. The **bumps cause water to flow over the flippers more smoothly**, giving the giant mammal the ability to swim tight circles around its prey." (McClatchy, 2008)

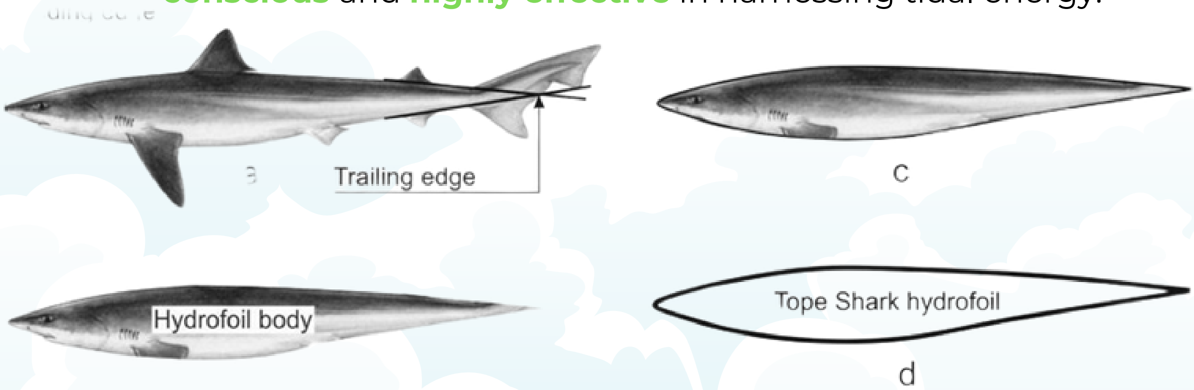


BYJU, 20223

"Fish have a streamlined shape body, in which head and tail ends are smaller than the middle portion (tapered ends). This streamlined shape is such that **water can flow around the body easily** and allows fish to move easily in the water." (BYJU, 2023)

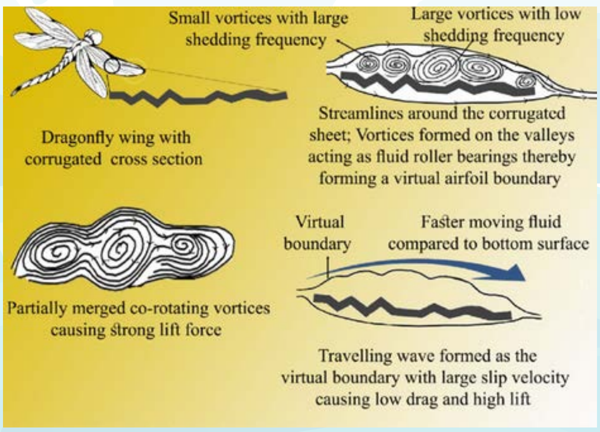
WHAT WILL BIOMIMCRY DO?

Incorporating biomimicry inspired by sharks and fish into the design of bladeless turbines can hold great promise for increasing efficiency in tidal energy generation. Bladeless turbines can **minimize drag, reduce turbulence, and enhance adaptability** to variable flow conditions. This also aligns with eco-friendly design principles, promoting sustainability and reducing the potential impact on marine life. The biomimetic design, drawing inspiration from nature's efficiency, contributes to the development of bladeless turbines that are both **environmentally conscious** and **highly effective** in harnessing tidal energy.



DEPECTION OF SHARK AS SHAPE FOR HYDROFOIL BODY (MURATOGLU, 2019)

ALSO IN CONSIDERATION:



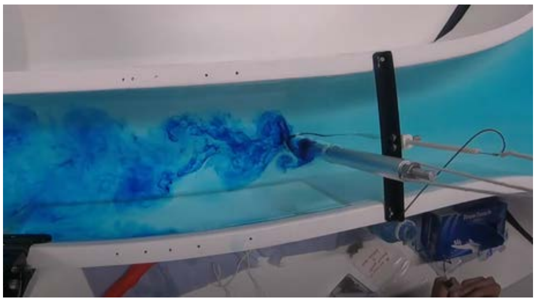
Agrawal, 2019 - Corrugated hydrofoil like dragonfly wing schematic.

"Corrugated hydrofoils are lately getting attention because of their superior aerodynamic performance compared to engineered hydrofoils at low Reynolds numbers (Re)." (Agrawal, 2019) The corrugations introduce a beneficial interplay with fluid dynamics, fostering the generation of vortices that **amplify lift and improve hydrofoil efficiency.** This design not only increases the lift force for a given water flow but also contributes to **drag reduction** by managing the boundary layer and promoting smoother flow.

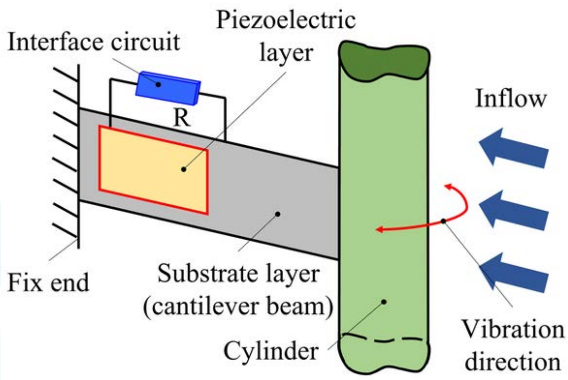
ENERGY COLLECTION
VORTEX INDUCED VIBRATIONS (VIV)

Vortex-induced vibrations are periodic oscillations or vibrations of a structure caused by the formation and shedding of vortices in a fluid flow, often observed in structures such as hydrofoils or underwater cables subjected to flowing water.

“The cylinder is free to oscillate in the direction transverse to the incoming flow. The cylinder is attached to a magnet that can move along the axis of a coil made from conducting wire. The magnet and the coil together constitute a basic electrical generator. When the cylinder undergoes VIV, the motion of the magnet creates a voltage across the coil, which is connected to a resistive load.” (Barraro-Gil, A. 2017)



Weymotuh 2018, oscillating cylinder in water to show VIV.

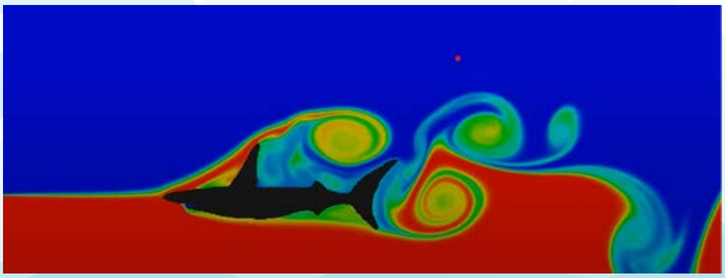


WU, Y (2022) - Model of flow-vibration collection cylinder

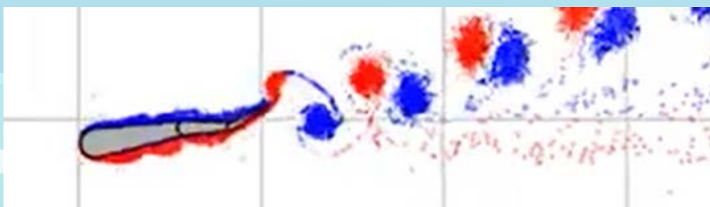
The key is to create a structure that interacts with vortices in the water flow. Piezoelectric materials are typically integrated into the structure, often near the trailing edge, where the vibrations are most pronounced. These materials convert the mechanical energy generated by the hydrofoil's oscillations in response to vortices into electrical energy,

PIEZOELECTRIC MATERIAL PLACEMENT

Piezoelectric materials would be embedded in the structure, particularly at locations where vortex-induced vibrations are most pronounced. Placing them near the trailing edge or areas experiencing vortex shedding optimizes the energy conversion process. In fish/sharks, the most vortexes like the diagrams shown are trailing at the end of the fin. This is where they would be placed and collected.



CFD Simulation of a shark 2D - mmnasr YT



CFD Simulation of swimming fish - Dynnikov YT

The harvested electrical energy would be then directed to an electrical system, where it undergoes conditioning and is fed into a generator. (WU, Y 2022)

DESIGN SHAPE AND FORM

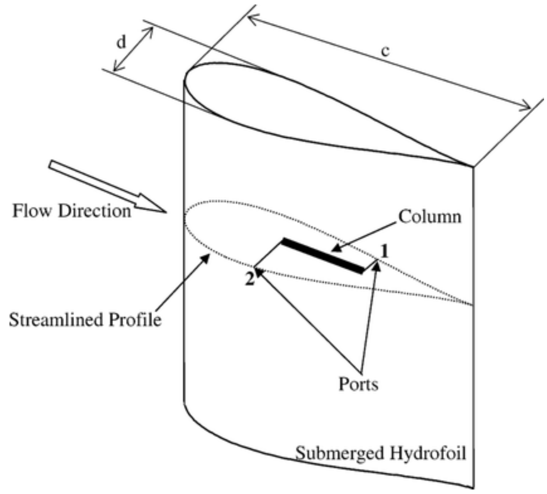
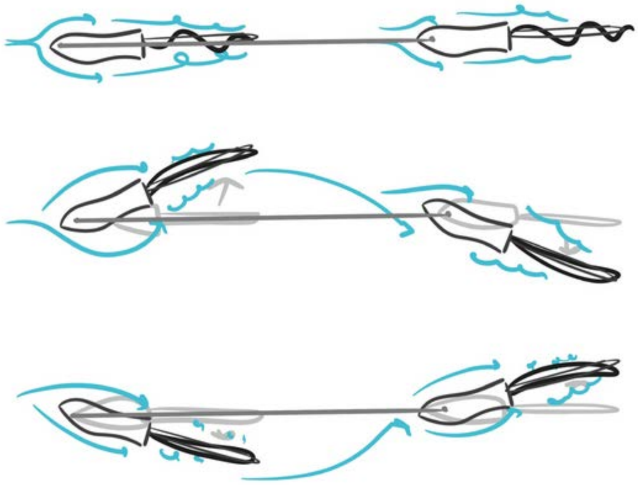


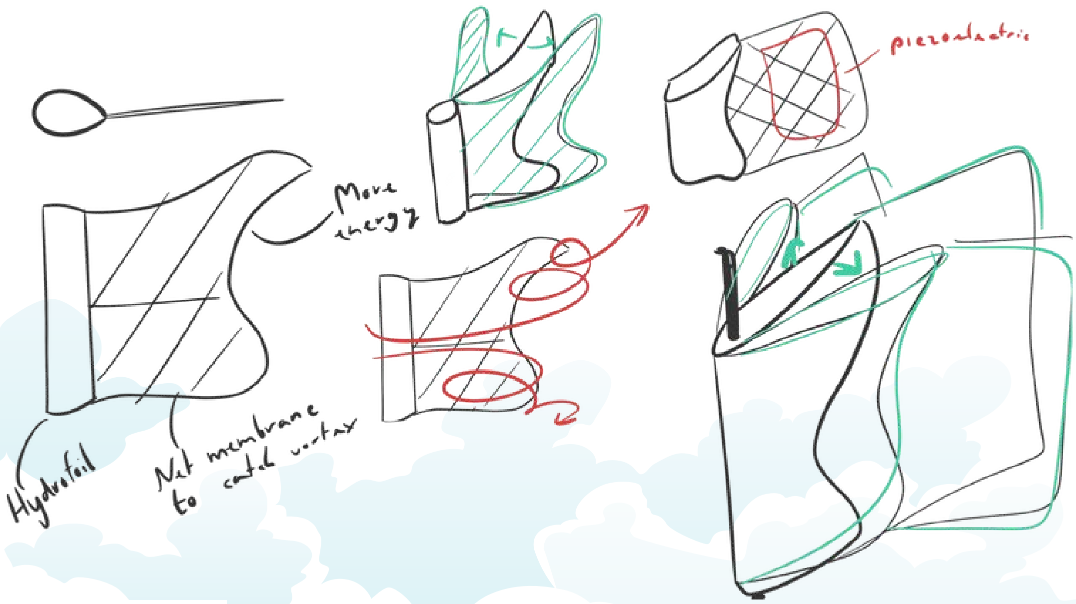
Illustration of a hydrofoil vertically submerged in a stream and aligned to flow direction. (Jawitz, 2007)

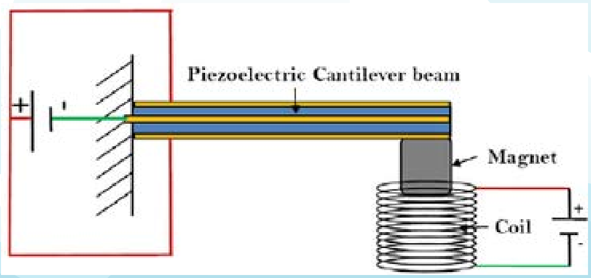


Movement study of the dual fins, moving opposite to each other to improving stability.

Initial ideation of the shape of the device, basing it off the above research. A shark-like fin design is proposed. Noted are the piezoelectric material placement and where the vortexes are the strongest.

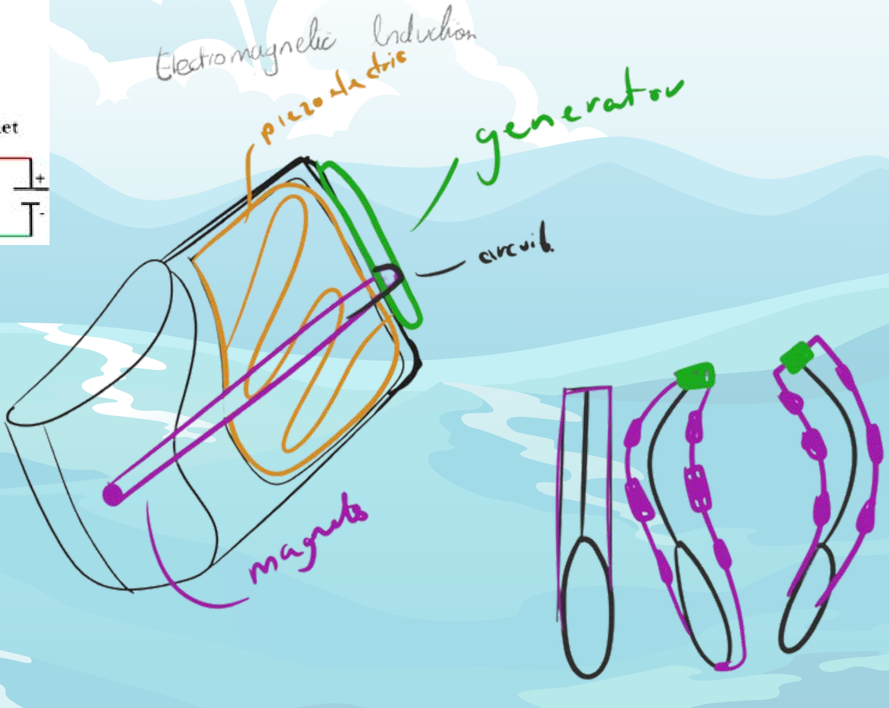
There is a further concept of using electromagnetic induction to stronger the electric field around the object, drawings of it are below.



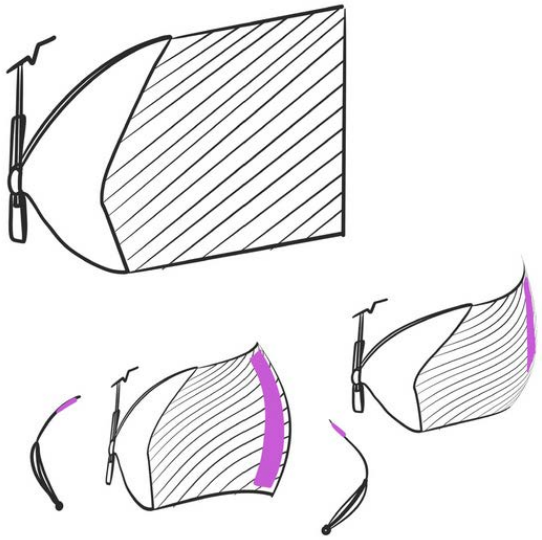


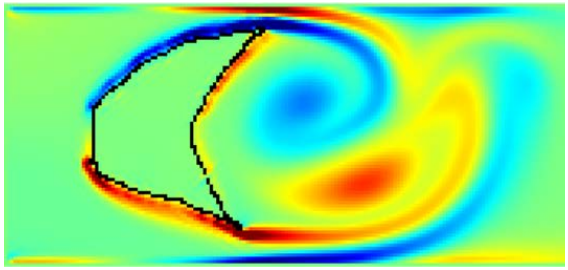
Schematic of a coupled piezoelectric-electromagnetic energy harvesting device (here a cantilever beam is used as the vibrating structure). - Prasad 2009

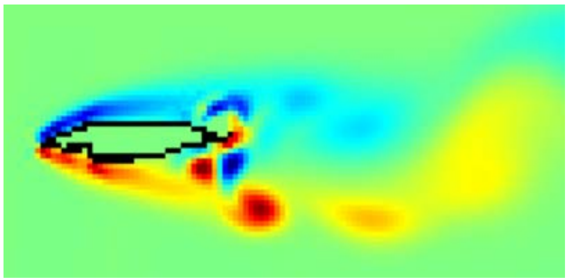
Using magnets can help create a difference in polarity and increase the output of the piezoelectric material into the generator.



DESIGN SHAPE AND FORM

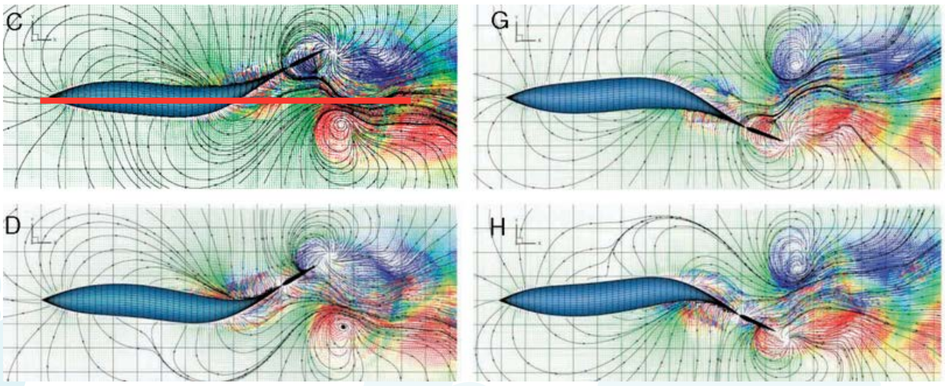






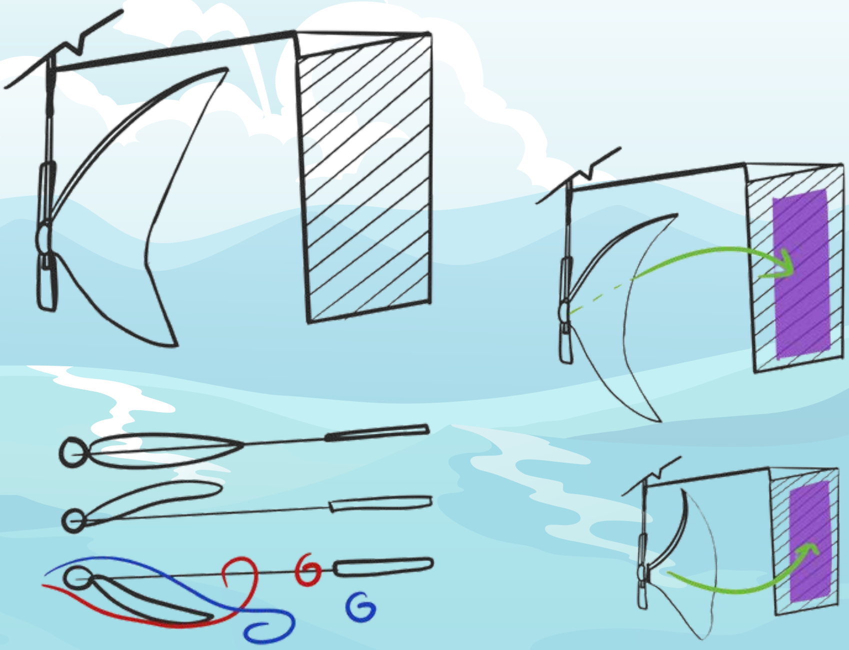
Above is a test on the feasibility of the design in an online CFD software. As seen the vortex are generated on both the X and Y axis with lateral movement. The y-axis tests focused on vertical movements, assessing how well the device adapted to variations in tidal flow and changes in water pressure. Simultaneously, x-axis evaluations gauged the lateral motion, mimicking real-world conditions to optimize the undulating membrane's efficiency in harnessing tidal energy.

In an alternative design approach, the device incorporates stationary piezoelectric material while allowing only the fin or membrane to move in response to fluid forces. In the figure we see how a fish swims and the red line represents the stationary material. This configuration offers benefits by simplifying the mechanical structure and potentially reducing wear and tear on the piezoelectric elements.

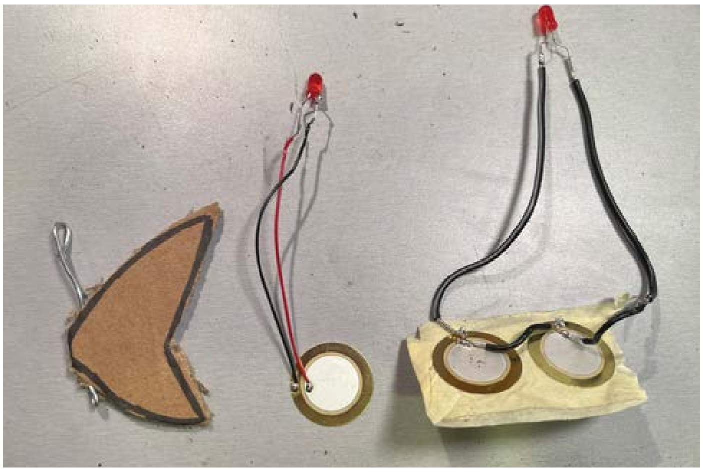


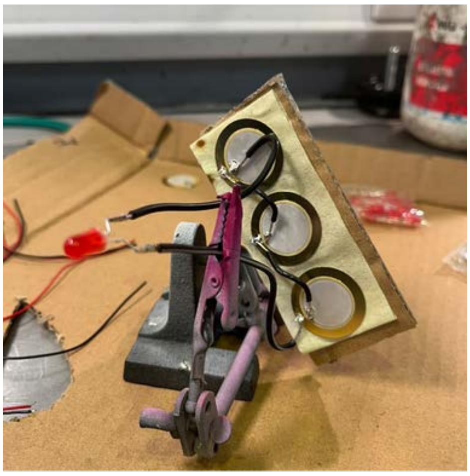
flow profiles for one period of the fish swimming motion viewed from above. (Wolfgang 1999)

With the stationary placement of piezoelectric material, maintenance may become more straightforward, and the focus on optimizing the undulating motion of the fin enhances energy conversion efficiency without compromising the durability of the electrical components.

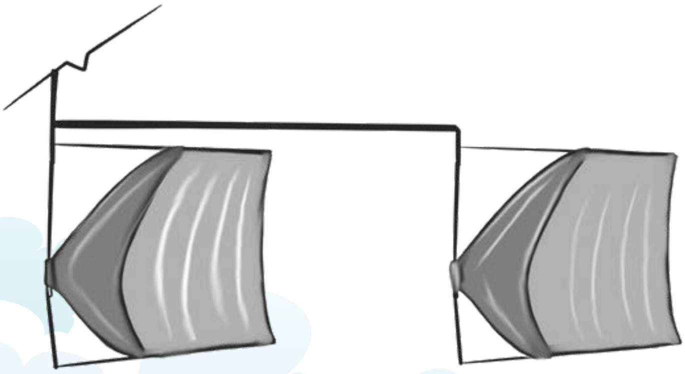


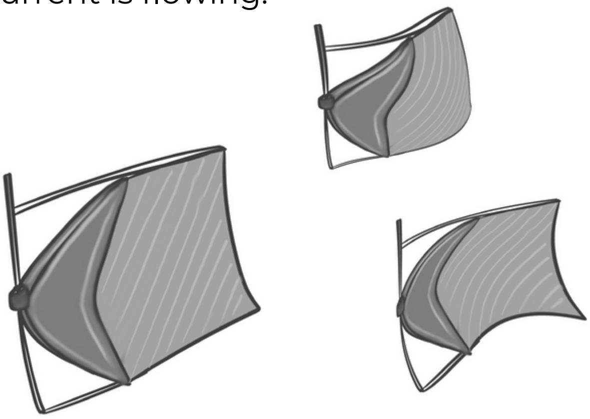
DESIGN SHAPE AND FORM





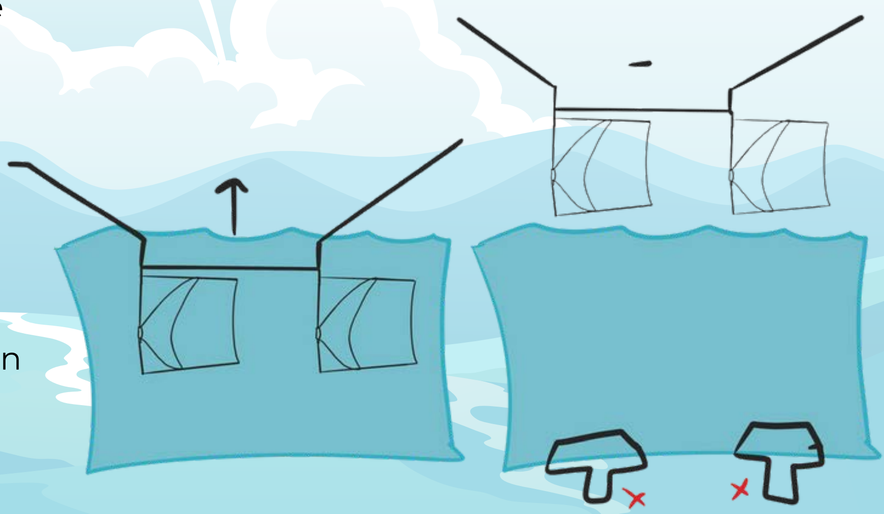
This is a small experiment that I conducted with piezoelectric disks and an LED. I attached the discs to a piece of masking tape and made a fin out of cardboard. I then used a hairdryer to mimic the flow of the current. When the piezoelectric disc is hit with a force, the LED lights up to show that current is flowing.





These are some final prototype design stages, where the hydrofoils have a dual design that help increase stability.

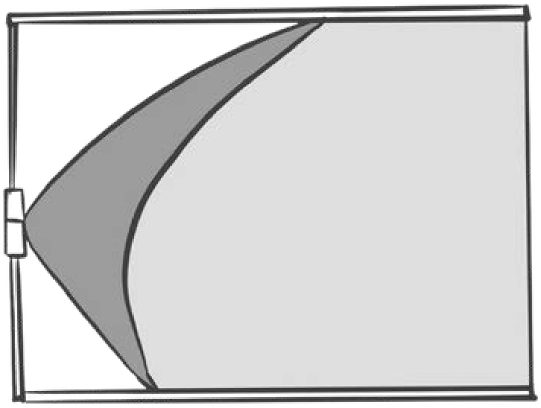
By adapting the design to be suspended rather than directly attached to the ocean or river flow, the impact on fauna can be significantly reduced, offering advantages in both environmental conservation and maintenance. Suspending the device allows it to gently sway or undulate in response to tidal currents, minimizing interference with marine life and habitats. Additionally, this configuration facilitates easier maintenance as the device can be raised for inspection, repairs, or replacements without requiring underwater interventions, providing a more accessible and environmentally friendly approach.

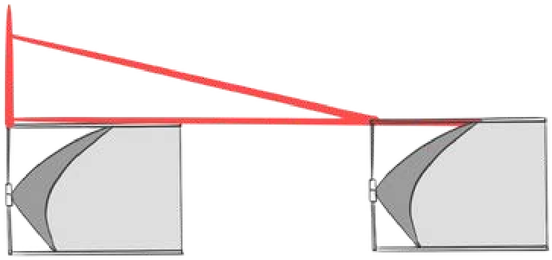


PROTOTYPE

The ‘rails’ hold the device in place and monitor the fluid movement of the fin. They also run the wiring for the generator of electricity.

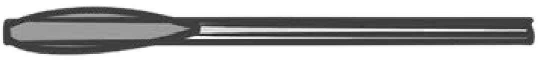
The device has two parts, one hydrofil fin and a membrane of piezoelectric material that collects the energy from the natural oscillating motion during currents.





The device is used in pairs to to stop energy loss and improve stability.

The device is attached to the top railing, reducing the impact it has on wildlife by not constructing underwater and easing the use of maintenance etc.



The device moves at 45 degree angles laterally.

For a mid-sized device in a location with moderate tidal flow, the device is estimated to generate around 500 kW. (The Engineer Articles, 2010)

MATERIAL SELECTION

Flexible Fin (Undulating Membrane):
Material: High-strength, corrosion-resistant elastomer or composite materials designed for flexibility and durability in underwater conditions.
Piezoelectric Material:
Material: Lead zirconate titanate (PZT) or polyvinylidene fluoride (PVDF). These materials are known for their piezoelectric properties and have been used in underwater applications.
Supporting Structure (Rails or Frame):
Material: Corrosion-resistant alloys, such as stainless steel or aluminum, designed to withstand the corrosive effects of saltwater. The frame should provide structural support while minimizing environmental impact.
Connectors and Fasteners:
Material: Stainless steel or titanium for connectors and fasteners to ensure corrosion resistance and structural integrity.
Cabling and Electrical Components:
Insulated electrical cables suitable for submersion, with connectors made from corrosion-resistant materials. Electrical components should be designed for marine environments, with protective coatings as needed.
Buoyancy and Ballast System:
Buoyancy materials: Closed-cell foam or other buoyant materials.
Ballast materials: Dense materials like concrete or lead for stability.
Protective Coatings:
Anti-fouling coatings to prevent the buildup of marine organisms on the surfaces.
Corrosion-resistant coatings for metal components.

CONCLUSION

In conclusion, the development of a tidal energy device featuring a flexible fin and piezoelectric material holds **promising potential for sustainable electricity generation** in my opinion. The theoretical material list emphasizes durability and resistance to underwater conditions, however there could be a future focus on exploring **biodegradable materials to minimize environmental impact** over time. The adaptability of the design could also be suspended or attached to boats! While further testing is crucial to validate its real-world efficacy, the project aligns with ongoing efforts by companies exploring similar concepts, demonstrating a shared commitment to innovative and environmentally conscious solutions in the field of renewable energy. Continued research, testing, and collaboration with experts will be essential to refine the design and contribute to the advancement of tidal energy technology. Thank you for reading through this document.

REFRENCES

Agrawal, A. (2019) Schematic of the 2-d flow around a corrugated Dragonfly Wing, Research Gate. Available at: https://www.researchgate.net/figure/Schematic-of-the-2-D-flow-around-a-corrugated-dragonfly-wing_fig3_336867509 (Accessed: 08 December 2023).

Barrero-Gil, A. et al. (2017) Harnessing electrical power from Vortex-induced vibration of a circular cylinder, Journal of Fluids and Structures. Available at: https://www.sciencedirect.com/science/article/pii/S0889974616306831 (Accessed: 08 December 2023).

Briscoe, N. (2022) 'The tide is nature's battery': How tidal power can help replace gas and oil, The Irish Times. Available at: https://www.irishtimes.com/business/innovation/the-tide-is-nature-s-battery-how-tidal-power-can-help-replace-gas-and-oil-1.4832193 (Accessed: 07 December 2023).

Charlier, R.H. et al. (2013) Design of a horizontal axis tidal current turbine, Applied Energy. Available at: https://www.sciencedirect.com/science/article/pii/S0306261913003607#:~:text=A%20horizontal%20axis%20tidal%20current%20turbine%20is%20designed%20for%20a,the%20hub%20to%20the%20tip. (Accessed: 07 December 2023).

EIA. (2022) U.S. Energy Information Administration - EIA - independent statistics and analysis, Tidal power - U.S. Energy Information Administration (EIA). Available at: https://www.eia.gov/energyexplained/hydropower/tidal-power.php#:~:text=Several%20tidal%20power%20barrages%20operate,MW%20of%20electricity%20generation%20capacity. (Accessed: 07 December 2023).

Emerson (2023) Problem-solving tidal energy technology with test, NI. Available at: https://www.ni.com/en/perspectives/problem-solving-tidal-energy-technology-with-test.html#:~:text=Currently%2C%20one%20of%20the%20biggest,expenses%20start%20to%20add%20up. (Accessed: 07 December 2023).

Gov, D. (2023) Tidal Energy. Available at: https://www.dover.gov.uk/Environment/Energy Advice/Renewable-Energy/Tidal-Energy.aspx (Accessed: 07 December 2023).

Gunnarson, P., Zhong, Q. and Quinn, D.B. (2019) Comparing models of lateral station-keeping for pitching hydrofoils, Biomimetics (Basel, Switzerland). Available at: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6784290/ (Accessed: 12 December 2023).

Hemery, G., Copping, A. and Overhus, D. (2021) 1,* , Andrea E. Copping and Dorian M. Overhus - Tethys, tethys. Available at: https://tethys.pnnl.gov/sites/default/files/publications/Biological_Consequences_of_Marine_Renewable_energy_Development_on_Marien_Animals.pdf (Accessed: 10 December 2023).

M. Nasr-Azadani, M. (2023) Fun with fluid-dynamics, Fun with fluid dynamics: Available at: https://sites.engineering.ucsb.edu/~mmnasr/Fun.htm (Accessed: 12 December 2023).

Marsh, J. (2023) Underwater turbines: A lesser threat to marine wildlife, Environment Co. Available at: https://environment.co/underwater-turbines/ (Accessed: 10 December 2023).

McClatchy, N. (2008) A whale of a turbine, The Guardian. Available at: https://www.theguardian.com/science/2008/jun/24/animalbehaviour.usa#:~:text=A%20West%20Chester%20University%20professor,on%20no%20other%20earthly%20creature. (Accessed: 07 December 2023).

NassarJ.M. et al. (2018) Bio-inspired Soft robotics: Material selection, actuation, and Design, Extreme Mechanics Letters. Available at: https://www.sciencedirect.com/science/article/abs/pii/S2352431617302316?fr=RR-2&ref=pdf_download&rr=831e2891484556ed (Accessed: 07 December 2023).

Rutledge, K. (2023) Tidal Energy, Education. Available at: https://education.nationalgeographic.org/resource/tidal-energy/ (Accessed: 07 December 2023).

SEAI (2004) Tidal Current Energy Resources in ireland report - SEAI, TIDAL ENERGY REPORT. Available at: https://www.seai.ie/publications/Tidal_Current_Energy_Resources_in_Ireland_Report.pdf (Accessed: 07 December 2023).

Vanarbeke, J. (2019) Working Group on marine benthal renewable developments - researchgate, Research Gate. Available at: https://www.researchgate.net/profile/Joop-Coolen/publication/332877010_Working_Group_on_Marine_Benthal_and_Renewable_Energy_Developments_WGMBRED/links/5cd02e10458515712e95a88e/Working-Group-on-Marine-Benthal-and-Renewable-Energy-Developments-WGMBRED.pdf?origin=publication_detail (Accessed: 07 December 2023).

Wolfgang et al. "Near-body flow dynamics in swimming fish." The Journal of experimental biology 202 (Pt 17) (1999): 2303-27 .
Zeng, Y.S. et al. (2022) Fluid-structure coupled analysis of flow-induced vibrations in three dimensional elastic hydrofoils, Marine Structures. Available at: https://www.sciencedirect.com/science/article/abs/pii/S0951833922000594 (Accessed: 12 December 2023).