Biomimetics – I Got 99 Problems and They Can All Be Solved by Taking Inspiration from the Natural World

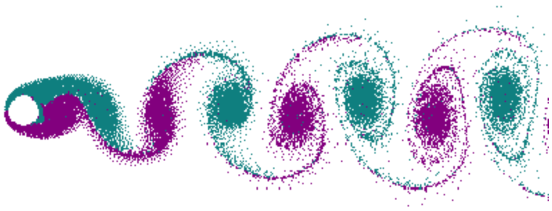
By Jack Whittle

So much of the human story is tightly intertwined with that of the natural world, and just as the beauty of our planet has inspired myths, legends, and great works of art, so too do the marvels of nature inspire our science and our engineering. The practice of building upon natural 'designs' in human engineering is known as biomimetics, and it is a field that is thousands of years old. Perhaps the first example is the adoption of using silkworms to produce silken fabrics which first began in China around 6, 000 years ago.

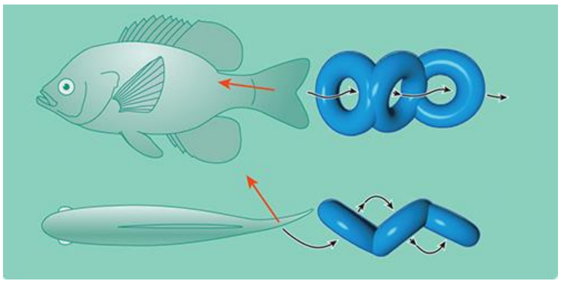
Since then, many ingenious inventions have sprung from the combined powers of human ingenuity and natural selection. One famous example you may or may not know as a biomimetic design, but you will surely have heard of it. In the 1950's, George de Mestral was walking his Irish setter, and the dogs fur became covered in Burrs from the Burdock plant. George struggled terribly to remove them from his dog and examined one under a microscope to investigate their incredible 'sticking' power. He observed that the seeds were covered in tiny hooks, which clung to his dog's fur with considerable force. This inspired his now famous invention, Velcro. He created two surfaces, one of small hooks and one of small loops, which when joined adhere to one another in the same manner as the Burrs did to his seeded setter.

In this article, I will share a few recent examples of biomimetic designs and will largely focus on those that have originated from the marine environment. I believe the oceans to be a vastly underutilised source of inspiration in science and technology. I hope that by illustrating some of the marvellous technological advancements and clever solutions that we have dredged from the depths, I might convince the struggling engineer to turn seaward for their inspiration.

Over recent decades, there has been considerable pressure to develop clean energy solutions, and wind power has been one of the most promising and successful options. However, it does have its issues. One being that spacing Horizontal Axis Turbines (HATs, the typical design) too close together drastically reduces their efficiency. One turbine extracts energy from the air stream, and thus any other turbines downstream have a reduced incoming flow-speed, which reduces their power output. Luckily, scientists from Caltech have a solution, and it comes from fish. As water flows around an object, oscillating vortices are formed in what is known as a Kármán Vortex Street (below).



This is a drag-generating vortex, meaning objects attempting to move through say air or water experience drag and are slowed down. Fish are a remarkable exception. As a fish swims through the water and undulates its tail, it sheds vortices in the water, but in a Reverse Kármán Vortex Street. This is a thrust-generating vortex, and it allows the fish to minimise drag as it swims as well as reduce any interference with nearby schooling fish.

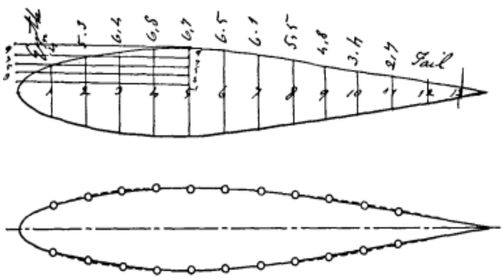


In 2010, a paper submitted to 'BioInspiration and Biomimetics' showed that Vertical Axis Turbines (VATs) in a configuration based on the shed-vortices of schooling fish can overcome the issue of spacing limiting power output. The VATs are arranged in a way that mirrors the arrangement of shed vortices from schooling fish and the rotational direction of neighbouring VATs is alternated. This arrangement was found to increase the power-output for a given area of land by over one order of magnitude compared to HATs.

Interestingly, the man after whom the Kármán Vortex Street is named, Theodore von Kármán, wrote a book titled 'Aerodynamics'. In it, he references Sir George Cayley, an English inventor who is considered by many to be the father of modern aviation and the first person to announce the principle of a rigid 'airplane'. Cayley was investigating how a more fusiform shape affects drag and appears to have been inspired by trout. Kármán compares a sketch of Cayley's, which shows a trout split into regularly sized sections (a), to a modern-day sketch of a low-drag airfoil (b). Forgoing the labels, the two are indistinguishable.

A)

B)



Fish have yet more to offer. In addition to their drag-reducing swimming strategies, fish altogether limit the contact that the surrounding water has on their bodies. Drag is caused by the frictional forces of a fluid as it 'sticks' to a moving body. The more viscous a fluid, the greater its drag. Fish overcome this by secreting mucus, a combination of lipids, proteins and long-chain polymers which reduces the contact their bodies have with the water as well as lowering the surface tension and viscosity of the water itself, further reducing drag. Barracuda create a mucus which lowers frictional drag by up to 66%, allowing them to reach speeds of 44kmh. This principle has been applied to boat hulls as well as water pipes, where long-chain polymers are often applied to reduce the drag of water and either increase the speed of boats or increase flow speed through pipelines.

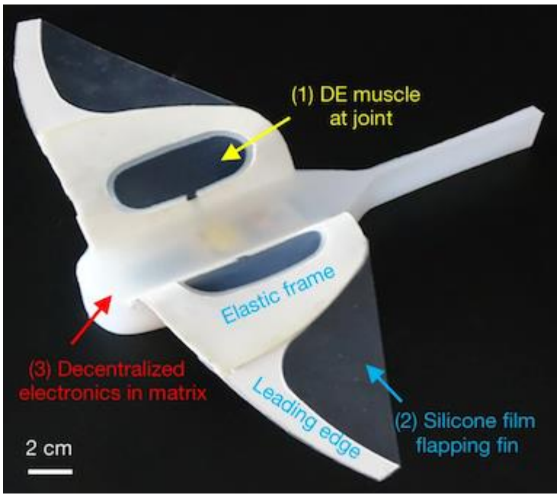
A recent paper revealed some of the exceptional properties of the exoskeleton of the hydrothermal vent crab, *Austinograea rodriguezensis*. Stainless steel 316, one of the most widely used steel types worldwide has a hardness value of 152, equivalent to roughly 1.49 billion pascals. The exoskeleton of the vent crab has a hardness of around 7 billion pascals.

The exoskeleton can be divided into 4 distinct layers. These are: the epicuticle, exocuticle, endocuticle and the membrane. The inner two layers, the exo- and endocuticle have what is known as a Bouligand structure. This is a layered and rotated microstructure. Multiple lamellae are stacked on top of another, each one rotated respective to neighbouring lamellae. This structure is credited with greatly bolstering the toughness and fracture resistance to any material it is a part of. One of the primary mechanisms by which this structure increases a materials toughness is crack deflection, which can be through 'tilting' or 'bridging'. Tilting describes how a crack moves along the direction of the fibres in a material until the energy release rate at the tip of the crack is so

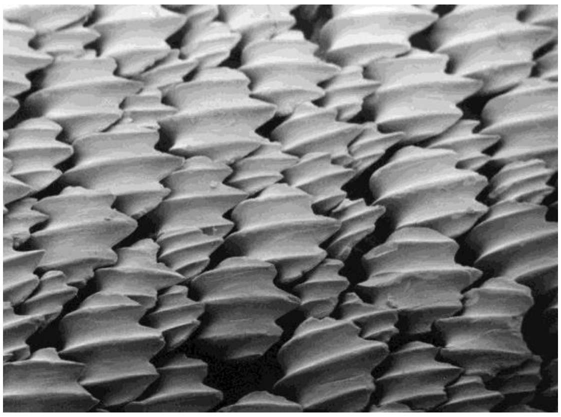
low it must drastically change direction and cut across the fibres. This is crack bridging. A combination of tiling and bridging results in a highly distorted crack which must take a very tortuous path, making further propagation less favourable and vastly toughening the material. In addition, the Bouligand structure can also keep multiple cracks from coalescing, sometimes referred to as crack 'twisting'. The biological material of this crab's carapace is expected to become a key component of biological engineering and biomimetics in coming years.

Robotics is a field which often takes inspiration from nature, and a few recent developments are particularly interesting. One centres around ocean exploration. Today, we have explored less than 20% of the world's oceans. There are a few reasons for this, chief among them being the harshness of the deep-sea environment. The electronic components of robots responsible for powering and controlling their movement are delicate and highly susceptible the immense pressures of the deep ocean. However, the internal structures of many animals are just as delicate, and yet animals like the snailfish are perfectly capable of operating under these extreme conditions.

A team of scientists from Hangzhou, China, have learned from the snailfish's body plan and designed a highly robust polymer body that can contort and deform under the high pressure without becoming damaged. In addition, contrary to the typical practice in robotics of tightly packing the electrical components, they were spread out to mirror the arrangement of bones in the skull of the snailfish making them much more pressure resilient. In a further effort to limit the rigidity of the components, the fins are not controlled by typical motors but by specially designed artificial muscles. Using this approach, the team were able to successfully deploy the robot down into the Mariana Trench to a depth of almost 7 miles.



Sharks have an array of adaptations that have made them one of the most evolutionarily successful animals on Earth. One example is their skin. Shark skin is covered in small teeth, and this has several interesting benefits, one of which is increased hydrodynamic efficiency. The dermal denticles of sharks generate vortices, areas of low pressure, which causes a greater degree of separation between the shark's skin and the surrounding water. The drastically reduces drag and allows sharks to swim incredibly efficiently.



This idea has recently been applied to aeronautics, where denticle-inspired structures have been added to the aerofoils to reduce drag for planes. One design achieved both drag reduction and lift generation simultaneously, with a lift-to-drag ratio that is 323% greater than aerofoils without the vortex-generating denticle structures.

Dermal denticles also provide anti-fouling properties to sharks. This prevents their skin from being colonised by sessile organisms such as barnacles as well as the build up of potentially harmful bacterial biofilms. Bacterial build up is a problem in various industries, the medical industry in particular. Thus, numerous studies have been conducted into the antimicrobial properties of sharkskin and how this ay be applied to surfaces within hospitals and to pieces of medical equipment. It is hoped that this may help in reducing the proliferation of infections within hospitals.

I expect to see more and more fascinating developments in the field of biomimetics. At the time of writing, more than 80% of the oceans remain unmapped, unexplored, and unknown. As such, I am especially curious to see what weird and wonderful inventions are roused from the minds of future inventors as we continue to explore our oceans, discover new species, and study the ever-impressive adaptations forged over millennia by natural selection. Anything we can do; nature can do better. It probably already has.