Speed bumps

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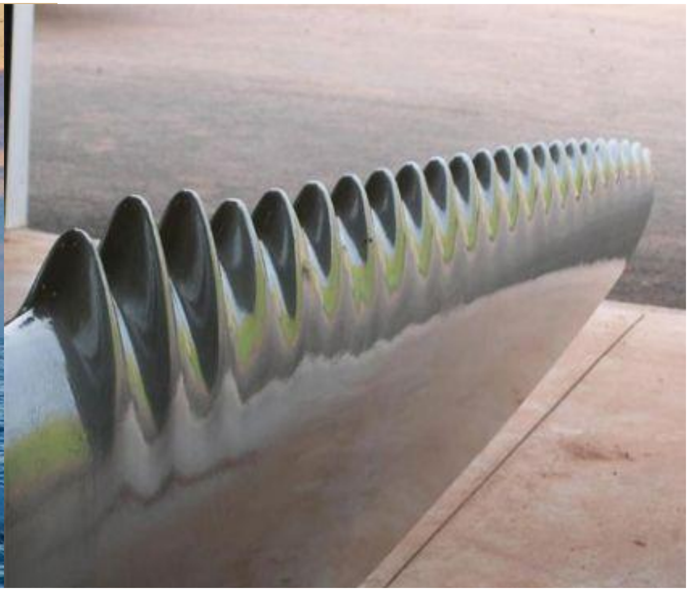


Imagine a school bus. That is the size of a Humpback whale. At thirty-five feet and thirty tons, humpback whales are some of the largest creatures of the ocean, with bumpy, barnacle encrusted skin. Yet instead of being slothful, cumbersome giants, these animals are acrobats. (1) The need to swim easily, quickly and with as little energy as possible to feed and migrate. In fact, their bumps actually add to the whale's swimming agility. Scientists and engineers studying the whale's bumpy fins have learned that whale fins cut through air better than airplane wings. By applying the principles behind the humpback whale flipper, they have created wind turbines that perform 40% better than conventional, smooth blades. (2)

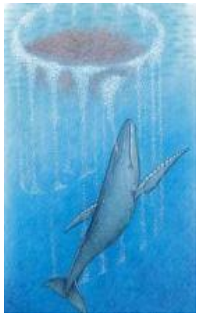
structural bio-inspiration

Winged Whales

Structural bio-inspiration

Humpback whales are known for immense displays of acrobatics when they jump high out of the water. Underwater they showcase their power and agility by spinning bubble nets to catch fish. A whale makes a bubble net but swimming in circles as it rises to the surface while expelling air from its blow hole. This leaves a trail of dense bubbles that trap fish. Bubble nets are a hunting technique that vary in size, dependent on the prey. When whales are trying to catch a school of fish, the nets can be 150 feet in diameter. On the other hand, they can be as small as 5 feet in diameter. (1) In comparison, a school bus turns at 40 feet. (3)

However a school bus has little in comparison to a humpback whale apart from length. One of the notifying features of a humpback whale are its flippers, which are longer than any other whales' and are located farther in front of its center of mass. The humpback whale's scientific name pays homage to these notable flippers, as *Megaptera novaengliae* means "big-winged New Englander." These "wings" have bumps on the forward edge of the flipper called tubercles that give the flippers a slightly serrated edge. From the side, they resemble airplane wings as they have the standard airfoil shape with a rounded leading edge and thinner trailing edge.



Similarly to wings, these flippers increase lift . Lift is an aerodynamic force that is perpendicular to flow. It keeps airplanes in the sky and whales from sinking. Typically there is an area of low pressure on top and high pressure on bottom. Pressure is force over area, so there is a small force pushing down and a larger force pushing up, the object (an airplane) will go up. In the same vein, drag is force against the airflow, and slows the object down.

Air behaves very similarly to water at high speeds, and therefore the physics of fluid dynamics relate to both whales and airplanes. Now the special thing about humpback whales is that they have bumps on their airfoils (flippers), while airplanes do not. Conventionally, the thought has been the smoother the better. Any edges or protrusions would cause drag force. That is why airplane wings these days are devoid of bumps. However seeing the maneuverability with humpback whales caused scientists to take a closer look at whales and see what was so special about these bumpy fins.

They created plastic models of the bumpy fins to put in a wind tunnel, which controls the air to flow at a speed which mimics water. The bumps separate air flow into vortices. This channels air into smaller areas which causes higher wind speed. High wind speed increases lift. A second effect of the bumps is that the channels of focus of air keep the air from being diverted and running down the length of the airfoil, which happens in conventional blades today. This increases drag. The end result is that bumpy airfoils have a better lift:drag ratio than a smooth wing. The researchers created a technology inspired from the bumps on whale fins called Tubercle Technology. Today they create wind turbines and fan blades for computers and hover crafts (4,5).

A fig, a flower and a stinger

Wasps have built-in drill bits. Specifically, the parasitic fig female wasp has a drill bit-like limb attached to her rear that she uses to puncture through tough, unripe figs and inject her eggs. These eggs hatch and develop into wasps inside the fig. This limb is called an ovipositor and is thinner than a human hair. Typically, the thinner something is, the more delicate and likely it is to break. This small needle-like ovipositor can be used many times to drill into the fig, so scientists are learning from the structure to create micro needles that can be incredibly thin and very long without snapping.

Liquefy soil

idea stage r m

Structural bio-inspiration

Wasps and fig trees have an interesting relationship over a 100 million years old. Wasps will pollinate fig trees and lay their eggs in fig flowers [2]. This is a classic example of a symbiotic relationship where there is a close relationship between two different species. However closer inspection shows that the textbook example of fig tree and the pollinator wasp is not as friendly as it seems. When a fig houses a pollinator wasp egg, it loses a seed., so the fig would loose all its seeds if too many pollinator wasp eggs were left alone to develop [2]. Parasitic wasps help keep the pollinator wasp in check by preying on their eggs. Female parastic wasps will target unripe, green figs to puncture and inject *their* eggs. These eggs then parasitize insect larvae (such as the pollinator wasp) growing inside the fig already, and develop inside those larvae—using them as shelter and food.

The parasitic wasp actually balances out the pollinator wasp and the fig, so all three species can continue to reproduce. Three isn't a crowd after all.

Diagram of the drill strucuture

The parasitic has a fascinating device that allows it to drill into the hard unripe fig and insert her eggs. Attached to its bottom is an unbreakable drill bit, called an ovipositor, which is 7-8 mm long , which is roughly a fifth the length of a fig. It is 15 um wide, which is thinner than a human hair. With this super thin, super small structure, the female wasp forces her way through the tough, outer skin of a fig to deposit her eggs. Any other human-made structure at that scale would break under that force, but is the wasp ovipositor has a few tricks to its name.

The ovipositor is actually tipped with zinc (which is present in high amounts in figs!). This makes it as hard as acrylic cement used in dentist offices on your teeth. It has teeth-like indentions similar to the human made drill bits to help bore into figs. Also, at the places along the shaft of the ovipositor, where it is expected to break, are tiny pits that help relieve stress and increase flexibility. The ovipositor can bend and flex as much as it needs, but its design means it cannot fracture when it buckles as would a regular drill bit. After puncturing through the fig, there are tiny sensors that help guide the ovipositor to the best locations. The wasp eggs are injected, and will turn whatever poor ladybug larvae growing in the fig into zombies upon hatching.

[1] http://newswatch.nationalgeographic.com/2014/05/28/wasps-insects-drill-bits-science-weird-parasites/
[2] http://www.sciencedaily.com/releases/2008/03/080311093345.htm
[3] http://jeb.biologists.org/content/217/11/1833.1

Ferrari of the ocean

idea stage r m

Clams seem simple, and they don't seem to do much, but clams are surprisingly smart. Researchers at MIT have scoured the Atlantic Ocean beaches to observe these animals in action. In particular, they were seeking the "Ferrari of the ocean", *Enis directus,* the razor clam. Although not bright red and roaring down the road, this clam is one of the fastest animals of the ocean. By burrowing into the seafloor, the clam can hide its entire body in a couple seconds. Take another look at these seemingly simple animals; , that shiny shell can dig 4 times its length in 3 minutes. Somehow, this clam knows how to liquidize the soil around it on the ocean floor, which allows it to burrow very quickly [2], and with less energy than we would use to put in an anchor or a pier pilling. Scientists think the humble clam holds secrets on how to make better anchors for sea cables, underwater vehicles, and more.

Behavioral bio-inspiration

Liquefy soil

Behavioral bio-inspiration

Enis directus is around 7 inches long, which is about the length of an average adult female hand. It can dig up to 70 cm (27.5 in) into the ground and burrows at a rate of 1 cm a second, which is a little less than half an inch a second. This seems quite spectacular seeing that the clam is only 7 inches to begin with, and lacks any digging limbs. However while this animal may be speedy, the real reason it's of interest to scientists is how the clam changes the properties of matter around it—and the applications of doing so [3].

The clam is not unexpectedly muscular or strong. By strength alone it could not push itself into the sand. The reason the clam can bury itself is its ability to wiggle very quickly while opening and closing its shell. This pumping suspends the sand particles in water, and the waterlogged sand turns into a medium similar to quicksand.

Quicksand is regular sand saturated with water, which reduces the friction between sand particles. This causes the sand to behave more like water; infamous phenomenon of sinking into quicksand. When the clam wiggles underwater and clamps its shell, it is agitating the soil particles and forcing water to separate the sand particles so they cannot hold weight [4] By forming quicksand, the clam can burrow easier through the ocean floor.

Diagram quick sand

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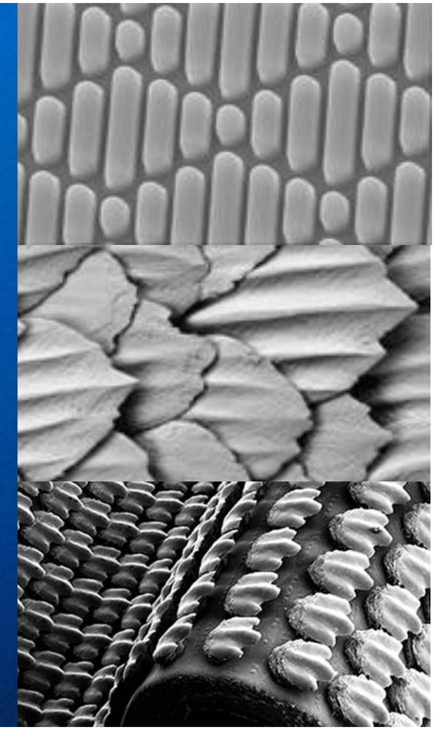
By studying how the razor clam forms micro pockets of quicksand, researchers have created robots that use similar movements to bury rapidly into the ocean floor to become super secure, lightweight anchors. One robot is RoboClam, and is half the size of a lighter made of pressure regulators and pistons [1]. As a smart anchor, it is 10 times more effective than regular anchors, and can be used to hold ships, buoys and aquatic sensors. It can bury itself further than regular anchors and hold them more securely. On the more dynamic side, this method can also be used to rid the ocean of underwater mines, lay down cables into the ocean floor and build an underwater infrastructure by digging into the ocean floor [2].

References

1. http://www.engineering.com/DesignerEdge/DesignerEdgeArticles/ArticleID/7318/Robot-Razor-Clams-Make-Better-Anchors.aspx
2. http://dspace.mit.edu/handle/1721.1/67605#files-area
3. http://newsoffice.mit.edu/2008/roboclam-1125
4. http://science.howstuffworks.com/environmental/earth/geology/quicksand1.htm

Triangles in the water



Sharks these days are nearly always associated with climatic, sinister music, an scary triangular fin sticking out of the waves, and are commonly known as a vicious predator. However, sharks have survived for the last 450 million years. There's a thing or two we can learn from them. Sharks have a few curious adaptations to help them swim quickly by preventing other organisms from hitching rides. Think about how things don't attach to shark skin, like they do to the bottom of a boat, or even the skin of a whale. These hitchikers add weight and increases the resistance to movement (like how it's harder to walk against the wind with an open umbrella). What keeps the shark clean are angular, teeth-like scales on their skin called dentricles. These skin scales are of particular interest, because they create water flow close the shark skin that keeps other animals from being able to stick. Shark skin like materials help keep boat hulls clean so they can move more easily and, without antibiotics, may be able to keep bacteria from growing in hospitals [1,2].

Structural bio-inspiration

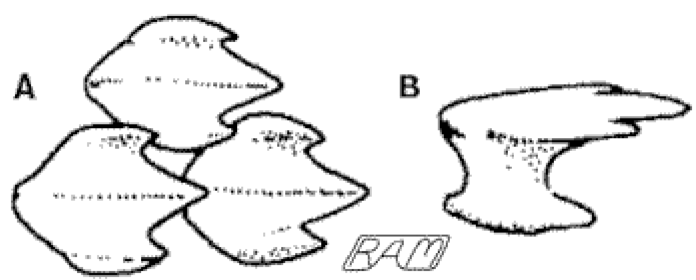
Many people have taken inspiration from sharks. In the olden times, sharks captured the imagination in Greek, Hawaiian, and Australian mythology as a figure of power, mystery and greatness [4]. In modern days, Speedo takes a competitive edge with an engineered swim suit that reduces the drag forces on swimmers with a textured pattern on the fabric similar to the channels on shark scales [5]. In science, sharks have inspired people for ages.

Taking a closer look a shark skin, there are V shaped scales that are called dermal dentricles. Dermal denticles follow the same engineering principle as fiberglass or reinforced concrete. By combining a strong material with a soft, flexible one you get the both of best worlds: a composite material that is both strong and pliable. There is a hard, crystalline mineral named apatite embedded in pulpy collagen protein. Dermal denticles literally mean tiny skin teeth, and share mineral characteristics to shark teeth. Fittingly, the dermal denticles are very small. Similarly to chain mail, they provide an amour that is strong but gives mobility.

On the top of the denticle are longitudinal grooves. If you petted a shark, there skin would feel like sandpaper because of these grooves. When traveling through water (or air at high speeds), it helps to be rough, because rough surfaces create very chaotic (messy) flows that creates little vorticies (whirls of water) close to the surface. This prevents the fluid very near the object from sticking to it and slowing it down. That's why golf balls have dimples, and the surface of fighter planes have v-shaped grooves. Sharks have been using the same principles of physics for millions of years. Without knowing anything about fluid dynamics, fighter jets or golf balls. By reducing drag, sharks become even better swimmers, cutting stealthily through the current without a sound to sneak up on prey [6].

These denticles has another advantage. The quickly moving water in the vortex reduces the contact time for organisms seeking to attach , and the roughened texture creates an unstable surface that makes it difficult for bacteria to colonize. You may see whales (and boat bottoms) with barnacles on their bodies, but never a shark.

A scientist took notice of this who worked on how to keep Navy boats clean. He realized sharks repel 85% of algae and dug deeper into the problem. He later created Sharklet Technology, which is an engineered surface microns thick that create a rough, unstable surface that is antibacterial. Currently, it is under studies to be used in hospital environments for counters, beds, and tables that could be physically germ-free. [9].



[4] http://www.sharksinfo.com/sharks-in-mythology.html#.U4ajAvmICSo
[5] http://www.speedousa.com/speedo-technology.shtml
[6] http://www.elasmo-research.org/education/white_shark/scales.htm
[7] http://www.engadget.com/2014/05/16/3d-printed-shark-skin/?ncid=rss_truncated
[8] http://jeb.biologists.org/content/217/10/1637.2.full
[9] http://brennan.mse.ufl.edu/research/antifouling.html