from

This is a story about a man named Fish who noticed something unusual about whale flippers and who, after nearly 30 years, turned it into a technology platform.

Frank Fish and a partner, Stephen Dewar, founded a company named Whale Power to market the technology, which takes its inspiration from the natural design of the bumps, or tubercles, on humpback whale flippers. According to Dewar, applying to airfoils what Fish and others learned from whales improves lift without increasing drag. He said that 24-foot-diameter fans based on tubercle technology use half the number of blades and move 25 percent more air and consume 25 percent less power than fans with conventional blades turning at the same speed. Whale-inspired fans are already available, and wind and tidal power blades could be next.

As startling as Dewar's claims sound, the story of how the fans reached commercialization is far more surprising. ➤

BY ALAN S. BROWN, ASSOCIATE EDITOR

whales to fans

a second look at a piece of sculpture led to a promising technology

▲ Humpback whale breach. Frederick Sound, Alaska

It began when Fish was earning a graduate degree in zoology in the 1970s. At the time, many researchers were interested in the biology and behavior of swimming animals. Fish, on the other hand, studied how organisms manipulate flows to swim or fly. With his professors, he investigated everything from fish dynamics to how muskrats created vortices with their tails. (Understanding vortices would prove important later.)

While at Michigan State University, Fish studied with Rollin Baker, the zoologist who directed the school's museum. Baker would review nature pictures from artists and comment on their accuracy. He might, for example, point out that the fox in the snow had no footprints or that a colorful bird had the wrong plumage for fall.

"I learned to look at artists' interpretation of nature with the eye of a biologist and see what facts they missed," Fish recounted. (This would also prove important.)

Shortly after he received his Ph.D. in zoology, Fish and the woman he would eventually marry were in Boston. When their planned canoe trip was rained out, they went to Quincy Market and wandered into a store of animal sculptures.

On a pedestal in the center of the room was a sculpture of a humpback whale. Fish walked up and started laughing. The store manager wanted to know what was so funny. "The artist got it wrong," said Fish, who knew a thing or two about critiquing artwork. "The bumps are on the leading edge of flippers, and that's not the way it's supposed to go."

"No, no," she insisted. "This artist is very careful." She pulled out a brochure with a picture of a whale breaching. Sure enough, the tubercles were on the front, not the rear, of the flippers.

"This went against everything I had been taught," Fish recalled. "When you ride on an airplane, you don't see bumps on the leading edge of the wing." He wondered why he did not see a flat surface that would produce smooth, aerodynamic flow.

Fish resolved to get hold of a whale, and there is a mechanism to do just that. Fish called friends at the Smithsonian Institution, who put his name on the marine mammals stranding list.

That is where this story stalled for nearly 10 years. Meanwhile, Fish built his reputation as an expert in the biomechanics of swimming. One day he walked into his lab and a student said, "Someone called for you about a dead whale in New Jersey."

He dialed and a woman told him that a dead whale had beached. He could pick up the flippers, but the animal was rotting so he had to do it fast. She estimated that the whale was 20 feet long. Since flippers are usually one-third as long a whale's body, Fish figured he could fit them into his Mercury Lynx.

The next morning, Fish drove to the shore. There he discovered the beached whale was really 30 feet long with 10-foot flippers. He stayed until dusk, removing barnacles with a knife and sawing the flipper in thirds with a hand saw.

"I wrapped them in plastic, dropped all three into the trunk, and watched the rear end of car sag," he said.

LAURENS HOWLE

⮝ Above: Model of a humpback whale flipper. Anyone who studied aerodynamics would assume bumps go on the trailing, not leading, edge. ➤ Right: Flipper models with and without leading edge bumps. Wind tunnel tests showed that the bumps improved lift and delayed stall at low speeds.

"That worried me. I didn't want to get stopped with a trunk full of rotting body parts in New Jersey."

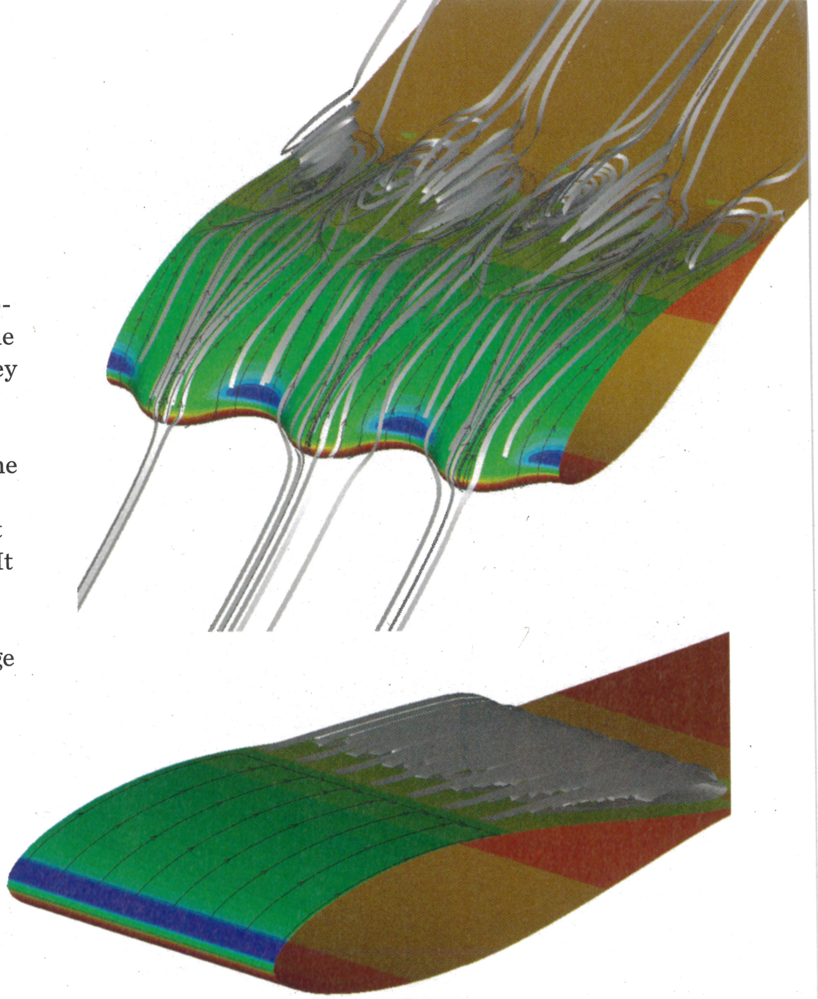
Back at West Chester, Fish stored the pieces in large freezers. In order to study them, he needed something more durable (and less pungent) than rotting slabs of flipper. At first, he thought he could make a cast. No luck. The flippers proved too large for some people. Others said they could not coat the flippers while frozen and they would not let them thaw out in their labs.

He considered smaller models. That involved cutting the flippers into thin steaks, photographing them on a grid, and building a CAD model from the pictures. He brought a frozen section to a colleague with high-powered saws. It locked up the band saw and ate the radial saw.

The flippers stayed in the freezers for years while he sought a way around the problem. Then he visited the large animal facility at the University of Pennsylvania's Veterinary School. On a hunch, he called its pathology lab.

"Do you have saw that can cut through whale flipper?" he asked.

"We have a saw that could cut through horse's head," came the reply. Fish took the segments there. "It was like slicing baloney," he recalled.



ERIC PATERSON, APPLIED RESEARCH LABORATORY, PENNSYLVANIA STATE UNIVERSITY

▲ Top, a CFD model shows how leading edge bumps channel flow into the valleys where they meet counter-rotating flows coming off neighboring bumps. This energizes the flow so it hugs the airfoil as the angle of attack increases. Bottom, a model of an airfoil without bumps.

bumps for a reason

Fish could now digitize his steaks to create a 3-D model of the flipper and puzzle out why the bumps, or tubercles, were on wrong side of the flippers.

The prevailing wisdom at the time, such as it was, held that the tubercles, which also covered the whale's face, were some sort of "whale acne." Fish thought they were there for a reason. The flipper, after all, was the equivalent of our arm, and the tubercles were like knuckles.

They were visible in humpback fetuses. Evolution, he reasoned, did not pass down traits without a reason. He saw that they were evenly spaced. The distance between tubercles was consistently 7 to 9 percent of the flipper's span, and they grew progressively smaller as they approached the tip. He ran some simple simulations and found the tubercles had a lot to do with drag.

Drag and lift are familiar to anyone who ever stuck a hand out the window of a moving car. Hold the hand parallel to the ground and it will slice through the air. Cant it slightly and it will lift upwards. The amount of lift grows in linear fashion as the angle of attack increases—up to a point. Too much and drag jerks the hand backwards.

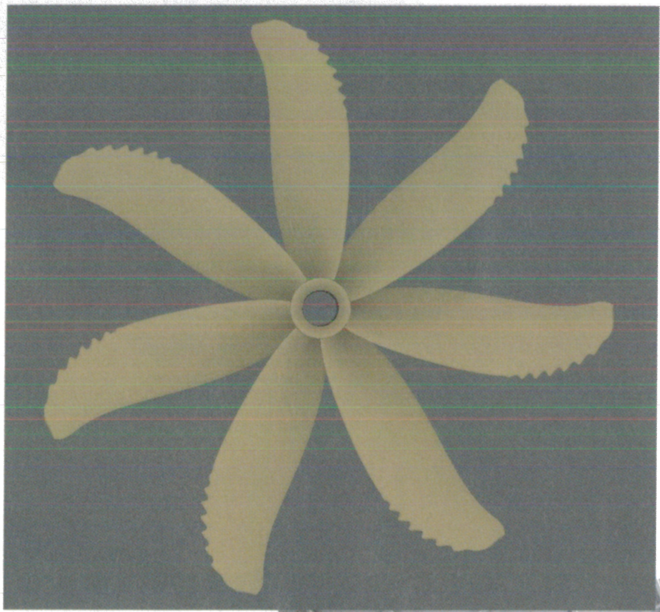
This is how wings and flippers work. "To maintain lift, we need to keep air or water flowing over the wing. Normally, wings allow an 11 to 12 percent angle of attack," Fish explained.

"More than that and you lose the lift. What happens is not enough air is moving over the wing. The flow detaches from the surface of the wing and creates an eddy current. You lose the pressure differential between the upper and lower side of the wing and you stall," he said.

Fish and Phil Watts, an engineer, developed a simple model and found the humpback's tubercles appeared to reduce drag. In August 2001, they presented their preliminary findings on the fluid dynamics of whale flippers at a conference on unmanned underwater submersibles.

That attracted the attention of Laurens Howle, a mechanical engineer at Duke University. Howle was familiar with the work of Vern Seifert, an aerospace engineer who had added leading edge "knuckles" to a Piper J5 airplane wing 20 years earlier. Fish and Watts had a simple model that explained some aspects of flipper performance. Howle resolved to learn more by building a plastic flipper and testing it at the Naval Academy's wind tunnel.

Howle's lab started with pictures of Fish's whale steaks and wrote software to recombine them into a CAD model he could build. "I didn't need to duplicate the exact geometry of the animal, just the relevant features. Then I made a second model without the bumps on the leading edge," Howle said.



▲ A seven-bladed propeller with leading edge bumps. It was one of many test articles designed for wind tunnel testing by Laurens Howle of Duke University.

➤ The wind tunnel tests informed the design of Whale Power's commercial fans. They move more air and use less power than conventional fans.

LAURENS HOWLE

WHALE POWER

He and two graduate students, Mark Murray and David Miklosovic, tested the flippers in the wind tunnel. The tests showed that at whale cruising speeds, the tubercles improved total lift and postponed stall.

Howle was not surprised that the tubercles improved lift. "The big surprise was that they increased lift without higher drag," he said. "Ordinarily, if you want more lift, you pay the price in drag. That was not the case here."

The wind tunnel experiments enabled the team to develop CFD models that showed why tubercles delayed stall. They formed evenly spaced hills and valleys along the leading edge of the flipper. The rounded hills created vortices that they deflected into the valleys.

Each valley was surrounded by two hills, and the vortices from each hill had opposite spins. When they mixed in the valley, they accelerated the flow of liquid to the back of the flipper. "It was like what happens in a pitching machine in a batting cage," Fish said. "They have two large wheels spinning in opposite directions. When you put a baseball between them, it accelerates it very quickly."

Ordinarily, the airflow over an airfoil separates from the surface when the angle of attack rises above 11 or 12 percent. The vortices, on the other hand, energized the airflow so that it adhered to the surface all the way back to the trailing edge. The result was more lift and less drag.

This explained the physics behind the humpback's unusual feeding patterns. Most whales are essentially giant sieves. They open their jaws and swim straight into a school of krill, plankton, or small fish, gulping down everything in their path and pushing the water out their baleen plates.

Humpbacks, on the other hand, work in groups called pods. They encircle their prey, releasing bubbles through their blowholes that form a curtain to confines their quarry within the circle. Then they tighten the circle. This concentrates their victims in a smaller and smaller area. Finally, they attack, gulping down a meal of densely packed fish.

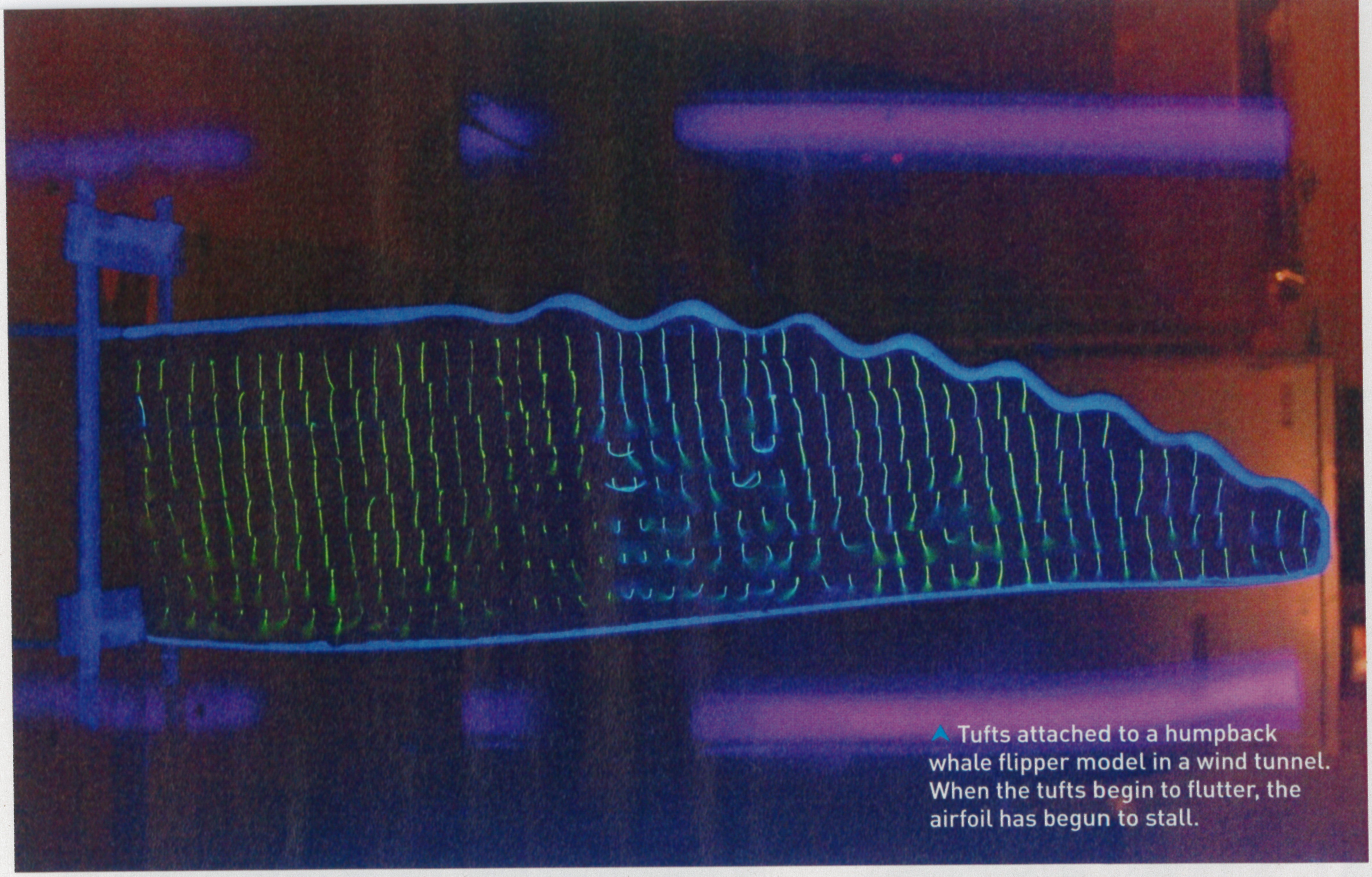
"The flippers act like wings, enabling them to bank and make turns," Fish said. "Why do they need tubercles? They have to cant at higher angles of attack to make the tight turn they need to concentrate their prey. If their flippers stall, it would be like going into a turn and hitting a patch of ice and being flung out tangentially. If they were to stall, the bubble net would be too large and their prey would get away."

It was a compelling story, and an interesting technology. Fish and Watts had patented the concept in 2002. After Howle's team and Fish published their findings, Fish and Watts began looking for a way to commercialize the technology.

selling the idea

It proved easier than expected. The research made a splash in the scientific press. This attracted the attention of Steven Dewar, a Toronto entrepreneur. He contacted Watts and they formed Whale Power with Fish in 2005. Howle developed many of the company's early designs.

Fans are tubercles' breakout application. Ontario-based Envira-North Systems licensed the technology and introduced its first fans, ranging from 8 to 24 feet in diameter, in Canada in 2009, and later to the rest of North America, Europe, and Asia. These high-volume, low-speed fans prevent air stratification in warehouses, large barns, and other industrial facilities. They can reduce heating and cooling bills by 20 percent.



LAURENS HOWLE

Tufts attached to a humpback whale flipper model in a wind tunnel. When the tufts begin to flutter, the airfoil has begun to stall.

A typical large fan of this sort extends 24 feet in diameter and has 10 blades. "We can go down to five blades, and they produce 25 percent more airflow and use 25 percent less electricity while operating at the same speed," Dewar said.

Typical fans shed vortices from the root off the tip, he noted. This builds up a pressure bubble that collapses into the return flow, which disrupts flow and causes stalling. "On our fan, those vortices hit the tubercles, which bang it back across the fan," Dewar said. "By the third channel, all the air is going 90 degrees across the blade and nothing is going off the tip. No other fan on Earth that can do that."

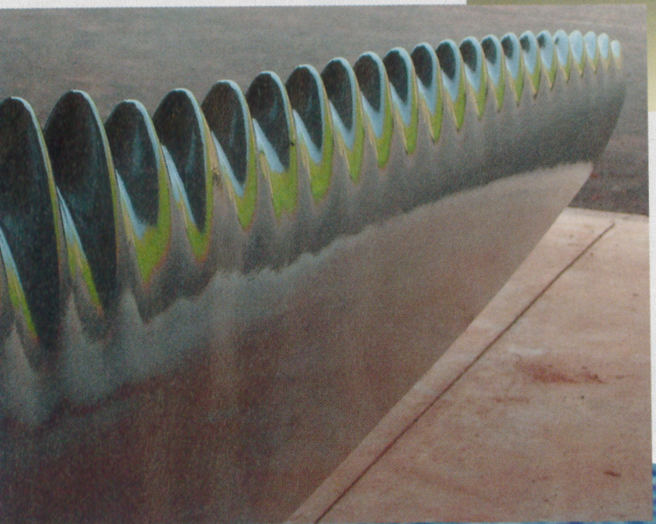
Dewar also sees a future for tubercle blades in wind turbines. During the first half of 2008, the Wind Energy Institute of Canada tested 5-meter tubercle blades on a 25 kW wind turbine. It found that tubercle blades reached full power at 12.5 m/s, compared with 15 m/s for conventional blades, and would produce up to 20 percent more electricity annually, depending on wind speed.

Other potential applications are under development. Dewar thinks tubercles might find a place in heating and cooling, and in low-noise fans for computers and servers. Howle believes they could be used in no-stall radiators used to cool diesel engines that run hotter to meet new emission standards. Murray, who took part in the original wind tunnel tests and now teaches engineering at the U.S. Naval Academy, believes tubercles' low-flow performance could drive turbines that generate power from tidal flows.

The technology is not a panacea, Howle cautions. Research has shown tubercles work only on thick, tapered wings operating in a very narrow laminar-to-turbulent transition regime. Outside these parameters, they could actually degrade performance.

Yet after thousands of years of hiding in plain sight, tubercles are emerging as a real, if limited, technology platform. And to think, it happened because a man named Fish was curious about a sculpture. ■

LAURENS HOWLE



Above, a model of a wind turbine blade with bumps on the leading edge.

Left, the actual fluke-inspired wind blade tested on Prince Edward Island, Canada.