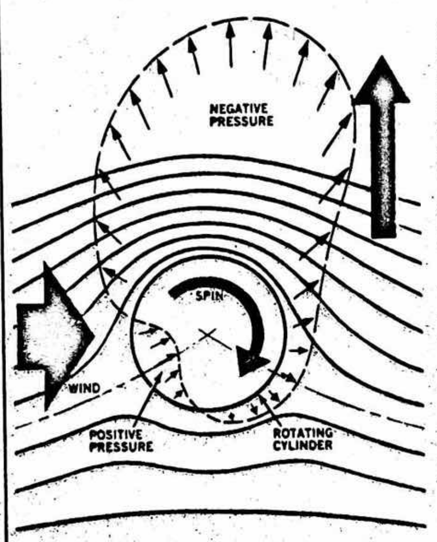
Barrel-blade windmill

—efficient power from the Magnus effect?

A light, low-cost turbine puts the aerodynamic force behind curved baseball pitches to work

By JIM SCHEFTER
DRAWINGS BY RAY PIOCH

Spinning with the Magnus effect



German physicist Gustav Magnus, studying the aerodynamic effects that puzzled artillerists for over a century, discovered that a ball spinning about an axis perpendicular to its flight path combines with the velocity along the path to produce an aerodynamic force at right angles to the flight path. That force, the Magnus effect, makes the ball curve from its normal trajectory.

This aerodynamic force can be illustrated by wind flowing over a spinning cylinder (left). The spin creates a thin layer of air that tries to adhere to the spinning surface. The interaction of this surface layer with the wind changes the pressure distribution around the cylinder. The combination of negative- and positive-pressure regions around the cylinder produces a significant upward lift force. The force can curve a baseball or turn a wind turbine.

WHITTAKER PEAK, CALIF.
Sunlight danced from an unusual windmill on this mountain ridge north of Los Angeles. Instead of blades, the 55-foot-diameter wind turbine before me had three aluminum cylinders attached to a teardrop-shaped fairing. The bladeless rotor, high atop a spindly tower, looked oddly unfinished.

Like those on a conventional machine, the barrel-like blades on this unique wind turbine carve a sweeping arc. But at the same time, each barrel spins on its own axis. Even in a moderate breeze the rotor spins faster and faster. If future testing verifies its efficiency, this new machine could become one of the least-expensive wind turbines on the market.

The windmill demonstrates the so-called Magnus effect, an aerodynamic force that Gustav Magnus discovered, makes cannonballs veer from trajectories—and enables baseball pitchers to throw curve balls (see box). In 1852 Magnus proved that if a circular object spins around an axis perpendicular to its flight path, a new aerodynamic force at right angles to the forward movement is created.

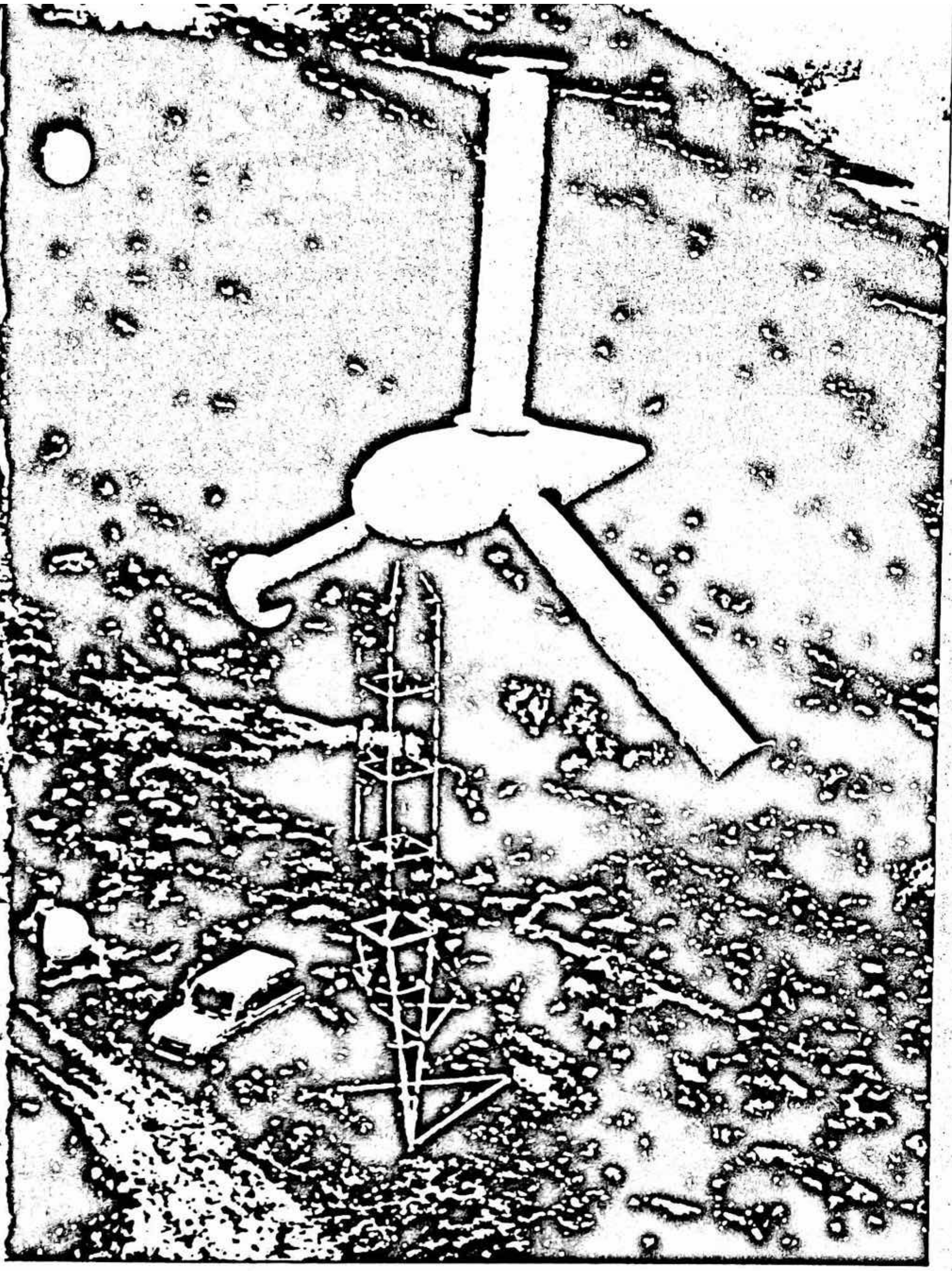
Virtually all wind turbines on the market [PS, July '82] rely on airfoil-shaped blades. These conventional blades, more complex aerodynamically than helicopter blades, are expensive to manufacture. In contrast, the long barrels on a Magnus-effect turbine are dirt cheap. Equally important, while conventional wind machines need some mechanism to limit blade speed in high winds, a Magnus-effect turbine can continue spinning in very high winds, capturing energy wasted with other designs.

The strange-looking Magnus-effect machine I saw resulted from more than eight years of effort by Thomas Hanson, a former helicopter engineer with experience at several aerospace firms. In the mid-1970s, as an engineering consultant, Hanson began searching for a low-cost-windmill design. His research led him to an obscure book in the Los Angeles Public Library that no one had borrowed for 27 years.

That book, *The Story of the Rotor*, by German inventor Anton Flettner, outlined how the Magnus effect could be applied practically. In fact, during the late 1920s the young German had helped build two storm-proof sailing ships with spinning cylinders instead of sails, plus a 65-foot-diameter Magnus-effect wind turbine that powered a Berlin radio station.

Hanson began developing a modern version of the Magnus-effect turbine in 1974. His first project was a 20-foot-diameter turbine. It worked. But Hanson discovered that windmills anchored to one site weren't suitable for research. He sought federal funds to build both a scale model of a larger turbine and test models that could be pushed by car to avoid waiting for natural winds. "Nobody was interested," Hanson says.

Three years later he revived the project, designing a 110-foot, 600-kilowatt machine under a Southern California Edison contract. Then, when the company failed to fund actual construction,



main-shaft power is mechanically coupled to a spin drive for the barrels. "About 10 percent of the output goes back to keep the barrels spinning," Hanson explains.

The remaining 90 percent would drive a generator. In a 40-mph wind, Hanson calculates his machine's output at 225 hp. Lacking a generator, Hanson spills the power through a "club prop," an eight-blade paddle wheel 61 inches in diameter. Says Hanson, "It's spinning up to 1,000 rpm when the turbine is at full speed."

Barrel rpm increases with wind speed up to about 40 mph, then remains constant, Hanson claims. The rotor thus reaches its maximum 40 rpm at that wind speed. "The lift force is dependent on the rotational velocity of the barrel. By limiting the barrel rpm at higher wind speeds, the rotor rpm cannot run away," he says.

And Hanson's design can handle high wind speeds. He believes his machine is almost weatherproof. One stormy morning he held up his portable anemometer at the site. The needle pegged at 80 mph. Glancing at the spot where his permanent anemometer was installed, Hanson noticed that it had blown away. "But the turbine wasn't damaged at all from the wind," he says.

The vagaries of wind, however, have brought out one problem with Hanson's turbine. It's a free-yaw machine: The combined forces of the wind and the Magnus-effect lift should keep it facing parallel to the wind. When wind flow is horizontal to the surface of the surrounding land, it does just that—even in gusts.

But the turbine is sited on a ridge that drops off steeply only 10 yards away. The windmill frequently experiences winds sweeping up from below. "When that happens, the force vectors yaw the turbine out of the wind, and it either slows or stops," Hanson says. "This isn't a turbine for mountainous terrain."

he redesigned a half-scale model and began on his own.

"The project moved in spurts until the Department of Energy got interested in 1980," says Hanson. With a $47,000 federal grant in hand, he pushed ahead.

His current design, built virtually single-handedly, uses three lightweight (200 pound) aluminum-skinned barrels, each 24 feet long and 45½ inches in diameter. Each barrel is mounted over a simple angle-iron hub truss. The entire rig, minus a generator, weighs just 6,300 pounds. Hanson erected the turbine by himself at the site, bolting the tower to the ground then pulling it upright with a small electric winch.

"There wasn't enough money for the complete system," Hanson says, explaining the lack of a generator. "But the turbine is designed to produce enough horsepower to run a 150-kW generator."

Hanson designed the internal mechanisms of the turbine (see how-it-works diagram), which capture the power produced by the triple-barrel turbine rotating like an ordinary windmill. (The Magnus effect from each barrel generates this rotary motion of the turbine, but the spin of each barrel is not directly tapped for power.) A simple trolley-track ring system is fix-mounted within the central fiberglass-covered nacelle. This eight-foot-diameter ring, the most expensive component in the turbine, was formed and machined to Hanson's specifications.

The turbine's rotary motion turns rollers pressed against this eight-foot ring. These rollers turn drive shafts connected to gearboxes linked to the main output shaft. But part of the

Flat-land tests

Hanson admits candidly that the turbine needs more testing. With help from Southern California Edison, he hopes to move the turbine to the utility's flat-land wind-turbine-development-and-testing site at San Gorgonio Pass near Palm Springs, Calif. As of this writing, the company was expected to make that decision soon.

"We have a definite interest in it," says Robert Scheffler, wind-energy manager for the utility. "It's a unique idea, and it seems to work."

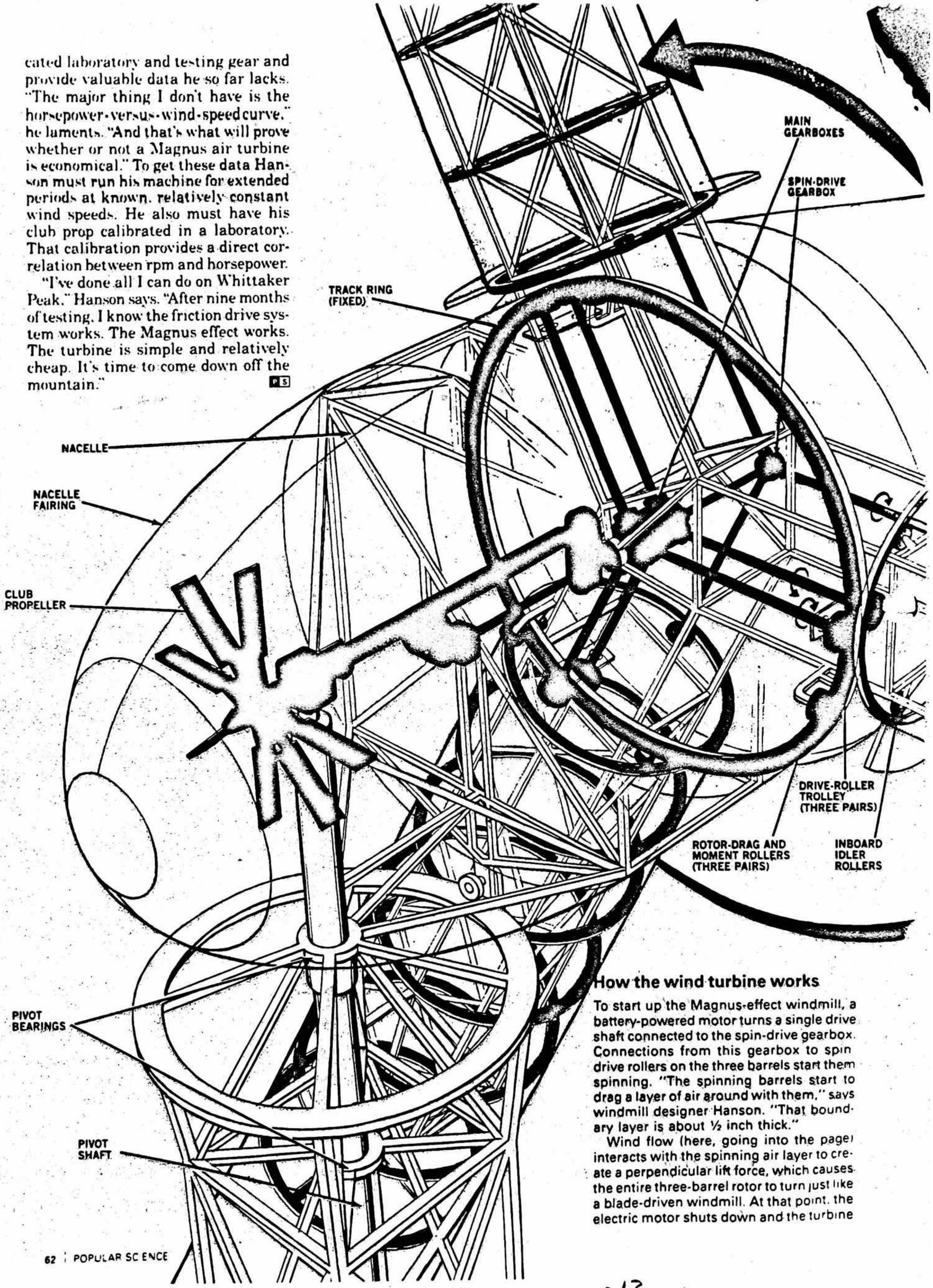
Installation at the SoCal Edison site would give Hanson access to sophisti-

Continued

12

cated laboratory and testing gear and provide valuable data he so far lacks. "The major thing I don't have is the horsepower-versus-wind-speed curve," he laments. "And that's what will prove whether or not a Magnus air turbine is economical." To get these data Hanson must run his machine for extended periods at known, relatively constant wind speeds. He also must have his club prop calibrated in a laboratory. That calibration provides a direct correlation between rpm and horsepower.

"I've done all I can do on Whittaker Peak," Hanson says. "After nine months of testing, I know the friction drive system works. The Magnus effect works. The turbine is simple and relatively cheap. It's time to come down off the mountain." PS

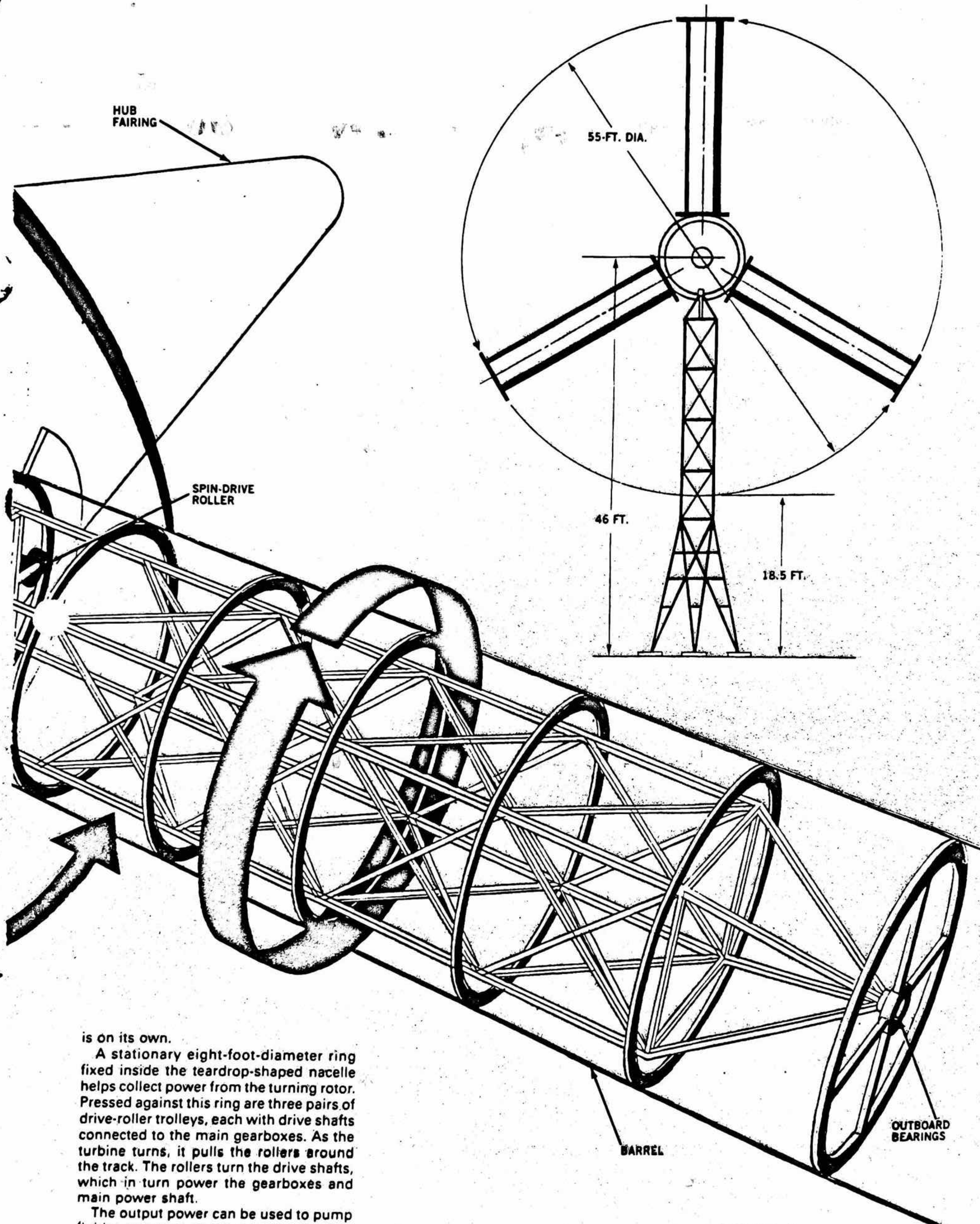


How the wind turbine works

To start up the Magnus-effect windmill, a battery-powered motor turns a single drive shaft connected to the spin-drive gearbox. Connections from this gearbox to spin drive rollers on the three barrels start them spinning. "The spinning barrels start to drag a layer of air around with them," says windmill designer Hanson. "That boundary layer is about ½ inch thick."

Wind flow (here, going into the page) interacts with the spinning air layer to create a perpendicular lift force, which causes the entire three-barrel rotor to turn just like a blade-driven windmill. At that point, the electric motor shuts down and the turbine

p13



is on its own.

A stationary eight-foot-diameter ring fixed inside the teardrop-shaped nacelle helps collect power from the turning rotor. Pressed against this ring are three pairs of drive-roller trolleys, each with drive shafts connected to the main gearboxes. As the turbine turns, it pulls the rollers around the track. The rollers turn the drive shafts, which in turn power the gearboxes and main power shaft.

The output power can be used to pump fluids, compress gases, or generate electricity like conventional windmills. The club propeller shown simulates a load.

14

Spin sail

harnesses mysterious Magnus effect for ship propulsion

● The Magnus effect was discovered in 1852, and a ship using it was sailed across the Atlantic in 1926. Its inventor predicted it would launch a new age of wind-powered ships. But cheap oil sank that idea. Now, with oil prices up, the Magnus effect ship is back. Its design has been worked out for ships of all classes, and instrumented tests have proved the device's effectiveness. The day of the rotor-assisted windship may at last be at hand.

By C. P. GILMORE

The sky was blue and the wind fresh one morning recently as I stepped aboard the yacht *Tracker*. The 42-foot craft with a strange, giant cylinder mounted on the forward deck was hanging at anchor in Edgartown Harbor in Martha's Vineyard, Mass.

A pair of legs protruded from beneath the tower, as though the thing was in the process of eating a man and only his legs remained. That wasn't the case, of course. Lloyd Bergeson, president of Wind Ship Development Corporation, explained that his son, Henry, an engineer, was making a change. The hull vibrated when the tower rotated at several hundred rpm, and Henry was bolting in a brace to stop the vibration. He crawled from under the tower and announced that the rig was ready for a test. Then he started up a lawn-mower-size engine just aft of the rotor.

As the engine put-putted to life and the tower began to rotate, the 17-ton *Tracker* suddenly lurched forward and to the right and was soon straining against the anchor. I thought it was going to drag the anchor and, with no one at the helm, go crashing through the scores of yachts moored throughout the harbor. Lloyd Bergeson, grinning widely, shouted, "Underway under rotor power."

That was my introduction to the Flettner rotor. Even though I understood the principle, it was hard to believe that that rotor spinning on the bow had actually propelled the boat forward. Yet the fact was undeniable; the yacht had lurched forward as though the diesel engine below decks had been started and shifted into gear.

Bergeson mounted the rotor on the *Tracker* to prove to the maritime community that the age of wind-assisted shipping is about to return and that ships using strange spinning towers on their decks can save enormous amounts of fuel as they ply the world's oceans. He has formed Wind Ship to promote the idea. And the world, apparently, is beginning to listen.

Physicists call the force that moves the *Tracker* the *Magnus* effect. It was discovered in 1852 by a German physicist, Gustav Magnus, who was trying to find out why spinning artillery shells sometimes curved in unpredictable ways.

What Magnus discovered is that a sphere or cylinder spinning in a moving airstream develops a force at a right angle to the direction of the moving air (see diagram overleaf). I discovered in Edgartown Harbor that the force has amazing power. It can develop hundreds of pounds of thrust on a craft the size of the *Tracker*.

The first attempt to drive a ship with the Magnus effect was made in the 1920s by another German physicist, Anton Flettner. He mounted two spinning cylinders, which have since been called Flettner rotors, on a schooner and sailed the ship across the Atlantic under rotor power in the spring of 1926.

Despite the fact that Flettner's rotor ship worked and at least one other rotor ship went into commercial service, the idea gradually died. "The shipping industry didn't care about saving energy," said Bergeson. "Oil was a dime a barrel and was replacing coal. And about that time Flettner turned to designing airplanes for Hitler."

Flettner rotor revived

In the early 1970s Thomas Hanson, a West Coast engineer who had been working on helicopter design, turned his attention to wind turbines. He discovered Flettner's work and became convinced that many of the problems of large wind machines could be solved by using Flettner rotors in place of the usual blades. The result of this work appeared on the cover of POPULAR SCIENCE last August.

Enter Bergeson. A naval architect with a degree from the Massachusetts Institute of Technology, he had spent his life in the shipbuilding industry, supervising the production of nuclear submarines for General Dynamics and functioning as general manager of two major shipyards.

The 66-year-old Bergeson stood on the deck of the *Tracker*, looking across the harbor with a sailor's squint. His white hair rippled in the breeze. "I had always wanted to sail across the Atlantic singlehanded," he said when I

Continued

15

asked how he got interested in sail-assisted shipping. "So in 1978 I did it." He sailed his 43-foot yacht, the *Cockatoo II*, to Norway by himself.

During the 31-day crossing, Bergeson thought about the shipping industry and became convinced that enormous amounts of money could be saved if ships used the wind to furnish some of their propulsion. They'd still have engines. But why not also have some sort of sail that would take advantage of the wind when conditions were right?

In 1979 he formed Wind Ship to promote the idea and, as his first major project, undertook a study of sail power for the U.S. Maritime Administration. His report, published in 1981, investigated different kinds of sail-assist schemes. It concluded that properly designed sails could be built to operate from the bridge with no additional crew, that they would be easier to maneuver than conventional ones, that such rigs would benefit both new ships and ships retrofitted with sails, and they'd save a lot of fuel.

Bergeson put his theory to the test in 1981. He designed a 3,000-square-foot sail for the 3,100-ton-dead-weight ship *Mini Lace*, a freighter operating in the Caribbean out of New Orleans. His calculations showed that fuel savings would average about 20 percent. After 18 months of operation, the ship's owner published the actual results. Savings had been a satisfying 24 percent. (Other companies around the world had been experimenting with sail assist, notably the Japanese tanker *Shinaitoku Maru* [PS, Dec. '80], but none did as well as the *Mini Lace*.)

Although the *Mini Lace* was a success, Bergeson's original study had investigated different types of sails. He had concluded that three—including the cat rig used on the *Mini Lace*—had the greatest promise. Another promising type was the wing sail, which looks like an airplane wing standing on end. The third was the Flettner rotor.

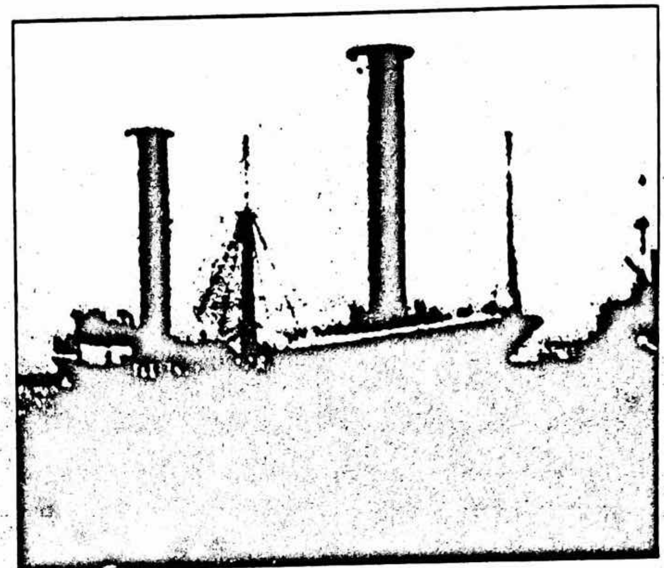
Windmill to the rescue

At about the time Wind Ship had done the preliminary engineering of a rotor design that could be tested, Bergeson heard about Hanson's work with the wind turbine. It turned out that the rotors Hanson had built were almost identical to those Bergeson had calculated he would need, so a Hanson rotor was shipped from California to Massachusetts, and the project became a joint enterprise between Wind Ship and Hanson's company, Windfree, Inc.

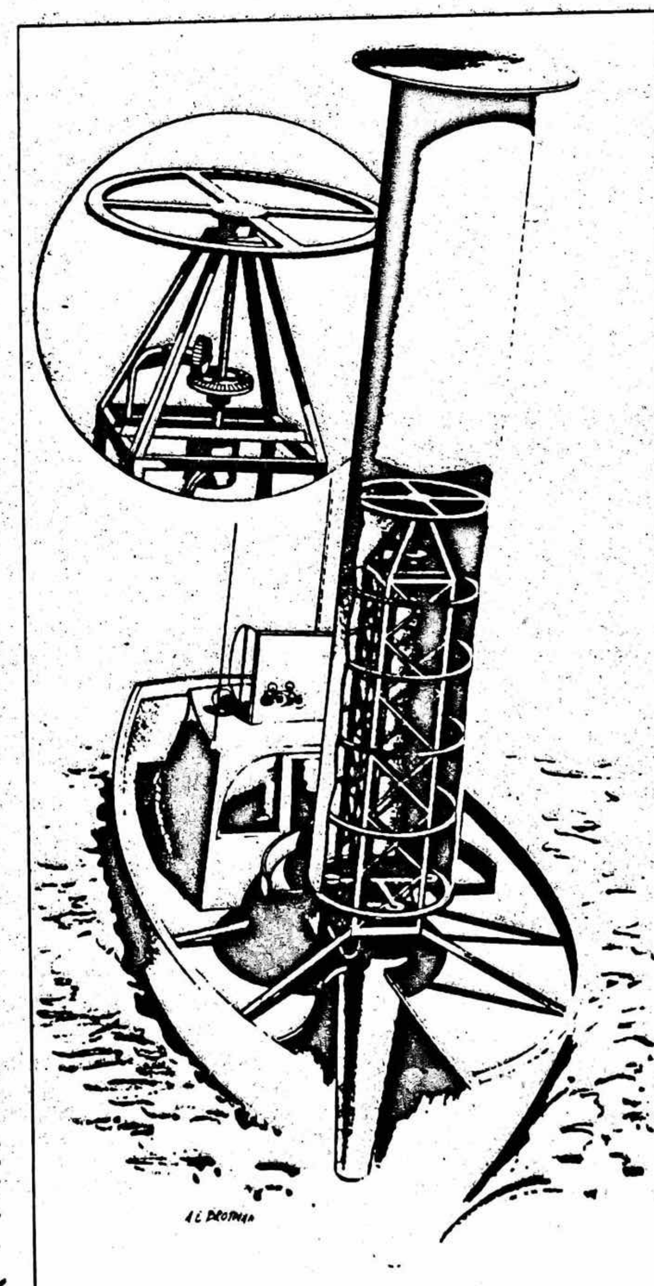
I first saw the joint enterprise, the *Tracker*, that morning in Edgartown Harbor. The most striking thing about it, of course, is that rotor. It's 42 inches in diameter and 24 feet high. It is driven—up to about 600 rpm—by a hydraulic motor (see diagram), which, in turn, is driven by a hydraulic pump turned by a small gasoline engine.

When the vibration problem had been solved, we got underway with the craft's owner, Dave Frantz, at the helm. We were the center of attention as we sailed between the rows of anchored yachts. With Frantz in control, the *Tracker* moved majestically through the anchorage at three or four knots and out into the open sea. With about an 18-knot wind, the boat moved easily at six knots under rotor power alone. By adding a little power from the diesel, Frantz eased it up to a little over seven knots.

Some funny things: You have to learn to sail all over again. The best point of sail is a beam reach—with the wind coming directly from one side or the other—because

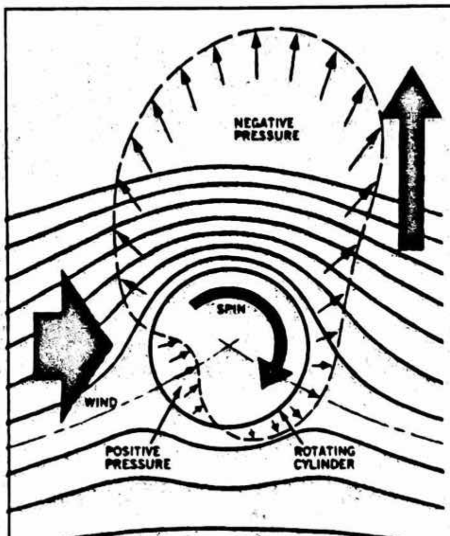


The first Flettner-rotor windship, the *Buckau*, was built by Anton Flettner and sailed almost 60 years ago. This picture is taken from February 1925 edition of POPULAR SCIENCE.

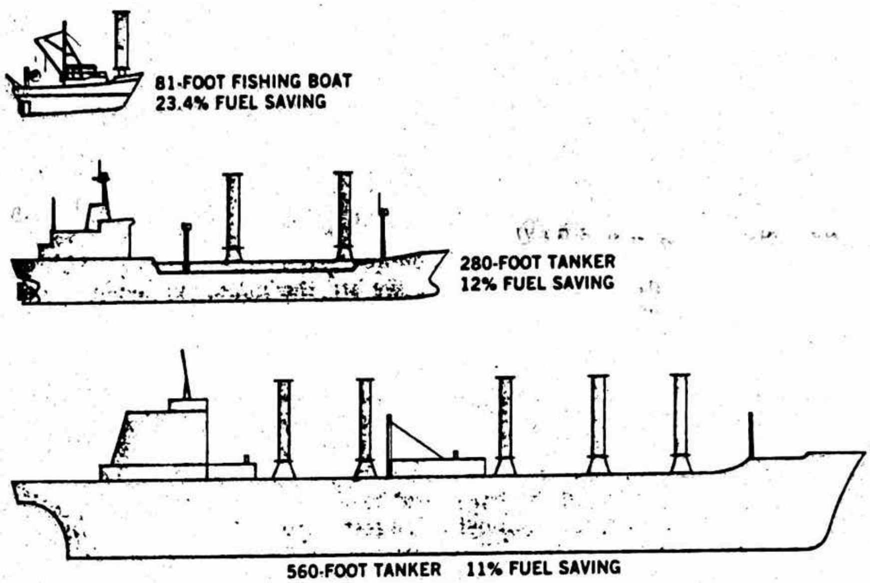


The weight of the rotor is supported by the bearing about halfway to the top; the bottom of the cylinder rides on three rubber wheels near the bottom. Entire structure is driven by a hydraulic motor just under the bearing, which, in turn, is driven by a gasoline-engine-powered hydraulic pump located on the ship's deck. Rotational speed, which is sensed by the idler (inset), under most wind conditions is about 400 rpm.

16



The Magnus effect, the same force that causes a spinning baseball or golf ball to curve, can generate enough force to drive a ship. The spinning surface of the cylinder carries a thin layer of air with it in the direction of spin. If wind is blowing across the cylinder, as shown, the moving airstream interacts with the surface layer of air rotating with the cylinder. This interaction generates a high-pressure area where the two forces are opposed and low pressure on the opposite side of the cylinder, where they move in the same direction. The pressure differential exerts force in a direction at a right angle to the wind.



Wind Ship has worked out sail-assist designs and calculated resulting fuel savings for many classes of ships and trawlers. Projected savings range from 10 to 30 percent, depending on characteristics of ship, rig, and wind.

then the force vector generated by the rotor is directly ahead. To tack, you have to stop the rotor and start it again in the opposite direction as you go through the wind. A rotor-powered boat can sail to within 25 degrees of the wind. That compares with the ability of conventional sail-powered vessels to sail to within about 45 degrees of the wind. The most peculiar anomaly: As you sail on a broad reach—say 135 degrees off the wind—the vector moment is actually such that the boat heels *into* the wind.

During the day I asked Bergeson how projected fuel savings for the *Tracker* had worked out with actual findings. He said that predictions were for a saving in the 20-to-30-percent range but that they had not had an opportunity to make accurate measurements. A week later, Tom Marriot, a member of the PS auto-test crew, drove to Cape Cod with the PS precision fuel-consumption measuring equipment and met the *Tracker*. Over the next few weeks, with the measuring equipment aboard, the *Tracker* went through a series of trials. The results are as follows:

Power mode	Average wind speed (knots)	Average boat speed (knots)	Average fuel saving (percentage)
Rotor-assisted	16.1	7.0	44
Rotor-assisted	12.9	6.0	27
Rotor sailing	17.7	5.3	100

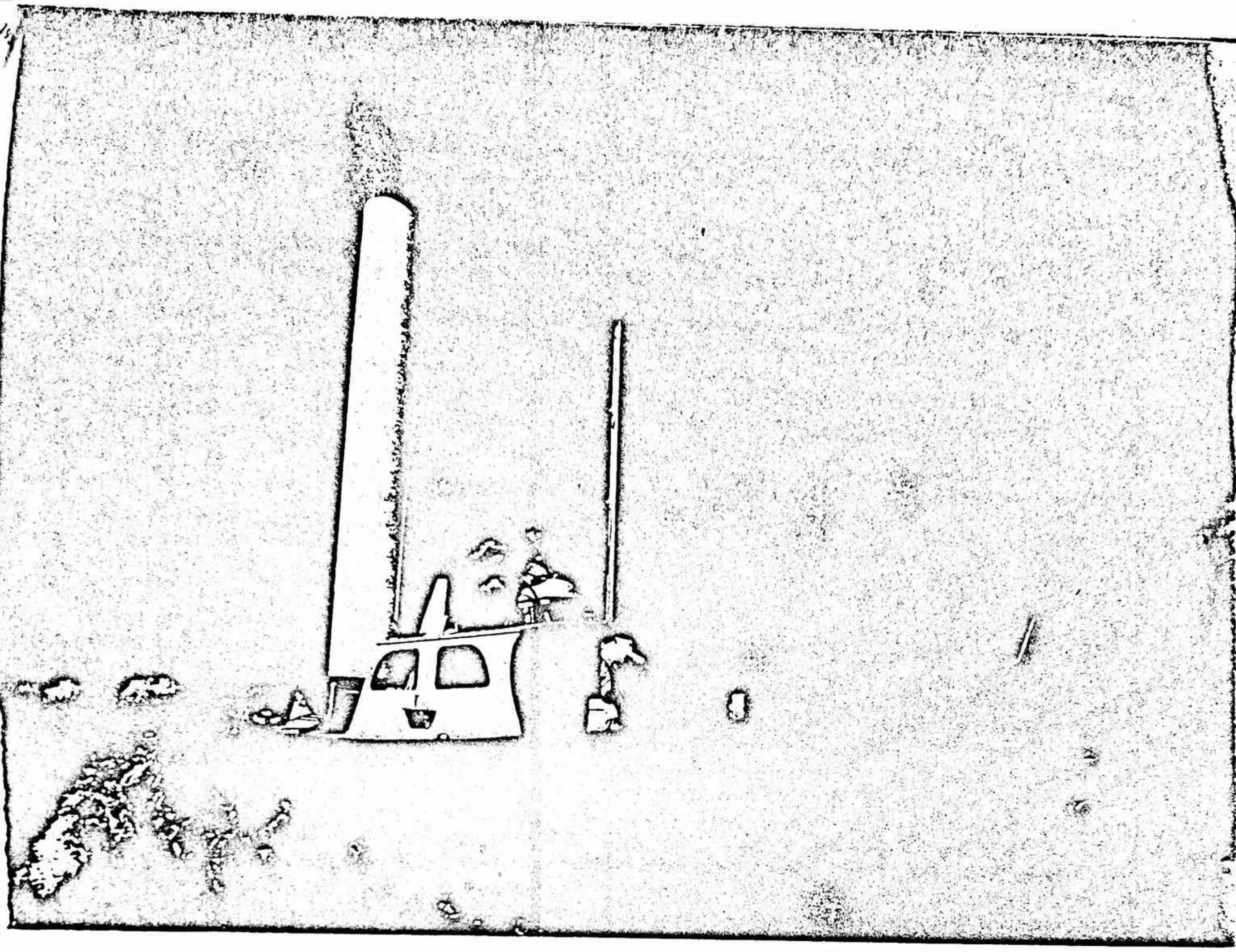
Under rotor power alone, the *Tracker* reached a maximum speed of 6.1 knots in an 18.4-knot wind and a true wind angle of 122 degrees.

Bergeson is demonstrating the *Tracker* to fishing-boat owners, talking to large shipping companies, and presenting scientific papers at maritime conferences. And interest is growing. He now has a Navy contract to study the conversion of a military sea-lift ship to rotor-assisted propulsion. He is also conducting similar studies for a number of independent shipping companies, including major oil and cruise-ship companies.

The economic potential is certainly there. Bergeson has calculated that the world's shipping fleet consumes 730 million barrels of petroleum a year at a cost of *$30 billion*. If only 20 percent of the world's fleet adopted sail assist, the saving would be on the order of 91 million barrels a year—almost $3 billion.

The payback to an owner can be astonishingly quick. The entire rig for the *Mini Lace* cost $250,000. But the owner's records show that the sail assist saves $48,000 worth of fuel a year. In addition, average speed is increased by five percent, which means that the ship can make more trips. Extra income from this source was $9,200. At that rate, the rig would pay for itself in a little over four years. But there's more. On the New Orleans-to-Jamaica route, where winds are usually favorable, the fuel saving was an incredible 36 percent, and the speed was up 18 percent. If the ship were used only on similarly favorable routes, the payback would fall to an astonishing 1.7 years.

Bergeson is totally committed to the idea of sail assist and thinks that it might come in three forms. The cat rig is useful in some applications, as demonstrated by the *Mini Lace*. But the wing sail is more efficient and might be appropriate in many applications. And the Flettner rotor, he believes, is the most efficient and can be smaller, lighter, and most trouble-free in operation. "As far as I'm concerned, I'm interested in finding the best way for every application," Bergeson says. "In the development of something like a nuclear submarine, you try two or three things to see which is best. When it comes to these sail schemes, I think they're all winners. They are complementary. I love 'em all, and I see a future for all of them." PS



Forty-two-foot boat travels at six knots in 18-knot wind under Flettner-rotor power alone. Using rotor-and-engine combination for greater speed gives up to 45-percent saving over engine alone.

Boat owner Dave Frantz is at helm; Henry Bergeson manipulates rotor controls. The rotor speed is indicated on a recycled Chevrolet speedometer.

Cylinder rotation is stopped by pulling a wire that brings brake shoe in contact with the inside of the cylinder. A more elegant version is in the works.

Proof-of-concept rotor has generated undesirable level of vibration. Crew spent considerable time modifying structure under rotor to solve problem.

18