THE AMATEUR SCIENTIST

Diverse topics, starting with how to supply electric power to something that is turning

Conducted by C. L. Stong

How do you supply electric power to a rotating device through flexible wires? What prevents the wires from twisting up and breaking? The usual answer is to put into the circuit a pair of slip rings. They are annular conductors mounted on insulators that are attached to the rotating object. Current is supplied to the rims of the rings through a sliding contact with a pair of electrically conducting brushes.

The electrical resistance of the sliding contacts varies slightly. The variation is of no significance in circuits that carry a substantial amount of power, but in low-power circuits changing resistance can introduce unacceptable noise. D. A. Adams (Route 8, Box 316-0, Tucson, Ariz. 85730) has solved the noise problem by patenting a device for making a direct electrical connection with flexible conductors between the fixed source of power and the continuously rotating load. The load can rotate indefinitely without twisting the flexible connection in two.

Adams' scheme can best be explained by a series of diagrams [*see illustration on opposite page*]. Imagine a turntable that floats in air. A strip of paper tape is fastened to the center of the turntable at its top. The tape then arches over the edge of the turntable and extends downward in the general shape of a question mark to a fixed point directly under the center of the turntable.

Assume that the turntable rotates counterclockwise as viewed from above. Beginning at the upper left in the illustration and proceeding from left to right, note that as the turntable rotates 90 degrees the paper strip rotates around the turntable 45 degrees. When the turntable has rotated 180 degrees, the paper tape has rotated around the turntable only 90 degrees. In short, the turntable rotates at twice the speed of the tape.

Note also that when the turntable has made a full revolution and the tape a half revolution, the tape has turned through 180 degrees with respect to its starting position but has not twisted! You should find it even more remarkable to observe that the first diagram is identical with the last one even though the turntable has made two full revolutions while the tape has made only one. Yet the tape still remains straight.

However fascinating these diagrams may be, are they of practical interest? The scheme requires that the turntable float in midair, which is hardly a practical arrangement. Adams accomplishes the same effect, however, with a mechanism that enables the tape to rotate completely around the turntable on all sides [*see illustration on page 122*]. The base of the machine supports a fixed bearing in the form of a hollow shaft that terminates at its upper end in a spur gear. This unit functions as a bearing for a hollow shaft that terminates in a spur gear at its lower end. The spur gear meshes with the similar gear of an electric motor. The upper end of this rotating hollow shaft is rigidly fastened to one end of a closed cylinder. Hence the motor can rotate the cylinder through the spur gears. The weight of the cylinder is borne by a ball thrust bearing.

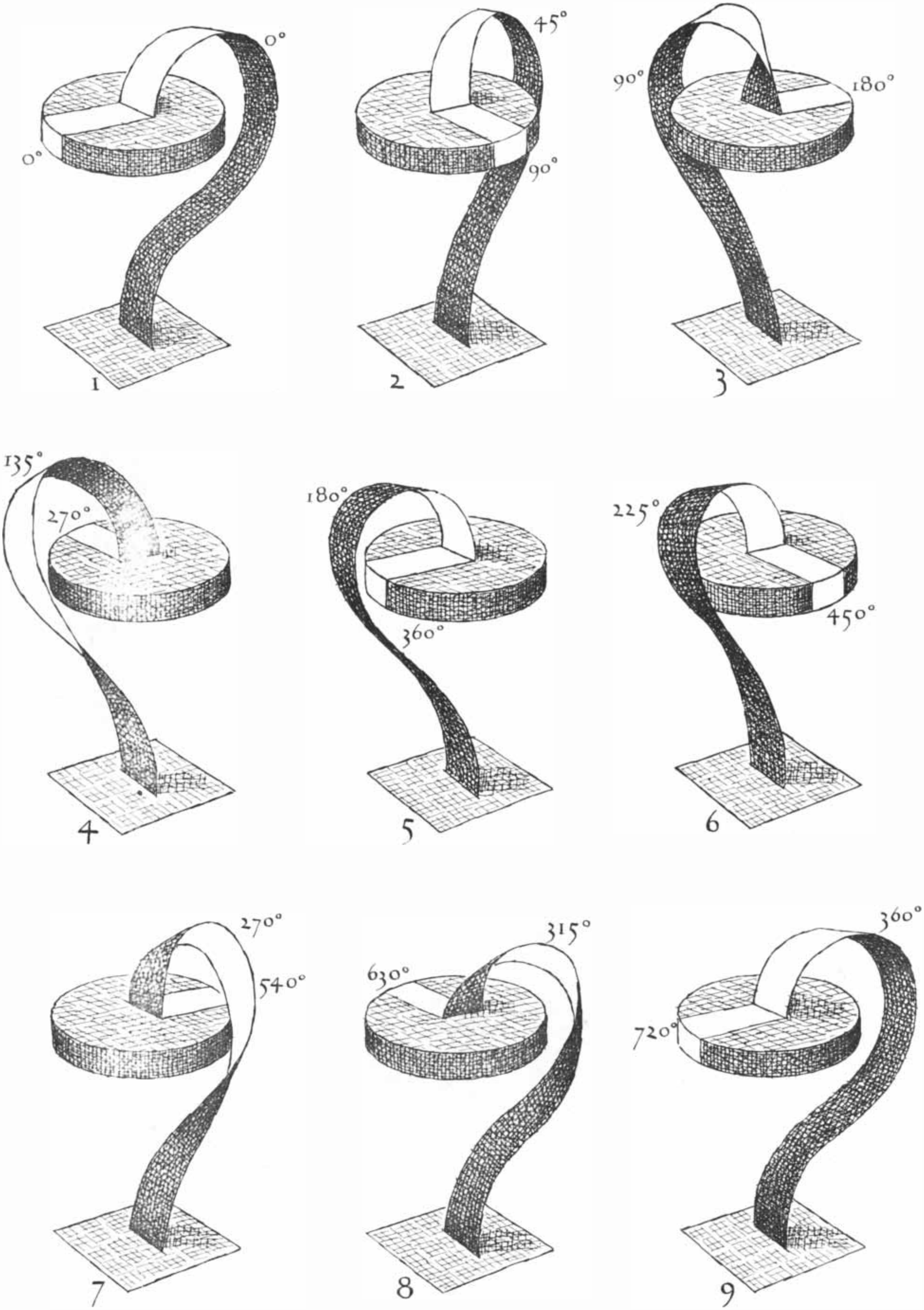
The spur gear that is part of the hollow shaft fixed to the base engages an idler gear supported by the bottom of the cylindrical container. The idler gear in turn engages a spur gear supported by a shaft that extends to the upper end of the cylinder, where it carries a second spur gear. When the motor drives the cylinder, the idler gear and its companion rotate as a planetary system around the sun gear that is fixed to the base. The upper end of the larger planetary gear engages a spur gear fixed to a turntable. The turntable is loosely supported by the upper end of the cylinder through a thrust bearing and hence is free to rotate.

An inspection of the system of gearing discloses that when the motor operates, the cylinder turns continuously. With the proper choice of gear ratios the turntable also rotates in the same direction but at exactly twice the speed of the cylinder. A pair of flexible conductors can be threaded up through the hollow pair of coaxial bearings at the base and then out of the cylinder through the small hole at the upper left. The conductors arch over the edge of the turntable and are attached to its upper center. The rig includes a rigid pipe for shielding the flexible conductors between the rotating cylinder and the top of the turntable. Thus the construction meets the requirements illustrated by the series of schematic diagrams but differs essentially in that a pair of flexible conductors have been substituted for the strip of tape.

It is apparent that uninterrupted connections of other kinds can be substituted for flexible electrical conductors. For example, hydraulic and pneumatic tubing without swivel joints or rotary valves can replace the wiring. So can channels for various gases, including air, chemicals and refrigerants. Moreover, a train of prisms can be arranged to transmit an image of all the movement (other than the rotary motion) of a specimen mounted on the turntable of a centrifuge. A biological specimen in a spinning centrifuge would appear to be motionless except for the distortions induced by the action of centrifugal force.

The scanning device would consist of four prisms rigidly mounted to the turntable through a framework that is in the form of a square-cornered *C*. Light rays from the prism configuration would be deflected through a right angle by a prism at the bottom. These rays, now fixed and horizontal, would fall on an eyepiece through which the spinning specimen would be observed [*see bottom illustration on page 123*]. The emerging rays would be constant, not intermittent as they are with the devices that now serve for examining specimens in centrifuges.

By omitting the idler gear at the bot-



Sequential models of D. A. Adams' antitwister mechanism tom of the cylinder and altering the gear ratio it is possible to make the turntable stand still while it is being encircled by the conductors. If the turntable is then fitted with a capstan and a motor-driven spool, it is possible to pull two wires through the machine and simultaneously twist them into a pair. The wires would be supplied by a pair of spools supported on a nonrotating shaft that is external to the base of the machine. Mechanisms of this type, which are called high-speed twisters, have had wide application in the electrical manufacturing industry.

This department for January, 1974, carried a description by Eugene F. Ruperto (Box 166, R.F.D. 1, West Alexander, Pa. 15376) of a homemade apparatus for picking up images of cloud cover as photographed by weather satellites. The signals transmitted by these vehicles may be relatively weak while the satellite is rising above the horizon or when it is about to set. For this reason it is customary to use receiving antennas that favor signals from a given direction and that can be pointed toward the satellite much as one would point a telescope.

Ruperto has made a directional antenna of the helical type that in effect increases the strength of the received signal by 13 decibels, thereby producing some 20 times the output of an omnidirectional antenna. The assembly is supported by an altazimuth mounting so that it can be turned toward any region of the sky [*see top illustration on page 124*]. Ruperto describes his antenna.

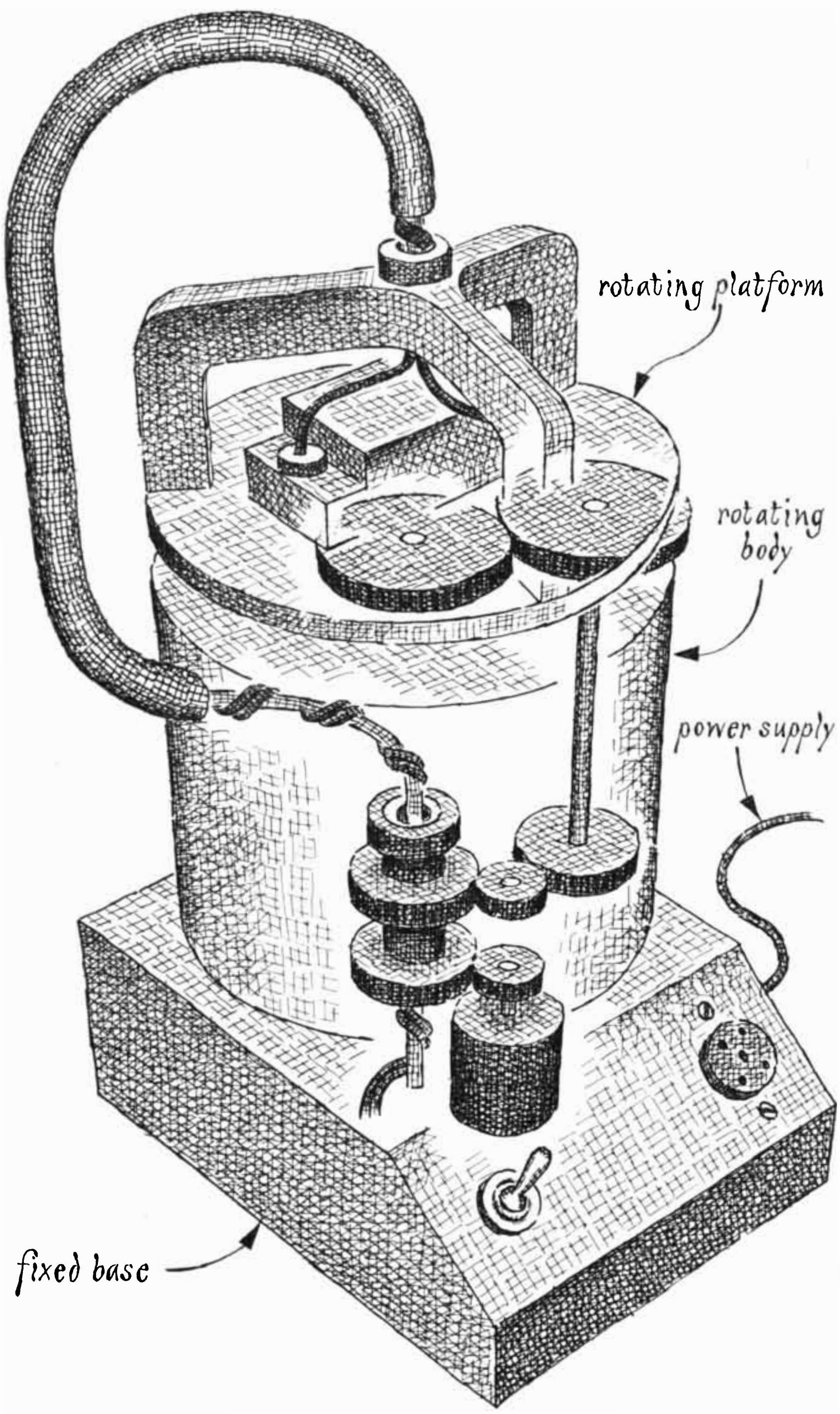
"Helical antennas have many attractive characteristics for observing a satellite. They are inexpensive and relatively light and can cover frequencies in the ratio of 1.7 : 1 megahertz. Their most pronounced disadvantage is their size.

"My antenna includes a wood boom that supports a helix of No. 6 hard-drawn copper wire through a system of radial wood struts; a ground plane of 1/4-inch aluminum tubing that resembles a spiderweb; an altazimuth mounting made of two wood blocks, and a counterweight in the form of a disk of concrete. The length of each turn of the helix is approximately equal to the wavelength of the signal. The wavelength is somewhat shorter in the metal than it is in free space because the energy is propagated through wire at a somewhat lower velocity than it is in free space.

"I determined the approximate wavelength in the helix with an old formula frequently employed by radio amateurs: Wavelength (in feet) equals 936 divided by the frequency (in megahertz). The frequency of the signal from the weather satellite is 137.6 megahertz. Hence the wavelength of the signal in the helix is 6.8 feet, or 81.63 inches, per turn.

"The No. 6 copper wire from which the helix was made was preformed by wrapping the wire around a 55-gallon wine barrel and then reducing the diameter by hand to a length equal to 81.63 inches multiplied by .31. The helix was then stretched so as to space its six turns a fourth of a wave apart, which amounted to about 21 inches between turns. The turns were bent by hand to a roughly circular shape about 26 inches in diameter. The inner end of the helix is bent in toward the center of the ground plane, where it enters an impedance-matching transformer.

"The ground plane consists of a square sheet of plywood, 18 inches on a



A machine embodying the antitwister principle side, that supports the ground-plane assembly. A sheet of aluminum is screwed to one surface of the plywood. To the base thus made a set of 16 lengths of 1/4-inch aluminum tubing is attached as a uniformly spaced radial array. The attachment is done with self-tapping metal screws. The sheet aluminum bonds the radial members electrically.

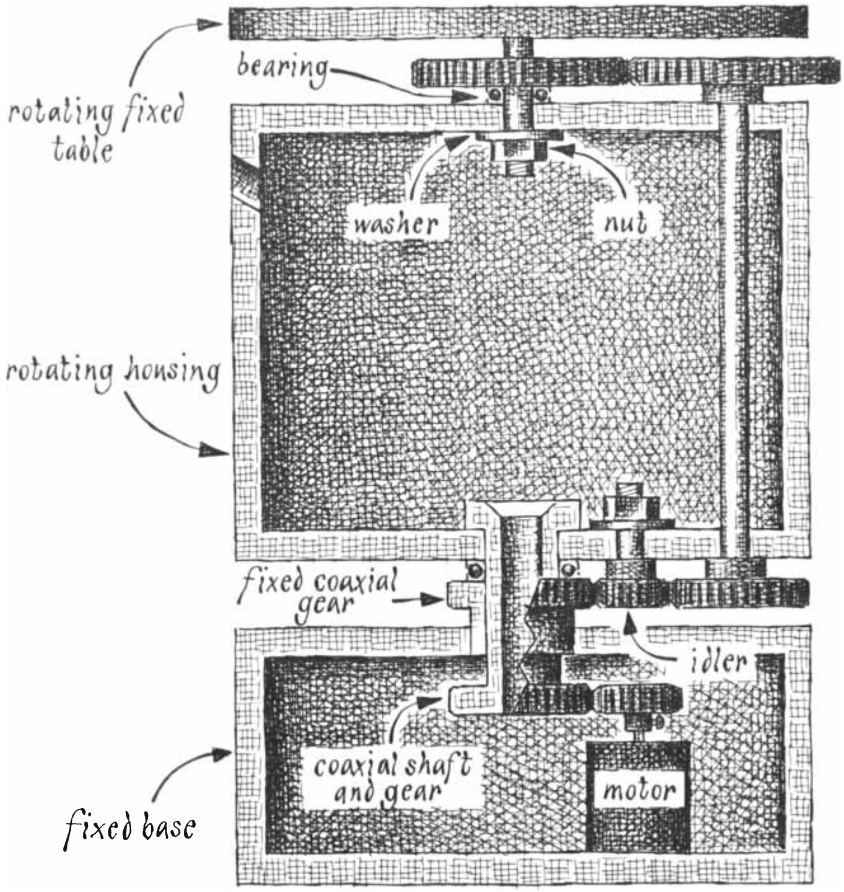
"In addition the radial members support a nested set of circular aluminum rings made of the same material. The output of the antenna is taken from the inner end of the helix and the ground plane. The electrical impedance across the output is approximately 140 ohms.

"This impedance must match the impedance of the transmission line that connects the antenna to the receiving apparatus. The commoner transmission lines are made of commercially available coaxial cable with an impedance of 50 ohms. An appropriate transformer for matching the 140-ohm impedance of the antenna to the 50-ohm impedance of the transmission line is a device that resembles a quarter-wave section of coaxial transmission line.

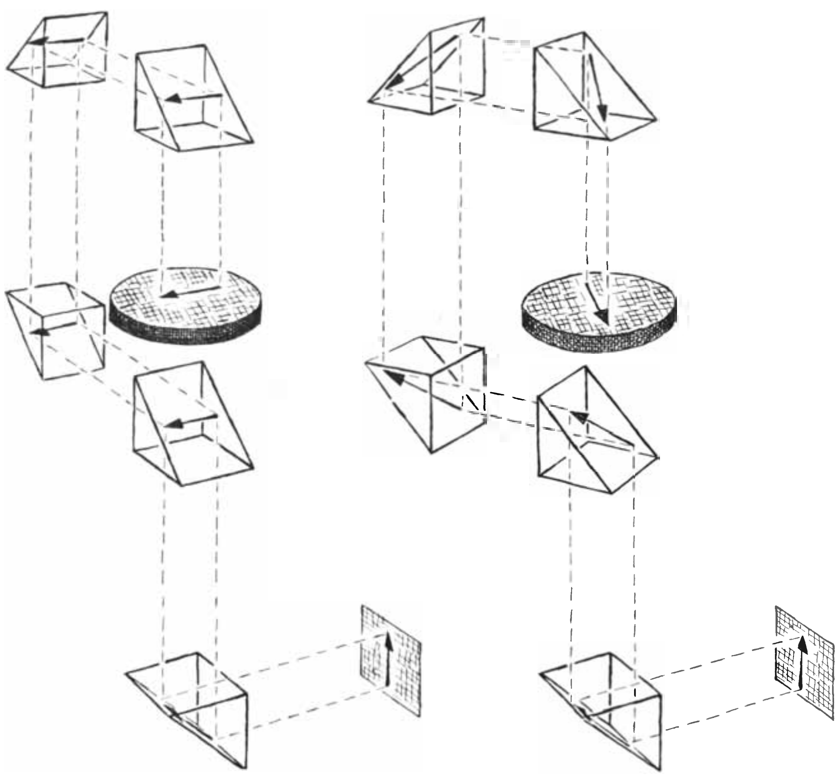
"My transformer is made with a copper pipe (inside diameter 3/4 inch) that encloses along its axis a coaxial length of the copper wire. The wire enters one end of the copper pipe through a Plexiglas washer. The inner end of the wire is soldered to the central terminal of a screw fitting that functions as a connector for joining the coaxial cable to the transformer.

"The impedance of the matching transformer must be equal to the geometric mean of the impedances of the transmission line and the coaxial cable. It is found by taking the square root of the product of the two: $(140 \times 50)^{1/2} = 7{,}000^{1/2} = 83.6$ ohms. The impedance of the transformer is equal to 138 log B/A, where B is the inside diameter of the outer conductor and A is the outside diameter of the inner conductor. The outside diameter of No. 6 ground wire is approximately .162 inch.

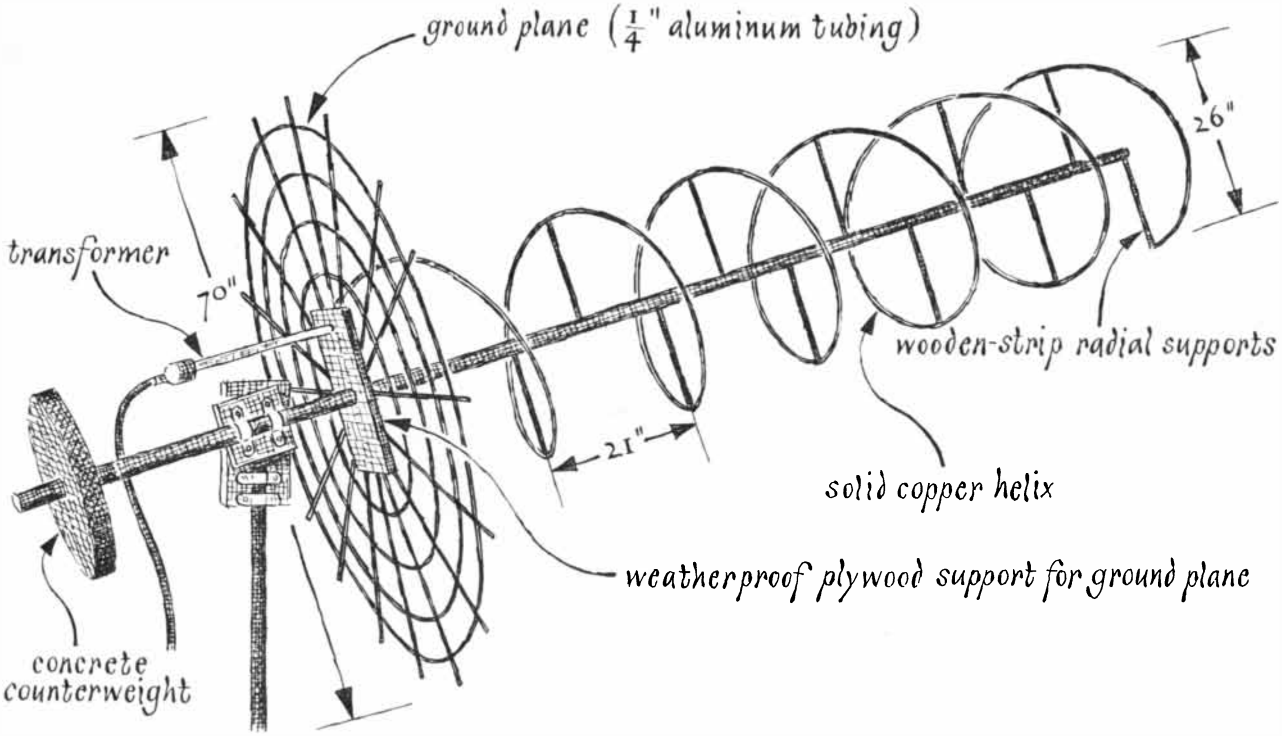
"Since the inside diameter of my copper tubing is .75 inch the calculation is $138 \log_{10} (.750 / .162) = 138 \times .666125 = 91.92$ ohms. The length of the transformer is equal to a fourth of the wavelength, or approximately 21 inches. The impedance of the structure is in error by about eight ohms. The error could be corrected by altering the diameter of the coaxial conductors, but the match is close enough for amateur work. A good electrical contact must be made between the copper pipe of the transformer and the ground plane of the antenna. I achieve it by mounting the coaxial fit-



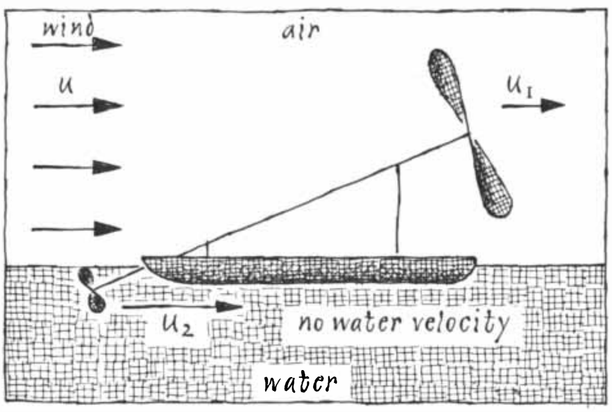
Cross section of the machine

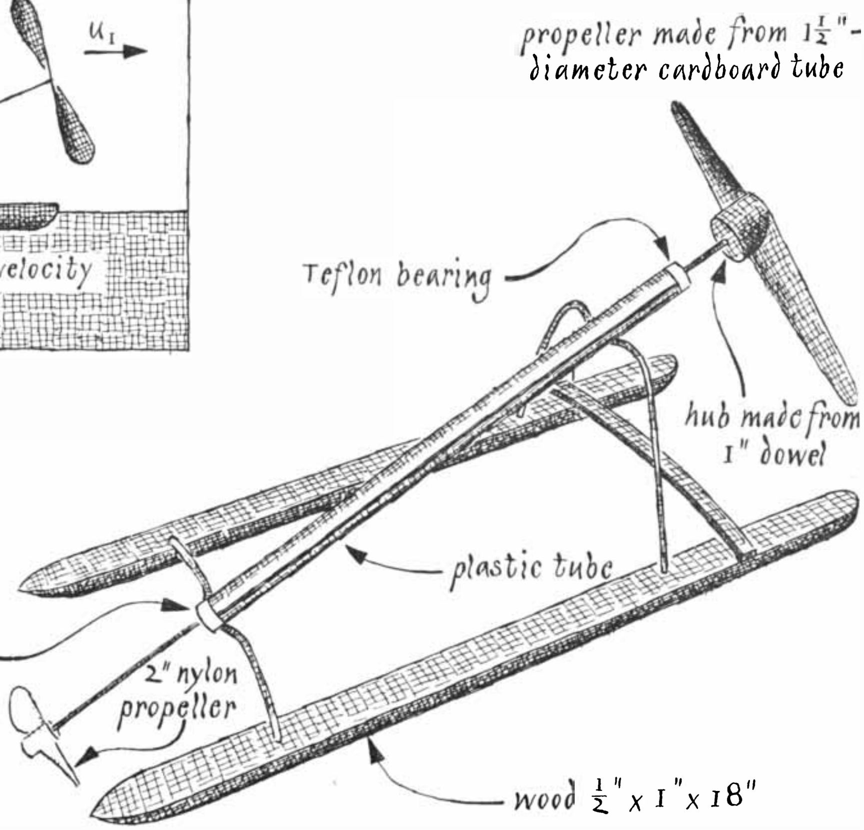


Train of prisms for imparting antitwist to an optical beam



Eugene F. Ruperto's helical antenna





"Push-me-pull-you" boat designed by Peter Kauffman and Eric Lindahl

ting to a brass plate that I brazed to the outer end of the pipe.

"In practice the antenna appears to have a signal gain of between 10 and 13 decibels through an angle of approximately 25 degrees on each side of the target toward which it is pointed. In other words, the directivity of the antenna falls to half power at the edges of a beam 50 degrees wide. It is not necessary to continuously track the satellite with the antenna. I determine in advance the azimuth at which the satellite has been predicted to rise and aim the antenna in that direction at an elevation of approximately 20 degrees. Usually the signal strength is adequate for making a good picture of cloud cover throughout the pass."

Seelye Martin of the department of oceanography at the University of Washington writes about this department's recent article [March] on sailboats without hulls. "It seems appropriate in a festive season of playthings to follow up this concept with a description of a toy boat that sails directly into the eye of the wind. It is the invention of Peter Kauffman and Eric Lindahl here in Seattle. We call it the 'push-me-pull-you' after the Dr. Dolittle animal with two heads.

"The boat consists of a propeller in the air coupled by a straight shaft to a propeller in the water [*see bottom illustration on opposite page*]. To reduce drag the shaft housing is mounted on a simple frame on top of a pair of pontoons. When the boat is placed on water in a wind with the water propeller upwind, the wind turns the air propeller and thereby the water propeller, which drives the boat into the wind.

"We have tried the boat in both laboratory and field tests. In the laboratory test, where the boat was in a large tank of water and a room fan was the source of wind, we placed the boat in front of the fan with the air propeller motionless. The breeze blew the boat away from the fan and started the propeller turning. As the propeller came up to speed, the boat stopped moving away from the fan and began accelerating toward it until the boat reached the fan.

"We also conducted a field test between two piers on Lake Union on a gusty day in February. The boat moved upwind over a distance of about 50 feet at a speed of about two feet per second in a strong wind with gusts of up to 30 miles per hour. The response of the boat to gusts is to slow down at first, because of the increased wind drag, and then to accelerate as the air propeller speeds up.

"There are some problems with the boat. If it becomes tilted at a direction of about 20 degrees to the wind, the air drag on the frame and the propeller tends to maintain the tilt. Moreover, wave motion can cause the air propeller to strike the water occasionally, so that the water propeller surfaces. Another problem is that too large a propeller velocity can pull the front end of the boat under water. In general, however, the force couple between the propellers manages to keep the boat headed into the wind.

"Why does it work? In the boat that you described in March, J. G. Hagedoorn replaced the sail of a sailboat with a kite and the keel with a hydrofoil. In the push-me-pull-you we replace the sail with a rotating airfoil and the keel with a coupled rotating waterfoil. The boat works for two reasons. First, the air velocity is much greater than the water velocity. Second, the energy of a moving parcel of air or water is proportional to the square of the air velocity, whereas the momentum is proportional simply to the velocity.

"To expand on this idea the accompanying illustration includes a sketch of the push-me-pull-you with the relevant air and water velocities. For simplicity we assume that the boat is initially stationary. We then estimate the drag and thrust forces on the boat caused by a parcel of air moving past the air propeller. Working out the calculations properly involves messy algebraic equations; the following is an extremely simplified version.

"The air propeller extracts energy from the parcel of air by reducing the air velocity immediately downwind of the propeller. If the wind velocity is 5 (in some convenient unit) upwind of the propeller and 4 downwind, the energy extracted is proportional to the difference of the square of the two velocities ($25 - 16 = 9$), whereas the drag on the propeller is proportional to the momentum difference ($5 - 4 = 1$).

"If the shaft has no energy loss, the water upwind of the water propeller has zero velocity and the water propeller is perfectly efficient, the water energy or water velocity squared behind the propeller is $(U_2)^2 = 9$, so that $U_2 = 3$, and the water-propeller thrust is proportional to 3. From this oversimplified argument on energy and momentum the thrust is three times the drag, so that if we release the boat, it will accelerate into the wind. Because of the difference in the effects of momentum and energy, the faster the wind is, the better the push-me-pull-you works."

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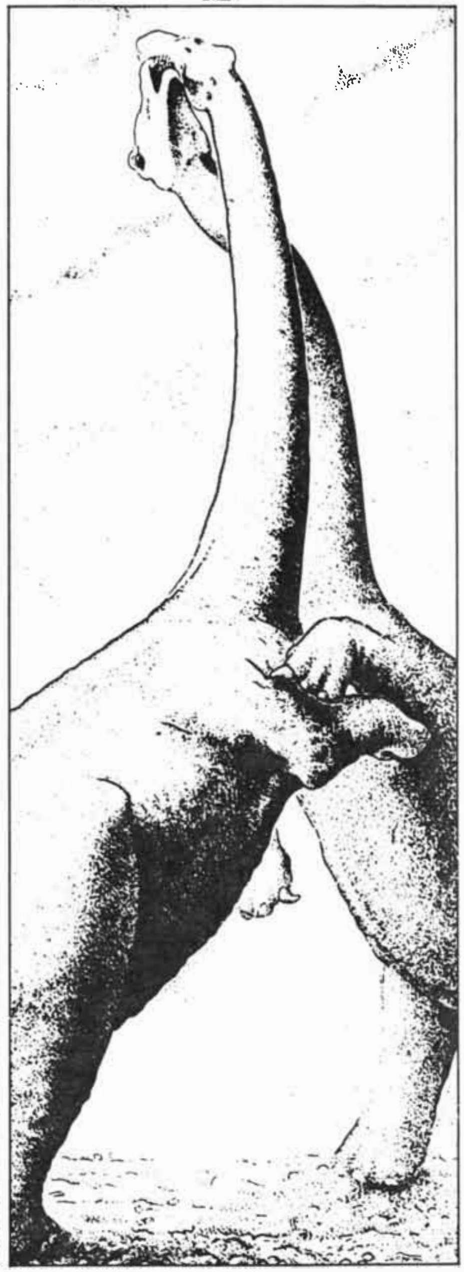

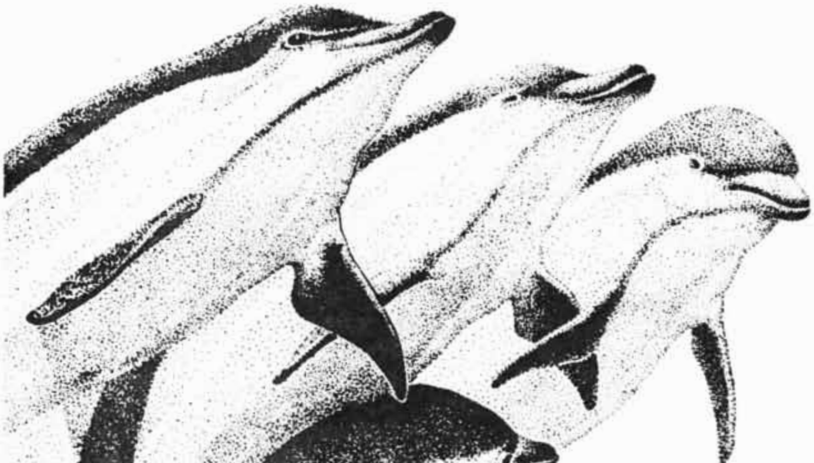

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