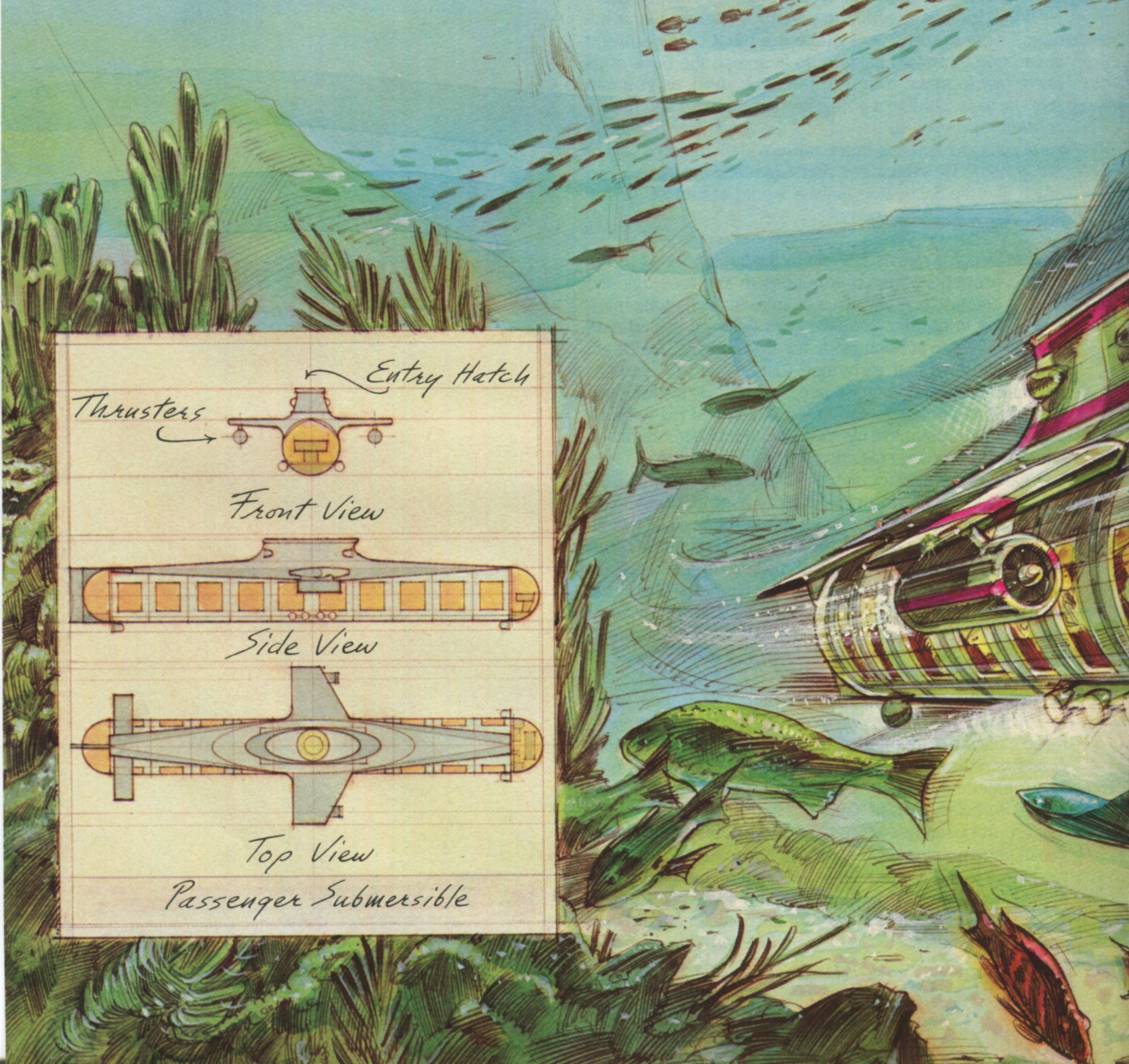
SUPER SUB OF THE FUTURE

A breakthrough design opens new vistas for scientists and even sightseers in the world beneath the sea.

BY NIGEL SITWELL AND JOHN SEDGWICK

Round-faced, bespectacled and intense, Graham Hawkes stands, hands on hips, in a cement-floored workshop in Dartmouth, Nova Scotia. Beside him, Hawkes's bubble-domed submersible Deep Rover dangles, like a giant goggle-eyed insect, from an A-frame hoist. Tangy ocean air wafts in through an open door at one end of the shop.

Fixing his visitor with intense blue

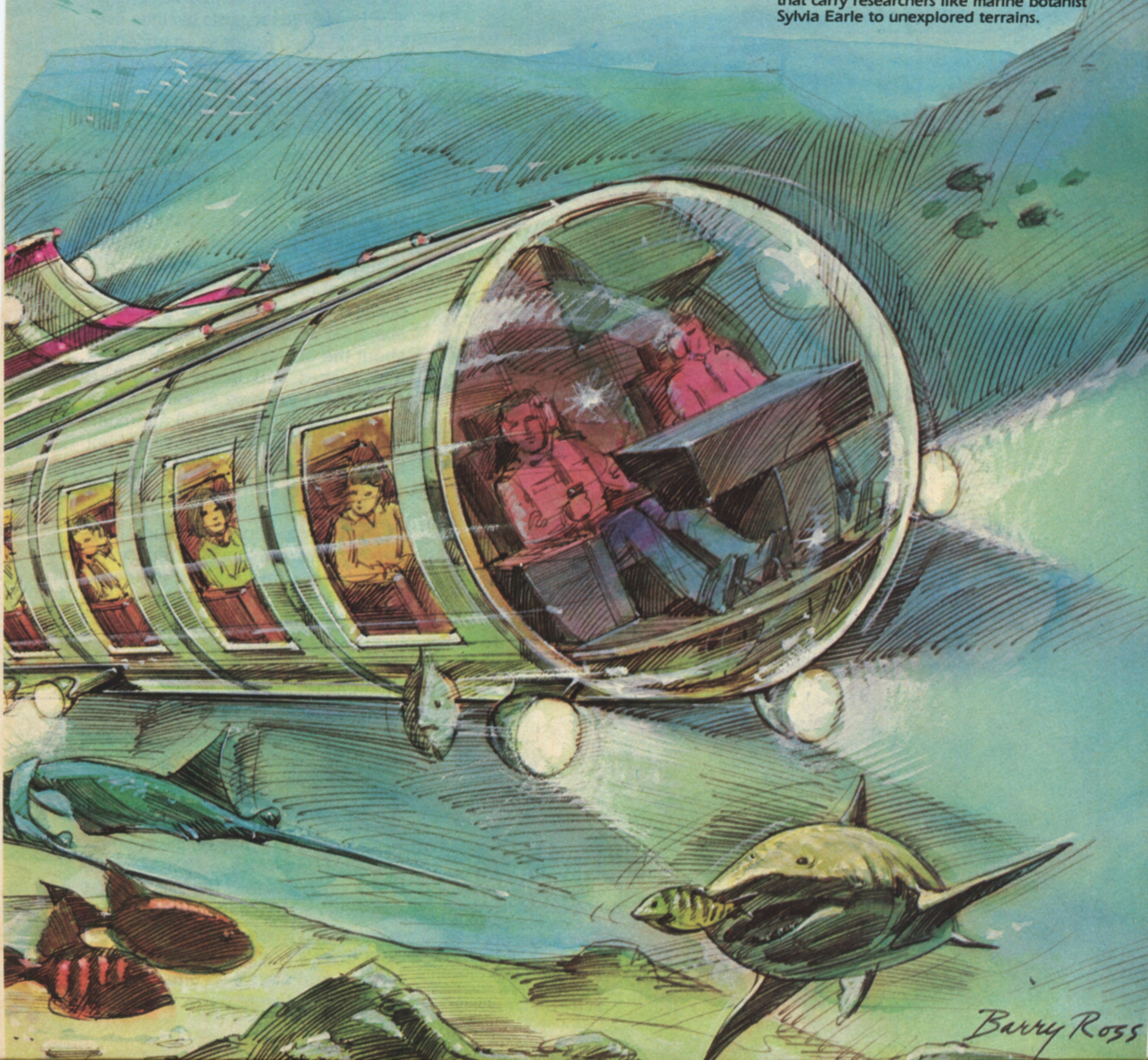


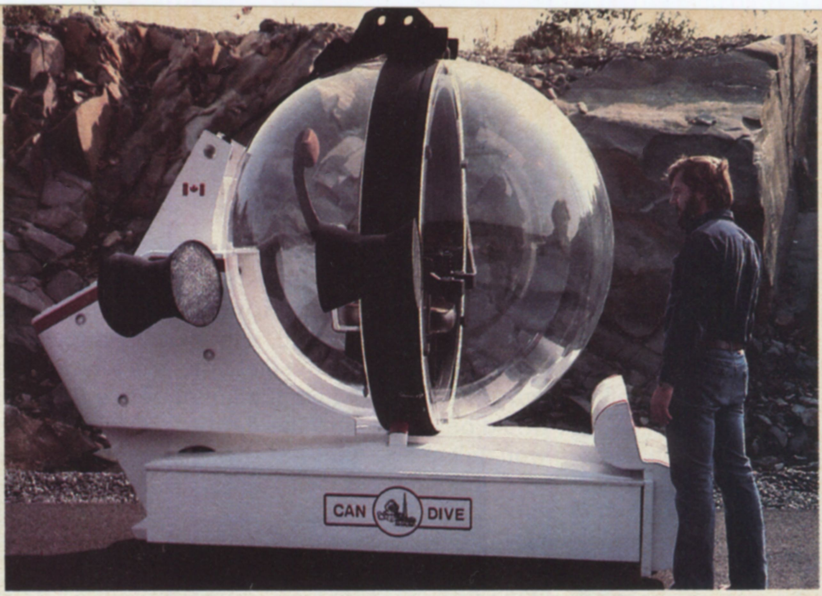
eyes, Hawkes says, "Look, if someone [told you he'd] discovered a dark continent covering three-fifths of the globe, with mountains and canyons and volcanoes, all of them almost totally unexplored—that would be pretty damn exciting, now, wouldn't it?"

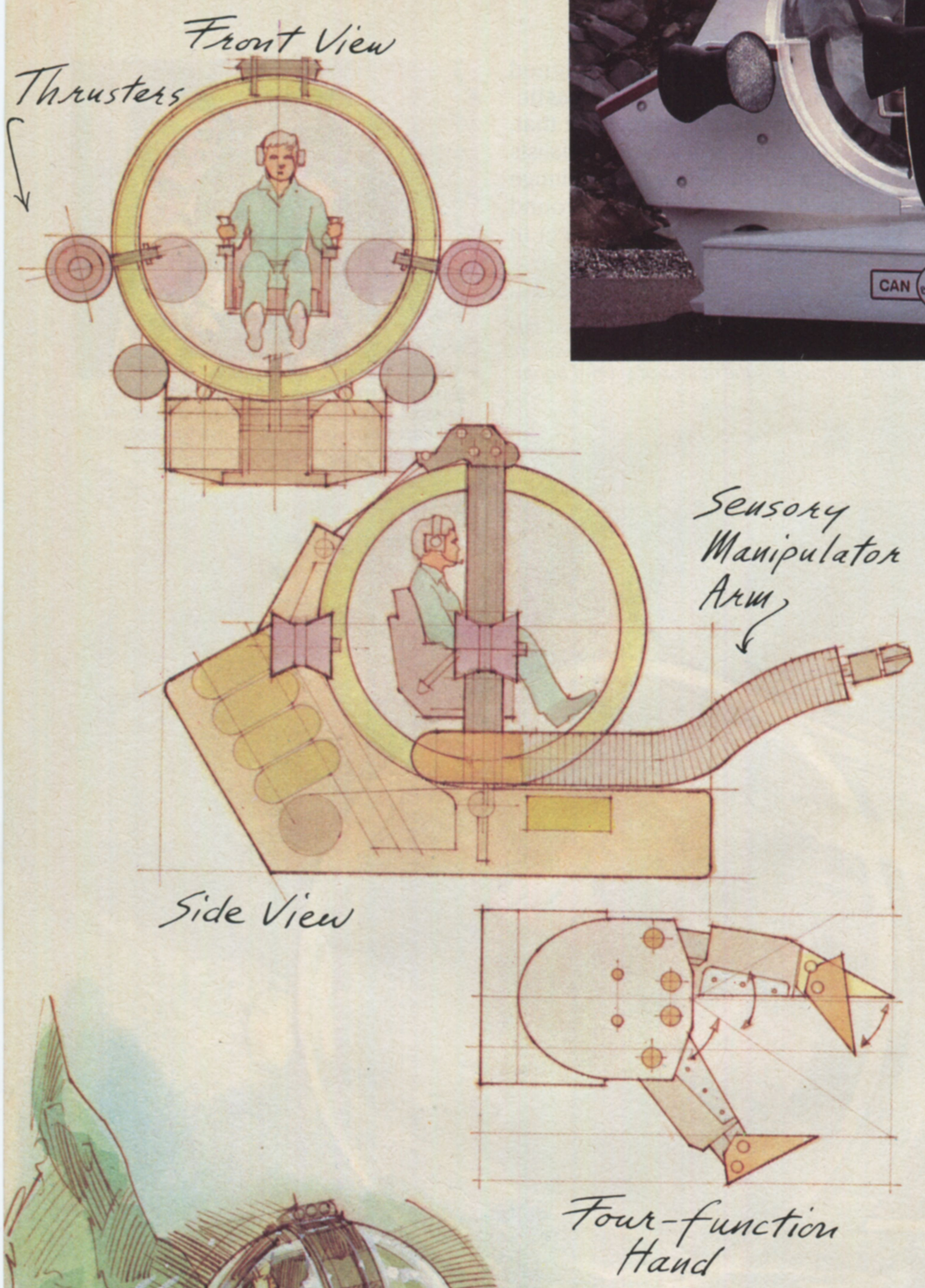
Well, yes, that would be pretty exciting. But the fact is, Hawkes points out, that we've already discovered just such a dark continent: It's the ocean floor. And now this brilliant 36-year-old British engineer has designed Deep Rover, a one-man plastic-domed, spherical submersible that, for the first time, will allow specialists with a minimum of training to plunge into the depths and gaze all around them as they explore or prospect in this last terrestrial frontier.

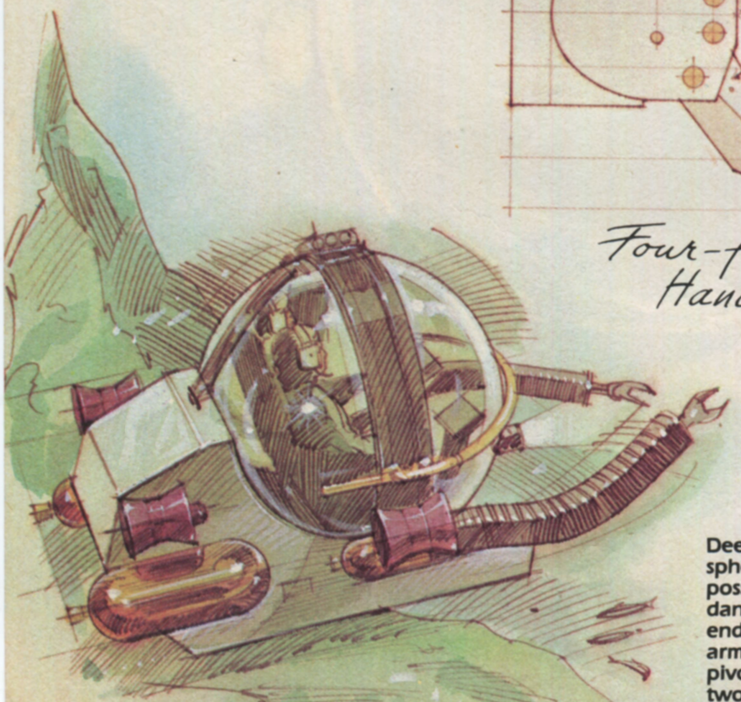
Nigel Sitwell, friend of Graham Hawkes, has been close to Deep Rover since its inception. John Sedgwick is the author of several books.

Heroes of the dangerous deep: Graham Hawkes designs advanced submersibles that carry researchers like marine botanist Sylvia Earle to unexplored terrains.









Deep Rover's acrylic sphere makes a 360° view possible and requires no dangerous cable. At the ends of its manipulator arms, the dextrous hands pivot, rotate and bend at two joints. A scale model (top) shows how compact the submersible will be.

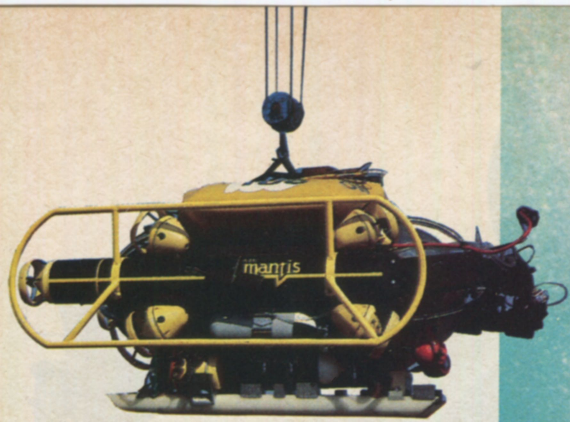
While other designers have developed massive, expensive vehicles to dive in, Hawkes regards his little five-foot-wide Deep Rover as an underwater Model T—cheap, efficient, reliable and one hell of a lot of fun. He is properly respectful of his submersible's many potential uses in oil and gas drilling, science, aquaculture and undersea mining. But, in keeping with his philosophy, Hawkes is most excited by the prospect of exposing a landlubbing population to the thrill and beauty of the undersea world.

"When most people talk about the ocean," he says, "they're not talking about the ocean at all. They're talking about the ocean's *surface*, the thing with waves and boats on it. The depths are unknown to them. At the ocean floor it is silent, still and completely black. It's like outer space, but it's very beautiful."

Hawkes is currently thinking of building an elongated version of the Deep Rover to serve as a kind of undersea tour bus that will introduce the public to the mysteries of the deep. Shaped like a stubby cigar and built out of sturdy acrylic plastic, the bus—just like the Deep Rover—would have oversized windows and the reassuring paneled interior of a passenger plane.

Departing, Hawkes envisions, from such seaside vacation spots as Hawaii, the British Virgin Islands or California's Monterey, the submersibles would take 10 to 12 passengers down 1,000 feet for $100 each. "Right now you can hire a plane or a boat to take you anywhere on Earth," he says, "but there's nothing to take you undersea. And there's so much to look at! If you just went down a few hun-

OPENING SPREAD ILLUSTRATION BY BARRY ROSS. PHOTOGRAPH BY ROGER RESSMEYER



Ungainly underwater armor lets a diver (below) walk the seafloor 1,000 feet down. Named Jim, it was designed in 1924. The modern Mantis encloses a prone diver (above) who uses interchangeable robotic hands to inspect and repair oil rigs.

Hawkes's next sub will be made of a ceramic material that can go to greater depths.

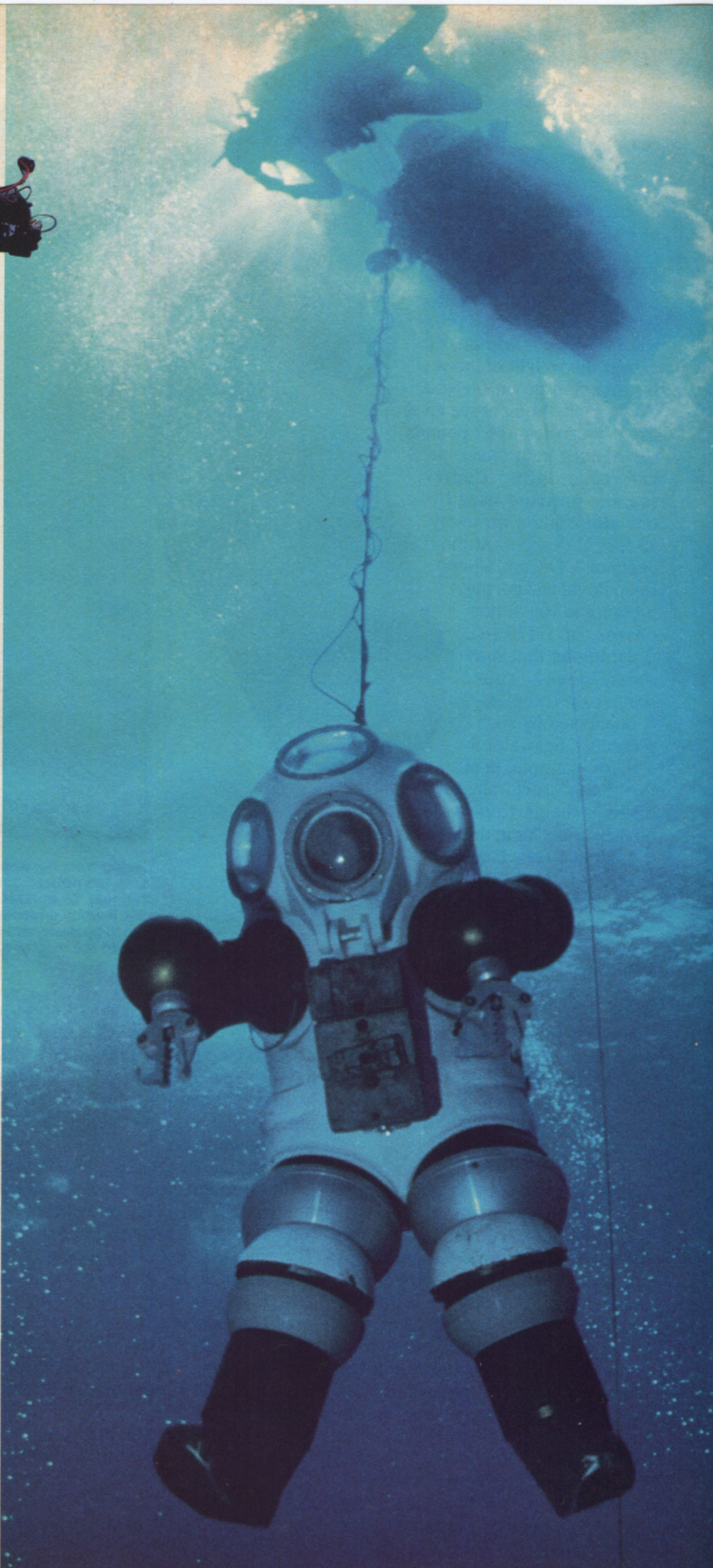
dred feet off Monterey, you'd see seals and otters and manta rays, maybe a shark or a whale. And seeing these animals in the ocean is as exciting as seeing lions and tigers in the wild."

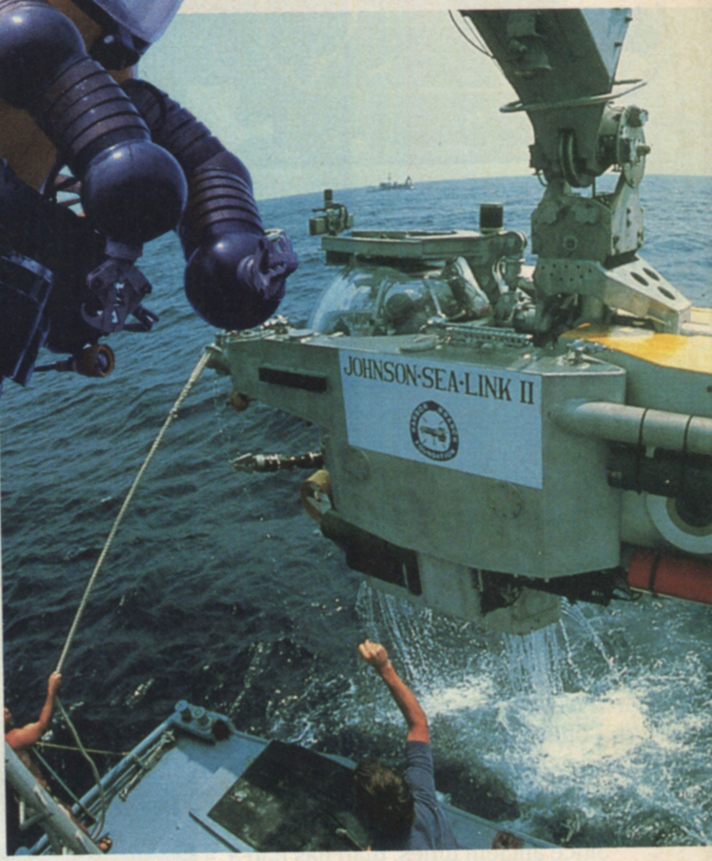
Since ancient times, man has had a powerful urge to go underwater, yet the history of underwater craft illustrates the many difficulties in diving down into such an alien environment. According to legend, Alexander the Great descended into the Mediterranean with a huge, open-bottomed glass bell from which he would emerge to swim about in the depths, periodically returning to gulp some of the air trapped inside the bell.

Two thousand years later, in 1776, the American inventor David Bushnell built the *Turtle*, a one-man, wooden-hulled, egg-shaped submersible designed to blow up British ships in New York harbor. (It failed.)

These two approaches to diving, separated as they are in time, represent the two main themes in human undersea travel. On the one hand there are the submarines—imposing naval vessels up to 590 feet long that carry 130-man crews and are designed for action against enemy craft. Their limit of descent is about 3,000 feet. On the other hand, there are the individual divers, wearing sophisticated diving gear designed to sustain them at dangerous depths. Such

ILLUSTRATIONS BY BARRY ROSS. PHOTOGRAPHS: LEFT BY GRAHAM HAWKES/DEEP OCEAN ENGINEERING, ABOVE BY SYLVIA EARLE/DEEP OCEAN ENGINEERING, RIGHT BY CHARLES NICKLIN/OCEAN FILM, LTD.





Rising from the depths, the Johnson Sea Link II is hoisted onto a recovery ship (above). Divers can enter and leave the JSL II while underwater. Wasp (left), worn by designer Hawkes, was the first suit to use thrusters, not human power.

PHOTOGRAPHS (LEFT TO RIGHT) SYLVIA EARLE/DEEP OCEAN ENGINEERING, AL GIDDINGS/OCEAN FILM, LTD., DANIEL NORD/OCEAN FILM, LTD., TOP BY CHARLES NICKLIN/OCEAN FILM, LTD., BOTTOM BY AL GIDDINGS/OCEAN FILM, LTD.

divers seldom operate below depths of 400 feet, though some record-setters have descended deeper.

The dangers faced by all deep-ocean explorers derive from one simple fact of physics: The deeper you go, the greater the weight of the water pressing down on you. On dry land, the air at sea level exerts pressure of 14.7 pounds per square inch (psi), or one "atmosphere." Undersea, the pressure rises by one atmosphere for every 33 feet of descent. At the depth of 3,300 feet, where Deep Rover will go, the pressure is 100 atmospheres, or 1,470 psi. Crushing as that may seem, many substances are completely unaffected by such pressures. Seawater itself, for example, is at that depth structurally indistinguishable from water on the surface or in the western Pacific's Mariana Trench, more than 35,000 feet down, at the ocean's deepest point. In 1960, the all-metal, two-man bathyscaphe *Trieste* set a still-standing record by diving to the very bottom of the Trench.

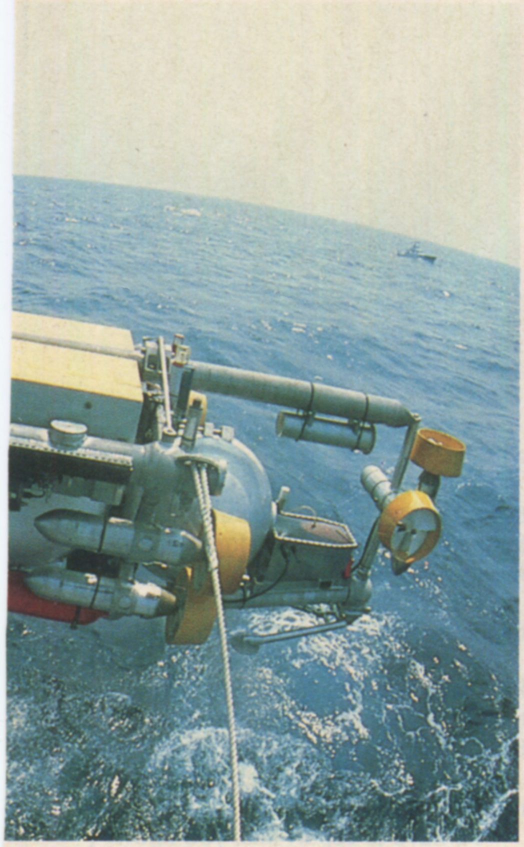
Because of the nature of molecular structure, all liquids and all solids can withstand immense pressures. The only things that can't withstand them are objects with hollow sections in their interiors, such as the hull of a submersible or the body of a human being.

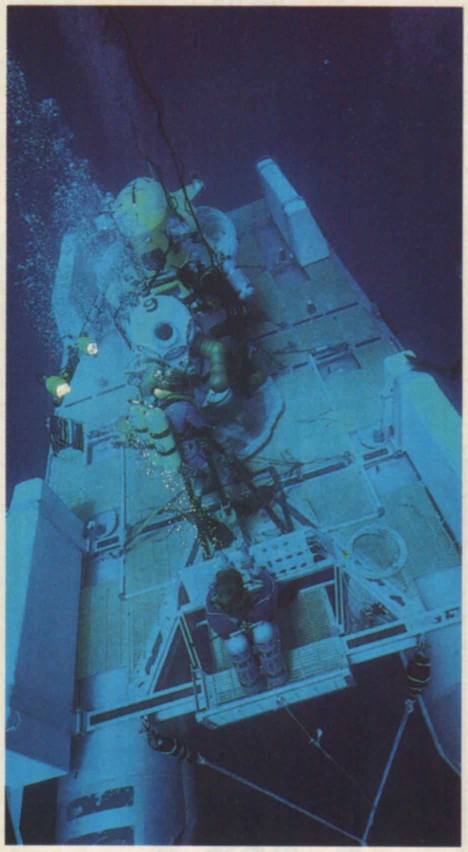
Before the pressure builds to bone-crushing weights, however, humans face the more immediate problem of obtaining a usable air supply. Beginning at depths of a few hundred feet, divers breathe a mixture of oxygen, nitrogen and sometimes helium under pressures equal to that of the water. The trouble is, pressurized gas diffuses into the tissues and bloodstream—hence the name, saturation diving. If the diver comes up too quickly, soluble gas forms bubbles in the blood. This condition, the famous "bends," is horribly painful and can kill its victims. About 20 saturation divers die every year. After descents down to their limit of 1,000 feet, divers have to spend as much as 10 days gradually decompressing in a special piece of equipment called a decompression chamber.

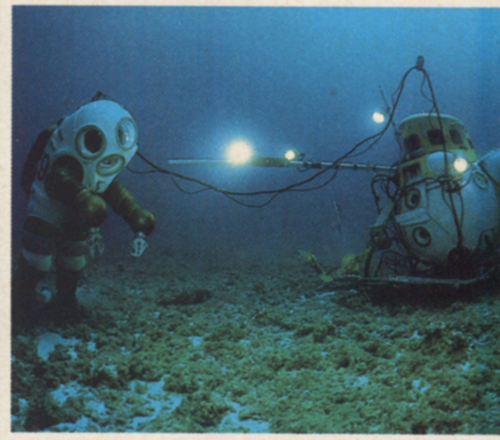
While the armored submarine can go freely to great depths, it is also expensive and unwieldy and allows for only severely restricted direct vision. The deep-sea diver is limited to relatively shallow waters, and he or she is always at risk. (The word "she" is used here advisedly—the marine botanist Sylvia Earle set a record in 1979 by descending 1,250 feet to the ocean floor in a one-atmosphere suit nicknamed Jim.)

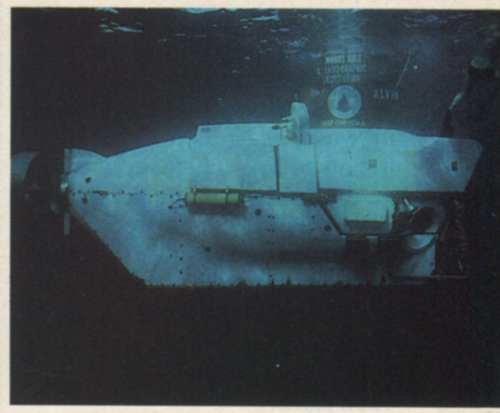
Hawkes believes he has combined in his Deep Rover the best features of the diving suit and diving bell. Encasing the operator inside a perfect sphere of five-inch-thick transparent acrylic plastic, the Deep Rover maintains the standard one-atmosphere pressure found on land and so avoids the time-consuming and expensive decompression procedure. Yet it can descend to 3,300 feet and still, with its battery-driven propellers spinning, retain much of the skill and maneuverability of the free-swimming diver. Rover's payload-carrying capacity is negligible, however, because it is designed primarily to carry explorers.

With Deep Rover, Hawkes has departed radically from conventional approaches to manned-submersible design, as exemplified by the world's most famous underwater vehicle, the mostly metal, three-man submersible *Alvin,* which in 1977 descended to 8,000 feet while investigating the extraordinary community of life forms living near warm-water vents in the deep sea off the Galápagos Islands. While *Alvin* is technically superb, it is









Tethered together, research vessel Star II and Jim explore a watery world (top right) after a descent on a recovery vessel (above). Alvin (lower right) carried scientists to geothermal vents, where they found bizarre new species.

quite unwieldy to operate and is so intricate that its interior has been compared to a Swiss watch. As Sylvia Earle, Hawkes's partner in submersible manufacturing, explains, "Basically, in *Alvin* you have to operate by committee. It seems that to do anything, even as simple as move the sub left or move it right, you have to ask somebody else. With Deep Rover you do everything yourself. But it's so simple to operate, you really just wear it like a suit."

The first Rover now hangs on its hoist in the Nova Scotia workshop. There it is being tested by Hawkes and will be used by the Canadian oil company Petro-Canada for tending its underwater oil rigs stationed in the North Atlantic.

For all its rugged functionalism, Rover looks entirely futuristic, like the sort of vehicle that Luke Skywalker might climb into if he was in a hurry to get to the next galaxy. The great plastic sphere rests on a kind of sled, or pontoon-platform, supporting auxiliary equipment that communicates with the bubble's controls through a cable.

To give its pilot a sense of touch, Deep Rover can translate texture into sounds.

We were struck by Rover's clean and spare geometry—the big acrylic ball that houses the pilot, the four shiny propellers, about a foot across, aligned alongside the bubble, and the flat surfaces of the black boxes containing such support equipment as 200-ampere batteries. Rover's equipment also includes tanks of compressed air (to control the ballast) and the long cylindrical manipulators—mechanical arms built of nylon and aluminum—that protrude out the front like a pair of claws on some space-age lobster.

"Deep Rover does have a certain elegance of design," says Hawkes proudly. "But the form just follows the function." Yet subliminally he must, for at least two reasons, have felt some urge to give his vessel the look of a spacecraft. For one thing, Hawkes himself was originally interested in aerospace design as a teenager in London but failed to win a place at a university to study the subject. Instead, he received a degree in mechanical engineering at Borough Polytechnic Institute, and that led to

Continued on page 100

CERN

Continued from page 98

By the middle of 1980, truckloads of equipment were roaring into Geneva. The 2,000-ton detector itself was fitted together on a sort of modified railroad track in UA1—Underground Area 1—a circular cavern about 100 feet below the surface. A second team, working in UA2, built a smaller detector. On July 4, CERN physicists put the Antiproton Accumulator through its first tests, which it passed with flying colors. Van der Meer's team received a complimentary telegram from their rivals at Fermilab: "Congratulations. You have the largest collection of antiprotons since the beginning of the universe."

Round-the-Clock Watch

Finally, on October 4, 1982, the search for W and Z officially began. Team members worked in round-the-clock shifts studying the particle tracks picked up by the detector. Physicists staged a sort of spontaneous sit-in at the UA1 control room, smoking and drinking buckets of coffee at three in the morning as their computer screens re-created the minute collisions in the detector.

Theorists had predicted that the Ws and Zs produced by proton-antiproton collisions should fall apart almost immediately, becoming one or two fast-moving electrons that would then shoot off at a wide angle from the beam trajectory. The spoor of the W—its signature, in the jargon—would be that electron track. (Strictly speaking, the W and Z could also decay into positrons, the antimatter equivalent of electrons.) Several weeks went by with no sign of a W.

Then, exactly as theorists had predicted, wide-angle electron tracks began to show up on the CRTs in the UA1 control room. At 3:00 P.M. on January 21, 1983, CERN announced that "UA1 has singled out five events in a total of a thousand million collisions revealing the expected signature of the charged W boson. The results also give a determination of the W mass on the order of 80 GeV [90 times the mass of the familiar proton], which is in agreement with the predictions of the electroweak theory." The W was followed five months later by the Z. Seven years' labor, millions of dollars and the professional reputations of scores of prominent scientists had been bet on a risky gamble that paid off.

Significant Findings

But such is the Alice in Wonderland world of physics that one answer oftentimes creates a greater question. The same 1983 test runs that unearthed the W and Z produced two more findings, each of great potential significance.

In what's now called the standard model of elementary particle interactions, the theories of the strong and electroweak forces fit neatly together. But for the picture to be as tidy as theorists would like, there must be six types of quarks. And despite a decade of searching, the sixth—or top—had never been seen. Like the W and Z, it is too heavy to produce easily in most accelerators. News of possible evidence for the existence of the sixth quark had percolated out early this year. But the researchers were not certain enough to announce their findings without extensive cross-checking. At the end of June, Rubbia began to start talking.

Before that, however, he had already proclaimed yet *another* discovery from the same run: more than a dozen inexplicable subatomic interactions. Unlike the top quark, which was expected, these new events are surprising, even baffling. Some of them are merely indicative of unexpected behavior on the part of the Z; others may point to the existence of new particles heavier than any ever seen; a third set of interactions has jokingly been referred to as "Zen events," because their bizarre, asymmetrical configuration reminded some physicists of the old Buddhist conundrum about the sound of one hand clapping.

> "Rubbia has found something very odd. If it holds up, it will be like nothing ever seen before."

Because these events were unexpected, they have created a tremendous uproar in the physics world. "He's found something very odd," Harvard physicist Howard Georgi says. "If it holds up, it will be unlike anything seen before." Physicist Robert Palmer of Brookhaven says, "We're terribly interested, of course, but one should be very careful before saying anything other than that this is both very intriguing and very unconfirmed." So far, UA1 and UA2 have only turned up a handful of events. The physics world is waiting with bated breath for the next scheduled runs on the CERN collider, which are scheduled to take place this month.

The United States has plans to develop a very large machine—the Superconducting Super Collider, or SSC—that some scientists call the Desertron because it is so big it will have to be built in the desert. Physicists are well aware that funding a $4-billion piece of scientific equipment in an era of soaring deficits and budget cutbacks is uncertain at best. The future of the U.S. particle-physics program hangs in the balance, and some pessimistic scientists here think it will still be that way many years after Carlo Rubbia goes to Stockholm to receive his prize. ■

SUPER SUB

Continued from page 65

his joining in 1971 a British firm that happened to be working on a submersible project for the Royal Navy. In the late 1970s he developed two pressurized diving suits, Wasp and Mantis, before coming to the United States and turning his attention to Deep Rover.

That same sleek, space-age feeling carries over to Deep Rover's interior. The spherical hull—inside diameter only 53 inches—hinges open along its vertical axis. One of the authors of this article stands just over six feet, and when he visited the Nova Scotia workshop he was hard put to squeeze inside the bubble without scratching the acrylic with his shoes.

900-Pound Contact Lens

The bubble actually consists of two individual hemispheres, whose edges overlap the line where the domes meet. Hawkes jokingly calls the two halves "contact lenses," but they weigh 900 pounds apiece and are five inches thick. They were cast in a mold in Los Angeles by Reynolds and Taylor, one of the three firms in the world capable of handling such a big job. Then an inch was machined away on either side of each dome to form a perfect hemisphere.

Anything less than perfection would be catastrophic, for only a perfect sphere can hold off the tremendous underwater pressures by distributing them equally about the domes' surfaces. In the future, Hawkes intends to use a glasslike ceramic for the job because it is even stronger. The certification authorities—Lloyd's of London and the American Bureau of Shipping—had little data on the ceramic material, however, whereas acrylic had been used for underwater portholes for some time. The bubble can resist stresses up to four times the expected load.

Like glass, and unlike the metal used in *Alvin* and the *Trieste*, acrylic has the critical advantage of being transparent. This means Deep Rover's pilot can see not only all around in front of him but also all around in back of him. One of the greatest fears haunting pilots of conventional submersibles is that they will get snagged from behind on one of the cables or fishing nets that litter the ocean floor. Unable to see to the rear, they may become even more entangled in their efforts to work free. But with their fore-and-aft view, Deep Rover's operators won't have that problem when under way.

The armrests of the Rover's upholstered seat are part of its control system. By turning the front of either armrest to the left, the pilot drives the Rover ahead to the left; by swiveling the armrest's rear to the right, he backs Rover to the left, and so on. Average cruising speed is two to three knots, roughly the pace of a leisurely stroll. The propellers—or thrusters, as sub-

Continued on page 103

SUPER SUB

Continued from page 100

mersible buffs call them—are turned by compact electrical motors powered by batteries.

Joysticks at each armrest control the seven-foot-long manipulators with which Rover probes the ocean floor. (These manipulators work only underwater, since their hydraulic system depends in part on water pressure for its operation.) A "trigger" on the far side of each joystick opens the manipulator's jaws, a pair of buttons next to the pilot's thumb rotates them, a larger button works the manipulator's "wrist" joint, and the whole joystick itself makes the manipulator's "upper arm" and "forearm" bend at an angle to each other. Hawkes himself says that after a few hours' practice, he learned to work the manipulator so delicately that, when he attached a pen to its claw, he was able to sketch a tiny shrimp, the *Euphausia superba,* and then sign his name. He showed us the sketch, and it is exquisitely detailed and realistic. The key, he says, is

> Acceptance will come—too much land is undersea to ignore the Deep Rover for long.

in the joystick's controls, which operate on a graduated "force-input" basis, instead of the on-off, all-or-nothing approach of, say, a light switch. For all their artistry, however, the manipulators are still powerful—each arm can lift 200 pounds.

In trying to replicate the skills of the saturation divers, who use their own arms and legs, Hawkes has even outfitted Rover's pincer tips with an ingenious system that gives the pilot the sensation of touch. It is conveyed, surprisingly, by sound. "I asked myself," Hawkes recalls, 'How can I get this tactile information to the brain quickly?' A gauge display would be distracting. The pilot's eyes are busy. Then I thought, 'What senses is the pilot not using?' I realized [the answer]—his ears. Listening to an orchestra, you can pick out the piano, pick out the percussion, hear the squeak of a violin. Your ears are in fact capable of processing far more data than your fingers ever will." Using the dimensions of pitch, amplitude and something called "pulse-width modulation"—which varies the rapidity of a warble or stammer—a transducer conveys the necessary tactile information to the pilot via headphones.

Wearing a headset, Hawkes himself quickly learned to distinguish between various materials—painted metal, plain metal, plastic and wood—while blindfolded by rubbing them gently with the manipulator's pincer. He says operators generally accommodate themselves so completely to the system that if the sound is shut off after just an hour or two, "they feel as if we'd turned off the lights."

In use, the manipulators will be able to feel the delicate vibrations that tell if fluid is flowing through a flexible underwater pipe or if a motor is running. They could also be used with some modification on dry land, in such fields as the nuclear industry, biomedicine and the defusing of bombs.

Hawkes dismisses TV cameras as sensory aids ("grossly inadequate"), but Deep Rover still may have a tiny pair—barely larger than a cigarette pack—on the manipulators' wrists to send back close-up views for observers watching on TV sets at the surface.

Despite what Hawkes sees as the evident advantages of using man-piloted craft, there has been considerable resistance to the whole idea of manned diving as risky, expensive and unnecessary. The controversy is analogous to the argument over manned and unmanned space exploration. Dr. Robert Ballard, a geologist with the Woods Hole Oceanographic Institution, feels that "unmanned technology will ultimately replace manned technology."

Hawkes responds that unmanned vehicles may have their place underwater, but that there is no substitute for human skill and intelligence working directly at the site—precisely the qualities that Deep Rover is designed to supply.

For their part, the big underseas-operations firms react to Hawkes's invention with a mixture of curiosity and caution. Steve Boulton, technical director of HMB Subwork Ltd, sees the potential as tremendous—if it works. "But I find it difficult to believe some of the claims," he says.

Realistic Solution

George Williams, director-general of the United Kingdom's Offshore Operations Association, is less guarded. "Deep Rover certainly has merit," he asserts, "and something like this is very much needed. I'm encouraged to see that our industry's problems are being tackled in what seems like a realistic way." And Hawkes is known for his realism. Adds Geoff May of the Society for Underwater Technology, "He is not on cloud nine."

Obviously, Hawkes himself is confident that there is a need for Deep Rover. He compares the state of underwater exploration and development to the early days of flying, when daring barnstormers assaulted the air, to general skepticism from the public. Acceptance will come, he says—too much of the land's surface is underwater for the world to ignore it for much longer. And when acceptance does come, Deep Rover will be there, ready to roam. ■