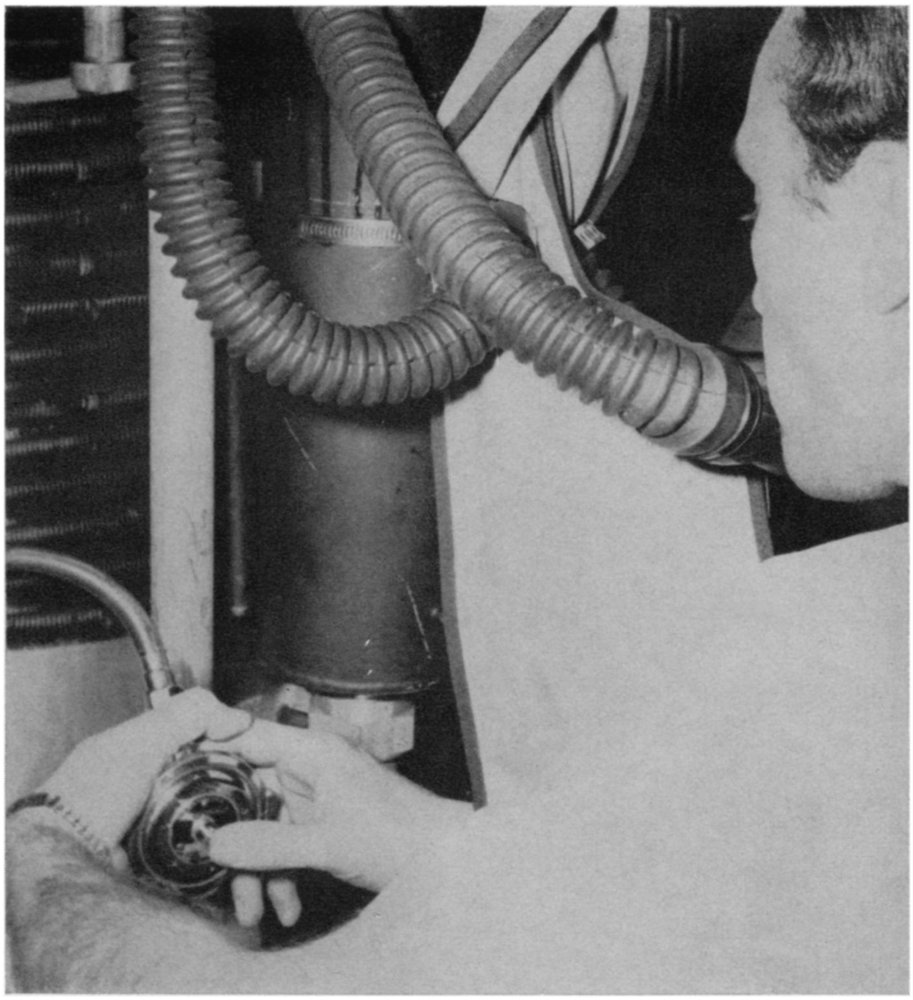


Sub-Marine Systems

A cryogenic scuba system here gets its first human tests.

CRYOGENICS

Aquanauts Get Liquid Air

Men beneath the waves are due for a helping hand, thanks to ingenious use of cryogenics.

by Jonathan Eberhart

Food, clothing and shelter used to be enough to get explorers to their goals. In the deep oceans, however, as in space, the most important consideration is air. Oceanauts can only begin their quests encumbered by the huge air tanks to which they are presently bound, and which must be changed or refilled every hour or two.

The biggest step in years toward freedom in the seas is being taken with air in liquid form at temperatures hundreds of degrees below zero. A number of liquid air breathing devices being developed around the country, even in their infancy, are already capable of outperforming most of the scuba (Self-Contained Underwater Breathing Apparatus) in common use today. Some would allow a diver to stay down as long as a day.

The simplest system is one being developed in Florida by an aerospace engineer, named Jim Woodberry, and Jordan Klein of Mako Products Inc. The most publicized of the lot, it is also the simplest, since it is almost identical with a conventional scuba unit except that instead of carrying tanks of compressed gas, it uses a liquefied mixture stored in vacuum-insulated metal bottles. The system is open-circuit—exhaled gases are not recirculated, but bubble into the water.

The nitrogen-oxygen mixture used in the system has a temperature, as a liquid, of more than 300 degrees F. below zero. Woodberry originally included dozens of coils of metal tubing between the bottles and the mouthpiece so that the liquid would have plenty of space in which to warm and expand into a gas that would not freeze the diver's lungs. Klein subsequently threw out this whole plumber's nightmare when he found that two short, straight lengths of tubing would do the job.

One planned unit is a commercial version that would provide about 12 hours of "down-time." This unit will weigh about 82 pounds. A conventional scuba of the same capacity, which would weigh four or five times as much, would require eight air tanks and would probably have to be handled on the surface with a winch. His system, Klein says, is "like microfilming gases."

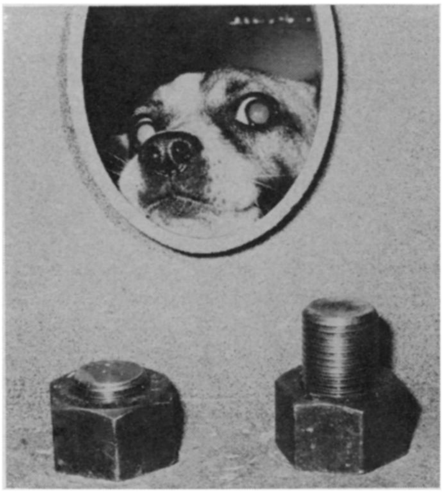
Test models of various kinds have been built in Florida, ranging from garish experimental designs to sleek, professional-looking sport rigs. Klein and his colleagues are negotiating with several potential manufacturers, while also considering adapting the principle to other applications such as small submarines and fixed underwater shelters.

When the Navy came by to consider the unit for diving under arctic ice, Klein threw in another invention, a simple heating coil which not only gave the cryogenic divers the advantage of increased down-time, but provided them with nicely prewarmed air to breathe. Of the arctic divers, Klein says, "They'd been breathing ice cubes up there."

Although liquid-air breathing devices are new under water, they've been around for years on land as respirators for firemen, miners, fighter pilots and even the launch pad technicians who handle toxic rocket fuels for the National Aeronautics and Space Administration. Recently the companies that make such systems have begun to look downward at the market that will soon be opening in "hydrospace."

One such manufacturer is Firewell, Inc., in Buffalo, N.Y., which has been making cryogenic breathing units for years. Recently the company began in secret to work on a liquid air diving unit. It is believed to be an open-circuit unit, with oxygen and nitrogen or helium combined through a proportioning valve from separate tanks. Firewell won't confirm that or anything else about their unit—an indication of the possible worth of the market—but an idea of the system's efficiency can possibly be drawn from the effectiveness of the company's firefighting respirators, which last two hours instead of 20 minutes as in the conventional units they replace.

The really spectacular performance, however, shows promise of coming from closed-circuit systems, in which the gas mixture is recirculated continuously while some adsorbent material removes the exhaled carbon dioxide. Since the inert gas—nitrogen or helium—which fills most of the system is not removed as it circulates, only a small tank of oxygen is necessary for greatly prolonged dives. Conventional closed-circuit systems are limited to depths of about 50 feet, however, since they either use pure oxygen—dangerous at high pressures for extended periods—or else are designed to maintain a constant oxygen percentage roughly equal to the 20 percent in the atmosphere. At a depth of, say, 300 feet, where the pressure is about 10 atmospheres, a diver with a constant-percentage system would be breathing 10 times as much oxygen as he would on the surface. High-pressure pure oxygen can literally burn up bronchial and lung tissues.



Sub-Marine Systems

Mrs. Smith after an hour at 1,000 ft.

Now, however, a promising solution is well along. It is a closed-circuit, but instead of maintaining the oxygen at a constant percentage, the system keeps it at a constant pressure, regardless of the pressure of the total gas mixture. In earth's atmosphere the oxygen pressure is about three pounds per square inch; the new system can maintain its oxygen at that pressure even at depths down to 2,000 feet, where the total pressure is almost 67 atmospheres. It is possible to adjust the oxygen pressure up to 30 psi if desired, which could be useful for short-duration deep dives because increased oxygen concentration can greatly reduce decompression time.

Called C-SCAPE, the device is being developed by Sub-Marine Systems, Inc., in Los Angeles. Halbert Fischel, the president, maintains that "cryogenic storage for its own sake is not worth the trouble." To gain a real advantage over conventional systems, he says, requires a much greater increase in submerged time than can be provided by simply keeping the breathing mixture in liquid form.

Since a cubic foot of liquid air expands into some 730 cubic feet of gaseous air, the advantage of pure cryostorage would seem at first to be great indeed. The air in conventional scuba tanks, however, though still a gas, is compressed at more than 200 times normal atmospheric pressure, which reduces the storage advantage of liquid air down to about 3.5 to 1.

C-SCAPE, therefore, uses cryogenics in a completely different way. In the system, exhaled carbon dioxide passes with the rest of the breathing mixture—oxygen and helium at present—through the system's processor which causes the CO_2 to turn to snow and fall out of the breathing loop.

Tests down to 1,000 feet have been run with dogs and a 185-pound Nubian goat named Shadow, using a chamber filled with compressed gas to simulate the ocean depths. The dogs—including one named Mrs. Smith, who spent an hour at maximum depth—came out fine; unfortunately, Shadow did not fare so well. A complication with her drinking system during a seven-hour stint at 1,000 feet allowed her to take some air into her stomach. Trapped there, it expanded when she "surfaced" following 39 hours of decompression. Engineers tried to make her belch and even fed the goat charcoal in an effort to adsorb the gas, but to no avail. The accident, says the company, was not the fault of the system, and could never happen to a man, who would simply expel the air by belching. The goat was sacrificed for an examination by Dr. Michael Greenwood, Navy physiologist, who performed the tests. Fischel points out that the animal was compressed to a simulated 1,000 feet and decompressed in 39 hours without bends—"an achievement which has no precedent in the industry."

As a next step Sub-Marine Systems plans to deliver a complete scuba system to the Navy in less than two months for human tests.

The uses of C-SCAPE, according to Fischel, could extend from the depths of the ocean up to research installations on land. Some version of the system might even find use in manned spacecraft, he says, though he admits that "because of the rarefied atmospheres involved the problems are somewhat different."

The notion of diving on liquid air is at least 10 years old, but the actual hardware has only recently come into being. Typical is Jim Woodberry, who designed his system in a week, then took two years to build a prototype.