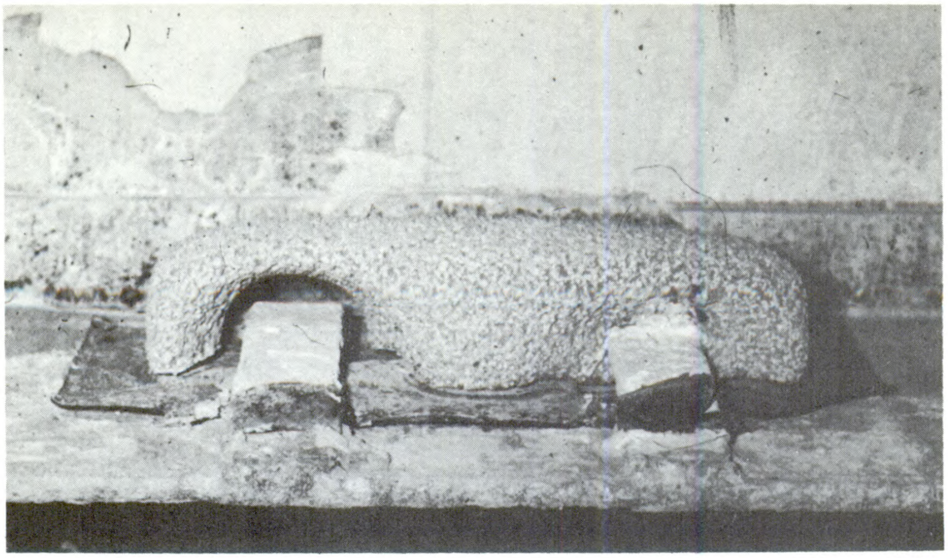
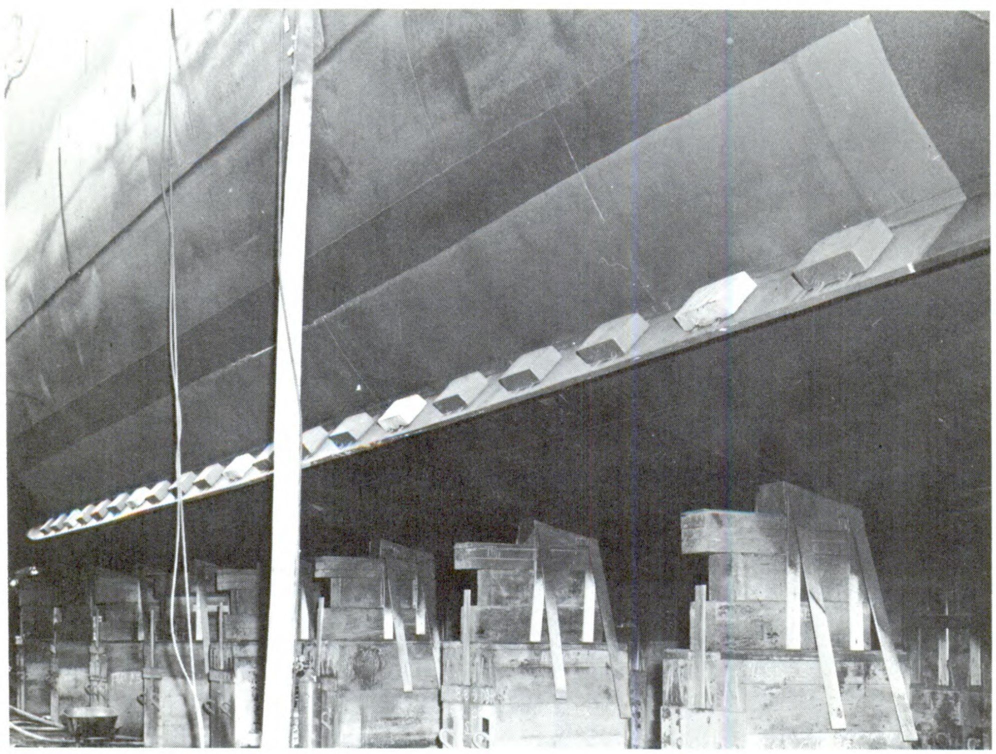
AVAL RESEARCH

REVIEWS

MARCH 1961



Close-up view showing corrosion of a magnesium sacrificial anode after 16 months of service.



Array of 20 magnesium anodes on the bilge keel of USS O'HARE, DDR 888. The light-toned blocks are uncoated; the others are coated with easily removed plastic.

A Step Forward in Cathodic Protection

Through the use of nuclear fuels, floating re-supply, and rotating crews, it is theoretically possible for a naval ship to remain at sea for years. But until recently, a ship had to be dry docked at least once every two years for below-the-waterline inspection — which usually resulted in replacement of one or more hull plates. The destruction was caused by electrolytic corrosion, resulting from galvanic action between the bronze propellers — acting as cathodes — and the steel plates serving as anodes. A small group of chemists and metallurgists at the Naval Research Laboratory, working closely with the Bureau of Ships, have been pecking away at this problem since the middle of World War II.

The classic protection, originated by Sir Humphrey Davy over a century ago, has been the installation of sacrificial anodes: blocks of a more reactive metal, such as zinc, fixed to the ship's bottom near the propellers. The metal blocks, having a higher potential, corrode instead of the steel plate. But unfortunately, ordinary sacrificial anodes are consumed in a year or less, leaving the ship unprotected. So the problem has been to lengthen the effective life-span of the protective system, by developing more effective sacrificial metals, or providing more efficient insulation of the hull from the electrolyte (salt water), or by balancing the difference in potential between anode and cathode; the latter is accomplished by impressing a carefully regulated electric current into the water near the ship.

The initial post-war effort of the NRL-BuShips program was directed to the protection of the hundreds of moth-balled ships laid up in various salt-water ports and estuaries. As was reported previously in this magazine (May 1952 and January 1955), the protection program succeeded in doubling the time between haul-outs for anchored ships — from once every 4 to 5 years to once in 7 to 10 years, thus effecting a multi-million-dollar saving in the cost of maintaining our Reserve Fleet.

The problem of protecting ships in commission is considerably more difficult, because the underbody insulating and sacrificial materials are subject to erosion by swiftly moving water. In addition, submariners strongly object to arrays of anode blocks on the hull because they create detectable noise when the boat is underway. For these reasons an impressed-current system is theoretically best, because the active anodes are fewer and smaller and the anode-cathode potentials can be counterbalanced precisely.

But impressed-current systems also have drawbacks. The instrumentation occupies considerable space and requires frequent attention, particularly when the ship is travelling from place to place in waters of varying salinity. Therefore sacrificial anodes— which can be installed and forgotten— seem more practical for smaller-crewed surface ships, up to and including destroyer leaders.

During the past two years various configurations of zinc or magnesium anodes have been sea tested on 18 ships: two submarines, three LST's, and eleven destroyers. Anodes were tried with and without insulation—generally large rubber "blankets," 6 to 8 feet square—and with and without plastic coatings. Most of the ships have been drydocked at least once, allowing the protective systems to be evaluated.

It was found that magnesium anodes can be relied upon to provide adequate protection for two years. Rubber shields, when used with uncoated arrays, apparently reduced the loss of excessive current to the adjacent hull, prevented corrosion and paint stripping around the anodes, and helped to increase the life of the anodes. The shields appeared to be unnecessary with coated anodes.

The most promising idea evolved from this phase of the Navy's cathodic protection research was the use of plastic-covered anode-blocks, installed in combination with uncoated ones. This permits the anodes to be sacrificed sequentially, instead of all at once. As one set of anodes begins to lose effectiveness — as indicated by measured loss in potential — another set can be placed in operation quickly and easily by sending a skin-diver down to remove the plastic. This simple expedient removes one of the most obvious faults of conventional sacrificial anodes; i.e., when the current emitted from the anodes is strongest (the blocks are whole), it is least needed because the hull paint is new; then, when the paint has deteriorated, so have the anodes. The sequential system permits a lesser current to be emitted evenly over a longer period.

The Navy scientists are now satisfied that a properly installed combination of coated and uncoated magnesium anodes will fully protect a vessel for at least three years. – A.T.D.

NRL LOFTI Satellite Launched

Navy scientists indicated that they were pleased with the performance of the Naval Research Laboratory's LOFTI (Low Frequency Trans-Ionospheric) satellite launched from Cape Canaveral on February 21. The 57-pound sphere was launched atop a Transit III-B satellite in an Air Force Thor-Able-Star rocket. Preliminary results show that LOFTI is receiving VLF (Very Low Frequency) signals from the Naval Radio Station NBA, Canal Zone. It is retransmitting these signals via VHF (Very High Frequency) to observing stations on the ground.

Although the planned 500-mile circular orbit was not achieved by the double-header launch, the accidental elliptical orbit is more desirable for the NRL experiment. The orbit – with a 110-mile perigee and a 613-mile apogee – is giving LOFTI a better sampling of the affects of the ionospheric on very low frequency radio waves than the original orbit. At its perigee, the 20-inch ball is passing through the earth's F_1 layer, a heavily ionized region approximately 100 miles above the earth. The NRL satellite has been designed to determine the propagation of VLF signals through the ionosphere.

Thermionic Energy Converters

J. J. Connelly, Jr., LCDR, USN
Power Branch
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Thermionic energy conversion—a method whereby heat is directly converted into electrical energy—offers a great potential for naval applications as a silent, highly reliable, energy-conversion system. It has the additional attractions of being compact, light in weight, simple, and highly efficient.

Energy-conversion systems can be defined for our purposes as those systems that withdraw energy from the energy reservoir of the universe and convert this energy into a form that can do useful work. The Navy is particularly interested in systems that can convert heat into electricity with a minimum of energy loss—this implies high system efficiency. In any energy-conversion system, the overall efficiency is the product of the efficiencies of each conversion step, thus the elimination of any step raises the maximum system efficiency. Direct-conversion systems, thermionic converters in particular, become very attractive as they eliminate several of the conversion steps. The mechanism of thermionic conversion consists of raising the temperature of one solid high enough so that electrons, by thermal agitation, are "boiled off." These electrons are then collected by another solid maintained at a lower temperature and, when these two solids are connected through an external circuit, a current flows to equalize the charge. This is known as the "Edison effect," for Edison first noticed it in 1883.

The only moving part in such a converter is the electron flow. In its simplest form it consists of two electrodes: a cathode (the electron emitter) and an anode (the electron receiver) in an evacuated chamber. This is shown in Figure 1. The conversion process is started when the cathode absorbs sufficient heat from some source to be raised to a high temperature whereby electrons are emitted into the interelectrode space, according to the Richardson equation:

(1) $$J = AT^2 e^{-\phi c | kt}$$

where J is the saturation current of the emitter, ϕ_c is the work function of the cathode material, and A is the Richardson constant. The relatively cool anode then absorbs electrons from the interelectrode space. A net flow of current takes place when these two electrodes are externally connected by an appropriately matched impedance.

The thermionic energy converter can be thought of as a heat engine using an electron gas as the working fluid. For example, in a gas turbine system, the compressor function is similar to that of the anode-vacuum interface of the thermionic energy converter, for they both absorb some of the energy. Likewise, the turbine function is similar to that of the cathode-vacuum interface, for they both change the form of the energy.

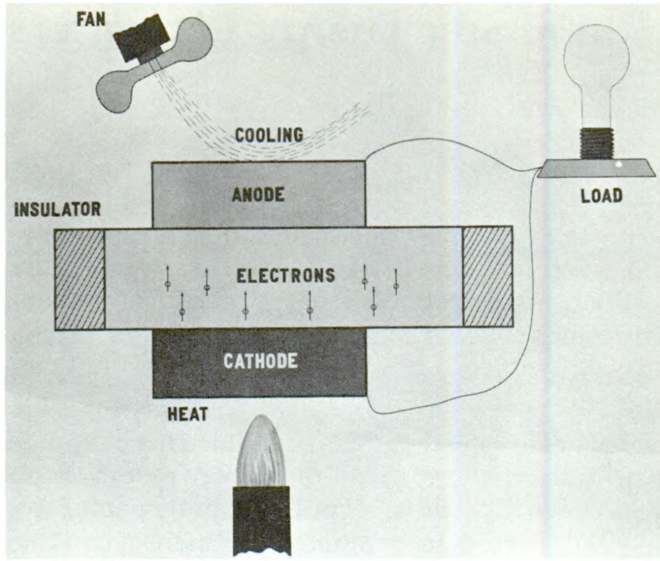
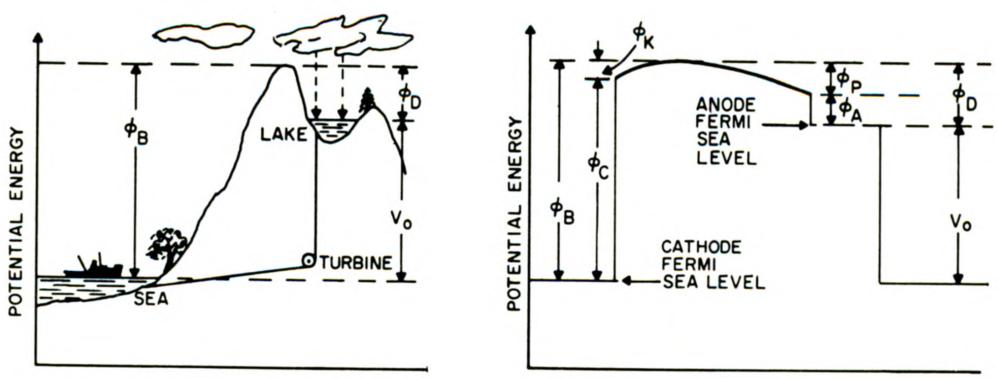


Figure 1 - Schematic diagram of a thermionic converter.

Also, irreversible losses, such as thermal radiation and thermal conduction, are common to both systems, and the frictional losses in the turbine system are analogous to the electrical resistance in the thermionic system.

Figure 2 illustrates the potential-energy diagrams for the energy-conversion systems occuring in nature (Fig. 2a) and in the thermionic converter (Fig. 2b). In Figure 2a, solar heat is supplied to the water molecules in the sea. Some are boiled off and, according to the amount of energy absorbed, rise to different elevations. Those obtaining more energy than indicated by ϕ_B can cross over the mountain and can condense into the cool mountain lake, giving up energy ϕ_D. If we then connect the lake to the sea through a turbine, we have the energy difference of $\phi_B - \phi_D$ or V_o left to due useful mechanical work.



(a) In nature (b) In the thermonic converter

Figure 2 - Diagrams of energy conversion systems.

By referring to Figure 2b, we can see that an analogous sort of conversion takes place in the thermionic converter. The electrons are boiled out of the cathode Fermi sea,* and those with sufficient energy to pass over the potential barrier ϕ_B can condense into the anode Fermi sea by giving up a quantity of energy equal to ϕ_D. Here again we have a potential energy equal to $\phi_B - \phi_D$ or V_O available to do work as the electrons flow from the anode Fermi sea to the cathode Fermi sea, only in this case, since electrons are flowing, the heat energy has been converted directly to electrical energy.

As with any flow of electrons in a vacuum, a space charge (the mutual electrical repulsion of the electrons) is formed in the interelectrode space which inhibits the electron flow from the cathode. This effect is indicated by the dome-shaped potential barrier in Figure 2b. As previously pointed out, the electron must absorb a quantity of energy equal to ϕ_B in order to overcome this potential barrier. We must first supply energy equal to ϕ_c, the cathode work function, to emit the electron and then we must supply it with an additional amount of energy, ϕ_K, to overcome the space-charge potential barrier. When the electron reaches the top of this barrier, it has a small amount of kinetic energy ($2KT_c$). The electron then falls down the potential energy curve into the anode Fermi sea, losing an amount of potential energy equal to ϕ_D. The ϕ_D, like the ϕ_B, is also made up of two distinct parts: ϕ_p, which is converted to kinetic energy and is given up as heat in the anode, and ϕ_A, the anode work function—the amount of energy necessary for the absorption of the electron into the anode Fermi sea. From the above, one can see that the space charge dependent part of the potential barrier must be minimized to reduce the transfer of heat, for this heat transfer to the anode lowers the efficiency of the converter system.

Two alternative techniques are being investigated at present to minimize this space-charge effect (see Fig. 3). The first involves restricting the interelectrode spacing to very small distances—in the order of a tenth of a mil. Converters using this technique are known as vacuum or close-spaced diodes. Unfortunately, severe technical construction problems and

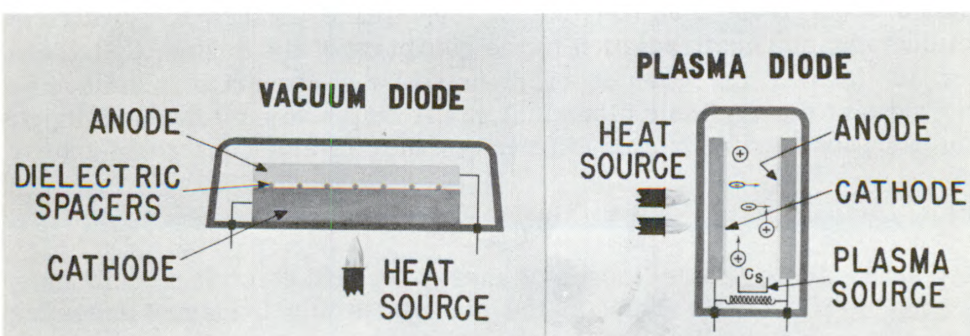


Figure 3 - Converter techniques for minimizing space-charge effect.

*The Fermi level is an electron energy level in a solid having a 50 percent probability of being occupied.

the maintenance of these close tolerances have limited the operating lifetime of units employing these diodes. The second technique involves neutralization of the negative space charge by employing a gas that can be readily ionized to provide positive ions in the interelectrode space. Converters utilizing this technique are known as plasma diodes. Noble-gas ions produced by energy bombardment and alkali-metal ions are being investigated for possible plasma-diode applications, for the introduction of these foreign ions and atoms influences the operation of the plasma-diode converters. Figure 4 illustrates the effect produced when an insufficient number of positive ions* are present: the space-charge effect (illustrated by the mountainous barrier) is lowered a small amount, but still presents a formidable obstacle. When the optimum number of positive ions is introduced into the interelectrode space (as shown in Figure 5), the space-charge barrier is eliminated and our heat losses in the converter are reduced. If an excess number of positive ions are present in the interelectrode space, however, the flow of electrons is impeded by frequent collisions, the resistance of the converter is raised, and the result is an excessive loss of energy (Fig. 6). Although the plasma-diode converters have the advantage of operating with larger interelectrode spacing than the close-spaced diode converters, the introduction of these plasma-forming materials into the plasma-diode converter imposes materials limitations on its operating lifetime.

EFFICIENCY

The area of application of thermionic converters is established by many parameters but in particular by the efficiency of the system. This efficiency will depend upon the geometrical design of the device, the properties of the plasma in the interelectrode spacing, the properties of the anode and cathode materials, and the heat conduction and electrical resistance in the system.

The ideal efficiency of the converter is limited to the theoretical Carnot efficiency of a heat engine operating with temperatures corresponding to those of the anode and cathode. In practice, however, losses occur from electron motion, heat-leaks through the electrical conductors, and heat radiation to the cold parts of the device. Considering all losses, the overall efficiency of the converter is defined as the ratio of the available electrical power output to the total heat input. The equation for the overall efficiency of the converter (η) would appear as:

$$\eta = \frac{\text{Output Electrical Power}}{\text{Input Heat Power}} \tag{2}$$

Neglecting Joule losses (losses of energy through electrical resistance, according to Joule's Law) in the electrodes and leads and assuming space-charge neutralization, equation (2) can be rewritten as:

$$\eta = \frac{\text{(Net current) (Output E.M.F.)}}{\text{(Net current) (Cathode Work function + Excess Electron Energy) + (Radiation Losses)}} \tag{3}$$

*The figures are applicable to the general treatment even though they specifically mention cesium.

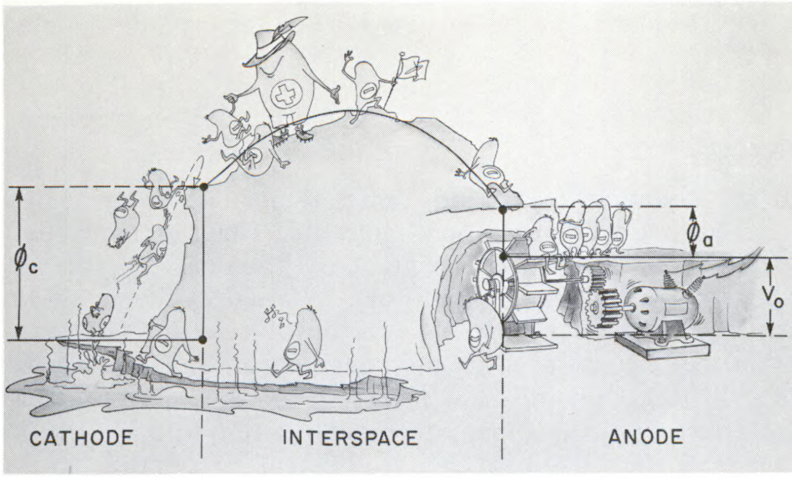


Figure 4 - Insufficient cesium ionization

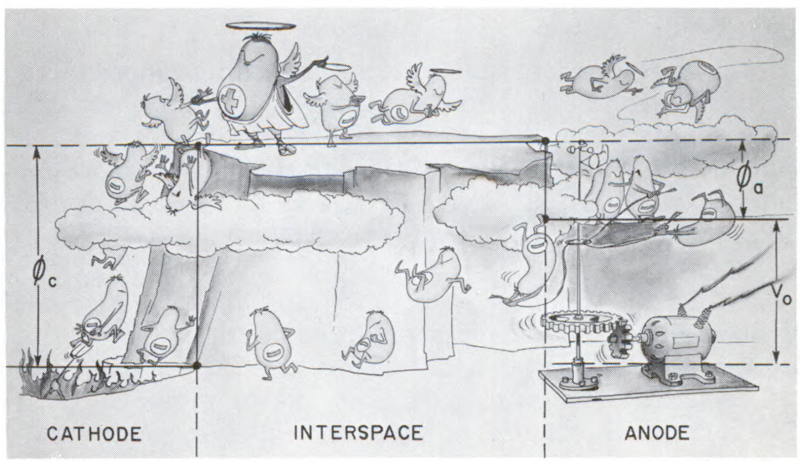


Figure 5 - Optimum cesium ionization

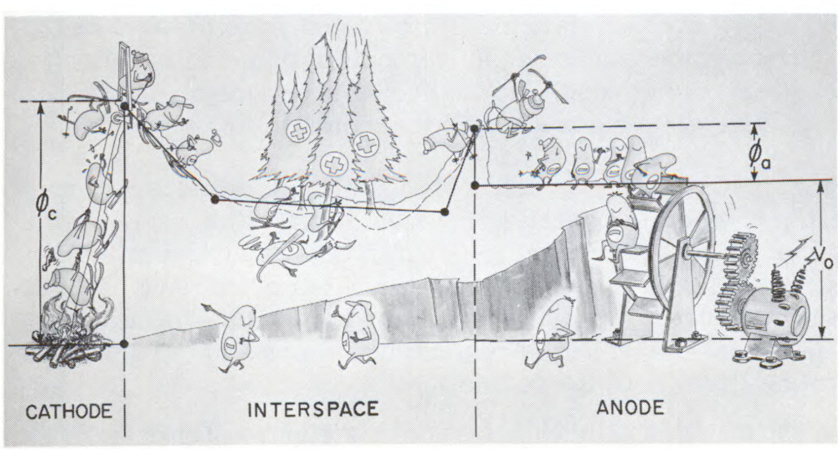


Figure 6 - Excessive cesium ionization

which, when using the notation of Figure 2B and letting I be the net current, reduces to:

(4)
$$\eta = \frac{\phi_c - \phi A}{\phi_c + 2\,KT_c + Rad./I}$$

The simplified equation (4), points out that the efficiency of the converter will be quite low for small net currents. Thus, high current densities are desired, but according to equation (1) are only obtainable at high operating temperatures. If the work function of the anode is decreased in order to increase the numerator of equation (4), care must be taken that it is not lowered to the point where a large electron counter-current will take place, thus reducing the net current. The efficiency of the converter, therefore, is closely allied to the various properties of the materials used, such as: physical properties, work functions, radiant emissions and reflectivities, electron emissions, and operating temperatures.

FURTHER CONSIDERATIONS

In order to decrease internal losses in the converter and allow its efficiency to more closely approach its theoretical value, we must consider in turn the effects of altering the properties of its various components. In addition to proper design, the source of heat for the cathode can have far-reaching effects on the system efficiency as pertains to operating temperatures and lifetime.

When the combustion of a fossil fuel is used for heat, the lifetime is limited by fuel supply and corrosion problems, and the efficiency is limited by the combustion temperature. These undesirable effects can be reduced or eliminated by the use of either solar or nuclear heat. The major limitations of a solar-heat system are the large size and necessary orientation of its collectors and its energy-storage facilities (for use when the device cannot receive solar energy). While nuclear systems have none of these problems they, instead, impose problems unique unto themselves. For, when thermionic converters are made an integral part of a nuclear reactor, they must have properties that enhance the conversion phenomenon without detrimentally affecting reactor operation. Considering all aspects, the nuclear-thermionic power-conversion system holds the greatest potential for naval use.

Since proper materials are basic to these considerations, we must first define the physical properties required of materials to be used in the various components. Comparing the desired properties with those known today, we find we must either improve the properties of materials presently in use or uncover different materials with improved properties. In all cases stability of materials is necessary for lengthening the operating lifetime of the device.

Because the cathode is the source of the electrons that make the entire operation possible, any improvements in it will in turn be reflected throughout the system. Theoretically, if the operating temperature of the converter is increased, its efficiency will also increase. But use of high temperatures can cause the cathode material to vaporize, thereby altering its spatial configuration, shorting out the electrodes and insulators, and adversely affecting the functions of the plasma and anode. It is therefore important that a good cathode material should have a low vapor pressure under operating conditions. Refractory materials are the most promising for cathode use. Refractory metals, such as tantalum, tungsten, and niobium, have the twin advantages of stability and resistance to thermal shock and stress. Intermetallic-compound cathodes, such as mixtures of uranium carbide and zirconium carbide, exhibit promise in systems where the converter is an integral part of a nuclear reactor (Fig. 7), for here the cathode becomes a fuel element of the reactor. Various other intermetallic compounds and ceramics are also being studied for use as cathode materials. Other problems involved in the selection of proper cathode materials are excessive radiant heat transfer, the diffusion of interelectrode gases into the cathode, and the variation of the work function (energy needed to emit cathode electrons) with the temperature and crystal orientation of the cathode material.

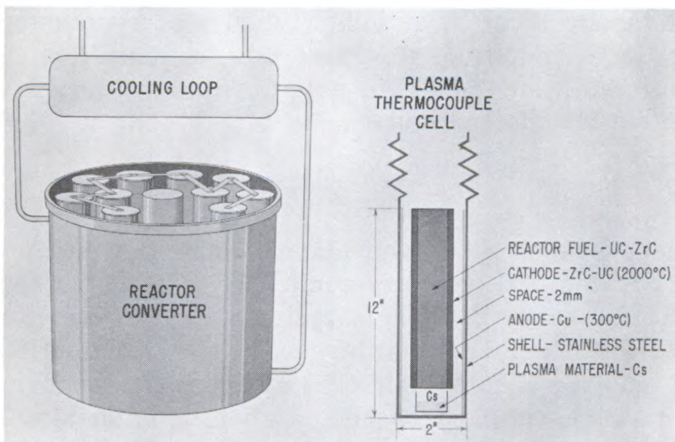


Figure 7 - Nuclear thermionic converter system

The anode, operating at lower temperatures, allows a greater choice of suitable materials than the cathode. Here, increased output voltage and efficiency are favored by a low anode work function, but too high a temperature will cause the anode to sublimate, contaminating the plasma in the interelectrode space, and destroying the highly reflective anode surface. Infra-red wave reflection is important in reducing the absorption of radiant heat from the cathode. Also, the anode material must be compatible with the plasma so that there will be minimal deleterious penetration of the anode surface by plasma atoms. Finally, effective anode materials must have a low electrical resistivity in order to minimize the heating of the anode—in accordance with Joule's law—by the current during energy removal.

Alkali-metal vapors, cesium in particular, are useful in neutralizing the space-charge effect by furnishing positive ions in the interelectrode space. Their advantages include: ease of ionization, low boiling point, and high mass (which lowers the ion-transport velocity). These metals have adverse effects, however, for they tend to deposit onto the electrodes and insulators, thereby altering their properties.

Noble-gas plasmas are also under study as space-charge neutralizers that would avoid the adverse effects of the alkali-metal plasmas. Two methods under study are the use of the highly energetic fission fragments—that result from nuclear reactions in the cathode of a nuclear-thermionic converter—to ionize the interelectrode gas, and the production of a gas discharge by pulsing the diode at a sufficiently high potential. The gas-discharge method may ultimately lead to direct A.C. power generation.

Since this converter is a low-voltage, high-amperage device, its seals, insulators and supports must be as electrically and thermally efficient as possible. Some of these components must have properties normally thought of as being incompatible for a given material. For example, the supports for the cathode must have a low electrical resistance and a low heat conduction; while the insulators between the cathode and anode must have a high electrical resistance and a high heat conduction. In addition, the materials for these components must be compatible with each other, be able to withstand irradiation, and be able to maintain low gas pressures.

SUMMARY

Both close-spaced diode and plasma-diode thermionic converters have been operated and have experimentally demonstrated a performance suitable for many practical applications. However, one must not be misled to the conclusion that large-scale application is here today. Much work must be accomplished in improving the performance of the converters through new approaches and better materials. To this end, the Power Branch of ONR is conducting a fundamental program which should result in shortening the lead time for the development of an integral nuclear-reactor thermionic-energy converter, such as shown in Figure 7. By use of converters of this type, many naval requirements for silent, long-term, compact, and highly efficient electrical power sources may be fulfilled.

World's Smallest Motor

Rising to the $1000 challenge of Prof. Feynman of CalTech, an engineer at Electro-Optical Systems, Inc., Pasadena, Calif., recently built a working electric motor that measures roughly 1/4th the size of a pinhead. It is a two-phase, permanent-magnet, synchronous type of motor composed of 13 parts. Although microminiaturization is an important field, no one has yet come up with a practical use for this one-millionth-horsepower motor. However, a few impractical uses come to mind, such as operating the merry-go-round for a flea circus, providing power for a personal ear-phonograph, or running a power saw for spider webs. - ONR, Pasadena.

Hydrodynamic Research with a Porpoise

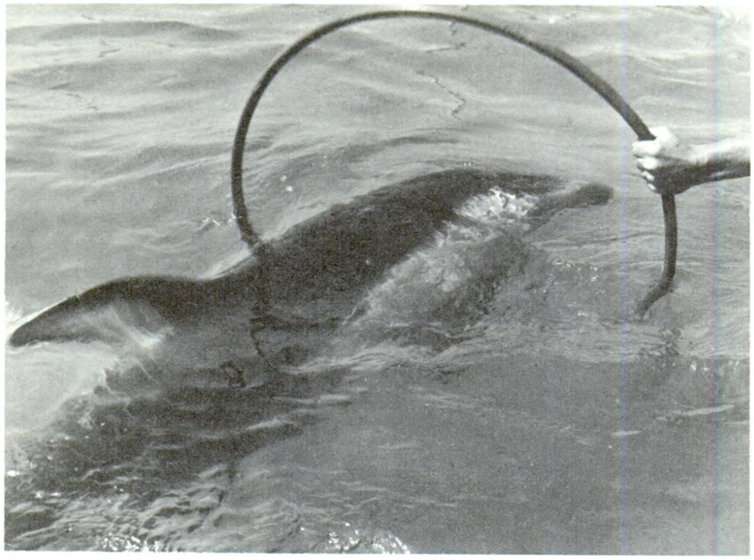
If present theories on the porpoise's secret of speed are correct, future subs and torpedoes may have heated skins that can ripple. For it is known that the porpoise is capable of swimming efficiently at great speeds with little drag or disturbance, of transmitting and receiving sounds over a distance of several miles, and of withstanding deep ocean pressures beyond the known physiological capabilities of other mammals. And the porpoise does all these things better than anything yet devised by man. Navy scientists studying these phenomena say the answers could change their concepts of torpedo design, underwater sound detection, and anti-submarine warfare.

Last spring, the Naval Ordnance Test Station, China Lake, Calif., commissioned Marineland of the Pacific, Palos Verdes, California, to catch and train a porpoise. Their catch, a six-foot, 180-pound female, is now owned by the Navy and has been named "Notty" from the first letters of the Station's name (See cover photo). She has been trained to "speak," to wear plastic rings and rubber suction cups, to swim through hoops and around obstacles, and to dash off at full speed or make a crash stop. Plastic rings of known drag characteristics are used to make hydrodynamic studies of propulsion and drag. "Notty" makes the ring adjustments herself. As she swims through an area in which particles of neutral density have been suspended in the water, her flow pattern is recorded by wide-angle cameras shooting at 400 frames-per-second. Colored dyes smeared on her skin have aided flow-pattern studies.

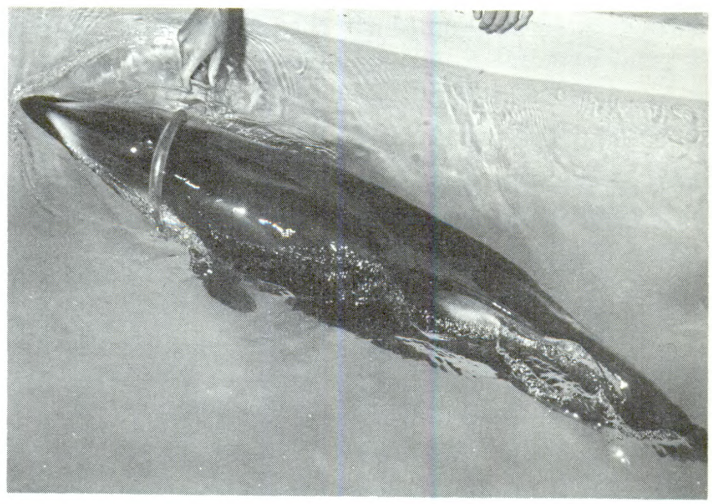
Porpoises swimming at speeds of 25-30 knots have been reported by competent ship captains, but so far "Notty" has failed to swim at more than 16 knots. China Lake scientists wonder if this superbly intelligent animal is failing to do better because of a show of temperament or because she felt confined in the tank. They are not certain. One theory of the porpoise's speed is its control of its skin to reduce drag. Around its nose, where a smooth water flow exists, the skin is nearly bloodless. Toward the tail, where turbulence and drag normally build up, the animal has a progressively increasing amount of blood vessels supplying blood to the skin area. Scientists say this greater vascular circulation toward the aft end could produce a smoother flow by decreasing water turbulence in two ways: through heat transfer to the water or by wrinkling the skin. The porpoise's heat transference has been recorded on photos by the Schlieren method which can determine temperature changes as minute as 1/200th of one degree.

Observations have indicated that a porpoise is apparently capable of delivering 10 times as much horsepower per-pound-of-muscle as other mammals (including dogs and humans). China Lake scientists are trying to determine whether or not this high power does exist, and if so, what inherent physiological differences are responsible for it.

The porpoise swims primarily with vertical movements of the tail maneuvered in a flat horizontal attitude. The fins are used as stabilizers



A hoola-hoop serves in hydrodynamic studies, for "Notty" swims during the approach, but glides through the hoop.



She is taught to wear a plastic ring of known drag characteristics.

Diver using an underwater camera to capture "Notty" in motion.

only. He is capable of jumping 15 feet out of the water and descending to 1000 foot depths (the whale can dive 3000 feet). One theory to explain this is that they may be able to filter excess nitrogen out of their blood. It is also known that these mammals can absorb enough oxygen to remain submerged for a long period of time. An explanation of all this may lead to the development of techniques enabling men to dive deeper and to escape from submarines without long periods of decompression.

Sound detection is one of the Navy's biggest problems in anti-submarine defense today and porpoises and whales are known to be capable of producing a variety of different sounds. It is believed that the porpoise has a greater sound range than the Navy's equipment, thus acoustics is another of the vital phases to which "Notty" is contributing. "Notty" is able to navigate while blindfolded. She does this by sending out sounds and then receiving them as they bounce back as echoes, much the same as a sonar transmitter. She can send and receive sounds ranging from 750 cycles to 300,000 cycles, a much broader range than you and I have. It is believed she makes some of the noises from a blow hole, similar to the whale's, in the top of her head. Other sounds are emitted from the larynx and other internal organs.

High-speed tape recordings of "Notty's" sounds have been made above and below water. Another research technique utilizes high speed photographs of her sound track as it appeared on an oscillograph screen. In addition to the Marineland program, the Navy has studied propoises extensively at the hydrodynamic-tow facility at Convair Aircraft, San Diego, Calif.

Oceanographic Cruises

The research vessels ATLANTIS and CHAIN of the Woods Hole Oceanographic Institute, Mass., have been making news of late. On 7 Dec. 1960, ATLANTIS passed what is believed to be a milestone unequaled by any other research vessel, for at that time she occupied oceanographic station No. 6000. This was the 5000th station actually occupied by the vessel, since numbering started with station 1000 on 26 July 1931. Since then, the vessel has steamed and sailed some one and one half-million miles, occupying one station for every 300 miles on the high seas. The ATLANTIS departed about 14 January for the Mediterranean with A. R. Miller in charge of the work. While there a study will be made of the effects of evaporation on the salinity and circulation in the Western Mediterranean. The ATLANTIS will return to Woods Hole about 16 April. The CHAIN was scheduled to depart about 19 February for two short cruises to the Bermuda-Bahamas region, followed by three months in the Romanch Trench area. She will call at Freetown and Sierra Leone during the cruise and is expected to return to Woods Hole about 15 May. - ONR, Boston.

An Approach to Turbomachinery Research

Power Branch Staff
Office of Naval Research

Many programs of research into basic or fundamental areas produce results which may never find an area of practical application. Other basic research results may be utilized by application engineers, but the path of utilization may be so long and devious that the specific research results utilized can never be identified. However, in a few instances, a research program may explore an overlooked but fertile area which produces results of widespread interest and immediate application. One such program was sponsored by ONR at Sundstrand Aviation, Denver, Colo. The objective of this program was to determine the factors governing flow through turbines operating in the low-specific-speed regime. This program has already resulted in newer and better applications of existing turbines, improved efficiency, and the invention of a new turbine, the Silvern tangential-flow turbine.

At the time this research began, much work had been done in the development of turbomachines at the other end of the spectrum, namely high-specific-speed turbomachines. These include the highly efficient aircraft jet engines and other air-breathing types. High-specific-speed turbomachines are characterized by a large volume flow, moderate working-fluid energy level, and tip speeds within the state of the art. The efficiency of such machinery is in the range of 70 to 88 percent. However, the development of high-energy fuels and propellants for missile- and high-speed torpedo-propulsion systems called for power systems which must operate with small volume flow rates, high working-fluid energy levels, and high tip speeds in order to provide reasonable efficiencies. Turbomachines answering this description are called "low-specific-speed" machines. At the start, little basic knowledge was available as to how the energy is extracted from the hot gases as they pass through the turbine buckets, and turbines were designed for low specific-speed applications by using purely empirical methods.

For low-specific-speed applications there were three types of turbines available: the partial-admission axial-flow turbine, the terry turbine, and the drag turbine (Fig. 1). There was no easy method of determining which of these turbines would be optimum for a particular job. The turbomachinery research program at Sundstrand changed the picture considerably.

Beginning with an empirical approach, which consisted of plotting constant efficiency lines for each type of turbine against the specific speed and specific diameter, a criterion for turbine selection was set up. Since the requirements of each turbine application determine the specific speed, it is possible from a graph of this type to select the turbine that will yield the maximum efficiency for a given application. However, Sundstrand's engineers did not merely plot constant efficiency lines for the present state of the art of each type of turbine. They went

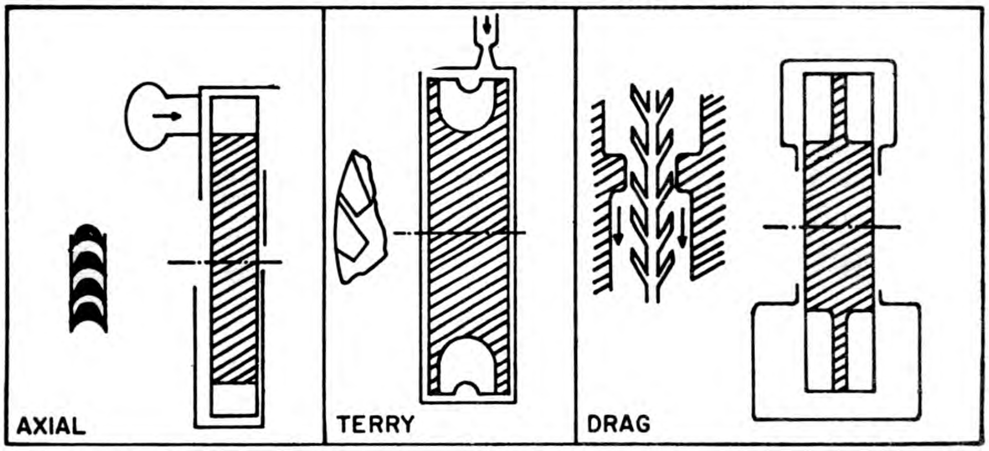


Figure 1 - Three types of low-specific-speed turbines.

on to analyze the energy losses in each turbine and found that by optimizing the turbine geometry, they could improve the state of the art (Fig. 2). It will be noted that, in the low-specific-speed range—where efficiencies of only 20 or 30 percent were achievable several years ago—it is now possible to obtain efficiencies of 40 to 60 percent.

When studying the partial-admission axial-flow turbine, the loss analysis made it clear that conversion of energy could be improved if some of the energy in the exhaust gases could be recovered. Multistage turbines—several turbines connected in tandem with the gas passing through each turbine—have long been used to extract the maximum energy from the gas. However, for many low-power applications, the conventional multistage turbine offers too large an increase in weight and complication for practical consideration. Therefore, a study was made of the possibilities of utilizing several pressure stages on one turbine disc, a device called the re-entry turbine, on which very little

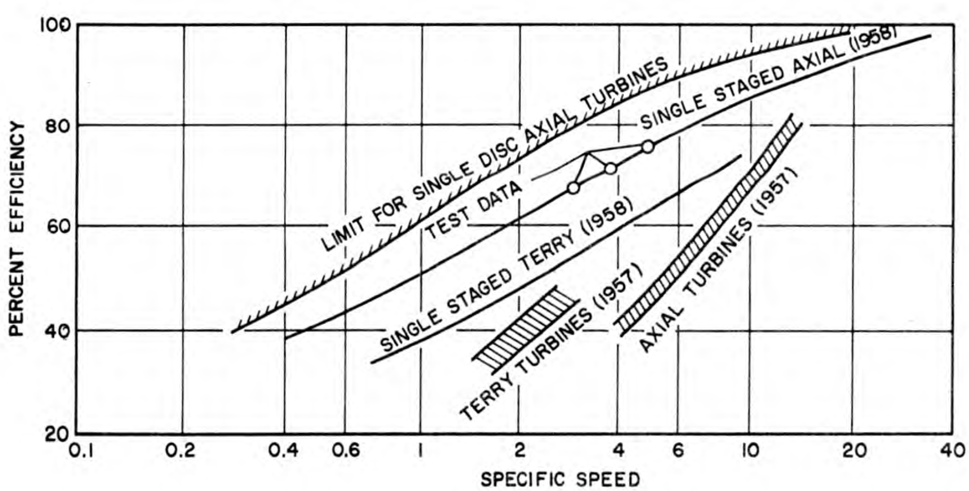


Figure 2 - Turbine efficiencies

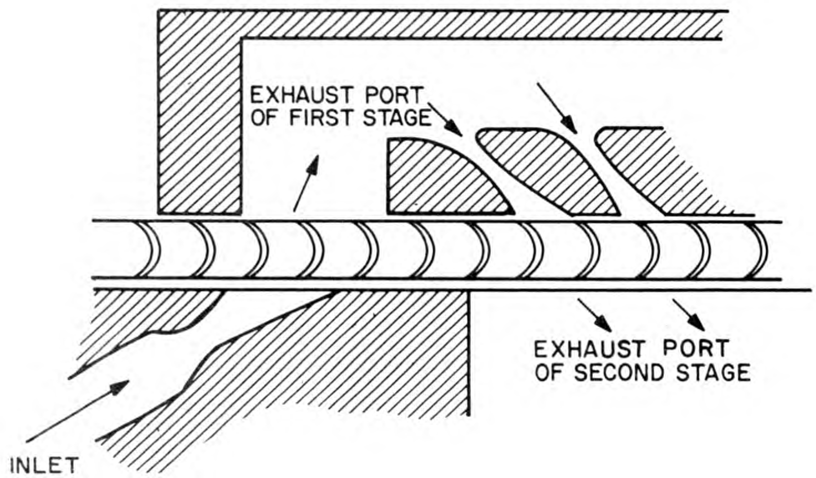


Figure 3 - Top view of two-stage reentry turbine.

information was available in the literature. As shown in Figure 3, the gas from the first-stage nozzle passes through the turbine buckets, is turned in the housing, and re-directed back through the turbine buckets through a series of second-stage nozzles. Since the gas passing through the second stage is cooler than the gas in the first stage, the turbine buckets are actually cooled. Therefore, a two-stage, single-disc, re-entry turbine operating on gas with the same inlet temperature, will run 100-300°F cooler than a single-stage, partial-admission turbine. Thus a higher gas-inlet temperature—and hence more energy—can be used with a given turbine material. Since more energy is being converted because of the higher initial temperature and because of the second pass of the gas through the turbine, the efficiency of the two-stage re-entry turbine will in most cases be 5 to 10 percent higher than the efficiency of a single-stage machine.

A drag turbine is a tangential-flow turbine, in that the gas is introduced tangentially to the wheel, flows around the periphery and is exhausted. According to classical theory, the shear action of the gas with the blades of the turbine caused the gas to drag the turbine in the direction of flow; hence the name "drag turbine." Most research on drag turbines by the industry had been directed toward ways and means of increasing the drag by changing the shape of the blades to increase the shear action. The net result of this approach was disappointing. It was noted, however, that the spacing between the blades affected the efficiency. As a continuation of their analysis of the energy losses in turbines, Sundstrand's engineers concluded that the effect of the spacing of the blades on efficiency was caused by a circular flow of the gas in the U-shaped channels formed by the rotor blades. "If this theory is correct," they thought, "it should be possible to design a turbine that could utilize the energy lost in this circular flow pattern."

So a mathematical expression, known as the Silvern tangential-flow theory, was written for such a turbine and a high efficiency was predicted. The Silvern tangential-flow turbine (Fig. 4) was designed

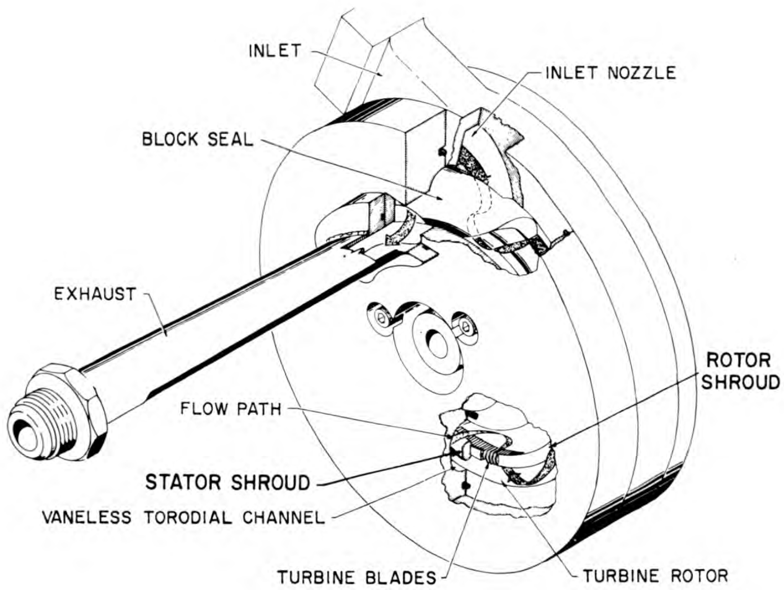


Figure 4 - The Silvern tangential-flow turbine.

and built as a result of this mathematical analysis. In it, the gas accompanies the rotor completely around the periphery of the turbine, exiting after 360° of travel from the inlet. The gas flows in a helical path, out of the turbine blades and re-entering them, perhaps several times, according to the pressure within the vaneless toroidal channel adjacent to the blades.

Later testing of this turbine proved that the predicted efficiency was obtainable. For low specific speeds, the Silvern tangential-flow turbine can achieve efficiencies in excess of 50 percent, while other turbines operating under the same conditions can attain an efficiency of only 20 to 40 percent. Also, because of its flow pattern, the Silvern tangential-flow turbine can operate on wet vapors without any loss in performance or erosion of the turbine buckets. This fact will make the Silvern method ideal for liquid-metal-vapor-turbines in closed-loop, nuclear-power systems.

Thus the ONR-supported research program, whose prime objective was to conduct an analytical investigation to evaluate the sources of losses in small, low-specific-speed turbines, has produced results which has made it possible to select the optimum turbine for each application and to double the efficiency of low-specific-speed turbines. It has also led to the development of a more efficient re-entry turbine and to the invention of the Silvern tangential-flow turbine.

The Proceedings of the Symposium on Hibernation (see Research Reviews article, August 1960) have just been published by the Museum of Comparative Zoology, Cambridge, Mass. It is available in two editions: cloth-bound for $4.50 or paper-back for $3.00.

Research Notes

Navy Retrieves Undersea Fuel Cache

The Navy's prototype 50,000-gallon undersea fuel cache, submerged on the floor of the Gulf of Mexico since last June, underwent its final phase of testing November 15, 1960, when the flexible rubber tank was retrieved and towed to Houston, Texas, for inspection and evaluation. A demonstration of the operation and recovery of the fuel container was made at the original test site in the Bay Marchand oilfields, some seven miles off the Louisiana coast. Navy research engineers attending the demonstration saw the cache emptied and then equipped with a redesigned manometer system, which will measure the cache's contents more accurately than the originally installed gaging system.

With its new manometer, the tank was then refilled and emptied to simulate a ship-refueling cycle. Afterwards, the prototype container and equipment were loaded aboard a barge and towed to the Brown and Root Shipyard at Houston for a detailed inspection. The 1200-barrel tank, one of the largest ever fabricated, is regarded as only a segment of a proposed undersea fuel system, capable of serving as a hidden emergency cache for fleet ships. Navy plans envision a submerged storage system of million-gallon containers—equal to 25,000 barrels—interconnected to a common header and holding sufficient fuel to service several destroyers and smaller craft. Submerged to approximately 52 feet in the Gulf, the filled fuel container is 20 feet wide and 68 feet long. When the container is empty, it is 22 feet wide and 70 feet long. The tank is fixed to the ocean bed by a tubular steel frame and a nylon harness forms a rig of over 80 by 33 feet. The prototype storage cache was built by the United States Rubber Company at Misawaka, Indiana, on an ONR contract under the technical direction of the Bureau of Supplies and Accounts. Hardware for the installation was designed by the Hanna Construction Company of Houston, Texas, under a subcontract with the United States Rubber Company.

If evaluation and testing proves such an underwater storage system to be feasible, the concept may be adopted by the Navy for refueling stations in strategic ocean areas for fleet ships, submarines, and aircraft. The undersea containers could also be used for the storage of gasoline, lubricating oil, crude oil at offshore petroleum operations, and possibly fresh water and other liquids.

Mr. Pellini Receives Award

Mr. William S. Pellini, head of the Metallurgy Division of NRL, received the Distinguished Civilian Award from the Hon. James H. Wakelin, Jr., at Pentagon ceremonies on February 10 for his work in selection and specification of hull-structure materials.

Expedition to North Borneo

A team of scientists from the Naval Medical Research Unit No. 2, Taipei, Formosa, under the leadership of CDR Robert E. Kuntz, MSC, USN, conducted an exceedingly successful survey of medical problems in North Borneo last fall. The invitation to visit North Borneo came from Dr. John Clapham, Director of Medical Services for the colony of North Borneo who, with his conferees, materially aided the scientific team in their efforts. Good local publicity and cooperation from the local Government made the work of the team much easier. The expedition provided the local medical personnel with technical information and over 6,000 biological specimens, including sera from hospitalized patients, stool specimens, birds, animals, amphibians, reptiles, and fishes and their parasites were brought back to the Research Unit for study. Some of the specimens were trans-shipped to museums in the United States and others to laboratories where further work will be done on them. Conferences were held with civilian and military health officials, hospitals were visited, and patients interviewed.

Expedition member tacking up a multi-lingual poster soliciting for all kinds of animals: birds, fish, reptiles, mammals, etc.

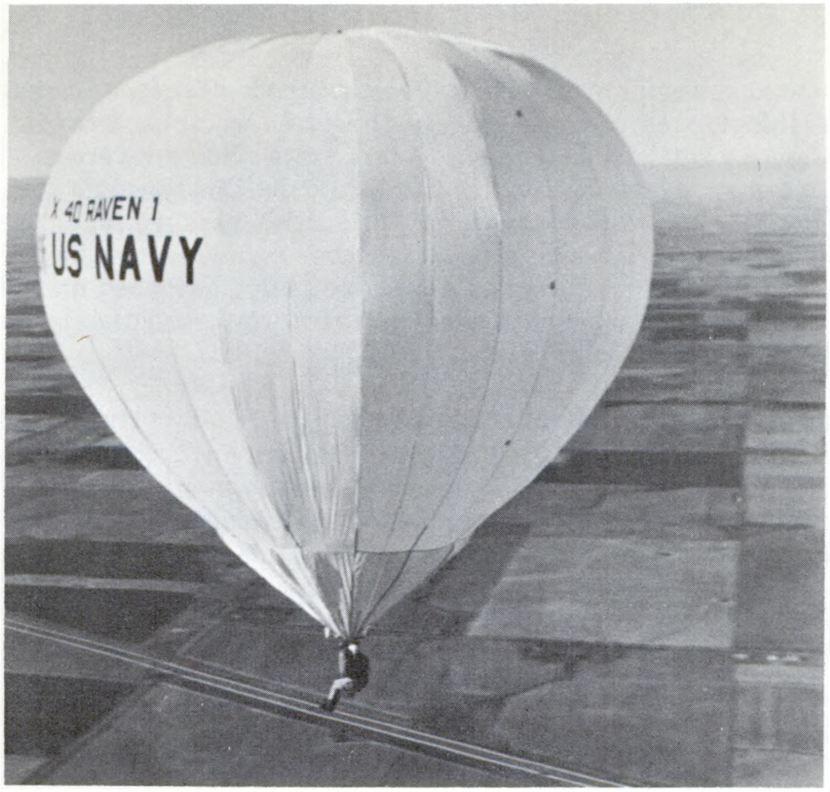
These surveys are important as they bring laboratory diagnostic procedures to areas where they are not available and the results are useful to the local practitioners of medicine. Such expeditions also provide the Research Unit with scientific material and a broad knowledge of the disease problems of the area that are significant to operations. Animal diseases are important economically to the people of the area and many of the infections are transmitted to man. Study of diseases in lower animals develops knowledge that is most useful in determining the preventive measures which are useful to both civilian and military populations. The survey was part of a broad group of geo-medical studies carried out by the Medical Department in various areas of the world. These studies are providing a knowledge of the medical problems and also the direction research must take if they are to be solved.

Hot-Air Balloon System Revived for Low-Altitude Use

Naval research has turned back the clock 200 years to the days of early ballooning and is experimenting with hot-air balloons. A series of tests was climaxed successfully when a hot-air ballon was recently piloted to 9000 feet in a two-hour flight from the Stratobowl, Rapid City, S. D. Research on a hot-air balloon system is being conducted by Raven Industries, Sioux Falls, S. D., under contract to the Office of Naval Research. The principal advantages of the hot-air balloon are economy of operation, greater load capacity, and greater flexibility in ascending and descending without requiring the use of ballast.

Although heating the air inside a balloon to provide lift was the original method of flying balloons, this method suffered from a severe restriction: the air inside the balloon must be kept hot to maintain lift. Lately, interest has been renewed because of the development of new fuels and portable burners and the advent of lighter and stronger balloon materials. A large burner is used to accomplish initial inflation on the ground. After this, a portable burner fed from propane gas tanks is carried inside the mouth of the balloon. This burner is kept going, and turning it up or down controls the ascent and descent of the balloon in the manner of an elevator. A high flame sends the balloon upward; a lower flame slows the ascent, levels off the balloon, or brings it down. The lower section of the balloon is fire-proofed with glass cloth.

The research work at Raven is under the direction of Mr. Edward Yost, who began exploring hot-air balloon systems while at General Mills, Minneapolis, Minn., under ONR contract. Mr. Yost also serves as a test pilot for the balloon system, making the flights while suspended in a swing seat with a backrest; his feet resting on a trapeze bar. In the recent flight he limited his ascent to 9000 feet. At the time, he was rising at the rate of 1000 feet per minute and estimated that he could have reached 20,000 feet. While he was descending at a rate of nearly 900 feet per minute, he was able, by turning up his burner, to stop his descent within about 20 seconds.



Test-pilot Yost suspended under balloon
during recent flight.

Another advantage of the hot-air system is the ease in preparing for a launching. In the test flight described above, the entire process required only 35 minutes. About half that time was consumed in unpacking and laying out the balloon just prior to lighting the initial inflation burner. Seventeen minutes after this burner was lit, Mr. Yost was airborne. The balloon presently being used in the experimental manned flights is made of nylon cloth with a Mylar plastic laminate. This balloon is about 40 feet in diameter, has a capacity of 30,000 cubic feet, and can carry a maximum load of 600 pounds to an altitude of 15,000 feet. It is re-usable, and more flights with the same balloon are planned. It is estimated that the approximate cost of fuel to operate a hot-air balloon of this size and with its present equipment is $1.00 per hour.

Since this type of balloon has a limited altitude capability, it is not considered useful for high-altitude scientific research. ONR which pioneered in the development of the high-altitude plastic balloon as an upper-atmosphere research tool, is studying the hot-air balloon for possible military applications at lower altitudes. For example, the development of this system could greatly improve military construction, transportation, and supply operations, since a three-million-cubic-foot balloon should be capable of lifting from 15 to 20 tons. Research work is still in the early stages, with the objective at present to achieve flights of longer duration.

Jet-Propelled Boat Used in Model Tests

Boeing has begun tests of high-speed watercraft shapes on Seattle's Lake Washington, using a jet-propelled boat (see inside back cover). The boat, a floating test laboratory, was designed to provide a level and stable platform for straightaway runs of up to 100 knots. Thirty-eight feet long with a 17-foot beam, the boat is shaped like a two-pronged fork. The two forward hulls form the fork prongs with the engine mounted in the fork "handle." Hydrodynamic models of hydrofoils and advanced marine vehicle designs will be suspended between the two forward hulls and pushed through the water at high speeds.

Walter Widberg, project engineer, said the Boeing planing platform is the first testing laboratory of its type. Ordinarily hydrodynamic-shape tests are made by towing the models at high speeds in a water tank. "The boat is to supplement the tow tank method," Widberg said, "and will provide an extension of this technique. Just as a windtunnel gives us more information about aircraft designs, the test boat will give us more information about watercraft designs. Hydrofoils and several other surface and subsurface hull forms will be tested." All testing will be conducted on quiet water during daylight hours on Lake Washington. It is expected the fork-hulled mobile laboratory will be completed in January. Detailed design work was done under Boeing contract by Philip F. Spaulding & Associates, Seattle naval architects and marine engineers. Each of the two forward, parallel hulls of the jet boat will have a cockpit and instrument compartment. The port cockpit will carry the boat operator; the starboard cockpit, the test observer. A jet engine, an Allison J-33 developing 4,600 pounds of thrust, will be mounted above the water well aft of the forward hulls. Models to be tested on the floating laboratory will be mounted on a controllable fixture between the two forward hulls.

A typical high-speed test run of the Boeing boat will last approximately one minute. The boat draws under one and a half feet of water and grosses some 10,000 pounds. The structure is primarily of plywood. It is expected that test runs will be conducted primarily at the south end of Lake Washington between Shuffleton and Kennydale. An alternate course, depending on weather conditions, will be parallel to the Lake Washington floating bridge.

UNIVAC Computer Installed

The Univac computer installed aboard the USS BAYA by Remington Rand has successfully completed its acceptance tests and is now in service, the U.S. Navy Electronics Laboratory publication "Calendar" reports. Designated the AN/USQ-20, it is the first general-purpose, stored-program computer to be used in this type of sonar data processing. Its application marks a new milestone in the growing fields of military system automation and antisubmarine warfare.

Navy Reactivates Hydrodynamic Research Facilities at Langley

The Navy's David Taylor Model Basin will begin operating the hydrodynamic research facilities at Langley Research Center, Langley Field, Virginia, early in January. This will give DTMB a salt-water tank for model testing, and access to a tank capable of testing models at a speed of 150 knots.

The facilities at Langley formerly were used by the National Aeronautics and Space Administration. They have been closed since December 1959. DTMB will use them to conduct research and development programs in the field of high speed craft and weapons such as hydrofoils, air cushion vehicles, hydro-skis, planing catamarans, steep-takeoff-and-landing seaplanes, torpedoes and underwater rockets. Programs will also be carried on for the Navy's Bureau of Ships and Bureau of Naval Weapons, while services will be provided to NASA and private aircraft concerns.

The test work will be done under the High-Speed Phenomena Division of the Hydromechanics Laboratory, DTMB, Carderock, Maryland. Initial staffing of the division will be 15 employees.

Antisub Warfare Research Center in Italy

Pennsylvania State University has been named to manage the antisubmarine warfare research center at La Spezia, Italy, through SIRIMAR-a non profit organization. SIRIMAR is an Italian contraction of International Society for Marine Research. The laboratory was organized in 1959 with nine NATO nations contributing scientists and technical data to help solve basic problems in the antisubmarine warfare field.

Policy direction for the research center is provided by the Supreme Allied Commander Atlantic (SACLANT) in coordination with pertinent NATO agencies. Countries participating are Canada, Denmark, France, West Germany, Italy, the Netherlands, Norway, the United Kingdom, and the United States. The Italian government has provided laboratory buildings and other facilities. Two major operating facilities have been acquired since the laboratory was formally commissioned: a 290-foot merchant ship (SS ARAGONESE), equipped as a seagoing research laboratory, and a large-scale digital computer. The center's personnel on December 1 consisted of 25 scientists, 31 military representatives, and a supporting staff of 99. The administrative responsibility for the laboratory was transferred to Penn State December 31 from the Raytheon Company, which initially organized and managed the center for SACLANT through SIRIMAR.

On the Naval Research Reserve

ONR Plans Research Reserve Seminar

The ONR Research Reserve Seminar for FY 1961 will convene in Washington, D. C., for 2 weeks beginning 5 June 1961. About 100 officers are expected to attend the meeting, which is open to all services. The ONR seminar is under the general direction of CAPT J. W. Jockusch, Jr., USNR, Special Assistant to the Chief of Naval Research (Research Reserve). Technical direction will be supervised by the Research Director, Dr. F. J. Weyl.

Again this year the conferees will meet as a complete group and later will form into small groups to study particular fields of research and development. The four fields of study will be as follows:

- Undersea Science and Technology
- Operations and Systems Analysis
- Navy Research in Material Sciences
- Life Sciences

Insofar as possible, officers will be allowed to select the area in which they have primary interest.

Seminars Planned for Fiscal Year 1962

Eleven Research Reserve seminars are planned by the Office of Naval Research for fiscal year 1962. Final approval on these seminars must be given by the Bureau of Naval Personnel. Further information will then be promulgated officially in BUPERS Instruction 1571.4 series. This Instruction is expected to be available in May 1961. The titles, places, and dates of the seminars presently planned are as follows:

Research Methods, Columbus, Ohio	10 July 1961
Nuclear Sciences, Idaho Falls, Idaho	24 July 1961
Naval Research Laboratory, Washington, D. C.	14 August 1961
Research Methods (West Coast), Seattle, Washington	14 August 1961
Research Planning & Management, Princeton, N. J.	21 August 1961
Nuclear Sciences, Brookhaven National Laboratory, Upton, L. I., N. Y.	18 September 1961
Nuclear Science, Oak Ridge, Tennessee	27 November 1961
Submarine & Diving Medicine, New London, Conn.	19 March 1962

Electronic Computers, Newburgh, N. Y.	2 April 1962
Research Reserve Seminar, ONR, Washington, D. C.	4 June 1962
Training Device Center, Port Washington, N. Y.	11 June 1962

NRRC 3-1 Sponsors Reserve Meetings in THIRD Naval District

Naval Reserve Research Company 3-1, New York, has arranged a series of Reserve meetings on "The Human Element in Scientific Research." The Commandant, THIRD Naval District announced the seminar in COMTHREE NOTICE 1520 of 26 January 1961. The program is under the direction of CAPT William Exton, Jr., USNR, and will be conducted at the Consolidated Edison Company auditorium in New York City. This seminar will consist of four sessions to be held on Monday evenings from 1930 - 2130. The program for the seminar is as follows:

27 February - "The Professional Consultant Looks at Research"
Panel: Dr. L. B. Hitchcock, Dr. R. Villers, Dr. D. B. Hertz

27 March - "The Social Scientist Looks at Research"
Dr. M. Stein, Professor of Psychology, New York University

24 April - "The Research Director Looks at Research"
Dr. J. Hannoch, Director of Research, Merck & Company

22 May - "Human Factors in Research"
Dr. R. T. Livingston, Professor of Industrial Engineering, Columbia University

22 May - "Summary and Conclusions"
CAPT W. Exton, Jr., USNR, Program Chairman

The Commandant, THIRD Naval District has authorized an appropriate duty drill point to be credited for each session attended. Attendance will be permitted at no cost to the government and the wearing of the uniform is optional.

Another Outstanding Company

The February issue of "Naval Research Reviews" listed Naval Research Companies from seven naval districts which were adjudged the outstanding Research Reserve Company in the district by the Commander, Naval Reserve Training Command. Since the, COMNAVRESTRACOM has designated a Research Reserve Company in the THIRD Naval District as the outstanding Naval Reserve Research Company. The Commanding Officer and company so designated is as follows:

CAPT Alphonse A. CHESTER, USNR   NRRC 3-2

Reserves Selected for Promotion

Four hundred and twenty-seven Naval Reserve Line Officers have been selected for promotion to Captain and 898 to Commander by the FY 1961 Reserve Selection Boards. Of this number, 55 are Research Reservists; 25 were selected for Captain and 30 for Commander. Ten of the Research Reservists selected are Commanding Officers of their companies. Congratulations are extended to these officers.

FOR CAPTAIN

	NRRC		NRRC
R. D. Bash	11-8	B. C. Laton	6-1
J. M. Bridger	5-9	C. W. Logan (C. O.)	4-1
R. K. Buchanan, Jr.	5-8	L. W. Love	13-6
D. C. Burdick	5-9	R. B. Martin	6-3
H. F. Burr	9-4	J. C. McConahay	11-9
J. A. Chambers	11-6	C. Miller	4-11
H. H. Chisman	4-4	J. R. Patton, Jr. (C. O.)	5-8
J. C. Craig (C. O.)	6-9	G. L. Ploetz	3-7
A. H. Healy	1-1	S. P. Schlesinger	3-8
E. M. Holk (C. O.)	11-8	V. Schreckengost (C. O.)	4-8
R. M. Keefer	12-6	E. P. Tomlinson	4-1
M. W. Keith (C. O.)	9-14	S. A. Wengerd	8-1
G. F. Kinney	12-8		

FOR COMMANDER

	NRRC		NRRC
C. L. Buchanan	5-9	T. T. Reboul, III	4-1
F. J. Callahan	4-8	L. H. Roberts	6-4
I. O. Ebert	9-16	A. Rowsemitt	1-1
F. J. Eppling	1-1	W. J. Sanders, III	6-12
E. B. Freyfogle	9-18	B. E. Sawyer	12-6
E. L. Fritz	12-5	P. H. Sidles	9-5
A. S. Hanson, Jr.	13-1	J. B. Simeone (C. O.)	3-6
D. Howland (C. O.)	4-7	P. W. StGeorge	1-1
T. F. Hurt	6-8	H. D. Strong, Jr.	11-2
E. F. Kehoe (WAVE)	5-8	J. W. Titus	5-8
E. G. Kovach	5-10	M. E. Toms (WAVE)	5-9
Q. W. Lindsey (C. O.)	6-6	N. L. Warren	6-18
F. D. Mason	6-6	W. E. Weeks	12-3
E. F. Palmer (C. O.)	9-8	C. L. Yarbro, Jr.	6-3
J. F. Place	3-8	D. S. Zachry, Jr.	6-3

Statistics based on the records of the Research Reservists selected for promotion are as follows:

OFFICERS SELECTED FOR CAPTAIN

Date of Rank		Designator	Year of Birth	
Earliest	8-28-43	1105 - 11	Earliest	1903
Latest	7-1-54	1355 - 8	Latest	1919
Median	1-1-54	1405 - 6	Median	1914

OFFICERS SELECTED FOR COMMMANDER

Date of Rank	Designator	Year of Birth
Earliest 6-1-46	1105 - 14	Earliest 1912
Latest 4-1-57	1315 - 2	Latest 1925
Median 7-1-55	1355 - 6	Median 1921
	1405 - 6	
	1455 - 2	

Research Reserve Seminar at Great Lakes, Illinois

For the first time in five years a Research Reserve Seminar will be conducted at Great Lakes, Ill. This seminar, which will convene for a two-week period commencing 11 June, 1961, is under the general chairmanship of CDR C. J. Schroeder, USN, the Commanding Officer, Office of Naval Research Branch Office Chicago. Assisting him in the planning and conduct of the seminar will be CDR L. P. Hoskins, USNR, Assistant for Research Reserve, ONR Chicago.

The theme of the seminar is "Research in the Modern Navy." An excellent program has been planned by Dr. A. R. Dawe, Chief Scientist and assisted by all members of the department. Sessions at the seminar will be devoted to lectures, panel discussions, and field trips. Quotas have been established for 50 Research Reservists for attendance at this seminar.

CAPT Hardy, USNR, Selected for Admiral

One of the three Research Reserve officers selected for RADM, USNR, is CAPT James D. Hardy, a member of Naval Reserve Research Company 4-2, Philadelphia, Pennsylvania. CAPT Hardy is no newcomer to the Research Reserve program, since he organized and served as the first Commanding Officer of NRRC 3-1, New York in 1949. Later he established a panel of NRRC 4-2 at Willow Grove, Penn., which is now a full-fledged company. He was also Director of NROS 4-1 and, during his Directorship, this unit received the Naval Reserve Training Command Commendation as the outstanding school of the FOURTH Naval District.

Dr. Hardy is a native of Georgetown, Texas, and received his B. A. and M. A. degrees from the University of Mississippi and a Ph.D. in physics in 1930 from Johns Hopkins University. He served as National Research Council Fellow in infra-red research at the University of Michigan from 1930 to 1932. For the next nine years he was associated with the Russell Sage Institute of Pathology, Cornell University, first as a Research Fellow and later as Research Associate. Before leaving Cornell University Medical College, he was designated Assistant Professor of Physiology.

And then in January 1941 Dr. Hardy became LT Hardy, USNR. His first active-duty assignment was at the Bureau of Ships, Electrical Mine-Sweeping desk. Eight months later he was sent to England as a

RADM James D. Hardy

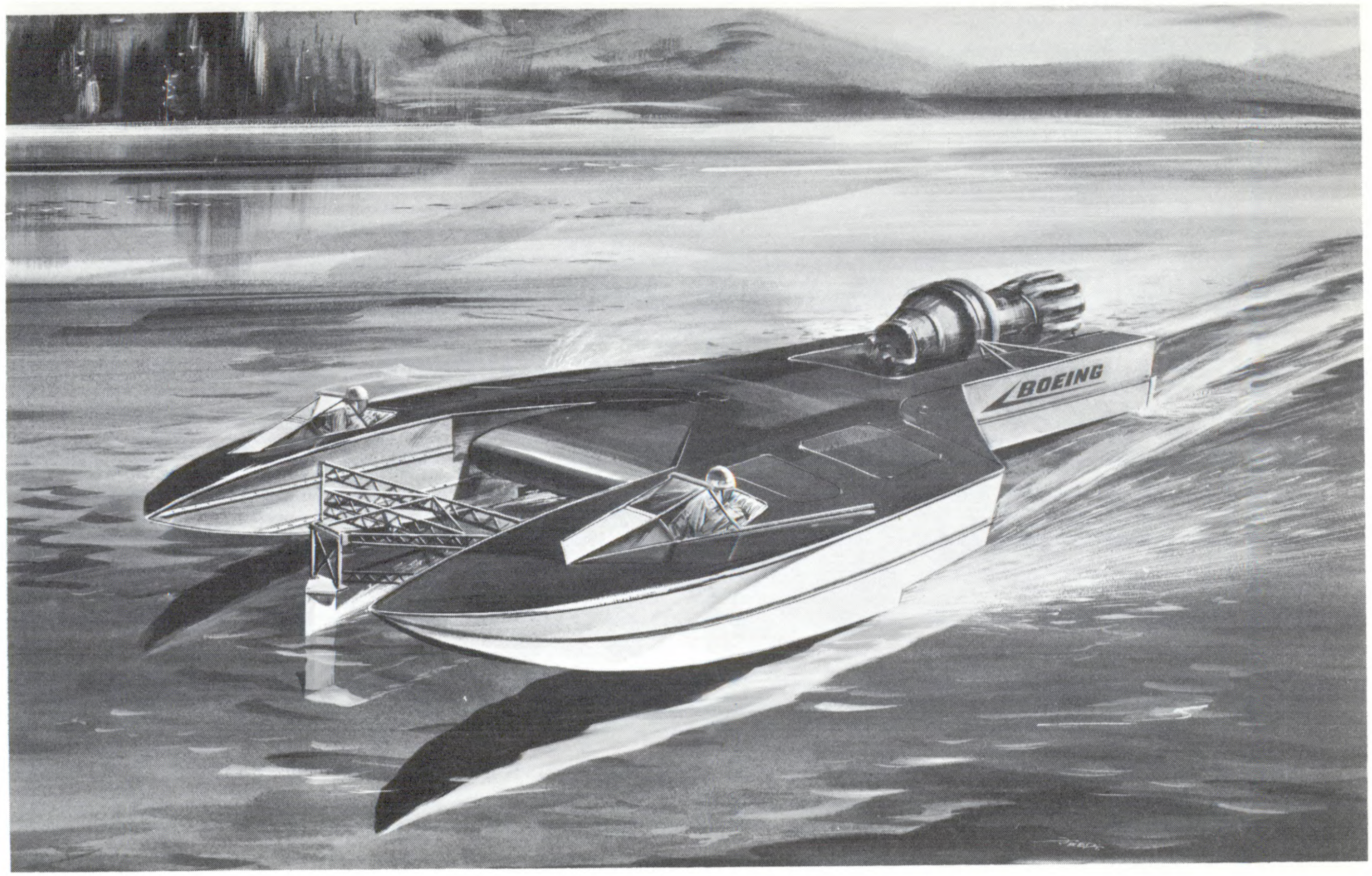
naval observer, where he remained until 1942. His next assignment took him to the Boston Navy Yard where he served as Officer-in-Charge of the Experimental Mine-Sweeping Section. He served in this capacity until 1943, when he returned to the European theatre. Here he served as Staff Mine-Sweeping Officer and Officer-in-Charge, Mine-Sweeping Group, where he took part in the invasions of North Africa, Sicily and Italy. Subsequently, he was designated Fleet Mine Officer for the invasions of Normandy and southern France.

CAPT Hardy's last tour of active duty was in the Mine-Sweeping Section of CNO and, while there, he took part in the preparation of the current U. S. Navy Mine Sweeping Manual. By the time Dr. Hardy was released from active duty in 1946, he had become a Commander in the Naval Reserve. In 1952 he was promoted to CAPTAIN, USNR. After he returned to civilian life in 1946, Dr. Hardy returned to Cornell University Medical College as Associate Professor of Physiology. In 1953 he was appointed Professor of Physiology at the University of Pennsylvania and Director of Research at the Aviation Medical Acceleration Laboratory, Johnsville, Penn. Dr. Hardy's principal fields of investigation are in the physiology of heat, cold, and pain and aerospace medicine.

Hearty congratulations are extended to CAPT Hardy by the Research Reserve on his selection to RADM, USNR.

Navy LT Charles Wilkes made the first geodetic survey of the Hawaiian Islands in 1840. Five miles from Honolulu Harbor (as the crow flies) he found a double estuary of the Pearl River known to the Hawaiians as "Puuloa." Fifteen feet of water covered the bay-mouth coral bar at its entrance. He reported that the bar could easily be dredged to permit passage of the world's largest ships. Today, Puuloa is called Pearl Harbor.

U. S. GOVERNMENT PRINTING OFFICE : 1961 O - 586432



Artist's concept of proposed Boeing jet test boat, see page 21. (Drawing courtesy of Boeing Airplane Co.).

IN THIS ISSUE

NAVAL RESEARCH reports highlights of technical progress in research by Navy laboratories and contractors and the development of important naval research facilities. The magazine is listed for sale by the Superintendent of Documents, U. S. Government Printing Office, Washington, D. C. Subscription price: $1.50 per year in U. S. and Canada; $2.00 per year, foreign; $0.15 per individual copy. Changes of address should be sent to Code 740, Office of Naval Research, Washington, D. C. The issuance of this publication approved by the Secretary of the Navy on 1 March 1961.

"Notty," China Lake's trained porpoise, demonstrates her water-exit capability. (See article beginning on page 11.)