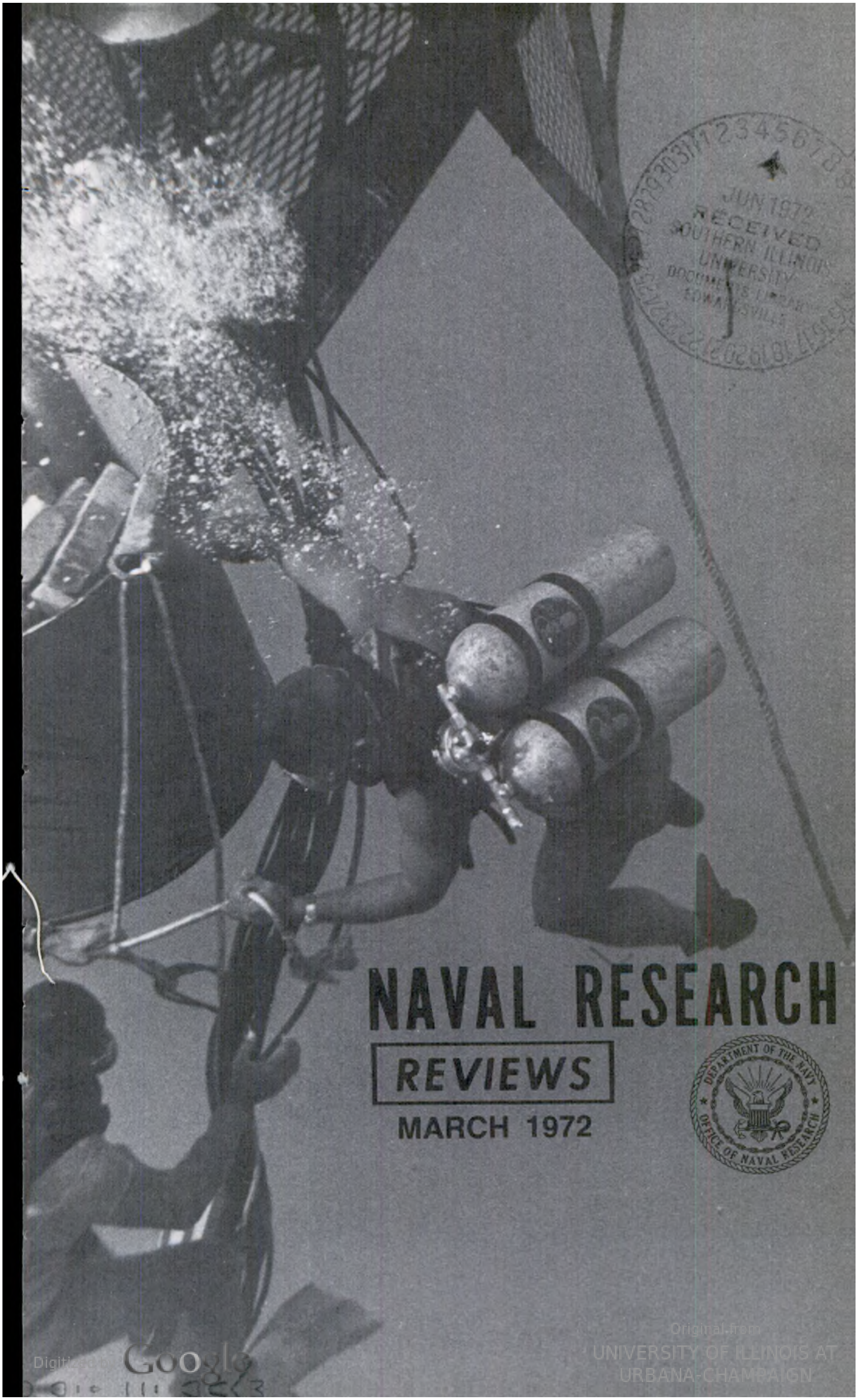
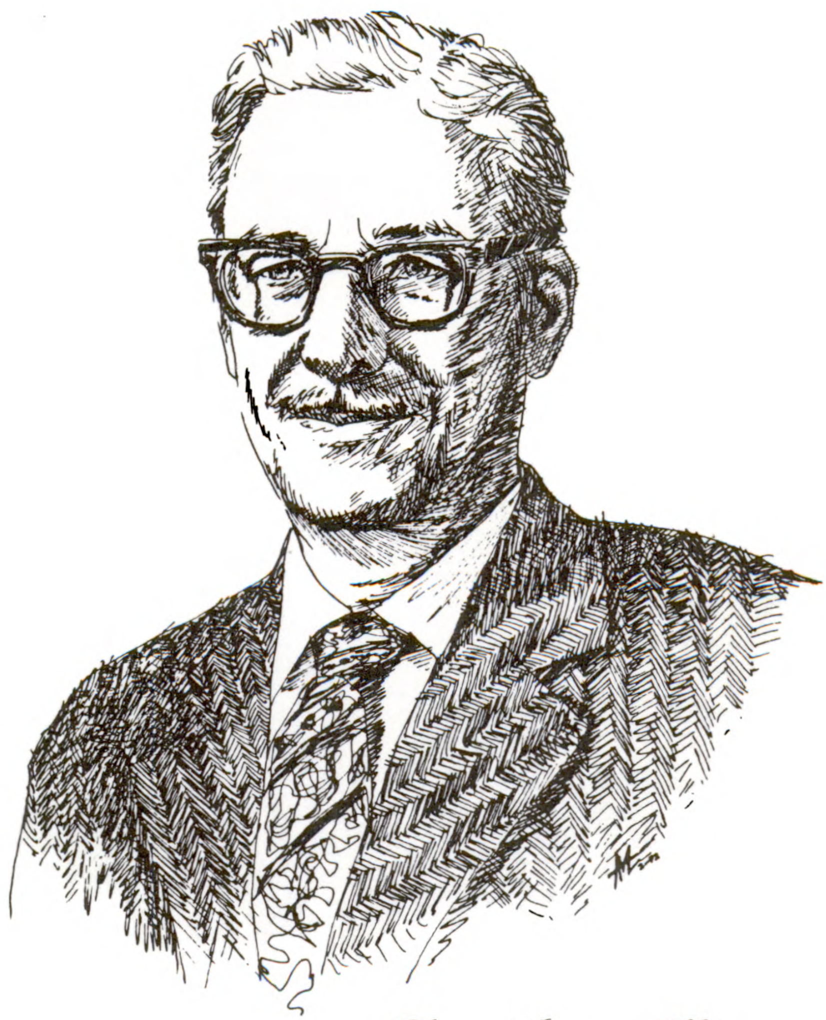


NAVAL RESEARCH REVIEWS

MARCH 1972

DEPARTMENT OF THE NAVY · OFFICE OF NAVAL RESEARCH

PROFILES IN SCIENCE



Dr. Peter King

Dr. Peter King, who recently retired as Deputy and Chief Scientist for the Office of Naval Research (ONR) began his government career at the Naval Research Laboratory in 1939 as an associate chemist and rose to the position of Associate Director of Research for Materials in 1954.

In 1960, he was awarded the Distinguished Civilian Service Award for his contributions to the development of a long-range atmospheric radiation detection program. This method provided conclusive evidence of the first atomic explosion by a foreign power. By measuring the amount of fissionable material in rain water, Dr. King was able to determine the bomb material and to fix the approximate time of explosion.

Before coming to ONR Washington, in 1966, Dr. King served as Chief Scientist for the ONR London Branch.

He has been awarded the Civilian Career Achievement Award for outstanding contributions to the Department of the Navy in the field of naval research.

Dr. King is a member of the American Chemical Society with numerous scientific papers and patents to his credit.

The Navy and the Challenge of Deep Diving

Rear Admiral Carl O. Holmquist, USN
Chief of Naval Research

The sea never changes and its works, for all the talk of man, are wrapped in mystery.

The sea has not changed since Joseph Conrad penned these words, but man's eternal curiosity, aided by advances in science and technology, has allowed him to probe deeper and deeper into the mystery of the ocean.

Man has tried to explore the underwater world since remote time and diving, with or without some crude breathing apparatus, was well practiced by the ancient Greeks and Romans. The earliest reference to this activity is made by Homer who mentions oyster divers in the *Iliad*. In the works of the Roman writer Vegetius is found a drawing of a diver wearing a helmet-like device with a long leather pipe leading to the surface. The surface end of the pipe was apparently kept afloat by a bladder. Other contrivances for exploring the sea continued to be proposed through the ages, but it was not until relatively modern times that significant progress was made in the field of diving and diver equipment permitting man to conduct a wide spectrum of underwater tasks.

Until the advent of the industrial revolution, man's progress into the depths of the sea had been very slow. The industrial revolution provided the technology necessary to the development of diving helmets, diving bells and air compressors. As the design of this equipment improved, and man went deeper and stayed longer in the sea, a strange new ailment was encountered. Medical science of the time was powerless against "caisson disease," or the "bends" as the ailment was called. Theories about its causes and proposed treatments abounded, but it was not until 1878 that the French physiologist, Paul Bert, showed the precise causes of decompression sickness and suggested the proper treatment.

The U.S. Navy has long been in the forefront in the development of diver technology. One of the earliest problems was nitrogen narcosis—that sense of drunkenness and euphoria that can affect divers breathing pressurized air for extended periods at depths below 100 feet.

In an effort to solve the nitrogen narcosis problem, the Navy and the Bureau of Mines in 1924 began to conduct joint experiments with breathing mixtures consisting of inert helium gas and oxygen. By 1927, the work had progressed to the point where human subjects could be used. In 1937, using a helium-oxygen gas mixture, two Navy divers

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reached a simulated depth of 500 feet in one of the tanks at the Navy Experimental Diving Unit, Washington, D.C.

These dry-land experiments were put to operational use in May of 1939 to rescue the crew of the submarine SQUALUS from a depth of 243 feet. The helium-oxygen diving technique was used in 640 dives to the submarine without death or serious injury. On the basis of data obtained during the SQUALUS dives and from laboratory simulated dives, the Navy established 380 feet as the new limit for operational diving, with 30 minutes of bottom time, breathing a helium-oxygen mixture.

Up to that time, the "hard hat" technique was used; that is, a diver was tethered with his air hose to a surface air compressor or gas supply. This tether drastically constrained his mobility. In the 1940's the development of the self contained underwater breathing apparatus (SCUBA) freed the diver from these constraints and allowed him to move about with relative freedom. With SCUBA, however, his depth-time is limited by the amount of breathing gas he is able to carry on his back.

Until the late 1950's, the limit for Navy operational dives was still 380 feet with 30 minutes on the bottom. Without complications, a dive of this depth and duration requires more than three hours of decompression. To overcome this unfavorable ratio of work-to-decompression time, the Navy developed "saturation diving." The first experiments in the field of saturation diving were initiated by the Navy in 1957 under the direction of Captain George Bond, MC, USN, using a standard decompression chamber and the climate-altitude chamber at the Naval Submarine Medical Research Laboratory in New London, Connecticut. These experiments were given the code name Genesis I.

The data derived from the Genesis experiments were used to pursue open sea experiments by a number of other groups, notably the American inventor Edwin Link in his "Man-in-the-Sea" experiments, and the French oceanographer Jacques Costeau in his "Conshelf."

The saturated diving technique capitalizes on the fact that, at a given depth, the amount of inert gas dissolvable into the body tissues is limited. After about 24 hours at a given depth the tissues become essentially saturated with inert gas at the pressure equivalent to that depth. The tissues do not absorb significantly more gas no matter how long the diver stays at that level. For example, a diver saturated to 300 feet requires the same decompression time whether he spends one day or one month at depth. For time-consuming underwater tasks, it is far more efficient for a diver to stay at depth and complete the job than to return to surface atmospheric conditions repeatedly, spending hours in decompression before each return.

The first phase of experiments was concerned with the reaction of animals under long-term exposure to pressure and snythetic gas mixtures.

Late in 1962, three men were exposed to a helium-oxygen breathing mixture at sea level pressure for six days. In the next phase of Genesis I, conducted early in 1963, three men spent seven days in a pressure chamber at a simulated depth of 100 feet. In the final phase, three men spent 12 days at a simulated ocean depth of 200 feet, again breathing a helium-oxygen gas mixture without ill effects.

The Navy's Man-In-The-Sea program took these dry-land experiments to sea. In the summer of 1964, the Office of Naval Research conducted the first *in situ* experiment off Bermuda. In this experiment, called SEALAB I, four men lived in a 40-foot long chamber or "habitat" at a depth of 193 feet for 11 days in relatively warm water.

SEALAB I was followed by SEALAB II , conducted off San Diego also by the Office of Naval Research. Three 10-man teams each remained at the depth of 205 feet for 15 days in cold water. One man remained at that depth for 30 days. In addition to living underwater and conducting a multitude of physiological experiments, underwater work tasks in simulated salvage, oceanography, and construction were performed. In total, the three teams achieved more than 300 man-hours of work outside the habitat. The third open-ocean experiment, SEALAB III, was planned to extend the operating depth of aquanauts to the 600-foot level for 60 days in waters off San Clemente Island, California. A tragic event, resulting in the death of one of the aquanauts, cancelled the experiment short of its planned goals (Figure 1).

Since then, other Navy experiments have placed divers at depths down to 850 feet in the open sea, and the Navy is now planning a program that will eventually take the Navy divers to well below 1,000 feet. Development of techniques for occupying habitations as well as for short-term dives at these depths, would give the Navy the ability to dispatch divers to any place on the continental shelf to perform any of a variety of tasks.

The spectrum of Navy underwater tasks include the following: rescue of personnel from disabled submarines; salvage of aircraft and ships; recovery of large and small objects such as torpedos, nuclear weapons and space hardware; reconnaissnace, surveillance and protection of beaches and harbors; underwater warfare; ship repair, and underwater construction and engineering; as well as extensive scientific gathering of oceanographic data. There are physiological and technological limits to man's penetration of the deep ocean, however, and we should know what these are. We must find out just how long and how deep man can venture into the open ocean. The goal is not to discover merely what depth a man can reach and remain alive, but rather the maximum depth at which he can perform useful tasks with safety and efficiency (Figure 2).

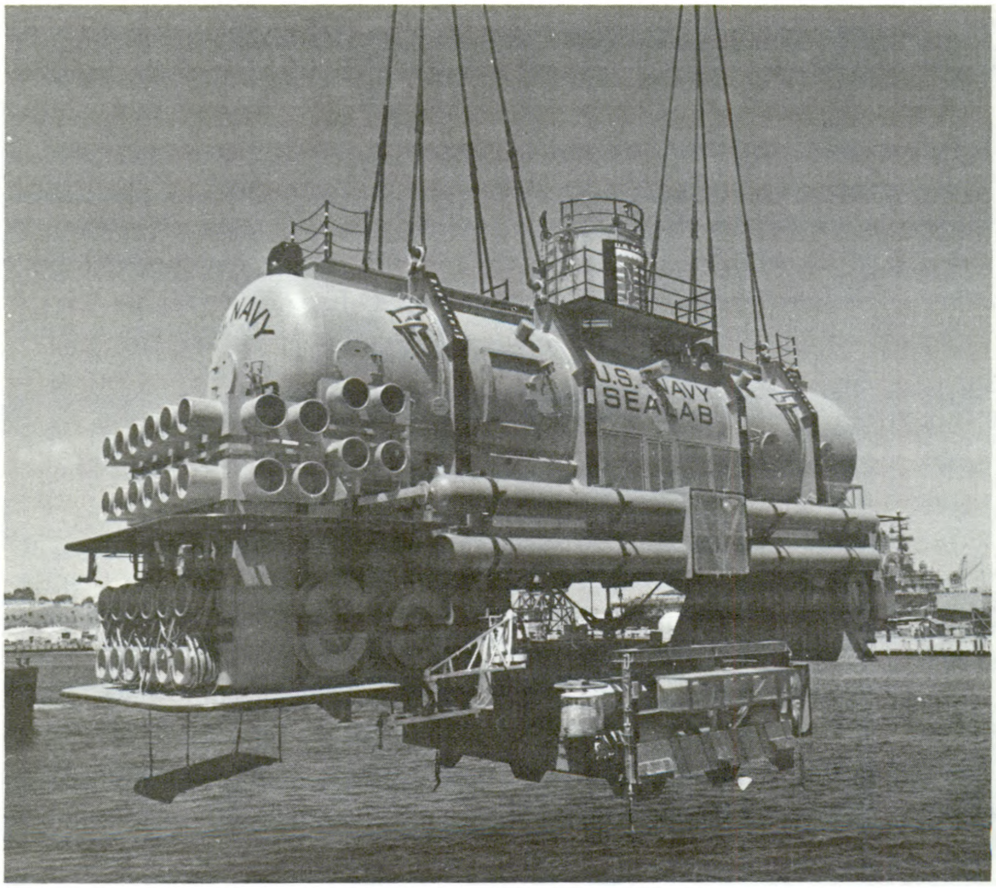

Figure 1 – Sealab II being readied for its first wet tests at the San Francisco Bay Naval Shipyard. The experiment was curtailed short of its goals because of the death of one of the aquanauts.

The physiological limits are imposed by the effects of hydrostatic pressure. Current physiological research is directed at such factors as decompression sickness, inert gas narcosis, gas density and viscosity as well as the area of body thermal equilibrium.

Decompression Sickness

A great deal of research is focused on the decompression process, the most familiar problem related to diving operations. When a diver spends an extended period in deep water, he breathes a special gas mixture that includes inert gases such as helium and nitrogen in order to prevent oxygen toxicity. The inert gases dissolve into his tissues at a rate depending on the partial pressure of the gas, the depth, and the gas already in solution in his tissues. Excess gases must be removed before he can return to normal atmospheric pressure, and this removal is accomplished by a gradual reduction of pressure which allows the inert gases to leave his tissues slowly. If this depression process

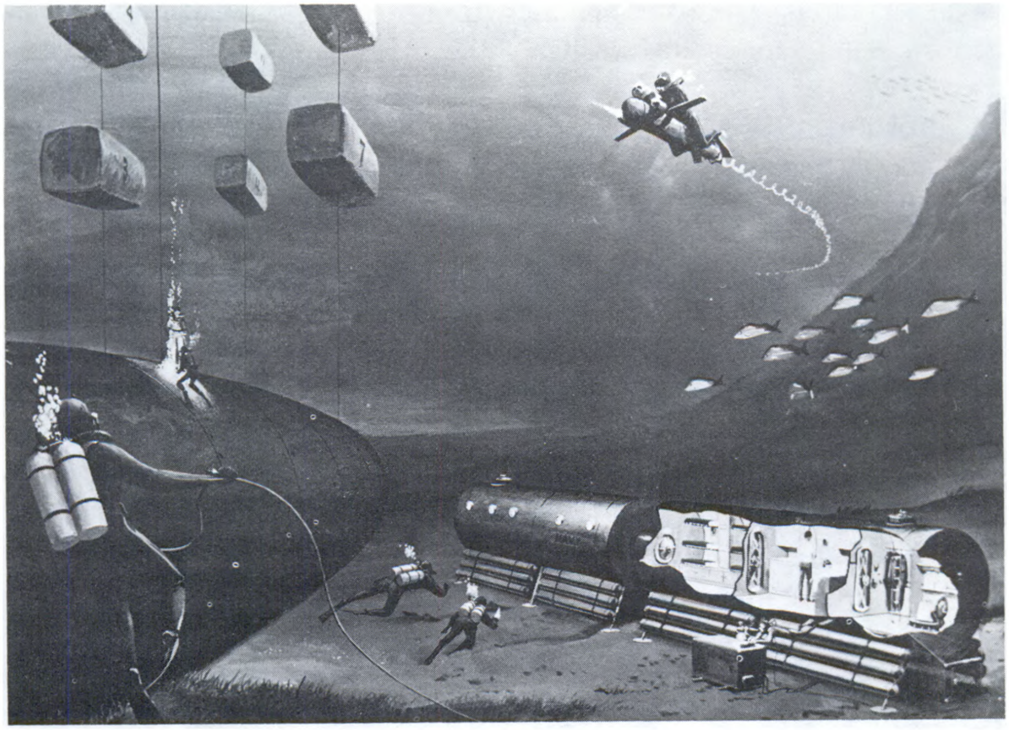

Figure 2 — Artist's concept shows the tremendous range of problems which must be solved in order to allow man to perform useful tasks at depths encountered on the Continental Shelf and beyond. In order to extend the useful working time at depth, habitats allow divers to utilize saturation diving techniques. Diver propulsion vehicles and protective clothing must also be developed so that more useful work can be performed while at depth. Sketch is of the Navy's Large Object Salvage System (LOSS) under development to allow raising of submerged objects weighing up to 1,000 tons from depths up to 850 feet.

occurs too quickly, the emerging gas forms tiny bubbles in the blood stream which can coalesce into large bubbles. These bubbles can block the capillaries or larger blood vessels, causing a variety of reactions known as the "bends." Effects range from itching, pain in the muscles and joints, to paralysis and even death. These reactions are the only signs that now enable us to recognize decompression sickness.

The safe rate of decompression is presently based on time tables developed from experiments with animals and the observation of human subjects. They are not foolproof, however, since the rate at which inert gas is released from the tissues depends on such individual characteristics as age, weight, physical condition, fatigue, or past diving history. As a result, one man in a group undergoing decompression may get the bends while the others have no problem. Decompression is also a time-consuming part of diving operations. For instance, a saturation dive at 500 feet requires about three and one-half days of decompression.

For some time the Navy has been investigating, in its own laboratories and through research performed under contract for the Office of

Naval Research, various techniques to speed up decompression and to increase safety to divers. Probably the first decompression aid to be discovered (1935) was the use of high oxygen tension, and this method will probably continue to be one of the most useful techniques for speeding up decompression. The technique calls for the use of a high concentration of oxygen in the breathing mixture, which, during ascent, speeds up release of the inert gases. This procedure, however, has its limitations since oxygen at high pressure can be toxic and may result in oxygen poisoning.

The use of multiple inert gases in breathing mixtures to aid decompression has been considered for several decades. The basic concept is clear, but results from actual trials are not yet conclusive. The fundamental assumption is that each gas in a mixture, or dissolved in body fluids, behaves as though it alone were the only gas present. The principle is that individual inert gases will decrease in pressure proportionately with the increase in the number of gases used. Thus the diffusion gradient is reduced. However, decompression still remains the most severe problem currently related to diving operations. The problem is complicated by the fact that there are many tissues in the body that become saturated at different rates. Reliable decompression tables (safe ascent rate) for extended depth-time dives are being developed through improved computation methods and experimental validation. It is estimated that, regardless of the inert gases used in a breathing mixture, the rate of ascent will not be increased beyond the ten minutes per foot now achieved. The prognosis is based on experimental data which indicate that exposure to high hydrostatic pressure during a dive causes breathing gases to be taken up in solution by all body tissues even those that saturate at the slowest rate. Furthermore, severe decompression sickness has occured after exposure to multiple gas mixtures. The explanation is that once a small bubble is formed, its growth can be rapid since it depends upon the sum of the individual pressures of all the gases in the tissues. The practical utilization of the technique therefore will have to await further development of foolproof methods for detecting bubble formation or potential bubble formation.

Inert Gas Narcosis

Gases such as nitrogen and helium, that are biochemically inert in the atmospheric pressure environment, are not so under increased pressure. Nitrogen, which is physiologically inert at sea level, has an anesthetic effect under pressure. At depths greater than 150 feet, the average diver is likely to suffer effects of nitrogen narcosis when breathing air. The effects include impairment of judgement and psychomotor ability, which can render a diver completely unable to cope with emergencies. Helium, has been found to be much less narcotic and is currently being used instead of nitrogen in almost all deep-sea dives. Some experiments are also being conducted to determine the narcotic effect of hydrogen since there are indications that hydrogen has even less narcotic effects than helium.

Gas Density and Viscosity

Increasing the pressure of any gas mixture increases its density and viscosity. A denser and more viscous breathing gas causes increased resistance to movement through the small respiratory passages. This resistance not only interferes directly with pulmonary ventilation—the lungs' bellow-like activity of breathing in and out—but also increases the work expended in breathing. A major method for reducing respiratory resistance at very great depths is the use of less dense and less viscous gases, such as helium or hydrogen. A technological solution to the respiratory resistance problem might be the development of a respiratory pump to assist in the work of moving air in and out of the lungs.

Body Heat Loss

The human body must maintain its thermal equilibrium within very narrow limits, and both high and low temperatures impose severe physiological stress. In water above normal body temperature a diver, even at rest, can develop a fever that could be increased by exercise. In water below normal body temperature, the unprotected man will lose heat about 25 times faster than he would in normal air at the same ambient temperature. Metabolic heat produced by exercise extends the tolerance to cold water, and the combination of insulation (wet suit) and work provides useful periods of time in water at temperatures down to 55-60 degrees Fahrenheit. Significant improvement in human temperature tolerance cannot be expected from the use of drugs or physiological adaption. Rather, human temperature tolerance must be achieved by the use of insulation and external heating methods properly integrated with the understanding of physiological heat exchange.

Hydrostatic Pressure Effects

If the problems of decompression, oxygen toxicity, inert gas narcosis, gas density and viscosity, and temperature can be solved or circumvented through physiological research and technological improvements, the final barrier to man's attempts to go deeper into the sea would be the direct effects of hydrostatic pressure—the enormous pressure of the weight of water on the body of the diver. Whereas the effects of pressure on human cellular structure and the resultant body functional impairments are essentially unknown, experiments have been conducted with animals and animal tissues that indicate the existence of direct pressure effects. A major difficulty in studies of this type is the inability to isolate the causes of observed effects. For example, deterioration of mental performance, which is ascribed to nitrogen narcosis, might really be the onset of pressure effects on the nerve cell structure. Tremors, sweating, dizziness and redness in the face, which might be ascribed to carbon dioxide, could also be the direct effects of hydrostatic pressure (Figure 3).

In any case, it has been demonstrated in recent decades that very high hydrostatic pressure effects on marine life include failure of gel formation, failure of cell division, failure of ameboid movement and inhibition of the growth of bacteria. Most of these effects develop at pressures above 1,000 atmospheres and appear to be related to volume changes in cells. This suggests the possibility that water pressure at the depths were man hopes to live for long periods might have some appreciable but less drastic effect. Recent simulated and operational deep ocean dives (greater than 600 feet) have suggested the possibility of some pressure effects on bone-muscle structures. Divers working at depths

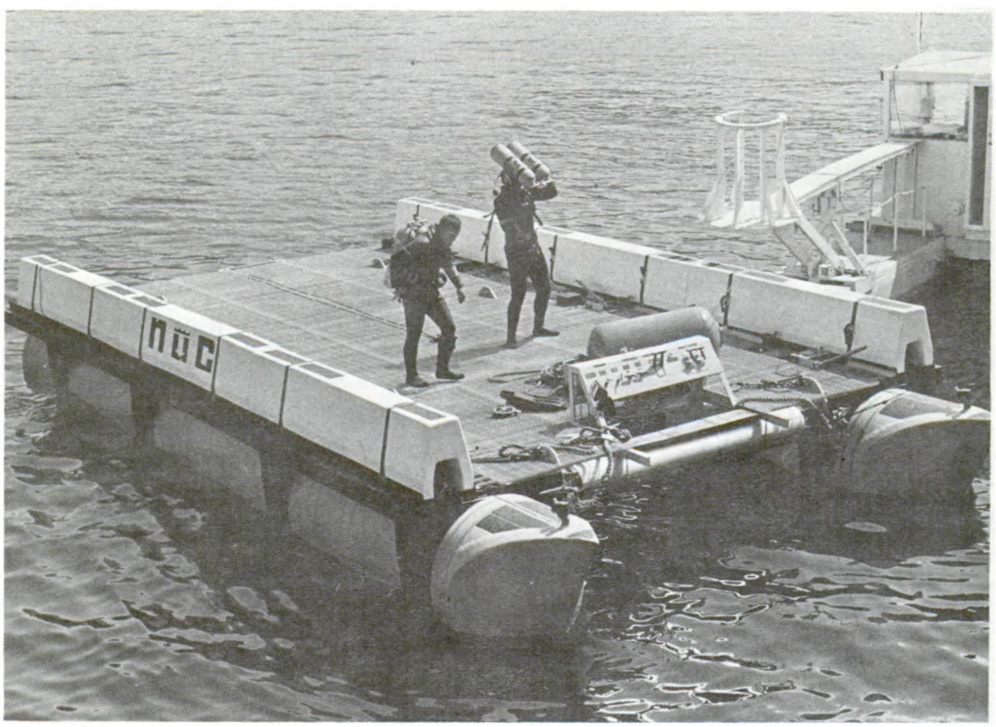

Figure 3 — Launch and Recovery Platform (LARP) under development by the Naval Undersea Research Development Center will allow launch and recovery of submersibles while still submerged to minimize problems in less-than-ideal sea conditions. Program is part of the broad range of technological innovations being accomplished by the Navy in the attack on diving problems.

exceeding 600 feet have shown an increasing tendency toward tremors, backaches and aching joints. Although the number of incidents cannot support firm conclusions, there appear to be some bone-muscle effects resulting from high hydrostatic pressures that must be investigated.

Fluid Breathing

Almost all the present problems of deep diving could be solved or greatly alleviated if new approaches to underwater life-support now under study should prove feasible. Among these new approaches are the techniques of fluid breathing and the use of artificial gills for gas exchange.

Experimental evidence indicating that the lungs of mammals can function as gills was first presented in 1962. It was found that adult mice, rats and dogs can live for several hours submerged with lungs filled with fluid—in salt solutions equilibrated with oxygen at high pressures. Under these conditions, the submerged mammals continued making respiratory movements, and were apparently capable of extracting adequate amounts of dissolved oxygen from the aqueous environment. Although completely narcotized, the animals were not fatally injured by hydrostatic pressures of up to 160 atmospheres which is equivalent to an ocean depth of one mile.

The potential practical importance of this phenomenon is clear. The problem of decompression sickness would be circumvented since the inert gas would no longer by present. No inert gas would dissolve in the blood and tissues of a diver with fluid-filled lungs; consequently, he would be free to ascend to the surface an any time and as rapidly as he desired without fear of bubble formation. The problem of inert gas narcosis would also be avoided. If the fluid breathing concept proves to be physiologically feasible in all ways, the depths that man can reach as a diver would be limited only be the effects of water pressure on cellular structure.

However, the use of the fluid breathing technique by humans is far in the future since all of the physiological effects of fluids on the lung tissues are still not known. Furthermore, a gas exchange in liquid-filled lungs is diffusion-limited and at least 60 times more work is required to propel equal amounts of water, instead of air, through the lung passages.

These factors seriously restrict carbon dioxide elimination in water-breathing mammals. In mechanically-ventilated water-breathing dogs, carbon dioxide elimination was always deficient. The use of fluid breathing techniques by man could only come about through extensive research into the effects of fluids on lung tissue and through solution of the problem of carbon dioxide elimination.

An artificial gill would give man the same ability that fish now have in obtaining oxygen. Fish obtain oxygen by diffusion from the water in

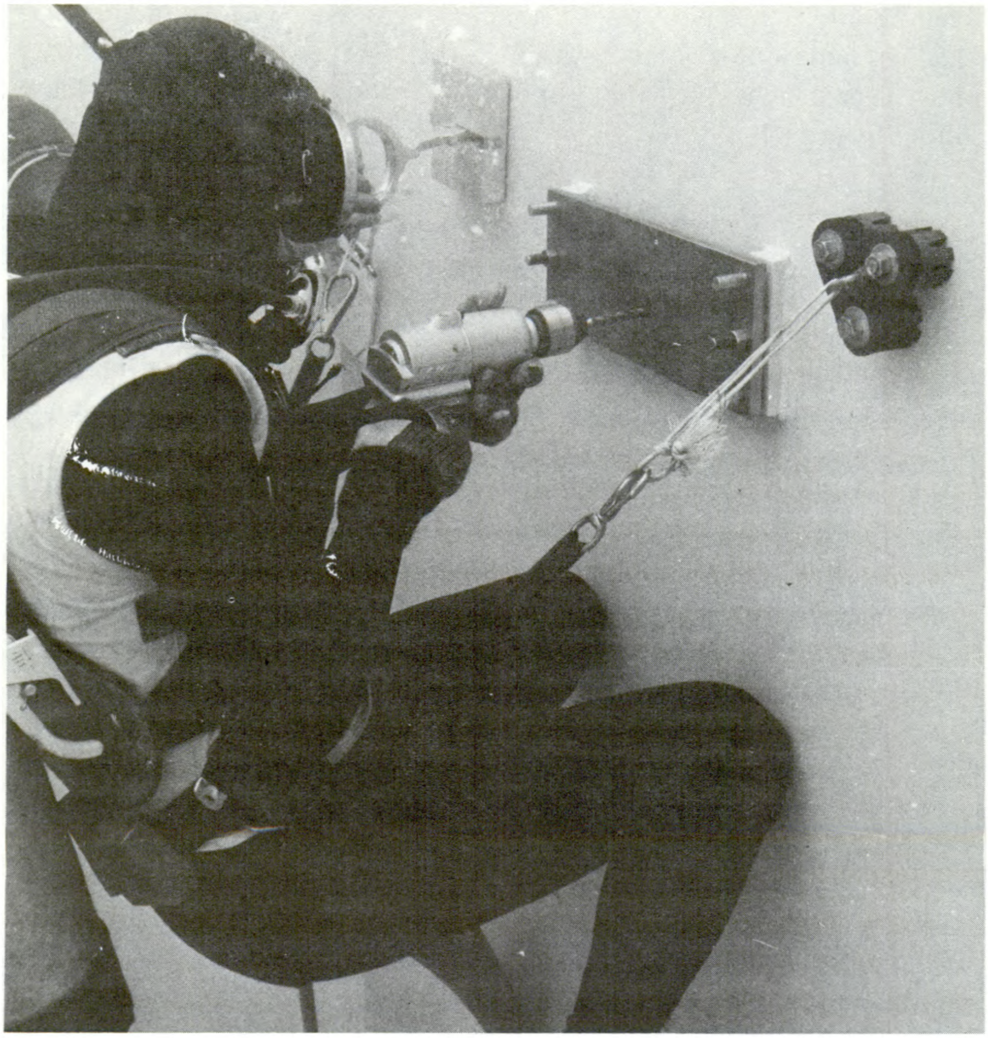

Figure 4 – Underwater tasks involving use of torque require systems that can counteract forces developed in the weightless environment. The diver shown above is drilling underwater while making use of what appears to be a restraining device held firm by magnetic clamps. The problem of force counteraction is encountered in the outer space environment also, and similar devices are under development to solve those problems. Note heavy gloves required to deep diver's hands warm.

which they swim and eliminate carbon dioxide in the same way. Diffusion takes place in the gills of fish where water and blood are in intimate contact, separated mainly by a series of cell membranes. The same physical factors that operate to supply oxygen and eliminate carbon dioxide in fish gills; *i.e.*, membranes with appropriate permeability properties, could be used in the design of artificial gills. An artificial gill, which could enable submerged men to obtain oxygen by diffusion from water, would have obvious advantages. Work on such gills has been conducted in several laboratories, and recently a patent was awarded to the designer of one. Any of the fluid-breathing methods would, of course, require considerable efforts to insure maintenance of body temperature. The ultimate system might be a combination of the fluid breathing technique with the extraction of oxygen from sea water by artificial gills.

Technological Research and Development

Research and development efforts in diving technology can be divided in two parts: the first associated with life support; the second, with functional support of the divers. Life support technology concerns itself with the hardware necessary to keep the diver alive and well in the ambient ocean pressure.

The attempt to increase diving depth is placing more stringent requirements on the makeup of breathing gas mixtures and the monitoring of gas concentrations. The physiological effects of oxygen, inert gases, and contaminants are generally proportional to partial pressure: the product of concentration and total pressure. Thus, the allowable concentration of any substance must become smaller as diving depth is increased. For example, at 100 feet, the safe percentage of oxygen ranges form 3.75% to 7.50% and carbon dioxide percentage from 0% to 0.50%. At 1,000 feet this range is from 0.48% to 0.9% for oxygen and 0% to 0.06% for carbon dioxide. Devices for sensing, monitoring, and controlling the gas environment more stringently at high pressure must be improved. Moreover, methods of detecting and eliminating contaminants, such as carbon dioxide and carbon monoxide, must be developed. Unless the components of gas mixtures can be reliably controlled, full exploitation of the diving capabilities of man will not be possible.

Closely related to the development of reliable sensing, monitoring, and controlling devices for providing a safe breathing gas environment at high pressures is the continuing development of reliable and safe closed-circuit, mixed-gas, self contained underwater breathing apparatus. Present day breathing devices are limited in depth and time capability because of the need to exhaust portions of the breathing gas during each breath. The open or semi-closed SCUBA devices do not fully exploit the full amount of gas a free swimming man can carry. The totally closed-circuit oxygen rebreather is limited in depth because of the problems of oxygen toxicity. A closed-circuit device where the breathing gas is mixed as needed, has been developed to extend the depth-time capabilities of current breathing apparatus. Certified by the Navy, the device, designated as the Mark 10, is able to extend diving time to about 6 hours at all depths of the continental shelf.

Extending the time and depth capabilities of diving apparatus to the deep colder depths will, of course, complicate the problem of body thermal equilibrium discussed above and make essential the development of heated diving suits and localized heat sources. Open-circuit hot water suits are being used successfully; however, the cumbersome umbilical is undesirable. A battery-supplied, resistance-wire heat suit was tried during the SEALAB II experiments, but it is limited by the available energy-density of the battery pack. The base of the heated suit problem, thus, is in the development of a compact energy source, which is a technological area that is receiving research attention for many areas of application. Ancillary equipments that are being developed to support divers include advanced head gear, depth gauge and decompression computers.

The second aspect of research in diving technology—functional support—is associated with the hardware and systems that aid the diver in accomplishing his underwater tasks, such as tools. Underwater tasks present problems that are encountered in similar jobs on land. One of these problems is the virtual weightlessness of divers which makes working underwater quite similar to working in outer space. Simple chores that require the application of torque, such as screw driving, nut tightening and bolting, need tools and systems that can neutralize or counteract the reactive force on the weightless diver.

Protective clothing such as gloves, needed to keep the diver comfortable when working in cold water, drastically decrease his efficiency in tasks that require fine tactile discrimination and finger dexterity. This may be compounded by poor visibility.

Numerous tools are becoming available for use in the underwater environment. Many of these were adapted from land tools to meet the waterproofing and pressure requirements imposed by the underwater conditions. In response to the need for improved tools, the Navy has been engaged in research to define the work capabilities of divers and the engineering criteria necessary for the design of specific underwater tools. Among these are tools for torqueing, cutting, drilling and punching, welding and fastening and miscellaneous tools having potential applications in underwater work tasks.

Besides underwater tools, functional support of the diver requires improvements and development of other aids such as communication equipment, navigation equipment, sonar and propulsion aids. One technological development now receiving attention by the Navy is the exploitation of self-supporting, ocean-floor diving stations. In existing techniques the man working and living underwater must depend on a surface support ship for air, power, communications and other vital elements for his operation. He must return to the support ship to be decompressed. This makes the success of the operation susceptible to sea conditions at the surface and the stability of the surface support.

An autonomous ocean floor diving station, incorporating its own life support systems, including decompression facilities and capable of some mobility would sever the umbilical cord that tethers him to the surface.

In this article only a few of the problems involving man and his ability to dive deeply with safety for long periods have been discussed. The psychological pressures that face him also require serious research. For example, little is yet known about the psychological effects produced by the anxiety of man who finds himself removed from the familiar and relatively secure *terra firma* and his ability to respond to emergency conditions. In the unfamiliar and alien world of the ocean bottom, dispossessed of normal social contacts, he undergoes sensory deprivations and is often unwilling to communicate with his fellow workers. In the underwater realm, the power of reasoning and performing mental tasks may be affected, visual perception is reduced, judgement of the relative distances of objects is impaired, manual dexterity is lessened, and the intelligibility of speech are perhaps best exemplified by the familiar "Donald Duck" effect encountered in helium breathing.

Understanding and developing solutions to problems such as these may take years of research and experimental work in simulated and real situations. Eventually man must conquer this barrier to permit him to roam and explore within the oceanic frontiers of the earth, to reap the bounties of the sea, and to unveil the mysteries of its depths.

New Compact Satellite Navigation Receiver Sets Ordered for Shipboard Use

New compact and more reliable satellite navigation receiver sets will soon go into shipboard use. The Navy has placed an order with the Magnavox Company for 32 sets to be used primarily on special purpose surface ships.

The equipment, an outgrowth of an integrated system developed by the Office of Naval Research (ONR), will be used in conjunction with the Navy Satellite Navigation System, better known as TRANSIT. Basically the TRANSIT system consists of several navigation satellites in circular polar orbit about 600 miles above the earth together with a precision network of ground stations which predict and record the satellites' constantly changing orbits. The satellites are capable of providing highly accurate, passive, all-weather world-wide navigation for ships at sea.

Each satellite is actually a self-contained navigation beacon. It transmits on two very stable frequencies, sending out timing marks at two-minute intervals and a navigation message which describes the satellite's position at each timing mark. By receiving these signals, the system user can calculate an accurate position fix.

Although TRANSIT has been in operation since 1964, the primary users until recently have been Polaris submarines and a few surface ships. The high cost and size of receiving equipment have limited its application. The existing receiver consists of three separate components.

(Continued on Page 28)

Triggered Lightning and Some Unsuspected Lightning Hazards

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This paper considers instances of lightning initiated by man's activities. These include the triggering of lightning by high-rise buildings and other tall structures; by rockets trailing wires; by the column of water thrown up by a depth-charge; by the large Apollo 12 rocket; by aircraft; and by thermonuclear explosions. All the incidents occur when the ambient electric field is some 10,000 volts per meter, and the voltage discontinuity between the conductor initiating the lightning and the adjacent atmosphere is about a million volts.

It is pointed out that solid-state devices and micro-circuitry, computers, plastics, and electrically composite materials, are all quite vulnerable to the effects of lightning. These components are being increasingly used in aircraft construction and operation. Also, as aircraft become bigger and faster they have a greater propensity to trigger lightning. Therefore it is concluded that the lightning hazard to aircraft operation is increasing.

We define triggered lightning as lightning that is caused by some human modification of the natural atmospheric environment. This definition excludes lightning that has been occasionally reported as occurring in dust-storms, in snow-blizzards, within the clouds above active volcanoes, and in association with earthquakes. All these lightning occurrences—although unusual—are in accompaniment to a natural phenomenon; the lightning is not due to any man-made activity.

Almost all instances of lightning triggered by man, either by design or by accident, involve the introduction of a long electrical conductor into a thundery environment where the general electric field is some 10 kilovolts per meter (kV/m). If the potential discontinuity between the tip of the conductor and the ambient atmosphere becomes about a million volts (10^6V) a leader-streamer is initiated from the conductor and triggered lightning can occur. We may differentiate between two main categories of triggered lightning:

(a) The conductor is connected to earth. Examples are shown in Figure 1. These include lightning triggered by a tall building, and discharges initiated by the sudden introduction of a conductor (depth-charge column of water; rocket carrying a wire) into a thundery environment.

(b) Conductor is in free flight. Examples are shown in Figure 2. They include discharges triggered by rockets (Apollo 12) and by aircraft.

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The writer of more than 50 scientific papers, Dr. Pierce specializes in atmospheric electricity and lightning.

Equipotential surfaces are indicated on Figures 1 and 2; however, the motion of, and the charges carried by, rockets and aircraft, may cause appreciable distortions from the representation of Figure 2. The greatest electric fields are where the equipotentials are closest spaced that is at the extremities of the conductors. It is at these points the the leader-streamers initiating lightning develop.

Franklin's classic kite experiment is an example of a conductor connected to earth and could well have resulted in an instance of triggered lightning similar to some of those on Figure 1. Fortuitously, but most fortunately for humanity in general and the U.S.A. in particular, Franklin's kite did not trigger lightning. Other kites flown later under circumstances similar to those of Franklin's experiment have, as indeed is occasionally to be expected, triggered lightning, with the result that the kite flyers have sometimes been killed (1).

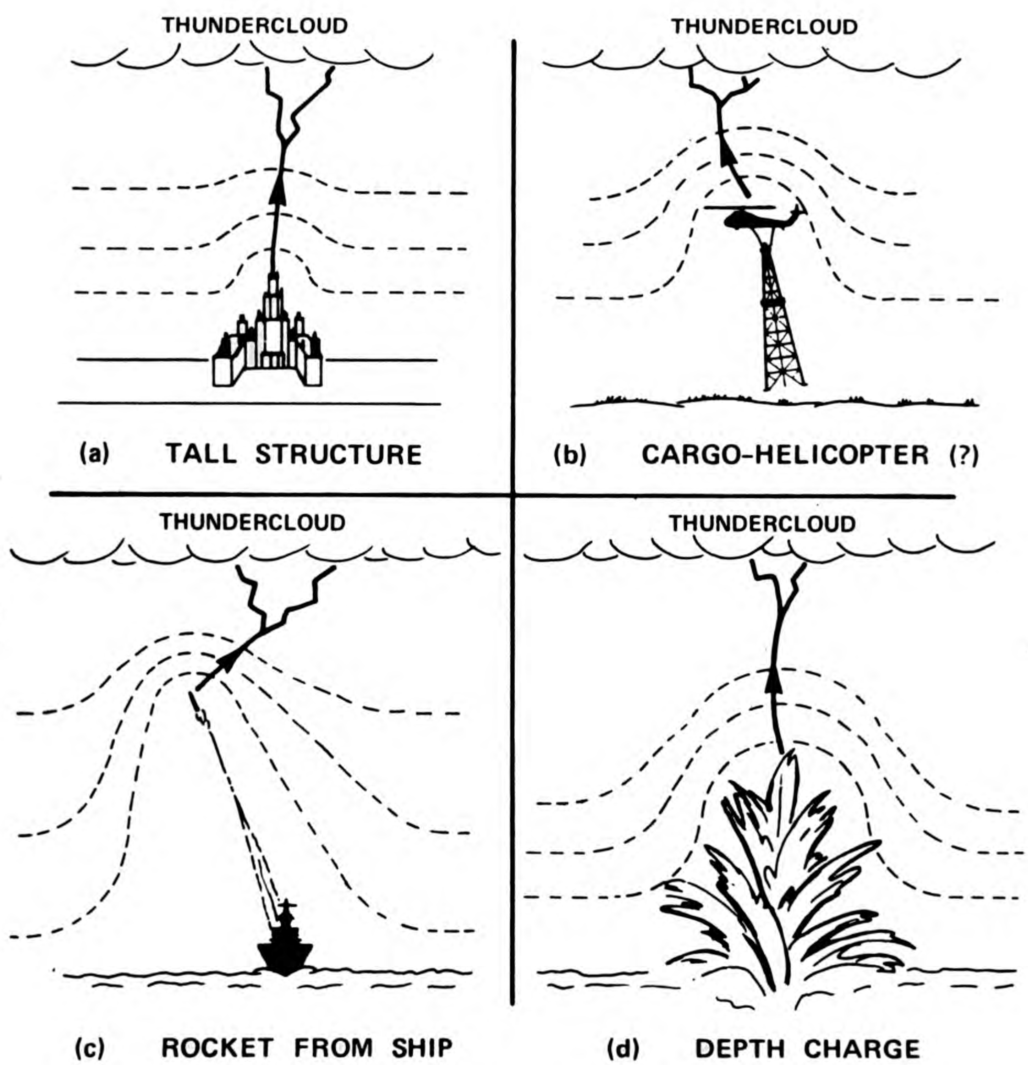


Figure 1 – Examples of triggered lightning

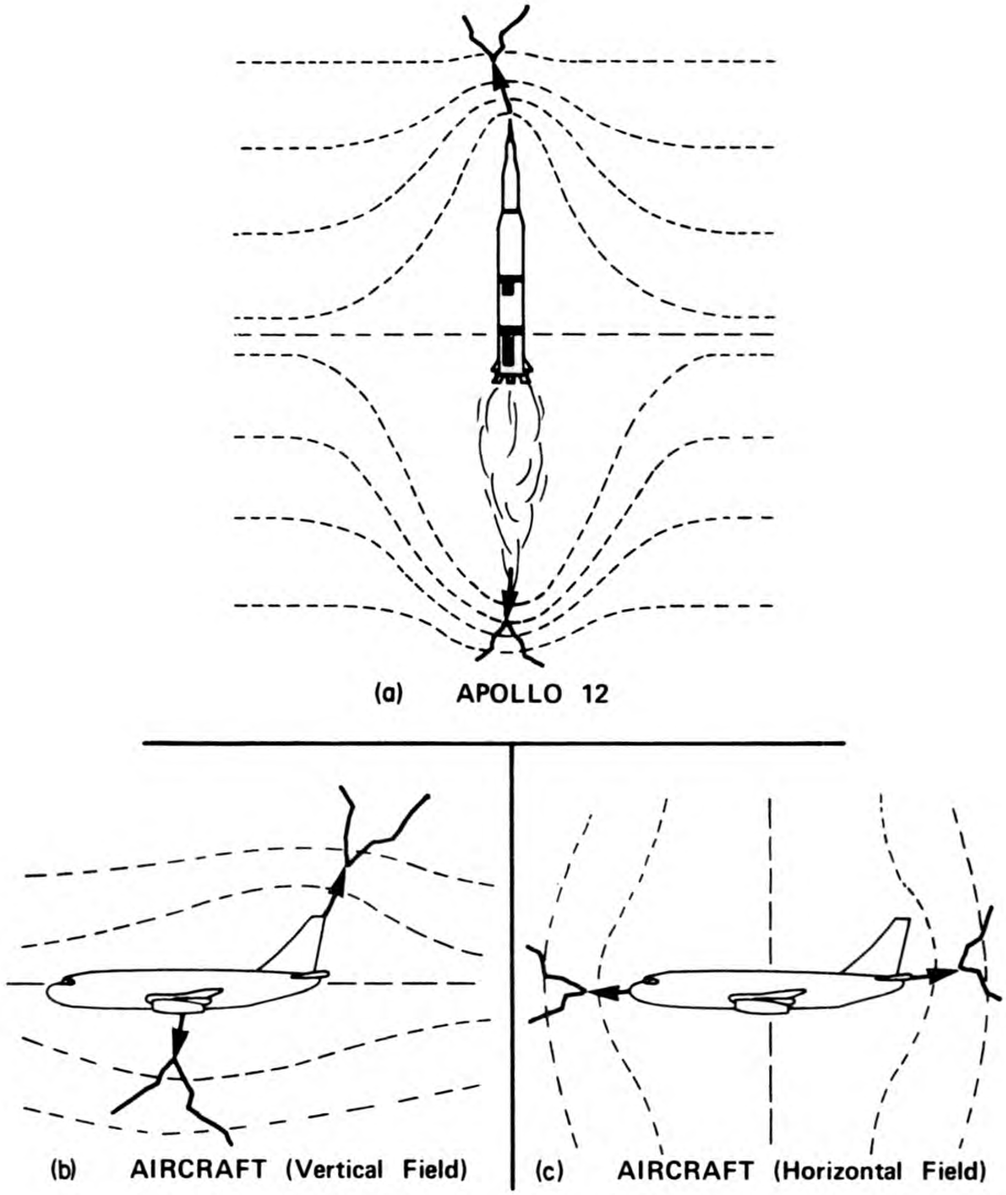
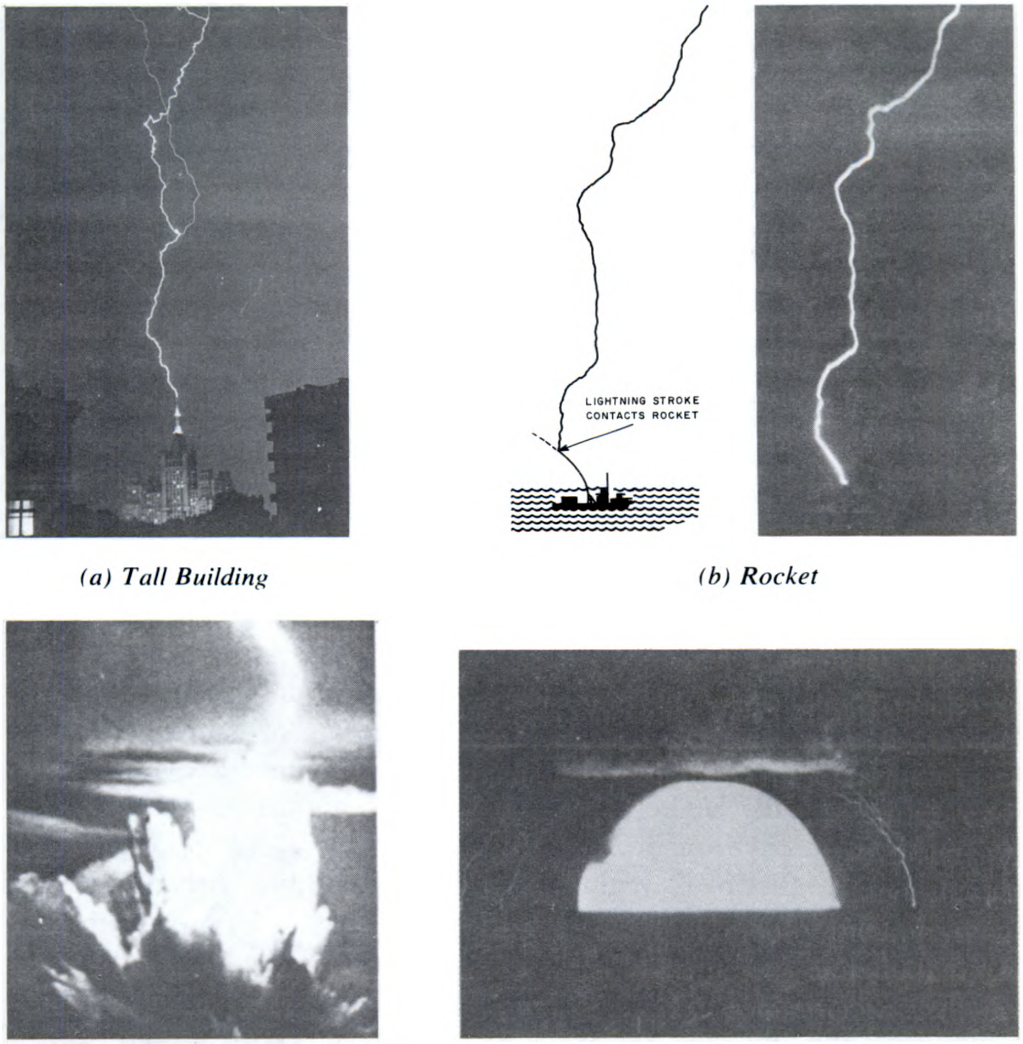


Figure 2 – Examples of triggered lightning

Lightning Triggered by Tall Structures

Conventional cloud to ground lightning is initiated by a leader that travels from the cloud towards the earth. However, the classic work of McEachron (2) on the Empire State Building showed that lightning to the building is usually started by a leader moving upwards from the tip of the building towards the charged clouds. In other words, lightning is triggered by the presence of the building. Figure 3(a) shows an example of lightning initiated by the tower of a prominent building in Moscow.

Figure 4 summarizes some data on the incidence of lightning flashes to tall structures (buildings, TV towers, *etc*.). The data are for temperate



(a) Tall Building *(b) Rocket*

(c) Depth Charge *(d) Nuclear*

Figure 3 — Instances of triggered lightning

latitudes and have been drawn for several sources (2-8). An adjustment to an isoceraunic (thunderstorm days per annum) level of 32 has been made. We note that structures less than about 150 meters (m) in height are only struck by conventional lightning. However, with increasing height there is a very rapid increase in the proportion of flashes initiated by the structure; for a structure height of 200 m it is about 50 percent, and at 400 m it exceeds 80 percent.

The conditions for the development of a leader-streamer from the tip of a conductor depend upon the electric field magnitude and configuration in the vicinity of the tip. The breakdown field must be exceeded over some distance from the tip and not only at the tip itself; otherwise, even such a minor breakdown as point corona would produce leader-streamers. In the case of a tall structure, the field configuration at its top is controlled by the general ambient field, E_a, the height, H, of the

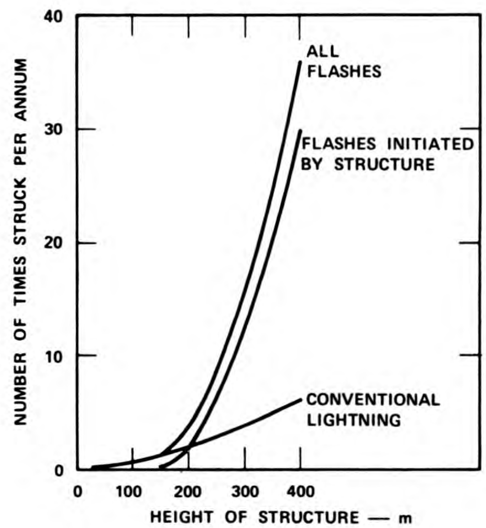


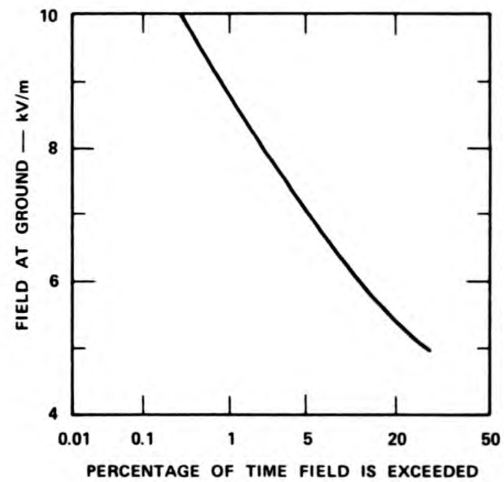
Figure 4 — Data on flashes to tall structures (isoceramic level—32)

structure, and its shape; this last, is a factor for which a normalizing adjustment between different structures is impracticable. However, we may define two parameters which can readily be estimated, and which are quantitatively indicative of the thresholds for the development of leader-streamers and accordingly for the triggering of lightning. These parameters are the general ambient field, E_a, mentioned above, and the voltage discontinuity V_d between the tip of the conducting structure and its atmospheric environment. For a tall building V_d is approximately equal to the product of E_a and the height of the building. Broadly speaking, the value of V_d, the voltage discontinuity, has to be greater than a certain threshold before a leader-streamer can be initiated; whether the streamer subsequently becomes self-propagating depends on a critical value of E_a, the ambient field, being exceeded. Thus both V_d and E_a are involved in determining the criterion for the occurrence of triggered lightning.

When there is a thundercloud overhead the strong electric fields at ground level cause points such as trees at the surface of the earth to go into corona. The resulting ionic space charge is distributed between the ground and the thundercloud, and it follows from Poisson's equation that because of the space charge the field should increase with increasing height. The magnitude of the increase is uncertain. It may be by tenfold ore more; it may be slight. The experimental evidence is confused. However, it is generally agreed that the field certainly does *not decrease* between ground and cloud levels. Also, because of the effective absence of surface points and irregularities over sea the surface ambient field is probably substantially greater than over land, while the increase of ambient field with height is less pronounced.

Figure 5 presents some data, derived from Simpson's measurements (9), regrading the magnitudes of the surface field (E_0) during a typical land thunderstorm. Obviously the field rarely exceeds 10 kV/m. We may

Figure 5 – Structural data on surface fields in a thunderstrom environment



associate this effective maximum experienced value for E_0 with the minimum height – 150 m – needed to trigger a lightning discharge (Figure 4). The product of these two figures gives us a rough threshold value of 1.5 million volts or so below which a lightning strike would be unlikely to occur.

Estimates of (the voltage discontinuity at a height H) V_H can also be made for certain specific structures. Bruce (10) deduced that discharges could be initiated by the Empire State Building when the *average* field between the ground and the tip of the building was only 5 kV/m. Since the height of the Building is 380 m this gives $V_H = 1.9 \times 10^6$V. Müller-
the height of the
Hillebrand (11) has discussed an instance of upward leaders occurring simultaneously from two towers, each 70 m tall, situated near the 600 m high summit of Monte San Salvatore. At the time the ground field E_0 was approximately 3 kV/m. Evidence (6) suggests that the "effective" height of the towers is increased by perhaps 200 m as a result of their location near the summit of a sharply peaked mountain, creating a voltage discontinuity at that combined height of 8.1×10^5V.

Solak (12) has pointed out (Figure 1(b)) that a cargo-helicopter when its load is near the ground acts effectively as a tall structure, and as such is vulnerable to a triggered lightning hazard when in a thundery environment. The hazard may be increased by the charge carried on the helicopter producing a local breakdown, and therefore a sudden conducting connection, between the load and the ground. Tethered balloons (13) are another type of tall structure that can initate triggered lightning.

Lightning Triggered by Rockets Trailing Wires

There have been many attempts to trigger lightning by firing rockets trailing conducting wires into thunderclouds. These efforts have met with little success over land. Over sea, however, Newman and his associates (14) have triggered lightning on several occasions; Figure 3(b) shows an example. The better success for sea as compared with land is to be expected, since because of the lesser point-discharge (and consequent space-charge) effects, the surface fields—and therefore the effective electrical perturbation due to the rocket—are greater over a sea-surface than over solid terrain.

Triggering over the oceans has occurred with the rocket at heights of between 100 and 300 m. The fields were about 18 kV/m both at the sea-surface and at the cloud base(15), giving voltage discontinuities of between 1.8 to 5.4 million volts at these rocket heights.

The Depth-Charge Incident

This famous instance (Figure 3(c)) of triggered lightning occurred when depth-charges were being tested in Chesapeake Bay during thundery weather (16). Much to the surprise of all concerned, when the plume of water thrown up by one charge had reached a height of about 70 m a lightning flash occurred to the top of the plume. The discharge was of long duration and persisted as the water-plume continued to rise. The flash included at least three component strokes.

No measurements of electric field were being made at the time of the depth-charge incident. However, measurements made under similar circumstances (15) suggest surface fields of perhaps 10 to 20 kilovolts per meter with a consequent voltage discontinuity at the height of the plume of 0.7 to 1.4 million volts.

The Apollo 12 Incident

The lightning strikes to the Apollo 12 space vehicle shortly after its launch on November 14, 1969, have been thoroughly investigated (17). It is generally agreed that the discharges were triggered by the presence of the vehicle. The flashes occurred when the vehicle was within cloud and at altitudes of approximately 2,000 m and 4,400 m. No lightning was reported in the immediate vicinity of the launch-pad before the launch, although a few isolated flashes probably occurred within 30 km of the launch area during the 30 minutes prior to launch (15). However, although the clouds above the launch-pad were not active thunderclouds they were undoubtedly strongly electrified, and a reasonable estimate (15,17) for the surface field is 3 to 4 kV/m.

Figure 2(a) is a diagrammatic representation of electrical conditions around the Apollo 12 vehicle in free flight. The representation is probably unrealistic for several reasons. It shows the exhaust as extending the electrically conducting length of the vehicle system by an amount approximately equivalent to the length of the rocket; the effective conducting extension by the exhaust could well be either much greater or much less than this. Figure 2(a) assumes that the vehicle-exhaust system has attained electrical equilibrium with its surroundings so that the potential of the ambient atmosphere and of the system at its midpoint are equal; because of the rocket motion it is unlikely that this equilibrium situation will ever be approached. Charges on the vehicle will distort the electrical representation of Figure 2(a). Experiments with instrumented rockets show that because of engine charging currents, rockets can acquire a sutstantial charge following lift-off as soon as the conducting connection with the ground is broken. Furthermore, vehicle impact with precipitation elements can devélop very large charges on the vehicles (18).

There are obviously considerable uncertainties in estimating values of ambient electric field and voltage discontinuity for the Apollo incident. Most workers in atmospheric electricity believe that with a ground level field of 3 kV/m the field within the cloud above would be at least 10 kV/m; we will adopt this figure as a minimum value for the ambient field E_a. For the case of an airborne pointed conductor in electrical equilibrium with its atmospheric environment the voltage discontinuity, V_d, at the ends of the conductor is also dependent on the "electrical" length of the conductor. We assume that electrical equilibrium is attained, but there are still difficulties for Apollo 12 in estimating the electrical length, since we must add a rather uncertain amount to the actual length—110 m—of the vehicle in order to allow for a conducting exhaust trail. Calculations (19) suggest that at an altitude of about 2,000 m, 300 m is not an unreasonable estimate for the conducting length of the exhaust trail. Ground-level observations show that during the launch of Apollo vehicles the exhaust maintains a conducting connection with ground over a length exceeding 100 m, while actual in-flight measurements made with other large rockets indicate that this connection is abruptly broken at a trail length of about 200 m. Since exhaust conductivity increases with altitude these ground level values are quite compatible with a trail estimate of 300 m and 2,000 m altitude. We will therefore consider the electrical length to be 400 m, (300 + 100), for the Apollo 12 incident. For the intra cloud field assumed, the voltage discontinuity at the tip of the missile would be two million volts.

Lightning Triggered by Aircraft

Although aircraft are often struck by lightning it is usually impossible to determine whether the flash was initiated by the presence of the aircraft or not. However, there are at least two (20,21) published accounts of several instances in which the lightning was almost certainly triggered by aircraft. In most of these cases the flashes occurred while aircraft were penetrating dissipating thunderstorms which had ceased to produce lightning; the only discharges that took place during these penetrations were to the aircraft. It is also understood (22) that during the development of the Boeing 747 test flights were made in which the aircraft was flown in and out of clouds that were strongly electrified but not actually generating lightning. The 747 was consistently struck soon after entering the clouds; no other lightning, except that to the 747, occurred.

If we accept that a certain voltage discontinuity is necessary in order to initiate a leader-streamer it follows that the bigger an aircraft (greater length) the more likely it is to trigger lightning. There are indeed indications that, under comparable environmental conditions, the large aircraft now coming into widespread service are struck more frequently than their smaller predecessors. However, the available statistics are limited in extent and need careful interpretation. There is also some evidence that high-speed aircraft experience more lightning strikes than their slower fore-runners. It is tempting to associate this behavior with an effective electrical extension—as in the case of a rocket—of the aircraft by a conducting exhaust plume, but even for a high-performance fighter aircraft the exhaust plume is only a few meters in length (23). However, it should be recognized that an aircraft in flight is trailed by a cloud of ions, generated within the engine exhaust and also by corona from the aircraft. This ionic trail although not of itself a good conductor is nevertheless much more conducting than the undisturbed atmosphere. It seems quite plausible that a lightning leader encountering such a trail could be "led" towards the aircraft, especially if—as is believed—photoelectric processes occur in front of the leader tip (17). Since an ionic exhaust trail will preserve its identity to longer distances behind the faster aircraft, the chance of strokes being diverted along the trail should increase with increasing aircraft speed.

Electric fields within thunderclouds are predominantly vertical in orientation but there can be substantial horizontal components as well. Figures 2(b) and 2(c) show diagrammatically the electrical conditions possibly leading to the initiation of leader-streamers from aircraft for the two idealized cases of entirely vertical and entirely horizontal fields. As in the case of Figure 2(a) the assumption—probably unrealistic—of electrical equilibrium with the ambient atmosphere is made, while the effects of charge on the aircraft are ignored.

The instances of triggered lightning to an F-100 aircraft reported by Fitzgerald (20) occurred when the pre-discharge ambient electric field was about 30 kV/m vertically and 6 kV/m horizontally. The maximum dimensions of the F-100 are approximately 5 m vertically and 15 m horizontally. It follows that—assuming equilibrium with the ambient atmosphere— the voltage discontinuities are 75 kV for a vertical flash and 45 kV for one horizontally directed. The strikes described by Cobb and Holitza (21) were to a DC-6 (vertical dimension 9 m: horizontal dimension 36 m) and occurred in lesser ambient fields of some 16 kV/m vertically and 2 kV/m horizontally. With the larger dimensions of the DC-6 the corresponding voltage discontinuities are still 72 kV and 36 kV.

An Unusual Incident

Figure 3(d) shows lightning triggered by the detonation of the first thermonuclear device; this event, of 10.4 megatons yield, was set off at Eniwetok in the Marshall Islands on October 31, 1952 (24). Figure 3(d) is an enlargement of one frame of a high speed film. Study (25) of the other frames reveals that the lightning discharges were initiated from surface structures and developed as upward leader-streamers in entirely the same manner as more conventional triggered lightning from tall buildings (Figure 3(a)).

In one respect, however, this example of triggered lightning differs from all the others we have considered. In the previous examples, man provided the perturbation in the electrical environment necessary for the triggered lightning, but the environment was created by natural causes. In the present instance, however, the charge producing the electrical environment is itself generated by the explosion. The charge is developed by gamma rays emanating from the detonation and interacting with the atmosphere to create Compton electrons. Calculations (25) yield a value of 30 kV/m for the field due to the gamma-Compton mechanism. The flashes were apparently initiated from antenna-towers and similar structures carrying instrumentation; 10 m would be a reasonable estimate for their height. Hence, the voltage discontinuity is 3×10^5V.

Summary and Discussion of Triggered Lightning Incidents

Table I summarizes the incidents of triggered lightning that we have considered; the table extends some information previously presented (26). The deduced values for ambient field and voltage discontinuity are quite consistent. Obviously if the electric field in the atmosphere is about 10 kV/m, and we introduce a conductor into that field so that the voltage difference between the conductor and the adjacent atmosphere approaches 10^6V, then we may expect triggered lightning. These two quite general criteria can readily be applied to predict the hazard represented by triggered lightning under many different circumstances.

There are only two entries in Table I which show very large deviations from the general pattern. There are the two aircraft incidents, for which the deduced values of the voltage discontinuity are less than 10^5V; the average for all incidents is of the order of 10^6V. However, it should be recalled that in the analysis any effects due to charge on the aircraft have been ignored. It is well known that when flying through clouds

Table I
Triggered Lightning Incidents

Type of Incident	Ambient Field (kV/m)	Length of Conductor (m)	Voltage Discontinuity (kV)
Tall Structures			
General Statistics	> 10	150	$\geq 1.5 \times 10^3$
Empire State Building	5	380	1.9×10^3
Monte San Salvatore Tower	≥ 3	270*	$\geq 8.1 \times 10^2$
Rocket Trailing Wire	18	100 to 300	1.8 to 5.4×10^3
Depth-Charge	10 to 20 (?)	70	0.7 to 1.4×10^3
Apollo 12	≥ 10	400†	$\geq 2 \times 10^3$
Aircraft			
F-100	6 to 30	15 to 5	45 to 75
DC-6	2 to 16	36 to 9	36 to 72
Thermonuclear	30	10	3×10^2

*Effectively extended by shape of mountain.

†Effectively extended by exhaust trail.

aircraft can become charged to such an extent that their potential may be several hundred kilovolts with respect to the neighboring atmosphere (18). This potential is presumably available to supplement the voltage discontinuity due to the ambient field alone, and thus lead to the initiation of leader-streamers. Certainly the charge carried by aircraft and rockets should be considered when their propensity to trigger lightning is being assessed. We have investigated two reports (20,21) of triggered lightning incidents to aircraft. It is perhaps very significant that in the first instance (20) strong charges were measured on the aircraft, while in the other case (21) the strikes occurred with the aircraft was encountering a mixture of rain and graupel; precipitation-impact charging currents are notoriously high under these conditions.

Some Unsuspected Lightning Hazards

Aside from structures and airborne vehicles there are other practical dangers associated with lightning. We have been familiar for many years with shocks to human beings, lightning effects on forests, and methods of lightning protection. However there are more novel aspects in which our way of life is being inconvenienced by lightning. Most of these newer hazards follow directly from technological improvements; such improvements often entail—unfortunately—an increased vulnerability to lightning.

A. *Vulnerability of Solid-State Circuitry*

The electrical interference caused by lightning may be separated into two main categories. We have the electromagnetic signals radiated into the atmosphere by the discharge, and the surges traveling along powerlines that are either struck or experience near misses. Extraneous noise inductively coupled into electronic circuitry is a familiar interfering factor in many systems. However, modern electronic systems make increasing use of semiconductors and low-signal level microcircuits, and these are much less tolerant of transient voltage and current surges than were the vacuum tubes and large electronic components of the past (27,28). Both induced coupling effects and surges introduced through power supplies can readily cause malfunctions and even permanent damage to transistors and solid-state diodes.

B. *Vulnerability of Computers*

Computer operations are perhaps especially vulnerable to lightning. The effects of power surges can range from the inconvenience of lost time, when the operation in progress has essentially to be reaccomplished, to the extreme of serious damage to magnetic disks, recording arms, and so on. Even more alarming are the possible results of a flash occurring very close to an insufficiently shielded computer. It appears that the magnetic and electromagnetic fields radiated by the flash can seriously modify the core memory cells of a computer. The consequences in such areas as banking, where customers' affairs are increasingly monitored by computer surveillance, could obviously be disastrous.

C. *Vulnerability of Modern Materials*

Modern technology involves the widespread use of plastics which—normally—are electrical insulators. Also, electrically composite materials, for example those which utilize fibers such as carbon or boron embedded in a plastic matrix, are being increasingly employed. The behavior of both plastics and composites when subjected to lightning currents is much less satisfactory than that of conventional metals, with the chance of material damage being much greater. There are also some subtle features. For example, as metals are replaced by less electrically conductive materials the inherent safety of shielding by "Faraday-cage" effects is reduced. Furthermore, in electrically inhomogeneous systems the currents are channeled preferentially into the better conducting media; therefore current densities and induced fields are increased and deleterious effects are consequently enhanced.

In some instances. many factors, related to modern developments, contribute to a lightning hazard. For instance, TV towers exceeding

300 m in height are now quite common structures. These towers are convenient high platforms for some equipment; examples are meteorological sensors and radio communication links. Almost inevitably the equipment will include solid-state circuitry and use plastic materials in its fabrication. Thus we have the structure, because of its height, triggering many flashes to the tower; we have vulnerable solid-state components experiencing this intense lightning exposure; we also have damage-prone plastic materials encountering the same exposure; and we have the secondary effects of diminished "Faraday-cage" protection and increasing channeling of lightning currents.

Table II
Lightning and Aircraft Operation

Trend in Aviation	Result	Lightning Hazard
Bigger Aircraft	More Triggered Lightning	Increased
Faster Aircraft	Minor Damage Increased by Wind-Loading	Increased
	More Triggered Lightning (?)	Increased
Better Climb Rate	Less Time at Lower Altitudes	Decreased
More Traffic	More Time in Holding Patterns	Increased
Greater Use of Plastics	More Material Damage by Strike	Increased
	Concentration of Current in Remaining Metal	Increased
Greater Use of Composite Materials	More Material Damage by Strike	Increased
	Concentration of Current in Remaining Metal	Increased
Greater Use of Solid-State Electronics	Greater Vulnerability to Lightning Transients	Increased
More Reliance on Electronic Flight Controls	Greater Vulnerability to Lightning Transients	Increased
More Reliance on Preprogramming of Flight on Airborne Computer	Greater Vulnerability to Lightning Transients	Increased

D. *Vulnerability of Aircraft*

The relationship between aircraft operation and lightning is presently one of much interest; there are strong indications that the overall lightning hazard is tending to increase. Some of the main areas concerned are listed in Table II; the list is not exhaustive but obviously the sum of present trends in aircraft design and operation acts to augment the lightning hazard. The civil jet aircraft of 1959 was constructed largely of metal; cruised at 35,000 feet and could thus avoid most active thunderstorms; was fitted with rugged electronics; and relied more during operation on pilot judgment than on automatic controls. By all appearances the supersonic aircraft of—say—1979 will be constructed of plastics and composite materials; will cruise at 60,000 feet; will use only solid-state circuitry and components; and will follow a present flight plan entirely computer controlled. A cursory examination of Table II shows that the lightning hazard will be much greater for the 1979 aircraft than for its predecessor of 1959, unless some of the problems discussed above are solved.

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(Continued from Page 13)

A few years ago ONR through the Scripps Institution of Oceanography sought to procure a limited number of miniaturized and reliable modular receiving sets for use aboard Navy oceanographic ships, which require high accuracy in navigation. This resulted in the development of an accurate and compact modular receiver, which is fully automatic in operation and easy to maintain by using modular units.

The new receiver integrates the three previous components and includes a computer for processing the satellite signal. The result is a "black box" roughly two feet square and weighing only a few hundred pounds. This compares to more than a thousand pounds for the previous equipment.

The miniaturized receivers were tested for 17 months aboard oceanographic research ships and some ships and aircraft in the fleet. The sets demonstrated extremely high reliability, consistently high accuracy, and negligible down time because of the modular replacement concept. In addition, the complete integration and compactness of the models make them easily portable, permitting rapid and easy transfer between ships or aircraft when required.

The group of 32 receivers that have been ordered incorporate a number of the same principles of the minaturized model with some minor improvements, such as a larger memory core for the computer. Magnavox is fabricating the receivers under a contract with the Naval Electronic Systems Command.

Research Note

Radar that "Sees" Under the Ground

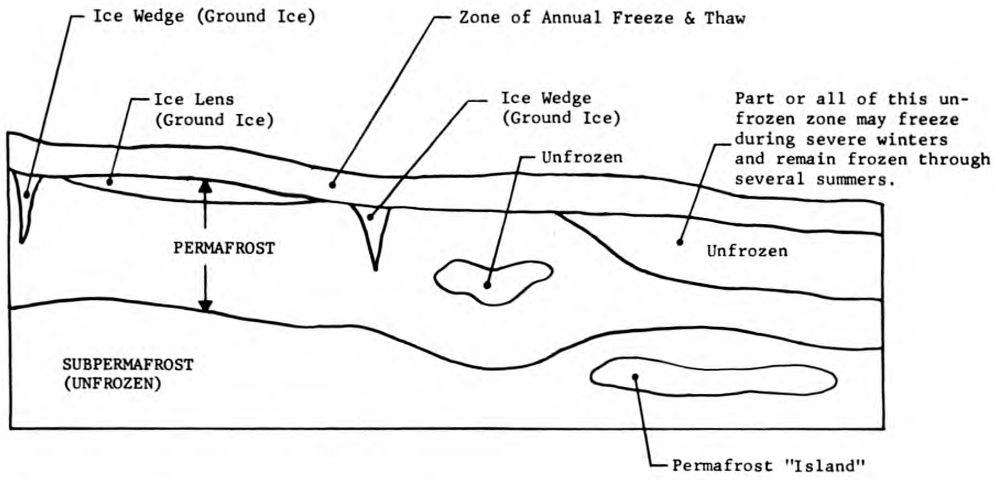
A radar that can "see" beneath the ground to variable depths is under study by the Navy as a possible system for detecting, locating and describing buried objects. The broad band pulse radar system was developed by Geophysical Survey Systems, North Billerica, Massachusetts. The company under a contract with the Office of Naval Research is exploring its application to Navy and Marine problems. The system, called Electromagnetic Subsurface Profiling (ESP), is portable and operates on a few watts of power.

Basically, the ESP System is the electromagnetic equivalent of the seismic method of geophysical exploration. The waves produced by the seismic sounder are known to propagate in a wide variety of materials. Since the seismic pulses are localized in time, it is possible to differentiate soil and rock strata by separating the received pulses on a time scale. The seismic pulse may be conceptualized as a burst of energy which is modified in velocity and shape as it progresses through the earth. The electromagnetic equivalent of the longitudinal acoustic waves used in seismic sounders is the transverse electromagnetic wave. These waves are produced electrically by discharging a battery into a special wave launching device. These discharges take place in the order of one nanosecond (10^{-9} seconds). A fast switch is used to create a time-limited signal which during the transmit cycle is sent directly to the wave launching device. The transmitted wave is reflected from the interfaces of various soil and rock strata and objects in the earth. Radar reflectance from the interface is governed by the differential in the electrical characteristics of the materials. These characteristics vary with priority, grain size, dielectric content, conductivity and moisture content.

The reflected signal is picked up by the same device used for launching the transmitted wave. A selector then channels the returned signal to a receiving device. A cable connects the unit with receiving and recording instruments in the recording trunk. The radar pulse are displayed in real time on a screen and are recorded on magnetic tape. They can also be printed out on paper as a continuous graph.

At this point, field interpretation of the raw data can often provide information sufficient for the project at hand. When data is more complex, or when detailed and permanent profiling is required, the print-outs are analyzed by a staff geophysicist. To assist him, the raw print-out data is refined by a variety of laboratory techniques. Replay of the tapes in the presence of electronic variables produces a more sharply defined profile. A computer further aids in location and identification by matching profile data against models constructed through previous experience and stored in a data bank.

One Navy application is the examination of permanently frozen ground, known as permafrost, in arctic and subarctic areas. Any construction or land use in these areas depends on understanding the nature and extent of subsurface conditions, particularly whether large masses of ground ice exist beneath the surface. If this is not carefully ascertained, significant ground subsidence can



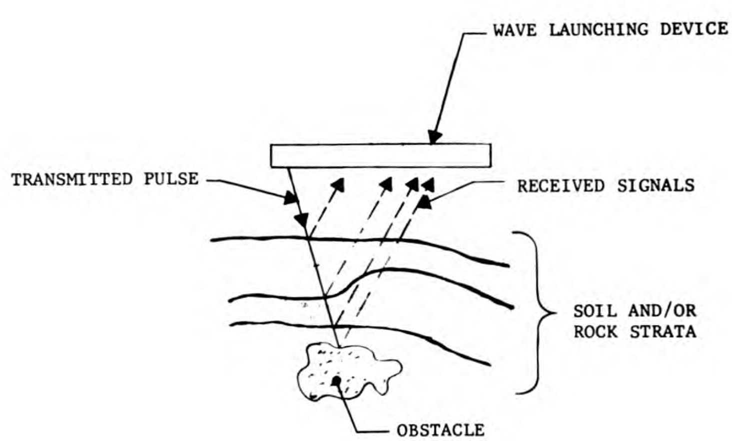
Generalized diagram of structural and compositional relationships with in permafrost and between permafrost and surrounding unfrozen soil (modified after Stearns, 1966).

take place, leading to costly repairs or abandonment of the structure. Presently borings are used but generally give an incomplete, and often misleading, picture of subsurface conditions. Seismic and other geophysical methods have been used with less success.

In one experiment conducted with the ESP system six tons of block ice were buried several feet down in sand and silt. The ESP profile clearly indicated the presence and location of the ice against the background of the sand and silt. Further tests are now being conducted in actual permafrost near Barrow, Alaska, the site of ONR's Naval Arctic Research Laboratory.

In other experiments the ESP radar precisely located various objects, including wire strand, wood and cement blocks, and metals, buried in naturally occurring deltaic sediments. In one test a tunnel was detected.

Further research is expected to devise new data processing techniques in order to display more clearly the configuration and signal response of buried objects. It is also planned to explore the development of an airborne ESP system.



Block diagram of ESP system

On the Naval Research Reserve

Promotion Selections

Congratulations are extended to officers listed below who were selected for promotion by the Fiscal Year 1972 Reserve Selection Boards.

There were 224 Naval Reserve line officers selected for promotion to Captain. One was a member of the Research Reserve Program:

Abraham, George	NRRC 5-9

There were 615 officers selected for promotion to Commander. Twenty-one were members of the Research Reserve Program:

	NRRC		NRRC
Baldwin, Robert C. (CO)	4-4	Leo, Paul P. (CO)	11-11
Brainerd, Walter S.	3-1	Levin, Roger L.	5-8
Chodorow, Alan M.	8-7	Mc Whorter, William C.	6-3
De Vorsey, Louis	6-9	Meggitt, William F.	9-16
Gartmann, Russell J.	4-1	Nelms, Harry A.	6-3
Gleason, Burton J.	9-5	Pietkiewicz, Wesley	1-7
Hall, Wilford H. (CO)	6-19	Prickett, Gordon O.	11-7
Hansen, Helmuth H.	4-3	Prince, William G. (CO)	9-3
Hohman, Glenn W. (CO)	6-8	Reavis, Marshall W., III	6-9
Huggins, Richard, Jr.	6-17	Rodgers, Tommie J.	9-4
Lawson, Donald R. (CO)	9-21		

Eleven of the officers selected were from the new field and ten from the old. Other statistics based on the records of the Research Reservists selected for promotion are:

Year of Birth		Date of Rank		Designator	
Earliest	1923	Earliest	5-1-63	1105:14	1405:2
Latest	1936	Latest	1-1-67	1106:1	1615:1
				1315:2	1685:1

Four officers were selected from the Staff Corps by the Fiscal Year 1972 Reserve Selection Boards.

One officer was selected for promotion to Captain:

	NRRC
Martin A. Rizack, MC, USNR	3-1

Three officers were selected for promotion to Commander:

	NRRC
Robert E. Boyle, MSC, USNR	5-4
Ralph J. Teynor, DC, USNR	13-5
David G. Warren, SC, USNR	6-6

Seminar Planned at NRL

The Naval Reserve Research Company 5-9, Naval Research Laboratory, Washington, D.C. will conduct a seminar at NRL, 14-25 August 1972.

The purpose of the seminar is to present current developments in oceanology, space science and technology, electronics and materials as they relate to the Navy.

Quotas have been established for the following Naval Districts: FIRST, THIRD, FOURTH, FIFTH, SIXTH, EIGHTH and NINTH. Quotas for ELEVENTH, TWELFTH and THIRTEENTH Naval Districts will be granted upon request.

Dive Under Arctic Ice

Recently scientists were scheduled to begin diving under Arctic ice to observe Pacific walrus from a small research submarine. They are seeking information needed to aid in conservation and management of this relatively unknown animal.

A team of biologists and oceanographers led by Dr. G. Carleton Ray of Johns Hopkins University will make a month-long series of dives in the Perry two-man submersible PC-8 in the Bering Sea. Support for their submersible operations is provided by the Commerce Department's National Oceanic and Atmospheric Administration.

Mother ship for the little submarine and the scientific team will be the USCGC *Burton Island*, an icebreaker provided by the U.S. Coast Guard. Operations will be carried out in the Bering Sea ice pack.

As a demonstration project of the marine mammals program, International Biological Program, the research is also supported by the National Science Foundation and the Office of Naval Research.

Dr. Ray and his team will observe behavior, acoustics, anatomy, and other characteristics of the animals and their environments both on the ice and, from the submersible, under the ice. Their objectives are to identify mating groups, determine sex ratios and social organization of these groups, and examine mother-young relationships. Walrus herds appear to be organized in a complex way. Finding out how they maintain contact in the mobile world of the pack ice is one object of the research. Some scientists believe that they do this vocally.

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The walrus has one of the largest of marine mammal vocabularies. Dr. Ray's group hope, with the aid of acoustic devices, to shed more light on this characteristic.

The scientists also plan to use telemetry to look at the undersea environment of the walrus. By attaching telemetry transmitters to some of the animals, they can track their daily dives to the bottom for food. The team will then use the submersible to examine closely the particular localities on the seafloor where the walrus feed. They hope also to observe the walrus in their undersea habitats.

Although marine mammals are more abundant in the Bering Sea than in any comparable area on earth, knowledge of many of them is fragmentary owing to the difficulty of access and rigorous climate. The walrus has been chosen as the first object of major study by this International Biological Program project because of the comparative ease with which it may be studied on and under the sea ice.

The Pacific walrus is a renewable resource of international importance, currently utilized only by subsistence hunters in coastal Alaska and northeastern Siberia. It is also potentially vulnerable to more intensive exploitation on sea ice on the high seas.

Cooperating in the study is the Alaska Department of Fish and Game and, for the telemetry, the Naval Undersea Research and Development Center.

Investigators on the project, in addition to Dr. Ray, are Dr. Robert Barsdate, Sam Stoker, Michael Gottschalk, and E. H. Miller of the University of Alaska; Dr. Francis H. Fay of the U.S. Public Health Service; and Steven D. Sult, Johns Hopkins University. Participating personnel from Perry Oceanographics, Inc., are Mike Adams, E. J. Michaud, and William Barton, Jr. Michael Sparling of Ocean Applied Research, Inc., will operate the telemetry.

NOAA support for the project is provided through the Manned Undersea Science and Technology (MUS&T) program, whose objective is to support both science and improved technology in undersea operations.

NAVAL RESEARCH REVIEWS publishes highlights of research conducted by Navy laboratories and contractors and describes important naval experimental facilities. Manuscripts submitted for publication, correspondence concerning prospective articles, and changes of address, should be directed to Code 109, Office of Naval Research, Arlington, Va. 22217. Requests for subscriptions should be directed to the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C., 20402. Subscription price: $1.75 per year in the U.S. and Canada; $2.25 per year, foreign; $0.20 per individual copy. The issuance of this periodical approved in accordance with Dept. of the Navy publications and printing regulations.

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SEALAB divers making final adjustments to the umbilical supply line of the undersea laboratory. *See page 1.*

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