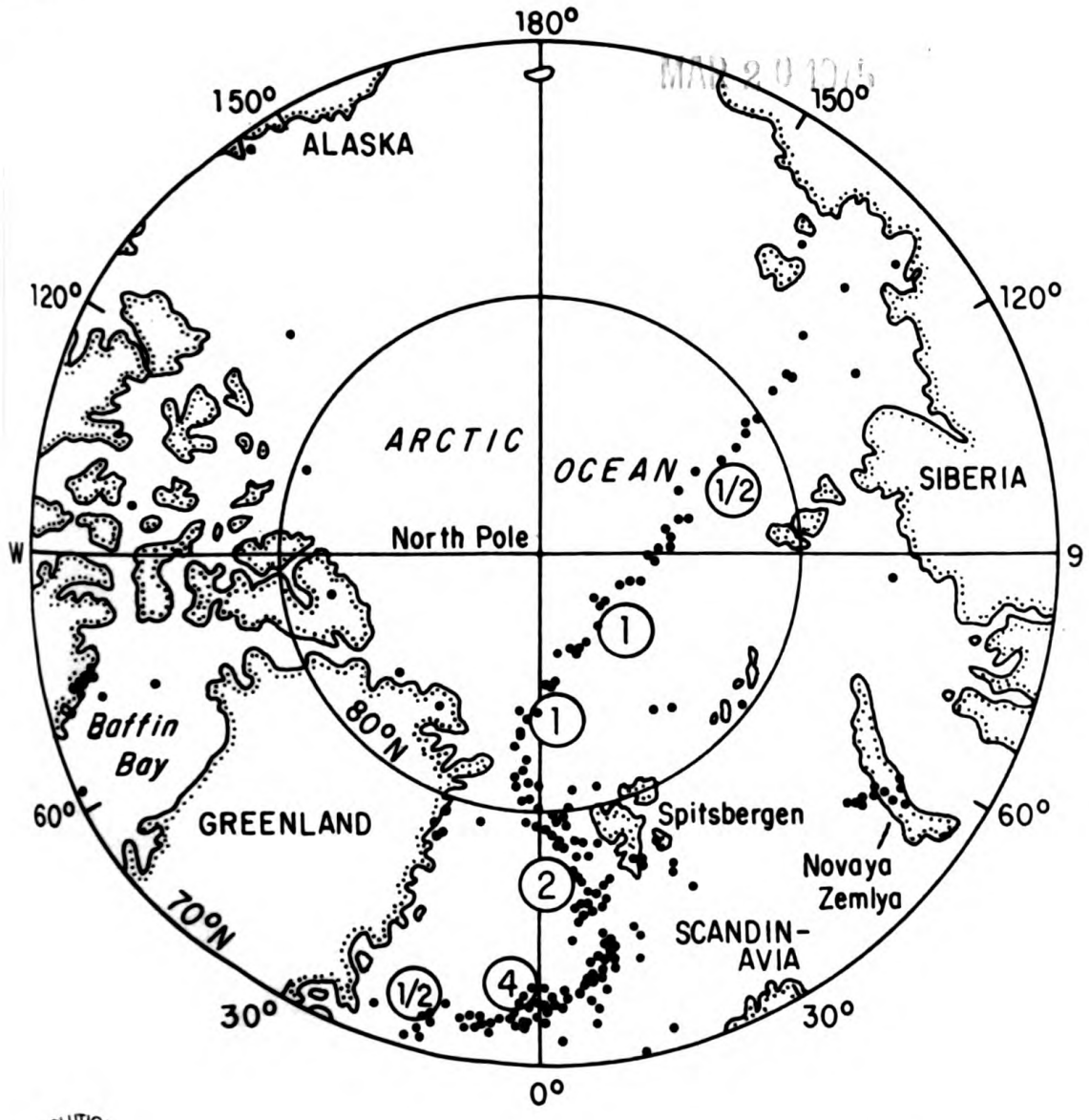
NAVAL RESEARCH REVIEWS

JANUARY 1975



PROFILES IN SCIENCE

Professor Robert O. Reid

Professor Robert O. Reid has been a physical oceanographer at Texas A&M University since 1951 and an ONR contractor for the past 20 years. He and his students have contributed significantly to the theoretical understanding of hurricane storm surges, ocean circulation and long wave theory.

Professor Reid is widely recognized as one of the outstanding educators in physical oceanography. He has received two awards for distinguished teaching and research at Texas A&M. He is the original editor of the *Journal of Physical Oceanography*.

Professor Reid was the first oceanographer to apply the Sverdrup relationship to oceanographic data in his classical paper, "The Equatorial Current of the Eastern Pacific as Maintained by the Stress of the Wind" (*J. Mar. Res.*, 1948). He has contributed significantly to the physical understanding of hurricane storm surges and is the recognized authority in the field. He and his students have studied extensively the hydrodynamics of tsunamis, Gulf Stream rings, hurricane-induced currents, edge waves, the circulation of the Gulf of Mexico and Caribbean Sea, and gravity waves.

Mechanism and Therapy of Shock

Lerner B. Hinshaw*

University of Oklahoma Health Sciences Center
and Veterans Administration Hospital

Before the development of civilization, man has been confronted with the problem of how to survive in spite of severe personal injury. Certainly throughout his history he has consistently suffered from the adverse effects of encounters with men or animals resulting in various injuries which left him severely wounded, incapacitated, dead or dying. No doubt, his earliest history would record innumerable instances in which he has suffered severe blood loss or other kinds of trauma precipitating the phenomenon known as "shock." In recent years, no less than forty kinds of "shock" have been described in the medical literature which still continue to plague man, including such generally recognized forms as "blood loss" shock, "psychic" (fear, fright) shock, electric shock, massive body injury shock, tourniquet shock, "bee sting" shock, and shock due to "super sensitivity" to drugs. In recent years, another form of shock has been recognized, identified, described, and intensively studied. It has been termed "septic shock," "bacteremic-shock" or "endotoxin shock," the later designation arising out of its purported cause, namely the release of a substance called endotoxin from the cell wall of certain bacteria. This lethal substance, when released in sufficient quantities from the site of an infection into the blood stream of man and animals, precipitates a severe form of shock often terminating in the death of its unfortunate victim. The general manifestations of the dying victim are low blood pressure and blood flow, unconsciousness, and depressions of most metabolic functions. This serious derangement of normal function is the primary subject of our investigations carried out during the past decade at the University of Oklahoma Health Sciences Center and Veterans Administration Hospital, Oklahoma City, Oklahoma. Multidisciplinary studies have been launched under the support of U. S. Navy's Project "THEMIS" beginning in 1968, and through continuous Navy support, have resulted in an effectively concentrated attack on the mechanisms of shock, with particular emphasis on endotoxin

*Lerner B. Hinshaw is Resident Professor of Surgery and Resident Physiologist at the Veterans Administration Hospital, Oklahoma City. His fields of interest are cardiovascular physiology, shock, and hypertension.

"septic" shock. The multidisciplinary faculty group at the Oklahoma City-based research laboratories has melded the professional skills of surgery, medicine, pathology, physiology, pharmacology and biochemistry. Attacks on the problem of shock have spanned the enormous gap between single cell research (biochemistry) and clinical treatment at the bedside (medicine and surgery). The first five years of research have been carried out at intensive levels in the basic science laboratories of the Health Sciences Center, a private research foundation (Oklahoma Medical Research Foundation), and research laboratories and intensive care units of the Veterans Administration Hospital. The earlier studies were culminated by an international symposium on shock conducted in Oklahoma City in October 1971, and published for world distribution in April 1972. Since that time, further research efforts have been directed primarily toward the heart and lung response to endotoxin, because the cardiopulmonary system has been found by our group to be among the most critically damaged anatomical regions in the body during the development of the intermediate phase of shock.

Recent clinical reports and summaries [1,2] have provided rather alarming news pertaining to man's failure to curb, let alone reverse, the debilitating and lethal effects of septic shock in the civilian population of this country. Aside from this disturbing situation, not enough has been learned from the medical experiences in the U.S. medical treatment stations and hospitals of Viet Nam, where numerous instances of septic shock were recorded. These latter cases were precipitated by the invasion of microorganisms and the subsequent release of endotoxin into the blood streams of soldiers wounded in battle. A recent report [3] has emphasized the increasing problem of septic shock in the civilian population and recounts the varied means by which it may be precipitated. Latest estimates place the incidence of septic shock in the United States at about 300,000 cases a year, with its involvement in 100,000 deaths a year [2]. Attempts to treat patients during the *early* stages of shock have achieved moderate success, while in the *intermediate* stage no real advances in therapy have been achieved during the past several decades. Its insidious nature is derived from the observation that shock may occur unexpectedly, joining a constellation of other patient disorders, additionally insulting multiple organ systems in the body. Estimates of therapeutic effectiveness do not appear to be adequately evaluated since there are marked differences in findings among investigators and clinicians alike, and the elusive nature of the pathophysiological processes has not been well defined. For example, one class of compounds—the steroids—are both championed and discouraged for use in treatment of clinical septic shock, and the basic

reasons for such typical differences of opinion are not adequately explained [4]. To make matters worse, the apparently proven published therapeutic interventions in animal endotoxin shock models could not be demonstrated even when investigators met together under one roof and conducted experiments under the scrutiny of one another [5].

It has become clearly apparent that this pathological disaster—septic shock—deserves the closest attention by the most dedicated and competent interdisciplinary teams in order to uncover its mysterious and elusive mechanisms, thereby opening up pathways to its prevention or effective treatment. The research programs of the Oklahoma City research group have followed the general format of attempting to uncover causes of the *initial* development of the endotoxin shock state, tracing the participations of all possible mechanisms as they advance the initial shock phase into *intermediate* and *later* stages, ultimately culminating in death. They have advanced the general line of attack by initially carrying out probing, feasibility experiments in an animal model, selected for study because of its availability, lesser cost, and relatively greater accessibility to previously published data for comparative purposes. Experiments are fully developed and completed and finally advanced to those studies especially designed and executed in a "subhuman" primate. This intermediate step in research strategy is considered essential since certain significant species' peculiarities of responses have been observed to occur [6-8]. Further, it is reasonable to assume that not all of these differences have been discovered, nor have their relative importances been adequately weighed in terms of relevance of application to the human patient in shock. The last step in our experimental process is to apply therapeutic findings discovered initially in an animal model, verified in subhuman primates, and then applied to the human patient. New observations are regularly being uncovered in our laboratoreis which bring to question currently accepted practices of clinical treatment in the human patient. If sufficient verifications of these results by various investigators are achieved, re-evaluations of current clinical therapeutic approaches will be undertaken, and clinical treatments may be modified.

The following experimental pathways are continuously under operation: Animal "shock model"→initial observations in an animal model→testing and verification of these findings through the experiments of other investigators→studies carried out in subhuman primates to more closely mimic the patient situation→attempted therapeutic trials in all animal models→applications to patient treatment finally undertaken and thoroughly evaluated.

The following description of our research in Oklahoma City will be unfolded to the reader in the way that results were presented to us from studies conducted in the laboratory.

Historically, the author's colleagues, working in the physiology laboratories at the University of Minnesota under the leadership of Dr. Maurice B. Visscher, were confronted with the following problem: Why did the blood pressure drop so severely and quickly following an injection of endotoxin in an experimental animal? The relevance of this question was apparent since blood pressures of human patients characteristically fall in septic shock. The beautifully designed studies of the Minnesota group subsequently revealed that the heart is performing its task well in the early phase of canine endotoxin shock, but that there is a marked reduction of blood flowing back to the heart from peripheral anatomical sites such as liver and intestine. Figure 1 is a pictorial representation of the heart and blood vessel system of typical animals. Research in our laboratories carried out in subhuman primates has shown that the early phase of endotoxin shock is precipitated by massive trapping (pooling) of blood in peripheral blood vessels, as was shown to occur in other animal models by the Minnesota group. The result of this peculiar action of endotoxin is that blood does not return to the heart but instead is displaced into veins and capillaries and therefore does not circulate to critical organs of the body. Blood pressure cannot be supported and falls to low levels, and the initial phase of "shock" is thus dangerously ushered in. Since blood flow and blood pressure are both subnormal, the various organs and body tissues do not receive adequate energy-producing fuels to meet their metabolic needs and their function begins to suffer even in the early phase of shock.

Figure 2 illustrates the general flow of abnormal events from the entrance of live bacterial organisms or endotoxin into the blood system, through a series of steps terminating in irreversible organ damage and death. This figure illustrates another interesting facet of our research, namely the answer to the next logical question, "*Why* does blood become trapped in peripheral regions of the body in endotoxin shock?" We have implicated a number of "vasoactive" chemical agents formed and released within the blood vascular system shortly after the introduction of endotoxin. These agents, including histamine and catecholamines (including adrenalin), among others, are explosively released into the circulating blood causing peculiar effects in arteries and veins: some arteries constrict (narrow) while others dilate (widen), and even more peculiarly, veins in some animals constrict while those in others dilate. The net effect of these perverse actions is that blood is sequestered peripherally and cardiac output falls to critically low

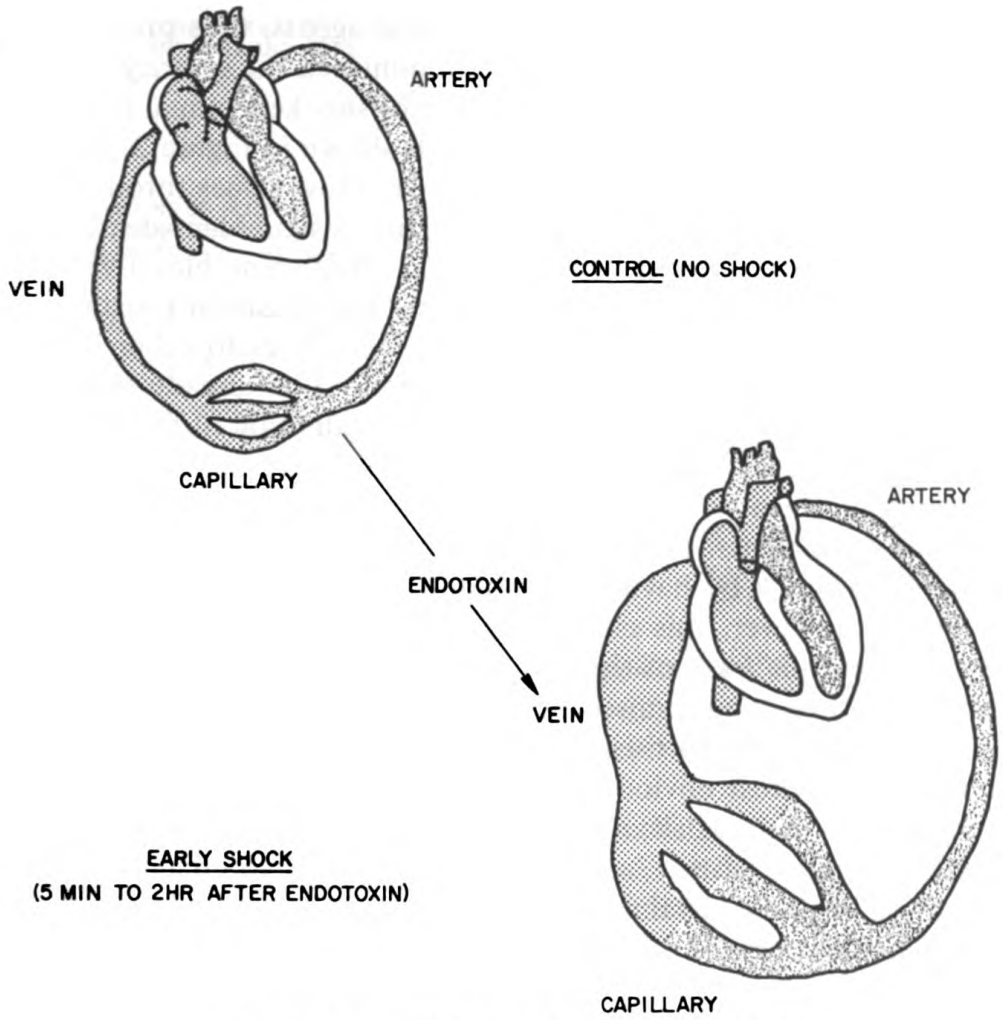


Figure 1 – Blood pooling in endotoxin shock

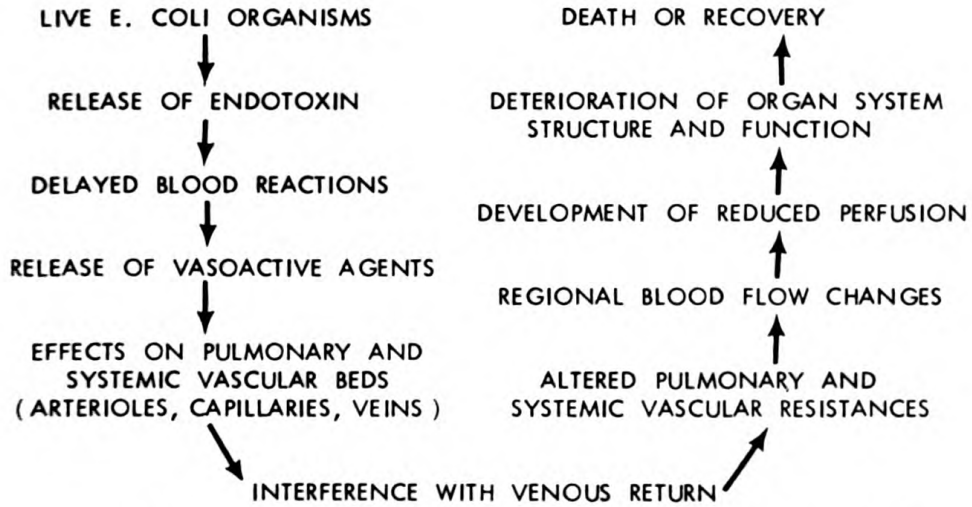


Figure 2 – General schema illustrating hemodynamic factors at work in the development of shock due to endotoxin

levels. Sadly enough, efforts to block these agents, thus preventing their actions on blood vessels, have not diminished the severity of the shock nor have they increased survival rate of shocked animal models. Our hypothesis, based on the flow of events shown in Figure 2, is that the initial drop in venous return is sustained at low values throughout the entire period of shock, thus contributing a significant degree of insult to the animal model. Due to the fact that some blood vessels constrict more than others; that is, their resistance (vascular resistance) to flow increases; blood is shunted from themselves to other organ systems. Since these events are superimposed on an already reduced venous return of blood to the heart, a further reduction of blood flow (reduced perfusion) can only exacerbate (make worse) the already deteriorating organ systems structure and function. Our hypothesis is that some organ systems suffer more than others (skin, muscle, kidney, intestine) in shock by having their blood flows cut to unacceptably low levels. However, this emergency action may ultimately destroy the animal on the basis of the eventual liberation of toxic substances from these flow-compromised areas into the general circulation. Is there an easy answer to this dilemma? No, not really, since we have found that the most obvious approach to circumvent such a chain of events doesn't help at all; namely, if fluids of various kinds (blood, plasma, plasma substitute, saline) are administered to increase blood flow, the animals die just the same, perhaps surviving somewhat longer.

Early in the course of our research it became apparent that the lung was occupying a crucial central position in the pathogenesis (course of unfolding) of endotoxin shock [9]. Since the earlier research of the Minnesota group, there has been a general awareness and appreciation of the role of the lung in shock both in the lower mammalian species and in subhuman primates. As research progressed during the past years of our Navy program, it became quite apparent that the lung may serve as a pivotal point in determining whether life would be extended or death would intervene in endotoxin shock. Lung damage and malfunction became the watch-word as a myriad of adverse changes were uncovered by the surgeons, internists and pathologists of our group. These pathophysiological manifestations are depicted in Figure 3 and involve virtually every anatomical structure of the lung: arteries and veins are abnormally constricted and capillaries become structurally damaged and leaky; white cells and debris from cellular contents become trapped in the lumina of capillaries; fluid begins to accumulate in lung tissue spaces and certain cell functions deteriorate; blood flow already reduced in quantity is shunted away from some regions while certain lung areas collapse. The net effect of this havoc is expressed in the reduction of blood containing

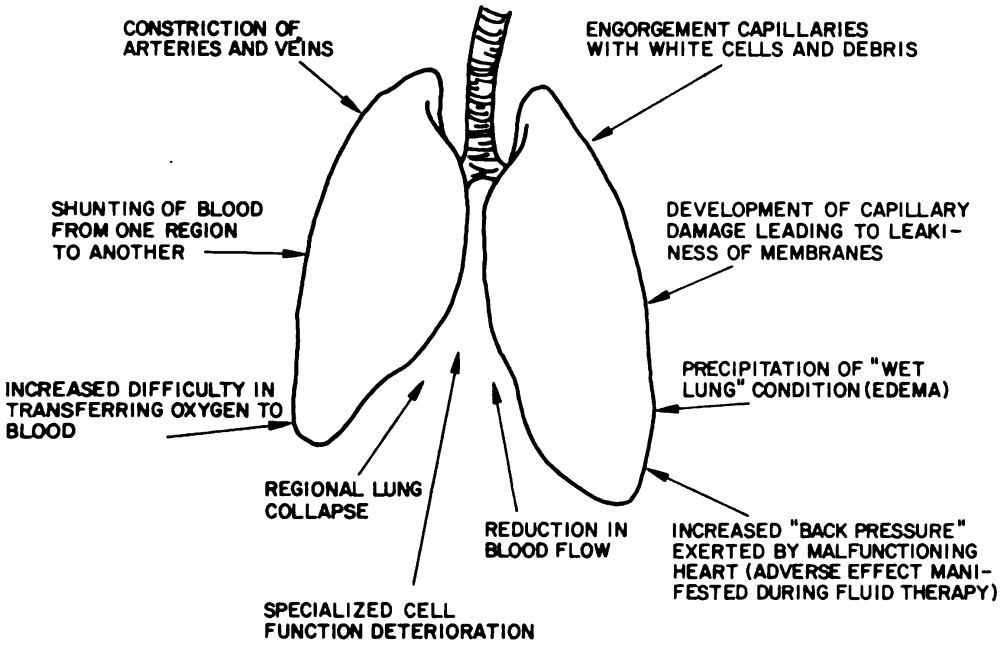


Figure 3 – Lung pathology and malfunction in shock due to endotoxin

adequate oxygen and in a generalized depression of specialized lung functions.

Our recent research has uncovered yet another facet of pulmonary (lung) dysfunction: we have documented the development of heart failure or dysfunction at 4-6 hours after endotoxin in both lower animals and subhuman primates [10-14]. The seriousness of this defect has escaped the clinical arena because the heart defect is hard to uncover with the usual clinical procedures, and because it isn't clearly manifested during conditions of shock when both blood pressure ("cardiac afterload") and blood flow ("cardiac preload") are abnormally low. We have found that the workload on hearts is very low during most of the shock period; however, when fluid therapy (generally practiced clinically) is administered, the left ventricular heart muscle cannot properly pump this extra volume due to depression of its contractile and filling properties. Blood therefore "backs up" in the lungs and adds further insult to the already deteriorating respiratory organ, and further pulmonary edema is precipitated by the increased back pressure [14]. Fortunately for the heart, its ruggedness and massive reserve permits it to recover when fluid therapy is withdrawn; however, the peculiar fragile characteristic of lung tissue does not allow for recovery from the edematous state. Death due to the "wet lung" syndrome typically ensues from the therapy thus employed.

Our laboratories are currently at work trying to determine the cause of heart failure in endotoxin shock. We have implicated low

coronary blood flow and a defect in the filling characteristics of the heart, probably related to accumulation of fluid in and between the contractile elements of the left ventricle. Deterioration of contractile function of the heart is regularly observed and is believed to be associated with the adverse actions of ions such as calcium, in combination with structural damage of the energy powerhouses (mitochondria) in the heart.

Figure 4 outlines our latest hypothesis concerning the mechanisms of shock due to endotoxin: the *heart* and *lung defects* have already been alluded to, but our most recent findings have clearly identified renal dysfunctions [15] and metabolic derangements [16] as performing major detrimental roles, as well as the implication of brain dysfunction which promotes cardiopulmonary peripheral vascular breakdown. The six kinds of defects–hemodynamic, heart, lung, kidney, metabolic and brain–are all depicted with interlocking lines connecting each of them. This is the central core of our hypothesis; namely that at least these six defects are interlocked together in a disastrous concert, each playing a supportive theme in the development of serious shock resulting ultimately in death.

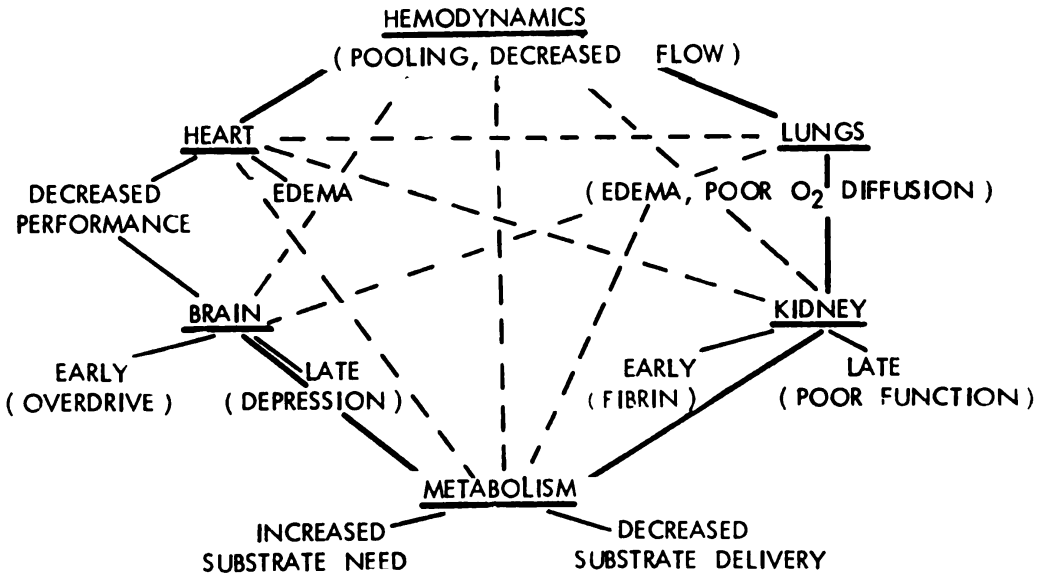


Figure 4 – Defects in experimental septic shock

The foregoing description of mechanisms of shock with occasional allusions to therapeutic attempts would be incomplete without mention that our laboratories have tried a number of regimens in studies of endotoxin shock. Those of these we have attempted since the Oklahoma Shock Symposium of 1964 [5] are as follows:

Regimen or Therapy	Reason for Use	Result
1. Fluids added to blood (dextran, etc.)	To increase cardiac output	No benefit to ultimate survival (extends survival time)
2. Anti-inflammatory agents (aspirin, indothacin, flufenamic acid, phenylbutazone)	To block adverse vascular constrictions and prevent edema	Prevents adverse hemodynamic effects but is of no use as a post-treatment of endotoxin shock to prevent death
3. Steroid (methylprednisolone)	To prevent breakdown of cells and improve cardiovascular parameters	No real hemodynamic benefit; damages lung, but improves heart function in some cases
4. Digoxin	To prevent or reverse heart failure due to endotoxin	Prevents heart dysfunction or failure given early or late after endotoxin
5. Steroids + fluid (dextran) + digoxin	To gain summed benefits from all three agents	No benefit to survival (only temporary hemodynamic benefits)
6. Glucose (hypertonic; i.e., concentrated)	To supply energy fuels	Improves hemodynamics and prevents death due to endotoxin in same animal models (complicated by coincident decreased insulin levels in subhuman primates)

Our laboratory has attempted many kinds of therapies; however, we have been consistently unable to prevent death once the endotoxin has entered the circulation. We accidentally discovered that all of one animal species subjected to this form of shock exhibited progressively lowering concentrations of blood glucose (sugar) in arterial blood, and eventually died when the blood sugar level reached critically low values. We asked ourselves what would happen if we simply infused glucose during the shock state and gave just enough to keep up with the animal's requirements. This we did, and were surprised to find several things:

(1) We had to give *huge amounts* of glucose in order to keep up with the animal's requirements. Far more was needed than anyone would have predicted. It was as if the "internal fires of metabolism" were burning with forest-fire intensity.

(2) We found that only *concentrated* glucose could be used; otherwise, animals would die by "drowning"–lung edema would result.

(3) We observed that animals given glucose over a relatively short period of time (5-7 hours) were apparently helped just enough so that they could capably fight the battle for survival themselves during the next 24 hours or more.

(4) We noted that giving glucose helped the animals breathe more effectively, kept their body temperatures normal instead of falling, made them more alert and comfortable, and prevented the ordinarily observed massive bloody diarrhea.

We are presently carrying out research in this form of shock in animals more closely related to man in order to make our results more clinically relevant and examine possible interfering factors of species differences. Our recent work has identified a clotting substance, plugging the kidney blood vessels [15], effectively throttling its blood flow and metabolic requirements, thus causing renal (kidney) failure to intervene at later periods (2-4 days of shock). On the metabolic side, we have observed that the heart shifts its metabolic fuels from fatty acids to lactate [17] and that the body as a whole runs out of glucose [16], thereby dying with superimposed "hypoglycemic" shock.

To summarize briefly, our laboratories have wrestled with the vast myriad of pathways instrumental in precipitating shock (low blood pressure and low blood flow with concomitant inability to meet required metabolic needs) following the injection of endotoxin or live *E. coli* organisms from which endotoxin is liberated. A number of pathways have been identified, studied and characterized in both lower

animal models and subhuman primate species with the goal of applying knowledge to the understanding of the human clinical shock entity, termed "septic" shock. A variety of therapeutic approaches has been attempted, some of which have successfully reversed or prevented adverse hemodynamic effects of shock or failure of single organ systems. Of these, only concentrated glucose has successfully prevented death. Serious additional problems have been uncovered in the subhuman primate making the application of glucose tenuous: hypoinsulinemia ("diabetic" effect) together with deposition of fibrin in the kidney provide further challenges to our laboratories for the development of a successful regimen which hopefully will be proposed for the human shock patient.

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Naval Studies Board of the National Academy of Sciences

With the concurrence and support of the Navy, the National Academy of Sciences has appointed a new advisory board tasked as follows:

> "With appropriate attention to the influence of the domestic economy, national objectives, social imperatives and anticipated military requirements, the Board shall consider and advise the Navy on scientific and technical problems affecting its ability to discharge its responsibilities in maintaining peace and national security."

This Board consists of a broadly based group of highly qualified, scientists and engineers from outside the Navy establishment and appointed by the NAS to provide the spectrum of knowledge and experience necessary for the broad range of tasks with which it must deal. Because the problems brought to the Board will involve research and development, many of its members are academic scientists who can be expected to assist the Navy in its efforts to insure an innovative, forward-looking and efficient program by contributing fresh ideas and viewpoints derived from their own research experience.

It is anticipated that the Board itself will be a continuing activity, maintaining general familiarity with the Navy's major programs, ready to advise the Chief of Naval Operations, the Secretary of the Navy or the Chief of Naval Research, as appropriate. Detailed studies will be carried out, in general, by ad hoc committees, panels or study groups, under Board auspices, guidance and review.

The Board consists of William H. Pickering, Chairman, Benjamin B. Bauer, David A. Bromley, John C. Calhoun, Jr., Francis H. Clauser, Eugene P. Cronkite, Sidney D. Drell, Ivan A. Getting, John A. Hornbeck, Alden R. Kuhlthau, Bernard M. Oliver, Joseph M. Reynolds, and Harrison J. Shull.

A Hybrid Optical/Digital Processor

David Casasent*

Carnegie-Mellon University

Since the advent of the laser, interest and research in coherent optical data processing has flourished. This discipline has touched application areas as diverse as nondestructive testing, biomedical diagnosis, and radar, to name only three. The reason for this widespread interest lies in the tremendous processing potential offered by an optical computer. Three major advantages of optical data processing (ODP) can be distinguished: optical processors are inherently two-dimensional spatial systems (when time is added they become three-dimensional systems); all points in a two-dimensional input to an optical processor are operated on in parallel; and all operations that can be performed require nanosecond processing and computational times. The powerful operations of Fourier transformation and correlation are the most used optical computations.

Optical systems are not without shortcomings however. One of the major limitations in the realization of an optical processor with high throughput has been the lack of a real-time, two-dimensional, electrical-to-optical input transducer. A block diagram of the processor to be described in this paper is shown in Figure 1. The upper section is a conventional optical data processing system [1]. P_0 is the input plane, L_1 and L_2 are Fourier transform lenses, P_1 is the Fourier transform or spatial filter plane while P_2 is the output or correlation plane. Real-time two-dimensional transducers, an electrically-addressed light modulator (EALM) and an optically-addressed light modulator (OALM), are used in planes P_0 and P_1. The transform plane P_1 and correlation plane P_2 are interfaced to a digital minicomputer shown in the lower half of Figure 1. This hybrid optical/digital processor [2-3] provides the normal optical processor with a real-time capability. But even more, it includes a digital feedback loop, whereby the system's mission can be controlled by the digital computer. The allocation of the various processing operations to the optical and digital sections of the system results in a more powerful and versatile overall system. The computing operations of transformation and correlation are performed optically, while the digital section performs the

*David Casasent is Assistant Professor of Electrical Engineering at Carnegie-Mellon University. His fields of interest are on-line real-time optical data processing; buffer memory systems; and high speed circuits in digital computers.

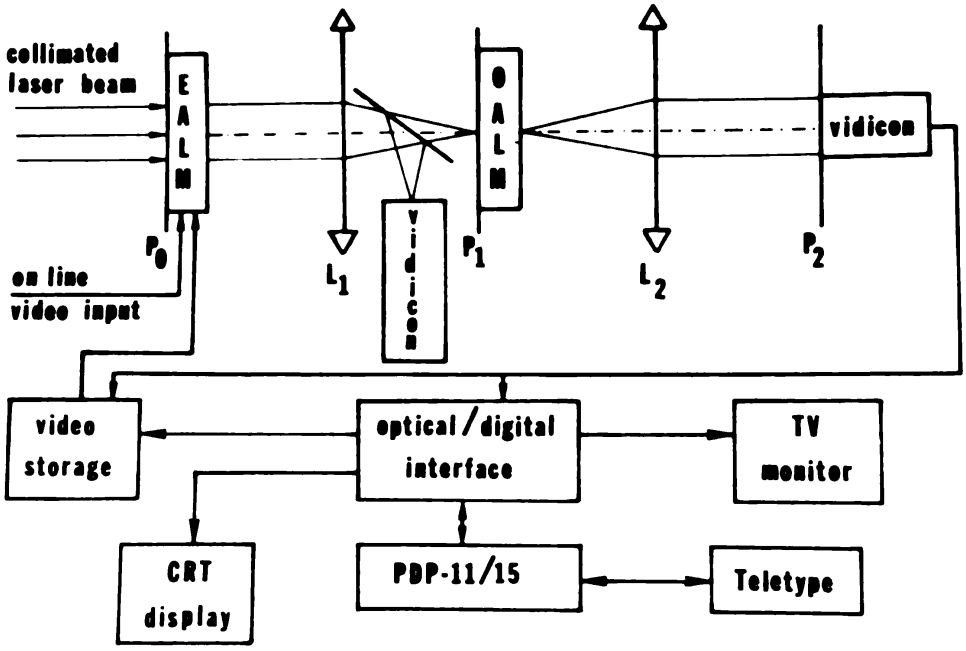

Figure 1 – Block diagram of the hybrid optical/digital processor.

analysis of the Fourier transform and/or correlation patterns, displays the desired results, controls the overall system (specifically the input data and data format, and the contents of the spatial filter plane) and allows the programmability feature of the digital computer to be fully utilized.

The remaining sections of this paper will describe the input transducers used, will describe the role and operation of the optical/digital interface, and will provide several examples of the performance of this hybrid programmable optical processor.

Input Transducer

A block diagram of the input transducer is shown in Figure 2a. It consists of a KD_2PO_4 target crystal on which a scanning electron beam (modulated with the input electrical signal) deposits a charge pattern corresponding to the input information. A collimated coherent light beam, passing through the assembly, is spatially modulated by the linear longitudinal electro-optic effect [4]. The second electron gun then emits a defocussed flood of low energy electrons at the target and thus erases the image by secondary emission. A complete write-read-erase cycle in 1/30 sec. with 1000 x 1000 point resolution is possible. The actual device is shown in Figure 2b and has been extensively discussed elsewhere [2,3].

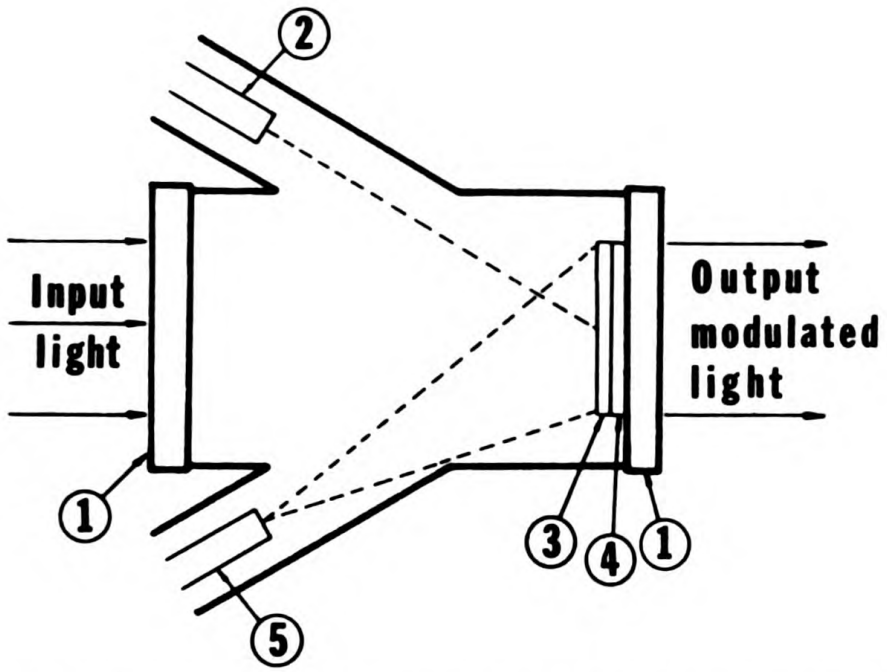

Figure 2a – Schematic of the input transducer EALM: 1 optical windows; 2 write gun; 3 target crystal; 4 transparent conducting electrode; 5 erase gun.

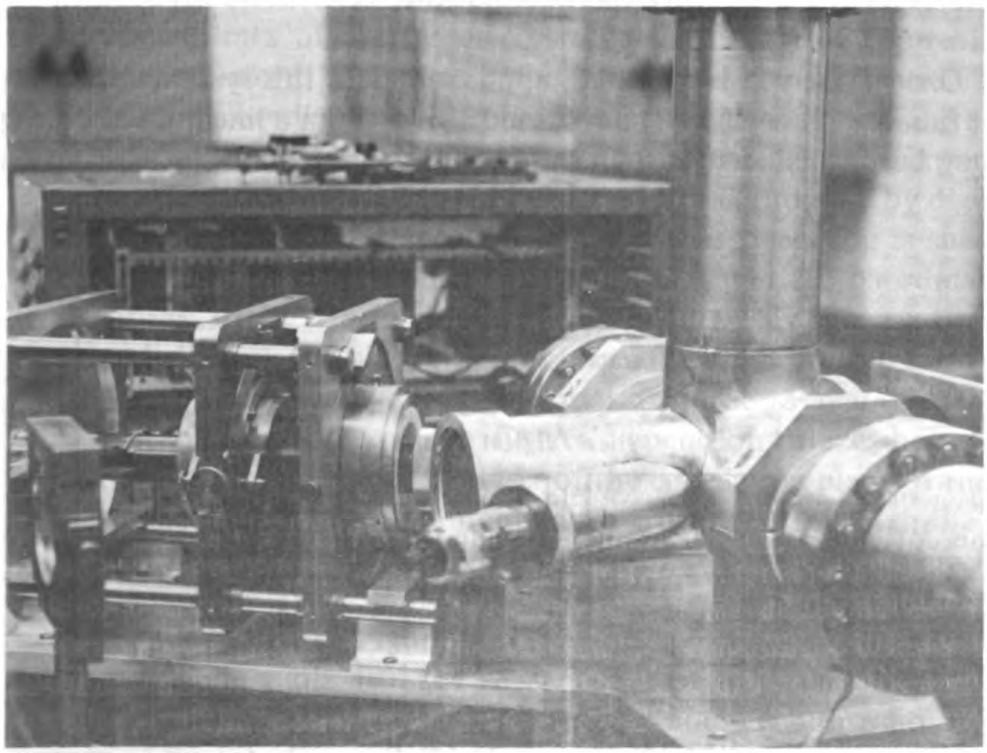

Figure 2b – Real time spatial light modulator.

Optical Digital Interface

The digital section of the processor must analyze the contents of the Fourier and correlation planes of the optical processor and make some decision based on the contents of these planes, the stored program, and the particular mission of the system. The contents of these planes are detected by closed circuit television cameras and fed to the digital computer through the optical digital interface in Figure 1. The contents of these planes P_1 and P_2 consists of bright peaks of light whose intensity and location are of importance. A block diagram of the interface is shown in Figure 3. Its purpose is to extract the location and intensity of the "important" peaks of light in planes P_1 and P_2. To accomplish this, the entire plane or frame of data from the vidicon is divided into a number of resolution cells, in which the number of cells is available from 2 x 2 to 96 x 240 under program control by the PDP-11/15 computer. Each cell is assigned the binary value "1" if the video level anywhere within the cell exceeds a threshold voltage, otherwise it is given weight "0". Thirty-two different threshold levels can be chosen, again by program control from the PDP-11/15. The digital section of the processor is shown in Figure 4. The remaining section shows examples of its use in optical computing.

Experimental Results

One of the most promising applications for this system appears to be in radar processing. The returned signals from a linear phased array may be processed to obtain the target's azimuth angle by writing the

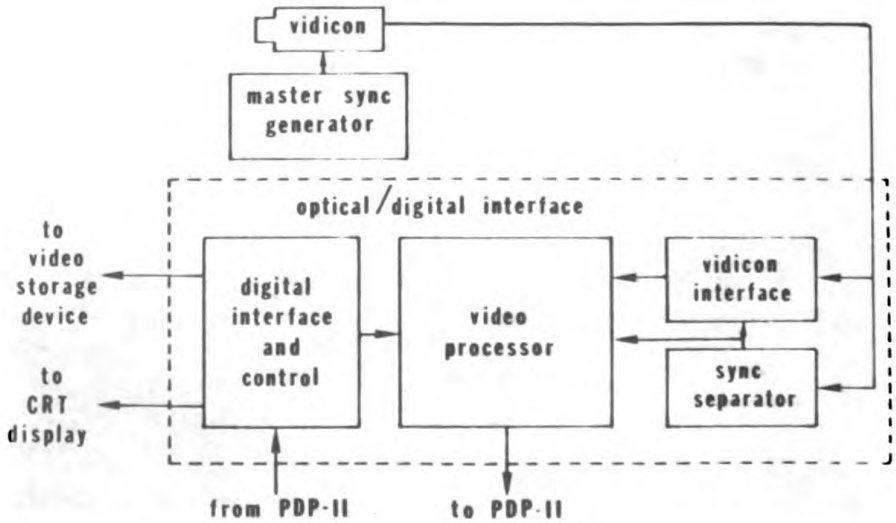

Figure 3 – Block diagram of optical/digital interface.

Figure 4 – Digital section of the programmable optical processor.

heterodyned returned signals from N elements of the receiver on N successive lines of the target crystal in the EALM of Figure 1. The Fourier transform of such an input pattern is shown in Figure 5a. The horizontal coordinate of the first order fringe term in Figure 5a is proportional to the target's azimuth and is the desired output. The optical/digital interface can easily extract this coordinate by digitizing the entire transform plane. The result of this operation is shown in Figure 5b. The interface has successfully located the coordinates of this peak of light and displayed the result. This scheme has been extended to planar phased array radar and linear FM step and pulsed Doppler radars and has been used to process real radar data.

A second example of the system's operation utilizes holographic matched filtering and an analysis of the correlation plane of the processor. Figure 6a shows an input paragraph of text in which the word "God" appears seven times. The results of a conventional correlation of this paragraph with a holographic matched filter of the word "God" is shown in Figure 6b. The strong cross-correlations present in text greatly obscure the seven peaks of light that occur at the locations at which "God" appears in the input. The thresholding feature of the interface now becomes important, and the binary digitized display of Figure 6c is obtained. From this the seven locations of

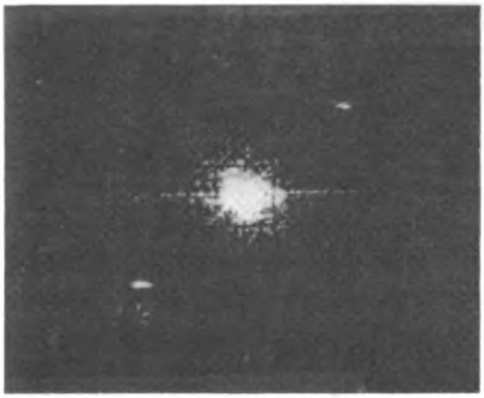

Figure 5a – Optical Output for linear phased array radar processing.

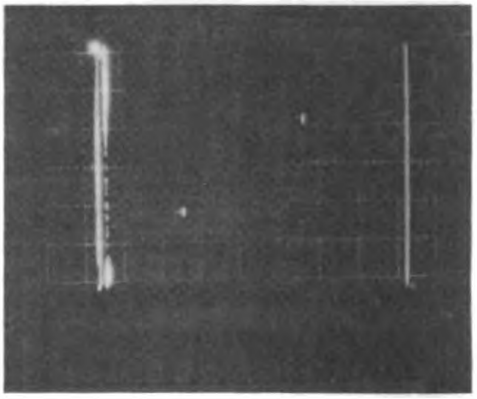

Figure 5b – Digital Display version of Figure 5a.

God performed many miracles in Indonesia because we had many needs. Americans do not have the same needs.

One day I was talking at a school in America, and one of the boys said, "That's what we need in America. We need miracles like that. We need to have water turned into wine in our church." And I said to that brother, "Well, there's no sense in God turning water into wine here in America. You have wine here. But grapes do not grow in Indonesia. Therefore, we have no wine. And we have no bread. So many times God needed to perform miracles. God always does miracles for a purpose. In America you have other needs. You need the power of God to reach souls for Jesus Christ. You can expect God to give you that. But if you have grapes, it's silly to ask God for grape juice."

Figure 6a – Input for text correlation example.

"God" in the input text have been extracted. This area correlation scheme has also been demonstrated on synthetic aperture radar imagery [3].

Conclusions

A hybrid optical/digital processor with a real time input transducer has been described, and brief demonstrations of its potential have been presented. Continuing research is concentrating on numerous refinements in the input transducer and the interface, on various other system applications, on an extension of the radar processing work to include correlation and digital feedback control of the input and its format, and on the use of the digital system to control and update the contents of the optical filter plane. This program is coupled with an investigation of various real-time OALM materials.

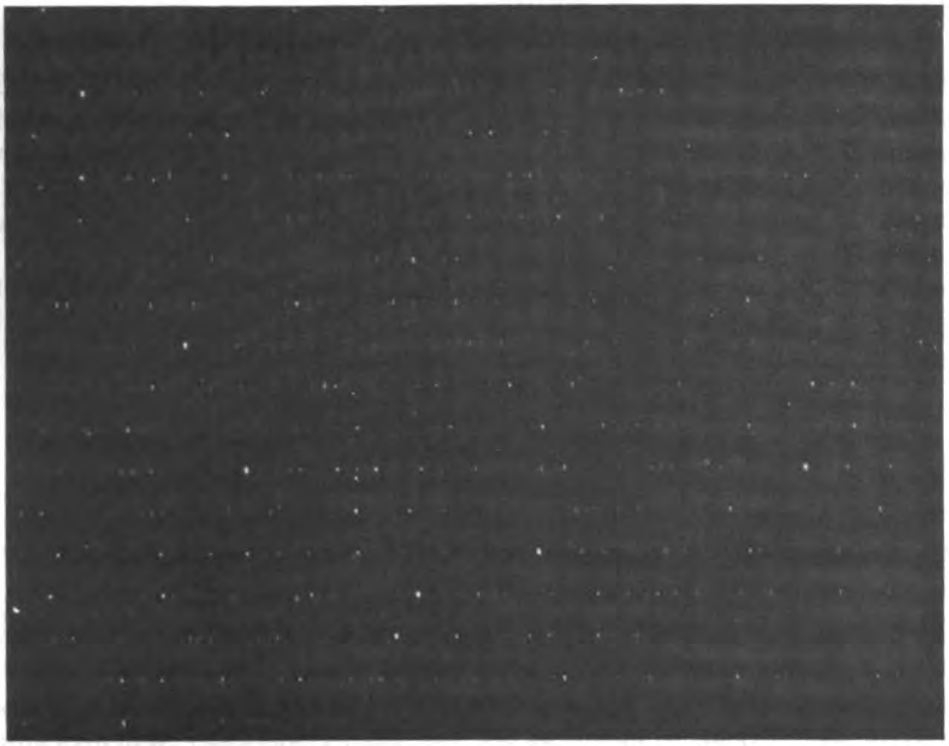

Figure 6b – Optical output for text correlation example.

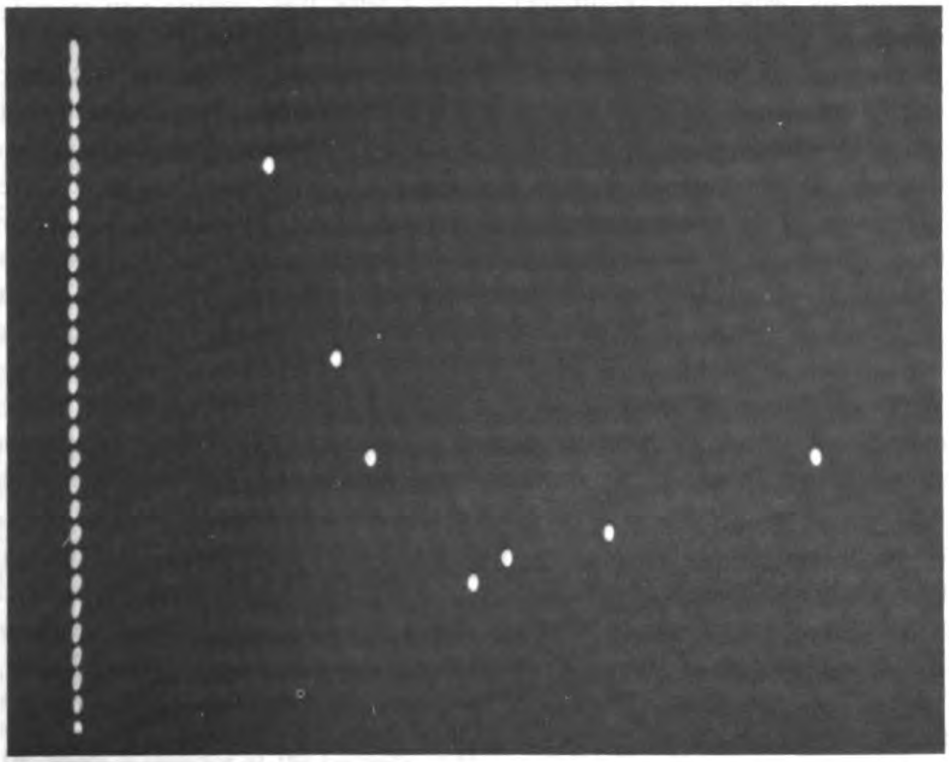

Figure 6c – Digital display version of Figure 6b.

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Superconductivity Application for High-Power Acoustic Transducers

The ability to generate high-power, low-frequency acoustic signals under water is a primary requisite to the development of any long range active sonar. Since present conventional hardware proposed to satisfy this need are very large and extremely difficult to handle at sea, the Naval Underwater Systems Center (NUSC) has investigated alternate methods of high-energy transduction. One available alternative is to use the superconductivity which certain materials exhibit at cryogenic temperatures, for this unusual property offers a new dimension by which the requirements for a very high density can be easily satisfied.

Under the direction of Dr. M. C. Karamargin of NUSC's Acoustic Research Division, a scaled-down superconducting transducer has been fabricated, with the superconducting coil made from niobium titanium multifilament wire wound on a spool. This coil applies the magnetic driving force to two ac-driven copper coils rigidly attached to moving pistons. Under initial superconducting test conditions, with the disk immersed in liquid helium, the coil sustained approximately 1.8×10^5 ampere turns, equivalent to a magnetic field of over 22,000 G. These values indicate the the full-size transducer should be capable of source levels of around 210 dB // 1μ Pa at 190 Hz, the resonance frequency.

With most conventional transducer designs, size must increase as the frequency is lowered. When superconducting transducer elements are considered, the amount of refrigeration required to keep the elements cold decreases as the applied frequency is lowered. This particular characteristic makes superconduction more attractive for low-frequency transducer designs. Furthermore, previously designed electrodynamic transducers using conventional copper conductors with source levels of about 195 dB // 1μ Pa can be redesigned with superconductors of the same size to yield source levels of around 235 dB // 1μ Pa. This 40 dB gain is brought about by the very high current-carrying capacity of the superconductor.

(Continued on Page 25)

A Tenative Hazard Chart for Submarines in Earthquake Zones

Hugh Bradner and J. D. Isaacs*

Scripps Institution of Oceanography

A tentative earthquake hazards chart for submarines has been developed. It gives a rough statistical estimate of the likelihood that a submarine will experience significant increase in apparent depth because of a nearby earthquake. The chart has been calculated for 20% pressure increase, lasting for about 1 sec. Factors are presented for converting to other pressures.

Although an extensive literature exists regarding observed effects of earthquakes on surface ships (see for example, Richter, 1958; Rossi, 1969), there is little if any published information on what happens to a submerged submarine near an earthquake. In an unpublished letter, Carter (1970) indicates that the depth gauge in his hovering submarine suddenly showed a depth increase of approximately 15%, then a reduced depth, and finally settled back to normal within a total time of less than four seconds.

The reason for the pressure pulse can be described qualitatively in simple terms; but an accurate quantitative statement cannot be given, even in statistical terms, because few accelerograms showing motion near to earthquakes are available. When a vertical compressional wave passes through water, the apparent weight of each element of fluid changes in proportion to its vertical acceleration. An element accelerated upward 8 ft. sec.$^{-2}$, or 1/4 g, would appear 25% heavier than its static weight. If the wavelength of the compressional wave is significantly greater than the depth of the submarine (a common situation in a seismic wave) then the whole column of water above the submarine is accelerated upward at the same time, and the submarine can be subjected to a large increase in water pressure. The increase of

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*Hugh Bradner is Professor of Engineering Physics and Geophysics at the University of California, San Diego. He is a fellow of the American Physical Society, and his field of interest is experimental physics.

Dr. Isaacs is Director of the Institute of Marine Resources, Scripps Institute of Oceanography. He is known for his research in the fields of waves, oceanographic instrumentation, military oceanography and marine resources.

pressure on a submarine at any depth could be calculated if the earthquake acceleration spectrum at that depth were known. Order-of-magnitude estimates of the effect can be made from theoretical and empirical relations for seismic motions. The present estimates are based primarily on engineering tables of expected accelerations, areas affected, and other earthquake characteristics summarized in *Earthquake Engineering* (Wiegel, 1970). Housner (in Chapter 4 of Wiegel) discusses existing measurements of strong motion ground acceleration and describes the accelerations qualitatively in terms of the earthquake magnitude, fault slip dimensions, and distance.

The calculation of the Hazards Chart involves three main parts, (1) The ground acceleration spectrum vs. distance and earthquake magnitude, (2) the water pressure vs. depth, acceleration, and oscillation frequency, (3) the statistics of earthquake occurrence. The steps are discussed in SIO Reference #72-18, and only the final results will be presented here.

Hazard charts are presented in Figures 1 and 2. These are the Barazangi and Dorman (1969, 1970) charts overlaid with numbers that show the calculated percent probability that a submarine will experience a 20% pressure change during one year of submerged operation in seismic regions that are shown as dense areas of dots. Regions of less than ½% probability are not marked. The probability of experiencing a 12% pressure change can be found by increasing the chart values by a factor of 5.4. And the probability of experiencing a 32% pressure change can be found by decreasing the chart values a factor of 10.

The assumptions made in calculating the chart are listed briefly here:

1. The worldwide number of shallow earthquakes is correctly given by Gutenberg and Richter (1965).
2. The magnitude distribution everywhere follows the relation, $\ln = 17.85 - 2.05M$, where n is . . . . . and M is . . . . .
3. The Barazangi-Dorman (1969, 1970) tabulations of earthquakes are valid in location and depth, but not in magnitude or total number. Many earthquakes of M_4 and M_5 were omitted.
4. The Barazangi-Dorman Shallow earthquake distributions in 10° latitude-longitude regions can be corrected by applying (1) and (2) to them.
5. The area covered by ground accelerations of different percentages of g is correctly given by Housner (in Wiegel, 1970).
6. The total area affected at any one level of ground acceleration can be found by calculating the actual area affected by earthquakes

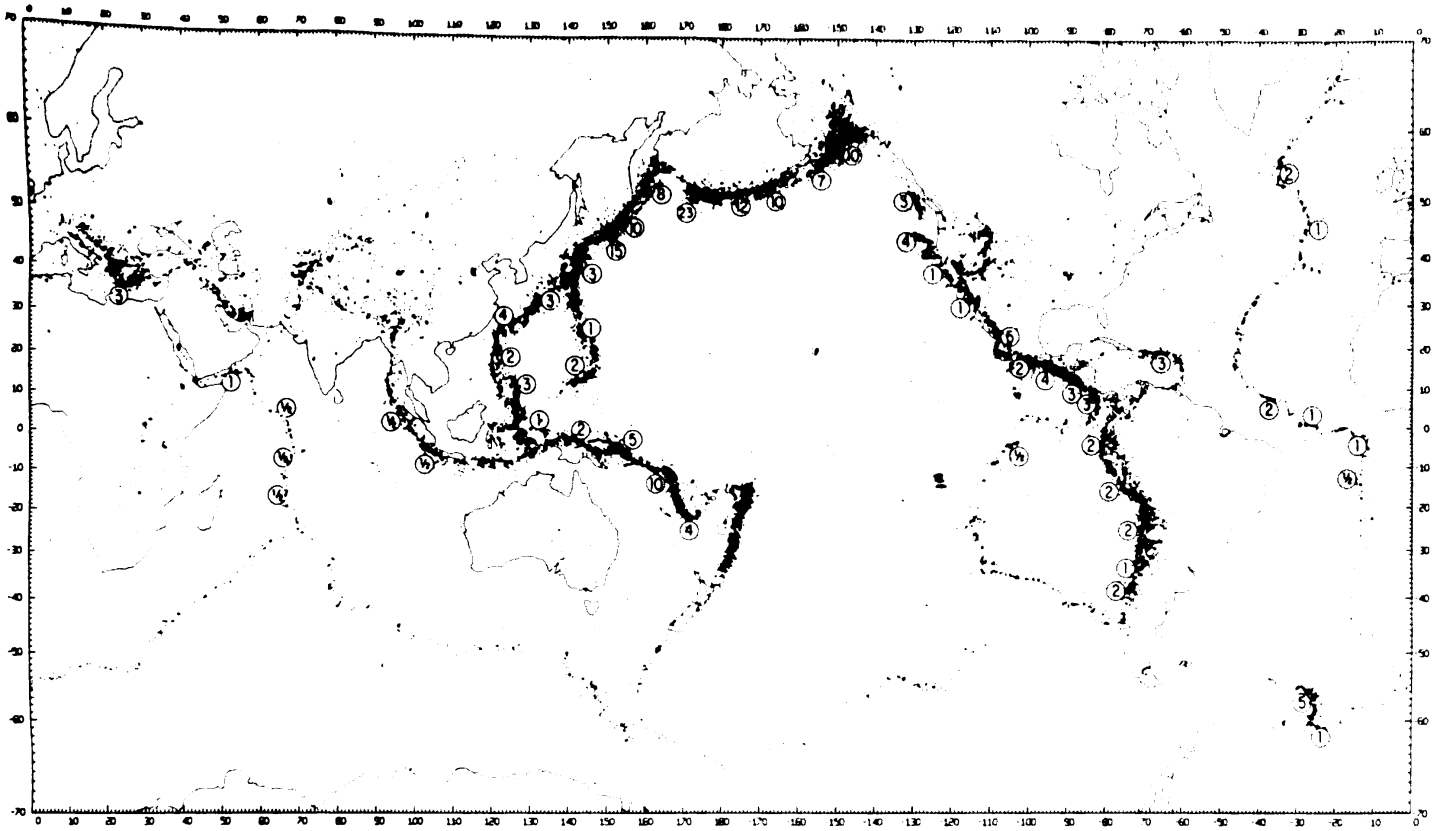

Figure 1 – Calculated probability (in percent) that submarine will experience 20% pressure change during one year of submerged operation. Calculations are based on world-wide seismic network observations for 1961-1967, The 23% value near the western tip of the Aleutian chain is anomalously high because of the Rat Island series of earthquakes. The 2% and 3% values near Chile and Japan are anomalously low compared with long-term observations in those regions.

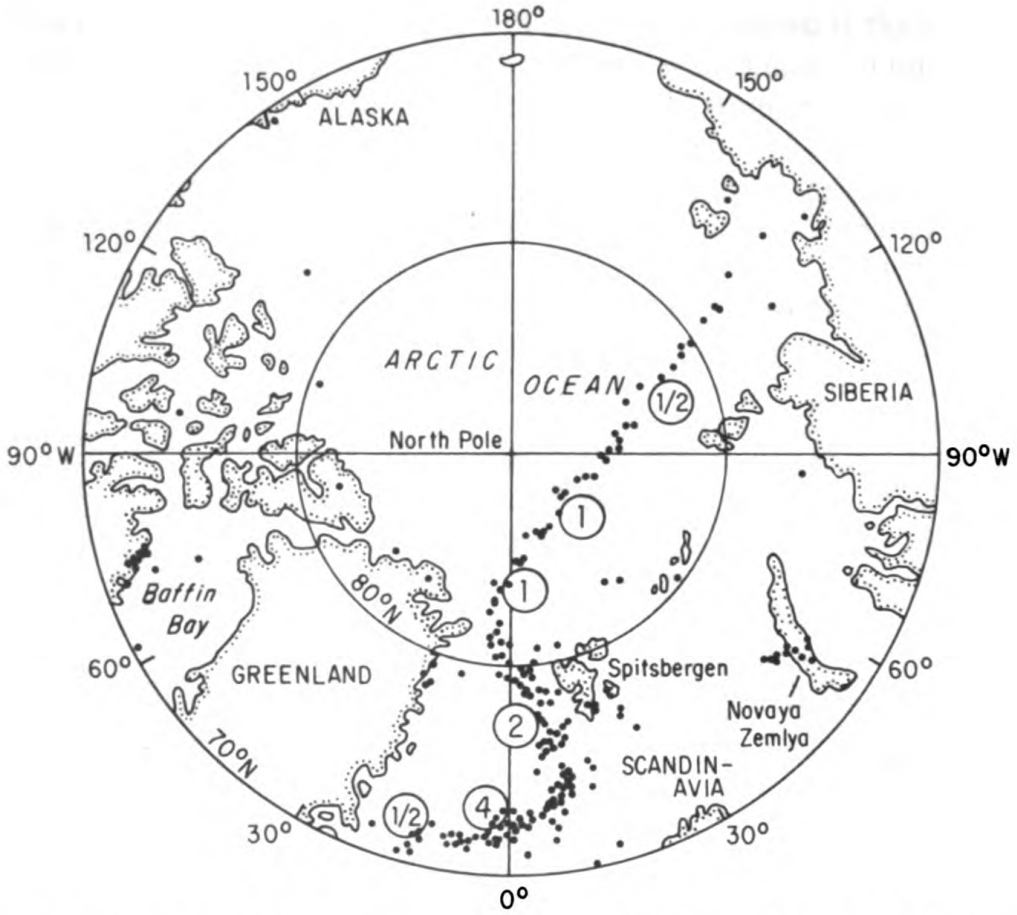

Figure 2 – Calculated probability (in percent) that submarine will experience 20% pressure change during one year of submerged operation.

of M_7 to $M_{7.5}$, and multiplying by the appropriate ratio factor from combining (2) and (5).

7. The submarine will experience an effective fractional change in depth corresponding to 80% of the fractional g acceleration.
8. The hazard is taken to be the probability that a submerged submarine will experience at least 20% increase in pressure at some time during one year of submerged operation in the immediate region of high seismic activity.

The Barazangi and Dorman seismicity charts are based on a seven-year period of observation and therefore are not truly representative of long-term seismicity in some parts of the world. The seismic activity appears anomalously high around the western tip of the Aleutian chain because of the Rat Island earthquakes. The long term seismic activity around Japan may be roughly a factor of three higher than it was during the 1961-1967 period. The activity around Chile is reported to be sporadically high, with extended quiet periods. 1961-1967 was a quiet period.

The reader is cautioned that the calculations are very rough. We believe that the resultant Tentative Hazard Estimates may be accurate to a factor of two or three. They are probably not wrong by a factor of five.

An area of high seismicity is considered to be a region with a concentration of earthquake epicenter dots on the chart. Operation 100 miles outside a well defined area of high seismicity will reduce the hazard of a negligible value.

Strong motion earthquake information is being extended rapidly (largely by work out of California Institute of Technology by Housner, Hudson, Trifunac and others). Present results indicate that accelerations may frequently be greater than the predictions of Wiegel (1970). The hazard to submarines should be reappraised in one or two years when a large number of strong motion records will have been analyzed.

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(Continued from Page 20)

The additional size and weight of the added refrigeration equipment would yield transducer densities on the order of 1000 watts/lb/kHz. Conventional transducer designs have usually obtained power densities much lower than this, with some magnetostrictive units yielding close to 20 watts/lb/kHz. Ceramic units have varied from 5 to 15 watts/lb/kHz with a typical average around 10 watts/lb/kHz. Other transducer types, such as hydroacoustic or conventional electrodynamic, have typically been much lower. Superconductivity designs can therefore offer at least a factor of 100 improvement in power density over typical conventional designs.

Research Notes

Solar Magnetic Fields

Magnetic fields rising to the surface of the sun indicate that something inside the sun is rotating slightly faster than the surface.

If you could walk on the sun with a compass in your hand, you would notice that some areas exhibit negligible magnetic field while others exhibit extremely strong ones.

Dr. Robert Howard, solar astronomer at the Hale Observatories, recently reported on a summary of data about the sun based on some 20 million observations of the solar magnetic field with the 150-foot tower telescope at Mt. Wilson Observatory over a span of eight years. The telescope is a facility of the Hale Observatories, which are operated by the Carnegie Institution of Washington and the California Institute of Technology. The Office of Naval Research supports this research on magnetic fields of the sun to measure and understand better the variations on the solar surface in order to predict solar flare activity. Navy communications, navigation and long range surveillance systems are degraded or completely disrupted by ionospheric and magnetospheric disturbances caused by solar flares.

Attached to the telescope is a magnetograph that completely scans the 864,000-mile-diameter solar disk every 90 minutes, mapping and measuring the magnetic fields, which reflect the movements of the glowing gases. The movements have been likened to the flow of ocean currents on earth. The magnetograph uses the Zeeman effect to record the presence, strength and polarity of magnetic fields in hot solar gases. A magnetic field splits each spectral line from a light source such as the sun. The greater the separation of the two parts of the line, the stronger the field. The magnetograms are published regularly in two technical journals, "Solar Geophysical Data" and "Quarterly Bulletin on Solar Activity."

The telescope is the only one that has accumulated a long daily record of solar activity with a magnetograph. The record is used by other observatories to study solar phenomena, by geophysicists to correlate the earth's magnetic storms with solar storms, and by space scientists concerned with the extension of the sun's magnetic fields via the solar wind through the solar system.

Dr. Howard found that the magnetic field lines emerging from the solar interior are not perpendicular to the surface (photosphere) but are inclined on the average almost a degree away from the direction of rotation. The astronomer sees this as an indication that the field lines are attached to something deep inside the sun, perhaps an inner shell, that is rotating slightly faster than the surface.

It has been known for some time that sunspots rotate faster than the surface gases as though they too may be linked to an inner, faster-rotating shell.

Eight years ago when the Hale Observatories' astronomer began his detailed magnetic observations, the east-west positive and negative magnetic lines rising from the photosphere were inclined toward each other about five degrees. Over

the ensuing years the inclination has lessened until now the lines rise almost parallel to each other. This may be linked with the solar cycle.

While the earth has one overall magnetic field measuring less than one gauss in strength, the sun has many regions characterized by much more powerful fields. In general there appear to be two kinds of solar magnetic areas, both developing from and reflecting internal activity. One kind, associated with sunspots, is very strong–averaging several thousand gauss. The other, not associated with sunspots, averages only several hundred gauss in strength.

The stronger fields associated with sunspots survive only as long as the spots, that is from several hours to several months. The lesser fields can persist for many months. They are confined into little bundles of field lines in the chromosphere (the solar atmosphere) and are continually on the move.

These bundles of field lines come from somewhere inside the sun. Some connect with opposite polarity fields and develop loops. Fiery gases cling to the loops and can be seen on the sun's edge as spectacular prominences.

Virtually all the magnetic fields (approximately ninety-five percent) are generated in the solar equatorial region, in contrast to the earth where the strongest magnetic fields are at the poles. The solar magnetic fields continually migrate poleward from the equatorial regions at an average speed of forty-five miles per hour while spreading out by being stretched by the sun's rotation which is at the rate of 4,500 miles an hour at the equator. The sun rotates once every 27-plus days, spinning faster at the equator than near the poles. The magnetic fields cancel each other when bundles of opposite polarities combine. They blend together and vanish. Ninety-five percent of the magnetic flux is canceled this way as the fields migrate poleward and before they reach 40 degrees solar latitude. That's less than half way from the equator to the pole. Magnetic fields that survive to reach the poles take about a year to migrate from 40 degrees to the pole.

All the magnetically active regions form near the equator due to a combination of rotation and the subsurface structure of the magnetic field.

The sun normally runs through an 11-year activity cycle, ranging from a quiet period into an active one with many sunspots, flares and prominences, and then back to quiet again. During the time of maximum activity, the large-scale fields are more negative than positive. Solar activity is more frequently associated with large-scale negative rather than positive magnetic fields. In this century most of the cycles have been ten years long. Often one hemisphere is more active than the other.

Roughly at the time of maximum activity the magnetic fields reverse polarity. Normally on the sun the northern and southern hemispheres have opposite magnetic polarity orientations. This means that if the leading edge of the magnetic fields in one hemisphere is positive and the trailing edge negative, the opposite will be true in the other hemisphere. The leading edge of a field is that part of it that is nearest the direction of rotation.

In the sun's northern hemisphere the field reversed in mid-1971 from negative to positive. The change occurred much earlier in the southern half. The two halves seem to act somewhat independently of each other. "Now all the activity

is in the south," Dr. Howard noted, "sort of making up for its fizzling out during the previous maximum. During the previous cycle the southern hemisphere was weak."

Pointing out that it is fairly common for one cycle to be more active than the other, Dr. Howard said that during the early 18th Century there was a 30-year period in which no sunspots were seen in the north at all. At the same time there were never more than two groups of sunspots at one time in the south.

"So the sun almost sputtered out as far as magnetic activity was concerned," he observed, recalling that records have been kept on sunspots almost since the time they were discovered by Galileo early in the 17th Century.

Frequently the magnetic fields on the solar disk show predominantly one polarity which should be an impossibility, Dr. Howard said. He suggests that this may have to do with the preferential orientation of field lines.

"For some reason the field lines from one polarity are inclined away from us and the other toward us," he said. "This may explain the apparent monopole behavior. We may not be recording those inclined away from us."

The research was assisted by the Office of Naval Research, the National Aeronautics and Space Administration, Air Force Cambridge Research Laboratories, and the National Science Foundation.

Letter of Appreciation–Skylab Program

Dr. James C. Fletcher
Administrator
National Aeronautics and Space Administration
Washington, D. C. 20546

Dear Dr. Fletcher:

I am taking this opportunity to extend my appreciation for the cooperation and enthusiasm of the Skylab team in acquiring information of keen interest and value to the United States Navy. The Office of Naval Research was very pleased to be asked to participate in the Visual Observation Experiment when it was requested last August by the crew of Skylab 4. Our efforts were coordinated by Dr. Robert E. Stevenson of our Branch Office in Pasadena, California, and he has reported to me on the outstanding success of this particular experiment.

The visual observations and photography of ocean features by Colonel Gerald Carr, Colonel William Pogue, and Dr. Edward Gibson have proven to be of great significance in our oceanographic research program. Their observational capability, together with the timely handling of information between the astronauts and the team led by Mr. V. R. Wilmarth at the Johnson Space Center (JSC), have opened an entirely new horizon in the study of oceanography.

The practicability of this ground/space team concept was firmly established in early December 1973 following our request to verify the existence of cold-water eddies. Dr. Stevenson had previously interpreted these eddies from Skylab 2 photography, and on 5 December 1973 he described the eddies to Dr.

William Lenoir, astronaut and member of the Visual Observations Team. A descriptive message was transmitted to the Skylab 4 crew that evening. The following morning, during the orbital pass over Houston, the Gulf of Mexico, and the western Caribbean Sea, all three astronauts observed the eddies and described them to the ground team in a real-time communication. That evening, through the planning of John Kaltenbach and Michael McEwen of the Viz Obs Team, a television pass was scheduled for the next morning over the Caribbean. As a result, Dr. Stevenson was able to view the eddies while Colonel Pogue trained the on-board television camera from one eddy to the next.

From this example of fine cooperation and communications between a well-managed ground team and the enthusiastic Skylab 4 crew came our belief that techniques for real-time ocean forecasting for tactical fleet operations are entirely feasible. Such possibilities are so promising that we employed an aircraft of the Navy's Weather Reconnaissance Squadron 4, Jacksonville, Florida, on 24 January 1974, to acquire ground-truth data along the Skylab flight line over the northeast Caribbean Sea. I can tell you now that those data from that joint NASA/Navy operation confirm the existence of ocean turbulence about which we previously could merely hypothesize.

The success of visually observing the cold-water eddies was a tremendous boost in confidence to the Skylab 4 crew. They readily accepted new requests from investigators. In fact, Colonel Carr became increasingly intrigued with ocean waves seen in the sun's reflection pattern, and this led to our learning of a wave-current interaction of direct concern to our transiting ships. The Office of Naval Research had funded a five-year study to determine the influence of currents on large ocean waves. The extreme difficulty of data gathering had resulted in the unsuccessful conclusion of the project. Colonel Carr's comment during the debriefing session in March, that it was very interesting how "waves extended continuously across the ocean only to terminate at the boundaries of major ocean currents," caused far more than a ripple of excitement to surge through Navy oceanography circles.

Further in-depth evaluations of the observations, photography, and information from the debriefing of the Skylab 4 astronauts are now under way through a contract from JSC to the University of Southern California, with Dr. Stevenson acting as advisor. Though the effort will require several more months, already one of the products has been ocean-current charts of the southwest Atlantic and the waters around New Zealand of greater detail than any previously available. The latter are now being made available to the New Zealand Ministry of Fisheries.

Without prior knowledge of the coastal currents around New Zealand, the Skylab 4 crew confirmed the flow as shown on our most up-to-date chart. Furthermore, their observations provided us with details of the currents some 1000 miles east of New Zealand that would have required months of measurements using even the most modern oceanographic techniques. Their verbal descriptions coupled with their well-chosen back-up photography have revealed turbulence around Chatham Island that is of direct significance to naval operations. These charts indicate the immediate value of the observations, and we can

clearly expect more information from the continued interpretation of the photos and visual observations.

I know that this outstanding experiment on visual observations could not have been implemented without the scientific atmosphere for the Skylab program created by Mr. William C. Schneider and carried through by the management at JSC of Dr. Christopher C. Kraft, Jr., Mr. Anthony J. Calio, and Mr. Kenneth S. Kleinknecht. Mr. Wilmarth and his Visual Observation Team members, noted earlier, were untiring in providing every means for the successful experiment, one that has opened so many new avenues of investigation.

The key to successful visual observations was, of course, the astronaut crew. They did so well, I am told, that their eyes and minds leapt from oceanographic to geologic to meteorologic evaluations with a coolness and rapidity that few others could attain. Their taped evaluations were accurate, yet filled with rational imagination. They were superb observers.

To all these men and NASA itself, I extend a hearty "Well Done!" We look forward with great pleasure to continuing these cooperative efforts, first during the Apollo/Soyuz Text Project, and then the Shuttle/Spacelab.

Sincerely yours,

M. D. VAN ORDEN
Rear Admiral, USN
Chief of Naval Research

Project Ocean Acre

In Project OCEAN ACRE, the Naval Underwater Systems Center (NUSC), in cooperation with the U.S. Naval Oceanographic Office, the Smithsonian Institution, and the University of Rhode Island has made detailed studies of acoustic, biological, and ecological characteristics of an ocean area about 60 nautical miles square by 4000 meters deep near Bermuda. In particular, the Center has conducted acoustic experiments to determine resonant frequencies of scatterers as well as scattering strengths versus time of day and season. Acoustic energy (1.3 to 15.5 kHz) was provided by hull-mounted and towed sources. For biological sampling NUSC has developed a precision sampling technique and taken biological samples to a depth of 2500 meters to relate type and habits of organisms to scattering strength. To date, NUSC has participated in fourteen cruises to conduct acoustic ranging and biological sampling experiments from which comprehensive data on volume scattering fluctuations and depth and size distribution of scatterers over daily, diurnal, and seasonal periods have been obtained in a systematic manner.

University of Rhode Island participants have concentrated on decapod crustaceans, with studies of the vertical distribution, seasonal abundance,

reproduction and feeding habits of the caridean prawns and specimens of the genus *Sergestes*. In addition, life histories, vertical distributions, patterns of vertical migration, and other aspects of the biology and ecology of a large number of the midwater species have been determined.

As part of Project Ocean Acre, conducted under the direction of C. L. Brown, head of the Center's Oceanography Division, NUSC has developed a mathematical model to furnish a computer printout of individual and total scattering strength values and resonance frequencies for any combination of up to 70 given fish species of any given mean standard length for any given frequency, depth, and population density.

In related experiments, reverberation anomalies have been uncovered that had heretofore been overlooked because of oversimplified experimental and analytical techniques. With NUSC's project-derived methodology, the near-surface biological scatterers, which can affect sonar performance markedly, have been identified. Because of the limits which biological reverberation implies on the operation of existing sonars, the sophistication of the biological model can be utilized to predict more accurately the detection capabilities of present systems, as well as guide the design of future systems. The predictive value of the Ocean Acre study may then be tested wherever appropriate data from other oceanic areas becomes available. Ocean Acre type data are already available for this use from the Mediterranean Sea.

In addition, the determination of the reverberation characteristics from Ocean Acre will allow comparisons with other oceanic areas. This will be an important product of the study.

Farfield ELF Propagation Measurements

In April 1974 the New London Laboratory of the Naval Underwater Systems Center published the results of a study of extremely low frequency (ELF) propagation parameters. This study was based on measurements of ELF magnetic field strengths made in Anchorage, Alaska and Sondre, Greenland by Center personnel and in Norway, Greece and Saipan by personnel from MIT Lincoln Laboratory during the same period in May 1972. These locations were chosen to be in the farfield of the transmitter described below.

At each location, the horizontal magnetic field strengths were measured in bands of frequencies centered at 45 Hz and 75 Hz to determine the average attenuation rates and relative excitation factors for daytime propagation. (The number and values of frequencies were chosen to minimize standing wave effects caused by the interference of the direct and round-the-world waves.) The field strength at each center frequency was estimated for each measurement site by averaging the absolute field strengths and weighting inversely according to frequency. Once this was done, the average attenuation rates and relative excitation factors were easily determined.

The transmitter for these measurements was a Navy test facility located in the Chequamegon National Forest in north-central Wisconsin, about 8 km south of

the village of Clam Lake. It consists of two 22.5 km NS antennas (one buried and one elevated) and one 22.5 km EW antenna, with the transmitting station at the intersection near the midpoints of the antennas. Each antenna is grounded at both ends.

The principal conclusion from these measurements is that auroral-zone effects are present at extremely low frequencies; it appears that variations in the daytime attenuation rate and relative excitation factor at 45 Hz and 75 Hz are an auroral-zone effect, rather than a direction of propagation effect. The work was performed by P. R. Bannister, J. R. Katan, E. A. Wolkoff, and W. A. Kraimer, members of the Electromagnetics System Department at NUSC. The Center's ELF measurement program directed by J. Merrill and D. A. Miller, is under the sponsorhsip of the Naval Electronics Systems Command, Special Communications Project Office.

No-Exhaust Engine for Underwater

This could be the direct result, and is indeed the challenging objective, of research and development of a new concept in underwater power source now being conducted at the Naval Coastal Systems Laboratory.

Such a system, using a well-known rotary-type engine as the basic source of power with propane gas (bottled gas) as fuel, has been built and tested at NCSL, with the initial effort proving very encouraging.

The system is based on using standard internal combustion engines treating their exhaust gases to remove combustion products and replenishing oxygen, and resupplying this gas to the intake. A number of engine characteristics necessary for use in such a system are almost peculiar to rotary-combustion engines. Basically, the system consists of the engine, a scrubber to remove products of combustion, oxygen replenishment, and fuel carburetion. Predictions based on data already taken indicate that a complete system including oxygen, fuel and scrubbing material would have two to three times the power and energy density of a silver-zinc battery/motor system. The cost of the power plant would be only a fifth to a tenth that of its silver-zinc counterpart.

In its initial testing, the engine has been operated totally closed with manual control of oxygen replenishment. Work is progressing in the Diving and Salvage Department of NCSL on development of a system with automatic controls for hands-off operation.

In an attempt at testing other fuels with the system, trial runs have been made using hydrogen. This brief effort also proved encouraging. Hydrogen did not prove quite as efficient as propane; however, the potential of hydrogen as a fuel is very promising both from an efficiency and energy density standpoint.

It is believed that power density with hydrogen fuel could be increased using one or more of a variety of techniques. The obvious benefit of using hydrogen is that water is the only combustion product, thereby eliminating carbon dioxide scrubbing equipment, and expendable chemical material. The potassium hydroxide now being used for CO_2 scrubbing represents almost half the weight of the present system.

A closed hydrogen fueled engine has tremendous potential as an underwater power source, the scientist at NCSL feel. They assert that energy densities should be several times that of existing and available power sources, and with no exhaust to be pumped overboard, the system should be depth insensitive, it being necessary only to design the engine container to have sufficient strength to withstand the external pressure. For shallow water depth, hydrogen could be stored most effectively in cryogenic fashion. For great depths, a metal-matrix storage system would probably prove to be of higher energy density.

Rather than the fabrication of engines, the NCSL effort will result in technology development ready for application to specific engines. The effort is aimed at filling in at least one gap in underwater technology, that in the area of 5-1000 horsepower high energy and power density, mid short duration mechanical sources.

Development of the no-exhaust underwater power source will advance the technology of propulsion of vehicles as well as provide the swimmer-diver with more reliable and durable power-driven tools.

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Editor: WILLIAM J. LESCURE NAVSO P-510

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Cover Caption

Calculated probability (in percent) that submarine will experience 20% pressure change during one year of submerged operation. *See page 21.*

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