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proceedings

A symposium

THE OCEAN AS THE OPERATING ENVIRONMENT OF THE NAVY

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Office of Naval Research
Department of the Navy
Washington, D.C.

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THE OCEAN AS THE OPERATING ENVIRONMENT OF THE NAVY

A Symposium sponsored by
The Office of Naval Research
March 11, 12, and 13, 1958
San Diego, California

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Office of Naval Research
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PREFACE

It is becoming more and more evident that full exchange of ideas and rapid communication of results are among the most powerful stimuli for scientific progress. The Office of Naval Research is, therefore, sponsoring Navy-wide symposia on various subjects in order to provide opportunities for scientific personnel of Navy laboratories and contractors to get together and to discuss problems of mutual interest. In view of the increasing importance of underwater operations, the general theme of this symposium is particularly timely. The program has been so arranged as to present the viewpoints of the scientist, the engineer, and the fleet officer, and I am certain that the personal contacts resulting from this meeting will plant the seeds for greater progress of the New Navy.

R. Bennett

R. BENNETT
Rear Admiral, USN
Chief of Naval Research

MEMBERS OF THE SYMPOSIUM PROGRAM COMMITTEE

Chief of Naval Operations - Captain R. H. Holden, USN
Commander C. L. Scherrer, USN

Bureau of Aeronautics - Mr. F. W. S. Locke
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Marine Corps - Dr. C. E. Wise, Jr.

Office of Naval Research - Dr. J. N. Adkins
Dr. I. Estermann, Chairman

CONTENTS

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OPENING REMARKS

I. Estermann
Symposium Chairman
Office of Naval Research

When we began to organize this symposium in the pre-Sputnik era, two questions were frequently asked. First, what is the value of such a symposium, and secondly, what is its purpose. The answer to the first question has been given already by your presence here - frankly, we did not expect such a wide audience, and it is a particular pleasure for me to bid you a cordial welcome. I hope that when you leave, you will have no doubts left about the value of this symposium.

The second question is more difficult to answer. As you know, there is an abundance of scientific meetings, and it may well be questioned whether the organization of an additional one really serves a worth-while purpose. Let me say that we in ONR do not consider these Navy-wide scientific symposia to be in competition with other meetings. In our opinion, they have a peculiar function which no presently existing type of meeting can fulfill. This function is intimately connected with the position of the scientist in the Navy and with his interaction with other parts of the Navy. Every member of an organization has the obvious duty to contribute to the mission of his organization. The scientist, however, has the additional duty to further the mission of science. While in the first respect his superiors are the proper judges of accomplishment, in the second respect, judgment can be exercised only by his peers. In the University environment, this opportunity is provided for by standard scientific journals and meetings of professional societies, plus a number of ad hoc conferences on specific subjects. The Navy scientist, however, can utilize this procedure only to a very limited extent. In the first place, he is usually more or less isolated from those in the Navy who have the responsibility for its performance, namely the leaders of the operating fleet. Secondly, his work is to a large extent classified and cannot be presented for judgment to the scientific community at large. It is therefore necessary to provide the opportunity to present it to a selected group of scientific peers -- and this is one of the reasons why we are assembled here. To break down the isolation, we have invited key people from the operating fleet and from the Material Bureaus -- the ultimate consumers of the Navy scientist's work. I am happy to see this group so well represented here today, and I hope that this symposium and those following it will help in establishing a closer bond between the scientist, the Bureau engineer, and the fleet officer, who after all are all members of the same team. The program has been so arranged as to give the scientists a forum for his advanced thinking, and to the others, a chance to present their current day-to-day problems for the scientists' consideration. We are sincere in our conviction that this interchange will contribute a lot to the future of the Navy Scientist and the Navy as a whole.

WELCOMING ADDRESS

Captain J. M. Phelps, USN
U. S. Navy Electronics Laboratory
San Diego, California

Good morning, Admiral Bennett, ladies and gentlemen.... We at NEL are indeed happy to have you here with us today and we welcome you to the Laboratory to take part in this Symposium on Basic and Applied Science.

You as a group represent a very selected combination of industrial, educational and governmental civilian and military professional competence that is assembled here to concentrate for several days on some of the basic problems affecting the Navy in its natural environment, the sea. We cannot begin to over-estimate or to measure the long term benefits to be gained by this very act of your taking time out to come here and to reflect and think about and concentrate on some of these fundamental issues that are going to be discussed within the next few days.

I hope that you will be stimulated and that you will gain some fresh points of view and insight into what the other fellow sitting alongside you or in this auditorium is thinking about and perhaps you can get a little new perspective on some of the problems you face from day to day. I think it is important that every once in a while we take the time out to do this. I think we have many solutions to our problems that are available. They are floating around some place and we concentrate on some of the details and forget many times to take ourselves outside of this overall problem and look at it with this broad point of view. I think that this sort of a meeting does enable us to do that. Now too often we justify meetings such as this on the basis of cross-fertilization of ideas, but I recommend that you forget for a moment this cross-fertilization and look beyond your present horizons for new ideas. What we need today are not just new ideas on what we already know about. We need some real inspirations to solve our problems. Success, so they say, is supposed to come to those who are actually prepared for it, and this type of a meeting helps us to get prepared; and I hope that this particular one, sponsored by the Office of Naval Research, will help all of us prepare ourselves to make better contributions to the overall Navy's efforts. So to each one of you I hope you thoroughly enjoy your stay at NEL, and during the few times you have outside of the Laboratory itself when these sessions are over, I hope you enjoy your stay in San Diego.

THE OCEAN VIEWED AS A MILITARY ENVIRONMENT

Rear Admiral Rawson Bennett, USN
Chief of Naval Research

The mastery of the sea has traditionally been the basic problem of the Navy. In successfully designing, building and operating a powerful modern Fleet both on the surface of the ocean and in the depths beneath, much depends on how well we understand the environment of the sea itself. Consequently it is most appropriate that the first specialized annual Navy science symposium should deal with the ocean as a military environment.

When I opened the first annual symposium a year ago in Washington, I noted that scientists throughout the Navy laboratories are widely separated by geography and administrative boundaries. I pointed out that one of the principal benefits of this symposium is that it brings together many of you working in related problems to exchange ideas and familiarize yourselves with one another's work.

Oceanography, because of the highly diverse aspects of this field, probably more than most scientific fields needs a closer drawing together of those whose work touches upon this area. For example, acoustics and biology are normally unrelated but in oceanography they have a direct relationship. In addition, geography, geology, physics, chemistry, metallurgy, and naval architecture all play important roles in this field.

The Office of Naval Research has more than a routine interest in the research in this field. In fact, our oceanographic contract research program represents the principal effort of the Government in the field of physical oceanography at private or non-government institutions. Through these contracts these institutions receive the major portions of their research funds for this program. This has been the principal means by which the United States during the past ten years has been able to move into a field which prior to World War II was dominated by Western European scientists and institutions. Recently Soviet Russia has taken the lead in the number and size of oceanographic vessels, but not in quality of research results.

We have also participated in setting up the new Committee on Oceanography, through which we plan to provide a national center for focusing attention on oceanography in the United States. The Committee is supported jointly by ONR, the Atomic Energy Commission, and the U. S. Fish and Wildlife Service. This group is to be called upon for advice on current oceanographic problems, and, in addition, will provide counseling, planning and coordination in long range oceanographic research.

For the first time there will be an established means through which the various oceanography institutions and laboratories with programs in this field may act as a unit. Individual members of the Committee have been appointed by the President of the National Academy of Science. In carrying out its work, the Committee has formed specialized standing and ad hoc panels and subcommittees with adequate staffs. One of the contributions the Committee will make will be to provide forums for the discussion of problems of concern to all branches of oceanography -- such as manpower, ship and laboratory facilities, instrumentation, data processing and similar common interests -- and foster the research for solutions to these problems.

Although the Navy is primarily interested in viewing the ocean as a military environment, it is characteristic of our research programs that more than just military development is benefited. For example, our interest in amphibious operations stimulated us to study sea and surf phenomena because of their vital role in the success of such operations. This led to giving us a better understanding of waves, sea and surf. We developed theories and then confirmed and modified them by aerial mapping of the sea surface. A practical result of these studies was a decision by the Military Sea Transport Service to route ships in accordance with meteorological and oceanographic conditions and forecasts. In a test, a ship routed in this manner arrived at a European port one and one-half days ahead of schedule while another ship following the customary great circle route arrived one day late.

Conversely work in oceanography pursued by investigators

with no military application or benefit in mind has proved to be of great value to us. An excellent example is the Navy's use of the Piccard bathyscaphe, the TRIESTE, for a program of deep sea research last summer. The TRIESTE was developed and built by Professor Auguste Piccard through his own interest in deep diving vehicles. Enough craft of this type could explore about 99 percent of the sea floors in the oceans of the world.

The Navy plans to use the TRIESTE not only to explore the ocean environment at great depths but also to evaluate the potentialities of the bathyscaphe both as a research tool and as a naval craft, such as a submarine rescue vessel or a deep diving submarine. In the series of 26 dives carried out last summer off the coast of Naples the emphasis was on the study of the field of sound in the ocean growing out of the Navy's great interest in underwater acoustics in submarine warfare. We combined investigations in biology, geology, and physics of the ocean depths in an attempt to identify sources of ocean sounds and to determine the sound transmission qualities of the ocean and the bottom.

One of the scientists who contributed so much to the success of the expedition last summer was Dr. Andreas Rechnitzer of your own Navy Electronics Laboratory. In fact, our program for next summer calls for us to bring the bathyscaphe to San Diego for a series of dives in this area. Even though most of the dives last summer were conducted just off the romantic Isle of Capri, my people tell me that they will be happy working here in San Diego next summer.

I have just barely touched on the many ways that the study of the ocean has a vital relationship to naval operations. We know that the ocean affects the weather and might give us the clue to long-range forecasting, that chattering fish can be a serious hazard to sonar operations, and that we can design more efficient hulls if we know more about ocean waves. Most tantalizing of all is the knowledge that the ocean contains enough deuterium to provide virtually unlimited cheap hydrogen fusion power if we can but solve the secret of how to obtain it.

Whether or not your interests are inclined toward the Navy, the ocean is an integral part of man's life. The ocean spawned the first living and growing thing and holds the key to our future civilization. Any new knowledge that can be gathered about this still mysterious environment -- as challenging as is outer space -- is valuable and urgently needed.

THE SCIENTIFIC PROBLEMS OF NAVAL OPERATIONS

Rear Admiral J. T. Hayward, USN
Assistant Chief of Naval Operations for
Research and Development

Admiral Burke wanted to send his regards to the Symposium and you won't object, I am sure, if I just cross off "scientific" on this talk and say "The Problems of Research and Development," because we have many of them.

In the reorganization in the Chief of Naval Operations' office he has designated my office the Assistant Chief of Naval Operations for Research and Development, where we have the overall programming and direction of the research and development program for the Chief of Naval Operations. We use the very able staff of Admiral Bennett, Chief of Naval Research, to assist us to do this job.

Of course we have many problems. If you look at the spectrum of war, you see what faces the Navy. We have all the way from the mega war down to the situation that you have in Indonesia today.

Now the research and development program of the Navy is to support the programmed objectives of the Navy, so this means that our problem is far from simple. You get missiles such as the BULLPUP, which stems from a requirement for the Marines for a conventional weapon to be used in local situations where it is necessary. Our general philosophy in those fields, of course, is the precise delivery of weapons on military objectives. There are a lot of places and a lot of times when you don't want to incinerate the whole countryside and you have a lot of friends. Now if you look at our program, we have divided the overall research and development program into two parts. Part One, which are Weapons Systems which lead to hardware. Part Two is the basic and applied supporting research of the Naval establishment. For your information, it runs a little bit higher in part two than it does in part one. If you look in the Part One situation as we exist today, the first thing on the priority list is the fleet ballistic missile or the POLARIS program. This consists of marrying a ballistic missile to a nuclear submarine. This, however, of course, just applies to the mega-war situation. I am sure most of you realize that this would be of little use to us in a situation such as Indonesia today. So we are faced with the problem of trying to keep a balanced situation. There are a lot of people who would put us all under the water and build nothing but POLARIS submarines. However, this would be very unwise. I am sure the opposition will go down any path if we don't go down, and if they can get us to just go down the path of general war we'll be eaten alive.

Now, in the situation of the POLARIS which is coming along very well---we actually have at the moment three boats programmed. These boats, of course, have sixteen ballistic missiles in them; they have a 600 pound war head; it's a 1500-mile nautical missile. We hope, if the Inyokern boys do their job, that we can launch it submerged, and as you can see, it is a very potent system, and it backs the Navy philosophy that we feel that the deterrent force should be flexible across the spectrum also. You shouldn't put all your eggs in one basket, not just in missiles, not just in manned aircraft, but you need a posture such that the enemy is given great pause before he attempts to attack you in the all-out situation. And you certainly pose a problem to him with this particular weapons system. Now, naturally, after seeing this and seeing what we can do in this, it really brings the ASW picture to the forefront.

There is one very important thing that has happened in ASW that most people don't seem to realize, and that is that there was a time when ASW was easy, when all that was coming was to sink you and you could always make the basic assumption that he was going to try and sink you, and we didn't realize how easy this made the problem and in a lot of instances he came just to sink you. Now when he comes, he is going to try and evade you and he is probably going to be a lot less interested in sinking a specific ship, particularly in the threat to our country from submarine-launched guided missiles.

Admiral Burke and the Vice Chief of Naval Operations have been very cognizant of this problem. They have set up Admiral Weakley, directly under Admiral Burke, as Op-001, who has the ASW problem complete, to see if we cannot really help ourselves in protecting the country from this guided missile threat from submarines. In addition, we have to do the conventional ASW job because we are a member of a free alliance, and the free alliance exists because of the seas, and if we cannot control the seas, the free alliance will fall. So we have both tasks to do.

Now, in connection with this, the second priority in our weapons systems are, of course, nuclear reactors. Most of our nuclear reactor program has gone into attack submarines to date. However, we do have the LONG BEACH and we do have a DLGN and we do have a CVAN. In an attack submarine we have found in recent exercises of the SKATE versus conventional submarines in the Atlantic that it is a very potent weapon. They can really kill the conventional submarine practically 95 percent of the time. The SKATE's remarkable performance really gives us great hope. However, when you begin to look at the problem, talking about scientific problems, suppose we could really communicate with our submerged submarines and vector them from the surface. You always get back to the inter-surface problem. We would really have a three-dimensional hunter-killer force.

As you know, today whenever we are running against enemy submarines, we usually always have to get rid of our own, get them out of the area, because there is no real way to communicate or to know where they are. On the East Coast they have tried some operational experiments using the UQC Equipment from a helicopter and have had real good luck keeping a submarine directly underneath one of our major ships and using it as part of the detection system. But these are not the answers obviously and we have a lot of work in the research and development field, particularly with the problems of detection, which is number one, of course. If we could just break that barrier of 4500 feet a second and get some method of detecting a submarine other than acoustic, we would be in business. Not only would we be able to have a really effective high rate of sweep but we would certainly be able to cover tremendous areas and would be able to detect where we cannot detect today. One of our ideas, of course, is to try and get the fixed wing airplane back into the picture of the detection field. It is a pretty bad situation at the moment, as you all know. We are trying everything from dunking from fixed wing aircraft to the JULIE system, of course, and the JEZEBEL system.

Now, in the problem of localization, we feel that with the JULIE coming along, we are probably pretty good, about 85 percent according to the results that we have today in this particular field.

However, one of our problems is the space we have to cover and the back-up forces required to really implement this particular problem against the submarine. There has been considerable thought given to the use of mines. In other words, we would use something such as the Mark 52 or this type of mine to protect and keep submarines off the great portion of our coast. As you know, the continental shelf in the Atlantic gives us this particular ability. However, we are faced with the international problems of the three-mile limit and I doubt very much if we will ever in peace time do it. We certainly don't overlook this particular way of using mines as a defense against submarines.

We are also looking into active systems, real large transducers, off the Atlantic coast, in addition, to back up the present SOSUS system, which unfortunately a lot of people think can tell the position of a submarine but really is only an alerting system at the moment. But this particular effort in ASW is the number one effort we have really in the R&D program. We are getting additional money for it, and we hope that by the additional effort that we can get some results. At the moment, of course, in Congress, where Admiral Bennett and I spend a good part of our time, this is a very well spoken about subject. It just seems that at long last everybody has awakened to the fact that the submarine poses a great menace not just to our ships but to the country itself.

Now, of course, no words of our problems would be sufficient or long enough if we didn't swell on space. Everybody is going to the moon these days, including ARPA (I don't know if you know about ARPA, which is the Advanced Research Project Agency which is coming into being with Mr. Johnson as Director and Dr. York as his Technical Assistant). All the service programs will be submitted to these people for review and implementation. In the Navy's part in this, of course, we have submitted the follow-on to the Vanguard using the second and third stages and another additional booster THOR, and we have also submitted the NOTS proposals on the five-and-dime satellite, as we call it.

We have in the Navy at the moment been designated to carry the ball as the executive agent for the satellite tracking systems that are run by the Department of Defense. We are in the midst of discussions now with the Army, the Air Force, the National Science Foundation, and the National Academy on this particular subject. This is a tremendous job and is going to involve considerable sums of money, I am sure. In addition, the Navy has been named the executive agent for the Pacific guided missile range out here at Point Mugu and South Camp Cooke, which incidentally, of course, has the only east-west launching sites, where you can launch polar ortibal satellites which you cannot do down in Patrick, Florida. I am sure that the program will be funded in the near future and we will have a pretty live national program. The Navy's position is that we felt there should be a national program and that no service itself should go off into the business of launching satellites---that it should be integrated into a national program. We had definite requirements for reconnaissance, communication, navigation . . . things of this kind that we wanted every bit as much as the other services. Of course, there is another side of the picture which is the purely scientific picture, in which we are naturally interested, also.

Now in the organization business, I am interested in the British organization. It is always very funny---as a matter of fact when I took this job over when the Sputnik went up, I was greatly amazed when there was all of a sudden a great hue and cry to reorganize the Joint Chiefs of Staff. I couldn't see the connection between the Joint Chiefs of Staff and my troubles in R&D. They had never said no to me in any way, and I was very much amazed to find out that the Supreme Court deliberated and Congress debated but the Joint Chiefs, they always bickered. It was my first introduction to this particular side of the organization. There is a great tendency in people to want to set up a monolithic structure in research and development, a centralized agency that does all of it. There is a great tendency for people to want to separate basic research from the services, which I am convinced is a very grave mistake, and the Russians as long ago as 1928 made two capitalistic decisions in this line, and the first one was to decentralize everything they could in the research and development business and they have something like 775 various institutes of R&D all doing various parts and pieces. They also let anybody who had a good idea submit designs whether they were contractors or not. Tubiloff and Sitkowski were the real people who made this decision; they convinced Stalin that this was the way to go.

And I am a great believer that we should keep our research and development decentralized. We in the Navy feel that if they take the basic research away from the services, this communication which is one of the biggest problems in this business, well we would lose it. Take the one subject we are all interested in, oceanography, in which incidentally I feel we have got to make a very much greater effort. I was quite successful this last week in getting into the budget a research ship. When I see the history of research ships in the Navy I am very much upset. They have tried for years and years and years and they have always fallen out. I think one of the reasons it has fallen out was that, with all due respect to the Bureau of Ships, maybe we should just have bought a ship and remodeled it rather than putting it in the regular ship building program because it was always put down at the bottom of the list.

I can assure you that we are going to make decidedly more efforts in this field of oceanography, and we are going to try and do the best we can in the ASW business. There has been terrific pressure on us (I don't know whether Admiral Bennett discussed it or not) to have an ASW laboratory. Well, this was fine but when you begin to think about it, I have built several in my day...you have air, surface, sub-surface, and you get a laboratory of about 3,000 people; as a matter of fact, it is a tremendous job. What we have come up with we are going to try and make a group on the West Coast and a group on the East Coast on this subject and, of course, the best way to do this is to get the Directors of NEL, Inyokern, Scripps---and as a matter of fact, Admiral Burke and Dr. James R. Killian now decided we should have a university tied up with it, so we are going to get Dr. Henderson from the University of Washington,---get these four people to sit down and come up with some recommended program. Of course, within this group you would have your weapons, your detection, you would have all of the ASW problems.

The West Coast lends itself a lot easier to this praticular situation than the East Coast does. You have the services here and I hope you will be able to come up with a real proposal on this. We intend to do the same thing on the East Coast with the Hudson Labs, USNUSL, Johnsville, and on the weapons side would probably be NOL. However, they have a much greater problem than you people have out here where you are a little more centralized.

I want to take this occasion to tell you that Admiral Burke is probably one of the strongets proponents of Research and Development. You may have read all of the trouble that the other services had with the universities and the research business. One of the first decisions that he made was that research would be the last thing that we are going to touch. And of course, over on our side of the building (over in Admiral Burke's shop) we have the greatest and highest respect for the Office of Naval Research. We can't say too much for Admiral Bennett, Dr. Killian, and his people. They have given the Navy a very excellent and marvelous reputation in the scientific world in the United States and also across the seas. It is why on every occasion that I can, I try to tell people in the Navy that are associated with this program just what a fine job ONR is doing and that we in the Chief of Naval Operations' office certainly know it and appreciate it. Thank you for being here.

MARINE CORPS OPERATIONS

S. R. Shaw
Brigadier General, U.S. Marine Corps

The role of the Marine Corps is that of a national force in readiness. This means a force ready for instant action in any of a wide variety of circumstances and places. Because the world is mostly covered with oceans any significant force in readiness must be capable of using the oceans to get to the scene of action - and to make amphibious landings on a hostile shore without additional preparation. This, of course, is the Marine Corps' unique characteristic.

To place Marine Corps R&D in proper context, I would like to briefly review a bit of amphibious history before we come to the present, and talk of the future. Prior to World War II, many military men had come to the conclusion that the firepower of the defense had made amphibious operations impossible. The Marine Corps and the Navy believed that this defeatist opinion could not prevail if the power of the United States was to be effective beyond our own shores.

By combinations of new doctrine weapons, equipment, and techniques and training, we introduced a revolutionary strategic capability to the world. This history of World War II is a story of an unbroken series of successful landings on hostile shores.

At the close of World War II, the military pessimists once again foretold the doom of amphibious operations. The nuclear weapon was said to have given the military commander such an increase in firepower, that no landing could be made. As it looked to them, the enormous concentration of ships and supplies of our World War II assaults was a natural target for the nuclear weapon. But these pessimists did not allow for the resources of American ingenuity.

The enormous increase in firepower which the nuclear weapon gave to the military commander was accompanied by the advent of another new device of utmost military significance. This is the VTOL aircraft as presently typified by the helicopter. It has proved to be as important an advance in tactical mobility as the nuclear weapon was in firepower.

Recognizing both the threat and the promise of nuclear weapons and the capabilities of the helicopter, the Marine Corps and Navy set to work to develop a new amphibious concept which would give the landing force the advantage of the quantum jump of the helicopter's tactical mobility, thereby attaining an entirely new magnitude of power, speed, and flexibility. Further, the new concept would provide for maximum exploitation of nuclear firepower in the attack, while at the same time reducing the threat of nuclear counterattack to an acceptable degree of risk.

The effect of the great increase in the tactical mobility of the landing force cannot be counted by adding it arithmetically to the great strategic mobility we already possess in our fleets. It must be measured by multiplying the two factors. The combination of the two -- the new tactical mobility we have gained, and the existing strategic mobility -- has endowed the amphibious attack with enormously greater impact and flexibility. This more powerful nature obtains under all conditions of nuclear or non-nuclear war.

With or without nuclear weapons support, Marine air-ground landing forces, organized, trained and equipped to exploit the speed and flexibility of the helicopter, can be projected by seapower deep ashore at any point on the world littoral without regard for the nature of the shoreline, and without necessity for direct beach attack. The shorelines of the world are no longer natural defenses against our attack. Hydrography no longer confines us to a few selected beaches whose advantages the enemy can see as well as we. The effects of weather are considerably reduced. The landing forces, covered and supported by the new aerial weapons of the fleets, closely coordinating their rapid maneuver with supporting Marine and Navy aircraft from carriers, can strike an enemy's defensive system with paralyzing strategic effect.

The ultimate goal of this concept is an all-helicopter assault which will provide maximum impact and freedom of action for the landing attack launched from the seas we control. We have not yet reached this goal. But we have made great strides. We can now make a two-pronged attack, one prong, the vertical assault by helicopter, deep in the hostile rear, and the other a coordinated surface attack across the beaches using conventional means of reaching the shore. The latter prong is now the major effort. We are working hard toward making the helicopter assault our major effort: When this is achieved, we will then proceed to our final objective, and the helicopter assault will become the complete assault. The capabilities we have now, gives this country's seapower far greater effect than was displayed in those great amphibious attacks of World War II. We are on the way to a capability which will assign to our nation's seapower an effectiveness of towering order.

The development of this concept emphasizes and multiplies the basic characteristics essential in the balanced fleet -- striking power, staying power, versatility, mobility and defensive power.

So much for our major doctrinal developments. The techniques we will use will continue to emphasize hard and savage fighting. We no longer will land at the water's edge and heavily crunch our way forward. We must travel light - and fight with rapid, bold maneuver.

To fit ourselves, our weapons and equipment, our techniques and training to this new method of fighting, requires many things to be done. We have accomplished a good deal already. Our developmental efforts are keyed to this goal. More must be done.

Now then, where does science and research activity fit into the developmental goal of the Marine Corps. The Marine Corps employs primarily, the coordinated effort of the Navy department done by the agencies of the Office of Naval Research, and the Bureaus, to provide us with the basis for development. Secondarily we employ the resources of the other military departments.

We have many of the same developmental problems that the other services do in such areas as communications and the intelligence. In addition we have some dandy puzzlers that are peculiar to our modern doctrine for amphibious assault.

Before mentioning some of these I should perhaps satisfy a question that may be in your minds as to where do missiles fit in Marine Corps' operations. Now, as some of you know, around Washington, when you say the word missile you are supposed to have an expression on your face, in your voice which indicates great overpowering urgency. Most of the time, the expression actually achieved may be described as frantic.

So you can see that missiles can be classed as urgent. Fortunately, at least for the Marine Corps, we have not had to acquire the same degree of urgency as the other services.

The Marine Corps is not involved in those great engines of massive destruction, the intercontinental and intermediate range missiles such as Titan and Atlas, Thor, Jupiter, and Polaris. The modern missiles the Marine Corps takes must be capable of being landed, relatively light and compact and ready for action without prolonged preparation. We have taken those that are suitable -- an artillery type, the Army's Honest John, an anti-aircraft type, the Navy's Terrier, fired from ground equipment developed to give us the first truly mobile guided missile outfit. When the Army's Hawk anti-aircraft missile is ready, with certain special equipment for landing force use, we will add it to our weapons. Our aviators use the same air-to-air missiles as the Navy, Sidewinder and Sparrow.

Now I intend to mention some areas where scientific thought, research and development can be applied to the greatest advantage in developing our combat capability.

One of these is the problem of specifying military characteristics of equipment to meet temperature extremes. Here I mean ground surface equipment. As many of you know it is the general practice to specify that equipment must operate at minus 65 degrees. This causes a great deal of effort to come out with gear which can meet this extreme requirement, but only after much time and money has been spent in trying to reach that extreme.

We in the Marine Corps have begun to question the wisdom of this practice. It is evident that these extremely low temperatures are only to be found in a very few, relatively small and very remote places of the world. The extreme lows in these places only occur for a relatively few days of the year. The probability that significant combat action could ever take place in these odd spots, in those few periods, seems very low indeed. Further, research in human activity indicates that no real fighting could take place in such weather. At such extreme lows, the only time a fight is likely is when you and an enemy reach for a piece of firewood at the same time. The question that we are asking ourselves is - is it really worthwhile to specify that standardized equipment should demand such low temperature capabilities. We believe it to be a question that deserves serious consideration by all of us.

Land mines are like the old Colt 45, they are great equalizers. They are the greatest menace there is to mobile forces and swift, decisive combat. The Russians use them in great numbers. Our past and present methods of finding them are rather primitive and usually painful. We usually blow somebody up as the first indication that mines are present. Then we search them out and dig them up, one by one. We need a means of finding them before we ever commit forces to a course of action. And then if we cannot avoid them, we want to get rid of them on a big scale, and fast. We don't have an answer to this one yet.

Another area where we are most anxious for early and significant development is in the power train we use in our military vehicles.

Almost without exception the power trains, over the years, have become more complicated, and heavier, requiring great precision in building - and repair - and more fuel to make them go.

I will freely admit that this situation is largely of our own making in the military services. Industry has engaged in the business of developing the power train of the vehicles so that women and children simply sit behind the wheel and let the vehicle do the driving. The refinements have been very enticing to the military. But as in most things enticing, there has been an additional cost. And not just the "slight additional cost" so dear to the heart of the automobile salesman.

The cost is measured in rivers of fuel. Fuel that has to be moved in steel ships and steel drums and vehicles - expensive in military manpower, materials and production cost. It is measured in the extra dollars paid to produce the complicated precision-built power trains. It is measured in the additional man hours for maintenance, and for handling of extra spare parts.

We need today military motors and transmissions that will reverse the trend we have been following. We need to energetically pursue some of the engineering features which are already being explored.

We need rugged, reliable, simple economical power train - for our vehicles. We need them badly.

I would now like to leave these big picture problems that appeal to Pentagon types and to big industry and turn to a couple of problems that we feel are every bit as important. In an era when a project has to cost a hundred million dollars or more to be recognized as important, these have the misfortune to be in the pocket change category. They are of the utmost importance to us, however, because they relate to the welfare and combat effectiveness of the individual Marine - who is the greatest asset the Marine Corps has.

The new methods of fighting will place a premium on the individual's capacity to fight in small units - and to endure the loneliness and privation of the battlefield. It will mean much to us to increase the individual Marine's confidence - and to reduce his possibility of becoming a casualty. It is here that one of our biggest unfilled needs can be found. The body armor of the individual combat Marine.

We now have armor. It is good as far as it goes. It protects against relatively low-velocity fragments - shrapnel.

Our present armor is a vest of ballistic nylon pads and rigid plates of doron. We also have a pair of armored drawers of ballistic nylon pads. These latter are affectionately known among Marines as the family jewel box. This armor is designed to protect the vital parts - to reduce the probability of a hit or wound killing the Marine.

We need to extend body armor to the arms and legs to reduce the probability of a man becoming a casualty at all. We want to keep him on the battlefield as a fighting man. We don't want to lose him to the doctor.

Whatever new ideas are necessary to make such armor possible - its attainment would be revolutionary. Our troops now have great confidence in their armor against ordinary shell fragments. Give them this new idea and every general staff in the world will have to make new calculations.

That's the first item. Now for a second. This too has to do with the individual Marine. Our new methods of fighting places a premium on keeping the combat marine effective and reducing the supply problem. One of our biggest problems - one that is with us every day - is food. Chow. Our present rations have great bulk. It takes a great effort and much time to distribute this bulk on the battlefield.

In the attack we now rely principally on two types of rations. One is the "C" ration. It takes 6 pounds per man per day. It is in awkward packages. The other type is the assault ration - the "K" type ration of World War II. It is relatively light and small. Both of these types have a major defect. Troops exhausted to the point of dropping wouldn't - or couldn't- eat them. They might take the meat part and eat that. But the rest of it was treated too many times like a low grade dog biscuit, which it did taste like. It was chock-full of vitamins, minerals, calories, etc. But it was so dull and tasteless, so hard to eat, that exhausted men dropped them on the ground and went to sleep rather than try to finish them.

What was the result? Under rugged combat conditions the troops lost their resiliency - they could not bounce back. Too exhausted to eat the dull food given them, they never recovered from exhaustion - it pyramided. As a result, tired men took more casualties than they needed to.

What we need is an assault ration of less than three pounds - so good that the troops will eat it all - so nourishing that they can exist on it for a week or more.

As you are probably aware, we Marines are justifiably proud of our well earned reputation for being the world's best fighting men. But we are not at all proud about accepting ideas or suggestions from anyone that will help us continue to deserve that reputation. We solicit your help in solving our problems so that we will be able to take some future Iwo Jima.

Thank you for your attention.

THE ORGANISATION OF BRITISH NAVAL RESEARCH AND DEVELOPMENT

R. V. Alred
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I feel a little out of place coming up here to talk on Organisation. It is a subject which receives so much attention in this country, a country where plans, schedules, programmes, slatings are all part of the daily life.

The impact of this was well illustrated to me the other day. I was taking a British visitor around, showing him the sights of Washington - the Lincoln Memorial, the Jefferson, the Capitol. Finally we came to the Washington Monument, and of course he had to go up and see the magnificent views from the top. There were not many visitors there, but one little man seemed to be attracting a lot of attention; he kept going from window to window, obviously in a state of great excitement, having a good look down from each window in turn. Finally, he couldn't contain his excitement any longer - he rushed up to the attendant and said "Say! When are you planning to get this into orbit".

I am sure that some of you are wondering how and why a talk on organisation found its way into a symposium having the theme "The Ocean as the Operating Environment of the Navy". However, a little reflection will show that it is an appropriate subject for this symposium. Just as equipment design has to take into account the influence of the sea, so also has the organisation of the scientists who are responsible for developing that equipment. They must be continually brought into contact with the oceans, with the ships, and with the men that man them. They must live with the navy, work with them, go to sea with them; otherwise they will produce equipment which doesn't do the job it was made for.

In the United Kingdom, naval scientists are spread amongst a large number of establishments whose work is controlled by various Admiralty Departments. These establishments are of two types, those concerned primarily with the development of material for fitting in the Fleet, and those concerned primarily with research and investigation.

The responsibility for meeting the material needs of the navy rests with the various material Departments in Admiralty, such as the Department of Underwater Weapon Material, and the Department of Radio Equipment; these Departments are naval manned. The development work is carried out in establishments generally having a mixture of scientific and naval personnel, with a Chief Scientist and Naval Captain in dual responsibility. The naval personnel are there as working partners, not as controllers. A list of the more important development establishments, together with the responsible Department of each, is shown in Table 1. The purposes of these various establishments are self-evident from their names.

Underwater Detection Establishment, Portland.
Underwater Countermeasures and Weapons Establishment, Havant.
Torpedo Experimental Establishment, Greenock.
Admiralty Signal and Radar Establishment, Portsmouth.
Admiralty Compass Observatory, Slough.
Admiralty Engineering Laboratory, West Drayton.

In addition there are a number of smaller facilities, such as the Underwater Launching Establishment, the Admiralty Oil Laboratory and the Central Dockyard Laboratory. The development establishments employ about half of our naval scientists.

The organisation of the research establishments is different. These are manned and administered entirely by civilian personnel - scientific or engineering - and they report to Admiralty Departments which are similarly civilian manned. Table 2 gives a list of the principal research establishments and their controlling Departments.

Admiralty Research Laboratory is mainly concerned with investigations in the fields of physics and mathematics - problems of oceanography, acoustics, fluid dynamics, etc.

Services Electronics Research Laboratory is responsible for research on electron tubes, storage tubes, solid state devices, etc.

Admiralty Materials Laboratory is concerned with physical and chemical research into new materials - plastics, ferrites, silicones, etc.

Naval Construction Research Establishment is concerned with investigations relating to the design of ships' structures.

Admiralty Experimental Works is concerned with investigations of hull shapes, stability of ships, etc.

In addition to those mentioned on the table, there are various smaller laboratories such as the Admiralty Hydro-Ballistic Research Establishment, the R. N. Physiological Laboratory, and the Admiralty Experimental Station at Perranporth.

These laboratories are responsible for researches and investigations not directly associated with dated naval requirements ; it is to these that we look mostly for our scientific breakthroughs.

You will have noticed that a number of different Admiralty Departments are responsible for the work in the various research and development laboratories. It is however a feature of our organisation that all the scientists in these various laboratories are in one scientific organisation - The Royal Naval Scientific Service - with central direction as regards careers, training, etc., and also as regards the science which they are applying in their various investigations. This gives a number of advantages compared with having completely separate organisations at the various laboratories:-

(a) The scientists have a common loyalty through a scientific chief direct to the Board of Admiralty; they have a common link with the Navy thereby.

(b) There is greater freedom of movement of personnel, with no feeling of disloyalty to one's previous laboratory.

(c) With the whole field of naval science available, there is a greater chance of a scientist finding the work which is most congenial for him, and which best suits his particular skills.

(d) There are a larger number of opportunities for promotion to higher posts (since consideration is not limited to persons in the particular establishment having the vacancy).

Transfers are good for the scientist; they give him a rejuvenation of outlook and a development of interest in new scientific fields. They are also good for the Navy; firstly, from the consequent cross-fertilisation of scientific ideas, which is essential if progress is to be maintained; secondly, from the more efficient use of available manpower, with transfer of effort as the changing needs of the Navy give emphasis first to one field and then to another.

I referred earlier to the need for the scientist to understand the Navy and its needs. It is primarily in the development establishments that this understanding is fostered. In these establishments the naval officer and the scientist are mixed at all levels of responsibility. I would like to dwell a little on the way they work together. In Admiralty Signal and Radar Establishment, as an example, there are about 270 graduate scientists, and about 40 naval officers of whom about 20 are line officers and 20 are electrical officers; these officers are on two-year appointments to A.S.R.E., and in most cases have had recent sea experience. The line officers are specialists in one or other aspect of naval warfare, such as gunnery, navigation, communication - and their duties are manifold. They work as a member of a project team (under the scientist Project Leader) ensuring that equipments being developed will meet the needs of the Naval Staff; they advise their parent Staff Division in Admiralty of the progress of development, and of new possibilities; they maintain liaison with the appropriate naval training school concerning handbooks and training aids for the equipment under development. The electrical officer similarly works as a member of the project team paying particular attention to reliability and maintainability of equipment. This is where the naval officer gets to know the scientist and his way of life. The naval officer asks for some particular facility and the scientist wants to know the justification for its inclusion; the scientist dreams up a new circuit, and the naval officer wants to know whether it is as reliable as the old one. Discussion goes to and fro as different problems - and different possibilities - arise. This is the breeding ground for ideas - ideas for meeting a naval operational need with a piece of engineered hardware - ideas for new operational concepts based on a recent scientific invention. Then the scientist and naval officer take the equipment to sea on trials - we have no separate Operational Development Force for the evaluation of our equipment. They learn at first hand how successful they have been in deciding amongst the many conflicting requirements and possibilities - and how unsuccessful, because there is always something they wish they had done differently.

Some say that development is slowed up because the scientist

is not free to develop equipment as simple engineering considerations would suggest. He must take into account the sometimes conflicting views of his naval officers. Further, if the naval officers are to have recent sea experience, they must change frequently. One then finds that different naval officers draw different conclusions from their sea experience, and a newcomer frequently tries to change things which have been pressed for by his predecessor. The scientist, who remains with the project throughout, must accordingly develop a critical attitude as to "why" not just "what" do you advise. And of course, it isn't long before he thinks he knows better than the naval officer - and one more scientist has then cleared the first hurdle in his naval education.

TABLE 1

ADMIRALTY DEVELOPMENT ESTABLISHMENTS

Establishment	Controlling Directorate
H.M. Underwater Detection Establishment, Portland	Director of Underwater Weapon Material.
H.M. Underwater Countermeasures and Weapons Establishment, Havant	Director of Underwater Weapon Material.
Torpedo Experimental Establishment, Greenock.	Director of Underwater Weapon Material.
Admiralty Signal and Radar Establishment, Portsmouth.	Director of Radio Equipment.
Admiralty Gunnery Establishment, Portland.	Director of Naval Ordnance.
Admiralty Compass Observatory, Slough.	Director of Compass Department.
Admiralty Engineering Laboratory, West Drayton.	Engineer in Chief.

Alred

TABLE 2

ADMIRALTY RESEARCH ESTABLISHMENTS

Establishment	Controlling Directorate
Admiralty Research Laboratory, Teddington.	Director of Physical Research.
Services Electronics Research Laboratory, Baldock.	Director of Physical Research.
Admiralty Materials Laboratory, Holton Heath.	Director of Engineering and Materials Research.
Naval Construction Research Establishment, Dunfermline.	Director of Naval Construction.
Admiralty Experimental Works, Haslar.	Director of Naval Construction.

AN ADDRESS

by Lee A. DuBridge
President, California Institute of Technology

It is a great pleasure to participate in this occasion in honor of two of my own friends. It was my pleasure to be associated with Bob Conrad during and after the war. I watched with great interest especially the way in which he so effectively participated in the initial organization of the Office of Naval Research. His intelligent understanding and wise guidance in those days were determining factors in the great achievements which can be credited to ONR in the past ten years. I shall return to this subject later.

The difficult and complex subject of this nation's research program in pure and applied science is being much discussed these days, and one hesitates to add any additional words to what is already a voluminous literature on the subject. Especially do I hesitate when I realize that I have no new thoughts to add; the best I can do is to arrange some old ideas in a different order, or to express them in different words. But I often take comfort in a saying that is attributed to Oliver Wendell Holmes which goes, if I remember correctly, something like this: "Sometimes it is more important to emphasize the obvious than to elucidate the obscure." It is a wonderful quotation, for emphasizing the obvious is one of my favorite occupations. Most speeches by college presidents, of course, do the same thing.

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Text of remarks at the banquet of the Second Symposium on Basic and Applied Science in the Navy sponsored by the Office of Naval Research, El Cortez Hotel, San Diego, California, March 11, 1958.

Nevertheless, the nation's research program is an important subject and it is well that we explore fully and repeatedly. It is a complex problem, so it pays to keep repeating and keep emphasizing its fundamental aspects. It is an ever changing problem -- so that our emphasis must shift from time to time.

Just now the country is engaged in a re-examination of its whole program of scientific research and development. This is all to the good -- and we can already see that worthwhile results will emerge. At the same time, we must be careful lest in the heat of excitement over recent events we act hastily or unwisely -- and thus cancel out the progress we may have made.

Our current excitement was stimulated by the first launchings of earth satellites. And these events, which can truly be classed as man's first steps into space, have caused an avalanche of sudden interest in space research. If we can get an object 1000 miles off the earth, we can get off 10,000 miles, 100,000 miles -- to the moon -- to Mars. True enough! But so what? Does this mean we must initiate a military conquest of the moon -- of all space? Are we going to have an American colony on the moon soon -- a 49th state?

Is the space around the earth soon to be filled with flying platforms equipped to spy on all the earth, and to drop hydrogen bombs when hostile events appear to be taking place below?

Unfortunately, these are not flippant questions; for all of these things and many more still more fabulous and flamboyant ones are being proposed and apparently seriously discussed in the halls of Congress, of the Pentagon, and in the columns of newspapers and magazines. Thus we are uncomfortably close to the situation where one of the great technical achievements in man's history, instead of stimulating a vastly improved and valuable program of real research, is being allowed to convert us into a nation of space cadets in which billions of dollars will be wasted on fanciful and fruitless and ill-conceived projects, while real scientific research is neglected or even destroyed.

So, with your permission, I should like to look at this problem very briefly in a very elementary way and ask how we can use the challenge of Sputnik to enhance rather than damage our nation's scientific strength. We have the opportunity of a generation to improve our research program. Let us not let it slip from us by diverting our attention to chasing butterflies.

Let us start by trying to clear up one simple matter. Let us remember that launching objects into space is not in itself a scientific achievement. It is an achievement of engineering or technology. The scientific problems relating to orbits in gravitational fields were solved by Kepler and Newton nearly 300 years ago. Newton computed the speed with which an object would have to be hurled in a horizontal direction to get into a stable orbit around the earth. But it took nearly 300 years of technological developments in rocketry, electronics, navigation, control and similar fields to accomplish the job. I am not denying that many good scientists contributed to these technological developments, nor that it did not take many discoveries in basic science to make them possible. But rocket launching is still a highly developed technology and is not a branch of science. That doesn't make rocketry any less interesting or less important or less valuable; but let us be careful of our terminology.

But, like many branches of technology, rocketry can be a very useful tool for the scientist and I think it is very important that we develop this tool to the utmost and use it boldly and intelligently for scientific purposes.

In order to discuss this matter, however, it is necessary first to clear away some illusions, some delusions -- and some downright lies. We need to remind ourselves that just because a couple of objects are now traveling around the earth in stable orbits is no sign that all of Buck Rogers' adventures and achievements are immediately possible or desirable. I admit that to deny the immediate possibility or feasibility of some of the common Buck Rogers notions is to open myself to the charge of being a shortsighted old mossback. That is a risk I will have to take.

And I am going to start out taking risks in a big way by saying flatly and firmly that I do not believe that the conquest and occupation of the moon have the slightest military value or interest. Nor do I believe that satellites floating around the earth are of the slightest use, in the foreseeable future, as bombing platforms or, indeed, for carrying out any other hostile act against an enemy except spying on him.

I think that the physicists and engineers who are listening to me will readily understand what I mean when I question the value of a satellite as a weapon-launching platform. People who are used to flying in airplanes, however, have grown used to the idea that if you drop something from a plane it falls to the earth -- and, indeed, if you just let go of the object at exactly the right place you can hit anything you please. Many such people find it hard to believe that if you try to drop an object from a satellite nothing happens. Exactly nothing! The object stays right there with you. Even if you give it a moderate push it will separate itself from you but slightly -- and then simply become another satellite, circling the earth alongside of the vehicle from which it was ejected. If you gave the object a more vigorous push, and in the backward direction, it would start falling to the earth -- but as it fell it would pick up speed, and since its angular momentum would remain constant it would simply fall to a lower orbit and rotate there with a shorter period -- and at a higher linear speed.

There is, of course, the possibility that by firing our bomb backward from the vehicle with a rocket blast one could conceivably bring the bomb to a condition of zero angular momentum at such a point that it would fall vertically and hit the target -- if the earth's rotation brought it into line at just the right instant. But, knowing the difficulty of accurate bombing from an airplane at 30,000 feet going 500 miles per hour (or 8 miles per *minute*), I defy anyone to be optimistic in the near future about accurate retrobombing from a vehicle a million feet above the earth and going 18,000 miles per hour, which is 5 miles per *second*.-

I don't say that this is ultimately impossible. I only say I don't see any sense to it when we will soon be able to launch ballistic missiles so much more accurately, effectively and economically, and hit any place we please without ever leaving the surface of the earth at all. Paradoxically, the large rocket has opened up the conquest of space; but for military purposes, has made space unnecessary.

But, of course, our space cadet replies by saying that he is going to place a stationary *platform* above the earth which can be maneuvered around like a magic carpet and from which a bomb can be dropped at will on any point. But there are several minor difficulties with that idea too. First, a platform which remains for a long time above a single point on the earth is not stationary at all, but is in an orbit which is rotating around the earth with the same speed as the earth's rotation -- namely, once in 24 hours. This is the stable period for an orbit which is about 23,000 miles up -- not a very handy bombing altitude! And a bomb released from such a vehicle would not fall at all, but would have to be ejected backward as before. Furthermore, one would be confined to targets exactly on the earth's equator, for that is the only great circle above which there can be an orbit which does not alter its latitude, and above which the vehicle could remain apparently

stationary. A stationary space platform at other latitudes is just not feasible. And who wants to bomb anything on the equator?

Finally, of course, our space enthusiast retreats to the moon and says he will launch his missiles from there. Well, more power to him! He'll find the temperature a bit variable (boiling water by day; liquid air by night!); will find the lack of air, water and any appreciable or usable source of energy a bit inconvenient; and will be bothered by the logistic problem of shooting his materials and supplies and weapons up there in the first place. Why shoot a load of explosives 240,000 miles to the moon, then 240,000 miles back to hit a target only 5000 miles away is more than I can understand. In addition, I'll guarantee to shoot 1000 missiles from the U. S. to Moscow while our moon man is waiting 12 hours, more or less, for the earth to turn around to bring Moscow into shooting position. Finally, it is interesting to note that a bomb projected on a zero-angular-momentum path from the moon to the earth will take just 5 days to get there! That's rather a long time of flight for any projectile. And we will hope the bombardier can figure correctly which side of the earth will be up by then.

I haven't even begun to recite the real problems of space warfare. Any physicist could quickly figure out many more. True, he could also figure ways of getting around some of them. But I suggest that when we make ourselves believe that because we've got one 30-pound satellite in orbit is justification for squandering billions of dollars in the so-called military conquest of space is jumping to premature conclusions, to say the least.

Military rocketry, of course, is very important. ICBM's and IRBM's are an essential part of our arsenal, and let's don't let space dreams interfere with our getting some more good reliable rockets soon. Also earth satellites for military reconnaisance purposes will have considerable utility -- and I am all for them. And there may be other unforeseeable uses. There is plenty to do without trying to nail the American flag on the whole solar system by next week.

But if some so far inarticulate military man should conclude that only a *moderate* program of space technology would satisfy his needs, he might still be convinced that we need to go in for space cadet projects solely for prestige purposes. Sputnik certainly shocked us into realizing the importance of technical prestige in the world.

Here, of course, we face horribly difficult problems that cannot be answered by scientific considerations alone. Granted there is no scientific advantage in giving the man in the moon a black eye or a scar on his cheek, how many million dollars is it worth to do it anyway -- just to show the world what a great people we are? I honestly do not know. My own advice would be to let the moon alone unless or until we are able to make a serious attempt to get information of scientific value. And I should like to suggest that American scientists, as a group, adopt a similar position -- namely, that we are not space cadets; that space stunts done just because they are stunts are not worthy of high priority unless they embody or assist in a real scientific experiment.

Now there are indeed many scientific experiments that ought to be performed and that we should be working on. The ONR-IGY program is a sound one and should be pushed. If we get busy with these and other programs, the scientific value will be great -- and to the thoughtful people of the world the propaganda value will also be great -- greater by far than for expensive and useless stunts.

But America faces a grave problem at the present time. Can we indeed persuade the people of the country and persuade Congress that large funds should be spent for sound scientific experiments in space science and technology, but that we should not waste large sums on pseudo-military, pseudo-scientific or Buck Rogers projects?

All of this, I must confess, seems to have little to do with the theme of this symposium on the science and technology of the oceans nor the purpose of tonight's dinner, which is to recognize a distinguished scientist for his contribution to the nation's military strength. But there are several connections between what I have said and what you are here for. Perhaps I should say I have thought up several excuses for talking to you tonight about satellite research. In the first place, the Robert Conrad medal is being awarded to a physicist who was a pioneer in World War II in the development of rockets for important military uses -- rockets which found wide use throughout the world and helped mightily to win many a battle on land, sea, and in the air. Many of today's rocket techniques stem from the work he helped to get started.

This same man also served as a close adviser at the end of the war to those who were organizing the Office of Naval Research.

Now I do not believe it is an exaggeration to say that the problems relating to the prosecution of scientific research which we faced at the end of World War II bear some resemblance to the problems we face today. We as a nation in 1946 were somewhat

flushed with the success of the technological projects in which we had been engaged during the war. The fact that our physicists, chemists, mathematicians and other scientists had deserted their science and had become successful engineers had given rise to a widespread impression that science and technology were the same thing. "At last," some people said, "we have discovered the secret of scientific research. Just organize big laboratories, hire lots of workers, spend lots of money and any scientific problem can be solved. Just look at the way the Army solved the problem of atomic energy."

Fortunately, those who were responsible for organizing the work of ONR had other ideas. The scientists in the great wartime laboratories of technology were about to return to their scientific laboratories in the universities. How were they going to be aided in getting their scientific work underway again? How were the universities to be helped to rebuild their shattered programs of research in basic science? And how were the laboratories of science to be enabled to make use of the great new techniques which had evolved during the war to aid in scientific exploration? It was a time of grave decision. The country might have decided that military technology was indistinguishable from basic science -- might have continued the wartime research in radar, rockets and atomic weapons to the exclusion of basic science. But a few people thought differently. Among them were Charles Lauritsen and Bob Conrad. They agreed that a way must be found to provide funds to the universities on a broad and free basis to aid in the re-establishment of basic science. And ONR was founded with that end in view. Years later, after the soundness of the ONR concept had been established, other agencies were created to assist in the task -- notably the National Science Foundation. But history will have to give the credit to ONR for blazing the trail and holding the fort during the critical postwar years.

Possibly we are in a similar position today. The satellite fever has created the impression that rocket technology is science, that space cadets are the true scientists of the future, and that the nation's only forward looking scholars are those who are planning to land on Mars.

Fortunately, the nation's scientific strength is far greater today than it was in 1946. Fortunately, there are other agencies joined with ONR in the promotion of science for its own sake. But it may take the combined resources of all of us to make sure that we maintain and strengthen our programs of basic science, that we use the great new tools of space technology for sound scientific purposes, and that we do not fritter away valuable resources and valuable talent on useless Buck Rogers stunts, or on false conceptions of the military value of what is humorously called space conquest. We ought to be able to justify the scientific exploration of space for its own sake, without pretending that it has a military value which it cannot possess.

A SURVEY OF HYDROBIOLOGICAL ASPECTS OF NAVAL OPERATIONS

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The term hydrobiology like its protean relative, oceanography, may mean various things to the various scientific specialists who collectively have established its rather nebulous boundries.

For our purpose, however, hydrobiology may be defined as the interrelationship of the biological components with the physical and chemical factors of marine, estuarine, and freshwater environments. It includes biological oceanography as well as limnology. In addition, hydrobiology serves as a convenient focal point for data derived from field and laboratory studies and experimental investigations in most of the classic biological disciplines.

In recent years, the United States Navy has developed a substantial interest in hydrobiology for it has become increasingly apparent that a variety of problems which confront the Navy in carrying out its assigned mission, stem from hydrobiological origins. In additon, information derived from hydrobiological investigations offer a basis for the eventual development of new and improved techniques, materials, components and systems which will be useful in Naval operations. Let us proceed to review some of the U. S. Navy's interests in hydrobiological research.

The prevention of marine biological deterioration and fouling has been a problem of concern to the world's navies since the days of antiquity. An inventory of the techniques, materials and gadgets which have been advocated and tried in this field would make fascinating reading indeed since in effect it would represent a history of man's scientific interests and activities relating to the sea. His efforts in discovering a means for preventing marine deterioration and fouling, however, have not been crowned with spectacular success. The problem continues to be a serious one both in terms of financial losses and operational impairments. The Prevention of Deterioration Center of the National Research Council has estimated that losses from marine deterioration in the United States run about $500 million annually. The Navy, in spite of its research, development and maintenance efforts to date, suffers annual losses estimated at between $50 million and $75 million. More serious, however, is the reduction in operational efficiency which results from marine biological deterioration and fouling. A senior Naval Officer once sized up the problem very neatly by stating that basically the service life of outboard equipment was proportional to its susceptability of attack by marine boring and fouling agents.

To the best of our knowledge, this thesis has not been subjected to vigorous statistical analysis. Nevertheless, one cannot argue with the evidence that marine plants and animals do attach themselves to the surfaces of man-made objects in the sea including pilings, ship and boat keels, hydrophones, transducer domes, harbor defense nets, moored mines, etc. Nor can we argue with the evidence that many of these organisms are able to attack these objects eventually destroying or greatly reducing their service life.

The aforegoing does not imply a criticism of the existing research and development activities aimed at controlling this problem. Indeed, the phenolic resins which were developed to reduce fouling on keels, and the many marine wood preservatives which have been developed since World War II have greatly increased the field service life of a variety of Navy equipments.

The fact remains, however, that most of the preservatives in current use were developed without a knowledge of their mode of action. Consequently, a large assortment of treatments and preservatives have to be employed to control marine boring and fouling pests in the many geographic and enviornmental situations in which the Navy carries on its operations. No one of the marine preservatives and/or treatments in common use today may be expected to provide full protection in every environmental situation of current or potential concern to the Navy.

This is true interestingly enough in spite of the fact that, although almost all phyla contribute to deterioration damage, most of such damage throughout the world is caused by organisms largely confined to two phyla: the Phylum Mollusca (the Teredo or ship worm), and the Phylum Arthropoda, Class Crustacea, (Limnoria or wood gribble, Balanus or barnacle).

One of the objectives of the hydrobiology research program is to obtain sufficient information regarding the chain of vital processes of the organisms responsible for deterioration and fouling to discover those "links" which appear to be most susceptable to interference and, thus, control. On this basis, it is possible to design chemical inhibitors for the control of the animals themselves without regard to their geographic or environmental situations. Such an objective, of course, calls for a well coordinated research program in hydrobiology including marine ecological, physiological and biochemical investigations. That the results will be well worth the effort is evidenced by the fact that such diverse fields as chemotherapy and insect control have made outstanding advances in recent years based on fundamental knowledge of the organisms involved. Even at the present annual level of Naval support of basic hydrobiological research, (less than one quarter of one percent of the estimated annual loss to the Navy from marine deterioration) the program is yielding rich dividends in knowledge for the control of these ubiquitous pests.

Marine organisms may be important causes of interference with underwater acoustic communication and detection systems. Since before World War II the literature has referred to the so-called "false target" problem caused by marine animals which represent acoustic targets sufficiently similar to targets of operational significance to present a serious problem to the sonar man. The World War II reports of submarine war patrols are replete with references to hazards resulting from sonar contacts with false targets. Even today, using equipment with a high degree of resolution, reports of false targets are not infrequent.

The so-called deep scattering layer, discovered in the early days of World War II is a classic example of biological interference with the transmission and reception of acoustic energies underwater. Another kind of biological interference is that which is represented by marine biological sound producers including fishes, shrimps, crabs, porpoises, etc. As most of us know, the sea is not the stark, silent deep as represented in the fiction of yester year. Indeed, acoustically it is more akin to Broadway and Times Square during the rush hour, and it is this feature, in large measure of biological origin, which constitutes a problem in the operation of passive listening devices. The ambient noise produced by a large school of sound emitting fishes can oftentimes result in a very poor signal to noise ratio.

Finally, there is an increasing body of scientific evidence becoming available which definitely implicates very small planktonic organisms as primary causes of biological interference with the propagation of acoustic energies underwater. Until recently, the acousticists and physicists concerned with submarine acoustics were of the opinion that very small biological particulates in the water were of insufficient acoustic target size to constitute an attenuation problem. While this assumption appeared to be valid when considering the acoustic effects of individual small organisms the fact remains that usually these individuals are not homogeneously distributed throughout the water column. On the contrary, they tend to congregate in response to changes in some of the factors of their local environment. Thus, for example, changes in light intensity or changes in the density of the medium may produce upward or downward movements of whole populations of planktonic animals. The result of congregation may be the development of a very substantial acoustic target.

The hope of developing a control of biological acoustic interference, except in very highly localized environments, is utopian indeed. However, there is one kind of information which can be obtained from basic hydrobiological research which would be of immediate practical value to the Navy. It should be noted that the types of biological interference with underwater propagation of acoustic energies have one characteristic in common. In each instance it results from the presence of individuals or populations of marine organisms which respond to changes in environmental factors. In other words, marine animals and plants, like terrestrial fauna and flora, exhibit seasonal and geographic variation in population, especially the populations on the continental shelf. It would be of great value to the Navy to be provided with data which could be used to anticipate the probabilities of encountering marine animal populations at various geographic locations according to species, seasons, distance from shore, depth, etc. Such information might well play an important role in planning a fleet exercise or operation. It would certainly be of considerable value to the submariner, for example, in predicting underwater sound conditions likely to be encountered, and in interpreting and evaluating acoustic information obtained in the field.

During the aforegoing discussion an effort has been made to illustrate in some detail a few of the Navy's interests in hydrobiology. There are a number of other hydrobiological problems of considerable concern to the Navy. The limitations of space do not permit a detailed presentation of these problems. However, it is hoped that the following inventory will serve to illustrate the diversity of Naval interests in this field.

1. Hydrobiological aspects of surface and submarine concealment:

Bioluminescence: During certain seasons of the year and in certain geographic locations, as for example, the Central Pacific Ocean, blooms of bioluminescent organisms occur in the oceanic waters at the surface and down to considerable depths brightly illuminating the sea when disturbed mechanically. Under these conditions a surface ship or a submarine close to the surface, a mine field or even a swimmer may produce sufficient disturbance of the water to result in the production of bioluminescent wakes and bow waves, which can be detected easily from aircraft.

Ambient noise: The changes in the quality and quantity of ambient noise of a biological origin due to the presence of a submarine, a newly laid mine or a team of underwater swimmers can increase the probability of detection by an alert enemy.

2. Survival at sea:

Successful survival at sea under emergency conditions may owe much to our knowledge of the habits and identities of dangerous organisms as well as the edible flora and fauna of the oceans. Similarly the chances for surviving a period of isolation on land is in large measure dependent upon our ability to discriminate the edible species of animal and plant from the poisonous and venomous forms. It is considered quite important to develop a series of antitoxins and antivenoms for self treatment in the field in instances when the individual has ingested poisonous forms or when he has been injured by the venomous freshwater or marine fishes which are abundant in many localities of interest to the Navy.

3. Protection of underwater swimmers:

This problem in large measure may be considered as part of the emergency survival problem. However, the necessity for minimizing the chances of failure of a mission involving underwater swimmers lends additional emphasis to the need for developing an effective deterrent against sharks, barracuda and other carnivorous animals. Also, the underwater swimmer is likely to come into contact with many carnivorous and venomous marine species usually not encountered by the life raft or island-dwelling survivor, as for example, moray eels, poisonous corals, sting rays, poisonous sea urchins, etc.

Thus, it is important that the underwater swimmer be provided not only with a practical knowledge of the behavior and habitats of these organisms but also with a means of coping with them or the injuries which they may inflict.

4. The role of marine biota in oceanic radioactive contamination:

As the Navy provides itself with an increasing number and variety of submarine nuclear weapons it must become increasingly concerned with the problem of controlling radioactive contamination resulting from their use. Toward this end, it is essential that we enhance our knowledge of the roles of marine flora and fauna both in the mitigation of radioactive contamination and in the spreading of contamination up through the food chain.

5. The biological effects of underwater blasts:

Closely related to the problem of controlling radioactive contamination is the problem of minimizing damage to commercial and game fish populations resulting from underwater explosive tests. The Navy through its hydrobiological research program is cooperating closely with State and Federal conservation agencies in developing a body of knowledge regarding the seasonal and geographic distribution of marine and estuarine fisheries. This information is invaluable in planning effective underwater explosive tests with a minimum of damage to valuable fish and shellfish species.

In concluding this phase of our discussion it should be mentioned that there are important hydrobiological implications in such operations as promining and mine countermeasures as well as anti-submarine warfare. Those considerations, however, must be reserved for secret presentation.

The aforegoing has dealt largely with Naval problems of hydrobiological origin. The research program in hydrobiology, in addition, plays a major role in encouraging investigations of marine and aquatic animals and plants as biological models exhibiting characteristics which are of interest to the Naval scientist. The hydrodynamic characteristics and mechanisms of propulsion of many of these animals are of interest to a variety of Naval specialists including surface ship and submarine designers.

Also, the abilities of certain marine and freshwater fishes to detect and identify targets and home on them from great distances deserves the attention of Naval scientists. The so-called

"long range" navigational skills of migratory fishes by which they are able in some manner presently unknown to man, to migrate over great distances and to arrive with great accuracy at destinations which in many cases proved to be the points of origin from which they migrated from 3-7 years earlier, is of obvious interest to the Navy. An elucidation of these phenomena may result in the establishment of new concepts and eventually to the development of new and improved mechanical or electronic sensors of direct value to the Navy.

No discussion of the Navy's program in hydrobiological research would be complete without mention of the possibilities of employing such biological agents as photosynthetic algae as a means of improving atmosphere control in enclosed spaces such as submarines. In this connection, it should also be mentinned that devices patterned after the gill systems of fishes deserve more attention as another possibility for improving our gas exchange systems in submarines.

In conclusion, the hydrobiology research program sponsored by the Office of Naval Research is designed to provide the basic information required to control or eliminate a number of problems of current concern to the Navy. The program is also designed to provide a foundation of information which may eventually lead to the development of new and improved techniques, materials and equipments which will be useful in furthering the Navy's mission.

It is noteworthy that hydrobiology has long constituted a field of interest to the Navy of the U.S.S.R. At present, the Russian Naval Academy is the only one known to the writer which requires its students to take a course in "Naval hydrobiology" which covers most of the problems presented in this paper.*

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* This writer, as a matter of personal curiosity, recently endeavored to compare the extent of USSR support of hydrobiological research (as noted in the open scientific literature) which he considered to have a relevance to Naval interests, with support of hydrobiology in this country. Since there was no way of determining the actual Russian expenditures in this research area, an estimate was made of how much it would cost to support a similar program in this country. The figures, although admittedly a crude estimate, nevertheless, may provide some basis for comparison. It was estimated that the hydrobiology program being conducted in the USSR (knowledge of which was derived from the open literature) would require approximately 18.3 million dollars for its support in the United States.

RESEARCH PROBLEMS OF SUBMARINE OPERATIONS UNDER-ICE IN THE ARCTIC OCEAN

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During the past eleven years, the U. S. Fleet has conducted a small but persistent study of submarine operations in ice covered seas. This study has given the diesel submarine the ability to live and work in ice fringe areas, the marginal zone from open ocean to about fifty miles inside the arctic pack.

With the advent of the nuclear powered submarine into the Arctic Ocean, as demonstrated by USS NAUTILUS last September, the vast north coast of the USSR was opened to patrol by submarine. It becomes, therefore, an exposed, ocean coastline as extensive as the U. S. Canadian coast from San Diego to the Bering Strait.

A submarine patrol from Pearl Harbor to Murmansk is no greater than from Pearl Harbor to Hong Kong. Furthermore, the ice canopy overhead provides unequalled protection against air or surface craft or, missile.

Though the arctic submarine closes the circle around the USSR, our advantage is not unilateral because the ice gives the Soviet submarines cover from their arctic ports through Denmark Strait to our North Atlantic coast. Furthermore, northern Canada now becomes a set of submarine passage ways including Hudson Bay, which reaches near to the heartland of the American Continent.

Submarine operations under sea ice have generated questions of ship engineering and properties of the ocean requiring immediate empirical answers. In this brief review, we can only state the questions. We shall also try to indicate which areas require research. It is long term research in ocean-cryology that will give us the understanding of sea ice we now lack and that will discover new concepts for submarines to exploit in the Arctic Ocean.

Obviously, navigation under sea ice means knowing ship's position similarly to open water, and similarly to open water, if we use bottom features to fix position, we need precise, detailed bathymetric charts of the Arctic Ocean and its approaches. For twelve years, the USSR has been actively engaged in charting the arctic ocean by aircraft landings on the sea ice. Their published stations are shown in Figure 1. Their published bathymetric chart is shown in

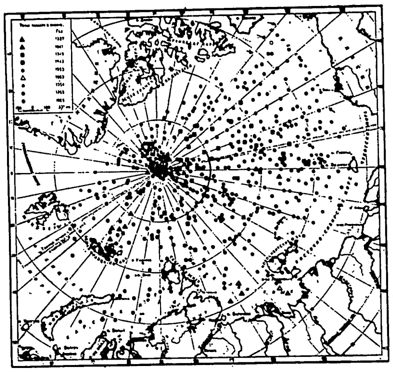

Fig. 1 - USSR Observations by aircraft landings

Figure 2. Ten years ago, we thought the Arctic Ocean to be a flat basin but we now find that it contains the Lomonosov mountain range and has complex bottom features valuable for navigation by bathymetry.

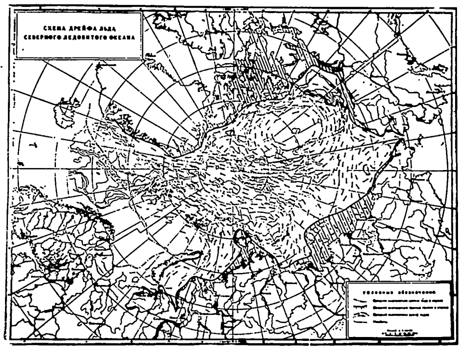

Fig. 2 - USSR Bathymetic and current chart

In contrast, the United States has two floating ice bases, namely Ice Island T-3 and the IGY ice floe Station A. We must catch up on bottom charting by using submarines which surface periodically to precisely fix position by radio methods and which, for example, use bottom planted sonar beacons for guidance to develop the features of seamount. U. S. and Canadian icebreakers must get on with the task of surveying the fringe areas, the Greenland Sea, the Lincoln Sea and the Canadian Archipelago.

Navigation by bathymetry is the old, reliable passive method. Another old reliable method is by star fix. Star fixes can be made much more accurate in ice covered than in open sea because the stable surface permits the use of the most precise theodolite and star angles can be cut with an accuracy equivalent to that of shore based observation. Star fixes may be particularly useful in clear sky, dark period of winter.

Of course, any electronic aid, e.g. LORAN, EPI, DECCA, RADUX is applicable to the Arctic Ocean. However, to use the electronic aid, to take a star fix, to deliver a missile, or to act as radar picket requires surfacing in sea ice, and therein lies the major problem.

To date, a topside sonar system has been the principal tool for under ice diving. The sonar system is required:

(a) to evaluate the type, distribution and thickness of the ice canopy;
(b) to guide ascents into water openings or brash ice, or
(c) to find the thin, recently frozen sheet ice in leads during winter operations.

Evaluation of type of ice canopy, for example, giant floe, small floes or brash ice, is required in order to decide in any particular area if speed should be reduced because probability of existence of a lead, or small water opening, or brash ice, is sufficiently high to warrant search for the particular opening in which to surface. The topside sonars must then guide the ascent into the opening by detection of all ice blocks above the vessel throughout the ascent, indicating their thickness and approximate size.

The topside hull should be smooth, curved clean swept in order to permit surfacing in ice cluttered leads or brash ice, or breaking through thin ice sheet which often forms over leads at any season. All through the hull equipment (radar, periscope, antenna, sonar and snorkel) should retract flush with protective covers into the topside surface. This hull type is essential to extending submarine operations into the winter season.

To date, our submarine experience has been entirely with summertime conditions, and the vertical ascent into a water opening has been used exclusively. The procedure is obvious. Let us assume the submarine is under an ice canopy similar to that shown in Figure 3, which is a composite of vertical photographs taken at an altitude of 3500 ft. over the Beaufort Sea in September. The conventional scanning sonar gives a fairly accurate picture of the canopy over a 2000 yd. circle, showing major openings and ice floes. A vertical sonar screen is used to observe the ice directly above the submarine and to determine its thickness. This vertical screen consists of five echo sounders evenly spaced along the topside of the boat. The submarine must maneuver directly under the water opening, observe

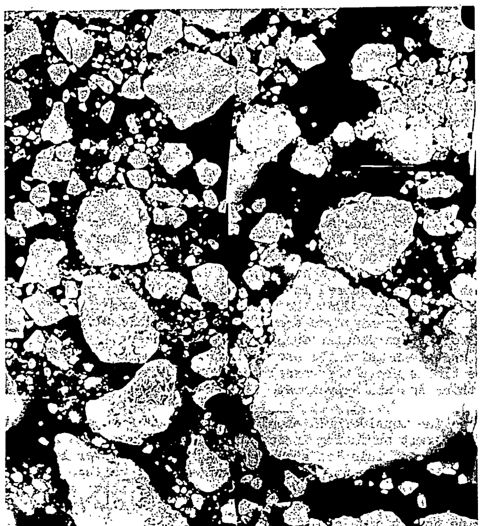

Fig. 3 - Vertical Photograph of Sea Ice. Scale 400 Yds.: Inch

relative drifts of sea ice overhead and make the stationary, vertical ascent, correcting as necessary to match drift of the sea ice. This is a slow process, taking, perhaps forty minutes to accomplish, but is necessary because of the present configured hull and the susceptibility of topside equipments to damage from collision with even small pieces of ice.

It is believed that with a clean, protected topside hull the ascent should be at slant angle, driving up with controlled speed into the slot in the ice canopy. Let us suppose, at a cruising depth of 600 ft., the decision has been made that the ice canopy is satisfactory for surfacing and speed has been reduced to about 5 knots. Suppose we use a sonar scanner of 2° total beam angle and sweep the surface 700 yds. ahead and find a slot sufficiently large. This 2° scanner should "see" all ice pieces 15 yds. in diameter or greater. While scanning our chosen spot of surface, which is perhaps about a 500 ft. square, we are moving ahead and at 500 yds. we start a 20° ascent, from 600 ft., controlling speed and buoyancy. At 500 yds., we should "see" all pieces of ice at least 12 yds. in diameter, moving on, we can detect smaller ice pieces and cut down the area scanned. At 150 yds. from our chosen surfacing touch point, keel depth 240 ft., we should detect pieces 6 ft. in diameter, or greater, i.e., something about 5 tons or greater. From here in to breaking surface, the scanner is looking at grazing angle to the surface and gives the final check of clear length of runway ahead of our touch point. It is then housed behind heavy steel cover to protect against collision with small ice chunks on breaking surface. From 150 yds. in to breaking surface, we use the vertical topside screen formed by five echo sounders spaced along the topside to tell us what shows up above the hull during the final break through to surface. Keep in mind, it is the vertical beam that tells us the ice thickness; the slant angle, scanning beam does not. These topside vertical echo sounders work right up to breaking surface and can sustain direct collision with ice, as has been demonstrated on NAUTILUS and by the echo sounder in any icebreaker hull.

In addition to the example just described of surfacing in water openings, the submarine must be capable of surfacing in brash ice of nearly 100% coverage as illustrated by Figure 4. The photograph shows REDFISH (SS 395), a Fleet class submarine, on station in brash ice 110 miles northeast of Pt. Barrow during August 1952. For five days REDFISH remained on this station, then without benefit of aerial reconnaissance or any other form of assistance and under complete radio silence, REDFISH submerged and proceeded under ice to find a water opening nine hours later in which to ascend. After batteries were recharged, another dive of three hours brought open

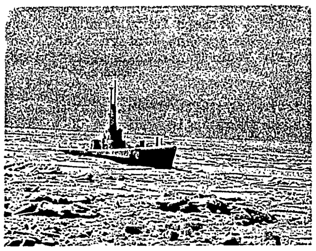

Fig. 4 - USS REDFISH (SS395)
in Sea Ice, Beaufort Sea

water near the Alaskan coast. These dives required more knowledge of the sea ice and detailed oceanography of the area than the more spectacular cruise of NAUTILUS last summer.

Under brash ice, the 2° beam scanner at slant angle would show practically a continuous ice sheet but at vertical position would detect the brash character. The ascent would be similar to our previous example to a keel depth of about 75 ft., then by vertical ascent and to choose a satisfactory spot to "shoulder" a way through the brash ice.

A third typical situation is the shallow area i.e. water 150 ft. deep, and there are many shallow areas of operational significance, for example, the Bering Sea, the Chukchi Sea, the great Siberian shelf and parts of the Kara Sea. In the shallow area, the 2° beam scanner serves the prime function of estimating depth of any massive ice ahead and determining the dimensions of a water opening in which an ascent is attempted.

Extending to winter operations, we have no experience except in the Bering Sea where surfacing should be possible wherever desired. In the Arctic Ocean, we must make winter observations for coverage, thickness and existence of fresh frozen leads. Can the submarine break through these ice sheets, or must we provide heat or explosive cutting methods? The winter operation, I believe you realize, is a vast problem, yet to be defined, let alone studied.

We depend on sonar to guide our ascents in sea ice; yet, we must admit we know very little about the acoustic properties of sea ice. From analysis of records taken on the topside vertical echo sounders, which operate at about 22 Kc, we believe summertime sea ice to be a volume scatterer at this frequency. It is acoustically like a ship's wake. 22 Kc sound is scattered back from throughout the entire volume of the ice and not from its bottom interface - in fact, this bottom interface is difficult to describe. A piece of overturned sea ice is shown in Figure 5, which illustrates the open

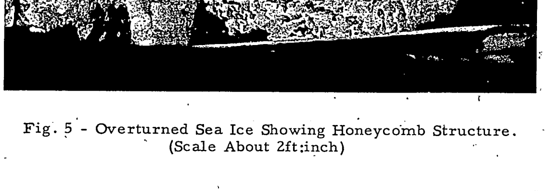

Fig. 5 - Overturned Sea Ice Showing Honeycomb Structure.
(Scale About 2ft:inch)

structure of the ice. This structure is free flooding and holds many air bubbles, which, as in wakes, are suspected to act as intense sound scatterers.

Sound observations have been made at one other frequency, namely, 1 Kc. These were conventional sound transmission runs to a distance of 100 miles under ice in the Beaufort Sea. It was these sound observations that kept REDFISH on station in the sea ice previously described and shown in Figure 4. The results indicate that at this low frequency the sea ice (in summertime) acts not as an intense scatterer but as a thin refracting layer against the near perfect reflector of the air boundry. The top reflecting boundry is not necessarily the physical topside surface of the sea ice because of the porosity of the sea ice. At 1 Kc. the reflecting interface is likely in the vicinity of the hydrostatic level of the sea within the ice structure; hence, giving a uniform reflecting boundry irrespective of large variation of height of ice above the sea surface.

The obvious questions: what are the properties at other frequencies? At what frequency does scattering take over? What about changes as freeze up sets in, autumn, winter and spring? There is here a long term research of the physics of sea ice, its growth and relationships to its acoustical properties.

In closing, I wish to simply mention other problems which we face:

1. The mechanical and thermal properties of sea ice as a function of growth, history and season so that we can design break through methods, thermal and/or mechanical.

2. The optical properties, including the amount of natural light under ice, the transparency of the water and the amount of light scattering, in order, for example, to estimate the assistance to be expected from a TV camera during the last 100 ft. of ascent into the ice canopy.

3. The electrical properties to determine, for example, radio transmission characteristics over sea ice with seasonal changes in salinity, or reception of VLF under sea ice by a trailing floating antenna.

4. Sea ice formation on wet surfaces, a problem somewhat analagous to icing on aircraft. For example, a most serious problem we are presently working on is the prevention of sea icing in snorkel head valves when snorkeling under winter conditions of air suction temperatures below the freezing point and loaded with sea spray. Other problems will appear in midwinter Arctic Ocean operations when periscope, antenna, radar, or missile emerges from below ice into air temperatures of -35°F.

5. Finally, a whole host of operational problems require study, for example, the detection and attack of another boat under ice, or the weapon and attack method on surface ships when in ice, or the use of mines under ice.

Perhaps, during 1957, the arctic submarine has come of age through the advent of nuclear power. Five or six years ago, our official position was that the transarctic submarine was still a fantasy. Yet, today the Chief of Naval Operations should, perhaps, consider adding a third force command to that of ComSubPAC and ComSubLANT, namely, ComSubARC.

REQUIREMENTS IN MILITARY OCEANOGRAPHY

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The term "military oceanography" was proposed by Seiwell (1, 2) with a rather restricted connotation, but I propose here to give it a much broader one.

To begin with, we need a definition of "oceanography." Some practitioners in the field during the last decade have wasted what seems to me to be a great deal of effort in attempting to settle whether "oceanography" is in itself a separate science, or a group of sciences; or whether it is a fraction of each of a number of inter-related disciplines; or whether perhaps it is not "oceanography" at all, but "oceanology" or "the marine sciences." I prefer to define oceanography as the scientific basis of seamanship, just as physics is the base of engineering, or nautical astronomy of celestial navigation, or chemistry of soap-manufacturing.

"Military oceanography," then, is the scientific basis of seamanship as it concerns military operations, taking the term "military" in its most inclusive sense. Military oceanography differs from the kind of oceanography commonly carried on for purely civilian pursuits in that it involves consideration of factors affecting devices such as submarines or ordnance, affecting problems such as detection or secure communications, and affecting operations such as wholesale destruction or delivery of vast quantities of men and material where no port facilities exist. On the other hand, military oceanography is for the most part unconcerned with much of the scientific basis of fishery seamanship -- the plankton counts; analyses for dissolved gases, nutrients, and trace elements; and year-class studies that currently occupy such an important place in fishery investigations.

The most significant military use of oceanography lies in its ability to predict occurrences in the sea. Some phenomena affecting the seaman have been under observation for so long that their prediction is taken for granted. Both the mariner and the seaside dweller have such confidence in the ability of the tide tables to predict sea level to 2 or 3 feet -- only 0.02% or 0.03% of the average depth of the ocean -- that events like the North Sea flood of January 1953 or Hurricanes Connie and Diane in New England in 1955 or Audrey in Louisiana in 1957 become horrible calamities. Yet model studies, theoretical computations, and other analyses made after the events have shown that the extraordinary heights of sea level reached in each of these cases have a firmly predictable basis. Unfortunately, these predictions cannot be issued a year or even a week in advance, and the complexity of the organization required to produce storm-tide forecasts and the public inconvenience that can result from a premature forecast that fails to be verified are factors tending to hinder development of comprehensive prediction services.

On the other hand, the tsunami warning service of the U. S. Coast & Geodetic Survey in the Pacific, which is based on the simple fact that earthquake waves arrive long before ocean waves, is a successful and valuable service, even though not every potential earthquake seems to produce a tsunami, and thus occasional warnings are distributed for waves that never materialize.

Two case histories from recent oceanographic operations of the Hydrographic Office will further illustrate the value of the prediction approach in seamanship. The first example is connected with the movement of cargo to the Arctic in connection with the construction and maintenance of the DEW-Line and other polar bases. When the requirement for this movement was first laid on the Military Sea Transport Service in 1951, so I am told, it was accompanied by unseamanlike stipulations as to times and dates at which certain deliveries had to be made in the North. Although the Navy and Coast Guard had been supplying weather stations and the Petroleum Resaerve for several years, there was a prevailing impression that "ice is where you find it;" that nothing therefore could be done about it; that schedules could ignore its presence; and that the resulting damage had to be accepted.

However, ice damage to MSTS vessels and other costs due to delay resulting from ice in 1951 reached the round total of $17,000,000, a sum which unfortunately had not been provided for in anyone's budget, and which even in the free-spending Korean War days was unacceptable to comptrollers. The subsequent development by Hydro for MSTS of an ice-forecasting and reconnaissance service with the expenditure of considerably less than $100,000 a year has been described by Bates, Kaminski, and Mooney (3). In 1952, costs of ice damage and delay to MSTS vessels were cut to $6,900,000; in 1953 they were only about $1,000,000; and the figure has stayed low in spite of greatly increased operations. In 1955, an exceptionally bad ice year, damage amounted to $4,800,000; in 1956 it was $2,100,000; and last year it was around $1,000,000.

It would be ridiculous, of course, to claim that an expenditure of $100,000 annually on oceanography led directly to savings of $10 or $15 million per annum. What manifestly has occurred, however, is an awareness on the part of those laying down the schedule requirements that it is no more seamanlike to attempt to take a ship from one port to another when ice conditions are unsuitable along the route than to attempt to cross a bar in a ship drawing 28 feet when there is only 26 feet of water on the bar. In the latter case, we have the tide tables to guide us; in the ice situation, the accumulated observations and experience of a century were inadequate, and systematic reconnaissance by trained observers, a special reporting net, and scientifically-based forecasts drawing on the principles of ice formation and drift, were required.

The second example comes out of recent developments by Hydro in methods for improving transoceanic crossings by surface vessels, from the standpoints of economy in time and fuel, comfort of personnel, and minimization of damage to ships and cargo. It is of interest to point out that oceanography became recognized as a science through Maury's dealing with this identical problem 110 years ago (4). For sailing vessels Maury laid down routes based on climatological averages which can scarcely be improved on today (although some of the record voyages by sailing

ships were on routes that differed widely from his recommendations). For steamers Maury was content to specify great-circle courses, and great-circle courses have been standard to the present day, far, far too long after the equipping of all ships with radio opened the door to the possibility of continuously monitoring their passages and furnishing guidance based on existing and predicted weather situations.

At Hydro we have applied a technique for making wave predictions to the five-day forecasts obtained from the Weather Bureau, to produce long-range forecasts of wave conditions (5). Knowing, from log book analysis, how various vessel types are slowed down by wave conditions, we borrow a "minimum time-track" technique from modern airline practice, to determine the route which will get the ship to her destination most quickly (6). We have furnished daily recommended routes to most MSTS sailings for the past two winters; recently MSTS has cut one day off its scheduled transatlantic passenger schedules. Here there can be no argument as to the direct result of putting seamanship on a scientific basis, and a saving of approximately 10% in time at sea, with increased passenger comfort, is an achievement I am proud to report.

What do we still need in military oceanography? Basically we need an increased awareness in the Navy that good seamanship involves science just as much as do the design and functioning of weapons, hulls, power plants, or communication systems. Specifically we need overall direction for putting all aspects of seamanship on a scientific basis. The Navy once had a Bureau of Navigation, whose chief ornaments were the Naval Observatory and the Hydrographic Office; but it turned into a Bureau of Personnel, and these two scientific organizations ended up together with the Office of Naval History under the Deputy Chief of Naval Operations for Administration. A look at this week's program reveals significant gaps in how other bureaus regard the ocean. Neither the bureau that is responsible for seaplanes, for example, nor the bureau that builds our docks and other underwater structures, appears to have anything to say on basic or applied science in this medium. And a main complaint of the oceanographic contractors with the other bureaus and with the Office of Naval Research -- or so it appears to me -- is the intermittent way in which money for oceanography is turned off and on, so that long-term programs of investigation cannot be carried through. The result is that these contractors, the source of most of the country's trained oceanographers, are discouraging any expansion in training, and are turning to non-military sources, such as the fishing industry, the IGY, and the great foundations, for their support. With a constant quantity of competent workers in the field expending an increasing effort on non-military work, we can only look forward to a decreasing total of work on military problems unless a firm policy is formulated at the top.

What else do we need in military oceanography? Analysis of my two case histories of successful prediction operations shows that in both programs the key was the obtaining of the necessary data. In Arctic ice forecasting, existing systems for collecting data were inadequate and we were required to establish our own system of collecting and reporting. In ship routing, on the other hand, we required nothing but a few hours of office time, since the weather reporting and analysis system of the Weather Bureau was already at hand, along with the Pierson-Neumann-James (7) method of wave forecasting, and the key to their application to ship routing, the effect of waves on ship speed, was available through analyses of logbooks, where, in accordance with the dictates of prudent seamanship, watch officers had regularly and religiously recorded weather, course, and speed.

These examples both pertain to surface conditions, where observations are made visually, and where experience at sea or in the air is the best training for an observer. For underwater conditions, however, and where observations are made instrumentally, other types of observer training are needed. Far too many pieces of naval underwater hardware are still being developed and tested under conditions where no attention is paid to the oceanography of the situation, and in environments such as Florida or the Caribbean that have no resemblance to the areas where they are most likely ultimately to be used. The association of trained oceanographers with these testing programs would not only provide information on the behavior of new hardware under varying ocean conditions, but would assist those responsible for the tests in choosing areas most suitable for the special requirements of tests, such as photography, aerial observation, underwater recovery, and the like.

We need to recognize also that oceanic conditions vary, and that the average picture may not necessarily resemble the instantaneous picture. For example, here is a portion of H. O. Pub. No. 225, showing average ocean surface temperatures in the North Sea for December, and alongside it is a chart showing the actual temperatures for December 1956. One is the climatic average for the ocean -- the hydroclime; the other the synoptic picture of the water -- the hydropsis.

The hydroclimic picture of the ocean is fairly well known, and the IGY will add a good deal, particularly in areas not well covered. For the hydroptic situation however, we still need to develop faster means of recording, reducing, storing, and, above all, recovering the data.

One final requirement of military oceanography concerns reporting units. It will be observed that my two isothermal charts of the North Sea show different thermometer scales. In these cost-conscious days, military oceanography cannot afford the luxury of having part of its data -- that taken by the military establishment itself or by its direct contractors -- in British units, and part -- that taken by scientists working as scientists, and by its foreign friends -- in metric units. The sometimes appalling complications that result are too long to detail here, but I estimate that perhaps 25% of our total oceanographic effort is wasted in making conversions between the two systems, that training takes at least 50% longer and that the overall reliability of our products is reduced at least 10%.

I am sorry to say that this dichotomy was forced on the Navy not by the Navy itself but by the scientists, stemming from a sacred cow attitude that simple seamen cannot be expected to understand complex units like meters, grams, or degrees Celsius. This attitude sadly underrates the capabilities of the U. S. bluejacket. If boots and midshipmen can learn to call the floor the deck and the drinking fountain the scuttlebutt, they can certainly master the simple system of measurement units that not only is part of the universal language of science but is the everyday system throughout all the world except that speaking English. When we seek to standardize our naval operations, whether in NATO, within the Western Hemisphere, or among the independent countries of Asia, we find ourselves out of step in our basic units.

Once an overall direction for military oceanography is established, one of its first moves should be to specify that all observations of the marine environment be expressed in metric units. And the sooner we start reckoning gunnery ranges in meters instead of yards, submarine depths in meters instead of feet, and oceanic soundings in meters instead of fathoms, the better off we will be. Changes are expensive, and they are always resisted, often merely because they involve something new; but even though this country can afford to consider occupying the moon, I maintain it cannot afford to continue the present wasteful system of duplicate units.

In summary, the present requirements in military oceanography are:

- I. An overall, coordinated program of investigating the sea.
- II. Expanded training of oceanographers.
- III. Close association of oceanographers with all phases of development and tests involving the ocean as an operating environment.
- IV. Development of data-collecting and handling systems to serve as the basis of predictions of conditions.
- V. Standardization on the metric system of units.

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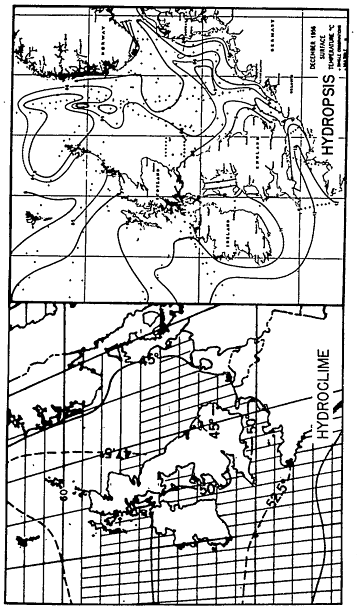

Figure 1. North Sea surface temperatures. Average for December (left); observed for December 1956 (right).

MAN AND THE UNDERSEA ENVIRONMENT

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Whenever man's normal environment is appreciably altered, almost the entire range of his physiological and psychological functions becomes affected to a greater or lesser degree depending upon the individual and on the severity of such alteration. This is equally true of the young novice making his first underwater swim across a pool, the deep sea diver or underwater swimmer, submariner, aviator , or our anticipated space traveler. Whenever it becomes desirable or necessary that man extend his activities into extremely unfriendly environments, certain precautions must be taken and provisions made to ensure that he will remain alive and operationally efficient.

With this kind of general approach there is no real dichotomy of the environmental problem whether we are considering deep sea or deep space operations. There is only a broad environmental spectrum, a very limited portion of which is reserved for man's normal **existence.** Certain regions of this spectrum contain factors which pose highly specialized problems but these do not severely influence the broad general problem of maintaining man outside his assigned sphere.

The medical and biological sciences concerned with this problem have not always been aware of the close relationship which exists among the various divisions of the environmental spectrum. Aviation Medicine, Diving and Submarine Medicine, Space Biology, and others have therefore evolved as highly specialized, and almost as highly isolated, fields of endeavor. Recently there has been a growing awareness within the individual environmental specialties of the similarity of their problems and of the possible mutual benefits which could be derived from increased cooperation in the exchange of ideas and information. At the present time a serious attempt is being made by members of these groups to effect a closer liaison and coordination. If full cooperation among all of the environmental specialists can be realized, the common problems will fall into their proper perspective and be resolved more quickly, leaving each group with only the special problems related to its sphere of interest. While the discussion which will follow is directed specifically toward the problem of man under the sea, it could, with only slight modification, apply to almost any adverse environmental condition.

Man is essentially a land-dwelling, air-breathing mammal regulated to live between sea level and an altitude of approximately 15,000 feet and between the Arctic and Antarctic Circles. He is designed to walk most efficiently on two legs with his major axis perpendicular to his direction of locomotion, and must maintain a body temperature within a narrow range centered around 37° C. As a direct result of postural design, the most highly developed muscle masses of the body are the so-called anti-gravity muscles of the back and legs and the greater part of the total energy expenditure is used in maintaining an upright position and working against gravity.

The undersea environment can best be characterized by a review of the unique properties of water shown in Table I. The first five of these properties are responsible for the fact that water is the one substance absolutely essential to all forms of living material. The high heat conductivity and capacity and the high latent heat of evaporation satisfy the necessary requirements in maintaining body temperature, the solvent action promotes distribution of foods throughout the body and the elimination of wastes and, the ionizing potential provides a catalytic medium in which metabolic processes can proceed at optimum rates. It is somewhat of a paradox that man should find that water is so ideally suited to his vital functions and yet, as a total environment, to be completely incompatible with life itself.

Table I: Unique Properties of Water

1. Highest Heat Conductivity
2. Highest Heat Capacity (except NH_3)
3. Highest Latent Heat of Evaporation
4. Outstanding Powers as a Solvent
5. Exceptional Catalyst
6. High Surface Tension
7. High Dielectric Constant
8. Optically Transparent
9. Efficient Conductor of Sound
10. Highly Incompressible
11. Standard Reference for Fluid Density

In spite of this incompatibility man has chosen to invade the undersea environment as early as 2-3000 B.C. Excursions into the sea were for a variety of reasons, not the least of which was for military advantage. The accomplishments of military divers, submarine forces, underwater demolition teams and small underwater swimmer attack groups have established beyond question the need for these activities in Naval operations.

With the advent of the diving bell and the subsequent development of deep sea diving gear, submarines and, self-contained underwater breathing apparatus (SCUBA), water as an irrespirable medium was no longer of primary importance. Underwater, as in any unfriendly surroundings, the problem is one of defining and maintaining an acceptable internal environment. The solution in each case will be unique to the individual man-machine system and its assigned mission.

The individual swimmer or free diver represents the simplest and most versatile of underwater man-machine systems. Table II lists the activities in which divers and swimmers have established competence. While these tasks are now performed routinely and with a high degree of success, very limited extension of these capabilities can be visualized from within our present frame of reference since man himself has become the major limiting factor in any consideration for increasing the depth, time or distance requirements.

Table II: Underwater Activities of Divers and Swimmers

Peace and War Time

Salvage
Inspection
Damage Control
Explosive Ordnance Disposal
Underwater Demolitions
Mine Recovery
Bottom Surveys and Mapping
Photography
Oceanographic Research

War Time

Clearing Occupied Enemy Harbors
Offensive Action Against Shipping
    Harbor Installations
    Other Shore Installations
Cloak and Dagger Operations

Many phases of underwater swimmer activities can be extended by engineering developments alone, but beyond a certain point, the end product becomes the submarine whose problem is, in itself, equally complex. It is therefore necessary that we obtain a complete picture of man and his relationship to his environment as a point of departure.

The first problem is that of something to breathe. At the increased pressures encountered underwater any known respirable gas or gas mixture has certain inadequacies beyond certain sharply defined depth-time relationships.

With air as the breathing medium, the normally high concentration of nitrogen begins to exert a noticeable narcotic effect at 100 feet and progresses to the point of incapacitation beyond 300 feet. In addition to its narcotic action, nitrogen dissolves slowly in body tissues during a dive and sufficient time must be allowed for nitrogen washout during decompression if the depth time relationships shown by the bottom curve of Figure I are exceeded (1). In deep sea diving these phenomena are not a serious handicap since an inexhaustable supply of air is available and the depth-time schedule is under the control of a surface tender who prescribes the proper decompression procedure. SCUBA divers are not so tended and have only a limited air supply. They must therefore exert considerable caution to avoid decompression sickness or "bends." Helium is used in deep sea diving to obviate the difficulty of nitrogen narcosis but it does not relieve the decompression requirement. Since the exact relationships between solution and washout of inert gases by the body are not sufficiently defined or understood, extrapolation of the helium deep diving decompression tables into the "SCUBA zone" or shorter-time, shallower-depth range is not feasible.

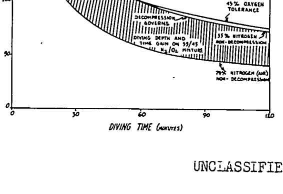

Figure 1. Nitrogen non-decompression and oxygen tolerance diving limits for 55/45 nitrogen-oxygen mixture (diving depth versus diving time). Drawn from Figure 116, p. 233, NAVPERS 10838-A2.

One method of extending the depth-time capability is through the use of artificial gas mixtures such as a 45% O_2-55% N_2. The advantages of such a mixture is shown by the shaded area of Figure I. This technique however has certain limitations as indicated by the crossover point for nitrogen and oxygen limitations since oxygen itself becomes toxic at elevated partial pressures. It has also been observed that oxygen tends to become toxic at slightly lower partial pressures in the presence of nitrogen than when breathed as a pure gas.

In spite of its high toxicity, pure oxygen has certain advantages in military operations. Since there is no waste, a considerably long gas supply can be carried, and with ample carbon dioxide removal, no exhaust bubbles are released and the equipment is quiet in operation. The limitations placed on the use of pure oxygen are shown in Table III. The mechanism of oxygen toxicity is not well defined and little is known about the quantitative effects of such factors as CO_2 and exercise which shorten the safe exposure time.

Table III (1)

Depth-time limits for diving on 100 per cent oxygen

Depth (feet)	Time (minutes)
40	15
35	20
30	30
25	45
20	65
15	90
10	120

The oxygen requirements for work underwater are also quite different from those for comparable work rates in air. Table IV shows a rough compression of values (1). At least a part of the increased requirement at rest may be attributable to a greater heat loss in water and to an increase in muscle tone, however, the oxygen requirements in air and under water for minimal exercise under isothermal conditions is not measurably different (2). At higher exercise levels the increased oxygen consumption required for each additional increment of measurable work is exceptionally high. This is evident from a comparison of drag data (3) (Figure II) with the oxygen consumption values of Table IV. Calculations show that the

TABLE V: SWIMMING SPEED OF VARIOUS ANIMALS

SPECIES	LENGTH	MAXIMUM OBSERVED SPEED FEET/SEC	MAXIMUM OBSERVED SPEED MILES/HR	RATIO OF MAXIMUM SPEED TO LENGTH
TROUT*	0.656	5.552	3.8	8.5
	0.957	10.427	6.5	11.
DACE*	0.301	5.229	3.6	17.8
	0.594	5.552	3.8	9.
	0.656	8.812	5.5	13.5
PIKE*	0.592	6.850	4.7	13.
	0.656	4.896	3.3	7.5
GOLDFISH*	0.229	2.301	1.5	10.3
	0.427	5.552	3.8	13.
RUDD*	0.730	4.240	2.9	6.
BARRACUDA	3.937	39.125	27.3	10.
DOLPHIN	6.529	32.604	22.4	5.
BLUE WHALE	90.	30.	20.	0.33
MAN*				
Submerged	6.	2.024	1.4	0.337
Surface**	6.	2.75	1.53	0.45

*Laboratory Observations

**Height Assumed (Crawl Stroke)

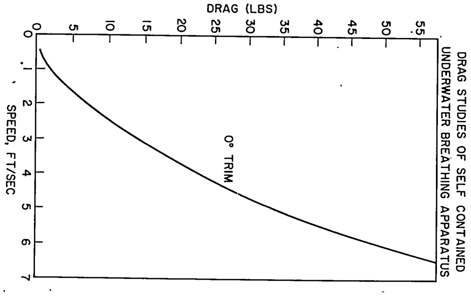

Figure 2. The exponential character of drag resistance curve as a function of water speed indicates the rapid rate at which any propulsion system will reach a limiting velocity. (1 ft/sec equal 0.68 mph)

work efficiency in underwater swimming is only about 5 per cent (3) as compared with 20-25 per cent for certain types of exercise in air (4). It is not clear at this time why oxygen consumption cannot reach the same maximum value in underwater work as in air regardless of the types or level of exercise performed.

Table IV: Oxygen Requirements

Basal - just "staying alive"	0.25 liters per min.
Quiet sitting	0.4
"Light" work - up to	1.0
"Moderate" work - up to	2.0
"Heavy" work - up to	3.0
"Exhausting" work - up to	4.0
Resting under water (just sitting quietly)	0.33 liters/min.
0.5 knot swimming (painfully slow)	0.8
0.85 knot swimming (about average)	1.4
1.2 knot swimming (too fast)	2.5

The comparatively high oxygen requirements and poor work efficiency have led to numerous suggestions that the mode of propulsion of fishes should be studied in order to obtain a more efficient coupling of the human muscle masses to water. Table V is a summary of the speed of fishes as reported by Gray (5) and of man as reported by Passmore and Durnin (6). It appears that certain fish and aquatic mammals are able to perform at a maximum rate of approximately 30 times that of man. If only a small portion of this difference can be bridged, many operational advantages could be realized.

The major advantages to increased water speed alone whether attained by man himself or through a mechanical aid would be the ability to operate against fast tides and currents or to shorten the time required to traverse a given distance. Increasing the range capability at present would not be a great advantage where totally submerged navigation is required since the necessary navigational accuracy is not now available in equipment which can be satisfactorily packaged for use by individual swimmers.

There are many problem areas in the field of individual underwater activities beyond those of a basic medical and physiological nature and of navigation. These include penetration of high turbidity, secure communications between individuals and with their parent craft, detection and identification of swimmers, underwater blast, deterrence and/or destruction, miscellaneous personal equipment, tools, etc. Most of these areas are more in the field of engineering than in biology and are therefore outside the scope of this discussion. However, no major developments should be undertaken without complete consideration of the other auxiliary equipment, the mission and, especially the man who must carry out the contemplated operation.

A summary of the total problem related to adverse environments in general indicates that operational capabilities are extremely short of immediate goals, because of the limitations of man himself. This is largely the result of the recent rapid technological advances which have produced such devices as deep bottom mines, the atomic submarine and artificial Earth satellites. Thus we have entered an era where man's capabilities and limitations, rather than those of the machine he operates, become the determining factor in the success or failure of operational missions.

Prior to these recent major advances, increases in performance capability were realized in only very small increments. The operator, in this latter situation could be provided for by simple extension of existing techniques for environmental control. An entirely new approach to the problems involved in maintaining man in the underwater environment has to be considered now that operational times and depths can be so greatly extended. The logical steps which must be taken are: (1) a complete understanding of man's normal environmental requirements, both physiological and psychological; (2) an adequate definition of an acceptable operational environment; and (3) provision of the necessary instrumentation for environmental measurement and control within the limits defined.

The realization of these steps will be greatly accelerated when the various medical and biological disciplines concerned with environmental problems have effected the close liaison and coordination of effort now being attempted. The ultimate goal of this combined group will be to define and establish the environmental conditions which will permit man to conduct operations wherever and whenever the need arises and to maintain operational efficiency for the duration of any required mission.

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INFLUENCE OF OCEANOGRAPHIC ENVIRONMENT ON UNDERWATER DETECTION

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INTRODUCTION

The influence of the oceanic environment on underwater detection becomes more important as sonar ranges are increased and greater emphasis is placed on target classification. Greater power in transducers alone cannot achieve the desired range and signal quality. We must also learn to use the transmission medium to our best advantage. This entails study of the underwater phenomena that cause attenuation, scattering, focusing, noise, and signal fluctuation.

The purpose of this discussion is to review briefly some of the known environmental factors that affect sonar performance and to speculate on others based on recent NEL studies.

FAMILIAR ENVIRONMENTAL FACTORS

Boundary Effects: The sea boundary effects are more obvious than effects in the medium. The sea surface has been observed to reflect and scatter sound depending upon its roughness(1, 2, 3) and to generate ambient noise.(4) Likewise, the sea floor features are important in the reflection, absorption, and scattering of sound.(5) The acoustic effects depend upon the characteristics of the sea floor such as its roughness, grain size, porosity, density, elasticity, and depth of sediment.(6, 7)

Refraction: Probably the best-known acoustic phenomenon of the medium itself is that of refraction.(8) When sound enters a thermocline or velocity gradient from above with a small downward angle, it is refracted with a decrease in intensity at some range below the gradient.(9) The returning echo is further attenuated by the effect of the thermocline, thus making detection unlikely in a shallow zone under strong negative gradients. This is sometimes referred to as a "bad sonar condition" or "bad gradient" (Figure 1).

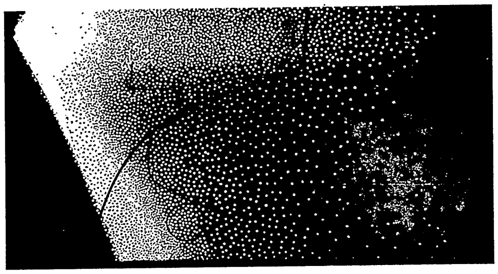

Figure 1. Lack of acoustic detection is frequently attributed to a "bad thermocline".

Mine-hunting and even submarine-detection operations have been curtailed because of the severe refraction imposed by the thermocline. Even minute thermoclines or thermomicrostructures give undesirable effects. Sharp gradients of only 0.1° centigrade can cause fluctuation of as much as 20 db in a vertical distance of only a foot or two when sound is transmitted at a low angle.(10)

Scattering: Scattering is also known to reduce the sound level and ability of detection. In addition to the scattering that takes place at the sea's surface and floor, layers of scatterers and even globs or patches have been observed. The most common of these is the deep-scattering layer.(11, 12) This layer is becoming operationally more important because of deeper targets and because of the increased use being made of the sound-channeling principle, which requires deep sound paths.(13, 14) Studies have shown that the deep-scattering layer undergoes diurnal migration and is most probably of biological origin.(15, 16)

Shallow scatterers are also present, especially on the thermocline.(17, 18) These turbid layers reduce both visual and acoustic detection.(19) As yet, few quantitative measurements have been made on the layers.

Noise: Ambient noise affects acoustic detection. The signal to be detected must be stronger or have a different characteristic than the background interference; consequently, a knowledge of ambient noise conditions is essential for assessing the detection potentials of a particular location at a particular time.

It is known that ambient noise is a function of the wind speed or sea state. Many of the denizens generate characteristic, identifiable sounds. However, not all the unwanted sounds have been satisfactorily explained.(4)

RECENT STUDIES OF ACOUSTIC VARIABILITY

The known environmental factors by no means account for all the vagaries of underwater acoustics. Much of the sound fluctuation experienced in acoustic detection cannot be adequately explained at the present time.(20, 21, 22, 23) Indeed, fluctuation has been referred to as "perhaps the most constant characteristic of sound in the sea."(24)

One notable example of acoustic fluctuation is that recently reported by Pinkston and others working in Chesapeake Bay.(25) Here, transmissions were recorded of 100-kc sound over a path of 250 feet in shallow water. They showed large short-time fluctuations in signal strength. The coefficient of variation of the sound intensity was commonly as high as 0.5.

Urick and Knauss,(26) also working in Chesapeake Bay, encountered short-term fluctuations in acoustic intensity as well as gradual fading of the signal. The short-period fluctuations were attributed to microtemperature structure changes, but the cause of the fading was not clear. Many false targets, called "angels," appeared during these tests. These targets were believed to be fish.

Other examples of extreme variability have been reported by Garrison and Shaw in Dabob Bay;(10) by Sagar off New Zealand;(27, 28) by Nanda in India;(29) and many others.

Blackout: Probably the best example of acoustic variability is that of blackout. This acoustic phenomenon, reported by Carsola and others of this Laboratory, is a condition in which the signal is attenuated or scattered to the extent that there is a near or complete loss of return.(30)

Blackout has frequently been noted off Mission Beach, San Diego, California, when using the AN/UQS-1 (100 kc mine-hunting sonar) at a depth of 10 feet with bottom-mounted targets in about 60 feet of water. Here signal loss was observed for at least a few minutes during nearly every one of 20 days of operation spread over a period of nearly a year. The duration of reduced intensity was from less than a minute to nearly an hour. One extreme loss amounted to more than 80 db with the target 50 feet from the hydrophone. Many of the short blackout periods were preceded or accompanied by intense scattering lines. Another interesting feature was that blackout occurred more frequently at night than during the day.

Although numerous unpredictable blackouts developed, only a few examples of the most distinct ones are compared with the water structure in Figures 2A to E. For example on 11 February 1955 blackouts occurred periodically, some intermittent and others more consistent, for several minutes. These are compared with the temperature and turbidity structure over a 4-hour period in Figure 2A.

At this time the water off Mission Beach had only a 2-degree Fahrenheit gradient from surface to bottom, yet numerous periodic blackouts were observed. Oscillations in the temperature structure are apparent, with maximum displacement of the middle of the thermocline as much as 10 to 15 feet. Although there is a slight rise in the thermocline there does not seem to be any abrupt changes in the water mass. The transparency too, from less frequent observations, is rather constant with slightly more turbid water at the bottom during the blackout period.

In another example, shown in Figure 2B, the only blackout

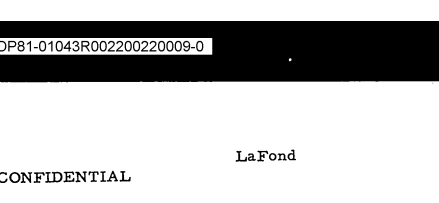

Figure 2A. Comparison of the time of acoustic blackout (represented by a vertical shaded band) with (A) the change of vertical temperature structure (°F) with time, and(B) the change of transparency (%) with time at the projector for three and one-half hours on 11 February in 65 feet of water off Mission Beach.

Figure 2B. Comparison of the time of acoustic blackout (represented by a vertical shaded band) with (A) the change of vertical temperature structure (°F) with time, and (B) the change of transparency (%) with time at the projector for two and one-half hours on 14 March in 60 feet of water off Mission Beach.

of the day (14 March) occurred between 2030 and 2045. The water transparency changed to a weaker gradient but the observations were made so infrequently that sharp changes were not apparent. The temperature recorded at 6 levels, on the other hand, showed a deep thermocline virtually on the bottom. Then 45 minutes prior to the blackout large vertical oscillations of the thermocline took place. The isotherms were displaced as much as 30 feet in 5 minutes. Four giant wave-like oscillations occurred under the receiving ship. Then came a period of total and partial blackout, followed by smaller thermocline oscillations at a higher level in the water. The water structure would indicate that both a vertical and a horizontal water boundary with turbulence, at least in the form of vertical oscillations at the interface, was passing the ship at the time of blackout.

Figure 2C shows other examples of the total and partial blackouts which occurred on 25 April. During the blackout period strong scattering lines were observed on the scope. The vertical motion as indicated by the temperature structure amounted to as much as 20 feet in only 60 feet of water. The entire thermocline appeared to rise and rather suddenly drop off, as if this section represented the boundary between two water masses. The turbidity also implies that the water at depth is more turbid after than before 2000, another suggestion of a change in water type.

The temperature and transparency conditions for a 2-hour period on 20 June are shown in Figure 2D. On this day numerous blackouts were observed but only one distinct example is reproduced. It occurred at the same time that a giant internal wave passed the transducer. The abrupt drop in the thermocline was as much as 30 feet in 3 minutes. The following rise was nearly as rapid. Subsequent oscillations gradually became smaller. The limited transparency data taken during this 2-hour period indicate a reduced stratification of the water and a tendency of mixing at the time of maximum waves.

The last example is a series of distinct blackouts which occurred around midnight between 19 and 20 July, as shown in Figure 2E. Here the strong shallow thermocline was fairly constant until 2220 when the thermocline suddenly oscillated at a rate of as much as 10 feet per minute. Three 15-foot oscillations took place in succession followed by oscillations at reduced amplitudes. The

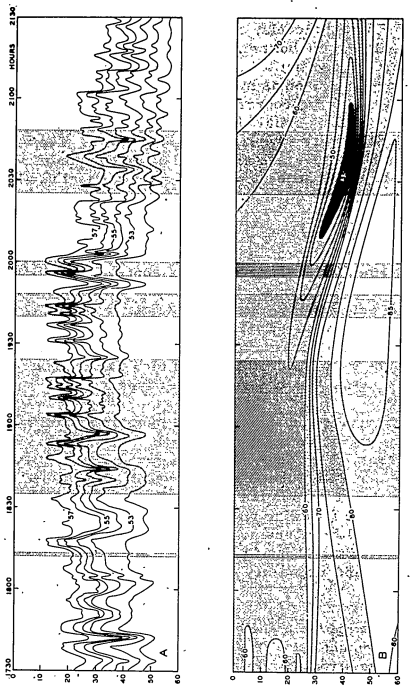

Figure 2C. Comparison of the time of acoustic blackout (represented by a vertical shaded band) with (A) the change of vertical temperature structure (°F) with time, and (B) the change of transparency (%) with time at the projector for four hours on 25 April in 62 feet of water off Mission Beach.

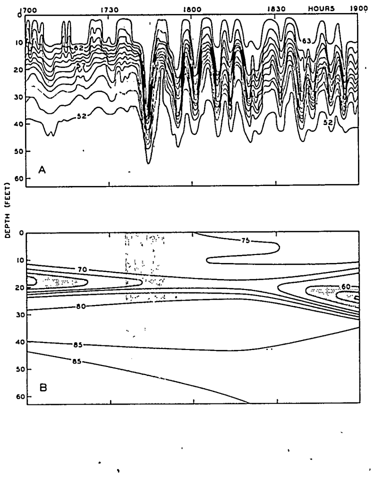

Figure 2D. Comparison of the time of acoustic blackout (represented by a vertical shaded band) with (A) the change of vertical temperature structure (°F) with time, and (B) the change of transparency (%) with time at the projector for two hours on 20 June in 63 feet of water off Mission Beach.

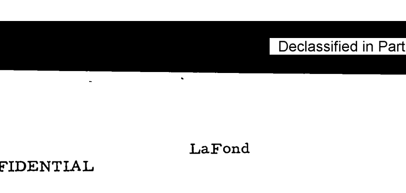

Figure 2E. Comparison of the time of acoustic blackout (represented by a vertical shaded band) with (A) the change of vertical temperature structure (°F) with time, and (B) the change of transparency (%) with time at the projector for four hours on 19-20 July in 60 feet of water off Mission Beach.

thermocline was 5 to 10 feet lower after the disturbance than before. The dense turbid layer became lower and less concentrated after the burst of internal waves.

Blackout has been observed only in the presence of internal waves. Many of the blackouts were accompanied by scattering lines; however, the presence of scattering lines did not always result in blackout.

POSSIBLE ENVIRONMENTAL FACTORS

In view of the above-described phenomena, this Laboratory has been exploring possible causes of acoustic loss, including both familiar and little-known environmental factors. Among the latter are internal waves, bubbles, sea-surface slicks, and plankton.

Internal Waves: One feature of the environment observed during all periods of blackout has been the presence of large vertical oscillations known as internal waves. (31, 32)

Internal waves consist of complex vertical displacements of the isotherms which appear to travel at different speeds and with changing patterns. They have been observed in all oceans with wide ranges of periods and amplitudes. (33, 34)

In the southern California area distinct internal waves have heights of 20 feet and a period which is frequently of the order of 10 - 15 minutes. However, many other shorter and longer periods are present. The waves have been observed to travel with speeds up to 0.5 knot with wave lengths of about 20 - 240 yards.

In several instances off Mission Beach, San Diego, the waves moved shoreward while decreasing in amplitude. It is even conceivable that they may break, as indicated by occasional positive temperature gradients. In any case the wave length and period of internal waves are variable and more than one could easily occur in the normal mine hunting range. Thus, the absence of waves at the projector does not preclude their presence in the target field.

The problem of refraction by internal waves was considered theoretically by assuming a typical three layer internal wave water structure. (35, 36) From temperature data shown in Figure 2 a typical internal wave was considered having the following characteristics.

Depth of water	60 ft
Depth of projector	10 ft
Top layer (depth)	0 to 30-8 $\sin\frac{2\pi x}{L}$ (Av. 30 ft) where x = range and L = 300
Middle layer (depth)	30-8 $\sin\frac{2\pi x}{L}$ (Av. 30) to 40-9.1 $\sin\frac{2\pi x}{L}$ (Av. 40 ft)
Bottom layer (depth)	40-9.1 $\sin\frac{2\pi x}{L}$ Av. 40 to 60 feet
Top layer (gradient)	0 ft/sec/ft
Middle layer	-4.8 ft/sec/ft
Bottom layer	-0.6 ft/sec/ft
Wave length at interface	300 ft
Beam pattern	-10 db at ± 8°

The interfaces of the thermocline are seen in Figure 3 to form two different sine curves. All acoustic ray paths passing through them are refracted by an amount which depends upon the angle of approach of the rays and the velocity discontinuity at each interface. For this particular problem the rays are considered to be traveling in a plane which is parallel to the direction of propagation of the internal waves. Total reflection is assumed at the sea surface and all sound energy reaching the bottom is assumed to be absorbed. This representation is an ideal situation, but it approximates the natural sea velocity structure more closely than any previously considered. Even in this ideal medium a great deal of computation was required for the multiple refractions and reflections for each 0.1° ray. This was nicely handled by the Electronic Computer Division of the Bureau of Ships. The detailed computation was carried on by means of the UNIVAC at DTMB.

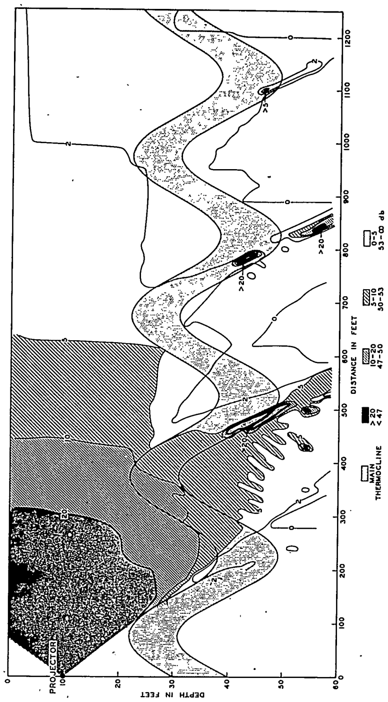

Figure 3. Relative linear sound intensity for sound rays passing through a three-layer medium containing internal waves. Values of intensity on graph are expressed in millionths of the value at 1 foot from projector along the horizontal from the projector. The equivalent transmission loss relative to one foot along the horizontal from the projector in dbs is also indicated.

Acoustic intensity of sound for each 10-foot interval of range and each 1 foot interval of depth were computed and contoured. The intensity at any point in the X, Z plane is based on an intensity of unity at one foot along a horizontal from the source. The values of the isolines have been multiplied by 10^6 to avoid very small numbers.

Above the thermocline the sound intensity decreases with distance from the source. Below the thermocline refraction focuses the sound rays as they pass through the internal wave into alternate high and low intensity zones. The divergence and convergence of the rays is directly related to the sinusoidal nature of the internal wave.

In this example, there is one high and one low intensity zone for each interval of one wave length. The high-intensity zones become narrower with increasing range, whereas the low-intensity zones become wider. This variation with range is caused by waves near the source acting as a barrier for those farther away, *i.e.*, fewer and fewer rays strike the waves farther and farther away from the source.

Under similar situations of internal waves off Mission Beach the AN/UQS-1 gave a return signal in the form of a banded presentation on the scope, as shown in Figure 4A. The light portion represents stronger signals. Note that the bands near the projector are wider.

Figure 4B shows another scope presentation with more detail. The indicated zones of high and low intensity are believed to be the result of the returning signal from sound focused on the sea floor at that time. Targets are obscured in the high intensity zones and thus detection possibilities are greatly reduced.

These bands of high sound level, believed to be caused by internal waves, also decrease in intensity with distance from the source due to spherical spreading of adjacent rays. Therefore the focusing effect of internal waves may be better demonstrated by anomalies in sound level which correct the previous computations for spherical spreading. These levels are expressed in db's; the reference distance is 1 foot.

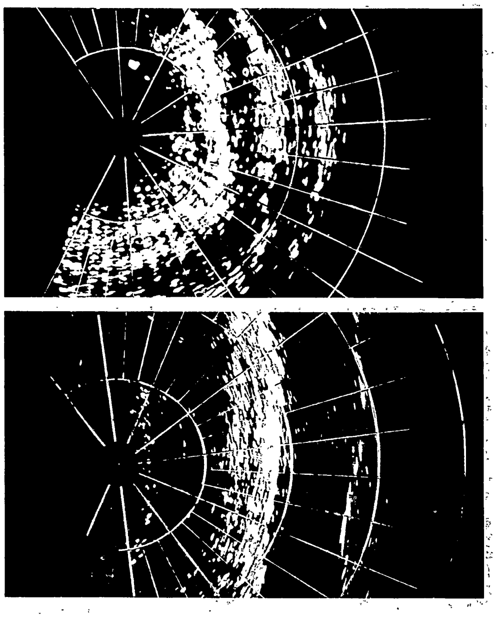

Figure 4. Examples of bands of high and low sound intensity shown on the scope of AN/UQS-1 at times of high internal waves.

Figure 5 again demonstrates the zonal concentrations (with negative anomalies) which are caused by sound focusing in internal waves and reflection from the surface. The transmission anomaly is expressed in db above and below the loss expected of normal spherical spreading. False targets are easily produced by such sound focusings. In nature moving internal waves of different sizes, as shown in Figures 2A through 2E, thus appear to be a major factor in acoustic detection by producing great variability in the return signal. Additional studies are underway.

Bubble Effects: Another environmental factor suspected of causing acoustic variability is small, even microscopic, bubbles. Laboratory studies indicate that gas bubbles can produce a great loss of sound energy if they are of the proper size in relation to the sound frequency. Fox,(37) for example, reported sound absorption due to gas bubbles about 0.11 mm in diameter to be as much as 30 db per cm at frequencies around 90 kc when the bubbles constituted only 0.02% of the volume. These bubbles are visible; in fact experiments in the Laboratory and at sea indicate that divers can visually distinguish individual bubbles as small as 0.06 mm in diameter. However, under normal conditions at sea no visible bubbles were observed to persist in the water column. They rose towards the surface, increased in size on reduction in pressure, and usually burst at the surface.

Visible bubbles very near the sea's surface are caused principally by the entrainment of air from breaking waves. In addition to visual observation, they have been recorded during periods of high winds with a NK7 echo sounder mounted on the bottom and directed upward in shallow water.(38) Other minor causes of the formation of bubbles in shallow water are sea-floor gas seepage, fish burps, and decomposition of bottom detritus.(39, 40) These visible bubbles are all transient in nature.

The best evidence of attenuation by still smaller, invisible, bubbles is from Warner of NMDL.(41) He used the AN/PQS-1 in a tank with induced bubbles. After the water had cleared the sonar still could not receive echoes from the side of the tank only 5 feet away. This condition lasted for two hours. From this significant discovery it appears that invisible gas bubbles can persist and cause attenuation for long periods of time. It is at least theoretically possible that such long-lived invisible bubbles exist beneath the sea

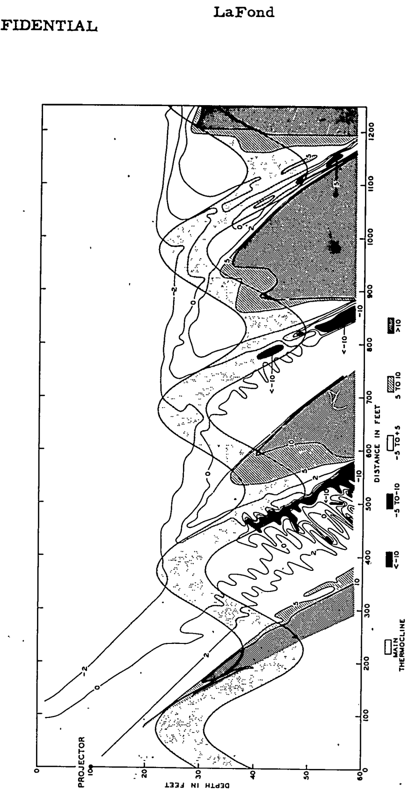

Figure 5. Transmission anomaly for sound rays passing through a three layer medium containing internal waves. Values of anomaly show the departure from normal spherical spreading which results from refraction, reflection, and directionality of projector; the values are expressed in dbs.

surface.

Bubble Production: One approach to the problem of bubble generation is through the study of the oxygen saturation of the water. Oxygen concentration at various depths and its relation to temperature structure and water transparency were investigated off Mission Beach.(42)

The oxygen content of the water in summer was found to be maximum below the surface and above the densest turbid layer in all cases, as shown in Figure 6. However, when the per cent saturation was determined for in situ conditions, that is, when the solubility was corrected for pressure, temperature, and salinity, the vertical saturation curves differed from the oxygen content curves.

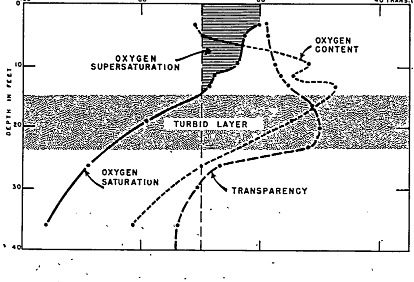

Figure 6. Vertical distribution of dissolved oxygen (content ml/L), saturation of oxygen, (%).

The calculations for in situ conditions, assuming nitrogen saturation at all levels, showed that the upper 12 to 14 feet were supersaturated with oxygen. The maximum supersaturation, which occurred at the surface, ranged from 120 to 148%. This high oxygen layer, probably derived from photosynthesis of plant organisms, occurred on the upper side of the layer. The increased light at the shallower depths facilitates a higher rate of photosynthesis, and therefore a greater potential oxygen production at this level.

Unusually high oxygen content is not surprising under conditions of high phytoplankton production. For example, during periods of high plankton blooms the waters near San Diego were observed to have an oxygen saturation as high as 200 per cent.(43) Pickard(44) reports that oxygen in the waters of the British Columbia inlets may be supersaturated as high as 170 per cent due to the action of large concentrations of phytoplankton. The significant thing is that supersaturation of water samples can be reduced by shaking, indicating the instability of the oxygen in the water.

Under high supersaturation conditions, a small bubble introduced either by organisms in the water column or from the surface may actually grow. However, these bubbles will tend to rise at increasing speed and be lost at the surface. Thus, persistence of these bubbles over long periods of time cannot be expected, unless either some mechanism exists for keeping them submerged or there is a source at depth. One possibility is that the particles responsible for the high turbidity of the water might attach themselves to extremely fine bubbles, thereby preventing or retarding their rise to the surface. Another possibility is that bubbles may continually or periodically generate in the water column.

The action of internal waves is still another mechanism by which oxygen bubbles may be produced. If supersaturated or nearly supersaturated water is brought up from one depth to a lesser depth the per cent saturation increases. The vertical displacement may amount to at least 30 feet as demonstrated by the height of the observed internal waves. Similar changes in pressure on oxygen-saturated water caused it to release bubbles in laboratory experiments which were performed in a pressure chamber by bubbling oxygen through water, releasing the pressure, and noting the formation of bubbles.

In addition to the reduced pressure on the crest of internal waves there is usually some turbulence associated with the thermocline as indicated by the visual distortion of objects when viewed through it, and the distortion of the vertical colored path made by dye marker when dropped through the water.(45) It is believed possible that this turbulence and the reduced pressure caused by dominant internal waves are of sufficient influence on supersaturated water to free some of the oxygen and other gases in the form of small bubbles in the sea.

Slicks: Several observers have indicated a strong correlation between the presence of slicks (glassy patches or lines on a rippled sea) and fluctuations in acoustic transmission and detection.(46, 47) Acoustic echoes are frequently obtained from water near slick lines. Sound transmitted toward some slick zones is sometimes completely absorbed or scattered, thus producing an acoustic barrier. Also unusually high readings are obtained on the AN/UQQ-1 wake (bubble) indicator when it is towed through a slick.(48)

Many types of slicks are developed in oceans, lakes, and harbors.(49, 50) (Figure 7). They result from the various water motions, wakes of ships, and local wind-induced motion. They may also result from contaminants, such as fresh water, organic material, oil, and foam concentrated as a thin film at the surface.(39) The concentration of contaminants in the San Diego region takes place primarily as a result of convergent motion set up by internal waves. Hence, slicks may provide a visual indication of the presence of internal waves.

The thermal structure of the water associated with slicks was investigated. With BTs and towed thermistors it was found that the surface water temperature in slicks was higher than the temperature between slicks by an average of 0.3° F in April and 2.0° F in August, with a maximum of 2.8°F. Assuming that higher temperatures are found at the immediate surface in spring and summer, this result would indicate that the immediate surface waters were moving toward and concentrating in the slick bands.(50, 51)

The oxygen and other gas saturation was found to be highest at the surface. Under a heating of 2°F the saturation of all gases will increase and some of the gas may be forced out of solution in slicks. Because of the high organic concentration, the bubbles thus formed can persist at the surface as foam. In some slicks during quiet weather, bubbles have been seen to suddenly emerge from the water, temporarily remain at the surface, and then burst. These

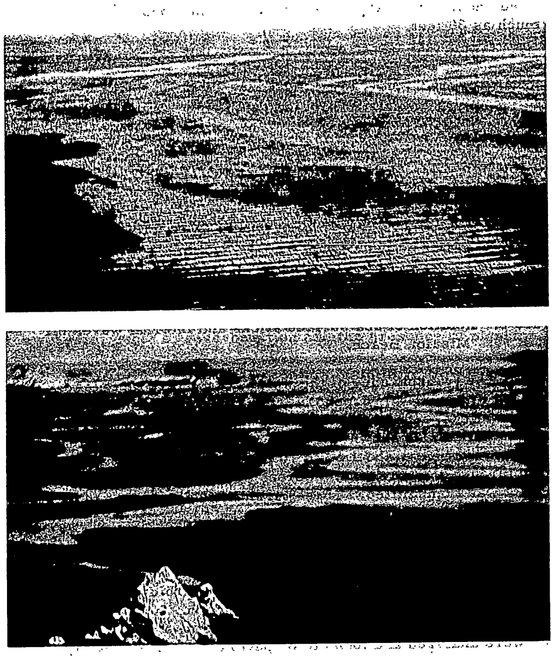

Figure 7. Sea surface slicks.

apparently are derived from the heating of gas-saturated water.

The vertical and horizontal temperature structure normal to slicks is shown in Figure 8. Note that the isotherms are depressed under nearly all of the slicks, and this depression may be as much as 30 feet.

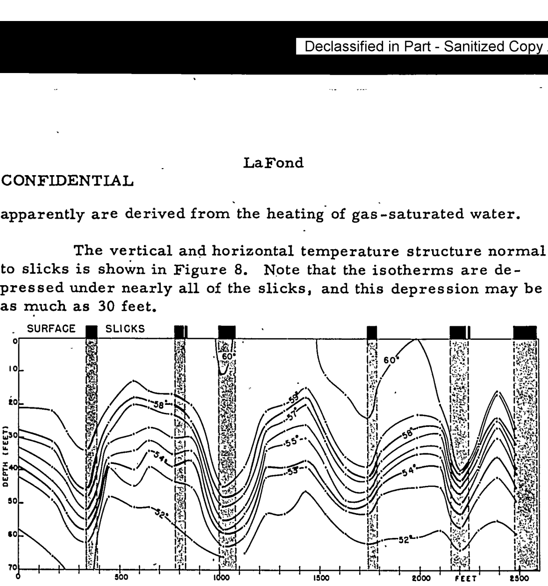

Figure 8. Relation of sea surface slicks and internal waves off Mission Beach.

The transparency of the water near slicks was also examined by towing a hydrophotometer at a constant depth under a series of slicks. Unusually high-turbidity zones were encountered under the slicks, as shown in Figure 9. In the relatively clear water between slicks about 60 to 70 per cent of the light was transmitted through a meter path, whereas under the slicks only 10 to 40 per cent was transmitted. These turbidity zones appear to be the result of surface convergence in the slicks.

The material causing the turbidity zones near the surface was found to be mainly organic. Some turbid water caused by plankton populations develops in situ. Other turbid water appears to originate from the shallow nearshore region. Net hauls and diver-collected samples of the material causing a shallow turbid layer were analyzed and found to be phyto and zooplankton alive and in varying stages of decomposition.

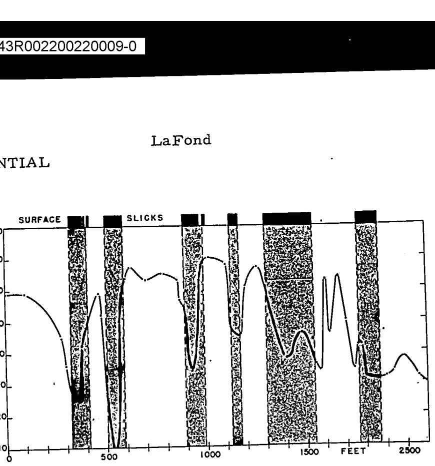

Figure 9. Relation of sea surface slicks and water transparency at 6 feet depth off Mission Beach.

Plankton: The ability of plankton to attenuate or scatter sound in turbid zones and in the open sea has not been definitely established. However, new evidence indicates a relationship between the seasonal cycle of reverberation and the presence of plankton.

The production of plankton is not uniform throughout the year. In the nearshore southern California area the greatest production is in the spring.(52) This probably also holds true for the offshore regions, where acoustic scattering measurements have been made from 1953 - 55.(53, 54) During the early Lorad studies the reverberation was measured for the entire annulus of the first 30 mile convergence zone. These data were plotted in Figure 10 by Mackenzie.(55) When the seasonal trend of his acoustic measurements is compared with the seasonal trend of plankton production for previous years there is a reasonable agreement. This would suggest a correlation between plankton in the sea and the higher reverberation observed in spring. Thus, plankton may be one of the many environmental factors which affect acoustic detection.

The preceding discussions point out various features of the environment which may affect detection. The problem, then, is to find ways and means of overcoming adverse environmental factors

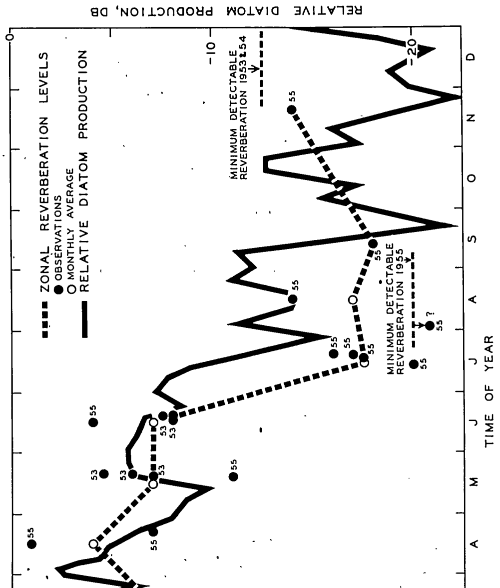

Figure 10. Comparison of seasonal diatom production (db = 10 log number of cells/L.) and zonal reverberation level.

so as to realize fully sonar equipment capabilities.

UTILIZING THE ENVIRONMENT

The possibility exists of modifying the oceanic environment so that it becomes more suitable for acoustic detection. In harbors or limited areas this may be appropriate. However, in the more strategic open sea, techniques of making these changes are still obscure. The more likely solution is to use equipment where it will utilize the environment to best advantage.

Variable Depth Sonar: One example of using the environment to best advantage is by the variable depth principle. By lowering a transducer below a marked thermocline (or velocity gradient) the range and probability of detection are greatly increased.(56) When the sound source and the target are below the thermocline, the refraction between the transducer and target is reduced. In fact, certain areas may be intensified by sound focusing above that of the normal spherical spreading of rays. Under these conditions, the thermocline may be a help rather than a hindrance in acoustic detection by VDS (Figure 11).

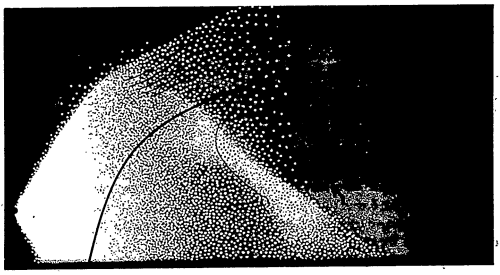

Figure 11. Avoiding the "bad thermocline" effects by use of VDS detection equipment.

The VDS not only combats the adverse velocity profiles but effects a decrease in grazing angle. When the sound rays strike the bottom at lower grazing angles the scattering coefficients are reduced.(57) The greater receiver depth aids detection because of the lower background noise level due to greater separation from the surface and ship noises. Even variability of temperature, salinity, and resulting refraction is reduced below the thermocline. Also, the effects of near-surface phenomena such as air content of water and micro-organisms are minimized. It is evident that the VDS effectively utilizes the environment to better advantage that the similar conventional hull-mounted gear.

Topography: For longer ranges topographic features can be utilized. Greatest ranges are attained when the sound makes the fewest reflections from the surface and bottom. This requires the least spreading of the rays and the deepest water. A desirable topography for long-range detection is a relatively steep continental slope and a flat reflecting floor. Each desired detection site must be surveyed for velocity structure and detailed topography. Off the San Diego area a suitable detection site would be near the bottom on the edge of the continental slope. Under the usual downward refraction in this region a direct-ray insonified zone could be produced which would bend down the slope, reflect from the bottom once, and retain sufficient energy to return a signal from a target located at or near the surface another 9 miles further out. Thus, the selection of proper environmental sites for detection equipments can materially increase detection ranges.

Sound Channels: For still longer ranges in deep water the channeling of sound energy by the refractive structure of the water can be utilized. Here the physical properties of the water column that control the sound velocity become increasingly important. The vertical band of sound rays leaving a shallow sound source are refracted downward by the permanent thermocline. Near the bottom the sound rays are refracted upward by the higher pressure and to some extent by the increased salinity at great depths. The band of sound rays reappears in annular zones near the surface at a distance of about 27-33 miles in the Pacific (Figure 12).

Sound transmission studies have shown that such cycles are repeated out to several hundred miles.(58) With suitable high-power,

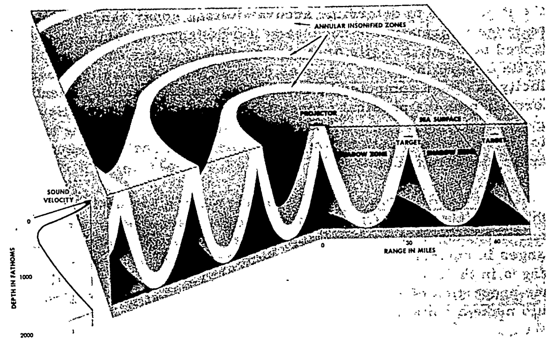

Figure 12. Utilization of sound velocity structure for sound channeling and longer detection ranges.

low-frequency active sonar such as Lorad, detection of targets in bands at ranges of about 30, 60, and 90 miles has been achieved.(59) Topographic highs, if they protrude into the insonified zones, will obstruct the sound path and restrict the detection range.(60) This method of utilizing the environment has resulted in reception of echoes from submarines at ranges over ten times as great as with conventional sonars. When both the sound source and receiver are at a depth near the axis of minimum velocity in the deep sound channel, one-way "Sofar" transmission ranges of thousands of miles have been achieved.(61, 62) Near-surface channeling of sound rays is also possible when the proper velocity structure is present and the surface is relatively smooth.(63)

Deep Water: Still another technique is to operate detection equipment at great depths where the background levels are very low and therefore detection potentials are greater. The bathyscaph or similar deep submersible could be adapted for this purpose.

Sound Velocity: A precise knowledge of sound velocity would make it possible to determine accurately long sonar ranges. Accurate range information is necessary if a distant submarine is to be attacked by an air missile or if the location of water entry of a missile at very long range is to be determined. Generally, sound velocity has been computed by theoretical methods using ancient information on the physical properties of water.(64, 65, 66) However, some recent measurements have been made to determine the average velocity over a long path and compare this with precise oceanographic measurements.(67)

Other Possible Means: This discussion has dealt largely with sonar detection. Other methods of detection may use the electrical, magnetic, or pressure fields set up in the water. Changes in environment detectable by infrared means or ionic changes in the ocean may be possible.(68) There must be still other properties of the sea which are not yet investigated which would make a suitable indicator of detection.

SUMMARY

In summary, there are many components in the oceanic environment that affect detection. As yet, from an acoustical standpoint only refraction and some scattering properties of the medium are known to any degree. In many instances, the causes of fluctuation in acoustic detection cannot be adequately explained on the basis of present knowledge. This points up the need for extensive fundamental studies of processes in the ocean.

Some possible environmental factors affecting acoustic fluctuation and detection are speculated to be (1) refraction in internal waves, (2) the presence of minute bubbles in the sea, (3) the near-surface boundary effects associated with sea surface slicks and (4) plankton.

Further investigations of these subjects should take into account the detailed spacial distribution of water properties, the relationship of the many oceanographic variables to each other, and short-period time fluctuations. The knowledge thus gained should allow acoustic conditions to be predicted and the oceanic environment used to fullest advantage.

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MICROSTRUCTURE OF THE OCEAN AS IT RELATES TO THE TRANSMISSION OF UNDERWATER SOUND

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INTRODUCTION

The purpose of this paper is to discuss some of the limitations imposed on the applications of underwater acoustics by the presence of small inhomogeneities in the volume of the sea. Although the inhomogeneities are extremely small and result in sound velocity changes of the order of 1/100 of 1%, the continuing action of these "scatterers" over long ranges results in large anomalies in sound propagation. In sound transmission, the effect of these inhomogeneities can yield a large fluctuation in signal intensity, as well as a "wandering" of the direction of sound energy propagation. Similar inhomogeneities in the earth's atmosphere have shown the feasibility of long-range, high-frequency radio transmissions which extend well beyond the normal limits imposed by the earth's curvature.

A great deal of effort, of course, has been expended in radio and radar studies of the effect of atmospheric and tropospheric "scatterers". So, too, in the acoustic field, problems of this general character have received increasing attention since World War II. In spite of this activity, from the designer's point of view, the information currently available on both the occurrence of such inhomogeneities in the oceans and the detailed effect on acoustical transmission is only now beginning to be understood. Hence, there has been little attempt to take such factors into account in the design of underwater weapons systems.

In the period immediately following World War II, considerable attention was paid to the problem of fluctuating sound levels. In ocean measurements there are, of course, many easily found reasons for the production of fluctuating levels - interference from the surface boundary, ship motion producing a misorientation of transducer patterns, etc. - which explain the bulk of these early observations. However, when careful experiments are performed which eliminate, insofar as possible, all of these obvious causes, there still remains a fluctuation in intensity which finally must be attributed to the medium itself. At about the same time, it was noticed that small temperature deviations were present in the ocean. There was a great deal of hope that these temperature deviations might, in the final analysis, be responsible for the residual hard core of intensity fluctuation, which had to this point found no other explanation.

For example, an early paper of P. G. Bergmann (1) in 1946 develops the theory of scattering of sound energy in a random inhomogeneous medium in the ray limit. Experimental work was carried out by Sheehy (2) in which he made direct measurements of the intensity fluctuation in direct transmission between two deep transducers. In addition, Liebermann (3) made a series of measurements in 1951 of the temperature deviations of the sea, using a submarine cruising horizontally at constant depth as a platform. In 1953 and 1954, Mintzer (4,5,6) published a series of papers concerning sound scattering in a statistical medium much as Bergmann envisioned, except that Mintzer's work was done in the wave limit of acoustic propagation. In a later paper by Potter and Murphy (7), the solution of the scattering problem for a particular statistical distribution, valid in both the ray and wave limits, was obtained. This work was entirely concerned with sound scattering in a medium which could be described on the basis of a fairly simple statistical model. More recent work reported by Skudrzyk (8) of ORL has extended the statistical model to the case of a medium exhibiting Kolmogorov turbulence. The statistical model is an attractive one from both the theoretical and experimental points of view, since it reduces a tremendously complicated structure to a few simple parameters which now describe only the average properties of the medium. However, like all statistical averaging processes, simplicity is purchased at the expense of eliminating knowledge of what occurs over short times. Thus, for an acoustic experiment lasting for a short enough time, the statistical model gives little information. In the language of statistical mechanics, the question is, "What time is required to assure the application of an ergotic hypothesis?"

Although, in some instances, the direct acoustic experiments have tended to support the theoretical conclusions on the basis of the various statistical models, there have been some notable failures, which lead one to the inevitable conclusion that, because of the various diverse mechanisms responsible for temperature changes and acoustic fluctuations, there are, in fact, several quite different models which must be employed.

DESCRIPTION OF MICROSTRUCTURE

The term "thermal microstructure" must be defined. In the great bulk of thermal observations made in the sea, the fundamental instrument has been the bathythermograph, which records temperature to about 1/2° F as a function of water depth. Hence, for present purposes, we will define thermal microstructure as temperature structure occurring in the volume of the sea whose deviations from the immediately surrounding water are of the order of a few hundredths of a degree Centigrade.

The Statistical Model

The statistical model used in most of these studies follows very closely the one developed by Liebermann on the basis of a series of measurements of the temperature deviations made on cruises in the coastal waters of the Pacific Ocean from San Diego to Alaska. The resulting record of the temperature deviation from the average as a function of horizontal displacement was random in appearance, and gave support to a statistical model of the thermal microstructure of the medium. It turns out that the medium may be described sufficiently well for fluctuation calculations on the basis of two parameters, if one is willing to make certain assumptions. The first parameter is the spatial autocorrelation of the temperature deviations. This is a measure of the intuitive notion that the deviation from the mean temperature at two points in the water which are close together would be expected to be about the same, while temperature deviations at widely separated points would be expected to bear little relationship to each other. The distance, "a", over which such correlations exist was found to be about 60 cm in the horizontal direction for this data. The second parameter, the root-mean-square deviation of the temperature from the average, is a statistical measure of the magnitude of the deviations. The experimental value for this parameter was about 0.05° C which, when converted to the sound velocity change, was of the order of 10^{-4}.

The existence of a correlation distance has resulted in a tendency to think of the temperature deviations as if they were "patches" of warmer or colder water. These patches naturally have an ill-defined shape, and no true boundary exists between one "patch" and another on the basis of this viewpoint. A sophistication of this model is achieved by allowing the correlation distance in the horizontal and vertical directions to be different. It is, of course, necessary to establish the correlation function, but, except for back-scattering, its form is not critical.

The Layered Model

As a result of an extensive study of the thermal structure and acoustic properties of Dabob Bay and the waters of Puget Sound by the Applied Physics Laboratory, a very different model was found necessary for describing the thermal microstructure of this area. In substance, the findings were as follows:

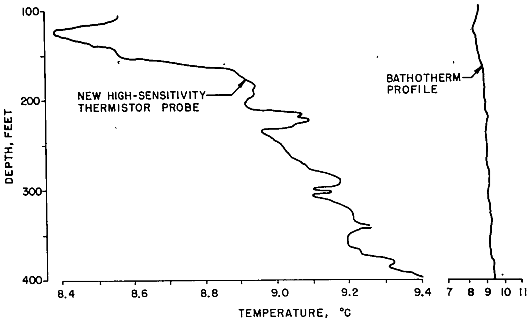

Figure 1. A Comparison Between the High-Sensitivity Probe and a Bathythermograph.

First, it was necessary to gain some idea of the detailed temperature structure not shown on bathythermograph readings. Figure 1 shows a comparison between two different instruments for recording temperature as a function of depth. The curve shown on the left was obtained utilizing a temperature probe with resolution better than 0.01° C. The extreme temperature range covered by this profile is 1° C; the bumps and wiggles, which are readily resolved, are of the order of a few hundredths of a degree C. The corresponding bathythermograph profile drawn to its usual scale is shown on the right.

Thus, an absolute temperature measurement as a function of depth, akin to a bathythermograph record but sensitive now to 0.01° C, revealed the existence of horizontal thermal layers. Within each layer, the temperature deviated, in general, from that of the water immediately above and below by about 0.1° C or less. The vertical thickness of these layers varies from a few feet to tens of feet. The most remarkable characteristics of this layered structure are the horizontal extent of the layers and their time stability. Extensive measurements in Dabob Bay show that such layers extend for hundreds of yards in the horizontal direction with the vertical temperature distribution substantially unchanged. We also find that such structure is, in general, very stable with time, remaining for many days once it is formed. Thus, we are led to an oceanographic model for this region which treats the thermal microstructure as strictly horizontal layers extending throughout the transmission region.

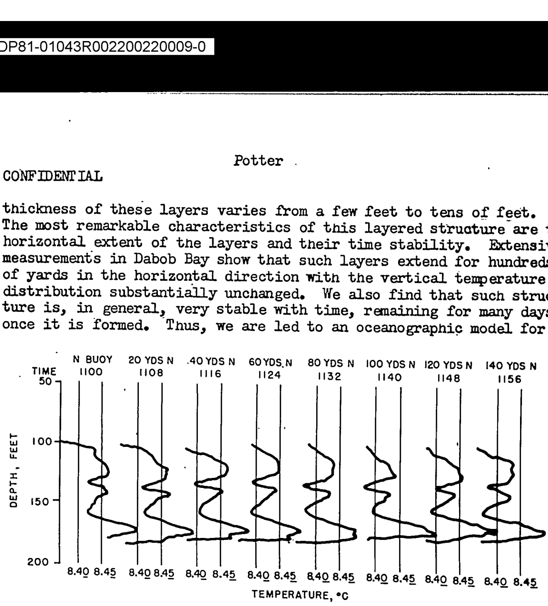

Figure 2. Variation in Temperature Profile Over a Distance of 140 Yards.

The evidence supporting the layered model as being representative of the actual conditions existing in Puget Sound and in some areas of the North Pacific Ocean appears to be convincing. The spatial extent of promontories on the temperature vs. depth plot can readily be seen in figure 2. The eight measurements shown in this figure were spaced 20 yards apart, covering a total distance of 140 yards. The impressive thing here is the fact that the promontories are clearly defined and are recognizable across this entire distance. As can be seen, there is a tendency for the shape of the temperature profile to change with distance.

Since the eight measurements involved were made consecutively, the time variations must also be considered. Figure 3 is the result of a series of measurements carried out at one location. This location was fixed by mooring to a buoy in Dabob Bay. The temperature drops, which were made every five minutes, give an excellent history of the changing profile with time. There is some gross water motion in Dabob Bay because of the tidally excited seiches, which account for the gradual change in depth of some of the promontories. It is naturally very difficult to obtain such measurements in the open ocean, where mooring buoys are not available. However, some temperature-depth curves taken off the coast of Alaska, unfortunately at widely separated stations, bear a remarkable resemblance to those found where layering is known to exist. Five of these are shown in figure 4.

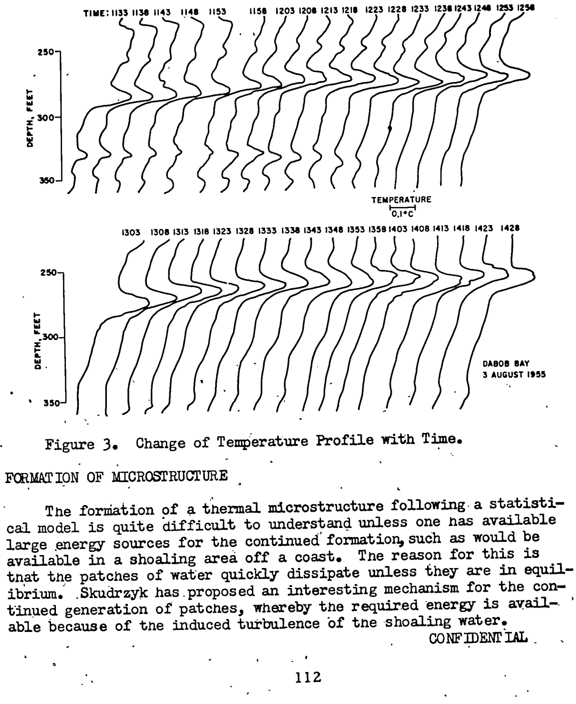

Figure 3. Change of Temperature Profile with Time.

FORMATION OF MICROSTRUCTURE

The formation of a thermal microstructure following a statistical model is quite difficult to understand unless one has available large energy sources for the continued formation, such as would be available in a shoaling area off a coast. The reason for this is that the patches of water quickly dissipate unless they are in equilibrium. Skudrzyk has proposed an interesting mechanism for the continued generation of patches, whereby the required energy is available because of the induced turbulence of the shoaling water.

The formation of layers of water has been studied quite extensively and is somewhat better understood. The major requirement for the production of such anomalies is the following: Imagine two large bodies of water which join at a common interface. Imagine that one body of water has a temperature and salinity distribution which gives rise to a monotonically increasing density with increasing depth (necessary for equilibrium). Now, if the second body of water is essentially isosaline and isothermal, and if its density is equal to that of the first body of water at some depth, then there will be an exchange of water between the two bodies of water.

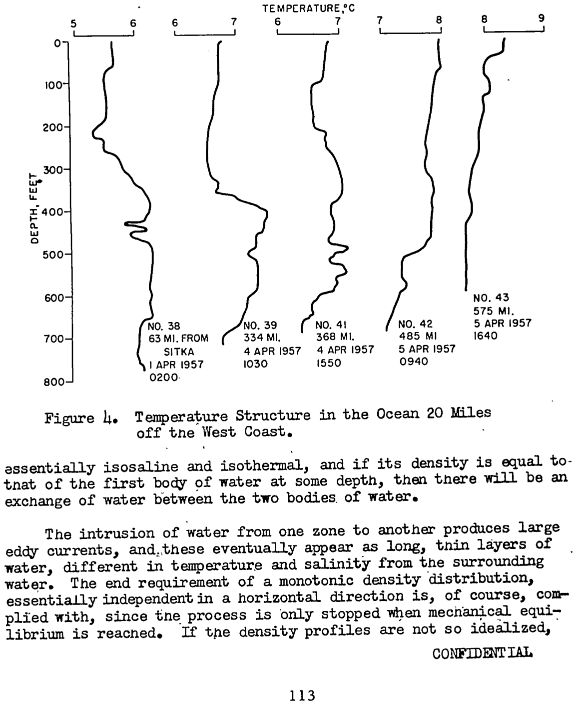

Figure 4. Temperature Structure in the Ocean 20 Miles off the West Coast.

The intrusion of water from one zone to another produces large eddy currents, and these eventually appear as long, thin layers of water, different in temperature and salinity from the surrounding water. The end requirement of a monotonic density distribution, essentially independent in a horizontal direction is, of course, complied with, since the process is only stopped when mechanical equilibrium is reached. If the density profiles are not so idealized,

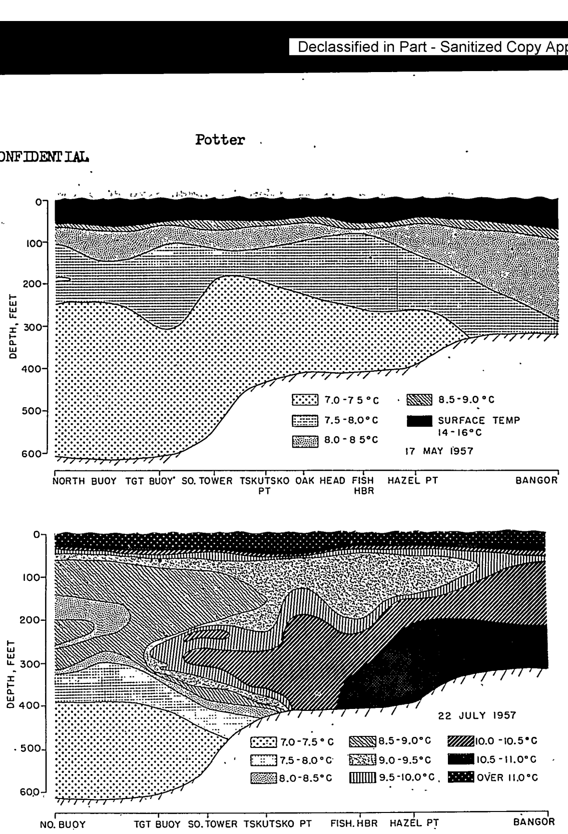

Figure 5. Isothermal Diagrams Showing Initial Stages of Flushing.

then there will be many layers formed. The dynamic process is quite rapid when compared with the thermal process; hence, the assumption of such an interface leads to a stable, layered water structure.

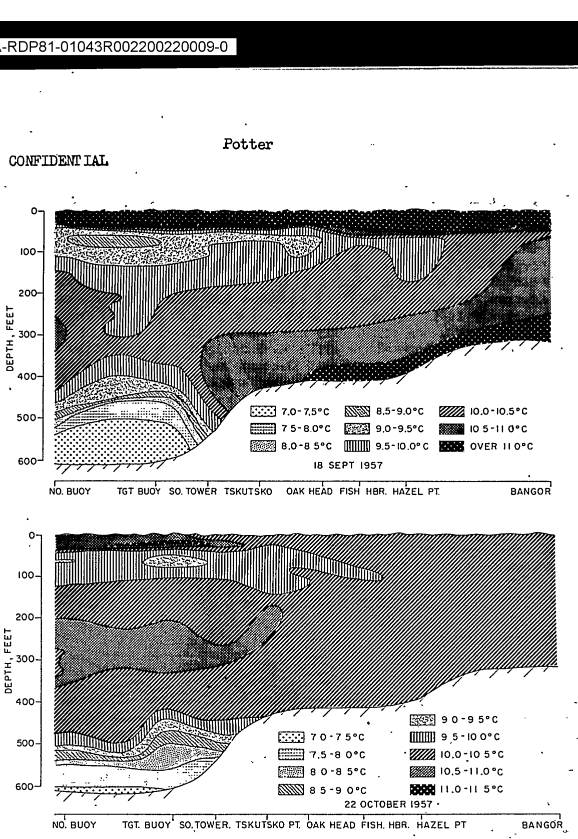

Figure 6. Isothermal Diagrams Showing Final Stages of Flushing.

The formation of layers in Dabob Bay is well illustrated by the isothermal diagrams for Dabob Bay and Hood Canal shown in figures 5 and 6. The first diagram of figure 5 is a late spring condition which, in general, gives a monotonically decreasing temperature profile. The surface water warms considerably in midsummer. In Hood Canal, there is sufficient turbulence caused by the large tidal action so that the water becomes well mixed and hence warmed throughout. Across the interface between Hood Canal and Dabob Bay there are now large horizontal density gradients. The Hood Canal water intrudes into Dabob Bay as shown in figure 6, and, even on the coarse scale of these figures, produces a well defined layering effect. When examined in detail, it is found that these layers are from a few feet to tens of feet thick, and ordinarily are several hundred yards in horizontal extent, the temperature difference being a few hundredths of a degree Centrigrade. In the first few months, the thin layers seem to fade away, leaving a residue of rather thick layers. At the end of six months, the layering is considerably reduced, and at this time the process is repeated, except that in the winter the intruding layers are colder than the existing water.

One of the outstanding features of this layered structure is the remarkable time stability of the structure. Once formed, such layers are in static equilibrium and, in the absence of sources of large mechanical energy - e.g., currents produced by waves - they remain in position. The mechanism remaining for dissipation is thermal conductivity. For layers or patches of any size (a yard or more in extent) the process of ordinary heat conduction is very slow. Calculations show that a year or more may be required before the temperature difference becomes immeasurable.

One might speculate that a mechanism equivalent to that in Dabob Bay is present in the open ocean. This could be the intrusion of water at the interface of an ocean current with the remaining water. This local production of anomalies may not be well defined, since the ocean currents are known to "meander" quite a bit, thus producing anomalies over a wide expanse. This, coupled with the long inherent life of the large layers, could cause a generally widespread occurrence of such anomalies. Some ocean measurements have been made by this Laboratory, as well as other groups, and strong evidence of layering has been found off the Alaskan coast, off Oregon, and in the San Diego area. Unfortunately, there is almost no information available in any other area and, except for Puget Sound, the present data is too meager to permit any analysis.

EFFECT ON SOUND TRANSMISSION

Of all of the effects which the thermal microstructure of the medium has on acoustic transmission, the most extensively studied has been that of intensity fluctuation. Figure 7 shows the experimental arrangement employed by APL in studying this phenomenon. In these measurements, an acoustic transmitter with a uniform azimuthal pattern

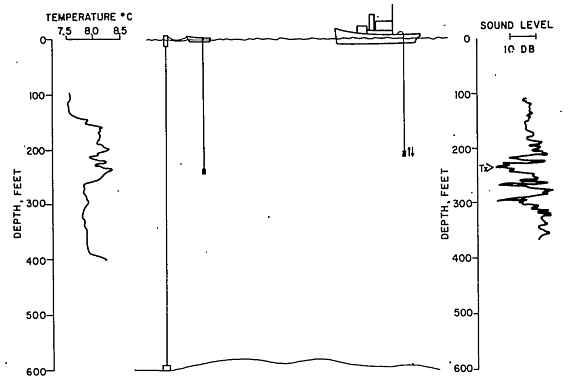

Figure 7. Experimental Arrangement for Sound Transmission Measurements.

is lowered to a convenient water depth. A receiving hydrophone, also with a uniform pattern in the horizontal plane, is used to probe the sound intensity of the directly received pulse as a function of depth. A fairly typical intensity-depth profile is shown on the right of this figure. As can be seen, intensity fluctuations can be in excess of 10 db. Figure 8 shows a fairly typical set of intensity-depth profiles taken at varying ranges from approximately 80 to 500 yards. These measurements were made in Dabob Bay in the presence of a layer approximately 20 feet thick having a temperature change of 0.1° C. One finds that the primary intensity fluctuations are concentrated at approximately the depth of the layer. The depth of the transmitter is indicated on the figure by T_x. If the medium exhibits essentially statistical properties, it is only possible to determine statistical properties of the intensity fluctuations. However, in the layered model it is tempting to try to calculate this intensity variation. Such a calculation is readily made in the ray limit.

Figures 9 and 10 are two examples of such a calculation, obtained utilizing a ray perturbation calculation applied to the actual

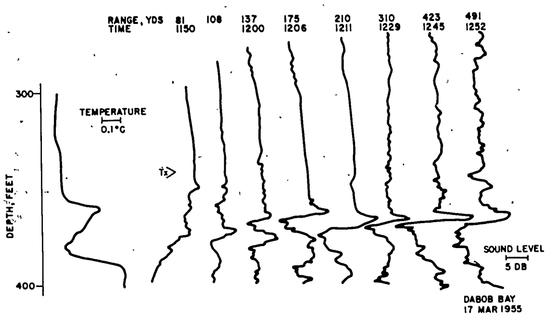

Figure 8. Effect of Temperature Layer on Sound Transmission at Several Ranges.

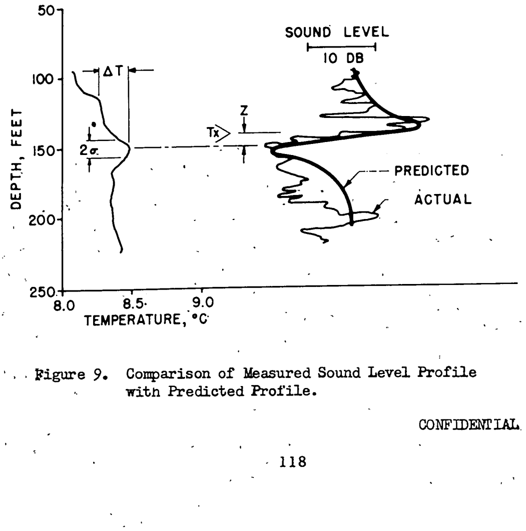

Figure 9. Comparison of Measured Sound Level Profile with Predicted Profile.

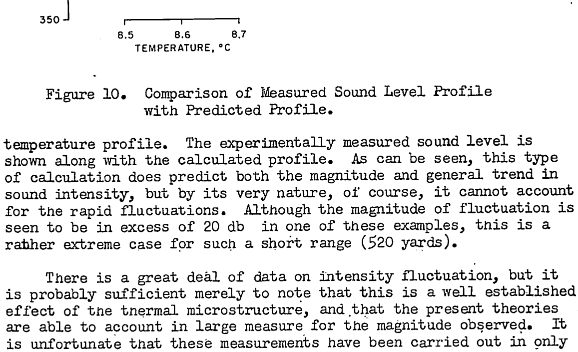

Figure 10. Comparison of Measured Sound Level Profile with Predicted Profile.

temperature profile. The experimentally measured sound level is shown along with the calculated profile. As can be seen, this type of calculation does predict both the magnitude and general trend in sound intensity, but by its very nature, of course, it cannot account for the rapid fluctuations. Although the magnitude of fluctuation is seen to be in excess of 20 db in one of these examples, this is a rather extreme case for such a short range (520 yards).

There is a great deal of data on intensity fluctuation, but it is probably sufficient merely to note that this is a well established effect of the thermal microstructure, and that the present theories are able to account in large measure for the magnitude observed. It is unfortunate that these measurements have been carried out in only a few selected areas and that little in a quantitative way is known about this effect in the open ocean.

In the design for current and future weapon systems, the problem of bearing wander of sonar information is at least equal in importance to that of intensity fluctuation. In this area, however, very little has been done. Several calculations have been made concerning the magnitude of the bearing wander due to a thermal microstructure

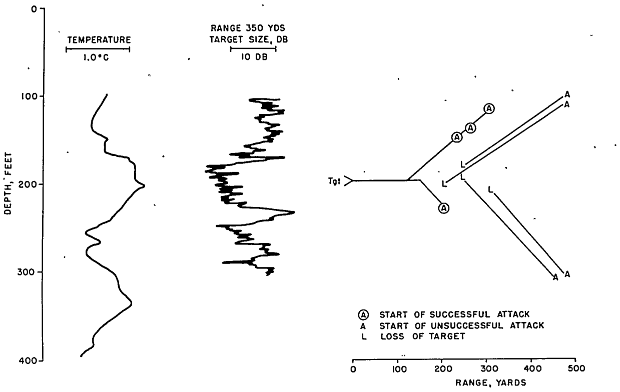

Figure 11. Effect of Temperature Layer on Performance of Mark 43 Torpedo.

under the assumption of a statistical model, although very little has appeared in the published literature. Because of the long ranges at which such an effect becomes important, it is no longer profitable to consider the idealized layered model given earlier. This comes about because the layers are probably between 100 and 1000 yards in extent, well less than interesting sonar ranges today. This model can be handled as a rather bizarre case of a statistical model in which the vertical and horizontal correlation differences differ by a factor of approximately 100. The only direct experimental measurement of this important effect was made recently at the Naval Underwater Sound Laboratory. The preliminary results neither agree nor disagree with previous theoretical calculations. This unfortunate situation arises rather naturally because of the almost complete lack of information concerning the properties of the ocean in the test area. Based on the best available information, the bearing wander can be expected to be of the order of 1/2° at 10,000 yards, rising to perhaps 1° at 40,000 yards, at least in those select areas of the ocean where information is available.

EFFECT ON WEAPON PERFORMANCE

The single case in which weapon performance was degraded by the thermal microstructure of the medium was observed with Mark 43 torpedoes in Dabob Bay. In this case, the torpedoes failed to home on a simulated acoustic target because of the loss of echo signal. This loss of target, termed an aborted attack, occurs primarily at the time of year when a strong layering situation exists in the bay. The Mark 43 torpedo has a vertically stabilized transducer, and for this reason can tell only if it is above or below the target. Because its normal homing trajectory is such as to bring it to target depth as rapidly as possible, it usually arrives at target depths at ranges in excess of 200 yards. As indicated earlier, the intensity fluctuation caused by a layered structure will be at a maximum when both transmitter and receiver are in the immediate area of the layer. The acoustic "holes" arising from the layers were found to be directly responsible for the aborted attacks. In order to demonstrate this point, the following experiment was run: A temperature measurement was made in the operating area, and from this a target depth was chosen which was predicted to give aborted attacks. Figure 11 shows the result of this experiment. The temperature profile is shown on the left. The center curve is the profile of the equivalent acoustic target size. The predicted acoustic "hole" at a depth of 200 feet is seen to have a magnitude of almost 10 db at a range of 350 yards. The trajectories of four torpedoes are shown at the right. As can be seen, in every case the torpedo lost the target on its first pass. This problem became so acute that it was necessary to provide the torpedo station with acoustic services during this critical period so that proofing could be continued. Although this is the only substantiated case of weapon degradation arising from the thermal microstructure, there have undoubtedly been many other unrecognized problems.

The implications to future weapon systems of the acoustic problems discussed in this paper are fairly obvious but, because of the lack of detailed information, the proper remedial action is not so obvious. The fluctuation in intensity results, of course, in lost information. The amount of information which is lost, and the manner of loss, depends upon the magnitude of the fluctuation and also on the mechanism. If one considers only the statistical model, the fluctuation from ping to ping of an active sonar system is random (assuming some motion of the submarine) and, as a result, one can readily calculate the statistical quantities which have bearing on the problem. These will include the net information rate, the probability of losing two or more consecutive pieces of information, and so on.

With the assumption of a random process, the method of analysis for optimum weapon performance is available and can be utilized. On the other hand, if, as seems more likely, the open ocean tends more nearly to the layered model, then the problem is greatly complicated. In this case, the high spatial correlation of the fluctuations (in the horizontal direction) means that the loss of one ping makes the probability of the loss of several additional pings high. It is as if there were "dead zones" in the water. The requirements on the remainder of the system are then made much more difficult, since information may be lost for relatively long periods. If it turns out that the layer-type problem is of major concern, then a quite sophisticated system will be required to give a reasonable operability. Similarly, the effect on fire control sonar will be more serious for the layered model. The possibility of losing contact with the target for fractions of a minute may rule out certain weapon systems, or may call for an even more sophisticated missile. Weapons are now failing to perform because of information loss, and with the necessity for increased homing ranges, a major change in homing philosophy will be required before satisfactory performance is obtained. Such a change would be in the direction of providing a better "memory"; then, when homing information is lost, the torpedo can continue along a most probable course instead of breaking off the attack and returning to a search phase. Naturally, additional functions which must be performed by the missile make the system more liable to equipment malfunction. As viewed from the overall system viewpoint, it may be desirable not to ask more of the missile, but to require more from the launching vessel, where human judgment is available.

The problem of fire control errors can receive no more than a superficial treatment at this point, since the fundamental data concerning bearing errors is not available. In principle, however, there are several basic weapon systems, differing in communication requirements between launcher and missile, which can avoid some of the problems connected with fire control error.

The weapon system making the most severe requirement on the fire control data is the classical predicted intercept weapon. In such a system, the target motion is presumed to be known and a predicted intercept point is calculated, taking into account the travel time of the weapon. The World War II torpedo firing system is, of course, an excellent example of this. At relatively short ranges, this weapon system is very effective, but as the range increases, the probability of success is greatly diminished. The principal reasons for the decrease in performance are:

(1) increased error in the target motion, which leads to

(2) increased error of predicted intercept position, which, in turn, leads to
(3) larger error in weapon delivery, and
(4) increased flight time, which makes evasive maneuvers very effective.

The most obvious way of regaining a high hit probability is to increase the radius of lethality of the warhead, either by adding homing or a special warhead. This change is effective for non-evading targets at ranges up to about 10,000 yards, but beyond that point it loses effectiveness because of the fire control errors of present sonar systems. The next step may be made in either of two directions: decrease the flight time of the missile or communicate with it to give in-flight corrections. The decrease in flight time is extremely effective at shorter ranges, but beyond 10,000 yards it appears that it will still be necessary to predict the target course. It is not possible to estimate the effective range with the added feature of predicted intercept; however, with present sonar accuracies, and with an evading, high-speed target, the upper limit of useful range may be considerably less than 20,000 yards. In addition to all of the data concerning the missile characteristics, it will be necessary to know the minimum errors in the fire control sonar system before evaluating the potential of this weapon system.

Another alternative, in-flight correction to the missile, is beset with similar difficulties, and to these must be added the additional complication of a prolonged loss of information at a critical time. Information loss, although disturbing in the other systems, is not critical, since the firing time can be delayed until adequate information is available; however, if in-flight correction is necessary, then adequate information during the flight is most important.

Additional weapon functions may readily be imagined, each designed to overcome some failing, but each, because of the increased complexity, tends to lower the reliability. The above situations serve to illustrate the choices which must be made. The choice of decreased flight time versus in-flight corrections will depend to a great extent upon the probability of obtaining adequate fire control information: For the short-travel-time missile, the requirement is high accuracy, with information loss being allowable; for the correctable missile, the major requirement is continuous information, with less accuracy allowable.

CONCLUSIONS

In considering the effect of thermal inhomogeneities on both acoustic weapons and fire control sonar, it has been impossible to state with real assurance what the limitations are, except to say that the limitations most certainly exist. The almost complete lack of experimental data on the aspects of the temperature structure of the ocean that are important in this problem, plus the absence of a theory of bearing error, means that no authoritative statement of the real effect on our weapons and weapon systems can be given. In the long-range underwater missile program, it now appears that the virtually unexplored field of sonar bearing error will assume great importance because of the impact of this one parameter on weapon system performance.

As can be seen, the present state of knowledge is quite inadequate to answer the pressing questions of the system designers. Enough exploratory work has been done, however, to show the nature of the problem, and to offer guidance for a thoroughgoing research effort.

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THE PAST, PRESENT AND FUTURE OF UNDERWATER CLASSIFICATION

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Where have we been, where are we now, and where are we going in the field of sonar classification? The following covers the highlights on these questions and show the several paths which may be taken that offer the most promise in solving the problem at hand.

First a little background. Statistics obtained from World War II data and more recent frustrations during ASDEVEX exercises emphasized the existence of a real problem. From one viewpoint the inability to determine, with a high degree of accuracy, whether or not an underwater object is submarine or non-submarine causes problems in logistics and tactical diversion. A classification system of low accuracy leaves sufficient doubt as to the immediate threat of a possible submarine that the general doctrine was to shoot anyway. This combined with the general ineffectiveness of ASW weapons resulted in a high weapon expenditure on many contacts of which few were real submarines and resulted in an early logistic shortage of weapons.

Today, however, with the increased threat of the submarine considered in more gross terms such as the exchange of coastal cities and industrial complexes for the lack of a successful detection and kill, one may consider again the shoot first philosophy. Such circumstances require that the accuracy of classification need not be high. In summary we see that the degree of solution of the classification problem required is closely interwoven with considerations of weapons and economics.

However, since it has been shown that consistent high accuracy of classification has not been possible in the past, a classical scientific problem did (and still does) exist, and is therefore a challenge deserving of an intensive research effort.

The term "consistent high accuracy" is quoted since there have been and still are situations where evidence indicates it is achieved. These are the cases of the selected few experienced sonarmen who seem to have a mysterious sixth sense which enables them to sort out the subtle characteristics of a submarine by aural methods. Thus one concludes that a general solution is to find out how the classification mechanism of the human mind works. It also appears that the sonar signal may contain sufficient information which, if properly analyzed and presented, could in itself result in satisfactory classification.

Under the leadership of the Bureau of Ships, the classification problem was tackled on a broad front. In addition to the Bureau laboratories, the U. S. Naval Research Laboratory and numerous University groups under contract were coordinated through a classification committee. The approach taken was classical - to first obtain data on submarine and non-submarine contacts from which differences, no matter how subtle, could be measured and studied. Several extensive classification cruises were planned and organized by the U. S. Navy Underwater Sound Laboratory for the purpose of collecting data and evaluating the various classification devices of the laboratories. It was soon realized that the returns of a 30 day cruise were meager as far as sample size was concerned and that a much more extensive effort involving the operating forces as data collectors was required.

Although cooperation of the Fleet Commanders was given, the conditions of non-interference with operations made the task nigh impossible and the laboratories returned again to their own ships and tape recordings. Also at this time, the various laboratories changed their emphasis toward the then more urgent long range detection problem. Today we find only a moderate but balanced effort directed toward a problem which once again is coming to the front.

A logical approach to classification by sonar is to examine what information the acoustic information can reveal about an underwater contact. The tabulation below lists the acoustic parameter and the information it contains.

Acoustic Parameter	Information
1. Amplitude	a. Size of object b. Structural highlights c. Double echo effect
2. Frequency	a. Motion of object by doppler b. Motion of medium in vicinity of object by doppler
3. Phase	a. Location of object in sound beam b. Shape and size of object c. Heading of object d. Reflection highlights e. Double echo effect

Thus we see that the sonar echo can reveal the size, shape, motion and unusual echo effects of underwater objects. A broad survey by NRL, of researchers in various fields, verified this conclusion and resulted in the recommendation that an extensive effort be devoted to techniques and devices for analyzing the sonar echo. This was done and each government laboratory or contractor contributed one or more devices for this purpose. The NEL High Power Short Pulse sonar, the MIT - ACIM, and the NRL Echotrap and SSI are a few examples.

Figures 1 through 4 illustrates the information that some of these devices are capable of displaying. It is shown that the sonar echo can be used to show the shape, size and motion of underwater objects and present such positive cues as highlights, wake effect and near beam double echo. Unfortunately, however, the illustrations show only what happens with good echoes at relatively short range.

Consider now several classification techniques that do not rely on sonar. One clever method used by the Japanese during World War II was to dump overboard a load of gravel and listen to the rattle on the submarine hull. MAD (Magnetic Anomaly Detector) is being continually improved and UEP (Underwater Electric Potential) research is progressing. Many ideas have been suggested and some have been put in practice. An example is the Navy Underwater Sound Laboratory's homing drone which seeks out the submarine and magnetically attaches itself to the hull. Another technique is the use of an MAD in a launched or dropped device, which, if placed close enough to the submarine, will send out a modulated tone received by the sonar. The problem of getting close may have a solution in a developmental attack system called LORELI now being developed by the Naval Research Laboratory.

Training may be used to improve classification potential. This has been demonstrated by the Navy Electronics Laboratory and its contractor Human Factors Research. Using a selected group of submarine and non-submarine recordings, training methods have resulted in producing a high efficiency in classification. The various classification aids and black boxes should be thoroughly evaluated and their relation to training considered. An example is the Echotrap, figure 5, which proved to be of little value to the operator for the conditions under which tested. The short range of the echoes precluded the trapping of an "average echo" and the limitations of the recorder prevented accurate doppler measurement. However, the echotrap philosophy is being revived for long range sonars where the dead time between echoes is large. Also, new digital recorders under development would be compatible with the measurement of doppler at the low frequencies of the long range sonars.

The rather narrow objective of the black box for classification caused NRL to take a broad look at the problem. It was decided that perhaps an approach would be to take advantage of all available experience and devise a simple computer which would consider all factors involved. This was the Classification Guide Rule illustrated in figure 6. It is a probabalistic-additive computer having a weighted yes-no undetermined output. It was sent to various training commands for comment and suggestions as to the weighing factors to be used. In general, the comments were quite varied but suggested application as a training aid and check-off list rather than something to be used during the classification process.

The idea of the computer persisted and NRL, with the cooperation of NEL, worked out the arrangements for a logical computer using a subtractive process and based on NWIP 24-1 the Fleet Classification Manual. The reasoning behind the computer is shown in figures 7 and 8. Thus the training (storage) and decision making (logical computation) have been transferred from man to machine. The computer is illustrated in figure 9.

100 of the computers were sent to Atlantic and Pacific fleet destroyers and destroyer escorts for evaluation and others were sent to Operational Development Force and several laboratories for comment. The results were varied but several general conclusions can be made. The fleet saw little value in it for solving the classification problem but did consider it as a valuable training aid. An evaluation by a contract laboratory implied the computer idea valid but suggested that the probabalistic - additive mode of operation should be used.

The classification potential of existing sonars such as the SQS-4 may be improved by the so-called integrated detection - classification station. The use of pre-formed beams and integrating multiple styli recorders with echo analyzing displays such as the gated A-scan and tactical range recorder are under current development by NEL and NRL, figure 10.

In summary it has been shown that there are devices that can classify at short ranges under good sound conditions. We also know that training can improve proficiency in classification and that the fundamental concept of the computer is sound. It therefore seems that the future course to take is:

1. Implement an extensive data collection program involving the operating forces.

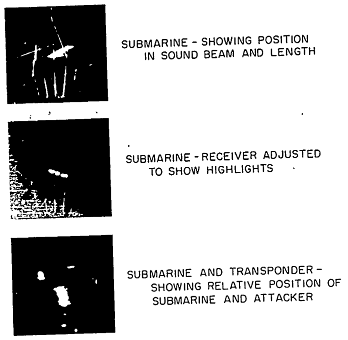
2. Develop training devices so that operators can get more "on target" time with the sonar.

3. Install in quantity, in fleet ships, those devices that show classification potential (SSI, gated range recorder).

4. Develop a new classification computer based on the experience gained and send out to the fleet for evaluation.

5. Review the existing classification manuals to include up-to-date and correct information.

6. And finally consider the integration of classification devices with new and developmental systems that are capable of localizing the target within effective range of these devices.



SUBMARINE - SHOWING POSITION IN SOUND BEAM AND LENGTH

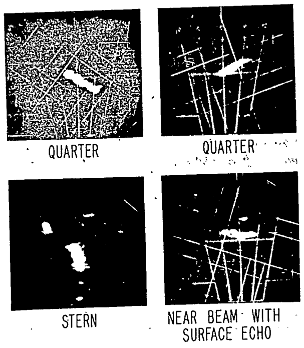
SUBMARINE - RECEIVER ADJUSTED TO SHOW HIGHLIGHTS

SUBMARINE AND TRANSPONDER - SHOWING RELATIVE POSITION OF SUBMARINE AND ATTACKER

SHORT RANGE SECTOR SCAN

RECEIVERS DISPLAYS

Figure 1



QUARTER

QUARTER

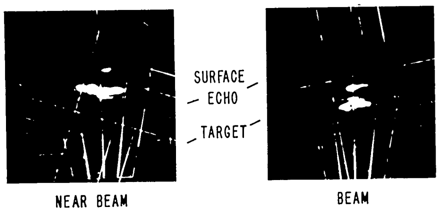
STERN

NEAR BEAM WITH SURFACE ECHO

SSI ASPECT

PRESENTATIONS

Figure 2



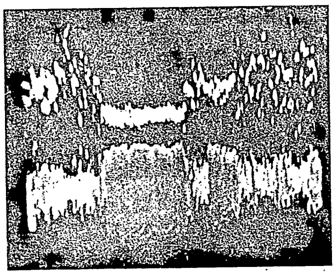
NEAR BEAM

BEAM

SSI SURFACE ECHO PRESENTATIONS

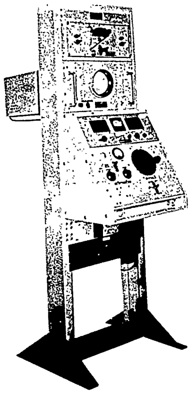
PULSE LENGTH: 3-5 MILLISECONDS
RANGE: 500 YARDS

Figure 3



ECHOTRAP PRESENTATION

Figure 4



NRL ECHOTRAP

Figure 5

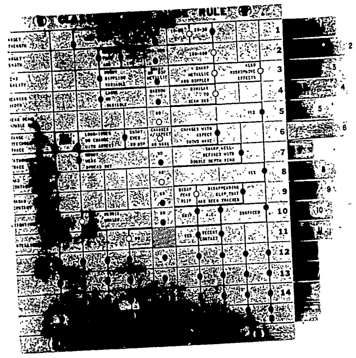


Figure 6

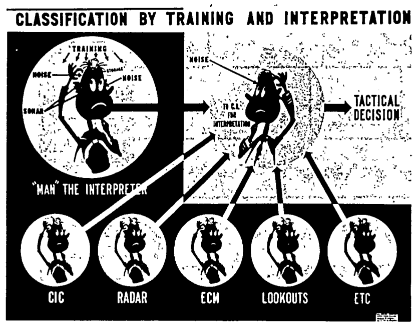


Figure 7

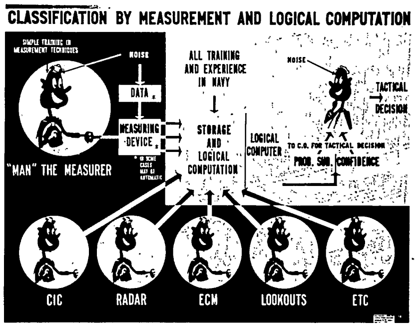
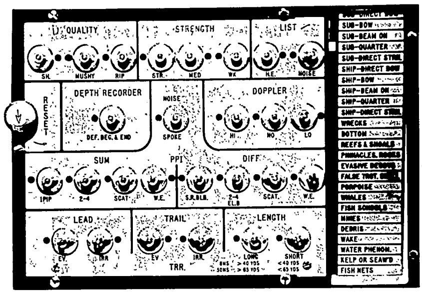
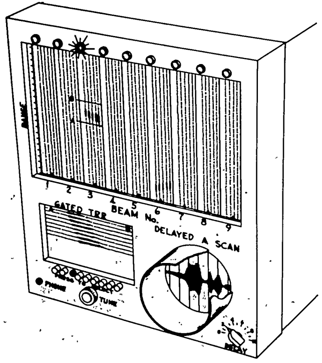


Figure 8



Sonar Classification Logical Computer

Figure 9



INTEGRATED
DETECTION-
CLASSIFICATION
STATION

Figure 10

THE CLASSIFICATION OF UNDERWATER TARGETS BY ACOUSTIC METHODS

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The importance of underwater classification is inescapable. It has been recognized by the Chief of Naval Operations in the promulgation of almost every ASW operational requirement, that classification techniques must be built in or be inherent in any equipment used in the detection and destruction of enemy forces. This has never been brought forward more forcibly than during the second World War. During this time when contacts with enemy submarines were numerous, it has been variously estimated that somewhere between 50% and 90% of the so-called contacts with enemy submarines were false.[1] That this fact is important is obvious when one realizes that about 90% of the expense of tracking down enemy submarines and trying to destroy them was unnecessary. The question we have to solve then in undersea warfare is how we can achieve classification. In this discussion we consider only acoustic methods of classification.

Figure (1)[2] serves to represent the various underwater objects which contribute to the confusion. These various underwater objects will return echoes to an active sonar and these echoes all must be distinguished one from another. The sonar operator must make the proper decision so that proper action can be taken. I will reserve most of my discussion for the subject of active detection, that is, the sonar equipment which sends out a signal and gets an echo in return. This is not to say that classification by passive acoustic means is unimportant, but rather that the problems involved with passive classification are for the most part easier of solution than those which are involved with active detection. Classification by listening is easier because we have situations in which a target is making a noise of some kind and since this noise must have characteristics of the target, these characteristics can be subjected to resolution and analysis. The situation in passive sonar has been simply stated by CDR Smallwood[3] in a recent issue of the magazine Combat Readiness, in which he maintained that a sound issued by a submarine and picked up by a passive device can be classified because it sounds like a submarine. This may seem to be a naive statement until one realizes that it is precisely true. Sounding like a submarine can mean that a characteristic signature can be analyzed by Lofar methods or that turn count or screw noises can be recognized aurally.

It has long been realized that proper interpretation of underwater sound echoes would offer much in the way of classification and this has been the subject of extensive work done by the Human Factors Division here at NEL in the analysis of cues obtained by sonar operators using conventional sonar equipment and in the training of operators in the use of these cues. Other laboratories have had the opportunity to investigate this aspect of classification and have done a lot of very useful research in the field. As a result of these analyses a series of study guides for ASW titled "Advance Target Classification" have been published by NEL as well as various Contact Classification catalogues. Management and Marketing Research Corporation of Los Angeles under a contract with ONR and in cooperation with NEL has written a series of technical reports on the Analysis of Cues of Echoes used by sonar operators. The utilization of cues by sonar operators reached the stage of the development of a mechanical device called the logical computer, an NRL development attempting to utilize these cues (figure 2). If the cues that the operator senses in a particular echo are placed in this logical computer then the computer will tell him the liklihood of the target being a submarine or not.

Turning to more sophisticated methods of instrumental analysis of acoustic echoes, it is obvious that equipment allowing classification of a submarine or other underwater target must use high resolution techniques. High resolution techniques are possible only if we use an elevated frequency and/or short pulses. The short pulse technique has been quite thoroughly examined by NEL using the original high power short pulse equipment, with various modifications thereto[5] and by Woods Hole[6], using explosive echo ranging. It has been known for some time that a submarine does impart some characteristic to an echo, but the determination of these characteristics in a unique fashion,

so that these characteristics could not be confused with something else has always been very difficult. One of the first attempts at high resolution classification, occurred at Woods Hole, early in the war when it was recognized that echoes from an echo sounder showed a different character depending upon the type of bottom from which these echoes were received. Figure (3) shows echoes from various types of bottoms. These were obtained with the NEL high power short pulse equipment[7] but they are introduced here to show that it is possible with high resolution to characterize bottom types. If this is true then it is indicative that possibly a submarine can be so characterized.

The high power short pulse project at NEL was originated in the beginning to develop sonar equipment which by virtue of utilization of short pulse would allow higher power with relatively modest equipment. This was done, but in the course of the evaluation at sea to see how the various modifications to the electronics were behaving, chemical recorder traces similar to figure (4) were observed. These traces are typical submarine traces obtained with this equipment which utilized a chemical recorder with the paper speed slowed down over the usual speed so as to get the visual integration that is seen on the trace. One can also see that the width of the trace depends upon the aspect of the submarine presented to the sonar. This was reported before but here we see it brought out very clearly. We see that the broad trace has been broken up when the sub approaches bow aspect and again at stern aspect. This will be pointed out in detail on some scope traces which I will show later. Figure (5) shows this break up even more, three distinct echoes are shown just prior to direct bow aspect and again just prior to direct stern aspect. These echoes are shown in detail by the scope expansions in the next series of figures, 6 through 11. Figure (6) shows a beam echo from a submarine on the surface, at periscope depth and at 190 feet deep, showing that the width of the trace is very slightly different, depending upon the target depth. The supposition is of course that the area illuminated by the sonar is somewhat less when the submarine is on the surface. The 190 foot depth shows clearly the surface echo, that is, the sound which strikes the submarine glances upward to the surface, is reflected from the surface back down to the submarine and back to the sonar equipment. Figure (7) shows the character of the echo near bow aspect and you will remember that in the chemical recorder trace the echo was broken up into three parts. In the absence of any better analysis, we assume that the three echoes that one sees, a few degrees off direct bow, are due to the bow, the conning tower and the tail surfaces, and as the submarine approaches direct bow aspect then the conning tower shadows the reflection from the tail surfaces and we see only the two echoes. This same picture is shown as one approaches the stern, figure (8). Here again we see the three echoes due to the tail surfaces, the conning tower and the bow and then directly on the stern the conning tower shadows the reflection from the bow. Figure (9) shows the traces as we go around the submarine from bow to beam and shows the lengthening of the signal as we approach the quarter and then shortening to the beam echo at 09°. Continuing this echo structure to figure (10), we see the beam to stern echoes, the beam echo again at 09°, the lengthening structure as we go around to stern and the last picture at 178° shows again the three echoes observed near the stern. Using this technique we were fortunate to obtain on the same scope trace some whale echoes and submarine echoes to show the difference between the sharp echo from the whale and the elongated submarine echo. Figure (11). This becomes one of the more common cues that the sonar operator can use to detect whether an echo is from a submarine. That is, the submarine echo has a definite length and this length is characteristic of the submarine. This is shown graphically in figure (12). Echoes which are shorter than this, or longer can definitely be said to be due to targets other than a submarine.

The possibility of characterizing submarine echoes by high resolution techniques offered so much promise that several modification kits or classification consoles, were developed and constructed to be used with conventional sonars and for the purpose, were fairly successful. Typical of these were the NEL short pulse modification kit, and classification console, the NRL Echo Trap, Range Rate Indicator and Sector Scan Indocator, the MIT Axis Crossing Indicator and that classification equipment par excellence the British Shadowgraph.[8] With the exception of the earlier Shadowgraph, these various devices were evaluated by the Underwater Sound Laboratory in 1954 and 1955. It is fair to say that echo analysis by high resolution and classification of underwater targets thereby is perfectly within the state of the art, and if classification is needed, it could be attained with sonar equipments operating from 10 - 12 kc on upwards. These of course are limited range sonar equipments.

Other techniques have been tried which can more correctly be described as true classification techniques, that is techniques which do not depend upon the analysis of ordinary echoes. One of these is the observation that using continuous transmission techniques, it is possible to observe a modulation of the returning echo from various aspects of the submarine if the propellor is in motion. For those who are unaware of continuous transmission

techniques figure (13) shows that if a continuous tone is sent out with a gradually decending frequency an echo will be returned continuously from a target and the difference in frequency between the outgoing signal and the returning signal will give a difference frequency which is a measure of the range. Now if the target is in motion there will be a returning signal which when beat against the outgoing signal will give a difference frequency which is different in slope than if the target were static. Figure (14). If a propellor by virtue of its motion imposes a doppler on the returning signal, this can be visualized by a series of dots in figure (15) and the reception of this signal will be a sequence of chirps, whose repitition rate depends upon the propellor rotation. Figure (16) shows the target angle with respect to the screws over which the phenomonen has been observed. You will notice this is not continuous coverage but it is also fair to notice that if this type of measurement were utilized together with the detailed echo analysis mentioned previously with high resolution short pulse equipment, then complete target aspect angles can be covered with target characteristics which will allow classification. Figure 17, 18 and 19 are examples of propellor modulation using single frequency continuous transmission. Figure 17, represents the submarine USS BAYA, speed 3 knots showing the frequency analysis of the difference frequency. The periodic character of the frequency change corresponding with the propellor beat is clearly distinct. Figure (18) is the same analysis taken from the USS CARP, speed 5 knots, depth 240 feet. Figure (19) is the same type of analysis, the submarine USS RAMORA, speed 12 knots.

Another technique which has been investigated has been the use of the graphic indicator display. This can be approached from the standpoint of classification and can be termed a true classification device. A brief review of the graphic indicator might be helpful at this point. If an input signal to a graphic indicator is a pure sign wave and if the reference frequency and the input signal frequency are equal, the display will appear as single straight horizontal line. Figure (20). Now then, if the incoming frequency is made greater than the reference frequency, the display will show a series of lines with negative slope. This slope will increase as the difference between the two frequencies increases. Similarly if the incoming frequency is less than the reference frequency, the series of lines will have a positive slope which will increase as the difference in frequency increases. The proposal to use this display as a classification system can be considered as a proposal to use a pulse whose frequency changes in the middle of the pulse. The pulse can be considered as a two frequency pulse or as two simultaneous consecutive pulses with the frequency of the second half or second pulse about 250 cycles above that of the first. If you were to illuminate a submarine with a pulse of this type then three successive conditions occur. Figure (21). The first condition is that reflections will show only the frequencies of the first part of the pulse because the second part has not yet reached the submarine. When this first portion of the echo reaches the receiver the total signal will be predominately the first frequency and then as both pulses reach the submarine and return to the receiver the signal is made up of both the first frequency and the second frequency due to reflections of adjacent areas along the hull of the submarine. When the first pulse has completely passed over the submarine, reflections are still occurring from the second half of the pulse. The receiver then receives a signal which is predominately the second frequency. These three conditions combine to produce the pattern illustrated in figure (20). Nothing has been said thus far about the effect of the pulse length of the separation between the two frequencies. Another basic assumption is that successive areas along the submarine will produce equal reflections. All of these above conditions apply to the question, "Can this signature be generated for a submarine contact?" If the signature can be generated, will it be unique for submarine? If many non-submarine contacts also generate the same signature then this technique is useless as a classification tool. It is believed however that the signature is unique for a submarine and this is based on the fact that a hull is a comparitively rigid structure which will provide uniform reflections or uniform variations or reflections along its length.

To investigate this idea, the high power short pulse experimental sonar was used as the primary equipment. The experiment was conducted with a sonar vessel circling a submarine at ranges under 1000 yards. The submarine was restricted to a forward speed of less than 2 knots. This first experiment produced dual beam oscillograms shown in figure (22) for pulse lengths 5, 10, 20, 30 and 40 milliseconds. All of these were for a frequency separation of 250 cycles per second which was shown to be about optimum. In each of the photographs in figure (22) shown below the pulse is the graphic indicator display. This is a rather characteristic display and is indicative of the correctness of the assumption. In C, D and E, figure 22, the pulse length is sufficiently long to show a complete graphic indicator display. Unfortunately these experiments were discontinued before it was made clear that non-submarine targets would not display a character of this sort and further work must be done before this can be called an answer to the classification problem.

Even if it appears that these high resolution devices provide an answer to the classification problem it should be remembered that these must all be classed as short range techniques. With increased emphasis on long range sonar and with all the Laboratories now working in the field of low frequency long range detection the problem of classification is again completely open and most of this prior work with higher frequencies and high resolution will not apply, at least will not apply totally to the SQS-4 sonars and particularly to those of still lower frequency under development. The problem of classification however remains with us and it is more necessary than ever that classification methods be devised to be used with long range detection systems. With the extreme long ranges which are now possible with such techniques as Lorad and Colossus, classification is much more important than it has ever been because the target must be classified at extreme range. Waste motion is much more costly these days in time and weapon expense.

It may be, however that the problem of classification may not be so important. There are some indications that using the lower frequencies which we need for long detection, targets other than submarines do not return echoes which can be in any way classified as non-submarine. With the experimental work with the Lorad equipment for example there has never been a target return other than from seamounts, which could be confused with a submarine. Targets smaller than submarines blend into the background of reverberation and only a target the size of a submarine is sufficiently prominent to be so classified. This is not to be taken as an optimistic ray of hope however because mush remains to be done. The variation of target strength with frequency is a research area which must be investigated to the utmost. We know quite a bit about the variation of target with frequency from 10 kilocycles on upwards. We can calculate theoretically the variation of target strength with frequency for simple models such as spheres and triplanes, but the calculations of target strength of a complicated target such as a submarine is impossible. Many good beginnings have been made in these theoretical studies by assuming models. This has been attempted in this Laboratory,[9] for Lorad frequencies, but to use these same formulas to try to calculate the variation of target strength with frequency becomes very difficult and the emperical method remains the one of choice. This variation of frequency should be carried on downward to the point where the target strength of the submarine begins to deteriorate because the wave length becomes an important dimension with respect to the length of the submarine. At just what frequency this does occur is the parameter we do not know and which is extremely necessary before we can think about beginning work on some of the more forward looking systems which are under consideration at the moment.

For example, there is in the thinking of several of the Navy Laboratories as well as contractors and various Bureaus, that some sea surveillance system, in whatever form it might take, which has as its objective, the flooding of a large ocean area with sound and the detection by perturbation of the sound field, the traverse of the target. It is obvious that this can only be done with some technique which utilizes a low frequency, and here again we have the problem of target strength and classification at low frequencies. As indicated before, this might not be a problem, but we do not know. In these sea surveillance systems the pulse length becomes quite long and in some cases becomes continuous. With this situation one has the possibility of using a fine grain analysis of the returning signal looking for modulation imposed on the return by some characteristic of the target, be this propellor modulation or hull vibration. It would seem obvious, with proper analysis of the returning signal, that there must be some characteristic imposed upon the echo by the target and it is this characteristic we must find if we are to find the answer to classification problems at extreme range.

As a last resort there are other techniques we can use, once a submarine or unknown target has been detected at considerable distance. Some local high resolution classifying device can be used in a sonobuoy, a small submersible dispatched to the area with acoustic and visual sighting equipment, or some such device as a torpedo with acoustic or visual sighting equipment and equipment for telemetering this information back to the mother ship. This same approach might result in a device dunked by a helicopter, by a blimp or by an ASW plane. Another possibility would be to vibrate the hull with close low frequency explosions. At NEL there have been devices developed recently which deliver most of their explosive energy in the low frequency region in the neighborhood of 10 - 50 cycles per second. If these can be made sufficiently cheap and sufficiently powerful they can be thrown away in large numbers over the area of a contact and hull vibrations could possibly be observed as signal modulation. Even in peace time we have had a need for these essentially contact classification devices as witnessed by the recent witch hunt in the Atlantic. Consider what could have been accomplished if we had available a small submersible with acoustic and visual sighting equipment. It would be perfectly feasible for relatively small cost to build a small submersible with television and

acoustic homing equipment and then with one of these witch hunt's in progress the submersible could be put overboard and swum right up to the object in question. The target could be observed and if it had a nameplate or a number this could be recorded or photographed. If this submersible had access for SCUBA divers, the diver could emerge from the vehicle and tie a ribbon around the conning tower of the submarine and there would be no question about the classification.

In our enthusiasm for the development of long range detection equipment, NEL might be accused of neglecting the classification problem. I hasten to say that we have not lost sight of the problem, but are more convinced than ever that classification is a problem which must be solved. We are content for the moment to look for possible techniques consistent with low frequency. With the construction of better analyzing equipment we intend to look for any sort of modulation which might be imposed upon the returning low frequency signal. In this there is some hope, but if necessary the operational forces can rely on the procedure of following every enemy contact knowing that at low frequencies the number of false contacts will be considerably less than it has ever been before.

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Note: A complete and comprehensive bibliography (NEL Report Number 727, 15 October 1956 (Conf)) has been prepared by J. E. Murrin. This covers as much of the classified literature as it was possible to find, published prior to 30 June 1956.

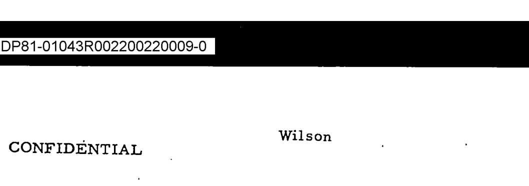


Figure 1. Underwater Objects Contributing to Echo Confusion

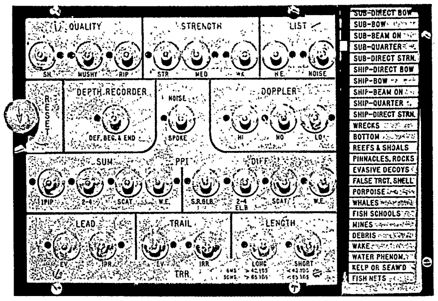


Figure 2. Sonar Classification Logical Computer

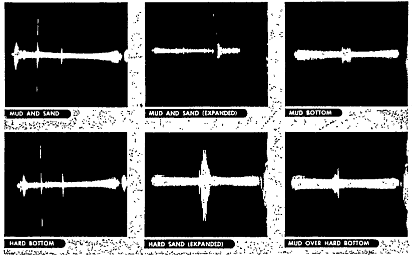


Figure 3. Bottom Echoes

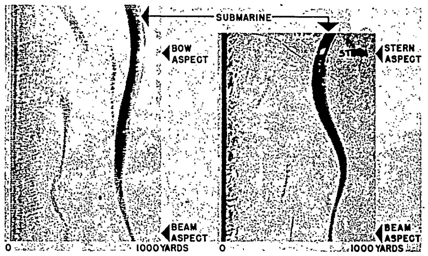


Figure 4. Submarine Track on the Chemical Recorder I

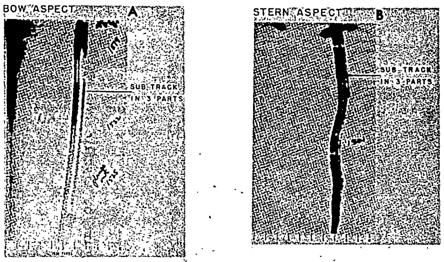


Figure 5. Submarine Track on the Chemical Recorder II

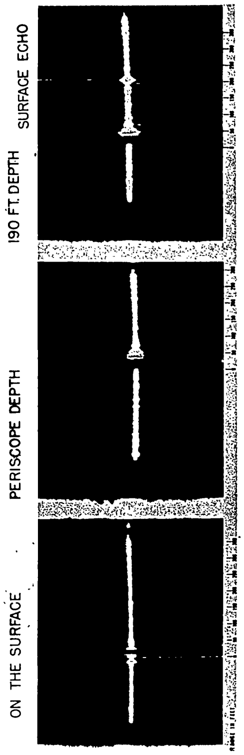
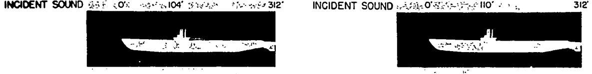


Figure 6. Oscilloscope Expansion of Submarine Beam Echoes



THIS STRUCTURE OBSERVED WITHIN APPROXIMATE 15° SECTOR ABOUT DIRECT BOW (000° TARGET ANGLE)

THIS STRUCTURE OBSERVED WITHIN APPROXIMATE 4° SECTOR ABOUT DIRECT BOW (000° TARGET ANGLE)

30 MSEC PULSE FLEET TYPE SUB SUB HOVERING AT PERISCOPE DEPTH

Figure 7. Oscilloscope Expansion of Submarine Bow Echoes

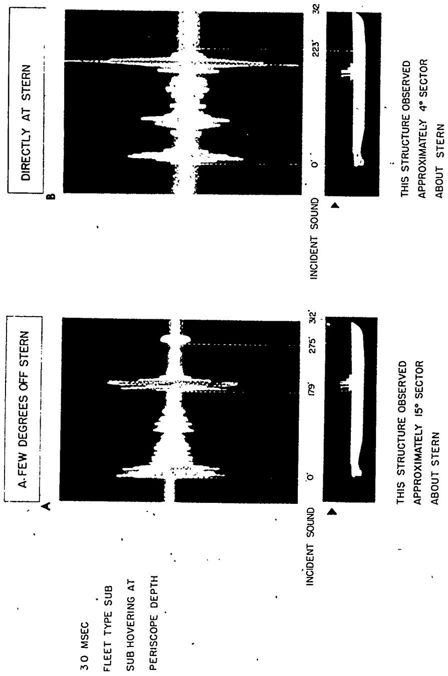


Figure 8. Oscilloscope Expansion of Submarine Stern Echoes

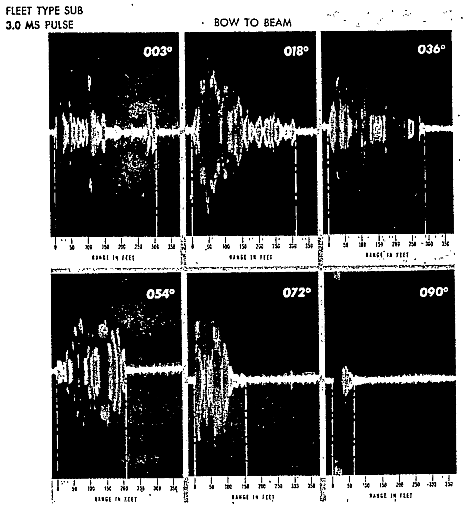


Figure 9. Submarine Echoes Going from Bow to Beam Aspects

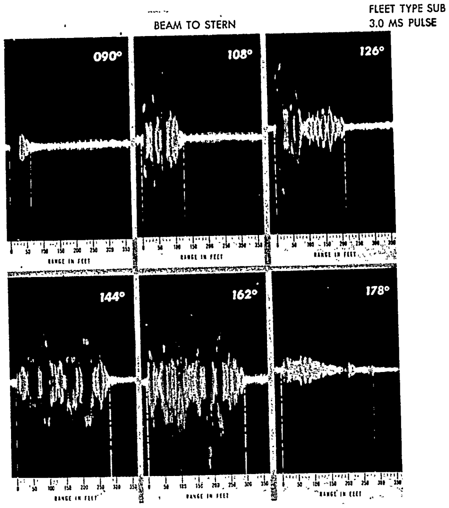


Figure 10. Submarine Echoes Going from Beam to Stern Aspects

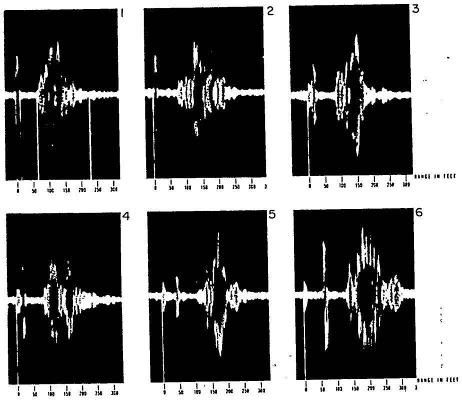


Figure 11- Simultaneous Trace of Whale and Submarine Echoes

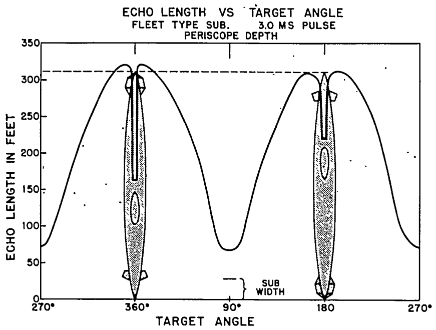


Figure 12. Variation of Apparent Target Length with Aspect

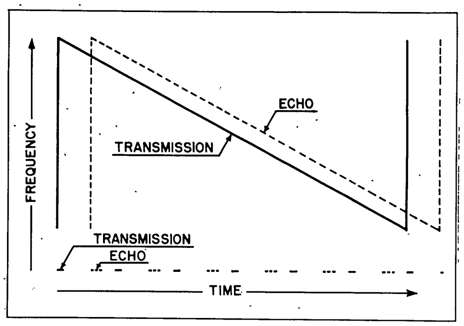
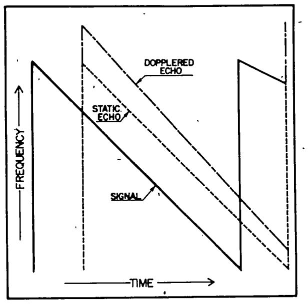


Figure 13. Comparison of Echo Time Available for Analysis of Pulsed Sonar and Continuous Transmission Sonar

Figure 14. Change of Slope of Returning Signal with Presence of Doppler



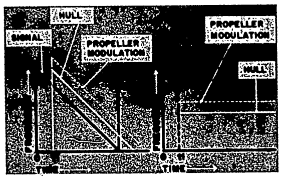
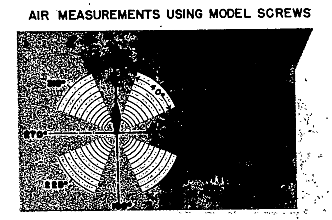


Figure 15. Origin of Doppler Echo Warbling Caused by Propeller Rotation

Figure 16. Aspect Angles in which Propeller Modulation Can Be Observed



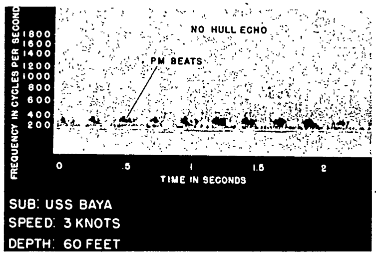


Figure 17. Frequency Analysis of Propeller Modulation - USS BAYA - 3 knots

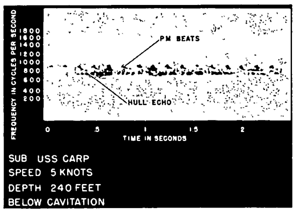


Figure 18. Frequency Analysis of Propeller Modulation - USS CARP - 5 knots

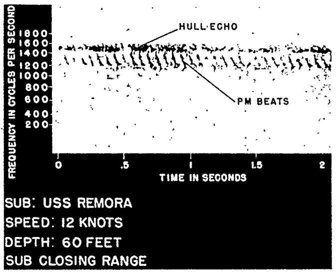


Figure 19. Frequency Analysis of Propeller Modulation - USS REMORA - 12 knots

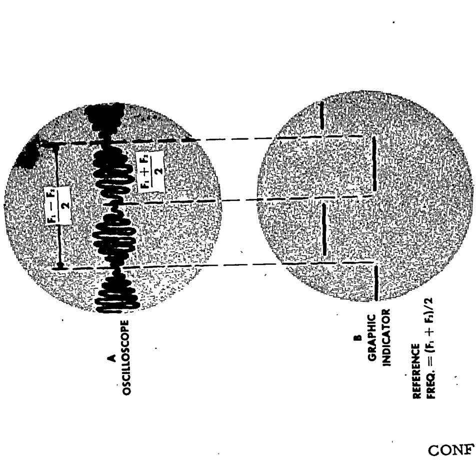


Figure 20. Double Pulse Graphic Indicator Display

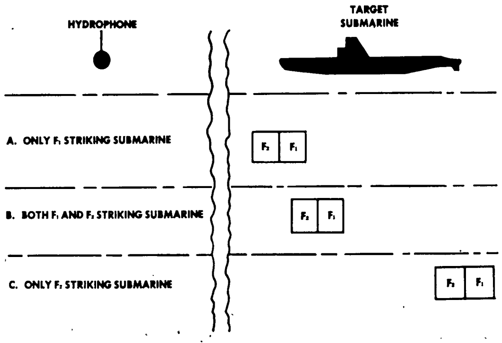


Figure 21. Showing how the Double Pulse is Returned from a Submarine Target

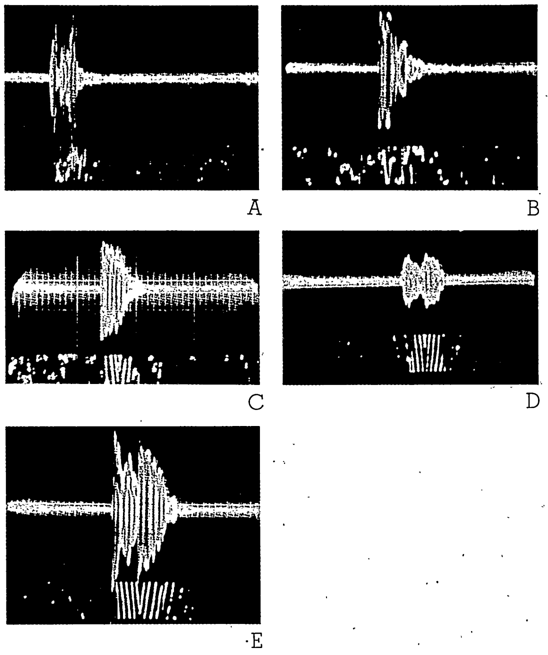


Figure 22. Experimental Traces Using the Double Pulse and Graphic Indicator

AN OPTIMIZATION PROGRAM FOR INSERVICE WEAPON SYSTEMS

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I.

REQUISITES FOR A SOUND WEAPON SYSTEM IMPROVEMENT PROGRAM

Quantitative Operational Data

This symposium has considered several of the effects caused by the operating environment of the Navy. Still another effect - of serious consequence - is the difficulty imposed by the ocean environment in securing quantitative data on operational performance. Laboratory tests and prototype evaluations have not adequately substituted for operational data. Quantitative data on inservice weapon systems, obtained in the operating environment, are essential to establish the causes and amount of variance between operational performance and theoretical capability and to provide a sound foundation for improvement programs.

In the past, the significance of this difficulty was suppressed by the slow rate of evolution of naval weapon systems. Over a period of time the accumulated experience of operators indicated where and what improvements were needed. This period of time would sometimes encompass one, or several, wars. Casualty lists, in war, were uncontestible measures of weapon system effectiveness. Navy forces are now faced with air and submarine threats that are greatly different from those of World War II - a mere 13 years ago - and which may even be beyond the capabilities of our present operating forces. The natural forces of evolution - that served us so well in the past - now appear incapable of producing weapon systems equal to the threats of the near future.

Measures of Effectiveness

For those of us that are overly fascinated with the speed of our technological advance, history warns us by many examples that weapon systems may be sound in concept and faulty in implementation. Those estimates of weapon system effectiveness that are based on design data or prototype tests assume specific operational parameters. It is not strange that these assumptions do not always carry over into practice; but in lieu of better information, the theoretical standards outlive the assumptions on which they were based.

A basic problem for those officers responsible for fleet readiness is how to measure the effectiveness of inservice weapon systems and, following that, how to optimize its effectiveness. Effectiveness must be measured to insure that current performance standards can attain the purpose of the weapon system for some, or all, of its operating parameters. Effectiveness must be measured in realistic operational conditions so that the normally optimistic theoretical or pre-service performance standards can be validated or adjusted to attainable and maintainable operational standards. Effectiveness must be analyzed so that all possible performance restrictions short of major equipment alterations are removed or corrected. These efforts require scientific analysis of all available operational data relevant to weapon system effectiveness.

Analysis of Effectiveness Factors

Unfortunately the relevant factors to the effectiveness of most naval weapon systems are excessively numerous. Relationships between human, environmental and material factors are, at least, incompletely understood. The chances are exceedingly small that a simple overall solution to the optimization requirement can be found by a purely theoretical analysis of raw data. On the other hand, observing the overall weapon system in actual operation provides the opportunities to locate unknown factors that have unduly restricted performance. When the restrictive factors have been precisely defined, ways and means to measure them quantitatively can be found.

By this means of searching out and correcting restrictive factors - one by one or two by two - we can continually evolve our weapon systems toward optimization. These steps are necessary whether the weapon system was introduced last year or ten years ago.

The operating forces have the best opportunity to detect the restrictive factors of performance and to initiate corrective action. It is safely assumed that no system component is placed in service that is known to be faulty. The operating forces are challenged to locate the causes of inferior effectiveness of a complex system, now in operation, and of which all components are believed to be satisfactory. It is a challenge that cannot be safely declined.

II.

A SAMPLE SOLUTION OF AN OPERATIONAL PROBLEM

Early in World War II, the submarine force in the Pacific experienced a large decrease in effectiveness over what had been expected. For example (1):

> Of the eighty Japanese ships that comprised the invasion force at Lingayen Gulf in December 1941, a defending force of five U.S. submarines sank only one ship.
>
> In the first three months of operations in the Philippine area, 28 U.S. submarines sank only 13 Japanese ships.

Unknown factors seriously restricted effectiveness. Through the concerted effort of many people, these factors were eventually isolated and restrictions were removed. Fleet Operating Personnel were major participants in this effort, which can rightfully be termed an operations research project. I would like to review this effort as though it were a formally conducted operations research project because it well emphasizes the great potential of the operating forces to assist in the optimization program. The first phase of the project was to review the opinions of the persons associated with the weapon system. The concensus was that:

> the tactics employed were excellent,
> the performance of the operators was exactly per instructions,
> the weapon was completely reliable,
> enemy ships were not sinking at the predicted rate.

These opinions should perhaps have been anticipated. They were asked for in the hopes that they would contain clues that would lead to a quick solution. In this case they didn't.

The next step was to isolate the factors that could produce such drastic reduction of effectiveness below the theoretical capability. Major factors included torpedo solution procedures, torpedo setting instructions, and the torpedo control system and its exploder system. An investigation of shipboard operating procedures found no deficiencies capable of producing gross losses of operational effectiveness. The misses had even occurred in the most simple of tactical situations: at short range against an anchored target. Torpedo settings had been checked, rechecked and checked again. The fault was concluded to be in the torpedo itself.

Deep running torpedoes were a World War I difficulty. They were noted as a World War II difficulty in January 1942 when the Navy Department reported that the Torpedo Mark 10 was running four feet deeper than set. No mention was made of the Mk 14, and it could be inferred that it did not suffer from the same deficiency. However, Admiral Lockwood ordered tests conducted on the Mk 14 by firing it from a submarine at a fish net 850 yards distant. The setting was 10 feet - the torpedo made a hole in the net at 25 foot depth. The Navy Department did not consider this a conclusive test because of certain technicalities concerning the trim. The test was reconducted in July 1942 with the same result. These tests were accepted and confirmed in August 1942. Material corrections were made promptly.

Correction of this factor did not increase effectiveness as expected. It merely introduced another factor which had apparently been suppressed: the problem of prematures. It was naturally suspected that the exploder system, which included the Magnetic Exploder Mk 6, was at fault. Many efforts were made to correct the suspected and actual faults of the magnetic exploder. Testing and quality control became very stringent - but the prematures continued. CINCPACFLT tolerated efforts to remedy the situation until July 1943 when he ordered all magnetic exploders inactivated. SOWESPAC submarines continued efforts to make them work until March 1944. In this example, the troublesome factor causing malfunctioning of the magnetic exploder was not clearly isolated. It well illustrates, however, an alternative result to successful operations research: If you can't fix it, get rid of it!

A footnote to this phase of our research project is that a backward step from an announced technological improvement requires more laborious justification than a mere forward step. A prominent industrialist expressed himself on this general subject as follows:

"You have no idea how much money you can save by locating trouble spots just as they get started, fixing them by throwing in any number of expediters that are needed, or by killing a project before it becomes so embarrassingly expensive that pride is at stake and you throw good money after bad to prove that you were right in the first place about the idea if not the profit." (2)

In fact an officer during the time of our synthetic project anticipated the preceding remarks concerning the high cost of pride in these words:

"It would appear far better to sink the enemy vessels encountered.....than to continue spoiling good chances just to prove that a really useless mechanism can be made to function a fair proportion of the time." (1)

Despite the correction of the second restrictive factor in performance, effectiveness still did not jump as expected. A third research phase was initiated that involved a series of field tests to determine the reliability of the torpedo exploder system with the magnetic exploder inactivated. The most enlightening test was conducted by Captain Daspit in July 1943. The tests were conducted against a large unescorted Japanese whaling ship which he had previously hit and stopped at sea. He first took station on the beam of the target and fired what was thought to be a killing shot. But it bounced harmlessly off the side. Then in keeping with the best traditions of scientific experimentation, he readied, rechecked and fired eight consecutive duds at the hulk. The ninth and last torpedo was brought home for inspection. A drop test made ashore proved the cause of error to be the excessive force of deceleration in the case of a normal hit. When the torpedo hit a glancing blow, the lesser force permitted the firing pin to move properly. The operations research phase was completed. Design technicians quickly corrected the deficiency and the first load of corrected torpedoes were sent to sea within three months. This third phase was the payoff. Effectiveness jumped and the road was cleared for a highly successful submarine war.

This fanciful distortion of history is not intended to embarrass any persons identified with a particular development. It was used to show, first, that scientists, designers, technicians and mechanics are individually and collectively susceptible to the human capability of erring. To safeguard against this negative capability the operating forces must question, measure, and analyze in a scientific manner the current effectiveness of service weapon systems. Secondly, our example was intended to show that great breakthroughs in effectiveness can come through several so-called incremental improvements as well as by the introduction of

an entirely new weapon system. Thirdly, the operating forces must translate the findings of their operational experience into quantitative terms. This is the most meaningful language that the operating forces can use with the Navy Department and industry.

III.

OPERATIONS RESEARCH APPLICATIONS TO NAVY OPERATIONAL PROBLEMS

Study the Purpose

Operations research offers a general procedure by which Navy operational problems can be analyzed. A first step is to state the purposes of the system under study with sufficient clarity to outline the project. The importance of this step should not be understated, but on the other hand we have all heard of groups that deliberated for months without determining what the problem was. Let us assume that the effectiveness of some operating weapon system, whose purpose is to kill submarines, leaves much to be desired. To add incentive, we can also assume that technicians, with money, are standing by to improve the system as soon as they are told by Operations Research where to concentrate their efforts. A first reaction of many researchers is that they would like the cognizant commander to specify the operating parameters of the system. What type submarine is the target? When? Where? What numbers and types of antisubmarine units are engaged in the effort? What are the detection ranges, tracking tolerances, weapon accuracy and fire power? How much ammunition is available to the unit and force? These are factors to be studied rather than established by decree.

Often the way to improve effectiveness is through correction of an erroneous operational parameter. Early in World War II, for example, it had been decided that the ideal place to explode an underwater weapon was several feet under the hull of a target ship. (1) Such an explosion would cause maximum loss of bouyancy. An analysis of actual merchant ship sinkings, however, revealed that the majority of ship losses were caused by loss of stability. This effect could be better produced by hits against the side of the hull.

Besides faulty parameters, there are obsolete parameters. Obsolescence can occur by administrative acts such as lowering the entrance requirements of the service school for operators; or by unexpected deterioration of some material components by aging. Ideally every factor should be currently evaluated, but this is obviously prevented by restrictions on time and manpower.

Researchers must have the good operational sense to restrict their efforts to the study of those factors that have a critical influence on effectiveness.

The study of individual factors should be conducted with appreciation for possible inter-effects and their collective effects on the weapon system. An inter-effect could be that time spent on maintenance affects time spent on operator training. When one factor loses value the collective effect might be kept constant by improving another factor.

This discussion concludes that the definition of a weapon system's purpose is dependent upon a full knowledge of its effectiveness. When an all weather capability is reduced to something available in sea states of less than two, or when a capability against all submarine targets is reduced to a capability against some submarines, it appears to me that the weapon system purpose has changed. This method of arriving at the purpose of a weapon system, however, will offer little guidance to the researcher. In point of time the purpose is apt to be defined near the end of the study, rather than at the beginning.

Search for Unduly Restrictive Factors

As soon as possible the weapon system must be observed in operation in order that the more critical factors in the problem can be determined. Rules of thumb, traditional procedures and popular assumptions of the operators are particularly helpful as starting points. A rather amusing example illustrates this point. It had been taught for years that you must never fire a long burst from a machine gun because the gun vibrated so much it shook you off your aim. It was only the first two or three bullets out of a burst that hit the target. One eager young scientist in World War II did not believe what he was told. He took some colored crayons and colored a bunch of bullets. He was able to show that, consistently, the only rounds to hit the target were the last rounds of the burst and not the first. (3) This episode has been remembered no doubt because it debunked a popular assumption. But it would have been an equally good example of operations research had it proven the validity of the assumption.

Our Navy has many generally accepted assumptions that need similar questioning. It is widely assumed that, for example:

1. Certain talented sonarman have a phenomenal ability to identify sources of sonar echo signals;

2. A hedgehog projectile can kill or damage a submarine;

3. The present fire power of antisubmarine weapons can produce sufficient hits to kill a submarine; and

4. Present ammunition capacity of ASW units is sufficient to support an antisubmarine engagement.

These assumptions may be correct but they may also be convenient arguments for maintaining present policies and procedures. An example of this occurred in the Civil War. It was proposed to arm the infantry with breech loading rifles in order to increase fire power. A muzzle loading gun required relatively little logistic support. The assumption of the War Department was that the rapid firing breech rifles would exhaust ammunition supplies in a few moments and leave the men helpless. Passing years have made the assumption sound foolish. But in 1862, the opinions of many Union Generals and even the President of the United States were unable to counter this basic but faulty assumption.

Opinions of operators must be considered as they are sometimes the only clue to the unknown, performance restricting component. The claim of some submarines in World War II that torpedoes were running deep sounded to some material officers like an excuse for a poor torpedo solution. But in this case the operators were proven right. A Canadian scientist recorded an incident that well illustrates that the operator's opinions are sometimes wrong. (3)

In the early desert tank battles, the British tanks proved superior to the German. They knocked them out at long range with little damage to themselves. Suddenly the situation was reversed. The British gunners discovered that the Germans had introduced a new gun sight of colossal proportions. This being the only change that they knew of, they also demanded new gun sights. Upon investigation it was found that there was no difference in accuracy of the two gun sights. Later investigation in the field determined that the Germans had increased the hardness of their tank armor without changing its thickness or appearance. The British shells were hitting as frequently as before, but were breaking up. The solution involved a change of ammunition.

Measure Effectiveness in the Field

Whether the intended course of action is based on the opinions of the operators, or on obviously critical factors in the system, or on the intuition of the investigators: the next step is to measure effectiveness in the field. This is the body of Operations Research. This is where the ocean environment becomes most annoying. Operating units leave no tracks. The point of weapon impact is fixed for only a moment. Naval engagements are short and action packed. Veterans of the engagements scatter rapidly to distant duties.

Without measures of effectiveness, researchers can only speculate. Data on effectiveness is needed, first, to analyze causes for variation between theoretical capability and operational performance. Statistics on the SQS-4 illustrate this point. (4) The most recent report on effectiveness by the Commander Anti-submarine Defense Force Atlantic Fleet states that the detection range of the SQS-4 equipped destroyers was about 2200 yards which comparatively is one-half the theoretical detection range of 4400 yards which was predicted by the Underwater Sound Laboratory. There are of course opinions as to the cause. Until the component steps that make up a detection can be evaluated on the basis of quantitative data, the problem cannot be conclusively resolved. The purpose of resolving the difference in performance is to correct the operations of the operators - if they are at fault; or the theories of the theorists - if they are at fault. In the example cited - the operation of the SQS-4 - the theorists have assumed detection was made by audio signals. The manufacturer's manual for the SQS-4 suggests that the operator rely primarily on the video display for detection, and the Fleet Sonar Schools training is tending to support this suggestion. This cursory and sample analysis into the causes of variance between theoretical and operation performance suggests that there are serious differences in concept as to how a detection is made. Researchers must carefully examine the assumptions on which previous effectiveness measurements were made.

Resolving differences between theoretical capability and operational performance will at least simplify the purposes and employment of the weapon system concerned. It will not produce a material improvement, but it will frequently show where the improvement can be made. The technical capabilities that may be attributed to a weapon system are not assumed to be a ceiling on operational effectiveness. For example, environmental and human factors research, which several agencies are pursuing continuously, promise means by which a technical capability can be increased.

Quantitatively defining the causes and effects of critical restrictions on system performance usually completes the research study. Senior command is then supplied with basic information to a consideration of costs and necessity for modifications to tactical doctrine, operational procedure and material.

IV.
MANPOWER FOR OPERATIONS RESEARCH

A crucial decision in Navy operations research is selecting the points within the Navy organization at which researchers can do the most good. Researchers must be in a position where they can directly observe the weapon system in operation. They need a broad license to inquire into the operation of all components and performance of all functions that contribute to the overall effectiveness of the weapon system. The conflicting needs of being close to the operator while possessing broad authority for inquiry seem to be best met at the level of the type commander.

Type commanders are convenient focal points in the collection of performance data on individual weapon systems. They are the greatest users of target services and ammunition. They schedule and review the greatest bulk of operational tests and exercises.

Men engaged in current operations are not considered to be the best candidates for Operations Research. One of the commanding officers' many problems is to instill the operator with confidence in present procedures and doctrines. It would complicate the problem if the operator was required to adhere strictly to instructions on one evolution and then experiment independently on the next. Analysis of such goings on would at least be difficult. Experiments need to be as carefully controlled as standard exercises and conducted in sufficient numbers to prove their merit.

Task Fleet Commanders and Commanders-in Chief now have a competent civilian and officer on their staffs who are educated in Operations Research. They are generally concerned with the optimization of a group of weapon systems - for example - all ASW units. They do not analyze a sufficiently large sample of standardized performances to compute an effectiveness value for each weapon system. They are analyzing problems on the second level of complexity before we have analyzed those on the first level. What is proposed here is not a re-direction of Operations Research but its expansion to include a capability to review the operation of each major weapon system or equipment system that is under the specific control of a type commander. It is assumed that there is no ready pool of trained and experienced researchers for this task.

What type of man do we want? A British scientist has described the character of an operations researcher as follows: (5)

1. Conceptual ability to see the matter as a functional whole and to see what needs analyzing.

2. The competence to do the necessary functional dynamical or statistical analyses.

3. The ability to do things the simple way.

4. The ability to present the answer in a straight-forward and understandable statement.

This is the definition of a good scientist or a man who would have been a good scientist had he so desired. This is also the definition of a good naval officer.

The conclusion of this paper is that the type commanders should include in their staff personnel who are solely concerned with operations research projects. Their task will be to investigate and analyze the performance of each weapon system, as assigned, and produce quantitative data on its effectiveness. The purpose of this task is to provide a senior command factual information on which to base tactical doctrine, operating procedures and material modifications.

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DISPOSITION OF RADIOACTIVE MATERIAL IN THE OCEAN

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INTRODUCTION

Additions of artificial radioactivity to ocean waters are primarily from nuclear weapons tests. Relatively small amounts of commercial radioactive waste products are deposited in deep waters. These two major sources of radioactivity are placed in carefully selected areas such that hazards to man from the activity are minimal. Expanded rates of world-wide testing of nuclear weapons and the disposal at sea of anticipated increases in amounts of reactor wastes raise important questions regarding the disposition of radioactivity in the ocean environment.

Because of the enormous dilution factor, the average level of radioactivity in the oceans of the world would not be expected to rise significantly from artificial additions anticipated in the foreseeable future. However, appreciably large local areas are affected by radioactive materials. In fact, due to the transport of individual water masses over relatively long distances, detectable amounts of radioactivity are known to have reached the shores of populated regions. For example, radioactivities from tests at the Eniwetok Proving Ground were carried to the coast of Japan by ocean currents. This condition coupled with the above-average fallout over Japan from U.S.S.R. tests has, understandably, produced acute reactions among the Japanese people.

It becomes necessary, then, to possess detailed knowledge of the different types of water movement in the ocean. It also becomes important to know not only the stability of water masses but also their age since the radioactivity of contaminants declines with time depending upon the half-lives of the radioactive materials. Upon the physico-chemical forms of the radioisotopes depends their uptake through the various food chains to organisms consumed by man. The quantity of radioactivity ultimately available to man is also dependent upon the permanence of the states in which the activities exist in water, namely, their ionic, colloidal and particulate states. Again, the dispersal of radioactivity may depend on the particular rates of absorption and adsorption by organisms or particles that by themselves move vertically and/or horizontally.

And so the disposition of radioactive material that reaches the ocean is directly related to the pattern of oceanic circulation, to the physico-chemical forms of the various materials, and to biochemical and metabolic processes of marine organisms in salt water. Of special importance is the ability of some marine forms to concentrate radioactivities.

These and related factors are reviewed in this paper, along with a discussion of cogent viewpoints and findings of investigators who are studying the marine problems created by artificial radioactivities in the ocean. Emphasis is given to certain factors pertaining to where and how to dispose of radioactive waste in the ocean. Also, brief references are made to two NRDL studies directly related to topics of the discussion.

In several parts of this paper, attention is directed to the need for more detailed knowledge of physical, chemical, and biological processes in the sea and, also, to the need for detailed analyses of basic principles underlying these interacting processes.

PHYSICAL ASPECTS

Radioactivities added to the ocean are subject to an immense dilution factor. However, some additions are known to remain in significant concentrations within a single water mass and to be transported many hundreds of miles. Vertical and horizontal dispositions of these radioactivities are along paths that are relatively unknown for most major oceanic systems. Biological and biochemical processes concentrate the radioisotopes to the end that the hazard becomes a highly mobile one, moving with the micro and macro-organisms -- a plague to man's ingenuity and resourcefulness.

Regarding the capacity of the ocean environment to dilute and absorb wastes over extended periods, it is recalled that the oceans cover about 71 percent of the land surface, that the mean depth of all oceans excluding adjacent seas is 4117 meters, that the volume of all oceans including adjacent seas is 1.37×10^{24} cm^3 (8).

Since the surface stratum of mixing above the main thermocline may be expected to extend to a depth of at least 200 meters, it is significant for this discussion to observe that the areas of the oceans (including adjacent seas) above the 200 meter depth level are: 13.3 percent for the Atlantic, 5.7 percent for the Pacific and 4.2 percent for the Indian Ocean. The volume of the upper 0-200 meter stratum of all oceans including adjacent seas is approximately 7.22 x 10^{12} cm^3. Studies of coastal upwelling by McEwen (12), and others have shown that water reaches the surface from depths not greater than 200-300 meters (23). This upper volume is one of mixed water whereas the deep strata are relatively stratified and slow moving.

Early progress in the study of mass transport in the ocean was made in studies of the North Atlantic waters. The first contributions from the Woods Hole Oceanographic Institution in the early thirties were based on the results of the "Nautilus" Expedition, one object of which was to obtain data in the deeper parts of the Polar Sea for understanding currents (24). Subsequent studies by that institution (5) contributed significantly to knowledge of circulation in the Western (North) Atlantic. Now possibilities for using radiatioactive materials as natural and artificial indicators of water movements are being explored (7).

Knowledge of <u>ocean circulation</u> provides a key to evaluations of radiological human hazards arising from the use of oceans as proving grounds for nuclear weapons and as <u>disposal centers</u> for <u>radioactive wastes</u>.

Radioactivity in Relation to Ocean Circulation.

It was stated in the beginning of this paper that oceanographic data are too often lacking in detail. This concept applies to ocean circulation. Measurement of the rate of directional flow of oceanic water masses was undertaken by Seiwell (21), (22). He studied the distribution of oxygen and phosphorus in the Western North Atlantic (west of 40th meridian and north to the 43rd parallel). On the basis of these two property indicators, he estimated that, at "Atlantis" stations between the approximate latitudes of 16° N and 1° N, the average velocity of the underlying layer-depth about 2000 meters - was between 1.5 and 2 cm/sec.

The use of naturally-occurring radioactive nuclides namely, potassium-40, tritium, carbon-14 and Uranium with its decay products, for estimating flow rate has been considered in recent years. Of these carbon-14 offers the most promise. It is formed from nitrogen in the atmosphere (secondary neutrons react with $_7N^{14}$ nuclei to yield $_6C^{14}$ nuclei) and transferred to the ocean as a result of exchange between the carbon dioxide of the air and the carbonate in the ocean. It has a half-life of about 5600 years. At the ocean surface, its concentration corresponds to about 15 dpm/g of carbon. Vertical currents carry carbon below the surface and it is cutoff from the supply of carbon-14. Since it continues to decay its concentration is reduced by the factor $2^{t/5600}$ below that at the surface where t = time the carbon has been below the surface. Thus, the concentration of carbon-14 provides an indication of the time at which the water in question left the surface. In other words, the carbonate constitutes a measure of the age of subterranean water masses and hence, because of its long half-life, the rate of movement of the very slow oceanic currents. The rate of flow of the North Atlantic Deep Water can now be studied from an entirely new approach and the early estimates of Seiwell and others can be checked. Herein perhaps, lies the basis for a satisfactory answer to the question of how many years is required for deep Atlantic waters of Polar origin to reach the equatorial region and return. The time to complete the circuit has been variously estimated to be hundreds or even thousands of years.

Kulp (11) has made a limited number of age determinations of deep, Atlantic waters and reports one age determination at 53°52.6'N 21°06'W for a 2743-meter sample to be 1750 ± 150 years. Thus, these data suggest that it takes about 1500 years for surface water from the Polar Sea to reach the latitude of Newfoundland in its Arctic-equator circuit. Kulp concludes "the time for the turnover of the oceans must be thought of in terms of several thousand years". More recent measurements suggest that this figure may need to be revised downward.

Significantly these very important findings not only have far-reaching applications to oceanography, but also to fundamental problems in geology and in the increasingly important subject of long-range weather forecasting.

The Disposal of Radioactives Wastes.

Wastes reach the ocean from weapon tests, from coastal runoff, and from waste disposal practices. Apart from deep water nuclear weapon tests, the surface 100-200 m stratum is affected by the first two sources. Disposal of hot reactor wastes concerns bottom strata, mainly.

Convection currents and wind movements produce vertical turbulence in the surface layer and largely determine its homogeneity and its depth. In contrast to deep water layers the velocity of the surface water stratum is fairly well-known throughout the world. Speeds ranging upward to 193 cm/sec or 90 miles per day are not uncommon. However, maximum surface velocities in the Gulf Stream fluctuate from 150 to 300 cm/sec (70 to 140 miles/day). Thus, in projecting time and distances at which water borne radioactive materials may be distributed, the use of average surface current speed must be employed with caution, just as indeed average radioactive fallout calculations must be interpreted with some reservations. The "Taney" and "Shunkotsu-Maru" surveys in the Pacific demonstrated a minimum westward drift of about 20 cm/sec or 9 miles/day. These surveys revealed significant differences between the waters (including fish) on the fishing grounds within the 3 currents-the North Equatorial Current, the Counter-current and the South Equatorial Current. Mariners were warned against use of sea water or exposure to spray in the areas having the highest degree of contamination. Caution must be exercised against assuming a rapid rate of dilution and hence low average activities. For example, the data from the "Shunkotsu-Maru" survey, conducted four months after the March, 1954 nuclear weapons tests in the Marshall Islands, showed significant levels of radioactivity as far as 2000 kilometers from Bikini indicating a possible westward drift of over 20 cm/sec or about 9 miles per day (13). The "Taney" survey was conducted 13 months after the tests and revealed significant levels of activity about 7000 kilometers downstream from Bikini.

In addition to these long-range horizontal movements, radioactivities are dispersed by diffusion resulting from turbulence and eddies. The coefficient of eddy diffusivity is usually more than a million times the corresponding molecular coefficient.

Quantitative knowledge of ocean turbulence is entirely inadequate. Large numbers of variables, difficult to measure, are involved in measuring eddy conductivity. Present information is largely restricted to local areas (14). Folsom reported that when fission products were introduced at the surface to a 100-meter thick surface stratum, it required only 28 hours for uniform, vertical dispersal of the radioactive material to the 100 meter depth (18). Here, then, is another aspect of oceanography in which generalized understandings no longer suffice to meet the present day research requirements.

Next, the question arises as to exchange between the one or two hundred-meter surface stratum lying above the thermocline and the subthermocline layer. The rapid density increase of the thermocline or pycnocline layer reduces or limits intrusion from above or

below to particles and organisms possessing certain levels of density and migratory capacity.

Data from the Marshall Islands tests show cross-thermocline exchange of radioactivity in local areas. As to how the exchange occurred--whether by mixing processes, ecological processes or by particulate matter--is not known. In general, the large vertical movements of the ocean layers occur most usually in high latitudes, at the equator, and along the West coasts of continents.

Reference has been made to the use of carbon-14 for estimating the age of bottom waters and rate of circulation. This information indicates the approximate time that bottom waters are isolated and hence bears on the problem of disposal of reactor wastes. Limited areas of the ocean are presently used for the disposal of low-level wastes. The ultimate fate and disposition of such radioactive substances is an open question. It is of interest to calculate, on purely theoretical grounds, the activity in ocean water that could result from the disposal of reactor wastes, the quantities of which are increasing rapidly and creating a serious disposal problem. Revelle and Shaefer (19) estimate that by 1965 there may be a total of some 80 tons of reactor fission products produced throughout the world. According to Renn (17) 80 tons of fission products, after 100 days' cooling, represent 3.9×10^4 megacuries of beta radiation and 2.5×10^4 megacuries of gamma radiation or over 1/10 of the total natural radioactivity of all the oceans. This latter figure is, of course, largely of academic interest. Of more significance, perhaps, is the estimated annual production of strontium-90 in the amount of 200 megacuries. Its long-range hazard is well known.

The main hazards that would result from disposals of reactor wastes in ocean waters are clearly local ones. Of course, the extent of localization is of great importance and therefore requires careful study. It is of some theoretical interest to relate, quantitatively, the dilution factor provided by the oceans to anticipated possible releases of artificial radioactivitics.

A conservative estimate by A. L. Smith of NRDL is that, by 1980, the quantities of long-lived material (1 year or more) for disposal annually in the U. S. alone will have an activity of about 10^{11} curies, which is equivalent to the amount of fission products produced by the detonation at about 1000 one MT nuclear weapons. Assuming twice as much from the rest of the world, gives a total of 3×10^{11} curies per year. The volume of water in the Atlantic Ocean (not including adjacent seas) is 3.24×10^{23} cm^3. Assuming complete mixing and no further decay, meanwhile, we get an activity in Atlantic waters of 1 x 10^{-6} μc/cm^3 which interestingly is an order of magnitude greater than the maximum permissible concentration for drinking water given in Handbook 52. Using for our calculation the volume of the oceans of the world including adjacent seas, namely about 1.37 x 10^{24} cm^3 , gives an activity of 2.3 x 10^{-7} μc/cm^3i.e., 2.3 times the acceptable maximum permissible concentration. Were this much waste to be limited to the dilution effect of the upper 200 meters of the oceans of the world including adjacent seas, a relatively mixed stratum, then the resulting activity could approximate 4.4 x 10^{-6} μc/cm or 44 times the maximum permissible concentration of mixed fission products for potable water.

But large volumes of high or intermediate level radioactive wastes are not likely to be disposed of in surface waters. Whether or not they reach surface waters from deep disposal areas, or how many years will lapse before they reach surface waters in potentially harmful quantities to affect man is dependent largely, but as we can see, not entirely, on the horizontal and vertical water movements at the selected point for disposal. Needed data on horizontal movements and vertical oscillations in deep layers are generally quite sparse. If several thousands of years are, indeed, required for the movement of Artic waters over the Atlantic Ocean bottom to the equator, this knowledge has practical application to the waste disposal problem (6), (27). The application must, however, remain largely dormant pending the provision of adequate data for its implementation and for thorough evaluation of potential hazards.

Radioactive wastes of the San Francisco Bay area that are subject to disposal in the ocean are handled under the direction of NRDL. Since 1 January 1952 the following approximate quantities of wastes have been disposed of:

13,000 55 gal drums, Vol. 100,000 cu. ft.
Est. activity - approx. 2000 curies

250 concrete blocks - Vol. 30,000 cu. ft.
Est. activity - approx. 25 curies

Dumping location - Long. 123° 9' W, Lat. 39° 38' N
until 5 August 1954

After 5 Aug. 1954: Area enclosed by:

Long. 123° 18' W - Lat. 37° 38' N
Long. 123° 24' W - Lat. 37° 43' N
Long. 123° 30' W - Lat. 37° 43' N
Long. 123° 30' W - Lat. 37° 38' N

Currently, the following studies are under consideration by NRDL:

a. Free fall study of waste packages in water at the disposal site to determine distribution of waste packages on the ocean floor after dumping.

b. Package system studies to determine if material remains confined during descent in water.

c. Core sample studies of ocean floor to determine distribution of radioactive contamination.

d. Liquid sample studies to determine uptake in water of radioactive materials from the disposal site.

e. An oceanographic study to determine ocean currents in the disposal area.

On the East coast, the Navy provides a waste hauling-to-sea service similar to that provided on the West coast. A Navy LST periodically picks up waste at East coast points from Virginia to New England, deck loads it, and dumps it at sea approximately 250 miles off shore.

Main waste suppliers are: Naval Research Laboratory, Washington, D.C., Westinghouse Atomic Power Division, Bettis Field, Penn., and Brookhaven National Laboratory, New York. During 1955, for instance, Bettis produced 1200 drums of waste weighing about 600 tons. The waste is shipped to Earle, New Jersey, where the Navy provides an LST loading service at $10.00 per ton. During 1955, Brookhaven National Laboratory transported 660 drums of waste to the Navy dock at Floyd Bennett Field, New York, where they were loaded onto the LST for disposal. No information is readily available on the volume of wastes handled by the Naval Research Laboratory.

In addition, there is a commercial disposal service, "Marine Crossroads", Boston, Massachusetts. This company accepts small quantities of waste from miscellaneous suppliers and deposits them in Boston harbor. 1)

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1)This waste disposal information has been provided by A.L. Smith, Health Physics Division, NRDL.

CHEMICAL ASPECTS

Contamination of the marine environment immediately raises the question: How does the contamination affect man? Can salt water still be used for fresh water reclamation? Are the great seafood resources of the ocean affected? What information is needed on the disposition and form of radioactivities to properly evaluate the hazards?

First it should be pointed out that the mass of introduced radioactive isotopes will be small in comparison with the mass of normal isotopes already present. The physico-chemical properties of uncontaminated seawater will not be changed significantly except perhaps in the immediate vacinity of the detonation. However, are the radioactivities resulting from a detonation in the same physico-chemical form as the normal inert element? Unless they are, they probably won't be introduced into biochemical cycles in the same manner as the normally inert element. Such long-needed studies are currently in progress at NRDL by N. E. Ballou. This consideration emphasizes the need for a more detailed quantitative analysis of normal chemical processes in ocean waters as a precursor of studies on the biochemical and metabolic behavior of radioactive forms. The chemical form in which radioactive isotopes are held in water determines, in large part, the length of time they are maintained in ocean strata where greatest biological damage can be done. The chemical form also determines their availability to biochemical and biological cycles.

Sea water contains upward to 40 or more elements in solution. They range from chlorine in the amount of 18,980 mg/kg, to phosphorus in the amount of 0.001 to 0.1 mg/kg, to radium of which there is 0.2 to 3 x 10^{-10} mg/kg (dissolved gases excepted). The natural radioactivity of ocean water is due to the presence of K^{40} (estimated total tonage 6.3 x 10^{10} with total activity of 4.6 x 10^{11} curies), C^{14} (56 tons and 2.7 x 10^{8} curies), Rb^{87} (1.18 x 10^{11} tons and 8.4 x 10^{9} curies) with lesser amounts of U^{238}, U^{235}, and Th^{232}, and Ra^{226} in smallest amounts (4.2 x 10^{2} tons and 1.1 x 10^{9} curies).

Sea water also contains particulate matter of organic and inorganic origin that plays an important role in the metabolism of the sea. Certain of the nutrient elements (e.g. phosphorus) fluctuate periodically as a result of metabolic uptake. Also, there are seasonal variations in the amounts of particulate matter present.

These considerations are basic to an appreciation of the chemical forms of radioactive contaminants, and the ultimate disposition of the added radioisotopes and particulate debris from artificial radioactive sources. Added materials may persist in solution in colloidal form or in the form of suspended particles. Some dissolved substances may be precipitated by sorption on the organic or inorganic particles already present. All forms of added material--dissolved, colloidal and particulate--enter the marine biochemical cycles. Some added materials remain a long time without damage to the food chains, some remain varying times with deleterious effects, some settle after varying periods to the bottom and are, in the main, lost to the food cycle.

As stated above, the chemical forms of added materials, their availability to food chains, and also their longevity are primary considerations in respect to <u>natural</u> contributions as well as <u>artificial</u> radioactive contributions from weapons or reactor wastes. In regard to natural conditions, periodic pier samples in Chesapeake Bay showed an abrupt decline in the concentration of inorganic phosphorus during the early fall. This decline was accompanied by a marked reduction in turbidity (15). Unfortunately, analyses for dissolved organic phosphorus and particulate organic phosphorus were not obtainable and so the decline was not explained. To understand horizontal, vertical and diurnal variations in inorganic phosphorus, it is necessary to measure the organic phosphorus content in relation to sorption on suspended solids.

Hayes and Coffin (4) accounted for the disappearance of radioactive phosphorus from water partly on the basis of sorption onto suspended solids. Part of course is removed by phytoplankton. Revelle (23) found the base exchange capacity of Pacific Ocean clay to be relatively high and to increase with decreasing particle size. Carritt and Goodgall (1) compared the number of H_2PO_4-ions in contact with an imaginary surface of unit area with the number of ions on the same area of solids. They calculated that if this phosphorus lost to the particles were distributed as a monolayer on the solids, there would be 9.2 x 10^{14} ions/cm^2 or an accumulation of over 10^4 times that in the bulk of the solution. Emphasis was placed on the apparent diffusion-controlled reaction that appears after adsorption equilibrium is established. The uptake of phosphorus from solution varied with salinity and with clumping of the suspended particles.

Thus, from the standpoint of biogenic metabolism in the sea, it is important to understand the rate of regeneration of phosphorus from the sorption complex in relation to environmental conditions and contact time. These poorly understood natural phenomena, such as absorption, have an important bearing on the ultimate disposition of artificial radioactive materials in sea water.

Of course the mass of radioisotopes originating from weapon tests is small relative to the existing amounts of normal isotopes in normal ocean water. The artificial radioisotopes exist as soluble and insoluble fractions. At NRDL, Greendale and Ballou (3) simulated the conditions of an underwater explosion and determined the distribution of certain fission product elements in terms of ionic, colloidal, and particulate states. The purpose of their extensive investigations has been to provide an estimate of the physical state of selected fission product elements following their underwater vaporization. It was early recognized that knowledge of the physical state of elements following a nuclear detonation is needed to understand the nature and extent of contamination, to provide information for preparing synthetic contaminants, to estimate radioactivity distribution, and among other things to provide useful information for evaluating biological hazards resulting from underwater atomic bomb detonations.

The elements studies were either those important at relatively early times after burst or those which represent the chemical group of such elements. The temperatures used were sufficiently high to convert all compounds into their constituent atoms.

Some of the results of the Greendale and Ballou measurements of the behavior of fission product elements in distilled water as well as synthetic seawater are presented in TABLE I slightly modified from TABLE I of their 1954 paper. Most of the elements listed in the table have important fission product isotopes. In the seawater solution, the elements iodine, strontium, antimony, and cesium were mainly in the ionic state with tellurium less ionic. Molybdenum was present chiefly as a colloid or particulate while the other elements, namely, cerium, niobium, ruthenium, yttrium and zirconium were essentially particulate. Whether the solid fractions are chemical precipitates or are produced by accumulations within organisms, they will tend to settle out. Certain ones, such as cerium-144, may be taken up by plankton organisms thus retarding their rate of deposition and slowing down the rate of removal of radioactivity from the water. The data in Table I refer to the particular conditions of concentration, temperature, and time indicated. Situations in which the variable conditions are different may well give altered behaviors.

The permanence of the fractional activities resulting from the ionic, colloidal and particulate forms of radioactive isotopes is poorly understood. It is recognized that the distribution of

elements between the fractions that are in these three respective forms may change with time. The nature of the equilibrium state between the three fractions and the exposed organisms remains to be disclosed. Detailed explanation must await more refined technics and more concerted effort.

TABLE I Physical State of Selected Fission Product Elements Following an Underwater Vaporization (After Greendale and Ballou, (3))

Element	Physical State (per cent)					
	Ionic		Colloidal		Particulate	
	Seawater	Distilled Water	Seawater	Distilled Water	Seawater	Distilled Water
Niobium	0.15	1.5	0.3	0	99.5	98.5
Yttrium	0.3	1.4	4.4	16	95.5	83
Ruthenium	0.3	1	4.7	4.5	95	94.5
Zirconium	1.2	1	2.5	4.4	96	95
Cerium	1.8	0	4	1.7	94.5	98.7
Cesium	70.5	50.5	7	38	22.5	11.5
Strontium	87	5.5	5.8	13	20.2	81.5
Iodine	89	81	8.5	14.3	2.3	4.5
Anitomy	73	3.5	14.5	55.5	12.5	41
Tellurium	45	21	43	65	12	14
Molybdenum	30	46	9.7	-	60	54

BIOLOGICAL ASPECTS

Considering the biological conditions that are affected by radiological contributions to the sea raises the question: what is the scope of this consideration? Broadly speaking, it covers the study of overall productivity of ocean waters. Here, recognition is given to the various productions of nannoplankton, phyto - and zoo-macroplankton, bottom fauna, fish and so forth. These primary productions are not all, however, since the mineralization processes also lead to organic production, e.g., by bacteria. Clearly, the amount of organic production per unit of time is a function of many variables that differ in the several trophic levels of the sea. Because of uncertainties arising from use of the productivity concept, some hydrobiologists such as Ohle (16) prefer to consider the energy cycle rather than the quantities of organic matter involved in the various life processes. All biogenic transformations of organic matter vary significantly in different strata. The energy flux measuring the productivity of the organisms in the surface layers may be very different from that characterizing the pycnocline, for example. It becomes important to understand how the flux of carbon is affected by artificial radioactive materials at the several trophic levels. This affords an example of more detailed approach to oceanic processes mentioned at the beginning of this discussion. The biological impact of radioactive materials is something more than just the uptake and accumulation of elements in organisms although, admittedly, this is one of the better known and more readily measured processes.

Brief consideration here may be given: (1) to an enumeration of the isotopes that are concentrated most in marine organisms, (2) to the relation of biological concentration to dispersal and transport of radioactive materials in the sea, and (3) to certain radiobiological findings by NRDL from studies in the Marshall Islands.

(1) The activity of a radioisotope in a plant or animal is a function of the ability of that organism to concentrate the isotope. Results of the June 1956 survey of radioactivity in the sea near Bikini and Eniwetok Atolls during the Spring 1956 test series of detonations showed that the average value of radioactivity in plankton was 71,000 d/m/g (wet), the range being from 1,300 to 1,100,000 d/m/g. This average activity proved to be 7,100 times the average for surface water. The plankton tows were made throughout the surface layer of mixed water to a depth of 200 meters (2). There is no reason to believe that the ability of an organism to concentrate the radionuclide differs from its ability to concentrate the stable counterpart of the radioisotope. Stable strontium and

stable calcium are bone seekers and their radionuclides are likewise bone seekers. Iron, phosphorus, iodine, zinc, and copper are concentrated in marine organisms by factors as high as 20,000 for phosphorus in non-calcareous algae and 2 million in vertebrate skeletons (10).

Usually, radioisotopes taken up by the primary producers such as diatoms, at the first trophic level, are mainly but not entirely in the ionized state. Radioactive particulate matter is concentrated principally by the primary consumers, the herbivores including entomostracans, at the second trophic level. Weapon test data have revealed that principal concentrators of particulate radioactive materials were mucous, ciliary and pseudopodial feeders among the zooplankters. Thus it is seen that concentration characteristics differ from one trophic level to another, from one species to another within the same trophic level. Krumholtz (9) has demonstrated that differences exist between individuals of the same species. Such individual differences are, of course, not necessarily significant in that they might be explained on a purely ecological basis. The carnivores are the secondary consumers and therefore all in the third trophic level.

(2) Regarding the role of organisms in transporting radioactivity in the hydrosphere, it is clear that the magnitude of the concentration factor determines, in considerable part, the transport from one trophic level to another. There is bound to be a loss in the transfer and likely a dilution effect depending upon the growth of the population and the constituent organism. Transfer over long distances due to fish movements is readily appreciated. No less important perhaps is the vertical transport by plankters from one stratum to another assuring, for example, a wider spread of exposure to secondary consumers. Conversely, long-lived animals such as certain fish and shellfish retain their accumulation of radionuclides in hard parts of the body until the animal dies and in some instances until long after death. Hence, other animals in the biosphere are protected to some extent at least against exposure. Involved are a whole complex of factors and considerations that dictate biochemical and biological analyses in great detail. Complicated food chains must be understood on a quantitative basis to properly evaluate the hazards from dispersal by these agents.

(3) Having mentioned briefly the radioisotopes that are concentrated most in marine organisms and the overall significance of this concentration to localization and distribution of activity, it may be of interest to review certain variations in activity with time following a detonation. The Marshall Islands were contaminated by the fallout from the March 1, 1954 nuclear detonation of Operation CASTLE. A number of institutions have conducted biological surveys of the area in subsequent years. One of these is NRDL. Rinehart, et al, (20) in their studies of the Islands proper 16 months following the detonations, included radiochemical analyses of the water and organisms in the adjacent inshore areas. These analyses were for Sr^{89,90}, Zr^{95}, Ru^{106}, Cs^{137}, and total rare earths, since these fission products comprise the bulk of the activity remaining after 16 months. Analyses of the large fish (> 150 g) showed that 40 percent of the total activity was in the skeleton. Muscle tissue contained about 15 percent of the total internal activity and the viscera contained 20 percent. The remaining activity was found in the gills and skin.

A comparison of the activities of the fish and clams collected at one year post-detonation and at one-month thereafter revealed that at one month the concentration of internally deposited fission products was 5 to 10 times that of fish collected at one year. They obtained some rather specific data on the extent of change in relative concentrations of activity in different organs of the fish. Clams contained considerably higher concentrations of radionuclides than fish from the same area.

Samples collected two years after the detonation of 1954 showed that the activity in fish was still almost 25 percent of that at one-year post-detonation and the tissue distribution of activity was relatively unchanged. However, there was no detectable activity in the ocean water, and only a small amount of strontium 90-about 200 d/m/liter-in the lagoon water. The beta-to-gamma ratio in whole fish approximated 1:2 in contrast to the 1:4 ratio at one year post-detonation. This 1:2 ratio is approximately the ratio of the beta-to-gamma activity of zinc-65, which is the principal radionuclide found in fish. Physical and radiochemical analyses of a number of fish showed that the high gamma-to-beta ratio was accounted for by the gamma from the induced activity, Zinc-65. The manner in which this induced activity is concentrated was not determined (25).

Significantly, the concentration of strontium-90, one of the longest lived fission products (25 years), was very low, contributing only a fraction of one percent of the total beta activity.

A most significant new finding was the presence of cobalt-60 in two samples of clams, _Tridacna gigas_. It comprised the major fraction of their total activity. Again at NRDL, Weiss and Shipman (26) investigated further this unanticipated occurrence of cobalt-60. The occurrence is noteworthy since cobalt-60 is not a fission product. It was assumed, therefore, that this nuclide was induced from an environmental precursor by the neutron flux accompanying the nuclear detonation. Cobalt-59 was advanced as a possible precursor since, when bombarded by neutrons, it undergoes the typical $(n\gamma)$ reaction to form cobalt-60. The accumulation of cobalt-60 from an environment that seemingly was infinitely dilute suggests that these clams possess an enormous capacity for concentrating this particular radioisotope.

SUMMARY

This discussion has reviewed cogent viewpoints and findings of investigators who are studying the problem created by artificial radioactivity in the sea. These studies are retarded by the all too fragmentary state of existing knowledge of physical, chemical, and biological processes operating under natural conditions in the ocean. While the addition of artificial radioactivity to sea water creates new problems, it possesses a potential, still inadequately explored, for contributing to the solution of long recognized problems.

This discussion has stressed the need for replacing generalized knowledge of ocean processes and environmental factors with detailed analyses of basic principles that underline interactions between physical, chemical and biological factors.

It has been indicated that detailed information is needed: (1) on the varied types of water movement, (2) on the age and stability of water layers, (3) on the factors determining horizontal and vertical dispersion of radioactivities, (4) on the physicochemical form of radioactivities resulting from a nuclear detonation, (5) on quantitative aspects of normal chemical processes in sea water as a precursor of studies on the biochemical and metabolic behavior of radioactive forms, (6) on the permanence of the fractional activities resulting from the existence of fission products in water in ionic, colloidal and particulate states, (7) on the nature of the equilibrium state between these three fractions and the organisms exposed to them, (8) on uptake and retention time of radioisotopes by organisms in different food chains, and (9) on the relation of biological concentration to dispersal and transport of radioactive materials.

Information on the amounts of radioactive wastes from land installations that are disposed of in the ocean has been summarized briefly.

Worthy of repetition is the fact that the present sparsity of detailed information outlined here does not permit an overall realistic evaluation of potential radiological hazards to man in the marine environment. These hazards may result from desirable uses of ocean waters contaminated or in danger of being contaminated by radioactive wastes. Continued uses of the ocean for food and, presently on a very limited scale, for radioactive waste disposal are necessary. Greatly expanded uses in the future are imperative even by conservative estimates of developments in the field of natural resources. Therefore, needed research on the oceanographic and ecological problems outlined here should not be postponed.

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RESEARCH TRENDS IN MARINE PROPULSION

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The remarks which follow will attempt to report activity of significance in the broad field of marine propulsion. All aspects of this field are considered except nuclear propulsion, which is treated in a separate paper. There will be reported here programs relating to surface and subsurface vehicles; manned vehicles and unmanned vehicles (weapons); whole propulsion systems and individual components. Organization will be by specific projects, with an effort made in conclusion to discern significant trends. Apology is made at the outset for generalizations, made in the interests of brevity, which may offend the informed specialist.

Turning first to power production devices, it is perhaps surprising to find steam receiving research attention at this late stage in its development. In cooperation with the ASME, more accurate thermodynamic data are being obtained at extreme temperatures and pressures. In response to the general demand for decreased specific weight and volume of prime movers, a 200 HP reciprocating condensing steam engine has been built which weighs but 2.2 lbs/H.P. complete with its high pressure flash-type boiler and accessories. This engine is being installed in a 28-foot plane personnel boat and will be thoroughly tested at E.E.S. Its quiet operation, coupled with low cost and reasonable fuel economy (0.77 lbs/HP-hr), recommended it.

The gas turbine engine is finding rapidly expanding application in the propulsion of fast surface craft where low specific weight and volume of power plant are mandatory. Current research aims primarily at the refinement of components of the familiar constant-pressure combustion engine with the objective of further reducing weight, size, and cost and improving efficiency. Some significant work is also being done on constant-volume cycles. Radial inflow turbines have been in volume production for several years, but until very recently no effort had been made to exploit their theoretical capability for reverse-direction operation. This capability has been demonstrated within the past few months at the initiative of the Bureau of Ships, using the mechanically simple arrangement shown in Fig. 1. Compared with an efficiency of 80% in the ahead (or designed) direction of rotation, an efficiency of 52% was realized in the astern direction, a figure quite adequate for propulsion applications, with the reverse gear accordingly eliminated. With the practicability of this feature established, additional

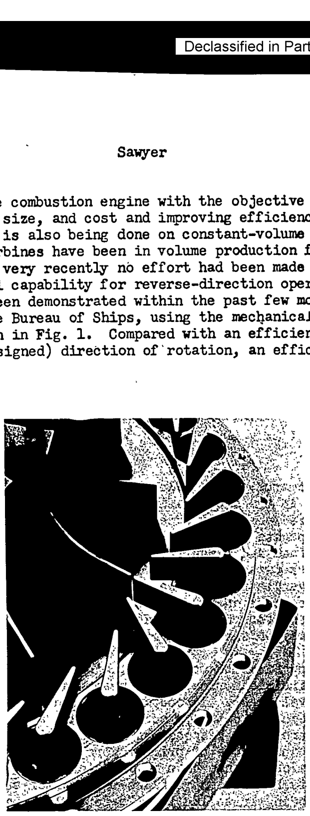


Fig. 1 - Radial Inflow Gas Turbine
Wheel and Reversing Nozzles

research will be required to optimize nozzle and blade shapes to meet particular requirements.

Recent developments in aerodynamics have resulted in higher pressure ratios per compressor stage and higher compressor efficiencies. Transonic-type axial compressor designs operating under conservative conditions show good efficiency and a reduction in size and cost, while achieving the relatively high pressure ratio per stage of 1.3. Effect on overall engine size is a reduction on the order of one-third.

Research efforts continue in the direction of cooling hottest components of gas turbine engines. With the theory rather well established, a single-stage water-cooled turbine with blades of low alloy steel has been successfully tested at gas temperatures over 1700°F. It has been concluded that the mechanical problems associated with liquid conduction cooling are not as complex as originally atticipated. The higher allowable temperatures of a cooled turbine will reduce engine specific weight and specific air consumption while permitting a simultaneous reduction of critical material content. An alternative to conduction cooling is transpiration cooling, for which the development of suitable porous structural materials is required. For this purpose, work is in progress on the development of production methods, including the sintering of metal powders and formation of blades by wire-winding to produce a material known as Poroloy. Blades produced by the latter process will shortly be tested in a jet engine. Transpiration cooling also shows promise for combustion chamber cooling, and solution to this problem is being accelerated by the efforts in the missile field to achieve rocket nozzle cooling by the same means.

In the materials field, both fiberglass and aluminum-iron-molybdenum alloy known as "thermenol" have been shown feasible for compressor blades. The fiberglass blades are made of reinforced fiber held together with phenolic resins. They are molded under high pressure and prestressed to four times design stress. The blades weigh only 16% as much as steel and 40% as much as aluminum, with a resultant drastic reduction in centrifugal stress. Vibration damping qualities are much superior to metal. Operation at 500°F for 750 hours has been demonstrated. Tensile strength is on the order of 80,000 psi.

Thermenol shows an ultimate tensile strength of 53,000 psi at 1200°F and is essentially equivalent to AISI type 403 stainless steel as a compressor blade material, while having lower density and superior corrosion resistance. It can be rolled, forged and extruded.

Small turbine wheels have been successfully fabricated with a cermet (titanium carbide in a nickel matrix) and will be spin tested at 2000°F.

We now turn to some less conventional power sources, the first of which is the continuous-feed primary battery which converts chemical fuels directly to electric power. Such batteries have been operated successfully on a variety of fuels and are attractive for underwater propulsion for two reasons: (1) In principle they should be capable of very quiet operation, particularly if gases are used for both fuel and oxidizer; (2) They are economical of fuel, electrochemical conversion of fuel to power being about twice as efficient as burning the fuel and using the combustion products to drive an internal combustion engine. The latter point is illustrated in Table I.

TABLE I

SPECIFIC FUEL CONSUMPTION OF SUBMARINE PROPULSION SYSTEMS①

Type System	Consumables (Storage State)	Spec. Fuel Consumpt. lb/HP-hr	Spec. Fuel Consumpt. ft³/HP-hr②
Diesel; closed cycle	Diesel oil; Liq. O_2	2.6	0.041
Diesel; closed cycle	Diesel oil; H_2O_2	5.0	0.066
Primary Battery	Sodium; Liq. O_2	1.4	0.022
Primary Battery	Sodium; H_2O_2	1.8	0.025
Primary Battery	Liq. H_2; Liq. O_2	0.8	0.029
Primary Battery	3000-lb gaseous H_2 -Liq. O_2	0.8	0.122

NOTES: ① Figures relate to gross power developed by plant and do not take into account parasitic power which may increase SFC for given SHP requirements.
② "As-stored" volume.

Research in the field of primary batteries has been underway for at least five years. The system which has received the most attention from the Navy uses sodium metal (carried in a mercury amalgam) as the fuel and oxygen as the oxidizer, although several other combinations of fuels and oxidizers are possible. The principle of operation is shown schematically in Fig. 2, which shows the promising materials oxygen and hydrogen as the consumables. It is recognized that there are many difficulties associated with such systems which remain to be resolved before they are ready for practical application. Sodium and mercury as battery components introduce a logistic problem and require even more careful handling than liquid oxygen or hydrogen peroxide, materials which were accepted aboard ship only with reluctance. Problems are also associated with the weight compensation of these materials as consumed by submarines. These and other obstacles are recognized and are being overcome at an encouraging rate. There appears to be nothing in principle to prevent practical application of the device after further development along clearly defined lines.

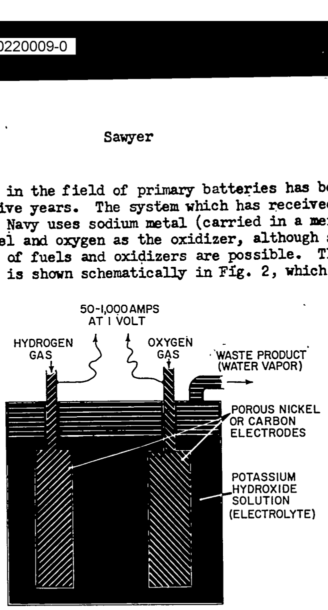


Fig. 2 - Schematic Diagram of Primary Battery Cell

More recently, a regenerative type primary battery has been successfully operated on a laboratory scale. This type requires no consumable materials in the battery circuit. Heat addition alone (at 700°C) is required to restore the reacted fuels to their useful states by recirculation after they have reacted chemically to produce electricity.

In the field of torpedo propulsion, an aggressive research program is being supported by the Bureau of Ordnance and its field activities. Most present-day submarine-launched service torpedoes use alcohol as a fuel with either compressed air or hydrogen peroxide as the oxidizer, the products of combustion being cooled by the injection of fresh water to an acceptable temperature for passage through a turbine which drives the propeller. The weight and volume of the fresh water diluent represents a sizeable fraction of the total power plant requirements. Widespread research effort has long been directed toward elimination of the requirement for carrying fresh water by finding means to make possible the use of sea water. Very recently, apparent success in this regard has been achieved by the Naval Underwater Ordnance Station at Newport by the injection of solium oleate (liquid soap) at the rate of 3% (by weight) of the sea water. The significance of this achievement extends beyond the almost complete elimination of the weight and space now occupied by fresh water carried as a diluent, because it makes practicable for the first time the use of much higher energy fuels. These would previously have required carrying of prohibitive quantities of fresh water diluent.

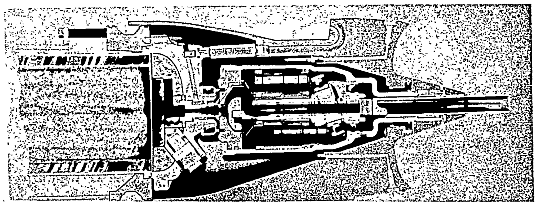


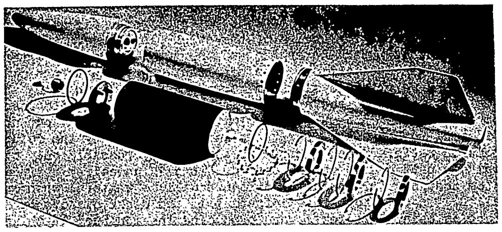
Fig. 3 - Solid Monofuel Torpedo Power Plant with Counter-Rotating, Reciprocating Engine of the Swash-Plate Type

In the interests of achieving greater simplicity and reliability of torpedo power plants and of reducing the maintenance and checkout requirements, solid monofuel systems are receiving attention. Successful tests have been made of power systems similiar to that shown in Fig. 3. The heat source is a solid cylinder, or

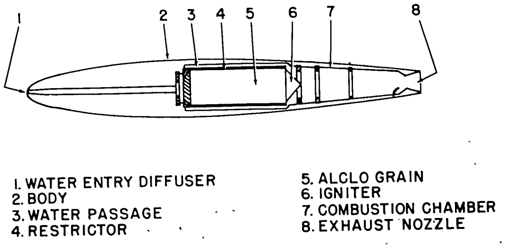
grain, composed principally of ammonium nitrate (oxidizer) and methyl acrylate (fuel). Gaseous products of combustion formed at 2200°F and pressures ranging from 1100 to 2000 psi are passed directly through either a reciprocating engine of the swash-plate or cam type, or a simple turbine. Both the engine and the turbine are salt water cooled in this application. The resultant power plants are comparable in size and weight to systems in current use, while enjoying the advantages mentioned above. Some increase in burning rate results from an increase in back pressure with increasing depth, but not sufficient to compensate for the power loss caused by the reduced gas expansion ratio. Speed control is accordingly possible only by dumping a part of the gas generated. This is undesirable since a system designed for operation at depth will be wasteful when running shallow. In an effort to eliminate this and other disadvantages, effort is being directed toward producing the monofuel in thixotropic form, i.e., as a material possessing some of the characteristics of a solid and some of a liquid. Such fuels could be stored as solids but pumped, valved, and burned as liquids, thus permitting speed control at varying depths without waste of fuel.

The water analogy of the familiar air-borne ramjet engine offers interesting possibilities for short-duration, high speed propulsion, especially for underwater missiles. This device might also be used in vessels to provide an emergency capability somewhat analogous to the use of jet assist for aircraft take-off. It consists simply of a non-water-reactive solid propellant, a mixing chamber which is pressurized by ram intake of sea water, and an exhaust nozzle through which the products of combustion (solids) and steam formed from sea water are ejected, producing thrust. Figure 4 illustrates this arrangement in an underwater missile called a "hydroduct". A 4½ inch diameter model of the hydroduct, burning a potassium perchlorate-aluminum mixture known as "alclo", has been exhaustively range tested for ONR and has shown notable ballistic accuracy at a speed of 120 knots.

As the hydroduct achieves greater depth and the back pressure increases, the steam velocity decreases and the thrust of the system deteriorates until the power plant becomes inoperative. This characteristic imposes an effective depth limitation of some 300 feet. By condensing the exhaust at an appropriate point, it is hoped that a low back pressure on the steam nozzle can be maintained, and the performance of the missile improved and made relatively insensitive to depth. Since the exhaust of the alclo hydroduct is completely condensable, a direct-contact condenser can be applied



(A) Components



(B) Assembly, Schematic

Fig. 4 - Alclo Hydroduct Test Missile

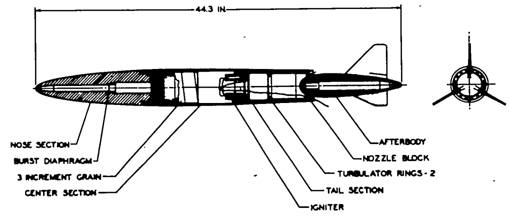


Fig. 5 - 4.5 Inch Alclo External Condensing Hydroductor Test Missile

to the system. In this configuration, shown in Fig. 5, the device is termed a "hydroductor".

Study and testing of the external-condensing hydroductor is being actively pursued. From the results of studies on the condensing of steam jets, it appears that this type of hydroductor is feasible. Under shallow-water operating conditions, the motor runs as a hydroduct. When the ambient back pressure increases due to greater operating depth, the external steam cavity is made shorter because of the increased pressure. The flow pattern changes under these conditions, so that some of this pressure may be recovered on the afterbody of the missile. Reduced drag results.

Recognition of noise level as an important military characteristic of naval propulsion plants has been an important factor in reawakening interest and research effort on thermo-electric generators. The thermo-electric generator is a device for converting heat directly to mechanical energy. It utilizes phenomena which have been recognized for years, among them the Seebeck effect, which consists of the appearance of an EMF at the terminals of an electric circuit formed from two dissimilar materials whose junctions are at different temperatures. The magnitude of the EMF is proportional to the temperature difference and the relative thermo-electric powers of the two materials. Although this effect has been utilized for many years in measuring instruments, the energy conversion efficiency for known materials, notably metals, was so low that it was not feasible to generate significant power by this means. A field unit was produced for the U. S. Signal Corps in World War II, however, and a Russian product is in common use in that country for operating home radio sets in remote locations. Recent advances in materials and techniques now make thermo-electric power generation possible for specialized applications and show promise of developing into economically competitive systems for primary shipboard power. Even closer to realization are thermoelectric devices operating in a sense opposite to the foregoing--that is, when direct current is supplied to a circuit of these materials, one of their junctions becomes hot and the other cold (Peltier effect). Operating thus as a heat pump, thermo-electric materials may be applied to refrigeration and air conditioning systems, eliminating the need for compressors. They may also be applied to evaporators, cooling the condensing side and providing heat for evaporation. The advantages which one would envisage for such systems include absence of moving parts, noise, or mechanical wear, complete reliability, minimum maintenance and operating costs, and possibly a reduction in plant weight and space requirements.

The limitations for power generation at present are relatively low efficiency (8% or less overall) and the need to develop new designs and fabrication techniques. Improvement in efficiency depends in part upon development of materials capable of operation at high temperature differences. Programs active in the Bureau of Ships and elsewhere on mixed-valence transition metal compounds and refractory semi-conductors are expected to result in efficiencies of 15-25% and to develop workable fabrication techniques. A 5 KW pilot plant is scheduled for test in 1959, followed by construction of a propulsion generator.

A series of electro-magnetic pumps producing jets of sea water might, in combination with a thermo-electric generator, propell a noiseless submarine of the visionary configuration illustrated in Fig. 6, which would have virtually no moving machinery.

A full appreciation of the extent to which creative imagination is being brought to bear on the problem of naval propulsion cannot be gained without reference to an effort to utilize the forces of nature in a manner extreme in its simplicity. This is the employment of the buoyant force to propell a submerged body. Such possibility arises in the case of a body released at depth, either from an initial position at anchor or from a submarine. Under ONR contract, a number of test vehicles, the first of which

Fig. 6 - Conceptual Design of Quiet Submarine Jet-Propelled by Thermo-Electrically Generated Power

is shown in Fig. 7, were extensively tested with primary emphasis upon their hydrodynamic noise characteristics. The vehicle illustrated was 29" in diameter and 168" long and had a displacement of about 3,000 lbs., a specific gravity of about one-tenth, and a drag coefficient of .063. Released vertically from a depth of about 150 feet, it reached a terminal velocity of about 60 knots in the

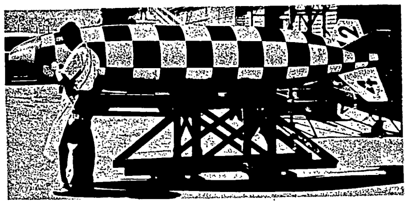


Fig. 7 - Buoyancy-Propelled Test Vehicle

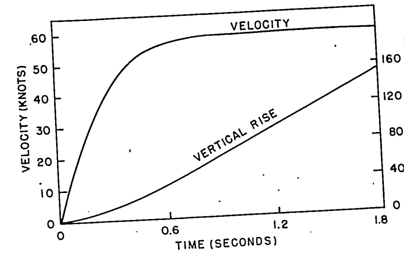


Fig. 8 - Flight Path/Time Relationships of Vertically Travelling Test Vehicle (SP.GR. 0.1)

manner shown in Fig. 8. Upon breaking the surface, this body rose slightly over 300 feet into the air, presenting a somewhat startling appearance (Fig. 9). To reduce terminal velocity, subsequent tests were made with smaller bodies (1000 lbs. displacement) with specific gravity increased to about three-tenths. These showed a terminal

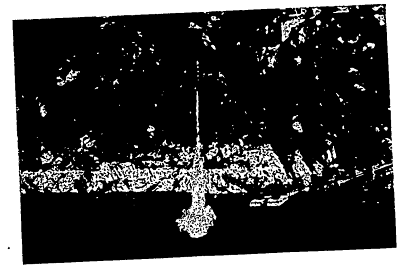


Fig. 9 - Water Exit of Buoyant Test Vehicle (SP.GR. 0.1) Released from 150 Foot Depth

velocity of 40 knots on vertical ascent and 30 knots at 38° glide angle (to the horizontal). Acoustic guidance by target noise was intended. Measured levels of hydrodynamic self-noise were unfortunately somewhat high for effective use of this type of guidance. This fact and the non-discriminating character of the device have led to suspension of effort to adapt it to a weapon system.

The second main subject area of this report is comprised of devices for application of mechanical power to propulsion. Propellers of the conventional type continue to profit from widespread research, so that today it is possible to design them with far better understanding of pertinent parameters (radial distribution of circulation, section shape, and effect of finite chord and hub) than was the case a few years ago. Evidence of the progress made is to be found in the significantly quieter operation of new designs without sacrifice of efficiency.

The supercavitating propeller (i.e., one designed to operate in a fully developed vapor cavity) has progressed from the laboratory stage to practical application. It is ideally adapted to the high rotative speeds which characterize gas turbines and other high-performance prime movers. For high vessel speeds (50 knots and above), its efficiency is distinctly superior to the conventional propeller. Although it merely matches conventional propeller efficiency in the lower speed range, possibility of improving this position by aëration is being investigated at DTMB. Noise characteristics are not as yet fully established. With scale effect in this field still indeterminate, full scale tests are required.

The term "guided flow propeller" may be used to identify a large family of propellers receiving current attention. A propeller operating in the familiar Kort nozzle shows to advantage when it is heavily loaded, as in tug or minesweeper applications--otherwise at a disadvantage. Enclosure in a tunnel stern has some usefullness in screening the noise of a conventional propeller and in improving uniformity of flow, but does not necessarily reduce cavitation. Only when flow guidance is carried to the extent found in a "pumpjet" do characteristics of broad naval interest appear.

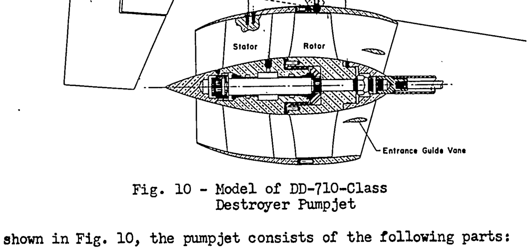


Fig. 10 - Model of DD-710-Class
Destroyer Pumpjet

As shown in Fig. 10, the pumpjet consists of the following parts:

1. An inlet section in which the flow is diffused or decelerated to provide the best compromise between cavitation resistance and propulsive coefficient for a given application, and in which the entering flow is turned parallel to the pumpjet axis.
2. A pumping section of one or more stages, each stage consisting of a rotor (or propeller) which imparts rotational energy to the fluid, and a stator which converts the rotational energy to static head.
3. A nozzle section wherein the head increase produced by the pumping section is converted to an increased exit velocity. The fluid acceleration may be wholly or partially internal.

The significant advantage shown by pumpjets is their quiet operation attributable to a delay in the onset of cavitation with increase in speed. From the point of view of efficiency, the pumpjet is at a slight disadvantage (about 5%) for normal operation, and at a very serious disadvantage (400%) when operating astern. Speed at which cavitation occurs is about 6 to 8 knots higher, however, providing

a significant military advantage. The delay in onset of cavitation results from increased pressure, lower relative velocity, and more uniform flow conditions at the propeller blades. Theoretical and model work on these devices has reached the stage where experimental verification is now needed at full scale. This will be possible with the installation to be made on a destroyer this year.

The propeller type showing to best advantage based upon current research is the counter-rotating. At DTMB, these propellers have shown both reduced noise levels and important increases in efficiency over other types. The optimum diameter is much less than for a single propeller. For the same diameter, set by practical limitations, the unit loading of blades is only half that of a single propeller, and the cavitation-free speed may be increased 40 to 50%. Propulsive coefficients on the order of 98% result from elimination of flow rotational losses experienced by single propellers, compared with an order of 81% for the latter. The related propeller efficiencies are 89% and 72% respectively. Imposition of counter-torque on the vessel hull is eliminated. Counter-rotating propellers integrate naturally with high performance counter-rotating prime movers, including electric motors and steam turbines being developed in the interests of weight reduction. Extention of application of these propellers may be expected.

One radical form of marine propulsion merits final mention. The high accelerations and high sustained speeds of certain fish have led to the supposition of very high "propulsive efficiencies" of these creatures. Biological research in progress for ONR has established this point. Carangiform, or "fish-tail", propulsion is receiving attention in several quarters, although not at the moment with naval support.

From the foregoing recitation of specific endeavors, certain trends in research effort related to naval propulsion appear. There is consistent emphasis upon reduction of size, weight, complexity, and noise of power plants, both conventional and new. Effort is being made to utilize both natural forces and the means of propulsion used by nature's creatures for our purposes. Exploitation of hydrodynamic analogies of systems developed for other media is active. There is a very promising general effort to use nuclear, electrical, or magnetic properties of materials to supplement or replace their mechanical properties. Reflecting a long-overdue reawakening of a national scientific consciousness, there is a general refusal to accept unsubstantiated limitations in all areas of technology and to gain an understanding of phenomena as yet unexplained, whether their areas of practical application are foreseen or not.

There must be no slackening, but rather acceleration, of the pace now established.

HUMAN LIMITATIONS IN NUCLEAR PROPULSION

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The propulsion of seagoing vessels has been altered radically from its inception to the present—from oars and wind to nuclear power. However, the human organism has undergone little or no alteration during the period. Granted that the human organism is somewhat more durable due to medical technology, it still has essentially the same requirements and limitations now as it had then. It requires nourishment and maintenance within a relatively narrow set of parameters. These parameters seem ever narrower when we consider the possibilities of modern mechanical equipment. Until we eliminate "on the spot" control of this equipment, we must carefully tailor it to the human being. This requires tremendous loss of efficiency, to the profound regret of scientific and engineering personnel. It is very unfortunate that we have a tremendous engineering capability and yet have to see it harnessed to a less efficient, but necessary component. This is true in all forms of propulsion—on the land, in the air and at sea. Aeroplanes themselves—not to mention rockets—already are beyond the capabilities of full human control.

At present the most obvious example of this human limitation is in our submarines' forces. Experiences with the NAUTILUS and SEA WOLF to date have proven the hardware, but also have pointed up the crew problem. With our conventional submarines we were forced to surface to recharge batteries, thus permitting the replenishment of the air supply. Prolonged submergence of our nuclear-powered vessels has brought us face to face with hitherto unencountered problems. Please note that I said unencountered, and not unexpected. For a simple example let us take the fact of smoking by the crew. This did not formerly constitute a problem or a hazard, but now there is a definite tendency to a build-up of carbon monoxide during long submergence with no air change. This, of course, showed that our previously satisfactory air scrubbers were not adequate for this newly-apparent factor. During the early work, new chemicals were introduced in the air scrubbers to increase the efficiency but, unfortunately, little positive information was available on the toxicity of these chemicals in confined spaces. The obvious and easy answer to the problem, of course, was to stop all smoking. But was this a good answer? After much deliberation this was felt to be impractical. Those of you who are smokers well understand this, I'm sure. In any case, it led straight to another reasonably new problem. That was the question of morale. We all know that morale is, and always has been especially high among submarines. But now we must ask ourselves if the human could maintain morale, and for how long, under prolonged submergence conditions. We must learn the answers to questions such as: How will the crew react to the absence of sunlight, limitations of fresh air and freedom of movement, and for how long? When will even the best of shipmates begin to get on each others nerves, and when will the fine edge of efficiency—so vital to a submarine crew—be lost? Operation HIDEOUT was a beginning toward an understanding of the problem but, of necessity, it was only a beginning. All the factors of habitability now assume a major importance. The colors of spaces, the opportunity for a bit of privacy for periods of time, actual physical comfort, as well as recreational opportunities, now become vital, not just desirable. These questions are being answered as time goes on, but we cannot say that they are all solved as yet. Nor can we say that they will be solved in the near future. As yet we have not had a trial period anywhere near the capabilities of our nuclear submarines. Somewhere along the line there will be a cut-off point determined solely by the crew, not the ship. It could even be the food supply, rather than the ability "to take it."

In passing, let us just briefly note the fact that there is very little information on the actual physical effects—from a medical standpoint—of prolonged submergence. For example, will the conditions adversely affect the ability of the body to resist infections or common colds? Will there be an alteration of function of various body processes to a degree sufficient to limit efficiency? We do not as yet know for certain—only time and experience will give us the answer.

Another problem of interest is the matter of personnel selection. Personnel have always been of a very high caliber; the objective was not necessarily to find supermen, but rather to select a type of man capable of efficient and dependable actions, having an ability to get along with his fellowmen under trying conditions. Now we must select this same type, but, in addition, there is the requirement to study and absorb advanced subjects as part of his training. How elite must this elite group be from a physical and mental standpoint? This obviously presents difficulties in manning from a military standpoint. Furthermore, not only does such a selection pose difficulties regarding numbers, but such a group could create dissention and morale problems among the rest of the Navy. Modest pride in self and service is an admirable quality to be encouraged, but would it remain at this level? This question is difficult to answer. Another aspect of this problem is attrition. Personnel selected early in the program were of such caliber that, during and shortly after training, many of them became eligible for a commission, thus depleting the already scarce enlisted ranks. Much has been done to improve the situation, but we must recognize it as a problem in personnel management.

In the field of toxicology we must again review our thinking and the state of the art. Tolerance limits are usually established on a working day, and work-week basis. Our exposures are on a 24-hour a day basis, with an unlimited number of days. Thus, all standards must be revised. Toxic products hitherto of little importance now assume a new stature. This is true because in earlier experience they did not have sufficient time to "build up" to hazardous levels. Now they may do so. Each and every agent aboard a submarine must be reevaluated. Radium has long been recognized as a serious hazard; yet it was freely used aboard submarines in luminous dials and markers. This was proper because the submarine had to surface at intervals short enough to prevent dangerous accumulation of radon gas. However, the NAUTILUS removed all such devices. The crew is even restricted to non-luminous wrist watches. Recently it was proposed that carbon tetrachloride be carried aboard a submarine to accomplish certain desirable radiochemical tests. Under average conditions the amount would be considered a possible risk, but not a real hazard. But on a long haul it might reach undesirable concentration levels in the air. Furthermore, we must also consider the production of hydrogen fluoride and hydrogen chloride as by-products of the combustion of freon which occurs in the burner for carbon monoxide removal.

Another simple, but important problem arose in the field of air conditioning. To be efficient, a man must function within certain narrow temperature parameters. We are all well aware of that, as well as we know that we have efficient air conditioners that serve us well; so why mention it? Simply because we have never been subjected to exposure to freon gas in such concentrations and for such long time periods as we now encounter. Can we tolerate the leakage of freon or must we seek a new refrigerant? This, briefly, gives you a rough idea of our new limitations in this field alone.

Let us now turn to the facet which perhaps you have been expecting to be the outstanding limitation. I refer to radiation exposure. Surprisingly enough, this has proven to be no limitation whatsoever. In fact, the classic statement is that you are better off aboard the NAUTILUS, submerged at sea, than you are ashore, because you are protected from the normal, ever-present background radiation. Many areas on the NAUTILUS are essentially free of any radiation at all. Even the so-called "radiation areas" are sufficiently low so as not to constitute a significant hazard, even on prolonged exposure. As a guideline, I will quote some figures recently given by the medical officer of the ship. Bear in mind that the presently-accepted exposure level is 15,000 millirem per year (or 15 Roentgens), and that the new proposed level is 5,000 millirem per year (or 5 Roentgen).

	Average Exposure per man per year
1. On NAUTILUS, 1955	173 mrem
2. On NAUTILUS, 1956	210 mrem
3. On SEAWOLF, 1957	204 mrem

(SEAWOLF data extrapolated from six (6) months' experience)

The maximum is thus only 1.4% of present standard and less than 5% of the proposed standard.

	Maximum Exposure Recorded
1. On NAUTILUS 1955	1438 mrem/year
2. On NAUTILUS 1956	2100 mrem/year
3. On SEAWOLF 1957 (extrapolated)	1126 mrem/year

Again considering 15,000 or 5,000 mrem per year, this is only 14% or 44% of permissible dose. Over 50% of the crew received no measurable exposure. The relatively high reading above was not received during operations, but is a result of maintenance work, in the lower reactor compartment, on radioactive components. There is greater hazard of exposure during upkeep periods in port than when the ship is operating at sea.

The relative increase in the exposure on the NAUTILUS from 1955 to 1956 is due to early plating of radioactive material within the system, and is not expected to increase to any substantial degree.

There is some small hazard present due to air borne radioactivity but this is readily controlled. It consists largely of argon present in the primary feed water make-up which is activated by a neutron flux. It is rapidly burned out. The concentration will depend on the amount of make-up feed water that is necessary. The prototype has been operated with a 100 gal/hour make-up with little hazard. An operating ship would not have such a leaky boiler.

It is thus evident that there is little, if any, human limitation from a radiation standpoint. The same or better conditions will, of course, prevail in our surface fleet.

One other potential limitation is that of contamination of the environment, with particular reference to enclosed waterways with limited circulation. Incidental to the operation of any water system, there is a certain amount of leakage which reaches the overboard discharge system. In this case, the leakage could be radioactively contaminated. However, operating experience on the NAUTILUS has shown that they stay well within the approved standards with no special precautions. If there should be above-standard amounts, it could be dumped into dock-side tanks or retained and dumped on the high seas, where it is rapidly diluted and dispersed. This has never been necessary. However, in all fairness, we must look forward to the time when there may be several nuclear-powered ships in the area. Perhaps other precautions will then become necessary. In this connection, it might be well to point out that seaboard States are becoming highly interested in this facet. Some are even imposing standards of their own for dumping in their own coastal waters. They are concerned in some cases with contamination of their water supply, or resort beaches. But mainly they are concerned with their oyster beds and fishing grounds. This is a proper concern and the Navy makes every effort to keep them informed on the subject. However, unfortunately, not too much is known about the up-take by sea life of radioactivity of the type associated with reactors. There has been research on the sea life of the Pacific Proving Grounds, but this involves bomb products. There is a great need for clarification in this area. At present we feel there is no hazard of any kind, but what of the future? It is very possible that States will impose operating conditions in certain waters which will seriously hamper a ship commander. Therefore, the most careful public relations must be maintained. There must be very close and cooperative liaison with interested State agencies to avoid unfortunate and unjustified restrictions.

As a side light on this issue, I might point out that, at a recent conference between BUSHIPS (Code 1500) and State agencies, a research problem arose which is indicative of possible future problems. The States felt that, since the Navy was releasing the radioactivity, it should do the research on sea life. The States did not feel they could afford the extensive research necessary, since they were not creating the possible hazard. The Navy, of course, could not undertake the program for all the States. So it becomes obvious that there must be a mutual agreement whereby all States involved and all interested government agencies will undertake a portion of this research to the mutual benefit of all. I am stressing this point because this area is of such a sensitive nature that any unfortunate remark or some ill-advised publicity could result in an embarrassing situation between the Navy and the States. The situation, of course, will be further aggravated when civilian ships begin to appear and thus further complicate the radioactive waste disposal problem. I believe it can honestly be stated that State authorities have the utmost respect for Navy operational methods. But will they have the same confidence in the relatively less-disciplined civilian crews? Although this may seem remote from our subject, nevertheless the restrictions will be as a result of effects on humans and may be considered as a human restriction in nuclear power.

For the sake of completeness, we must mention briefly the nuclear propulsion of aircraft, because here the human becomes a critical limiting factor. To shield the human, as we would like, would result in an unflyable aeroplane. Extremely delicate compromises are necessary. Although the Air Force is the prime investigator in the field at present, the Navy has the greater need and, indeed, the capabilities. Extremely large runways ashore in isolated areas are possible, but impractical. Many runways would be required for dispersal, if for no other reason. But the Navy has unlimited, essentially free, runways located throughout the world—namely the Seven Seas—not to mention lakes and rivers. Flights, with the ever-present possibility of accidents, would be on—and over—unpopulated water areas. Furthermore, the advantage of nuclear power is less in its speed than in its range. And the Navy has long maintained long-range, sustained reconnaissance by air. If, indeed, a large plane is required, unlimited water runways would be preferable to concrete runways. Parking and dispersal of planes would be more practical on water than on land. In the event of a major accident, it is far better to have the possible contamination in the sea rather than over a populated area. Thus, we again see the vital limitations imposed by human beings on the utilization of nuclear power. This is true not only of the military crews, but, indeed, of the civilian populace in the environment.

In summary, let me point out that I have not attempted full coverage of the field nor, indeed, full analyses of any of the limitations mentioned. I have only attempted to point out a few that have already arisen, and a few others that may arise in the future. These problems all require solution and, particularly, it would be far preferable to avoid and prevent them wherever possible.

I can only say that we are faced with necessity of wedding nuclear propulsion to a "horse and buggy" human body. The compromises will be many and the frustrations great. There is no question that nuclear propulsion is here to stay. Any small bit of new information you may discover will hasten an ultimate solution. Please keep in mind that there are many areas where no one is ahead of you. So we can carry on the Navy tradition of leading—not following.

POSSIBILITIES FOR REDUCING SHIP MOTIONS AT SEA

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Introduction

For many reasons the reduction of ship motions at sea is a desirable goal for both merchant and naval vessels. Usually the velocities and accelerations associated with motions in waves are particularly objectionable, and, for a given frequency of encounter, the maximum values of the velocity and acceleration components are directly proportional to the amplitudes of roll, pitch, heave, etc. Thus, motions may have a serious effect on the functioning of machinery, instruments, and gun-control devices. Furthermore, accelerations are believed to be primarily responsible for seasickness and frequently cause shipboard accidents to personnel. The reduction of motions, consequently, can be expected to improve the functioning of any ship.

The subject of ship motions at sea cannot be considered separately, however, from course and speed as motions invariably can be reduced by changing course or reducing speed. Since most ships at sea are usually trying to get somewhere as quickly as possible, either of these steps is undesirable. Hence, the greatest value of any measures for reducing ship motions may lie in attaining higher speed or more direct course in storm seas. Within the same upper limit of accelerations for safe and efficient ship operation, a vessel with better motion characteristics can either maintain higher speed or a more desirable course than another vessel in the same storm sea.

Other more indirect effects of ship motions on speed and performance in waves also should be considered. For example, in the case of a fully loaded cargo ship, shipping of water in head seas is a more serious threat to its safety and speed than motions or accelerations. Hence, an increase in freeboard or perhaps a modification in the forward flare may improve performance without making any change in the amplitudes of motions. Alternatively, a ship can be designed to cope with large quantities of water over the bow, as in the case of the new Canadian destroyer-escorts of the St. Laurent class (see Figure 1). This involves a clean foredeck, an effective breakwater for deflecting water overside, additional strength in the underdeck structure, and -- in the case of cargo ships -- strong watertight steel hatch covers forward. Such a ship could operate safely with more severe motions than a conventional ship.

In other cases, particularly when ships are not fully loaded, the critical factor in sea behavior may be slamming. It is significant that a comparatively fine ship with well-rounded bottom sections forward may slam less than another which actually pitches more violently. The former ship, consequently, may be able to maintain higher speeds than the latter in the same rough sea.

Nevertheless, in the cases discussed above, a reduction in amplitudes of motions would improve conditions by reducing both shipping of water and slamming, thus permitting higher sea speeds. The reduction of ship motions is, therefore, for many reasons an important goal for both commercial and naval vessels. Except perhaps for small hydrofoil craft which can rise clear of the surface waves and submarines which can go below them, research has not yet revealed any panacea by which ships can be made to go at high speeds in rough seas without objectionable motions of some kind. What can and cannot be done in this direction is the subject of the present paper.

This survey has been prepared in part under contracts Nonr 263-09 and Nonr 263-12, sponsored by the Bureau of Ships through the David Taylor Model Basin, and in part under contract Nonr 263-10, sponsored by the Office of Naval Research. Related experimental work (see Figure 2) at the Experimental Towing Tank, Stevens Institute of Technology, has been carried out under these same contracts and under contract N6onr 247-05.

Control of Rolling

Ship motions at sea are usually resolved into six components for study: the angular motions of roll, yaw, and pitch, the translatory motions of heave, surge, and sway. Some are more troublesome than others, but when one or two are reduced the others are apt to become more noticeable. Rolling has received particular attention ever since the days when steam replaced sails and the steadying effect of canvas was lost. Because of the fact that the forces involved in rolling are small, it has proved feasible to reduce these amplitudes drastically by the use of various anti-rolling devices. The simplest device is the bilge keel, which has been generally accepted in shipbuilding for many years. Its effectiveness can be explained on the basis of the theory that irregular storm seas contain many regular component waves of a wide range of periods superimposed on one another. Like a musician's tuning fork, a ship will respond much more violently to a particular wave period (or frequency) than to any other. This period is the natural rolling period of the ship. Consequently, most serious rolling occurs in the natural period of the ship and, therefore, may be classed as synchronous rolling. In any oscillating system, simple damping is always effective in reducing synchronous oscillation. This explains the reason for the effectiveness of the bilge keel: by increasing the damping of roll, it gives a marked reduction in serious synchronous rolling.

For moderate and high-speed vessels a much more effective method of reducing rolling appears to be controllable fins. Such devices are so effective that the rolling problem appears to have been solved in principle, except for low-speed vessels for which an activated tank or gyroscope system is applicable (see Figure 3). But this does not mean that further research is not needed, as roll control is not perfect. There are problems of the inter-action or coupling of other motions, particularly yaw, of obtaining increased effectiveness with reduced weight and cost, of avoiding structural failures of fin shafts, etc. Furthermore, the system for the control of roll needs to be co-ordinated with the steering system.

It is interesting to find that the more effective anti-rolling devices become, the more noticeable is the lateral motion of sway. When the beam of a ship is small in relation to the length of a wave, the ship partakes of the motion of the wave particles. Side sway is caused by the lateral component of the orbital wave motion shown in Figure 4. To cope with sway, Chadwick (1) called attention to the advantage in redefining the objective of roll stabilization in terms of stabilizing to the "apparent" rather than the real vertical ("Scheinlot" control in the German literature). As shown in Figure 4, the apparent vertical is the line of action of the resultant of the centrifugal and gravity forces, and in long waves this resultant is perpendicular to the wave slope. This simply means that if a ship is held to the apparent vertical it will have a sufficient heel angle at all times so that the thwartship component of gravity acting on any part of the ship or person aboard will exactly balance the lateral acceleration due to sway. An observer on board the ship then will feel upright because the lateral accelerations will not be noticeable. Only the vertical accelerations due to heaving and pitching (and small surging accelerations) will be apparent. Except for very short wave components, in which the true vertical is a better reference, apparent vertical control can be applied generally to roll stabilizers when comfort is the criterion. For some military applications the true vertical may be needed, and in this case the effect of sway cannot be

avoided.

Control of Other Motions

Considering next the use of rudders to control angular motion in the horizontal plane (yawing), the main objective of the helmsman or the automatic pilot usually is to maintain an average course for the ship without attempting to limit greatly the periodic yawing in response to the encountered waves. There appears to be little doubt that present-day steering gears and automatic control devices could be improved in this respect. Furthermore, yawing undoubtedly could be reduced if this were considered desirable or necessary. This would require a quicker rudder response and a more refined control system similar to that used for anti-rolling fins, as described by Schiff and Gimprich (2). Because of the strong coupling between roll and yaw, particularly in quartering seas, anti-rolling fins have a strong effect on steering. In fact, a ship actually can be steered by the use of anti-rolling fins alone. It would seem that the goal should be a single control system for the lateral motions of roll, yaw, and sway, operating side fins and stern fin (rudder) in the most effective manner.

Of the modes of motion in a longitudinal plane, surge involves comparatively small accelerations and usually is not considered objectionable, except perhaps from the point of view of propulsive efficiency. If control were to be attempted it would involve tremendous margins of propulsive power, quick response of power plant to demands for rpm change, and a control system based on longitudinal motions and acceleration. Nothing of this sort is known to be under consideration at the present time.

Heaving and pitching motions are the most difficult to overcome and are the most serious problem, since they involve large vertical accelerations and may cause shipping of water, slamming, and propeller racing. Furthermore, when other motions are controlled or reduced, they become even more noticeable. Consequently, the balance of this paper will deal exclusively with these "symmetrical" modes of motion, under the assumption that methods are available for solving the other motion problems.

To what extent can special devices, either active or passive, be effective in reducing heave and pitch? It will be easier to answer this question after considering these motions in a more general way and discussing the effects of hull proportions and form.

Nature of Pitching and Heaving

Ships are comparatively long, slender bodies, and the waves they encounter have lengths of the same order of magnitude -- some shorter, some longer. Hence, the forces involved are large, and no one has even suggested that one try to reduce pitching or heaving to near zero, as has been attempted in the case of rolling. However, there is a possibility of reducing the motions significantly and improving the phase relationships between motions and waves.

Research in regular head seas has brought three important facts into prominence (see Reference 3): (1) the amplitudes of motion are greatest in the vicinity of synchronism between the period of encounter and a ship's natural period of oscillation (see Figure 5), (2) phase relationships leading to wet decks and slamming also are characteristic of synchronism (see Figure 6), and (3) waves appreciably shorter than the length of a ship do not cause serious motions even at synchronism (see Figure 7). On the basis of these general facts, it appears that there are two directions in which significant reduction of pitching and heaving amplitudes can be sought: avoiding synchronism with waves of ship length or longer, and reducing the magnification effect which causes increased amplitudes near synchronism as shown in Figure 5. Each of these possibilities will now be discussed in turn.

Considering the avoidance of synchronism, it is obvious that in a regular swell this undesirable condition can be avoided by changing either course or speed. If the speed is changed, synchronism can be avoided by either an increase or a decrease. Regarding the speed for pitch synchronism as the critical speed, slowing down brings the ship into the subcritical range and speeding up into the supercritical range.

The velocity of a single deep water wave is given by the "celerity"

$$c = \sqrt{gL_w/2\pi} \quad ,$$

where L_w is the wave length, g is the acceleration of gravity, and any consistent units may be used (i.e., ft., lb., sec.) . Although wave celerity increases with wave length, it turns out that the period of encounter with head seas increases as the waves become longer. This can be seen from the following equation for period of encounter;

$$T_e = \frac{L_w}{v + c} = \frac{L_w}{v + \sqrt{gL_w/2\pi}} \quad ,$$

where v is the ship speed.

By equating the period of encounter, T_e, to the natural period of pitching, T_p, the critical speed, v_c, can be determined for any wave length. In non-dimensional form it is given by

$$\frac{v_c}{\sqrt{gL}} = \frac{L_w/L}{T_p/\sqrt{L/g}} - \sqrt{(L_w/L)/2\pi}$$

Or, with V_c in knots, L_w in feet and T_p in seconds,

$$\frac{V_c}{\sqrt{L}} = \frac{0.59\ (L_w/L)}{T_p/\sqrt{L}} - 1.34\sqrt{L_w/L} \quad .$$

This relationship is plotted in Figure 8 from Lewis (3). For other headings a simple cosine correction must be introduced. The above expressions defining the conditions for synchronous pitching show two things. First, the critical speed is higher the longer the wave length. Second, the critical speed in any wave length is higher as $T_p/\sqrt{L}$ is reduced.

When a ship encounters irregular storm seas, the situation does not remain so simple. Oceanographers have shown that storm seas can be considered as being composed of a great many regular wave trains, of varying length and direction of travel, all superimposed on one another.[8] They also have confirmed the observations of seamen that shorter waves are formed first in a storm. As the wind continues to blow, longer components are formed without seriously affecting the smaller components. For a particular wind velocity the sea reaches a limit when it attains its "fully developed" state. If the wind increases in strength, not only are the component waves believed to be higher, but -- when the fully developed state is reached -- longer components also will be present.

If a ship is able to attain a sufficiently high speed so that its period of encounter with the longest important wave component is shorter than the natural pitching period, the ship will be in the supercritical condition for that particular storm. Most ships can attain this condition only in moderately heavy seas, i.e., in light winds or in stronger winds of short duration. Hence, in general, whether or not a ship can attain the supercritical condition depends both on the sea state, as indicated by wind velocity and duration, and on the ship's natural pitching period. This is shown for the case of head seas in Figure 9 which is taken from Reference 3. At other headings the ship must reach even higher speeds to attain the supercritical condition.

Since short wave components are present in both severe and moderate storm seas, it is impossible to avoid synchronism with all component waves by reducing speed. However, model tests have shown that waves appreciably shorter than the ship do not cause serious motions even at synchronism (see Figure 7). Hence, speeds which are low enough to avoid synchronism with waves of ship length and longer generally lead to moderate motions. This condition may be termed the subcritical range, and for head seas it depends only on the ship length and the natural pitching period, i.e., on the ratio $T_p/\sqrt{L}$ as shown in Figure 8. All ships must at times reduce speed in storm seas to attain the subcritical condition. For seas approaching off the bow instead of from directly ahead, still lower speeds are required to attain the subcritical condition. The reason for this is that the effective wave-length increases as the heading angle to the waves increases. However, wave steepness is reduced on an oblique heading, and, therefore, the net result may be an improvement. In following seas most ships steaming at ordinary speeds are always in the subcritical range. This explains the advantage of heaving-to with wind and sea astern, provided that the ship can be kept under control.

A High-Speed Subcritical Ship

It may be of interest to consider possible ship designs aimed specifically at subcritical or supercritical operation.

Destroyers are much-maligned ships. They are small, their calm-water speed is high, and their rolling characteristics are bad. Hence, they are ideal candidates for the installation of anti-rolling fins. However, it perhaps will be agreed that destroyers can safely maintain much higher sea speeds than other vessels of their size -- for example, small cargo ships. Violent motions in a rough head sea would cause both vessels to reduce power in order to ease slamming, to reduce shipping of water, or to cut down accelerations, but the safe speed of the destroyer would be considerably higher than the cargo ship. Likewise, at the same speed in the same head sea the destroyer would have less motion than the cargo ship. This advantage of the destroyer results from its low period ratio, $T_p/\sqrt{L}$, which, in turn, is a consequence of its slender proportions, as shown by a low displacement-length ratio, $\Delta/(L/100)^3$. In short, a destroyer can attain higher speeds in irregular storm seas before encountering synchronism with wave components of its own length, i.e., before getting out of the subcritical range. This is explained more fully in Reference 3.

One way of reducing the amplitudes of motions is therefore to raise the critical speed. In order to do this for a ship of a given size (displacement) one must first reduce the pitching period as much as possible. This can be done by concentrating weights near midships and keeping the waterplane as full as possible. The second step is to increase the ship length and reduce the other dimensions correspondingly in order to make the ship as long and slender as possible (low $\Delta/(L/100)^3$). At the same time the freeboard should be increased roughly in proportion to length. The increase in ship length also may reduce the natural pitching period significantly. At any rate, both reducing T_p and increasing length serve to reduce $T_p/\sqrt{L}$; and Figure 8 shows that this permits higher speed before synchronism is reached with wave components of ship length and longer.

An example of one possible outcome of this trend is a "stretched out" destroyer recently tested at the Stevens Experimental Towing Tank under an ONR-sponsored project. The characteristics of this model in comparison with a typical destroyer are given in the following table. Lines and photographs of both models are shown in Figures 10 and 11, respectively.

	Destroyer	Lengthened Destroyer
Length on LWL, L, feet	5.720	7.200
Breadth, feet	0.608	0.535
Draft, feet	0.208	0.186
Displacement, pounds	24.5	27.7
Freeboard at bow, F, feet	0.280	0.350
Freeboard ratio, F/L	0.049	0.049
Longitudinal radius of gyration	0.24 L	0.26 L
Natural pitching period, T_p, sec.	0.60	0.92
$T_p/\sqrt{L}$	0.25	0.38

It is believed that heavy weights such as fuel bunkers could be concentrated more amidships than is usually done, provided special attention is given to the matter in design. This would be of further advantage in reducing $T_p/\sqrt{L}$ for the lengthened ship. Admittedly there would be many serious problems in the design of such a slender ship, particularly longitudinal strength and tranverse stability. It is assumed that anti-rolling fins certainly would be installed and would tend to minimize the problem of stability under way.

Ship motion studies suggest that further reduction in motions could be obtained by the use of more V-form sections forward, which would not only increase the damping but would tend to reduce the natural pitching period. Since destroyers have broad flat sterns, V-form forward sections also would provide better balance between the ends. Some increases in resistance could be accepted because the lengthened destroyer has significantly less ehp in calm water than the original design (about 40 percent less at 34 knots).

In order to compare the sea performance of these two ships, the following data obtained from model tests at the Stevens ETT in the same irregular head seas have been tabulated by Lewis and Numata (4). This sea pattern corresponded closely to that expected at sea when a 32-knot wind has blown steadily for about 18 hours.

Ship Speed, Knots	Ship	Dbl. Pitch Amplitude, Deg.		Dbl. Heave Amplitude, In.	
		Average	Average highest 10%	Average	Average highest 10%
0	Destroyer	5.3	10.8	1.12	2.28
0	Long Destroyer	3.5	6.5	0.65	1.39
12	Destroyer	6.7	13.7	1.64	3.33
12	Long Destroyer	4.1	7.3	0.82	1.71

The table shows that under comparable conditions the motions of the lengthened ship are appreciably less than the conventional destroyer. The accelerations also were reduced correspondingly.

A study of comparative tests in regular waves by Numata and Lewis (4) indicates that in a storm sea in which the conventional destroyer can attain a speed of say 20 knots the longer vessel should be able to attain at least 30 knots with equal amplitudes of motions, which is a 50 percent increase in speed. It should be recognized, however, that the vertical accelerations would be greater in the latter case because of the shorter natural pitching period of the lengthened ship. (Maximum acceleration = $2\pi S^2/T$, where S is the amplitude of motion). Consequently, the speed for equal accelerations is somewhat lower than 30 knots.

It will be noted that the freeboard ratio for the lengthened destroyer model was the same as the destroyer, and, as a result, the forward deck usually was dry in irregular tank waves. Because of the model's fineness, no difficulty in respect to slamming was encountered. In short, the long slender ship offers distinct possibilities for reduced motions in rough seas and, hence, attaining higher sea speed. However, there is obviously a practical limit on how long and slender a ship can be built.

A High-Speed Supercritical Ship

Another approach to the problem of reduced motions and higher speeds in rough seas is to strive for supercritical operation. This is a difficult condition to achieve, except in moderate seas, but the possibility is being explored at the Stevens ETT. The basic aim is to attain a long natural pitching period and high ship speed. The latter requirement means that a slender ship like a destroyer is needed for low resistance, but one not necessarily as extreme as the lengthened subcritical ship described above. Arrangement of ballast tanks and other heavy weights near the ends would help to lengthen the pitching period, but a very fine waterline would be even more helpful. In view of the fact that a ship in supercritical operation tends to plunge through the waves rather than to ride over them, it would seem to be unfeasible to attempt to keep water off the foredeck. Accordingly, a low freeboard and a heavily built deck would seem to be the best way to cope with the water and at the same time would permit a very narrow waterline. In short, an ideal ship would be a surfaced submarine made longer and more slender in order to attain high surface speed.

Figure 12 illustrates a possible design for a supercritical ship of this type. The normal waterline would be used for good weather operation, while in bad weather large peak ballast tanks would be filled for the purpose of lengthening the pitching period in several ways: by increasing the displacement, by increasing the radius of gyration, and by reducing the waterplane area. Anti-rolling fins also would be an important feature of this design. A model is being built to the lines of Figure 12, and it is hoped that preliminary test results will be available when this paper is presented. Characteristics of the model are given below in comparison with the typical destroyer. It is estimated that a 400-foot ship with an eight second pitching period might be expected to attain the supercritical condition in most storms at a speed of 40 to 45 knots (see Figure 9).

	Destroyer	Semi-submerged Ship *
Length on LWL, feet	5.720	5.720
Breadth, feet	0.608	0.540
Draft, feet	0.208	0.250
Displacement, pounds	24.5	24.5
Freeboard at bow, F, feet	0.280	0.100
Freeboard ratio, F/L	0.049	0.017
Longitudinal radius of gyration	0.24 L	0.30 L
Natural pitching period, T_p,sec	0.60	0.96
$T_p/\sqrt{L}$	0.25	0.40

*At deep draft for high speed operation in rough seas.

Many technical problems would be involved in the practical design of such a supercritical ship: very large power, sufficient interior space with a small deckhouse and large ballast tanks, how to obtain an adequate structure to withstand high impact loads, etc. Undoubtedly the problems could be solved if there were a military mission for a vessel of the following characteristics:

1. Very high speed in both calm and rough seas,
2. Small amplitudes of motions (rolling, pitching, and heaving), but fairly high vertical accelerations,
3. Possibly high impact and vibratory oscillations,
4. Limited space for crew accommodation, armament and equipment.

Ship Improvements in Critical Range

Practically all ships when heading into rough head seas at normal speeds soon find themselves in the critical range where synchronism occurs between the natural pitching period and a band of wave components of ship length or longer. Violent pitching and heaving motions, with high vertical accelerations, are then experienced -- along with wet decks and sometimes slamming. Slowing down, or turning and running away from the seas, will invariably bring the ship into the subcritical range wherein synchronism occurs only with component waves less than ship length. Motions are then more moderate and phase relationships are such that less water is shipped forward and slamming, if any, becomes less frequent. This raises the question as to what means can be applied in the design of a ship to reduce the amplitudes of motions when the ship attempts to operate in the critical range, assuming that the main ship characteristics and proportions have been settled.

If one is concerned mainly with the shipping of water and slamming, much can be gained by increasing freeboard, improving flare, reducing bottom flatness, etc. But for the reduction of motions, which is the subject of this paper, more drastic measures must be considered. It has been shown that the most violent pitching motion is generally in response to the near-synchronous wave components. Under such circumstances, as with any oscillating system, simple damping is an effective way to reduce motion amplitudes (see Figure 5). Two possible ways of doing this appear: modification of the hull form and installation of auxiliary devices.

Theory and experiment have shown that filling out the waterline is a hull form modification which is beneficial in reducing pitching and heaving. Hence, any increase of beam and use of more V-form sections are generally desirable steps in the design stage. Fortunately these measures also tend to shorten the natural pitching period, which raises the critical speed range slightly. Abkowitz (5) has shown that concentrating weights near midships increases the damping, as well as shortening the pitching period. Important as these effects are, the writer does not expect more than modest reductions in motion amplitudes by such means.

The use of external devices offers somewhat more promise than changing the hull form. The evaluation of different possibilities requires a consideration of the characteristic phase relationships between the motions at the ends of the ship and the encountered waves at synchronism. A study along this line at the Stevens ETT showed that the typical flow at the bow has a wide variation in direction during a motion cycle, so that fixed fins in this location develop large angles of attack. At the stern the direction changes are much smaller (see Figure 13). This means that fixed fins should be very effective devices near the bow but not at the stern, a fact which experiments have confirmed. On the other hand, theory and experiment indicate good potentialities for controllable stern fins which can develop high lift by adjustment of their angle of attack. The following table gives the amplitudes of motion for a Mariner model in waves of 1.3 model length and height 1/60 of the length at a ship speed of 15 knots with different fin arrangements:

	Double Amplitude, Degrees
No fins	7.4
Fixed bow fins	6.4
Fixed bow and stern fins	6.0
Fixed bow fins and movable stern fins	5.4

In the case of the movable stern fins, a sinusoidal motion was given by means of a motor, its phase being adjusted to give the greatest possible reduction in motion amplitudes. For such a device to be effective in irregular storm sea conditions an elaborate control system, of course, would be required.

Results of trials of fixed bow fins on the U.S.S. Compass Island, a converted Mariner, will be awaited with great interest.

Conclusions

Although the problem of reducing ship motions at sea is difficult, several directions for obtaining this end are available. Simple improvements in hull form or shape seem to be less promising than radical changes in proportions and other basic characteristics. These radical developments involve obtaining either sub or supercritical operation, if possible. In addition, fixed bow fins and/or controllable stern fins appear promising for ships which at times must operate in the critical pitching range, while anti-rolling fins already have brought the problem of roll and side sway near solution.

The author particularly invites comments as to the possible military value of the high-speed supercritical type of ship described in this paper.

Acknowledgements

Research at the Stevens Experimental Towing Tank referred to in this paper has been the joint effort of many staff members. In particular, the author wishes to acknowledge the contributions of Professor B.V. Korvin-Kroukovsky and Miss Winnifred Jacobs in theoretical work, and of Messrs. Edward Numata, John Dalzell and Clay Odenbrett in experimental work. The research has been carried out over a number of years with the active encouragement and advice of Dr. K.S.M. Davidson, Director, and Allan B. Murray, Assistant Director, of the Experimental Towing Tank.

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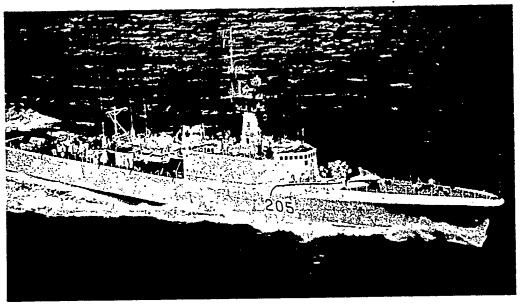

FIGURE I

Canadian Destroyer of the "St. Laurent" Class

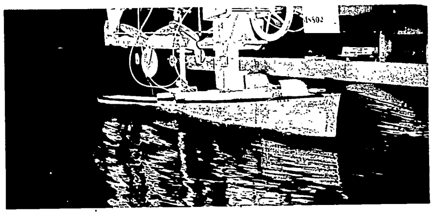

FIGURE 2

Destroyer Model in Head Seas
(Stevens Experimental Towing Tank)

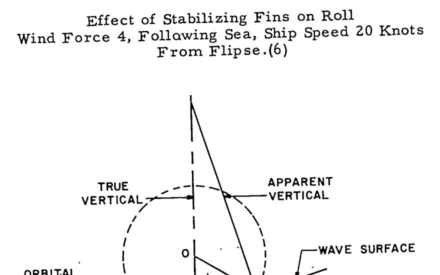

FIGURE 3

Effect of Stabilizing Fins on Roll
Wind Force 4, Following Sea, Ship Speed 20 Knots
From Flipse.(6)

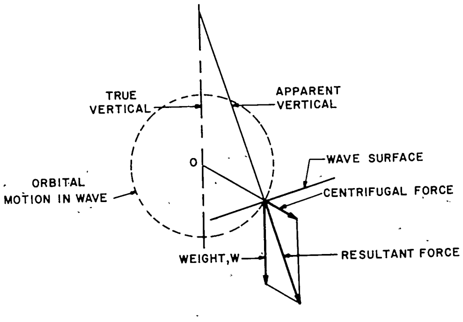

FIGURE 4

Forces Acting on a Small Body in a Wave

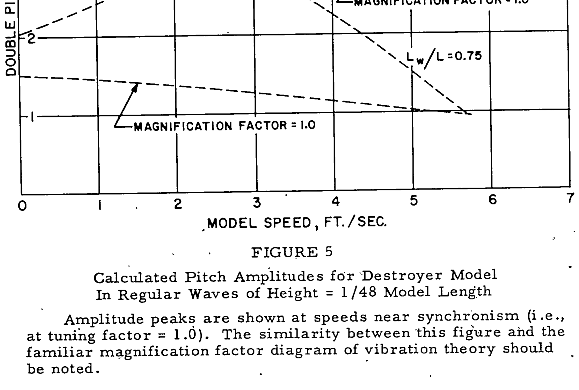

FIGURE 5

Calculated Pitch Amplitudes for Destroyer Model
In Regular Waves of Height = 1/48 Model Length

Amplitude peaks are shown at speeds near synchronism (i.e., at tuning factor = 1.0). The similarity between this figure and the familiar magnification factor diagram of vibration theory should be noted.

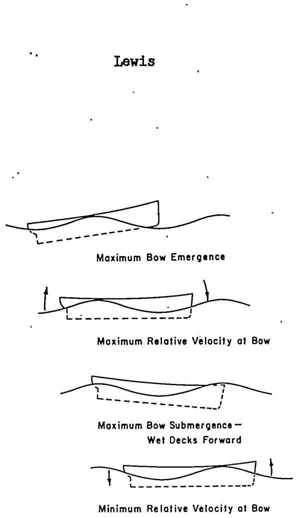

FIGURE 6

Typical Ship Behavior at Speeds for Synchronous Pitching in Regular Waves

This illustrates the characteristic "phase lag" of about 90 degrees between exciting moment and pitching response.

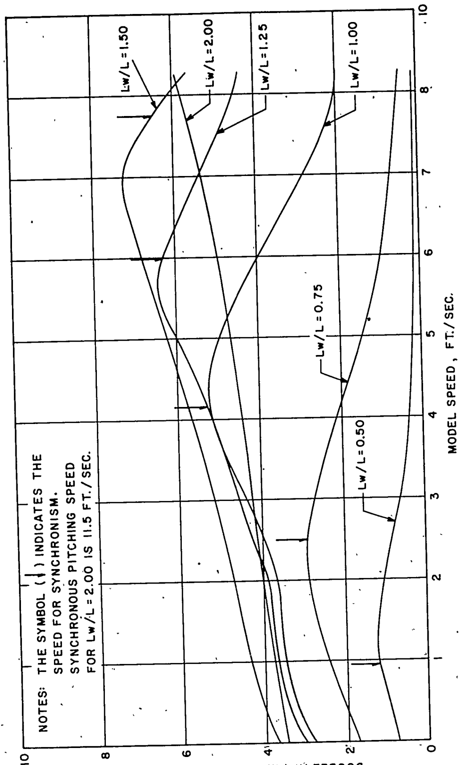

FIGURE 7

Pitching Amplitudes Determined by Model Tests of a Destroyer In Regular Head Seas

Wave height is equal to 1/48 model length. The locations of the peak amplitudes of motion are indicated in relation to synchronism. Moderate amplitudes are shown in waves shorter than the model length, even at synchronism. From Lewis and Dalzell (7).

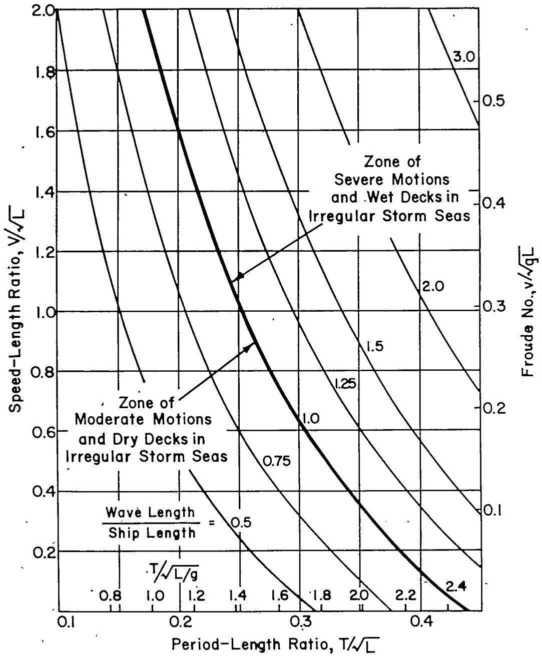

FIGURE 8

Theoretical Speed-Length Ratios for Synchronous Oscillation
In Regular Head Seas of Different Lengths

Defining Typical Zones of Severe and Moderate Motions
In Irregular Seas

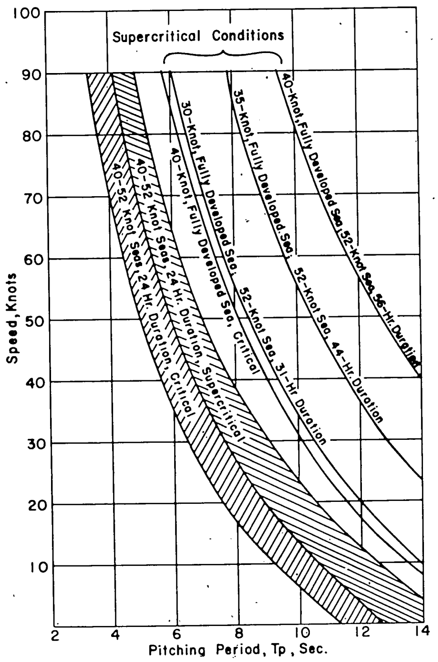

FIGURE 9

Ship Speeds for "Critical" and "Supercritical" Operation
In Various Typical Ideal Storm Seas

Based on Neumann's ideal storm sea spectra. (See Reference 8)

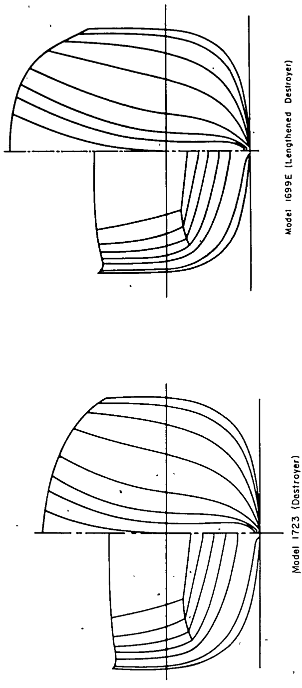

FIGURE 10

Body Plans of Destroyer Models Tested
(Stevens Experimental Towing Tank)

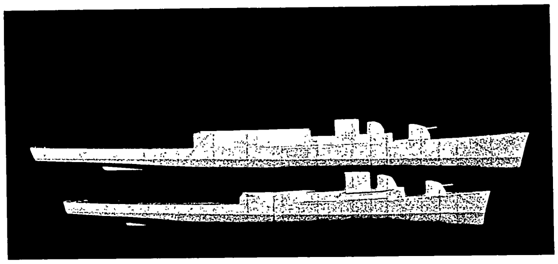

FIGURE 11

Destroyer and Lengthened Destroyer Models
(Stevens Experimental Towing Tank)

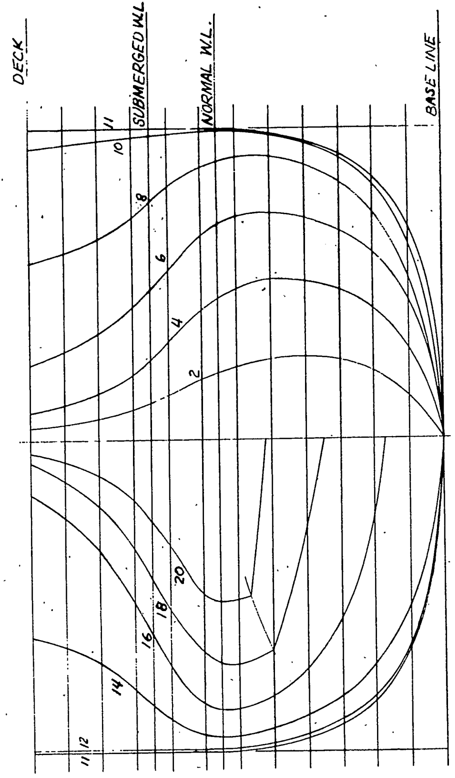

FIGURE 12

Body Plan of Proposed Ship for High-Speed Supercritical Operation

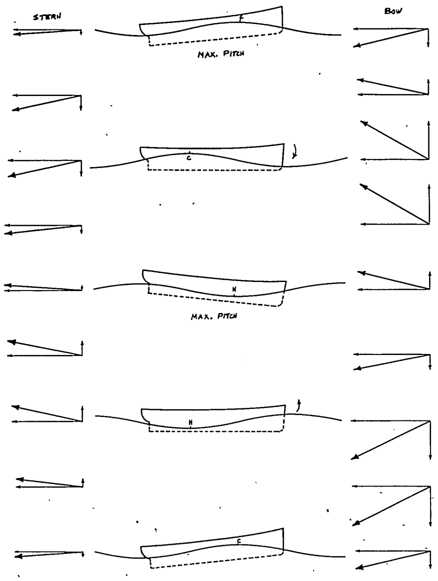

FIGURE 13

Diagrams Showing Direction of Flow at Bow and Stern. Series 60 ($C_b = 0.60$) Model in Waves 1-1/2 x Model Length Height = 1/48 Model Length at Synchronous Speed (No Fins)

SOME RECENT RESULTS IN WATER-ENTRY MODELING*

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INTRODUCTION

The use of small-scale models to simulate full-scale conditions is a common practice in underwater ballistics, as it has long been in aeronautics, ship design, and other domains of fluid mechanics. The chief purpose of small-scale modeling of the water entry of bombs, torpedoes, and other projectiles is generally the determination of the underwater trajectories and water-impact forces. The problem that must be resolved in water-entry and underwater-ballistics modeling is the importance of each of the parameters (Froude number, Reynolds number, cavitation number, mass density ratio, etc.) as it affects the motions of model and prototype in the practical case of predicting prototype behavior from model tests. The problem arises from the fact that these parameters are incompatible for modeling in a single experiment, i.e., the scale relations for the physical quantities are not the same for each parameter. Thus, for economy and ability to design practicable experiments, it is necessary to determine the minimum number of modeling parameters which guarantees similitude within the accuracies established as acceptable.

In this paper some recent studies in water-entry modeling which have been conducted at the U. S. Naval Ordnance Test Station, will be described. The purpose of these studies is to develop a technique for modeling the water-entry and underwater trajectory in cavity behavior of momentum-propelled missiles entering water under conditions of cavity flow.

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Essentially the water entry of a missile under conditions of cavity flow may be divided into two phases: The first phase begins with missile water contact and ends with the establishment of flow about the missile. This phase is brief and extends over only two or three calibers of missile water penetration. The second phase begins with the establishment of flow and ends with cavity collapse. During the first phase, for oblique water entry, the forces acting on the nose of the missile are asymmetric; consequently the missile will undergo an impulsive change in angular velocity in the vertical (pitch) plane which influences its subsequent underwater trajectory behavior. Therefore, any proposed technique for modeling the water-entry and underwater trajectory behavior of missiles must include modeling the missile water-entry pitch behavior during the first phase.

After the first phase of water entry the missile in the second or cavity phase will either ride down the center of the cavity, or strike one side of the cavity. The cavity will eventually be shed, leaving the missile with water contact on all surfaces. The trajectory of the missile will be very markedly influenced by its behavior in the cavity phase. If it stays in the middle of the cavity, the trajectory will be essentially a continuation of the air-flight trajectory. If on the other hand, it strikes the side of the cavity, one of three things can happen: (a) the tail may bounce out, and the missile will oscillate in the cavity, resulting again in an essentially linear trajectory during the cavity phase; or (b) the tail may remain in contact with the cavity wall resulting in a curved trajectory; or (c) the missile may broadside if the restoring force is insufficient. From this it is evident that the size and shape of the cavity will affect the underwater trajectory, and any proposed technique for modeling the water-entry and underwater trajectory in cavity behavior of missiles must include modeling the cavity.

Early mathematical treatment of the high-speed water-entry modeling problem with friction, cavitation, compressibility and surface tension effects neglected, indicated that by using geometrically and dynamically similar models and scaling the water-contact velocity as $\sqrt{\lambda}$ where λ is the model-prototype scale factor (one-to-one Froude scaling), mechanical similarity should obtain and water-entry pitch be modeled. However, water-entry pitch modeling tests under conditions of cavitating flow (1) have shown inconsistent results when Froude scaling[1] alone is considered, and demonstrate its inadequacy for modeling. This inconsistency has been shown to be

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[1] In this report the Froude-scaling technique is defined as the launching of geometrically and dynamically similar models with model water-contact velocity scaled in accordance with the Froude law.

due, at least in part, to pressure reduction in the separation area beneath the missile nose immediately after water impact (underpressure effect). Further theoretical treatment shows that in addition to Froude scaling, the air pressure over the water surface should, in general, be scaled as λ (one-to-one Froude and cavitation-number scaling) in order that the underpressure effect may also be properly scaled to a useful accuracy. Theory also indicates that gas-density scaling is necessary to scale the gas dynamic pressure $(1/2)\rho_g v_g^2$ for water-entry cavity modeling, but this constraint may not be necessary for missile water-entry pitch modeling. The Reynolds number, which is an index to boundary-layer condition is not modeled; but for sufficiently high prototype and model water-entry velocities, Reynolds numbers for both prototype and model will correspond to transition from laminar to turbulent flow close to the nose, and the effect may be negligible.

Three water-entry modeling programs were conducted. These consisted of: (a) missile water-entry pitch modeling, (b) vertical water-entry cavity modeling, and (c) oblique water-entry cavity modeling. In the missile water-entry pitch modeling program, one-to-one Froude and cavitation-number scaling, with and without the added condition of gas-density scaling, was used. In the water-entry cavity modeling programs, one-to-one scaling of the Froude and cavitation numbers and gas density in various combinations was used. The missile water-entry pitch modeling program will be discussed in detail, and the water-entry cavity modeling programs briefly.

MODEL-PROTOTYPE CONSTRAINTS AND RELATIONSHIPS

Water-entry theory (2, 3) indicates that under the condition of one-to-one Froude and cavitation-number and gas-density scaling, with geometrically and dynamically similar models, missile water-entry and cavity space-time similitude will obtain. Hence the missile water-entry pitch and underwater trajectory in cavity behavior will be properly modeled. The theory will not be presented here, but the model constraints and the model-prototype relationships derived from theory on the basis that water is used for both model and prototype are as follows:

Let the ratio of the model diameter to the prototype diameter (modeling scale factor) be given by

(1) $$\lambda = \frac{d_m}{d_p}$$

The model constraints are:

(2) $$\ell_m = \lambda \ell_p$$

(3) $$m_m = \lambda^3 m_p$$

(4) $$I_m = \lambda^5 I_p$$

The atmospheric pressure modeling constraint is

(5) $$p_{am} = \lambda p_{ap}$$

The gas-density modeling constraint is

(6) $$\rho_{gm} = \rho_{gp}$$

Model launching constraints are also given by Eq. 10, 12, 13, 14, 16, 17, and 18 since the initial boundary (i.e., water-contact) conditions must satisfy these equations.

Corresponding points along the geometrically similar trajectories are identified by equal distances in diameters or calibers:

(7) $$s_m = \frac{d_m s_p}{d_p} = \lambda s_p$$

The time similitude gives

(8) $$t_m(s_m) = \sqrt{\lambda}\, t_p(s_p)$$

or

(9) $$s_m(t_m) = \lambda s_p(t_p)$$

where t_m and t_p are the model and prototype times for corresponding points. At the instant of missile water contact $t_m = t_p = 0$ and $s_m(0) = s_p(0) = 0$.

Other model-prototype relationships are as follows:

(10) $$v_m(t_m) = \sqrt{\lambda}\, v_p(t_p)$$

(11) $$a_m(t_m) = a_p(t_p)$$

(12) $$\xi_m(t_m) = \xi_p(t_p)$$

$$(13) \qquad \theta_m(t_m) = \theta_p(t_p)$$

$$(14) \qquad \sqrt{\lambda}\,\dot{\theta}_m(t_m) = \dot{\theta}_p(t_p)$$

$$(15) \qquad \lambda\ddot{\theta}_m(t_m) = \ddot{\theta}_p(t_p)$$

$$(16) \qquad \alpha_m(t_m) = \alpha_p(t_p)$$

$$(17) \qquad \psi_m(t_m) = \psi_p(t_p)$$

$$(18) \qquad \sqrt{\lambda}\,\dot{\psi}_m(t_m) = \dot{\psi}_p(t_p)$$

For proper water-entry cavity modeling, geometric similarity will obtain, with linear dimensions of the model cavity scaling as λ at time $\sqrt{\lambda}t$. A diagram of the attack, pitch, and trajectory angles is given in Fig. 1.

WATER-ENTRY PITCH MODELING

EXPERIMENTAL PROGRAM

The purpose of this study was to evaluate one-to-one Froude and cavitation-number scaling with and without gas-density scaling as a technique for modeling missile water-entry pitch behavior under conditions of cavity flow. Large-scale (22.4-inch-diameter) prototype missile data were available and 2-inch-diameter models were used.

Prototypes

A survey of the available prototype data indicated that an ogive and disk-ogive series of head configurations (4) would be suitable for these modeling studies. This series of head configurations is shown in Fig. 2. The head configurations range from the fine-nosed 3.5-caliber ogive to the blunt disk-cylinder, and include the hemisphere and disk 0.25-caliber ogive heads which have been used in practical application. The heads were attached to a dummy Mk 25 aircraft torpedo afterbody (Fig. 3a) whose length was 101.4 inches. The head lengths ranged from 42.2 inches to 51.7 inches, giving missile lengths of 143.6 inches to 153.1 inches (6.4 to 6.8 calibers).

The missile parameters are shown in Tables 1 to 6. The diameter of the missiles was 22.42 inches. The center of gravity for all missiles was situated within 0.01 inch of the longitudinal axis of symmetry. Because of the difference in the shape of the heads and their consequent difference in mass and in distribution of mass, it was found impossible to adjust all the missile parameters to the same values. Hence the parameters will show variation for the different head configurations. Since variation of the water-contact angle of attack in the modeling program would have expanded the scope of the program considerably, it was decided to restrict these modeling studies to launchings made at zero or near-zero water-contact angle of attack.

Launchings were made into fresh water and at atmospheric pressure from the Fixed-Angle Launcher at the Morris Dam Torpedo Range, San Gabriel Canyon, Azusa, California (5). This launcher has an angle of inclination of 19 degrees with the horizontal. Launchings used in the modeling studies were made at a nominal water-contact velocity of 400 fps. Because of changes in the lake level and variations of the air trajectory due to variations in missile velocity, the actual trajectory water-contact angles ranged from -20.5 to -20.9 degrees. The water-contact angles of attack ranged from -1.6 to 1.4 degrees. The water-contact yaws of the missiles were small, all yaw angles lying within the range ± 2.3 degrees. Consequently it is reasonable to assume that the effect of yaw on the water-entry pitch behavior is small. Since the model yaws, as will be noted later, were also small, this parameter was not considered in the modeling studies.

Calculation of the cavitation numbers which would obtain over one missile length of water penetration indicated that these numbers for all head configurations studied would be less than 0.05. Comparison of this low cavitation number with results obtained in other studies (6, 7, 8, 9) indicated that water entry for all prototypes would take place under conditions of cavity flow.

Water-entry pitch and velocity data were obtained by means of a flare camera. This camera and the methods for reduction and evaluation of the data have been previously described (5, 10). Data were obtained for 2-millisecond time intervals. The resolution of the prototype water-entry velocity versus time data was not sufficient to determine the instants of missile water contact accurately. In order to determine the instants of water contact, highly resolved model oblique water-entry acceleration data (11) were scaled to construct curves of the decrease in prototype velocity as a function of time after water contact. These curves were then fitted to the prototype velocity data to establish the instants of water contact. It is believed that the estimated instants of water contact are accurate to within ± 1 millisecond.

Models

Two-inch-diameter geometrically similar models of the prototype head configurations previously described (Fig. 2) were used in these studies. Since the water-entry pitch modeling studies were to be made at most over one missile length of water penetration under conditions of cavity flow (one-to-one cavitation-number scaling), where the tail did not contact the cavity wall, it is reasonable to assume that the configuration of the afterbody in the neighborhood of the tail and the tail itself would have little or no effect on the water-entry pitch. Therefore, in order to avoid the considerable expense involved in constructing an afterbody which would be geometrically similar to the prototype dummy Mk 25 aircraft torpedo, a cylindrical afterbody with a tail of simple design for missile underwater trajectory stabilization was used, as shown in Fig. 3b. The length of all heads was 3.6 inches and consequently the over-all length of all missiles was 12 inches (6 calibers). The models were made of 24 ST Dural and had internal adjustable weights to adjust their parameters so that they would be dynamically similar to the corresponding prototypes.

For 2-inch-diameter models and 22.42-inch-diameter prototypes, $d_m = 2$ inches, $d_p = 22.42$ inches, and from Eq. 1 the scale factor is

$$\lambda = \frac{2}{22.42} = \frac{1}{11.21} \qquad (19)$$

The scale factors for the other model parameters are obtained from Eq. 2, 3, 4, and 19. The scaled model parameters and experimental data are given in Tables 1, 2, 3, 4, 5, and 6. The center of gravity for all models was situated on the longitudinal axis of symmetry. Since the prototypes were launched at atmospheric pressure, $p_{ap} = 1$ atmosphere and from Eq. 5 and 19 the scaled model air pressure $p_{am} = 1/11.21$ atmosphere. The nominal prototype water-contact velocity $v_p(0) = 400$ feet per second and from Eq. 10 and 19 the scaled model water-contact velocity $v_m(0) = 119.6$ feet per second. The prototype nominal trajectory water-contact angle is -20.5 degrees and the nominal water-contact angle of attack zero degree. From Eq. 12, 13, and 16 the model nominal water-contact trajectory and attack angles must be equal to the respective prototype values.

Because of limitations in the launching facilities, it was not possible to scale the prototype water-contact conditions for

all launchings. Therefore, corrections had to be made to compare model and prototype data. It should be made clear, however, that these corrections were made to assess the modeling technique, not to overcome the limitations of the equipment.

Since the model launcher had no provision for inducing controlled pitch velocities, it was decided to correct both prototype and model water-entry pitch to zero water-contact pitch velocity (satisfying Eq. 14). The corrections are given in Appendix A.

For some prototype launchings the scaled water-contact velocities for the model (as required by Eq. 10) were as much as 11 percent above the maximum water-contact velocity available with the model launcher. Therefore it was necessary to correct the prototype water-entry pitch data to the nominal water-contact velocity used for scaling. These corrections are given in Appendix B.

The water-contact yaws of the models were small, all yaw angles lying within the range ±0.5 degree. Launchings of the models were made into fresh water at a nominal water-contact velocity of 119.6 feet per second and 1/11 atmosphere absolute air or gas pressure in the Variable-Angle Variable-Pressure Launching Tank (12) in the Hydroballistics Laboratory, Naval Ordnance Test Station, Pasadena, California. The nominal trajectory water-contact angle was -20.5 degrees and the water-contact angles of attack were small, lying within the range -0.20 to 0.55 degree. Therefore the nominal water-contact angle of attack is taken to be zero. Water-entry pitch and yaw data were obtained with the Optical Whip Recorder (10, 13) at time intervals of 0.8 millisecond if the change in water-entry pitch was low, and 0.4 millisecond if the change was high. Simultaneous side-view camera data (14) were also obtained which permitted correlated analysis of the missile water-entry pitch and water penetration as well as water-entry cavity growth and development.

For one-to-one Froude and cavitation-number scaling, the models were launched with 1/11 atmosphere absolute air pressure over the water surface and, with the addition of gas-density scaling, a heavy gas was used at the same pressure. It was not possible to scale the gas density completely as required by Eq. 6 since a sufficiently heavy gas for this purpose was not available. However, partial scaling of the gas density was achieved, and it is believed that the modeling results obtained with this partial scaling will be of value in assessing the merit of one-to-one Froude and cavitation-number scaling where the gas density is completely scaled. This will be taken up again later.

In describing gas pressures and densities, it was found convenient to define reference standards. Since average ambient conditions of temperature and pressure at the Morris Dam Torpedo Range (where prototype tests were conducted) and the Hydroballistics Laboratory, approximated 20°C and 740 mm of mercury, it was convenient to define 1 atmosphere as 740 mm of mercury. Gas densities are described in terms of a gas-density coefficient ρ', which is the ratio of the density of the gas (irrespective of its associated conditions of temperature and pressure) to that of air at 20°C and 740 mm pressure.

The partial gas-density scaling was obtained with the heavy gas Freon 114B2 (dibromotetrafluoroethane) (15) which has a density nine times greater than air under the same conditions of temperature and pressure. Theoretically it should be possible to obtain a gas-density coefficient of 9/11 = 0.818 at 1/11 atmosphere. However dilution of the gas with water vapor (gas-density coefficient 0.62 at 20°C temperature and 1 atmosphere pressure) would tend to decrease the gas-density coefficient. The vapor pressure of water at 20°C (ambient laboratory temperature) is 17.54 mm and at 10°C it is 9.20 mm. From Dalton's law of partial pressures, the gas-density coefficient for equilibrium gas-water-vapor mixtures at 1/11 atmosphere in the presence of water is 0.69 at 20°C and 0.79 at 10°C. Therefore there would be an appreciable gain in partial scaling by chilling the water to 10°C. The increase in water density at 10°C over that at 20°C is only 0.15 percent, which could be ignored. For these reasons the tank water was chilled to 10°C for the launchings which involved gas-density scaling. However, experimental gas-density coefficients differed from the theoretical value because the tank pressure gauge was inadequate for accurate metering of heavy gas and precise control of tank pressure. An accurate manometer has since been installed which permits closely controlled gas-density coefficients and pressures.

The Variable-Angle Variable-Pressure Launching Tank was evacuated to the vapor pressure of the water and the residual air washed out by introducing a small amount of Freon and re-evacuating. This operation was repeated three times, after which Freon was again introduced and the tank pressure brought to 1/11 atmosphere. In order to ensure homogeneity, the gas was stirred by a small fan in the dome of the tank. Immediately before launching, the fan was stopped and a gas sample withdrawn. The gas sample, taken at tank pressure, was drawn into a calibrated gas-density balloon and the gas density determined gravimetrically.

RESULTS

One-to-One Froude and Cavitation-Number Scaling

Modeling studies with one-to-one Froude and cavitation-number scaling were made for all head configurations and the model and prototype basic water-contact data are shown in Table 7. It will be noted that for four head configurations, the prototype water-contact velocities were as much as 11 percent above the nominal water-contact velocity of 400 fps. No attempt was made to Froude-scale these higher velocities since the model launcher performance gave indication that it was operating at the extreme upper range of its operating limit. Hence an increase in launcher speed to model these prototype velocities might have resulted in damage to the launcher. This could have caused several months' delay before the program could be resumed. For this reason it was considered better to launch the models at 119.6 fps nominal water-contact velocity and correct the prototype data to 400 fps nominal water-contact velocity by Eq. 24 and 25 (Appendix B). Since the prototype velocity correction was, at most, 11 percent, it was felt that this correction would not modify the validity of the data for the modeling studies. No correction was made for the small deviations in model water-contact velocities.

The model and prototype water-entry pitch data are shown in Fig. 4 to 9 inclusive. Model data are denoted in the figure legends as "F, σ Model Data". Both model and prototype water-entry pitch data have been corrected to zero water-contact pitch velocity by Eq. 20 and 21 (Appendix A) and are shown as the change in pitch after water contact. The model and prototype time scales are in the ratio 1: $\sqrt{11.2}$ (Eq. 8 and 19) which should obtain for modeling. In addition, measurements of the model and prototype water penetration were made. The penetration, expressed in calibers, was plotted to the respective model and prototype time scales and compared. The agreement was good. In no case did the model and prototype penetration data for corresponding scaled times deviate more than 7 percent over a penetration range of 5 calibers, which was approximately the range of penetration that could be compared.

A third scale was constructed by plotting the averages of the model and prototype penetration expressed in calibers for corresponding scaled times. This scale is also given in Fig. 4 to 9. The deviation of experimental data from this scale is at most 3.5 percent.

For the disk-cylinder head the modeling equipment did not permit obtaining model data over more than about 4 calibers of water penetration. In order to obtain data for an extended range of penetration, launchings were made for which the equipment was programmed to obtain data over a later range of penetration extending to 5 calibers. Water-contact pitch and pitch velocity data could not be obtained for these launchings, but since these water-contact conditions were nearly constant for successive launchings, the values obtained from previous launchings were used to correct the data obtained for the extended range launchings. The data for the extended range launchings (ML 1475 to 1478 inclusive) are shown in Fig. 9 for a range of 4 to about 5.5 calibers water penetration.

One-to-One Froude and Cavitation-Number and Gas-Density Scaling

Modeling studies with one-to-one Froude and cavitation-number and gas-density scaling were made for the hemisphere, disk 0.1-caliber ogive and disk-cylinder head configurations. The basic model water-contact data are shown in Table 8, and the model and prototype water-entry pitch data are shown in Fig. 6, 8, and 9. The model data have been corrected to zero pitch velocity by Eq. 20 (Appendix A) and are shown as the change in pitch after water contact. The data are denoted in the figure legends as "F,σ, ρ Model Data".

DISCUSSION OF RESULTS

One-to-One Froude and Cavitation-Number Scaling

From Fig. 4 to 9 it is seen that water-entry pitch modeling to within the accuracy of the prototype data was obtained for five head configurations. For the disk 0.1-caliber ogive head, the change in nose-down pitch was about half that of the prototype and modeling was not obtained. From its position in the series it is not immediately apparent why modeling of this head should be worse than the others. However, the change in water-entry pitch for this head was small, being less than that of the other heads tested, and consequently the pitch-inducing force, which is the resultant of hydrodynamic and underpressure forces, must also be small. The configuration of this head indicates that the hydrodynamic component of the pitch-inducing force is small and in the same direction as the underpressure force. Therefore this head would be expected to be more sensitive to nonmodeling of the underpressure force due to nonscaling of the gas density than heads such as the hemisphere or disk-cylinder whose configurations indicate that the hydrodynamic component of the pitch-inducing force is appreciable. The dispersion of the model data curves is also indicative of the sensitivity of the disk 0.1-caliber ogive head, and the above conclusion seems to be substantiated by further studies on the heads with the added condition of gas-density scaling. This will be discussed later. Since prototype water-entry cavity data were not available, it was not possible to study the effect of nonscaling of gas density on fluid flow.

In summary, the results indicate that while water-entry pitch modeling with one-to-one Froude and cavitation-number scaling may be adequate for head configurations which show decided change in water-entry pitch, the technique must be viewed with suspicion for heads which show small pitch change.

One-to-One Froude and Cavitation-Number and Gas-Density Scaling

Since the results of modeling tests using one-to-one Froude and cavitation-number scaling have indicated that this technique is not completely adequate for water-entry pitch modeling, it was decided to extend the tests to include gas-density scaling. Limitations on time and funds restricted further tests to three head configurations. Therefore it was decided to conduct these extended tests on the hemisphere, disk 0.1-caliber ogive (for which modeling was not previously obtained) and disk-cylinder head configurations. Complete gas-density scaling could not be obtained, as previously stated, due to the unavailability of a sufficiently heavy gas. However it is believed that the results obtained with 0.7 to 0.8 complete scaling can be used to assess the feasibility of this technique where the gas density is <u>completely</u> scaled, since other studies (16) indicate that there is very little change in the water-entry cavity using one-to-one Froude and cavitation-number scaling when the gas-density scaling is varied from 0.7 to 1. Reference 16 is briefly discussed under Oblique Water-Entry Cavity Modeling of this report.

From Fig. 6, 8, and 9 it is seen that water-entry pitch modeling to within the accuracy of the prototype data was obtained with one-to-one Froude and cavitation-number and gas-density scaling where the gas density is at least 0.7 scaled. It is significant (although expected on the basis of theory) that modeling of the disk 0.1-caliber head configuration was obtained without any reduction in modeling agreement obtained for the other two configurations with one-to-one Froude and cavitation-number scaling. For the hemisphere head the modeling agreement remained unchanged, while the disk-cylinder head showed increased nose-down change in pitch and the agreement appears to be better. Evidently the inclusion of gas-density scaling results in proper modeling of the underpressure effect and water-entry pitch modeling is obtained.

The disk 0.1-caliber ogive head was very sensitive to gas-density scaling, the disk-cylinder was less sensitive, and the hemisphere head showed little or no sensitivity, which indicates (as previously surmised) that heads which show small change in water-entry pitch are more sensitive to gas-density scaling.

The model water-entry cavity data for both scaling conditions were not sufficiently resolved to permit further investigation of this point. Although the complete set of head configurations was not tested, and complete gas-density scaling was not achieved, the results indicate that water-entry pitch modeling within the accuracy of the prototype data will be obtained with one-to-one Froude and cavitation-number and gas-density scaling.

It should also be noted that one-to-one Froude and cavitation-number and gas-density scaling models some of the initial boundary conditions which are necessary for modeling the subsequent underwater trajectory. Since other studies (16, 17) indicate that this technique models water-entry cavities for at least 20 calibers of missile underwater travel, it seems feasible that one-to-one Froude and cavitation-number and gas-density scaling can be used to model simultaneously missile water-entry and underwater trajectory in cavity behavior. Reference 17 is briefly discussed under Vertical Water-Entry Cavity Modeling of this report.

CONCLUSIONS

Studies were made to evaluate (a) one-to-one Froude and cavitation-number scaling, and (b) one-to-one Froude and cavitation-number and gas-density scaling as techniques for missile water-entry pitch modeling. A series of ogive and disk-ogive head configurations were used. The prototype missiles were 22.42 inches in diameter and the models 2 inches in diameter. Nominal prototype water-contact conditions were: 400-feet per second velocity, -20.5-degree trajectory angle, and zero angle of attack. Studies were made over about 5 calibers of missile water penetration. The main findings may be summarized as follows:

1. With one-to-one Froude and cavitation-number scaling, modeling to within the accuracy of the prototype data was obtained for all head configurations except the disk 0.1-caliber ogive. This head showed the least change in pitch at water entry and it is inferred that the discrepancy in modeling arises from nonmodeling of the underpressure effect due to the absence of gas-density scaling. The results indicate that while modeling with one-to-one Froude and cavitation-number scaling may be adequate for head configurations which show decided change in water-entry pitch, the technique must be viewed with suspicion for heads which show small change.

2. With one-to-one Froude and cavitation-number and partial gas-density scaling, modeling was obtained to within the accuracy of the prototype data for studies restricted to the disk 0.1-caliber ogive, hemisphere and disk-cylinder heads. Although the complete series of head configurations was not tested and complete gas-density scaling was not achieved, the results indicate that water-entry pitch modeling to within the accuracy of the prototype data will be obtained with one-to-one Froude and cavitation-number and gas-density scaling.

3. One-to-one Froude and cavitation-number and gas-density scaling properly models some of the initial boundary conditions which are necessary for modeling the subsequent underwater trajectory. Since other studies indicate that this technique models water-entry cavities for at least 20 calibers of missile underwater travel, it seems feasible that one-to-one Froude and cavitation-number and gas-density scaling can be used to model simultaneously missile water-entry and underwater trajectory in cavity behavior.

VERTICAL WATER-ENTRY CAVITY MODELING

EXPERIMENTAL PROGRAM

The purpose of this experimental program (17) was to investigate the importance of gas-density scaling in conjunction with Froude and cavitation-number scaling in vertical water-entry cavity modeling. Since no large-scale prototype data were available, and time and expense precluded obtaining them, it was decided to conduct a modeling-with-models program in which a 2-inch-diameter model was used as the prototype missile. The results of these studies could be used to evaluate the feasibility of modeling with the larger scaling ratios that are required for modeling a prototype service missile.

The simplest type of entry cavity was desired for initial study and consequently an axially symmetric cavity was selected. Such a cavity is formed when the trajectory and axis of an axially symmetric missile are vertical at water entry. A test schedule was established to investigate the effect of the following scaling conditions on water-entry cavity modeling:

1. One-to-one Froude-number and gas-density scaling
2. One-to-one Froude and cavitation-number scaling
3. One-to-one Froude and cavitation-number and gas-density scaling

A simple shape consisting of a hemispherical head, cylindrical body section, and camber tail was used for the modeling studies (Fig. 10). The hemispherical head shape was selected for several reasons. First, it was known from previous investigations (18, 19) that change in atmospheric density caused large differences in the vertical water-entry cavity of a sphere. Therefore it was expected that changes in atmospheric density would produce measurable differences in the vertical water-entry cavity of the hemispherical-head missile. Second, this head shape has the added advantage of relative stability at water entry which reduces the chance of the density effect being obscured by any fluctuations of the cavitation number or small differences in missile attitude at water entry. The contours of the body and tail sections of the missile were selected for ease in machining. An arbitrary length-to-diameter ratio of six was chosen for the missiles.

Launcher restrictions limited the prototype model to a diameter of 2 inches. Two smaller models, 1 inch and 1/2 inch in diameter, geometrically and dynamically similar to the prototype, were used (Fig. 10). Model dimensions were scaled according to Eq. 2, 3, and 4. Prototype and model dimensions are shown in Table 9.

Prototype and model launching conditions are shown in Table 10. Launching constraints on model velocity and orientation are given by Eq. 10, 12, 13, 14, 16, 17, and 18. Nearly all experimental missile water-contact velocities were within the range ± 3 fps of their nominal values. Nominal missile entry angles were 90 degrees trajectory angle and zero angle of attack (or yaw). However, launcher vibrations gave the models varying angular velocities in air flight with the result that missile water-entry orientation and angular velocity varied from launching to launching. Therefore it was not possible to study the modeling of missile orientation in the cavity.

For prototype launchings, gas pressures of 0.5 and 1.0 atmosphere absolute and gas-density coefficients of 0.4, 0.8, and 1.0 were used to obtain different scaling ranges of the cavitation number and gas-density coefficient. Gas pressure and density were scaled according to Eq. 5 and 6 respectively.

Launchings were made into fresh water in the Variable-Angle Variable-Pressure Launching Tank. Entry velocities were measured with a photoelectric timer during the air flights of the missiles, and side-view pictures of the missiles and underwater cavities were taken with a rotating-disk camera illuminated by Edgerton-type flash lamps. The time along the missile trajectories was determined from the known flash rate of these lamps. Adjustment of the cavitation number and gas density was made by varying the gas pressure and the composition by the use of mixtures of air, Freon 12 (dichlorodifluoromethane)(20), Freon 114B2, and helium. A detailed description of the technique for the adjustment and gravimetric determination of gas density is given under Water-Entry Pitch Modeling. The water temperature for all launchings was 10 ± 2°C and the gas temperature 18 ± 3°C.

It should be noted that although this program seems similar to a previous study (18), it differs in two significant points: first, missiles instead of spheres were used since it could not be assumed that water-entry cavity behavior for a missile shape with a hemispherical nose would be the same as that of a sphere; second, the specific purpose was the evaluation of scaling techniques, whereas the other study was more general in nature. A complete discussion of this vertical water-entry cavity modeling study is given in (17), but some of the results and the conclusions of the study will be presented here.

RESULTS AND DISCUSSION

It was observed over a range of 24 calibers of missile water penetration for which comparison could be made, that one-to-one Froude and cavitation-number and gas-density scaling produced excellent modeling of the water-entry cavities. Failure to scale the cavitation number only slightly impaired the quality of modeling obtained. These results are illustrated in Fig. 11, which shows the effect of the scaling conditions for a missile water-penetration distance of about 7 calibers.

On the other hand, it was observed that when the gas density was not scaled, cavity modeling did not occur. This is illustrated in Fig. 12, which shows that while the cavities are initially similar, later in the trajectory (aside from deformations caused by the missile tail striking the cavity wall) they became quite different in shape. The cavities became excessively large as the model diameter, and hence the atmospheric density, decreased.

It was also noted that good water-penetration distance modeling was obtained for all modeling conditions studied. Furthermore, there is no evidence that the penetration distance was affected by the modeling condition. At 0.05 second prototype time after water contact, all missile penetration distances were within the range 23.9 ± 0.7 calibers. This was the greatest penetration distance for which modeling comparison could be made. It was not possible to study the modeling of missile orientation in the cavity, since launcher vibration gave the models varying angular velocities in air flight.

The result was that missile water-entry orientation and angular velocity varied from launching to launching.

CONCLUSIONS

The following conclusions were drawn from observation of the vertical-entry cavities formed by 2-inch, 1-inch, and 1/2-inch-diameter hemispherical-head missiles, scaled in accordance with the Froude law to be geometrically and dynamically similar:

1. One-to-one scaling of Froude and cavitation number and gas density produced excellent modeling of the entry cavities during this series of tests.

2. Fairly good agreement among the cavities was also obtained with one-to-one scaling of Froude number and gas density in absence of cavitation-number scaling.

3. One-to-one Froude and cavitation-number scaling did not model the water-entry cavity. The cavities became excessively large, and cavity closure occurred later and became more erratic as the model size was decreased.

4. Good water-penetration distance modeling was obtained for all modeling conditions studied. The penetration distance was not affected by the modeling condition.

5. It should not be concluded from these tests that one-to-one scaling of the cavitation number need not be observed in modeling the water-entry cavity, because cavitation number may prove more important in scaling cavities formed by missiles of other shapes.[2] Furthermore, missile water-entry pitch modeling and other oblique water-entry behavior modeling studies (21, 22) require that the cavitation number be scaled.

OBLIQUE WATER-ENTRY CAVITY MODELING

EXPERIMENTAL PROGRAM

The study of vertical water-entry cavities previously discussed in this report, and studies by other investigators (18, 19), have shown, first, that one-to-one scaling of Froude number and gas-density coefficient are necessary for satisfactory modeling of the vertical water-entry cavity; and, second, that the additional condition of one-to-one scaling of the cavitation number slightly increases the accuracy of modeling. One-to-one scaling of only the Froude and cavitation numbers was reasonably successful in modeling oblique water-entry motion (water-entry pitch modeling) and underwater trajectory behavior (21, 22, 23) for several missiles in the Controlled-Atmosphere Launching Tank at the California Institute of Technology and in the Variable-Angle Variable-Pressure Launching Tank at the U. S. Naval Ordnance Test Station. However, no systematic data were obtained on the size and shape of the cavity, nor were the few instances of failure to model the trajectory fully explained. It was therefore decided to study scaling techniques for modeling the oblique water-entry cavity in some detail, in order to ascertain both the role of the cavity in determining missile performance and the sensitivity of the cavity to scaling conditions.

The purpose of this experimental program (16) was to investigate the importance of gas-density scaling in conjunction with Froude and cavitation-number scaling in oblique water-entry cavity modeling. Consideration of the oblique water-entry cavity suggested that two types might prove particularly sensitive to gas-density scaling. The first type is formed when the missile enters water at a shallow angle and quickly contacts the top cavity lip. The top lip of such a cavity has a narrow cross section and relatively low inertia. Therefore it might be more sensitive to change in the small dynamic pressure of the gas than cavities having lips of wider cross section. The second type is a narrow cavity which tends to close quickly at the water surface. This one was selected because the surface closure of the narrow vertical cavity was known from previous studies (17, 18, 19) to be extremely sensitive to variations in gas density. This experimental program was primarily designed to investigate the effect of various scaling conditions on the modeling of these two types of cavities.

The modeling-with-models program, discussed under Vertical Water-Entry Cavity Modeling, was continued because both time and expense precluded obtaining large-scale prototype data. Two-inch-diameter prototypes and 1-inch-diameter geometrically and dynamically similar models were used in the oblique cavity study. The results of this relatively inexpensive investigation can be used to judge the feasibility of modeling of the larger scale ratios which would arise in modeling a full-size service missile.

A nose shape consisting of a truncated cone with a 10.5-

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[2] This conclusion is supported by the oblique water-entry cavity modeling study (16) which is the third part of this report, but it was not completed in time to be referenced in (17).

degree generating angle and 0.313 caliber flat was selected for one of the missiles because it was known to throw a narrow cavity. This nose required a tail shape which would exert some stabilizing effect during the underwater trajectory. The contour shown in Fig. 13 meets these requirements and is easy to fabricate. For the other missile, a simple right-cylinder nose shape (Fig. 14) was selected because it was known to experience the strong nose-down whip at shallow water-entry angles necessary to drive the missile tail into the top of the cavity quickly. The addition of a simple cylindrical body and tail were sufficient to control underwater trajectory. The physical parameters of the missiles are listed in Table 11.

The diameter of the prototypes was 2 inches, the limit set by the physical dimensions of the launching facility. The models were 1 inch in diameter. Originally it has been planned to use 1-inch and 1/2-inch-diameter geometrically and dynamically similar models of each prototype. However, the 1/2-inch-diameter models, which weighed only about 0.01 pound, could not be included because the water-entry attitude and velocity could not be controlled adequately by a launcher designed for far heavier missiles.

The launching program was originally designed to investigate the behavior of the two types of cavity under the following conditions:

Scaling Condition	Froude No., F	Cavitation No., σ	Gas-Density Coefficient ρ'
1. One-to-one Froude-number, cavitation-number, and gas-density scaling	51.8	0.073	0.8 0.1
2. One-to-one Froude-number, and cavitation-number scaling	51.8	0.073	$\frac{0.8 p_a(\mathrm{atm})}{p_{std}(\mathrm{atm})}$
3. One-to-one Froude-number, and gas-density scaling	51.8	$\frac{0.292}{d(\mathrm{in.})}$	0.8

The behavior of the narrow cavity was of sufficient interest to add intermediate gas-density coefficients of 0.2 and 0.5 to Scaling Condition 1. Nine other gas-density coefficients between 0.59 and 1.9 (the maximum coefficient obtainable at σ=0.073) were investigated with the prototype model only. Scaling Condition 3 was also extended for this prototype to include gas-density coefficients of 0.2 and 3.5, the minimum and maximum coefficients obtainable at σ=0.146.

Additional scaling conditions were also investigated with the right-cylinder prototype. Condition 3 was modified by ρ' = 0.2, and the condition F = 51.8, σ= 0.036 and ρ' = 0.8 was also investigated.

Launching constraints on model velocity and orientation are given by Eq. 10, 12, 13, 14, 16, 17, and 18. The truncated-cone missiles were launched at 39 ± 0.2 degrees trajectory water-contact angle and the right-cylinder missiles at 20 ± 0.2 degrees. Nominal prototype and model scaled water-contact velocities were 120 and 85 fps respectively. Experimental velocities were within ± 4 percent of their nominal values. Water-contact angles of attack and yaw were less than 1 degree for prototype missiles and 2 degrees or less for the truncated-cone model and 5 degrees or less for the right-cylinder model. Angular velocities of the prototype missiles at water contact were less than 5 degrees per second, except for two launchings for which they were less than 10 degrees per second. Gas pressure and density were scaled according to Eq. 5 and 6 respectively.

Launchings were made into fresh water in the Variable-Angle Variable-Pressure Launching Tank. Missile linear entry velocities were measured with a photoelectric timer during the air flights of the missiles. Angular velocities and attitudes in air flight were determined by the Optical Whip Recorder. Side-view pictures of the missiles and underwater cavities were taken with a rotating-disk camera illuminated by Edgerton-type flash lamps. The time along the trajectories was determined from the known flash rate of these lamps. Adjustment of the cavitation number and gas density was made by varying the gas pressure and the composition by the use of mixtures of air, Freon 12, Freon 114B2, and helium. A detailed description of the technique for the adjustment and gravimetric determination of gas density is given under Water-Entry Pitch Modeling. The water temperature was 10 ± 2°C for all launchings.

A complete discussion of this oblique water-entry cavity modeling study is given in (16). The present discussion does not allow space for an adequate presentation of modeling comparisons, but it will present results obtained with the prototype missiles and the conclusions of the study.

RESULTS AND DISCUSSION

The response of these two cavities to variation in scaling conditions was sufficiently different that the experimental results will be discussed separately.

Prototype Truncated-Cone Missile

As expected, the cavity formed by this missile was quite sensitive to change in gas-density coefficient. The entirely different character of the cavities formed at low and high gas densities in otherwise equal systems is illustrated in Fig. 15 and 16. At low densities, the cavities are large and continue to grow after the end of the photographic record, while at higher densities the cavities close at the surface and soon begin to disappear.

The response of this oblique cavity to the various scaling techniques was similar to that of the vertical cavity: that is, one-to-one scaling of the Froude and cavitation numbers and gas-density coefficient modeled the cavity to a high degree of accuracy during the first 20 diameters (calibers) of missile underwater travel. Failure to scale the cavitation number did not prevent good modeling, but when the gas-density coefficient was not scaled, modeling did not occur.

The position of the truncated-cone missile was modeled by all scaling techniques during the first 20 diameters of underwater travel. The prototype and model trajectories were indistinguishable; the prototype and model traveled 20 diameters in 45 milliseconds prototype time, and the inclination curves deviated within the limits of data accuracy.

Prototype Right-Cylinder Missile

Two groups of launchings were made with the right-cylinder prototype in order to record as much of the underwater trajectory as possible. The first group covered air flight, water entry, and approximately 15 diameters of the underwater trajectory. In the second group, which covered a later portion of the trajectory, the missile travelled approximately 20 diameters under water before recording started. The film records of this group contained neither entry-attitude data nor entry points. However, the air flights of the first group were highly repeatable; at water entry the deviations of the missile axis from the air trajectory were within the range 0.4 (+ 0.1, - 0.2) degree <u>nose down</u> in the vertical (pitch) plane and 0.4 ± 0.2 degree in the horizontal yaw plane. The angular velocity during air flight was always less than 3 degrees per second. With the water level held constant in the launching tank, as it was in the second group of launchings, the entry point of the missile

was reproducible to within less than 1/8 diameter. Hence it is reasonable to assume that the attitudes of the missile and the positions of water entry, although unknown, fell within the range of values quoted above.

No attempt was made to make the data from the two groups of launchings continuous, because scaling conditions and measurable parameters were somewhat different. Furthermore, although the entry point of the second group of tests could be considered reproducible within 1/8 diameter, its exact location could be estimated only within two diameters.

The trajectory and attitude of the right-cylinder missile were more sensitive to variations in the gas-density coefficient than the cavity, while the opposite was true of the truncated-cone missile. Furthermore, the right-cylinder missile was quite sensitive to changes in cavitation number, while the truncated-cone missile was not. The trajectories and inclination of the missile axis for several scaling conditions are shown in Fig. 17 and 18. The inclination of the missile axis alone was sensitive to change in scaling condition during the early portion of the trajectory. After 15 diameters of underwater travel the inclination curves deviated 9 degrees. After about 20 diameters of travel the trajectory became flatter with decreasing gas-density coefficient or cavitation number, resulting in a vertical spread of 3 diameters in the trajectories and 35 degrees in the missile inclination after 28 diameters of horizontal travel.

Figure 19 shows typical cavity photographs taken under each scaling condition. The cavities are all still quite similar in appearance after 20 diameters of travel. Differences appear only as the cavities begin to collapse about the missile. These rather small differences in cavity collapse were considered significant because the cavities from duplicate launchings were so similar that the photographs of Fig. 20 appear like two prints of the same negative although they were taken from different launchings. It is quite possible that the differences in missile motion were caused by cavity collapse.

Unfortunately model data could be obtained only during the first 15 diameters of underwater travel. During this portion of the trajectory both trajectory and cavity were unaffected by change in scaling condition, and excellent modeling resulted from all conditions investigated. Thus although these tests established the need for some sort of gas density and cavitation-number scaling, they did not confirm the adequacy of one-to-one Froude and cavitation-number and gas-density scaling.

CONCLUSIONS

The Truncated-Cone Missile

1. One-to-one Froude-number and gas-density scaling, either with or without one-to-one cavitation number scaling, provided excellent modeling of the cavity formed by the truncated-cone missile during the first 20 diameters of underwater travel. When the gas-density coefficient was not scaled, cavity modeling did not occur.

2. The cavity was extremely sensitive to gas-density scaling, particularly in the range $0.4 < \rho' < 0.8$.

The position of the missile during the first 20 diameters of underwater travel was modeled by all scaling techniques.

The Right-Cylinder Missile

1. The cavities and trajectories of the right-cylinder missiles were almost independent of scaling conditions during the first 15 diameters of underwater travel. Good modeling of both resulted from all scaling techniques investigated.

2. After approximately 20 diameters of underwater travel, the cavity, the trajectory, and the attitude of the right-cylinder prototype were greatly affected by changes in either gas-density coefficient or cavitation number. No comparison could be made with the model because valid model data could not be obtained for this portion of the trajectory.

APPENDIX A

MODELING CORRECTION FOR PITCH VELOCITY AT WATER CONTACT

It is evident that over one missile length of water penetration small water-contact pitch velocities will produce small changes in water-entry pitch. Since these small changes would have only a slight effect on the water-entry forces, the water entry pitch due to water-entry forces should not be appreciably affected. Hence the effect of water-contact pitch velocity would be additive, and both prototype and model water-entry pitch may be corrected to zero water-contact pitch velocity by means of the equations

$$(20) \qquad \theta_m(t_m) = \theta_{me}(t_m) - \dot{\theta}_{me}(0)t_m$$

$$(21) \qquad \theta_p(t_p) = \theta_{pe}(t_p) - \dot{\theta}_{pe}(0)t_p$$

where the subscript e denotes experimentally obtained water-entry pitch and water-contact pitch velocity data.

APPENDIX B

MODELING CORRECTION FOR VELOCITY AT WATER CONTACT

From Tables 7 and 8 the model water-contact velocities for all head configurations and the prototype velocities for the disk 0.1-caliber ogive and disk-cylinder head configurations were close to the nominal values used for scaling and no velocity correction was made. For the other head configurations it was necessary to correct the prototype water-entry pitch data to the nominal water-contact velocity. The method of correction will now be taken up.

It was observed from the original prototype data for the 1.5- and 3.5-caliber ogives, hemisphere and disk 0.25-caliber ogive head configurations (and can be seen from the slopes of the model curves in Fig. 4 to 7) that nearly all of the change in pitch velocity takes place soon after water contact. Hence nearly all of the change in pitch velocity takes place during a regime in which the pitch is nearly constant. Therefore the change in pitch velocity is very nearly impulsive and is closely connected with the change in the transverse velocity of the nose in the flow-forming stage, since the product of the pitch velocity change and the distance from the instantaneous center of rotation to the nose of the missile is proportional to the change in transverse velocity of the nose. Now the change in transverse velocity of the nose is proportional to the water-contact velocity $v_p(0)$. The reasoning, (10) briefly is as follows: for forces on the head which may be assumed proportional to $v_p^2(0)$, the time during which the forces are unbalanced (acting on the lower side of the head and not the upper side) varies as $1/v_p(0)$ so that the impulse will vary as $v_p(0)$. Therefore the change in pitch velocity is proportional to $v_p(0)$. Then for missile data that has been corrected to zero water-contact pitch velocity, we have very nearly

$$(22) \qquad \theta_p(t_p) = cv_p(0)t_p$$

where c is a constant. Now let $v_p(0)$ be the nominal water-contact velocity and $v_{pe}(0)$ an experimental water-contact velocity where $v_{pe}(0)$ differs slightly from $v_p(0)$ so that the character of the flow-forming stage, and hence c, remain unchanged. Then

$$(23) \qquad \theta_{pe}(t_{pe}) = cv_{pe}(0)t_{pe}$$

From Eq. 22 and 23 the corresponding times after water contact for which the change in pitch is the same, are given by

(24) $$t_p = \frac{v_{pe}(0)}{v_p(0)} t_{pe}$$

and the pitch-versus-time data for the nominal water-contact velocity are determined from the experimental data by

(25) $$\theta_p(t_p) = \theta_{pe}(t_{pe})$$

where the relation between t_p and t_{pe} is given by Eq. 24.

NOMENCLATURE

a	Axial acceleration of nose of missile, ft $\sec^{-2}$.
D_{max}	Maximum diameter of cavity containing missile, in.
d	Diameter (caliber) of missile body, in.
F	Froude number, $F = v/\sqrt{dg}$
g	Acceleration of gravity, ft $\sec^{-2}$
h	Depth of missile below water surface, ft
I	Moment of inertia of missile about any transverse axis through the CG, slug ft^2 or lb in.^{2}
L	Length of cavity containing the missile, in
ℓ	Distance from nose to CG of missile, in
m	Mass of missile, lb
p_a	Atmospheric (air or gas) pressure, lb ft^{-2}
p_g	Sum of the gas and vapor pressures in the cavitation bubble acting to keep the bubble open, lb ft^{-2}
p_{std}	Standard atmospheric pressure (740 mm mercury pressure)
R	Reynolds number, $R = vd/\nu$

s	Missile water penetration measured along trajectory from point of water contact, ft
t	Time from instant of missile water contact, sec
v	Velocity of missile, ft $\sec^{-1}$
v_g	Velocity of gas, ft $\sec^{-1}$
α	Missile angle of attack in pitch, deg. Angle in the vertical plane between missile axis and direction of motion, positive in the sense of nose-up rotation
λ	Modeling scale factor, $\lambda = d_m/d_p$
ν	Kinematic viscosity, ft^2 $\sec^{-1}$
ξ	Trajectory angle of missile, deg. Path angle with respect to horizontal plane, positive in climb
θ	Missile angle of pitch, deg. Angle between missile axis and horizontal plane, positive in the sense of nose-up rotation
$\dot{\theta}$	Pitch velocity, deg $\sec^{-1}$
$\ddot{\theta}$	Pitch acceleration, deg $\sec^{-2}$
ρ'	Gas-density coefficient (ratio of gas density, irrespective of temperature and pressure, to density of air at 20°C and 740 mm mercury pressure)
ρ_g	Density of gas, slug ft^{-3}
ρ_w	Density of water, slug ft^{-3}
σ	Cavitation number, $\sigma = (p_a + \rho_w gh - p_g)/(1/2)\rho_w v^2$
ψ	Yaw of missile, deg. Angle between the missile axis and vertical plane containing the trajectory, positive when missile tail is to the right as viewed from the rear

SUBSCRIPTS

m	Model missiles
p	Prototype missiles

From Eq. 22 and 23 the corresponding times after water contact for which the change in pitch is the same, are given by

$$(24)\qquad t_p = \frac{v_{pe}(0)}{v_p(0)} t_{pe}$$

and the pitch-versus-time data for the nominal water-contact velocity are determined from the experimental data by

$$(25)\qquad \theta_p(t_p) = \theta_{pe}(t_{pe})$$

where the relation between t_p and t_{pe} is given by Eq. 24.

NOMENCLATURE

a	Axial acceleration of nose of missile, ft sec^{-2}.
D_{max}	Maximum diameter of cavity containing missile, in.
d	Diameter (caliber) of missile body, in.
F	Froude number, $F = v/\sqrt{dg}$
g	Acceleration of gravity, ft sec^{-2}
h	Depth of missile below water surface, ft
I	Moment of inertia of missile about any transverse axis through the CG, slug ft^2 or lb $in.^2$
L	Length of cavity containing the missile, in
ℓ	Distance from nose to CG of missile, in
m	Mass of missile, lb
p_a	Atmospheric (air or gas) pressure, lb ft^{-2}
p_g	Sum of the gas and vapor pressures in the cavitation bubble acting to keep the bubble open, lb ft^{-2}
p_{std}	Standard atmospheric pressure (740 mm mercury pressure)
R	Reynolds number, $R = vd/\nu$

s	Missile water penetration measured along trajectory from point of water contact, ft
t	Time from instant of missile water contact, sec
v	Velocity of missile, ft sec^{-1}
v_g	Velocity of gas, ft sec^{-1}
α	Missile angle of attack in pitch, deg. Angle in the vertical plane between missile axis and direction of motion, positive in the sense of nose-up rotation
λ	Modeling scale factor, $\lambda = d_m/d_p$
ν	Kinematic viscosity, ft^2 sec^{-1}
ξ	Trajectory angle of missile, deg. Path angle with respect to horizontal plane, positive in climb
θ	Missile angle of pitch, deg. Angle between missile axis and horizontal plane, positive in the sense of nose-up rotation
$\dot{\theta}$	Pitch velocity, deg sec^{-1}
$\ddot{\theta}$	Pitch acceleration, deg sec^{-2}
ρ'	Gas-density coefficient (ratio of gas density, irrespective of temperature and pressure, to density of air at 20°C and 740 mm mercury pressure)
ρ_g	Density of gas, slug ft^{-3}
ρ_w	Density of water, slug ft^{-3}
σ	Cavitation number, $\sigma = (p_a + \rho_w gh - p_g)/(1/2)\rho_w v^2$.
ψ	Yaw of missile, deg. Angle between the missile axis and vertical plane containing the trajectory, positive when missile tail is to the right as viewed from the rear

SUBSCRIPTS

m	Model missiles
p	Prototype missiles

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TABLE 1. Model and Prototype Parameters
3.5-Caliber Ogive Head (Fig. 4)

Parameter	Prototype (22.42-in.-dia)	Model (2-in.-dia)	
		Required by Froude Scaling	Model Used
Diameter, in.	22.42 +0.020 -0.010	2.0000	2.0000 ± 0.0002
Length, in.	154 ± 1/8		12.0
Mass, lbs	Between 1560 and 1565 ± 1/2	1.108	1.112 ± 0.005
Distance from nose to CG, in.	71.1 ± 1/4	6.343	6.35 ± 0.01
Moment of inertia about transverse axis through CG	745 ± 5 slug ft^2	19.51 lb in.^{2}	19.64 ± 0.15 lb in.^{2}
Contour tolerance, in. on radius	0.040		+0.000 -0.001

TABLE 2. Model and Prototype Parameters
1.5-Caliber Ogive Head (Fig. 5)

Parameter	Prototype (22.42-in.-dia)	Model (2-in.-dia)	
		Required by Froude Scaling	Model Used
Diameter, in.	22.42 + 0.020 - 0.010	2.0000	2.0000 ± 0.0002
Length, in.	154 ± 1/8		12.0
Mass, lb	Between 1495* and 1496 ± 1/2	1.061	1.096 ± 0.005
Distance from nose to CG, in.	71.1 ± 1/4	6.343	6.35 ± 0.01
Moment of inertia about transverse axis through CG	756 ± 5 slug ft^2	19.80 lb $in.^2$	19.99 ± 0.15 lb $in.^2$
Contour tolerance, in. on radius	0.040		+0.000 -0.001

*For one prototype launching (FAL 2855), the missile mass was 1480 lb.

TABLE 3. Model and Prototype Parameters
Hemisphere Head (Fig. 6)

Parameter	Prototype (22.42-in.-dia)	Model (2-in.-dia)	
		Required by Froude Scaling	Model Used
Diameter, in.	22.42 + 0.020 - 0.010	2.0000	2.0000 ± 0.0002
Length, in	154 ± 1/8		12.0
Mass, lb	1526 ± 1/2	1.083	1.084 ± 0.005
Distance from nose to CG, in.	69.5 ± 1/4	6.200	6.20 ± 0.01
Moment of inertia about transverse axis through CG	771 ± 5 slug ft^2	20.19 lb $in.^2$	20.12 ± 0.15 lb $in.^2$
Contour tolerance, in. on radius	0.040		+0.000 -0.001

TABLE 4. Model and Prototype Parameters
Disk 0.25-Caliber Ogive Head (Fig. 7)

Parameter	Prototype (22.42-in.-dia)	Model (2-in.-dia)	
		Required by Froude Scaling	Model Used
Diameter, in.	22.42 + 0.020 - 0.010	2.0000	2.0000 ± 0.0002
Length, in.	154 ± 1/8		12.0
Mass, lb	Between 1583 and 1586 ± 1/2	1.124	1.130 ± 0.005
Distance from nose to CG, in.	63.7 ± 1/4	5.683	5.68 ± 0.01
Moment of inertia about transverse axis through CG	743 ± 5 slug ft^2	19.46 lb in.^{2}	19.46 ± 0.15 lb in.^{2}
Contour tolerance, in. on radius	0.040		+0.000 -0.001

TABLE 5. Model and Prototype Parameters
Disk 0.1-Caliber Ogive Head (Fig. 8)

Parameter	Prototype (22.42-in.-dia)	Model (2-in.-dia)	
		Required by Froude Scaling	Model Used
Diameter, in.	22.42 + 0.020 - 0.010	2.0000	2.0000 ± 0.0002
Length, in.	144 ± 1/8		12.0
Mass, lb	Between 1544 and 1545 ± 1/2	1.097	1.103 ± 0.005
Distance from nose to CG, in.	63.7 ± 1/4	5.683	5.68 ± 0.01
Moment of inertia about transverse axis through CG	694 ± 5 slug ft^2	18.18 lb in.^{2}	18.37 ± 0.15 lb in.^{2}
Contour tolerance, in. on radius.	0.040		+0.000 -0.001

TABLE 6. Model and Prototype Parameters
Disk Cylinder Head (Fig. 9)

Parameter	Prototype (22.42-in.-dia)	Model (2-in.-dia)	
		Required by Froude Scaling	Model used
Diameter, in.	22.42 + 0.020 - 0.010	2.0000	2.0000 ± 0.0002
Length, in.	144 ± 1/8		12.0
Mass, lb	Between 1551 and 1552 ± 1/2	1.100	1.109 ± 0.005
Distance from nose to CG, in.	63.7 ± 1/4	5.683	5.68 ± 0.01
Moment of inertia about transverse axis through CG	694 ± 5 slug ft^2	18.18 lb $in.^2$	18.35 ± 0.15 lb $in.^2$
Contour tolerance, in. on radius	--	--	--

TABLE 7. One-to-One Froude and Cavitation Number Scaling. Model and Prototype Water-Contact Data for Launchings Which are Presented in Fig. 4 through Fig. 9.

Prototype				Model			
Launching No. (FAL)	Velocity (fps)	Trajectory Angle (deg)	Angle of Attack (deg)	Launching No. (ML)	Velocity (fps)	Trajectory Angle (deg)	Angle of Attack (deg)
3.5-Caliber Ogive Head (Fig. 4)							
2841	416	-20.6	-1.4	1522	117.5	-20.30	0.42
2842	418	-20.7	-0.3	1523	119.2	-20.30	0.22
2848	416	-20.7	0.7	1525	118.9	-20.30	0.34
2849	419	-20.7	-1.0	1526	120.6	-20.30	0.19
1.5-Caliber Ogive Head (Fig. 5)							
2855	446	-20.7	-0.2	1510	120.3	-20.30	0.47
2856	430	-20.9	0.2	1511	120.3	-20.30	0.55
2858	425	-20.8	0.8	1513	120.5	-20.30	0.53
2860	430	-20.7	-0.5	1514	121.8	-20.30	0.37
Hemisphere Head (Fig. 6)							
2664	415	-20.7	-0.2	1268	120.8	-20.30	0.07
2668	411	-20.7	-0.6	1269	120.2	-20.30	0.01
2671	412	-20.6	0.2	1311	119.0	-20.30	0.15
				1312	118.2	-20.30	-0.20
Disk 0.25-Caliber Ogive Head (Fig. 7)							
3105	430	-20.5	-0.2	1487	119.8	-20.30	0.17
3107	428	-20.6	0.2	1489	120.5	-20.30	0.13
3117	417	-20.7	-0.9	1490	120.6	-20.30	0.16
3118	421	-20.6	0.2	1494	120.9	-20.30	0.07
Disk 0.1-Caliber Ogive Head (Fig. 8)							
3163	394	-20.9	-0.9	1503	122.4	-20.30	-0.17
3164	398	-20.8	1.4	1504	119.6	-20.30	0.23
3165	398	-20.8	0.9	1505	118.9	-20.30	0.41
				1506	119.3	-20.30	0.33
Disk-Cylinder Head (Fig. 9)							
3187	400	-20.8	1.0	1256	117.8	-20.30	-0.04
3188	401	-20.8	0.4	1258	120.6	-20.30	-0.18
3191	403	-20.8	1.4	1259	121.0	-20.30	-0.06
3192	401	-20.8	-1.6	1264	119.7	-20.30	-0.13
				1475	119.6	-20.20	*
				1476	120.0	-20.20	*
				1477	122.1	-20.20	*
				1478	122.4	-20.20	*

*Angles of attack not known but probably within the range -0.5 to 0.5 deg.

TABLE 8. One-to-One Froude and Cavitation Number and Gas Density Scaling. Model Water-Contact Data for Launchings Which are Presented in Fig. 6, 8 and 9*

Model				
Launching No. (ML)	Velocity (fps)	Trajectory Angle (deg)	Angle of Attack (deg)	Gas Density Ratio
Hemisphere Head (Fig. 6)				
1730	119.8	-20.30	-0.33	0.75
1732	119.8	-20.30	-0.41	0.76
1733	119.9	-20.30	-0.49	0.68
1735	122.9	-20.30	-0.40	0.65
Disk 0.1-Caliber Ogive Head (Fig. 8)				
1720	122.2	-20.30	-0.62	0.59
1721	121.9	-20.30	-0.67	0.80
1722	122.1	-20.30	-0.62	0.84
1723	121.7	-20.30	-0.80	0.82
Disk-Cylinder Head (Fig. 9)				
1725	120.8	-20.30	-0.82	0.71
1726	120.3	-20.30	-0.80	0.82
1727	120.9	-20.30	-0.90	0.80
1728	119.6	-20.30	-0.83	0.82

* Prototype water-contact data are given in Table 7.

TABLE 9. Prototype and Model Dimensions

Dimension	2-in.-Diam. Prototype	1-in.-Diam. Model		1/2-in.-Diam. Model	
		Required by Froude Scaling $\lambda = 1/1.999$	Used	Required by Froude Scaling $\lambda = 1/4.012$	Used
Diameter, in.	1.998	0.999	0.999	0.498	0.498
Length, in.	12.016	6.011	6.005	2.995	3.007
Weight, lb	1.128	0.139	0.141	0.017	0.017
Distance of CG From Nose, in.	5.90	2.95	2.92	1.47	1.47
Moment of Inertia[a], lb in^2	15.61	0.489	0.49	0.015	0.015

[a] About a transverse axis through the CG.

TABLE 10. Vertical Water-Entry Modeling Studies With Hemispherical-Head Models

Model		Froude No. Scaled, F = 51.8 Cavitation No. Not Scaled Gas Density Coeff. Scaled, ρ' = 0.8			Froude No. Scaled, F = 51.8 Cavitation No. Scaled, σ = 0.073 Gas Density Coeff. Not Scaled			Froude No. Scaled, F = 51.8 Cavitation No. Scaled, σ = 0.073 Gas Density Coeff. Scaled, ρ' = 0.8			Froude No. Scaled, F = 51.8 Cavitation No. Not Scaled Gas Density Coeff. Scaled, ρ' = 1.0		
Diameter, in.	Velocity, ft sec^{-1}	Gas Pressure, atm	Gas Density Coeff.	Gases Used	Gas Pressure, atm	Gas Density Coeff.	Gases Used	Gas Pressure, atm	Gas Density Coeff.	Gases Used	Gas Pressure, atm	Gas Density Coeff.	Gases Used
2	120	1	0.8	A + He	1/2	0.4	A + He	1/2	0.8	A+F12	1	1.0	A
1	85	1	0.8	A + He	1/4	0.2	A + He	1/4	0.8	A+F12	1	1.0	A
1/2	60	1	0.8	A + He	1/8	0.1	A + He	1/8	0.8	F114B2	1	1.0	A

NOTES:
Triplicate launchings made for each water-entry condition.
One atmosphere pressure is taken to be 740-mm Hg (ambient at laboratory and Morris Dam).
A = air, He = helium, F12 = Freon 12 (dichlorodifluoromethane).
F114B2 = Freon 114B2 (dibromotetrafluoroethane).

TABLE 11. Prototype and Model Parameters

Dimension	Truncated-Cone Missile			Right-Cylinder Missile		
	2-in.-diam. Prototype	1-in.-diam. Model		2-in.-diam. Prototype	1-in.-diam. Model	
		Required by Froude Scaling λ = 1/1.999	Actual Parameters		Required by Froude Scaling λ = 1/1.999	Actual Parameters
Diameter, in.	1.998	0.999	0.999	1.998	0.999	0.999
Length, in.	14.95	7.48	7.46	10.61	5.31	5.31
Weight, grams	591.5	74.05	75.57	474.1	59.35	59.13
Distance of CG from nose, in.	7.97	3.99	3.93	5.35	2.70	2.65
Moment of inertia,[a] lb in^2	21.44	0.672	0.672	12.59	0.394	0.389
Cone angle	10°30'	10°30'	10°24'	.....	.....	.....
Diameter of nose flat, in.	0.619	0.310	0.318	1.998	0.999	0.999

[a] About a transverse axis through the CG.

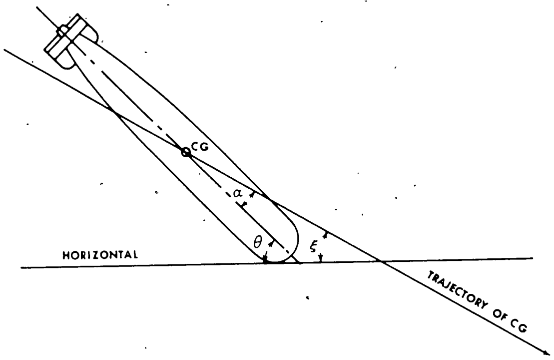


FIG. 1. Diagram of Missile Showing Attack, Pitch and Trajectory Angles. All Angles as Shown are Negative.

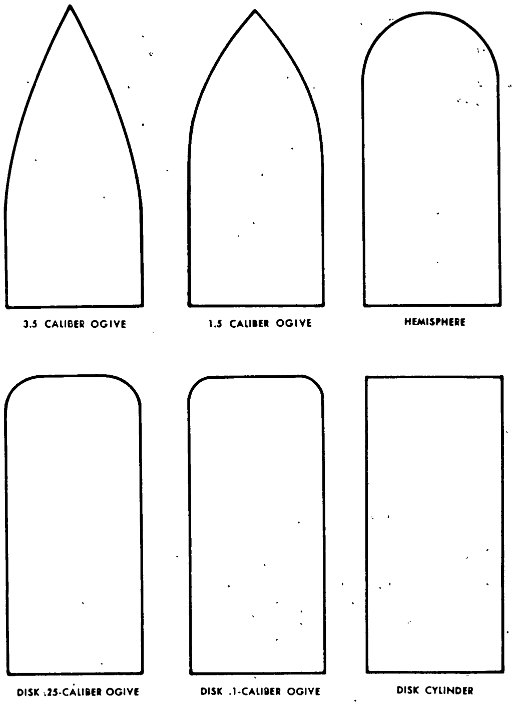
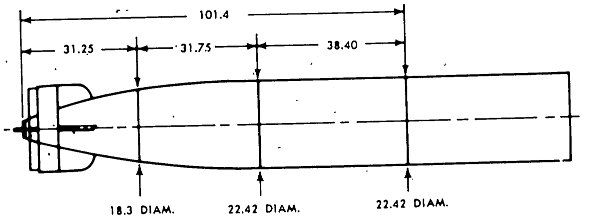
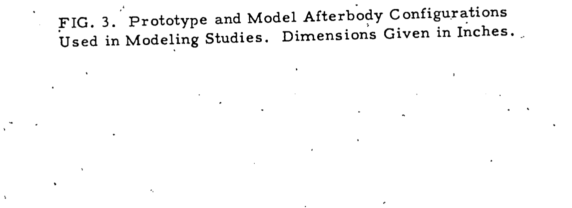


FIG. 2. Head Configurations Used in Water Entry Pitch Modeling Studies.

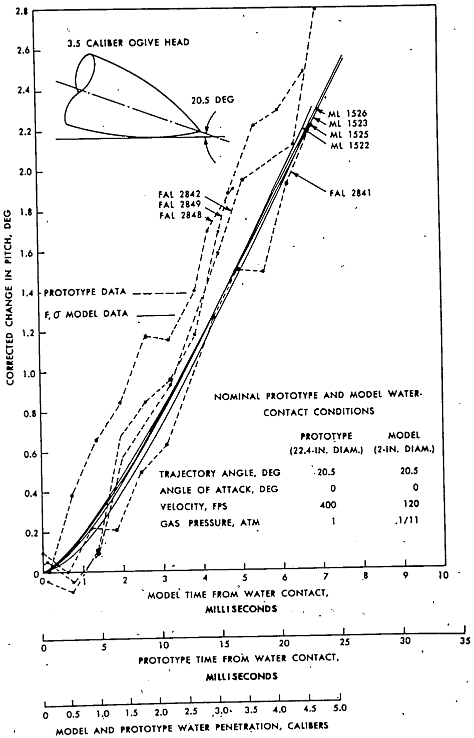


(a) PROTOTYPE DUMMY MK 25 AIRCRAFT TORPEDO AFTERBODY WITH DISK CYLINDER HEAD



(b) MODEL AFTERBODY WITH DISK-CYLINDER HEAD

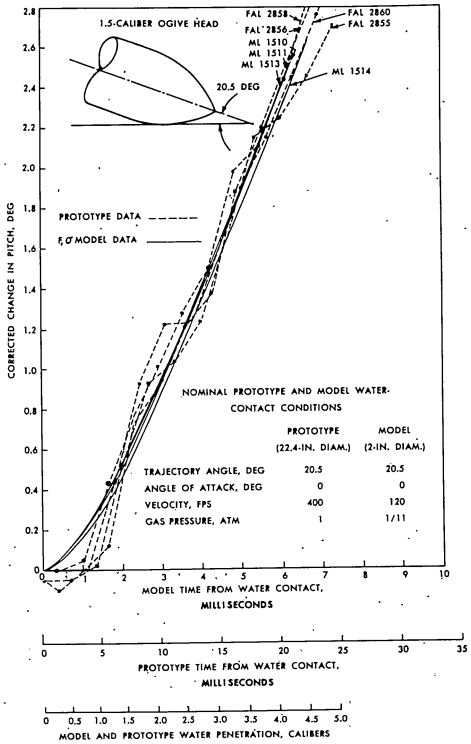
FIG. 3. Prototype and Model Afterbody Configurations Used in Modeling Studies. Dimensions Given in Inches.



NOMINAL PROTOTYPE AND MODEL WATER-CONTACT CONDITIONS

	PROTOTYPE (22.4-IN. DIAM.)	MODEL (2-IN. DIAM.)
TRAJECTORY ANGLE, DEG	20.5	20.5
ANGLE OF ATTACK, DEG	0	0
VELOCITY, FPS	400	120
GAS PRESSURE, ATM	1	.1/11

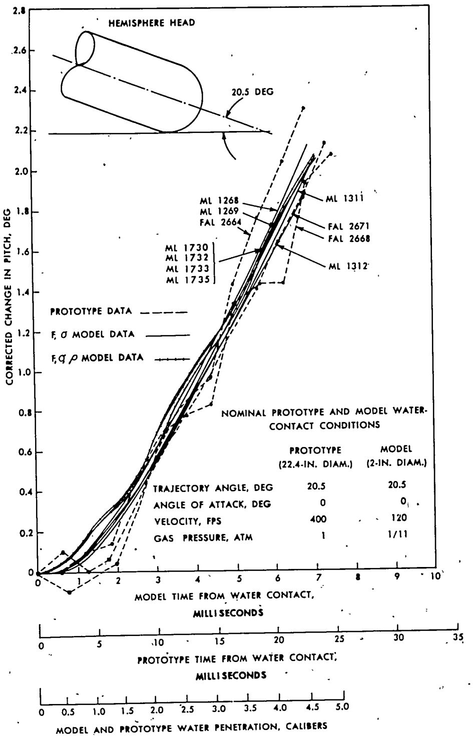
FIG. 4. Prototype and Model Water-Entry Pitch Data (3.5-Caliber Ogive).



NOMINAL PROTOTYPE AND MODEL WATER-CONTACT CONDITIONS

	PROTOTYPE (22.4-IN. DIAM.)	MODEL (2-IN. DIAM.)
TRAJECTORY ANGLE, DEG	20.5	20.5
ANGLE OF ATTACK, DEG	0	0
VELOCITY, FPS	400	120
GAS PRESSURE, ATM	1	1/11

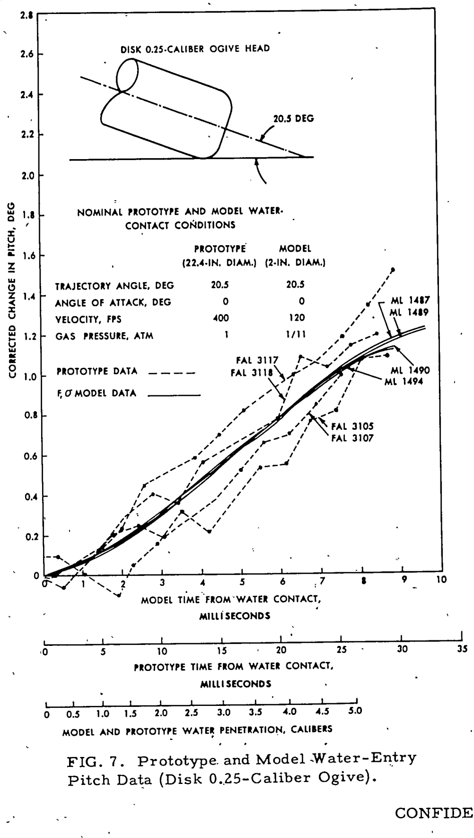
FIG. 5. Prototype and Model Water-Entry Pitch Data (1.5-Caliber Ogive).



NOMINAL PROTOTYPE AND MODEL WATER-CONTACT CONDITIONS

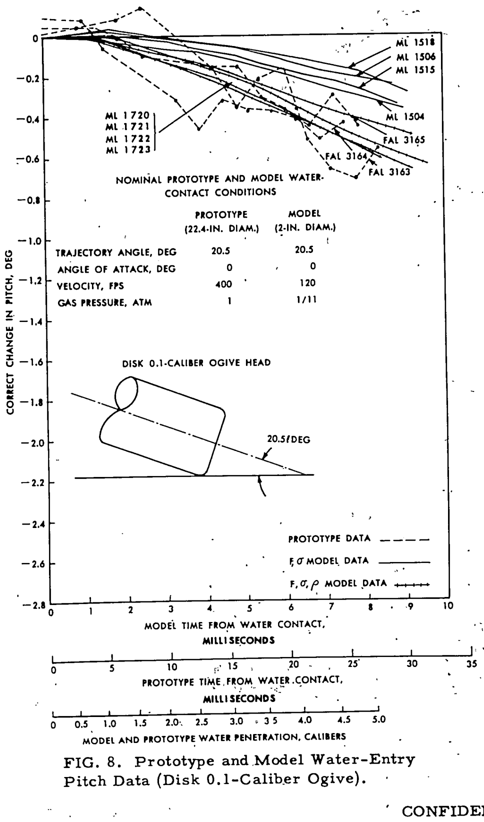
	PROTOTYPE (22.4-IN. DIAM.)	MODEL (2-IN. DIAM.)
TRAJECTORY ANGLE, DEG	20.5	20.5
ANGLE OF ATTACK, DEG	0	0
VELOCITY, FPS	400	120
GAS PRESSURE, ATM	1	1/11

FIG. 6. Prototype and Model Water-Entry Pitch Data (Hemisphere).



	PROTOTYPE (22.4-IN. DIAM.)	MODEL (2-IN. DIAM.)
TRAJECTORY ANGLE, DEG	20.5	20.5
ANGLE OF ATTACK, DEG	0	0
VELOCITY, FPS	400	120
GAS PRESSURE, ATM	1	1/11

FIG. 7. Prototype and Model Water-Entry Pitch Data (Disk 0.25-Caliber Ogive).



	PROTOTYPE (22.4-IN. DIAM.)	MODEL (2-IN. DIAM.)
TRAJECTORY ANGLE, DEG	20.5	20.5
ANGLE OF ATTACK, DEG	0	0
VELOCITY, FPS	400	120
GAS PRESSURE, ATM	1	1/11

FIG. 8. Prototype and Model Water-Entry Pitch Data (Disk 0.1-Caliber Ogive).

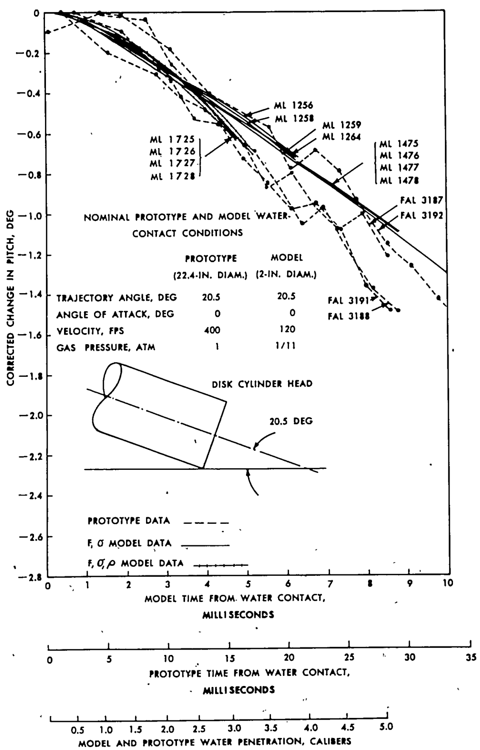


FIG. 9. Prototype and Model Water-Entry Pitch Data (Disk-Cylinder).

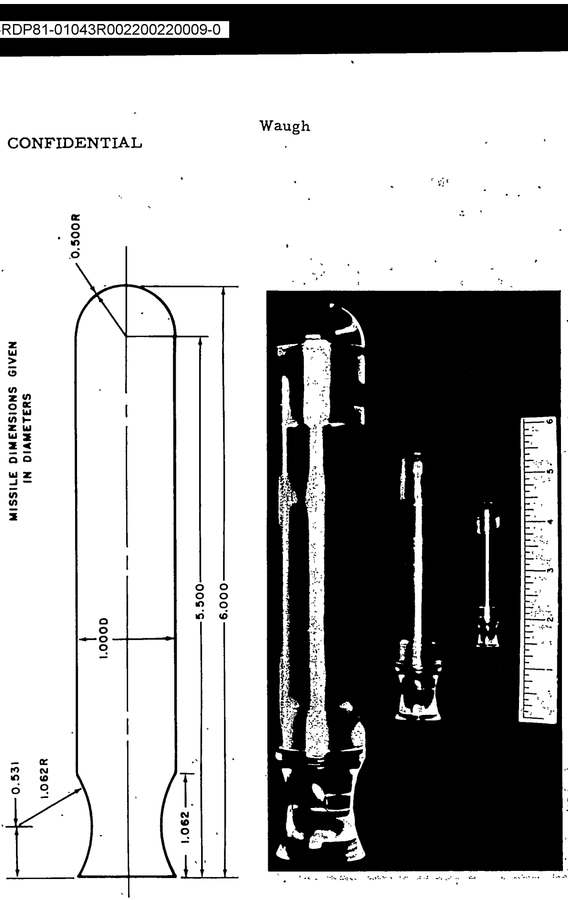


FIG. 10. Missile Configurations.

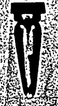
SCALING CONDITION	2-IN.-DIAM. PROTOTYPE	1-IN.-DIAM. MODEL	1/2-IN.-DIAM. MODEL
$F = 51.8$ $\rho' = 0.8$			
σ	0.146	0.292	0.584
CAVITY LENGTH SCALED TO PROTOTYPE DIMENSIONS, IN.	15.0	14.4	13.6
L/D_{max}	3.13	3.18	3.15
$F = 51.8$ $\rho' = 1.0$			
σ	0.146	0.292	0.584
CAVITY LENGTH SCALED TO PROTOTYPE DIMENSIONS, IN.	14.1	13.2	14.4
L/D_{max}	3.18	3.08	3.29
$F = 51.8$ $\sigma = 0.073$ $\rho' = 0.8$			
CAVITY LENGTH SCALED TO PROTOTYPE DIMENSIONS, IN.	14.8	14.6	14.4
L/D_{max}	3.06	3.05	3.14

FIG.11. Shape of the Vertical Water-Entry Cavity. One-to-one Froude-number and gas-density scaling with and without one-to-one cavitation-number scaling.

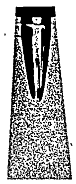
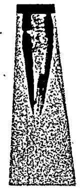
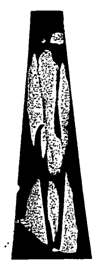
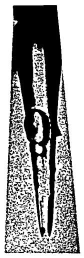
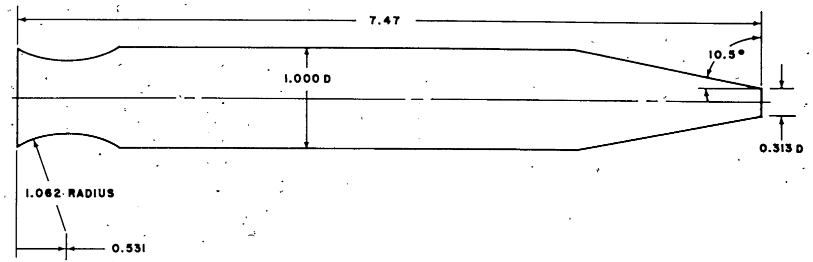
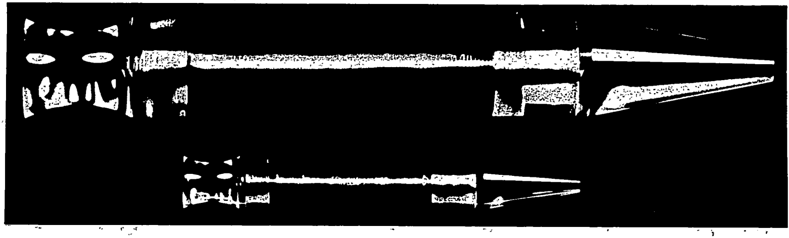
SCALING CONDITION	2-IN.-DIAM. PROTOTYPE	1-IN.-DIAM. MODEL	1/2-IN.-DIAM. MODEL
$F = 51.8$ $\sigma = 0.73$			
ρ'	0.4	0.2	0.1
CAVITY LENGTH SCALED TO PROTOTYPE DIMENSIONS, IN.	13.7	14.8	16.0
L/D_{max}	2.61	2.78	2.78
$F = 51.8$ $\sigma = 0.073$			
ρ'	0.4	0.2	0.1
CAVITY LENGTH SCALED TO PROTOTYPE DIMENSIONS, IN.	36.7	40.5	38.4
L/D_{max}	8.54	4.54	3.73

FIG.12. Shape of the Vertical Water-Entry Cavity. One-to-one Froude-number and cavitation-number scaling.

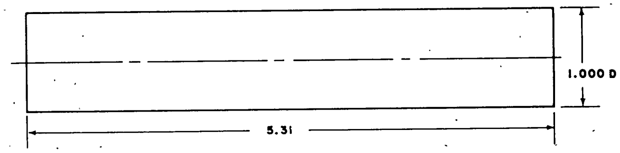


(a) Missile dimensions in diameters.

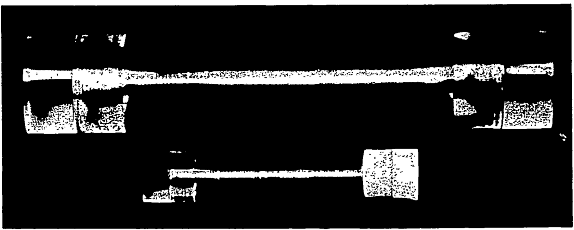


(b) Model and prototype.

FIG.13. The 10.5-Degree 0.313-Caliber Truncated-Cone Missile.

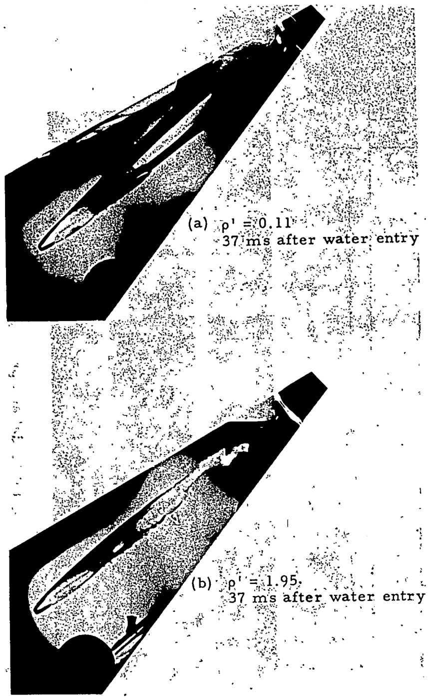


(a) Missile dimensions in diameters.



(b) Model and prototype.

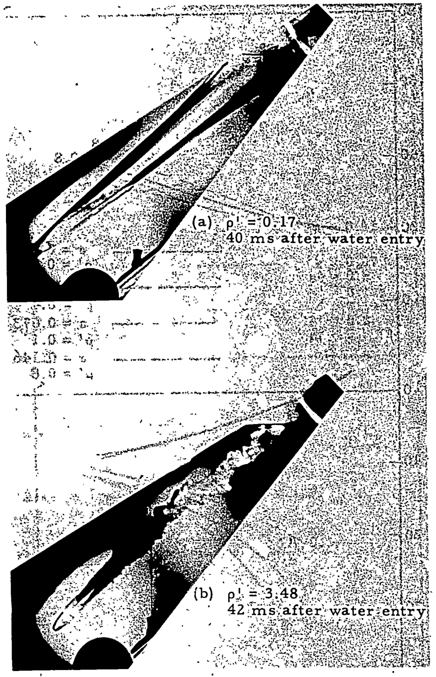
FIG.14. The Right-Cylinder Missile.



(a) ρ' = 0.11
37 ms after water entry

(b) ρ' = 1.95
37 ms after water entry

FIG. 15. Truncated-Cone Prototype: Effect of Change in Gas-Density Coefficient on Cavity. (σ = 0.073.)



(a) ρ' = 0.17
40 ms after water entry

(b) ρ' = 3.48
42 ms after water entry

FIG. 16. Truncated-Cone Prototype: Effect of Change in Gas-Density Coefficient on Cavity. (σ = 0.146.)

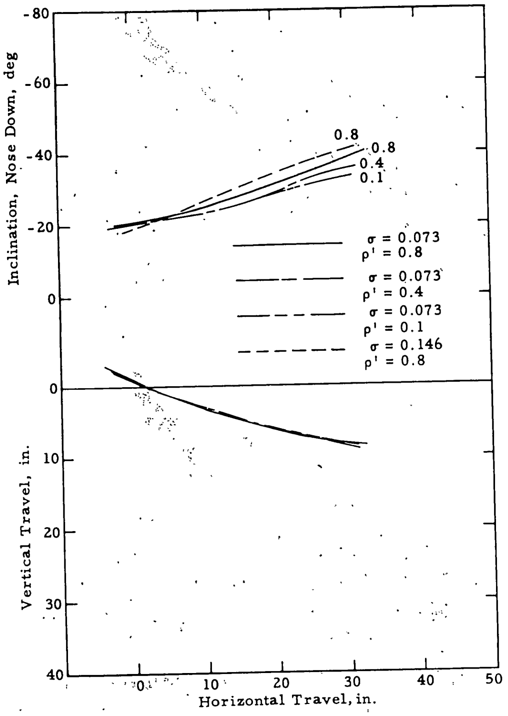


FIG. 17. Right-Cylinder Prototype: Trajectory and Inclination During the First 15 Diameters of Underwater Travel. (F = 51.8.)

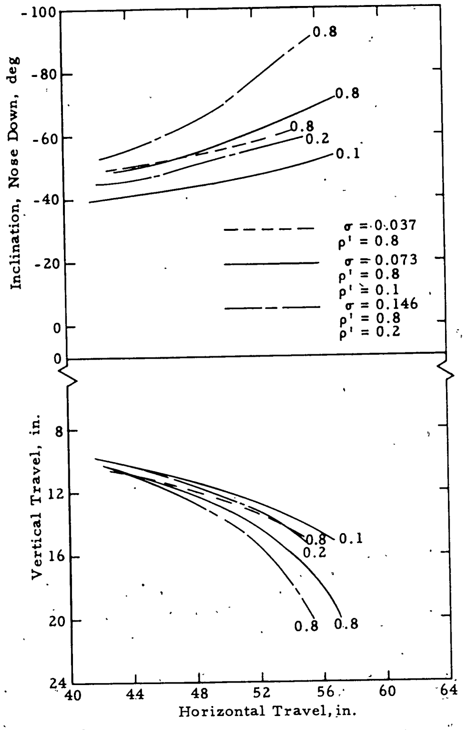


FIG. 18. Right-Cylinder Prototype: Trajectory and Inclination Between 20 and 28 Diameters of Underwater Travel.

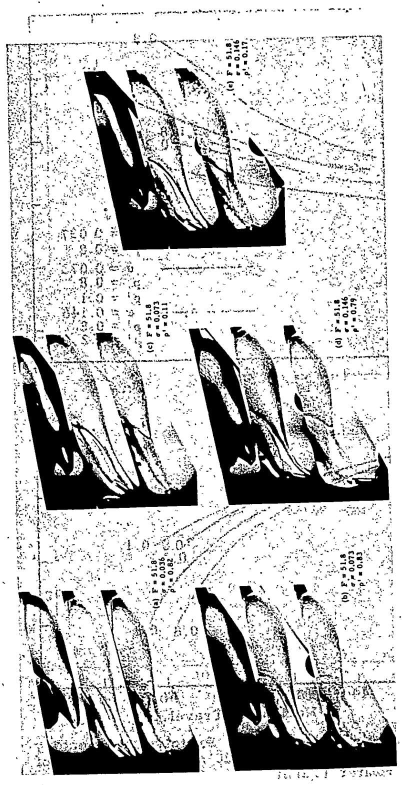
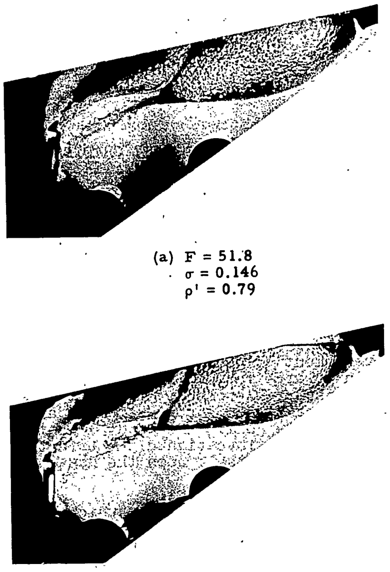


FIG. 19. Right-Cylinder Prototype: Effect of Scaling Condition on Cavity. The first photograph in each series was taken approximately 120 ms after water entry. The second and third were taken 50 and 70 ms, respectively, after the first.



(a) F = 51.8
σ = 0.146
ρ' = 0.79

(b) F = 51.8
σ = 0.146
ρ' = 0.79

FIG. 20. Right-Cylinder Prototype: Reproducibility of Cavity Under Equal Scaling Conditions. (Cavities photographed within 2 ms of same time after water entry.)

THE EFFECT OF SOUND VELOCITY GRADIENTS ON THE DAMAGE RANGES FOR AN UNDERWATER EXPLOSION

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Introduction

The development of weapons which can destroy all targets within a large radius is of vital concern to the Navy. A considerable amount of effort is expended yearly in a wide variety of programs which are directed towards this ultimate goal. The study I shall describe here was undertaken to investigate the effect of one attribute of the ocean itself upon the damaging potential of weapons fired underwater.

In most instances, the range to which an underwater explosion will damage surface ships or submarines depends primarily upon the nature of the shockwave transmitted through the water to the target. In pre-nuclear warfare days, when a 700-pound depth charge was a rather large weapon, the shape and magnitude of the damaging shockwave from an underwater explosion could be predicted quite well from the principle of similarity (1)*, provided the explosion took place in so-called "free water", i.e., in water deep enough for the shockwave to reach the target before interfering reflections from the water surface or bottom became significant. The pressure in the shockwave generated by an underwater explosion rises almost discontinuously to a peak value, and then decays exponentially. Out to the ranges of practical interest, shockwaves from a high explosive charge propagate as such steep-fronted exponential waves whose maximum pressure and rate of decay are predictable functions of the size and composition of the explosive charge and of the distance the wave has travelled.

The shockwaves from underwater nuclear bursts also propagate initially as steep-fronted exponentials. However, since nuclear bursts produce shockwaves of high pressure which are lethal out to much greater ranges than those of high explosive charges, some consideration has recently been given to a new factor which influences long range shockwave propagation in the ocean, viz, the effect of refraction due to variable sound velocity.

In a study of refraction effects on underwater shockwaves, the Woods Hole Oceanographic Institution, under a Bureau of Ordnance contract, performed a series of tests with small (21 pound and 56 pound) TNT charges fired in a flooded quarry under highly refractive conditions (2). Records of the shockwave pressure-time histories at various positions showed that in some regions the wave shapes were grossly distorted from the exponential form customarily assumed. By combining several figures from publications by Brockhurst and Arons (2, 3), I have constructed Figure 1, which shows the velocity profile in the quarry, the ray diagram computed for a 50 ft source depth, and sketches of some pressure-time histories at various positions.

In Figure 1, the dashed shockwaves are those which would be expected in isovelocity water, or, in other words, are the shockwaves predicted from the similitude equations for TNT. In speaking of the shockwaves and shockwave parameters I will use "isovelocity" and "similitude" interchangeably. Although the shockwaves at short ranges are accurately predicted, Figure 1 shows how far from reality the similitude relationships are in the highly refracted regions. Along the caustic of the ray diagram, we see shockwaves which have peak pressures several times as large as the similitude value. Below the caustic is a region of multiple shock arrivals, where secondary pressure rises occur. Above the caustic, in the zone of divergent rays, the shockwaves are attenuated, especially at shallower depths.

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*See References at end of paper.

It is evident from these sketches of the refracted and isovelocity shockwaves that if one calculates a damage range on the basis of either the shockwave peak pressure or the shockwave impulse (which is $\int p dt$, the area under the pressure-time curve), the damaging radius of a charge fired under refractive conditions may differ substantially from the isovelocity, or similitude, approximation for that same charge. The Woods Hole quarry data, which provided the first sizable collection of refracted shockwave records, were used to compare isovelocity and refracted damage ranges for submarines, in the manner described below. As I will note later, portions of this study utilize estimates based on acoustic ray theory rather than actual measurements, since, as seems to be inevitable, we found as we progressed that not all positions of interest here had been included in the experimental study. We are indebted to Mr. Brockhurst (WHOI), who has assisted in all phases of this study, for all of the estimates based solely upon acoustic theory.

Damage Criteria Used

Following the suggestion of Dr. Keil of the Bureau of Ships' Underwater Explosions Research Division, the criterion for damage used here was the concept of excess impulse, which lends itself nicely to this particular study. Dr. Keil and his group have made extensive studies of damage ranges derived with this criterion. The significance of the excess impulse damage rule is shown in the sketch of Figure 2. The excess impulse rule states that in order for a shockwave to damage a submarine, (a) the total pressure at the submarine (hydrostatic plus shock) must exceed the static collapse pressure of the target, and (b) the impulse in that portion of the wave which is above the static collapse pressure must exceed a certain critical value. In Figure 2, pressure is the ordinate and time the abscissa. On the left-hand side of the sketch, the excess impulse is shown for the usual type of exponential shockwave in isovelocity water. On the right-hand side, two types of refracted shockwaves illustrated in Figure 1 are compared with the same isovelocity shockwave, which is shown as a dashed line. For the shockwave along the caustic, where the pressure is higher than similitude, the excess impulse is increased; and for the decreased shockwave within the attenuation region the excess impulse is decreased. Thus, refraction effects increase the damage ranges in some areas and decrease the ranges in others.

Method of Scaling

It was necessary to scale the quarry data up to a realistic oceanic situation. This required establishing first a distance scale which would translate the quarry profile and ranges into reasonable full-scale conditions. Mr. Brockhurst determined that a range scale of 21 converted the quarry velocity profile into something resembling actual oceanic profiles in regions of the North Atlantic Ocean. The refraction pattern of the quarry is unchanged if all linear dimensions are multiplied by a constant. Thus, with a range scale factor of 21, the quarry data permitted examination of an oceanic area extending from the surface down to about 1000 ft, and out to about 8,000 ft range.

A number of charge weights typical of nuclear weapons were considered. Weight and range scale factors were combined to provide conversion factors which were applied to the pressure and time scales of the quarry pressure-time histories. It was assumed that the similitude relationships applicable to pressure and time scales of unrefracted shockwaves were also a reasonable first approximation for the refracted pressure-time histories. For the exponential shockwave the pressure, p (t), within the shockwave at any time, t, behind the shock front is:

$$p(t) = p_m e^{\frac{-t}{\theta}}$$

The similitude equations for TNT are (4):

$$p_m = 2.16 \times 10^4 \left(\frac{W^{1/3}}{R}\right)^{1.13}$$

$$\theta = 0.058\, W^{1/3} \left(\frac{W^{1/3}}{R}\right)^{-0.22}$$

where p_m is peak pressure (psi), θ is the exponential decay constant (milliseconds), W is charge weight (pounds) and R is slant range (ft). Scaled values of pressure and time were obtained from the quarry records using the relationships:

$$p_1 = p_2\left[\left(\frac{W_1^{1/3}}{R_1}\right)\left(\frac{R_2}{W_2^{1/3}}\right)\right]^{1.13}$$

$$t_1 = t_2\left(\frac{W_1^{1/3}}{W_2}\right)\left[\left(\frac{W_1^{1/3}}{R_1}\right)\left(\frac{R_2}{W_2^{1/3}}\right)\right]^{-0.22}$$

where the subscript "2" refers to quarry data and the subscript "1" to the nuclear yield.

The refracted damage ranges were determined for a variety of charge weights. We were, of course, particularly interested in charge weights for which the isovelocity damage ranges happened to fall within highly refractive regions of the ray diagram. I have chosen the results from three such charge weights to demonstrate how lethal damage ranges may be affected by the refraction pattern.

Damage Ranges

For the remainder of the time I shall talk in terms of the scaled dimensions, that is, the lethal damage ranges expected from a nuclear underwater burst in the ocean. I must point out here that the damage curves I will show to illustrate the refraction effects are only qualitatively significant; too many things remain unknown about both the damage mechanisms and the shockwave behavior for the following curves to be considered exact. We must also remember that the location and magnitude of refraction effects depend upon details of the acoustic profile present. Since the refracted pattern differs markedly when the source depth is varied within the same velocity profile, I will show results from two burst depths for approximately the same nuclear yields.

I. 1050 Ft Burst Depth

In Figure 3 you see the velocity profile and the ray diagram for a weapon detonated at 1050 ft depth. (These are the same conditions as Figure 1 and correspond to the deepest burst depth in the quarry tests.) The three dashed lines are the unrefracted damage ranges for three different weapon sizes, weights A, B and C, which were chosen because they lie in the refractive region. The yield corresponding to weight B is twice that of weight A, and the yield corresponding to weight C is six times that of weight A. These dashed curves show the greatest distance from the charge at which a submarine would receive lethal damage from the indicated burst. At any point between the curve and the explosive source (1050 ft deep at zero range) the target would be killed. As the target submarine gets deeper, the damage zone extends to a larger horizontal range, because the hydrostatic pressure constitutes a larger percentage of the required collapse pressure. The damage ranges are decreased for targets near the surface, since the rarefaction wave which is reflected from the water surface reduces the positive shockwave pulse.

In Figure 4 we have added to the unrefracted damage ranges the corresponding refracted damage ranges, shown as solid lines. One of the most obvious changes in the damage ranges is that now the symmetry of the curves has disappeared. As one would expect from examination of the refracted shockwave shapes, the damage ranges appear to be decreased near regions of ray divergence, and increased near regions of ray convergence.

At shallow depths, the refracted damage curves for the different weights show about the expected increase in range for increased charge weight. However, down at about 500 ft, the refracted curves for the different weights are converging while the refracted curves continue parallel. If one could believe that these curves were quantitatively correct, Figure 4 would indicate that for attacking a submarine submerged at 500 ft in this refraction pattern, the smallest nuclear burst treated here (Wt. A) is lethal considerably further out than one would have expected, but that increasing the charge yield by as much as a factor of six (Wt. C) does relatively little towards increasing the lethal range.

The possibility of realizing increased damage ranges from a deep nuclear burst, due to increased pressures along a caustic, is an appealing idea. However, from Figure 4 we can see the dangers of relying upon refraction to increase a weapon's damaging potential. For weights between A and B, the caustic does indeed increase the damage range if the target is below about 400 ft; however, for targets at shallower depths, refraction may slightly reduce the range even for these yields. For yields smaller than Wt. A refraction has little effect on damage ranges, and for yields of Wt. C and greater refraction decreases the damage range for targets at any depth. In order to increase the ranges, an ideal combination of charge yield, target and burst depths, and acoustic structure must exist. Consequently, at our present state of knowledge it appears that for practical considerations caustics should be thought of primarily as possible sources of danger to our own submarines, rather than as a means of increasing lethal ranges.

II. 420 Ft Burst Depth

The picture is quite different for bursts at a shallower depth. In Figure 5 we have the ray diagram and isovelocity damage ranges for the same profile and approximately the same yields, but with the source, or depth of burst, up at 420 ft. **These damage ranges are slightly smaller than those for the deeper burst, due to a shorter duration shockwave, but are not significantly different from the unrefracted curves of the previous slides.** However, the refraction pattern is, of course, materially changed by the change in source depth. Since the source, or burst,depth is very near the depth of the major thermocline here, there is no caustic, and a large percentage of the field now lies in the divergence zone.

The refracted damage ranges are added, again as solid lines, in Figure 6. The shallower portions of these refracted curves were estimated with the help of Mr. Brockhurst's ray theory calculations. Theoretical estimates were used from the surface down to depths of about 550 ft for Wt. A, 300 ft for Wt. B and 100 ft for Wt. C. The remaining portions of these curves were obtained from the scaled quarry measurements.

Here the effect of the shockwave attenuation zone is markedly shown. The refracted damage curves coincide with the unrefracted ones near the surface. However, at about 250 ft depth, where the shockwave decrease becomes significant, the refracted damage curves begin to deviate, and refracted damage ranges become very much smaller than the unrefracted ranges as the target depth increases. The refraction effects become larger as the yield increases. In fact, according to these curves, for targets below 250 ft, damage ranges for all three weights are less than the isovelocity values and there is relatively little increase

in damage range when the charge weight is increased by a factor of 6.

Before venturing a few generalizations I would like to repeat that the charge weights chosen for this study were specifically those whose damage ranges would be affected by the refraction pattern of the particular profile measured in the quarry. Obviously, had we used smaller weights, for which the isovelocity damage ranges fell in essentially unrefracted portions of the field, no such extreme deviations would occur. Similarly, since the refraction is generally greater at greater ranges, larger charge weights would have produced even more distorted damage curves. Other profiles, with different refraction patterns, might show entirely different results for these same charge weights.

Summary

Although it is obvious that we cannot interpret these data as representing the effects of refraction under all circumstances, the results of the study described here lead to the following generalizations:

(1) For some target-charge configurations in some portions of the ocean where nuclear weapons may be used, the effects of refraction may materially affect the damaging radius of the weapon. Although the case discussed here represents only one specific oceanic profile, the profile is typical of those which occur in large areas. Hence, for important practical reasons the question deserves continued study.

(2) In general, the practical significance of refraction effects lies in the possible loss of damaging potential, due to divergence zones, rather than in possible gain in damaging potential resulting from convergence zones. In this connection, the choice of burst depths for tactical purposes may be affected by refraction patterns.

(3) The effects of refraction on damage ranges are usually larger as the charge size increases.

Future Work

I will mention briefly some of the work which is continuing on this subject. To date, no successful analytical means of predicting the shockwaves in a refracted field has been found. Work is continuing on this problem. We are beginning to acquire some valuable additional experimental data from scale-model work by Professor Hall of the University of New Hampshire, under a Bureau of Ordnance Contract (5, 6). Professor Hall has devised a small tank in which various thermal profiles can be constructed; by recording the refracted shockwaves produced when detonator caps are fired in the tank, he can provide information on a number of profiles and source depths. Mr. Brockhurst, at Woods Hole, is particularly concerned with the application of acoustic ray theory to the problem; we are now able to make rapid ray theory calculations on the IBM 650 machines at NOL. With the combination of scale-model data and theoretical calculations, we hope to develop a semi-empirical picture of the part that the ocean's thermal structure plays in weapons effectiveness.

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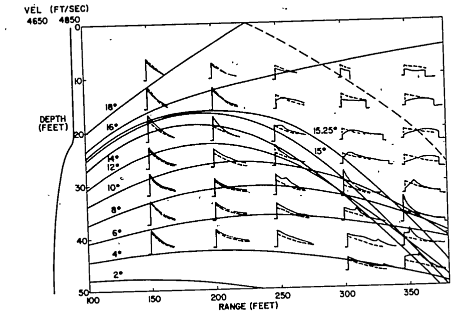

Figure 1. Ray Diagram and Pressure-Time Curves for Quarry Shots Fired at 50-ft Depth

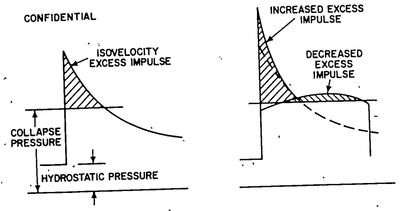

Figure 2. Significance of Excess Impulse Damage Rule for Isovelocity and Refracted Shockwaves

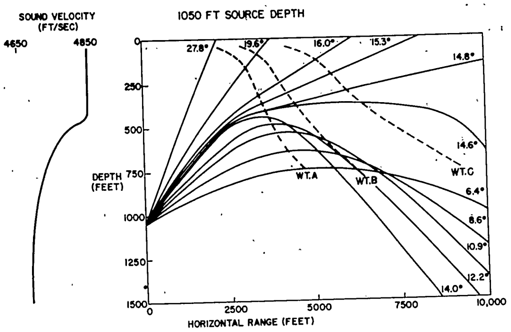

Figure 3. Ray Diagram and Unrefracted Damage Ranges for 1050-ft Burst (Source) Depth

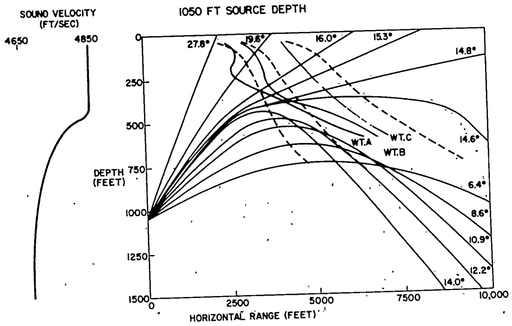

Figure 4. Refracted and Unrefracted Damage Ranges for 1050-ft Burst (Source) Depth

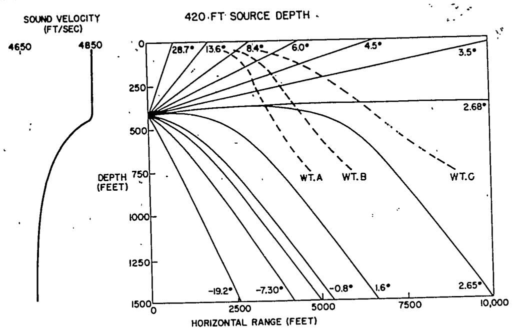

Figure 5. Ray Diagram and Unrefracted Damage Ranges for 420-ft Burst (Source) Depth

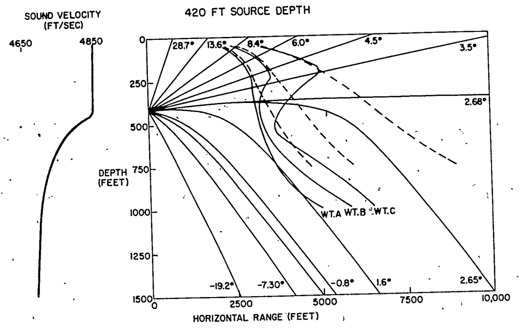

Figure 6. Refracted and Unrefracted Damage Ranges for 420-ft Burst (Source) Depth

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OFFENSIVE SEA MINES

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The title of this paper is "Offensive Sea Mines". This title indicates that sea mines and minefields are offensive and it is believed that those who are required to traverse minefields with their ships or deal with them from a countermeasure standpoint will agree with this interpretation.

Mines are spoken of as being either offensive or defensive depending on the type of field in which they are planted. In order to cover the situation and to avoid repetative breakdowns in this presentation, all types of mines will be considered to be offensive.

As an introduction to mine design, mine warfare, and the environmental sea conditions that affect them, I would like to say that the mine is regarded as a unit in a minefield and in mining parlence the minefield is usually considered to be the weapon. It is, of course, obvious that the efficiency of a minefield is largely dependent upon the efficiency of the individual mines.

The value of a minefield is gauged by the threat that it produces. This threat has to be established, maintained over a length of time, and in many cases, disestablished. The ability to design effective and versatile mines that will produce a successful minefield is the challenge that faces the mine designer.

It is obvious that all of the environmental factors that affect mines and mining cannot be considered in this paper, so I have placed in four categories the ones I intend to talk about. They are as follows:

1. Water Entry.
2. Stability and Life.
3. Actuating and Firing Mechanisms.
4. Explosives and Explosive Effects.

These factors are arranged in the order of a mine's lifetime; that is, from the time it enters the water until the time it leaves the water as a detonated explosive.

WATER ENTRY

The first item to be considered will be the process of getting the mine into the water and satisfactorily locating itself in the required position. At first glance, this process would appear easy, for if the mine is dropped into the water and it is negatively bouyant, it will sink to the bottom. But the process is not easy for all mines, particularly aircraft planted mines. Mines launched from a submarine are the easiest to get into the water. Here the static pressure head and the launching pressure are the principal forces to be considered.

Surface planted mines are limited in height and speed of launching. These mines are assemblies of boxes, spheres, and other non-streamlined objects, held together by turnbuckles, wire straps and mechanical fasteners, and do not give the impression of strength and ability to withstand shock. However, they do fulfill service requirements.

When the design of aircraft planted mines was started in the early part of World War II, the mine designer ran head on into the water entry and bottom striking problem. Striking the water wasn't so bad but striking hard sand or rock bottom usually resulted in a damaged mine. Aircraft mines are cylindrical in shape and have a slenderness ratio of about 4 to 1. Most mines have a slant section on the nose and a tapered section on the tail. The slant nose section causes the mine to broadside in the water and kill its forward velocity. All models of U. S. Navy aircraft mines except one are fitted with parachutes to control the water striking velocity which usually falls in the range of 160 to 200 feet per second. The Navy has one free falling mine which has a terminal velocity of about 700 feet per second. This mine can strike the water at its maximum velocity and still be successfully laid on hard sand bottom in a minimum of about 50 feet of water.

The water entry problem becomes more difficult if the surface is covered with ice. Several years ago this type of planting was tried, using stockpile mines. Airplanes loaded with a total of eleven (11) mines of six different types took off from the Naval Air Station, Patuxent, Maryland, and planted the mines in Portage Lake in Northern Michigan. The lake was covered with ice 16 to 24 inches thick.

Figure 1 shows the hole made in the ice by a Mark 25 mine which is parachute retarded. The diameter of the hole is approximately 25 inches.

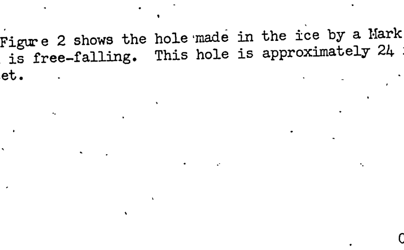


Fig. 1. Hole in ice made by Mark 25 **Mine**.

Figure 2 shows the hole made in the ice by a Mark 39 mine which is free-falling. This hole is approximately 24 feet by 19 feet.

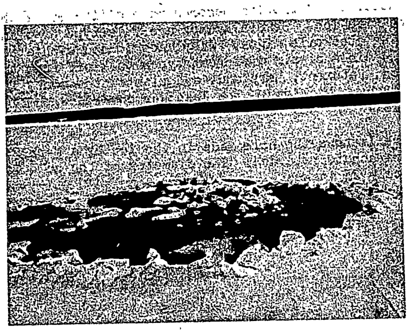


Fig. 2. Hole in ice made by Mark 39 mine.

Next spring, after the lake thawed, 8 of the 11 mines planted were recovered. Six of the recovered mines were in operable condition. This is an overall reliability of 75% which is considered very good for this type of operation.

STABILITY AND LIFE

Now that we have considered methods employed to get the mine into the water, the next category of items to be considered will be those affecting stability and life.

Moored mines will be considered first. Bottom conditions and currents will affect the planting of moored mines. Figure 3 illustrates these conditions.

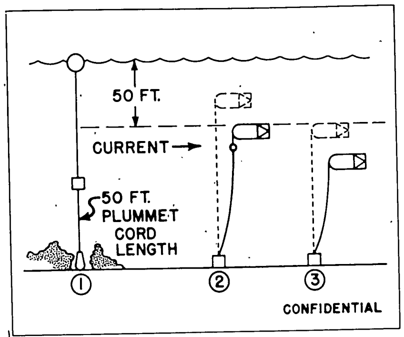


Fig. 3. Methods of setting case depth of moored mines.

Figure 3-1 shows the plummet method of case depth determination. In this example the mine case is to be anchored at 50 feet below the surface. Therefore the plummet cord is 50 feet long. Although this method is classic and time honored, it has a number of recognized faults. On occasions, the plummet will not sink and strike the bottom directly under the anchor; on coral and rough bottoms the plummet and anchor may come to rest on different levels. These conditions will affect the depth taking of the case.

The second method of anchoring the mine case shown in Figure 3-2 employs a hydrostat at the mine case. When the case has risen to the planting depth, the hydrostat operates and anchors the mine. To do a good job of depth taking this type of mine should be planted at slack water. In a current the mine will plant at the set depth from the surface and due to the dip caused by the current, will be too close to the surface at slack water. In a newly developed mine, a new method of depth setting is employed. Figure 3-3. This mine assembly includes the delayed rising principle wherein the assembly sets on the bottom until the case is released by a settable delay with a maximum setting of 30 days. At the time the case is released, even when a strong current is running, instruments in the anchor measure the distance the anchor is from the surface and meters out the right amount of cable to locate the case at the proper slack water depth.

Besides influencing the mine during its planting stage, currents are the cause of the bothersome factor called dip, which is the distance the case is pulled down due to the current. Pamphlets on mines and mining contain dip tables. All of these tables are based on the premise that the current is uniform in direction and velocity from the surface to the bottom. Although mine designers have known for years that this condition practically never exists, the tables are still in use.

Figure 4 shows an observed current profile 225 miles east of Charleston, South Carolina, where the surface current is about 2.6 knots and the current drops off to practically nothing at one-third the depth - approximately 6000 feet.

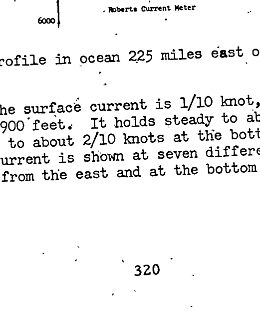


Fig. 4. Current profile in ocean 225 miles east of Charleston, S.C.

In Figure 5 the surface current is 1/10 knot, increasing to 1/2 knot at about 900 feet. It holds steady to about 2000 feet and then decreases to about 2/10 knots at the bottom. The direction of the current is shown at seven different depths. At the surface it is from the east and at the bottom it is from the north.

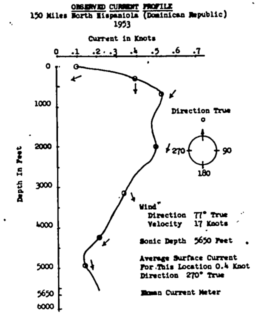


Fig. 5. Current profile in ocean 150 miles north of Dominican Republic.

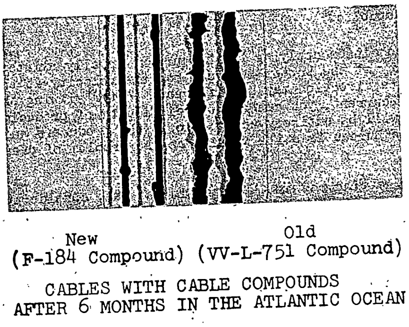
One condition applying to the current usually exists; that is, the velocity at the bottom is less than the velocity at the surface, although its direction may be different. After viewing these few samples of current, you can see the difficulty of producing dip data that will be entirely acceptable to the producers and to the users. The Bureau is still working on the problem of presenting dip data.

After getting the mine located in the sea, consideration will be given to the conditions that affect its life, such as wetness, corrosion and marine growth.

Wetness is a natural sea condition that should be confined to the outside of the mine case. When water enters the case the mine is usually ruined. For this reason, openings in a mine case are kept to a minimum. These openings are fitted with gaskets, such as flat bolt circle, flat ring, tongue and groove and "O" ring. It would appear that anyone in this audience, with a maximum of five minutes instructions, could successfully assemble any type of closure; however, to get this done successfully, on all occasions thruout the service, is very difficult. A few years ago, a Fleet unit planted 25 Mark 6 moored mines, our oldest mine of this type, in a service test program. A short time after the plant, the minefield was swept and not a single mine was encountered. It appeared that all the mine cases leaked and sank to the bottom. This happening illustrates the interdependence of the mine designer and the people who assemble the hardware.

Standard procedures are taken to combat corrosion such as painting, plating, and insulating dissimular metals. Mooring cables, which are probably the weakest link in a moored mine system, are given an anti-fouling treatment. For a number of years an anti-fouling cable compound was used that contained phenylmercuric salicylate. This compound had poor keeping qualities and was a health hazard when used. Several years ago the Naval Research Laboratory developed an anti-fouling cable compound identified as NRL F-184. This compound contains mercurous chloride and is not a serious health hazard.

Figure 6 shows the improvement of anti-fouling properties of the new compound over the old compound, after 6 months in the ocean.



New (F-184 Compound)

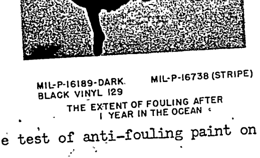
Old (VV-L-751 Compound)

CABLES WITH CABLE COMPOUNDS
AFTER 6 MONTHS IN THE ATLANTIC OCEAN

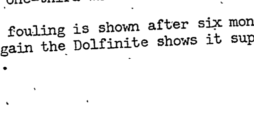
Fig. 6. Life test of cable compounds.

Fouling is not only detrimental on mooring cables, it is also harmful on moored mine cases. Until recently, mine case drawings have specified a vinyl base anti-fouling paint, black in color. A commercial paint, named Dolfinite, is now available which is giving results superior to the vinyl base paint.

Figure 7 shows the fouling present on moored mine cases after one year exposure in the ocean. The part of the cases painted with Dolfinite is much cleaner.



DOLFINITE & MIL-P-16738 (STRIPE)



MIL-P-16189-DARK BLACK VINYL 129

MIL-P-16738 (STRIPE)

THE EXTENT OF FOULING AFTER 1 YEAR IN THE OCEAN

Fig. 7. Life test of anti-fouling paint on mine case.

Figure 8 shows a plastic test cylinder which had one-third of its surface painted with red vinyl No. 121, one-third with black vinyl No. 129, and one-third with Dolfinite.

The extent of fouling is shown after six months' exposure in the ocean. Here again the Dolfinite shows it superiority as an anti-fouling paint.

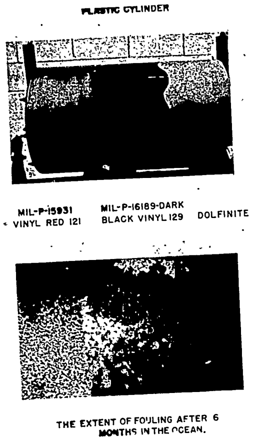


Fig. 8. Life test of anti-fouling paint on test cylinder.

Bottom mines are, in general, not bothered by corrosion and sea growths and their position and stability on the bottom is mainly controlled by the bottom structure. In soft mud bottoms, aircraft mines frequently bury their noses in the mud and take up various positions making an angle with the bottom. On hard sand, coral and rock bottoms, the mines usually lie flat. Burial of bottom mines to a certain extent is regarded as beneficial, in fact this is considered to be one type of countermeasure protection. Magnetic influence mines can be completely buried without harm. In acoustic and pressure mines, complete burial of the hydrophones would appear to be detrimental; however, under actual field tests burial of the hydrophones has not seriously affected the sensitivity of these mines.

Cylindrical mines seem to be ideally constructed to roll on the bottom. However, in actual practice, once these mines get settled they are very stable.

In a field test conducted by the Narragansett Marine Laboratory, a number of Mark 36 mines (1000 lb., aircraft planted, bottom mines) were planted in about 35 to 40 feet of water off the Southern Coast of Rhode Island on sand and gravel bottoms. The mines were observed for movement from time to time, and some examples of the results obtained are as follows:

In 143 days exposure, one mine moved about 2½ feet and changed its heading 10 degrees. Another mine in 137 days moved 5 to 9 inches. During this test two hurricanes passed over the area. The stability of the mines under the test conditions mentioned above is, I believe, very surprising.

I can't leave the subject of stability without saying a few words about the stability of moored mines. These mines are supposed to have the property of "walking". I say "supposed" because this property is hard to pin down with reliable statistics. It is probable that on occasions a moored mine planted in fairly shallow water on a hard bottom with the case near the surface will "walk" during rough weather; that is, move from its planted position. When a ship runs into a mine in an area adjacent to a charted moored minefield, it is customary to blame the mine for being out of position rather than blame the ship for being out of its course. Reliable data on the possible movements of moored mines are not available.

ACTUATING AND FIRING MECHANISMS

Before considering mine firing mechanisms, I would like to mention the auxiliary mechanisms used to maintain the safety, arming and disarming of the mines.

The arming cycle of most mines is started by the removal of mechanical safety devices when the mine is launched from its carrier. After entering the water, two characteristics of the environment are used to continue the arming cycle; these characteristics are hydrostatic pressure and wetness. The hydrostatic pressure head is a very reliable characteristic and is employed to align detonators, start clocks and close electrical circuits. The wetness of the water is used to dissolve soluble washers and energize electrolytic arming cells.

The temperature range of sea water is fairly favorable to sea mines. The temperature of sea water is usually given as ranging from about 28°F to 96°F. This temperature range is favorable to mines and mining and is a natural condition for which mine designers are thankful.

When we come to consider mine firing mechanisms, we find they are divided into two division; namely, contact and influence. Under contact there are two types, horns and galvanic. The horned mine is self contained as far as its firing means is concerned. The galvanic mine uses the sea water as an electrolyte between the copper plate on the mine case and the steel ship which makes contact with the copper antenna extending from the mine case. This type of firing device was invented and used in World War I, and was, I believe, the first use of the sea in the firing system of a mine.

Influence firing mechanisms in practical use today belong to three basic kinds and combinations thereof; namely, magnetic, acoustic and pressure. The ocean background has negligable effect on the firing characteristics of the magnetic mine.

In the category of acoustic mines the ocean plays a considerable role. The first acoustic firing mechanism to be used in U. S. mines in World War II was an intermediate frequency device which fired when the noise level reached a set amplitude in the 300 cycle band within a certain time. Figure 9 illustrates the build-up of the ship signal with time.

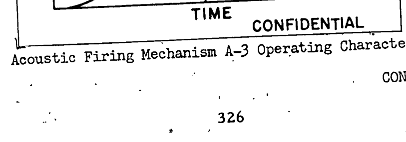


Fig. 9. Acoustic Firing Mechanism A-3 Operating Characteristics.

A countermine protective circuit, which peaked in the 1000 cycle band, was included in the mechanism which blocked the firing circuit when a sharp steep front noise reached the microphone from an explosion or explosion-like phenomena.

The second acoustic firing mechanism developed and used in service in World War II was a low frequency device which peaked at 15 cycles. This device was actuated by rate of change and amplitude in sound level.

Figure 10, illustrates the functioning of this device. If the rate of change falls below the line A, no fire will occur. If the rate is between lines A and B, actuation will occur and if the rate is above line B the device will protect. The low frequency firing mechanism was found to be suitable for use against cargo vessels that have a strong noise output in the low frequency band. The firing pattern is also good.

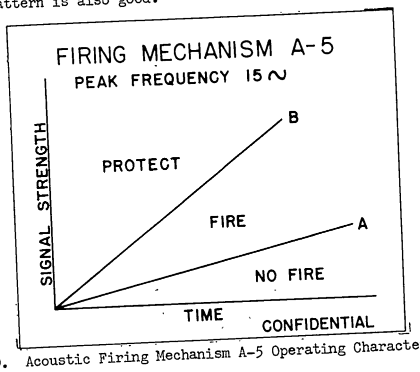


Fig. 10. Acoustic Firing Mechanism A-5 Operating Characteristics.

An interesting phenomena was discovered during the development of this mechanism; that is, the low frequency mine was fired by a distant explosion. When conditions were favorable the ground wave reached the mine before the water borne wave. This ground wave with reverberations and attenuation appeared to the mine to have the same characteristics as the noise from a near-by target.

Since World War II, two new acoustic firing mechanisms have been developed that are in service mines. One is a low frequency device with its peak sensitivity at about 30 cycles. This mechanism is used in a fairly small aircraft planted mine; that is, the 500 lb. size. This mine is designed to be used in rivers, harbors, and canals with barges and other typical river traffic as the primary targets. This firing mechanism employs principles similar to the ones described above.

The second mechanism developed since World War II is designated Firing Mechanism Mark 21 and is used in a new series of 1000 and 2000 lb., aircraft planted mines. This mechanism can be used singly or in a two mechanism combination, such as the magnetic-acoustic and pressure-acoustic or a three mechanism combination, such as the magnetic-pressure-acoustic.

The older acoustic firing mechanisms described above are dependent almost entirely on the amplitude of the ship's signal. The strength of the ship's signal received at the mine varies almost inversely with the distance from the ship and, since the older acoustic mechanisms are actuated at a certain amplitude level, a noisy ship creates this actuation level at the mine earlier than a quiet ship. Because there is a wide variation of sound output amplitude of various ships, a mechanism set to be actuated by the signal of a comparatively quiet ship within the desired damage range may be actuated by the signal of a loud ship outside the damage range. The same loud ship within the damage range may countermine the mine rather than actuate it.

To overcome the disadvantages of the amplitude actuation, Firing Mechanism Mark 21 uses circuits that depend upon mathematical derivatives of the logarithm of the envelope of a ship's signature, making response practically independent of the signal amplitude.

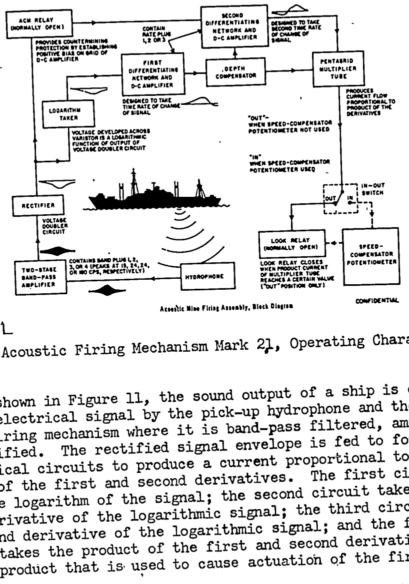


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Fig. 11. Acoustic Firing Mechanism Mark 21, Operating Characteristics.

As shown in Figure 11, the sound output of a ship is converted into an electrical signal by the pick-up hydrophone and then applied to the firing mechanism where it is band-pass filtered, amplified, and rectified. The rectified signal envelope is fed to four mathematical circuits to produce a current proportional to the product of the first and second derivatives. The first circuit takes the logarithm of the signal; the second circuit takes the first derivative of the logarithmic signal; the third circuit takes the second derivative of the logarithmic signal; and the fourth circuit takes the product of the first and second derivatives and it is this product that is used to cause actuation of the firing circuit.

A new firing mechanism, designated the XA-1E, is under development. This mechanism has been designed primarily to fire against the quiet running submarine, and, in spite of its high sensitivity, the mechanism is at present highly resistive to sweeping.

This mechanism is a two channel device, comprising a localization channel and an anti-countermine channel. The sound pressure variations in the sea are detected by two hydrophones of new construction. One is a low frequency and the other is a higher frequency hydrophone. The output of these hydrophones is processed in a manner similar to the procedure described in the explanation of the Firing Mechanism Mark 21. In addition to the signal processing described above, the firing mechanism contains discriminator circuits that recognize characteristics of the noise output of ships as distinguished from the noise output of acoustic sweeps.

The next attribute of the ocean, to be considered, used by the mine designer is the change in pressure at the mine caused by the passage of a ship in the vicinity of the mine. This attribute is highly important to mine designers because it is this phenomena that is most difficult to reproduce from the countermeasures standpoint. However, the pressure detector has limitations that must be recognized. Swells and waves can produce a condition at the mine that duplicates target signatures. Thus, the mine is subject to spurious firings and for this reason this type of mechanism is almost always used in combination with other detectors. Since this mine is spoken of as a pressure mine, some people get the impression that it is actuated by increasing pressure. This is not so, the phenomena detected is a decrease in pressure. An interesting example of this misunderstanding occurred several years ago when an article appeared in the Reader's Digest, the title of which was, "The Threat of the Pressure Mine ". The article pointed out the need for a countermeasure to this menace. You can well imagine that an article of this kind in a widely read publication brought forth a number of suggested solutions. About half a dozen of these solutions were sent to the Bureau of Ordnance and in all of these, the sender assumed that the change in pressure was positive. One man on his second try did get the correct condition.

Figure 12, illustrates a typical pressure signature of a target ship taken in the keel plane. You will note that at the bow there is a slight increase in pressure followed by a negative change which is sustained to a point near the stern. The pressure detector of World War II mines was designed to open a contact when the pressure drop was a set amount and the contact remained open until the change fell below the set level. If the "time out" of this contact was 10.5 seconds or greater, the detector recorded a pressure "look". This "look" in combination with a magnetic "look" fired the mine.

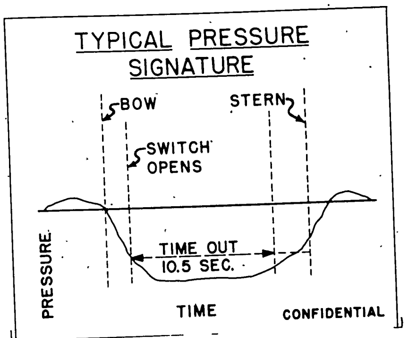

Fig. 12. Typical Pressure Signature of a Ship.

In recent years a new presure mechanism has been developed that is used with the new 1000 and 2000 lb. mine series. The pressure detector consists of two systems - a hydraulic system and detection system known as the pressure electrolytic cell which transforms the negative pressure differential into two electrical currents. One is called a pressure sensing current and is proportional to the square root of the pressure change in the sea water The other is called the integrator current and is proportional to the amplitude and duration of the pressure sensing current. The integrator current actuates a relay in the firing mechanism that closes a break in the mine ship-count circuit. The pressure sensing current actuates an auxiliary relay which is used to initiate other operations in the mine circuit.

EXPLOSIVES AND EXPLOSIVE EFFECTS

So much for firing mechanisms, we will now consider explosives and explosive effects. It is felt that this item should come at the end of this paper, for the explosive is the payload of the weapon and when it detonates there is a certain amount of finality to the situation. The question can be asked, is the presence of the ocean beneficial or detrimental to explosive effect. It is the judgment of the experts that the explosive effect is enhanced by the presence of the sea. This is particularly true of a fully submerged submarine where the hydrostatic pressure head adds to the pressure on the hull from a nearby explosion.

Figure 13, shows damage curves for a typical mine against a typical ship.

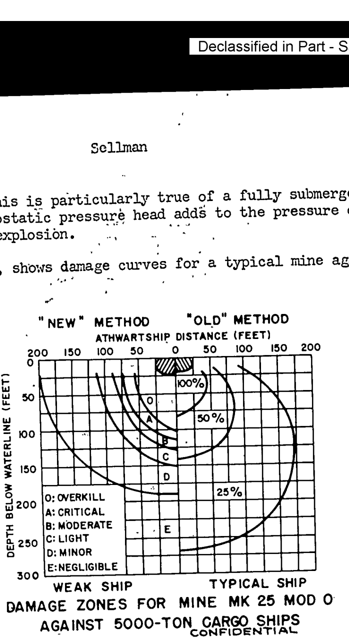

Fig. 13. Damage Zones of Explosive Effect for "Old" and "New" Method of Presentation.

For a number of years, damage range curves as shown on "old" method, were used to depict the damage done to targets by explosives.

In recent years new damage range curves have been produced that are based on new data and a re-evaluation of old data. "New" method on this figure shows the new curves for the same type of target and explosive as shown in "old" method. The main difference in these two sets of curves is that the explosive is shown to be more effective under the keel adjacent to the ship on the new curves and more effective on the sides near the surface. In the old curves the damage effects are shown on a percentage basis, on the new curves it is shown as damage zones that are named, which it is believed, is more descriptive. Explosive experts feel that chemical explosives, as presently developed and used, have about reached their limit in effectiveness. Mine designers are considering nuclear

explosives for greater effect in future mines.

In this paper I have tried to give you some information on the environmental factors that affect mine design and how the mine designer uses the factors that are beneficial and how he has learned to live with the ones that are detrimental. A thorough knowledge of these environmental factors, coupled with the ingenuity of the mine designer, will make the offensive sea mine of the future still more "offensive".

TOXICOLOGICAL AND HEALTH HAZARDS OF GUIDED MISSILES

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The Rocket Age has given rise to new weapon systems which have greatly increased the defensive and offensive capabilities of the Navy. These increased capabilities, however, have not been without their price in the form of personnel hazards and, in some cases, are limited by the capacity of the human crew to live and function in the environment created by the presence and/or operation of the weapon system.

The personnel hazards of concern are of four general types; blast pressures, temperature and flash-burn hazards, high intensity noise, and noxious gases. The ground forces are able to avoid these problems to some extent by relatively great separation of men and machine during the launch phase of system operation. Such a solution, however, is not practical aboard an operational naval vessel. Certain topside positions such as gun mounts, gun directors, air defense stations, bridges, etc., must be manned during general quarters. The degree of hazard involved in manning such positions during the shipboard launching of guided missiles is the principle subject of this paper.

Pressures aft of a launched missile may be either higher or lower than atmospheric pressure, depending upon the locus of the position in the exhaust pattern. The static exhaust pressure in the region of the nozzle is usually not much greater than atmospheric. In an ideal rocket where expansion is complete, the static exhaust pressure would equal the ambient pressure. On the other hand, the dynamic or velocity pressure in the exhaust cone of a rocket is dangerously high even at fair distances from the rocket nozzle. Examples of static and dynamic pressures are the barometric and wind pressures involved in a wind storm. Even though the static or barometric pressure is low, the dynamic pressure on an object positioned so as to oppose the velocity of the wind may be of sufficient magnitude to result in damage to the object. It is this dynamic pressure which constitutes a hazard to personnel in the vicinity of the missile launcher. An additional hazard is created by the Bernoulli effect of the rapidly moving exhaust stream. The Bernoulli effect is best demonstrated by blowing air between two suspended sheets of writing paper. The rapidly moving air between the sheets of paper results in a static pressure in that region below atmospheric causing the sheets to be pressed together by the higher ambient pressure outboard of the paper. In the same manner, the static pressure in and near the rapidly moving downstream exhaust drops below atmospheric to an extent dependent upon the velocity of the stream in that region. This rapid drop of pressure may lift deck treads, peel name plates from bulkheads, and cause these and other such debris to be propelled at high velocities downstream. Such unbalanced forces may also result in the unintentional opening of hatches, doors, pressure-relief valves, and blowout patches (1).

The temperature of a missile exhaust may be of the order of several thousands of degrees and may remain highly elevated for a considerable distance downstream, depending upon the degree of afterburning of the exhaust products. Since the residence time of the flame is very short for missiles of high initial acceleration, the temperature of nearby materiel of reasonable mass is normally only rendered warm to the touch. Short-lived elevated air temperatures of several hundreds of degrees occur for quite some distance directly aft of the launched vehicle, but the short residence time and the very low heat capacity of air combine to produce only slightly elevated temperatures in the case of the ship's structure and massive materiel. Paint, canvas, frayed ends of manila lines, etc., however, may be ignited by the exhaust flame or heated to the point of combustion by the hot gases directly aft of the flame zone. It should be noted that missiles of the antiaircraft type and larger give rise to flame zones of 50-75 feet aft of the booster rocket.

The temperature or burn hazard to personnel is of a different order of magnitude (2). Serious flash burns may be produced some 100-125 feet from the launcher area. Shipboard animal studies have shown that the fur of a rat may be ignited even though untouched by flame some 85 feet directly aft of a launched TERRIER missile. Further studies indicated that a definite flash burn hazard existed for at least an additional 20-30 feet. A sentry accidentally exposed to a deflected missile exhaust received a hair singe at about 110 feet from the launcher.

The noise of a rocket engine is primarily due to aerodynamic turbulence in the jet stream and is essentially a white sound, i.e., approximately uniformly distributed throughout the octave bands from 20 to 10,000 cycles per second. The acoustic energy produced is to a first approximation proportional to the kinetic energy of the jet stream, and the sound energy output of rocket engines may be related empirically to parameters which are associated with the jet stream kinetic energy such as thrust and mass discharge rate. This energy is not radiated uniformly in all directions, but has marked directional characteristics. The directional pattern of noise radiated from the exhaust of a rocket engine varies with the design parameters but, in general, the maximum over-all sound level occurs at an angle of approximately 45° to the exhaust axis. The variations in sound pressure levels may exceed 15 decibels at equidistant positions on bearings abaft the beam of the missile, with the noise level increasing to a maximum on the quarter, and falling off again thereafter.

It should be noted that because of the logarithmic nature of the decibel unit, the firing of two similar rockets at the same time will result in an increase of 3 decibels in the noise level. Also, the attenuation of airborne noise is such that the level is lowered by approximately 6 decibels for each doubling of the distance from the sound source.

Aboard the guided missile cruisers, topside personnel at positions nearest the TERRIER launchers are subjected to sound levels of the order of 150 to 155 decibels. The threshold of pain is thought to be of the order of 125 decibels. Fortunately, the missile noise is of very short duration. In order to permit a comparison of missile noise with a familiar reference sound, determinations were made of sound levels produced at normally manned positions during the firing of the main and secondary batteries aboard a heavy cruiser (3). Analysis of these data showed that high sound levels such as those produced at topside manned positions during the shipboard firings of TERRIER missiles are not new to the Navy and are actually not as intense as some familiar gunfire noises. Missile sound levels at After Air Defense, the topside manned position nearest the TERRIER launcher, were found to be intermediate between those produced during the firing of adjacent 3-inch and 5-inch guns and far less than the noise level on the Flag Bridge during the firing of a six-gun salvo from the main battery of 8-inch guns.

Guided missile power plants of the liquid rocket type utilize a variety of toxic and corrosive chemicals as fuels and oxidizers, the handling of which aboard ship presents the Navy with quite a problem. Examples of such chemicals used in liquid propellant combinations are aniline, hydrazine and its derivatives, various alcohols, hydrocarbons, boron hydrides, fuming nitric acid, liquid oxygen, hydrogen peroxide, and liquid fluorine. Needless to say, the Navy has preferred to avoid the problem of handling such materials aboard operating ships through the development and use of solid propellants. The boron hydrides are examples of high performance liquid fuels which are accompanied by a high toxicity price tag. The recently scrubbed TRITON ramjet surface-to-surface missile was to use fuels of this type and was to be carried aboard submarines in much the same manner as the REGULUS missile. In the closed atmosphere system of such a submarine, the vapor from one jigger of such a fuel evenly distributed in the submarine air would have greatly exceeded the estimated operational health limits. Before the formation of the POLARIS project, the JUPITER and its liquid oxygen oxidizer was considered for shipboard use. The POLARIS will utilize a composite solid propellant. With the exception of certain presently considered prepackaged air-to-air missiles and an auxiliary power unit under development for the TERRIER, missiles utilizing liquid rocket propellants have not been accepted in the Navy for operational use.

The solid rocket motors of operational Navy missiles make use of two general types of propellants; double-base propellants principally consisting of nitrocellulose plasticized with nitroglycerine, and composite propellants wherein a solid oxidizer such as perchlorate or nitrate is suspended in a plastic fuel-binder. The vapors evolved during shipboard storage of motors using such propellants have so far constituted no great problem. The primary products of combustion are carbon dioxide, carbon monoxide, water, nitrogen, hydrogen chloride (perchlorate composites), and small amounts of metallic additives such as lead. The major source of possible toxic consequences is the entrapment of these combustion products in confined spaces which have possible ports of entry of the gases exposed to the direct supersonic blast of the booster rocket. Therefore, the degree of hazard as far as combustion products are concerned is a function of ship design and reliability of seals around hatches and other closures as well as the composition of the propellant used in the booster motor.

At present, the Navy has three surface vessels designated as guided missile ships; two heavy cruisers, the USS BOSTON (CAG-1) and the USS CANBERRA (CAG-2), and one destroyer, the USS GYATT (DDG-712), all of which fire the TERRIER surface-to-air missile.

During the structural firing tests conducted as part of the readiness for sea trials of each ship, studies were conducted to determine the degree of hazard to personnel produced by firings at missile attitudes considered to be the most dangerous (1-8). In the case of the CANBERRA, a documentary movie (9) was prepared to illustrate the techniques employed in the shipboard investigation of the personnel hazards of concern, i.e., blast pressures, high intensity noise, temperature and flash-burn hazards, and noxious gases. These CANBERRA studies were coordinated by Morton Goldman of the Johns Hopkins Applied Physics Laboratory (present address the Ramo-Woolridge Corporation, Patrick Air Force Base, Florida), who also was responsible for blast pressure studies. Sound studies were conducted by Andy Asti of the Philadelphia Naval Shipyard, with burn studies under the direction of Lee Green of the Naval Air Development Center, Johnsville, Pa. My laboratory at the Naval Medical Research Institute, Bethesda, Maryland was responsible for noxious gas studies aboard all three ships.

MOVIE

(15-minute edition of Reference 9)

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UNCLASSIFIED

Office of Naval Research. ONR-3 [CONFIDENTIAL] A Symposium - THE OCEAN AS THE OPERATING ENVIRONMENT OF THE NAVY [Unclassified Title] 339 pp. and figs., March 1958.

The Office of Naval Research, in sponsoring annual symposia on basic and applied science in the navy, has in March 1958 covered the subject of the oceans and many topics related to the seas Twenty-five technical papers were presented on topics of navy-wide interest such as hydrobiology, buoys, Arctic oceanography, underwater acoustics, radioactivity in the seas, marine propulsion devices, hydrodynamics, and underwater ordnance. Presented in this volume are seventeen technical papers covering the unclassified and confidential presentations. [Unclassified abstract]

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A symposium

THE OCEAN AS THE OPERATING ENVIRONMENT OF THE NAVY

Office of Naval Research
Department of the Navy
Washington, D.C.

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THE OCEAN AS THE OPERATING ENVIRONMENT OF THE NAVY

A Symposium sponsored by
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March 11, 12, and 13, 1958
U.S. Navy Electronics Laboratory
San Diego, California

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Washington, D.C.

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PREFACE

It is becoming more and more evident that full exchange of ideas and rapid communication of results are among the most powerful stimulii for scientific progress. The Office of Naval Research is, therefore, sponsoring Navy-wide symposia on various subjects in order to provide opportunities for scientific personnel of Navy laboratories and contractors to get together and to discuss problems of mutual interest. In view of the increasing importance of underwater operations, the general theme of this symposium is particularly timely. The program has been so arranged as to present the viewpoints of the scientist, the engineer, and the fleet officer, and I am certain that the personal contacts resulting from this meeting will plant the seeds for greater progress of the New Navy.

R. Bennett

R. BENNETT
Rear Admiral, USN
Chief of Naval Research

CONTENTS

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THE CANADIAN PROGRAM IN UNDERWATER RESEARCH

Dr. J. J. Green
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Canada's underwater research program is divided between the Atlantic and the Pacific. Perhaps this comes about quite naturally because Canadians have always been preoccupied with the two great oceans which flank their country, back even to the days before we became a nation. Indeed the dream of the Fathers of Confederation and those who went before was to build a united Dominion from sea to sea, a dream attained less than a hundred years ago. In testimony of this the Canadian Coat of Arms (Fig. 1) carried the motto "A Mari Usque Ad Mare" reminding us of the aspirations of those early Canadians and the breadth of our land--sentiments which can readily be shared by our American friends whose forefathers had similar aspirations. As further testimony, carved in stone over the door of Canada's Parliament Building (Fig. 2) are the words of one of our poets "The Wholesome Sea is at Her Gates, Her Gates Both East and West".

Our underwater research program grew out of and is geared to the needs of the Royal Canadian Navy, the primary mission of which is to detect and destroy enemy submarines. In this mission the Royal Canadian Air Force also plays an important role through its operation of the shore-based long-range anti-submarine aircraft which complement the surface craft and the carrier-based anti-submarine aircraft of the Navy. The Canadian defence program does not include the development of weapons for the destruction of submarines for in the interests of economy of effort and standardization we are prepared to adopt those developed by our allies. Our efforts have instead been directed towards the problems of detection and location of submarines and for good reason too. For if the Canadian poet considered the sea as wholesome at our gates, the Canadian Navy and the scientists

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Our Atlantic research is centred principally at the Naval Research Establishment, Dartmouth, N.S. (Fig. 3). Founded by the Canadian Navy in 1943 initially to handle the degaussing of Canadian ships it very soon turned its attention to submarine detection and the problems of sonar equipments. When the Defence Research Board was created in 1947 the Naval Research Establishment was transferred from the RCN to DRB, but it has continued to attack these underwater problems for the Navy and with very active and important assistance from the Navy itself particularly in the form of Naval vessels provided and operated by the Navy for the use of our scientists.

The unwholesome water conditions off the east coast came in for active study beginning about 1942. At that time the only oceanographers in Canada were those employed by the Fisheries Research Board and their services were promptly available for this important defence problem. This mutually advantageous cooperation has continued to the present day and our fundamental research program in oceanography is planned and undertaken on a cooperative basis between the Defence Research Board, the Fisheries Research Board, the Navy and other interested government departments. From the point of view of anti-submarine defence this program has been the essential starting point for the improvement of sonar equipment and the development of new techniques to circumvent the obstacles with which nature has confronted us.

One year after DRB assumed control of Naval Research Establishment we created our second centre for underwater research, the Pacific Naval Laboratory at Esquimalt, B.C. (Fig. 4) The land profile of this western coast is essentially a flooded mountainside in contrast to our east coast which is a flooded plain with shallow waters extending for about 800 miles eastward from the tip of Nova Scotia. In the deep and sheltered inlets of our west coast we discovered a near-perfect environment for carrying out undersea research in a variety of reliable conditions providing excellent control. At PNL our efforts were directed towards fundamental studies of sound transmission under water and the nature of undersea echoes. In particular emphasis has been placed on studies of time and space fluctuation of underwater sound and its relation to temperature and turbulent microstructure.

Both east and west coasts have oceanographic stations manned by the Fisheries Research Board to carry out, using Navy vessels, the study program which I have already mentioned as being derived on a cooperative basis. The work is done in close collaboration with our two naval research establishments. From the waters adjacent to our coasts surveys have extended to the north-west Atlantic, and north Pacific and the Arctic in cooperation with the United States. Data from the north Pacific surveys are now so prolific that our Pacific Naval Laboratory is planning to produce an analysis of the acoustic structure of the north-east Pacific which should be an important addition to our knowledge of sonar conditions.

It is understood that the U.S. Navy Hydrographic Office has plans for producing Oceanographic Atlases in addition to Oceanographic Prediction Centres. It would thus appear that in this area of research considerable value could be obtained through mutual U.S./Canadian collaboration.

The growing prospect of hostile submarines with a missile-launching capability has focused attention on the possibilities of long-range detection and in Canada top priority is now assigned to research directed toward the development of a capability for detection of such submarines at distances remote from our coastline. The undersea programs of both our naval research establishments have accordingly been moved out from the coastal waters into the open ocean approaches. During recent years a third ocean, the Arctic, has been added to the two with which we have been so preoccupied. The capability for long-range under-ice cruising by atomic powered submarines as demonstrated by the Nautilus in her penetration of the Arctic to 87° north has awakened us to a realization that the northern menace can indeed be a serious one. This will call for sharply increased scientific research directed to Arctic matters including those of special significance to undersea warfare, as recently recommended by the Arctic Research Advisory Committee of the Office of Naval Research and the Arctic Institute of North America.

Both NRE and PNL, our two naval research establishments, have made contributions to our basic knowledge of the nature of sound transmission and reflection in the ocean. The objective here is to be able to predict the signal to noise ratio for both active and passive sonar systems. The answer is, of course, dependent on all the factors which attenuate and scatter the desired sound in relation to all the various types and intensities of sound which make up the background noise. For the older types of sonar equipments which operated in the 15 to 30 kilocycle range their functioning has been so well explored that their performance can be reasonably well predicted once the oceanographic conditions are known. Our knowledge of the transmission and reflection of lower frequency sound is progressively less complete. Since attenuation due to absorption is roughly proportional to the square of the frequency the demand for very long sonar ranges will only be met by a shift to low frequency equipment, perhaps in the order of 1 kilocycle. In this range knowledge is almost completely lacking and future efforts must be concentrated on this area.

With what I have said so far as a brief introduction to the philosophy underlying the Canadian approach to underwater research, I would like to turn now to a closer examination of some of our programs and what we hope to get out of them in the immediate or near future.

Our most ambitious project has been the variable depth sonar developed over the last eight years at NRE in an effort to at least minimize if not to capitalize on those unwholesome water conditions off our east coast. The initial concept was of a small sonar set which could be towed at sufficient depth beneath the search ship so that the sound beam would avoid some of the very adverse refractive effects which occur in the first 100 feet or so beneath the surface and might even benefit from the layering or channelling of the water. As the project developed it was decided to take advantage of the hydrostatic pressure provided by the towing depth to increase the power of the sonar without fear of cavitation. It has accordingly become a medium-power sonar with an acoustic output of five kilowatts. There are further characteristics of a variable depth sonar which are worth noting. Theoretically self-generated noise from ship's machinery and wave action should be less intense at a deep sonar than at a hull-mounted one. However, this has not proved to be the case in practice to date due to the fact that the hull-mounted transducer is effectively shielded by the hull from the main source of noise, the ship's propellers, whereas it has been difficult to shield the towed transducer entirely from this source of noise. However, new ship noise reduction techniques are expected to provide this isolation for the towed transducer. On the other hand quenching of the sound by air bubbles, a common phenomenon with hull-mounted sonars particularly in high sea states, cannot occur with a variable depth sonar. Analysis of sea trials has indicated that for about

55 percent of the time the variable depth sonar at 150 feet depth has a decided advantage over the hull-mounted sonar. The latter has a small advantage over V.D.S. for 35 percent of the time and for the remaining 10 percent of the time neither sonar is of any usefulness.

The V.D.S. project can usefully be considered in four parts. The first concerns the design and development of the sonar itself and its associated inboard control and display equipment. The second item is the towed body which houses the searchlight transducer. The third component is the streamlined cable and the fourth and final item is the mechanical gear which involves the winches and other equipment for handling the cable and the towed body in both the streamed and secured conditions.

The sonar utilizes a transmitter weighing about 4000 lbs. capable of delivering into the transducer 10 kilowatt pulses of 80 millisecond duration at a maximum repetition rate of one per second. It operates at a frequency of about 12 kilocycles per second. The transducer consists of 72 active elements each of which is a piston shaped sandwich of aluminum and barium titanate with a hexagonal shaped head some 2¼ inches across. These elements are assembled in an aluminum case with a neoprene face cemented to the heads of the elements, giving a radiating face about 15 inches by 30 inches. The transducers are manufactured to have resonant frequencies of about 9.5, 11.0, 12.5 or 14 kilocycles per second so that as many as four search vessels can operate together without mutual interference. Beam widths are about 20° to the 3 db points. Split-beam direction finding for fine bearing accuracy is incorporated in the design, the transducer being split vertically to form the two beams. A magnetic compass heading system indicates the terrestrial bearing of the transducer but consideration is being given to replacing this with a gyro compass. The receiver has been designed for flexibility and the noise is low enough so that under no condition is range limited by receiver noise.

The towed body, known as Trilby, is eleven feet long, 5½ feet high and 2½ feet wide (Fig. 5). It weighs 5600 lbs. when ballasted for towing at 150 ft. depth at a speed of 24 knots. The body is towed in a position such that the line from body to the screws is not less than 30° above the body, so that the ship's noise is excluded from the main beam. The body is constructed of aluminum with a suitable internal framework of the same material. Lead ballast is carried in the bottom of the body, covered with a layer of sound absorbent material. The transducer is isolated to a considerable extent from propeller noise by a suitable arrangement of reflectors in combination with sound absorbent material. Stabilization of the body is achieved by the twin tail surfaces attached to the body and the lead ballast.

The cable, which has an overall diameter of 1.14 inches, consists of a number of conductors and coaxial cables covered by two layers of armoured cable. The fairing is of semi-hard rubber with a cross-section five inches long and one inch wide reinforced with nylon cord. It is secured to the cable by clips rivetted to the fairing every nine inches. The attachment of the clips to the cable permits the fairing to swivel, which is desirable if the cable and fairing are not to deflect laterally from the line of tow.

The ship-board towing gear is designed for over-the-stern towing (Fig. 6). The drum of the towing winch can accommodate some 75 feet of unfaired cable plus 325 feet of faired cable. A topping lift winch is included in the design which enables the body to be lifted and secured inboard when not in use.

The sea trials of this V.D.S. equipment have confirmed the calculated range of about 8500 yards for 50 percent probability of detection under conditions of isovelocity and a beam-on target. Bearing accuracy is ± 3° to 5°. The maximum depth for towing at 25 knots is 150 feet but this can be increased to 250 feet if speed is dropped to 16 knots. In the north-west Atlantic the sonar conditions indicate little value in towing at depths greater than 150 feet.

For the future, consideration is now being given to a program of sea trials to explore by experiment the possibilities for 15,000 to 20,000 yard sonars using still higher power equipment operating at a frequency between 5 and 12 kilocycles per second. In the meanwhile the Royal Canadian Navy is on the point of commencing operational trials of the existing equipment, a task which will be allotted to their Operational Evaluation Group.

Canada has two projects concerned with fundamental studies of the propagation of low frequency sound. One of these, project "Starfish" is going on at NRE on the east coast, where the interest is strictly in shallow waters, that is, less than 100 fathoms and the other at PNL, project "Swiftsure" which is concerned mainly with deep water and the transition from deep to shallow water. As mentioned earlier such researches may have important applications in extending the range of submarine detection capabilities to much greater distances than with existing equipment.

The east coast project is based on studies of sound propagation and ambient noise at low frequency using a number (10) of hydrophones mounted on three towers laid in the form of a right angled triangle in twenty fathoms of water some five miles out to sea. The towers are also instrumented with recording thermometers and wave height indicators. The results, to date, indicate that ambient noise correlates with wind velocity rather than with sea state. The "twenty cycle" phenomenon has also come in for some attention and without doubt appears to have its source in an animal passing at a range of two or three miles and generating about 10 H.P. of acoustic energy. The shallow waters of our east coast approaches are again unwholesome when it comes to long-range detection, the problem here being one mainly of reverberation. Shallow water tests at low frequency undertaken by the U.S. and U.K. under somewhat ideal conditions have shown good promise however, and we hope that our own work at NRE will have some wholesome results.

The west coast project "Swiftsure" has, during several cruises, given some indication of the propagation characteristics of low frequency sound in the deep ocean. The emphasis now is on the influence of specific oceanographic features on low frequency sound propagation. One of the nearby lagoons is being used as a large model basin, with suitable instrumentation, for the application of normal mode theory. Promising results have been obtained in correlating the observed signal levels with modes of propagation as a function of frequency and water condition.

The question of explosive echo ranging follows naturally from this discussion of low frequency propagation because it is the low frequencies in the spectrum of sound generated by underwater explosions that endow EER with whatever promise it may have as a technique for locating submarines. We in Canada have been investigating EER since 1953 with a team of personnel drawn from the RCAF, the RCN and DRB. Close cooperation has been maintained with similar work going on in this country (Project "Julie") and we have reached the point where an interim system is being installed in Service anti-submarine aircraft.

Two recent studies have been completed in Canada which are of some significance. The first of these emanated from our Operational Research Group and was concerned with submarine detection probabilities as a function of radial error of the datum point, submarine speed, number of sonobuoys and time late on datum. The results point up the need for EER ranges of 12,000 yards if high speed submarines are to be detected by a single aircraft, even when the radial error of the datum point is kept to about six nautical miles and the minimum time late on datum is achieved.

The second study was undertaken by NRE and was an appraisal of the capabilities and potentialities of EER as applied to ships, helicopters and fixed-wing aircraft. The general conclusion was reached that inadequate knowledge of all the factors involved plus the critical dependence on the environmental conditions permitted only broad limits to be set for the system performance predictions. In the fixed-wing aircraft sonobuoy system it was concluded that detection ranges in excess of 2000 yards should not be expected in the North Atlantic during the summer months with their accompanying adverse refractive conditions. At other times ranges in excess of 10,000 yards are possible in deep water (in excess of 500 or 1000 fathons) but reverberation will limit the technique in shallow water, except possibly under certain ideal conditions, although our knowledge is as yet inadequate to predict the shallow water ranges with any degree of certainty. In all cases system directivity both as regards the explosive charges and the hydrophones will be the key to whatever success is attained.

Operating from destroyer escort vessels in deep isothermal water EER can be expected to provide detection ranges up to about 7000 yards as compared with 10,000 yards for existing sonar equipment under the same conditions.

In the case of anti-submarine helicopters it is possible to provide an EER system which would out-perform, range-wise, the dipping sonar system, in deep water but it would be necessary to go to additional complexity if target bearing information is to be provided. The NRE study revealed no material advantage in the application of EER techniques to ship-helicopter teams except possibly in the case where the ship itself has little or no submarine detecting ability. The report of NRE concludes that the need for more extensive EER research and development is clearly indicated. In particular, the underwater acoustics of EER and the strength and characteristics of the echo and the nature of shallow water reverberation need more study. This work would, in general, be in support of the fixed-wing aircraft program. It is also necessary to develop directional explosive sources and hydrophones. For the helicopter, which has special capabilities and needs, experimental equipment and techniques should be developed in the EER field to exploit these to the full. Finally, the work indicates the importance of operational research for revealing more fully the strategic and tactical aspects of future anti-submarine systems in which EER would be a part.

I am sure that many of you are familiar with the excellent work done in Canada on the cathodic protection of ship's hulls and underwater fittings against corrosion. However, you may not be aware of the interesting manner in which this work began. Some years ago one of the scientists of our Naval Research Establishment was interested in the electric potential of ship's hulls and the underwater signatures arising therefrom. To investigate this in detail he set up an array of anodes along the hull of one of our ships and was surprised at the peculiarities of the signature he obtained. Not long after the ship was dry-docked and an opportunity was afforded the scientist to examine the hull in detail. He was immediately struck by the close correlation between the potential signature of the hull and the corrosion patterns on the hull. He recognized that the corrosion was an electrochemical process in which the sea-water is the electrolyte and various portions of the hull plating, rivets and fittings are the anodes and cathodes. The idea occurred to him that if he could provide an anodic material of suitable potential the hull might be protected from corrosion at the expense of this anodic material. His observations of the corrosion of galvanized rivets, which progressed rapidly when the protective galvanic coat became inhibited by surface deposition, led him to experiment with materials which would not become coated and inhibited. The scientists at NRE have used materials ranging from simple magnesium alloys, steel anodes held at appropriate potential by an impressed current, silver-lead alloys and platinum plating. In general, the anodes are fastened to the hull at various locations along its length and have resulted in very substantial savings in ship repair bills. Cathodic protection of ships against underwater corrosion is now standard practice in the RCN. This research and development program has led directly into others concerned with underwater paints suitable for use with cathodic protection and the problems of electroplating and surface coating which have paid dividends in other applications beyond the immediate one of naval interest.

My concluding remarks will deal briefly with a program on which we have been working for some ten years. The hydrofoil is by no means a new device, it has in fact been with us for some fifty years. Nevertheless, it is not commonly used in surface vessels as a means of support preference having been shown always to the displacement hull for low speeds and at higher speeds the planing bottom. Figures 7, 8, 9 and 10 are photographs of the HD-4 hydrofoil craft designed and constructed by Dr. Alexander Graham Bell and Mr. F.W. (Casey) Baldwin in Nova Scotia about fifty years ago. If it were possible to develop a fully satisfactory hydrofoil craft it might have a number of advantages, including the ability to travel at high speeds even in rough water combined with a minimum vulnerability from submarine attack. We began with the development of a five-ton hydrofoil craft on which valuable engineering information and experience were gathered. This led to the construction by Messrs. Saunders-Roe of a fifteen-ton boat, the Bras d'Or, which it was hoped would have improved characteristics and would be large enough to establish the practicability and usefulness of such craft (Fig. 11). Delivery of this vessel to Halifax took place last year and it is now being instrumented for an extensive experimental program for the derivation of more engineering knowledge and practical experience with this novel type of craft.

The Bras d'Or has a displacement of 17 tons, is 59 feet long with a deck beam of $12\frac{1}{2}$ feet and 24 feet over the forward hydrofoils. Hull clearance at full speed is $3\frac{1}{2}$ feet, the span of the hydrofoils is 5 feet 2 inches. Power is provided by two Rolls Royce "Griffin" engines of 1220 max. continuous h.p. (max. 1815 h.p.). The hull leaves the water at 17 knots. Estimated maximum speed is 50 knots with most economical cruise being at about 30 or 35 knots depending on sea state, giving a range of 120 to 160 nautical miles.

Fig. 1 - Canadian Coat of Arms

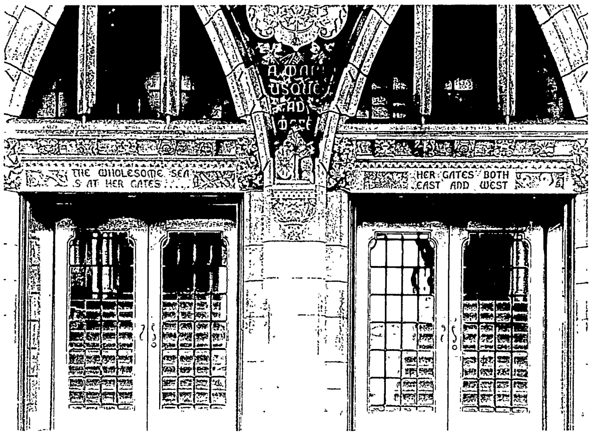

Fig. 2 - Main Entrance to Parliament Buildings, Ottawa

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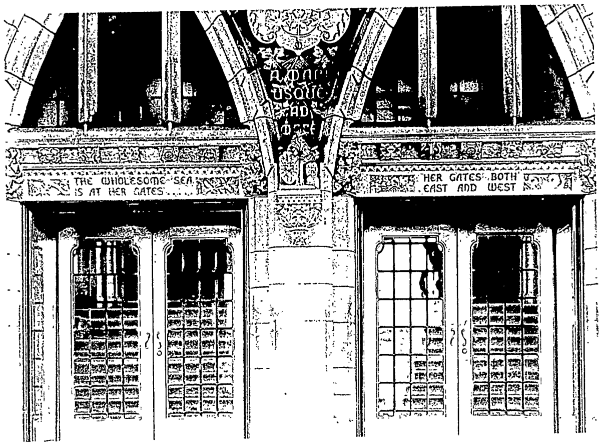

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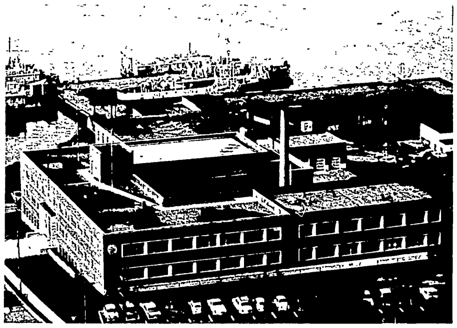

Fig. 3 - Naval Research Establishment, Dartmouth, Nova Scotia

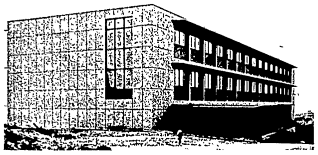

Fig. 4 - Pacific Naval Laboratory, Esquimalt, British Columbia

Fig. 5 - Towed Body Employed in Variable Depth Sonar Project

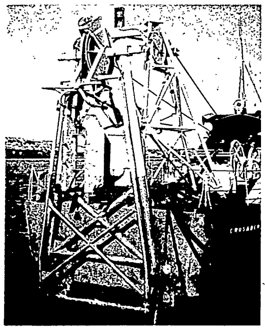

Fig. 6 - Towing Gear for Variable Depth Sonar Project as Installed on HMCS "CRUSADER"

Fig. 7 - HD-4 Hydrofoil Craft at Baddeck, Novia Scotia
(Courtesy of National Geographic Society)

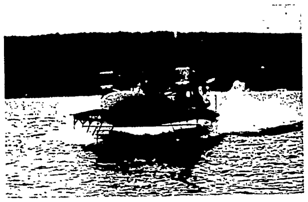

Fig. 8 - HD-4 Travelling at Seventy Miles per Hour on Baddeck Bay
(Courtesy of National Geographic Society)

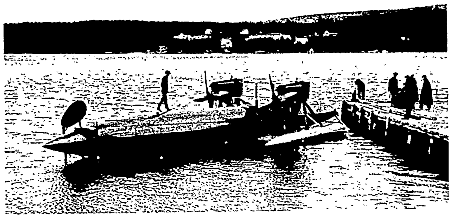

Fig. 9 - Three-quarters Stern View of HD-4 at Dr. Graham Bell's Laboratory Wharf
(Courtesy of National Geographic Society)

Fig. 10 - Cockpit of the HD-4 with Dr. Alexander Graham Bell, Mr. F. W. Baldwin at the Wheel, and Crew Members
(Courtesy of National Geographic Society)

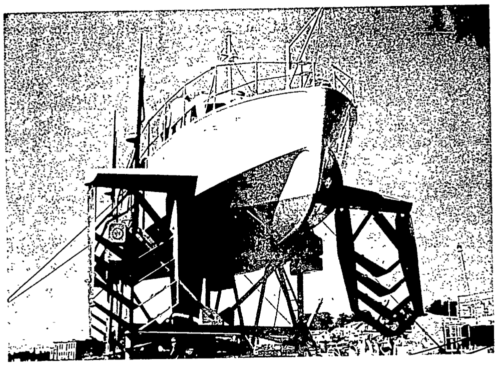

Fig. 11 - The BRAS D'OR

DEEP MOORED INSTRUMENT STATIONS

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Over the past five years several of us at Scripps Institution of Oceanography have worked on the development of deep moored instrument stations, that is, surface instrument stations moored to the bottom of the deep sea. This work was supported by The Office of Naval Research, The Armed Forces Special Weapons Project and The University of California. Figure 1 shows one of the skiffs that we use as the surface instrument station of these moorings, and Figure 2 shows a scale drawing of the type of mooring that I will discuss. The speck on the surface is one of our largest oceanographic vessels. There are other types of moorings, and we also are working on and have used completely submerged moorings, but in this discussion I am going to restrict my remarks mainly to moored surface stations of the taut-wire type, with which we have had more experience.

I will mention the history of such moorings, discuss our experience and describe the present system and the techniques of its installation and servicing.

I will also consider the significance of this development to oceanography and to the study of the environment of the Navy.

In addition I will present what I believe to be a potential ASW approach built around such moorings, with some Polaris, LFA, and SSK-air team ideas thrown in for good measure.

Oceanographers have long felt the need of maintaining position in the deep sea for conducting serial observations of internal waves, temperatures, ocean currents, etc., or for navigational control for carrying out bathymetric, magnetic, and other surveys. Electronic and celestial navigation often have not been adequate for these purposes. Hence, oceanographic vessels commonly have been moored in the deep ocean, by means of their special dredging cables, for the purpose of taking serial measurements. Such a procedure results in excessive scope and high cable strains and also is quite incompatible with the requirements of surveying, since the vessel, of course, is immobilized.

In attempts to avoid these deficiencies, oceanographers from time to time have lowered a variety of moorings to the bottom, ordinarily utilizing whatever was at hand. Many a reel of BT wire, coils of 21 thread and even hanks of marlin have been commandeered from reluctant bos'ns and consigned to the deep, attached to old cylinder liners, and ballast pigs on one end and GI cans, oil drums or dan buoys on the other.

Even though such jury rigs were usually attempted on seamounts in depths of 500 to 1000 fathom, they suffered from unpredictable behavior (often riding under when first lowered), excessive scope, and short life. Dr. Ewing of Lamont made early, successful and well-conceived slack wire moorings on the Mid-Atlantic Ridge and more recently Frantz and Vine of Woods Hole have made many moorings of the slack type with synthetic cable. We have found these unsuitable for our purposes because of the scope and variability.

In 1952 on Operation IVY, Willard Bascom, Walter Munk and I put over three taut-wire moorings on the 700 fathom seamounts north of Eniwetok Atoll. These were characterized by a submerged float below the level of wave action that provided most of the buoyancy, a piano wire to a discoidal anchor weight, and a short-scope pennant to a surface buoy. The pennant was steel wire and otherwise unbuoyed. These moorings survived for only one to seven days and failed because of chaffing and electrolysis, but carried out their job.

It was apparent that a mooring in which the pennant was concave downward suffered from two faults: it was subject to high inertial loading by wave motion and hence to serious chaffing, and in slack weather tended to sink and foul the submerged float.

On WIGWAM test, Lewis Kidd and I put out the first series of moorings of the taut-wire type with a buoyed pennant to a glass plastic skiff, and with more attention to the problems of electrolysis and dynamic loading. The buoyed pennant solved all of the problems that nature threw at us and promptly introduced a new problem. That is, the 300 to 500 feet of buoyed pennant floating on the surface became an apparently unavoidable target to the larger Task Force ships, constituting one of those lachrymose experiences to which Admiral Bennett referred this morning. These moorings carried strobe lights for survey control, and wave measurement devices. The weather prevented our returning to these stations to arm the wave measuring instruments, so that part of the development was unsuccessful. Nevertheless these skiffs constituted the final absolute position control by which the WIGWAM surveys were resolved.

The efficacy of these systems in covering large areas of the ocean was evident, and Robert Huffer, Feenan Jennings and I put them to good use in studying the fallout from the large events of Operation REDWING. Some twenty or more moorings were put in and maintained over a 4000 square mile area of the northeast trades north of Bikini Atoll. A few of these moorings were in 700 fathom on Sylvania Seamount but most were in 2000 to 2700 fathom of water. Full attention was given to the problem of installation, electrolysis and dynamic loading. Many of the moorings lasted during the entire series, which extended over a five month period. Figure 3 shows the distribution of these stations for TEWA shot, all on the weather side of Bikini.

During the period, the surface skiffs were picked up and replaced with re-armed skiffs a dozen or more times. Original installation time of a deep station was about 45 minutes and replacement of the surface float required about 5 minutes.

The skiffs carried fallout measuring instruments, penetration recorders, lights and radar targets.

Again the principal mortality resulted from engagements with Naval vessels. Out of a total of about 30 installations, two were lost from apparently natural causes, about 5 were keelhauled and one was the inadvertent aiming point of a multi-megaton air drop.

We carried out all installations and service from the ATF SIOUX. Air reconnaisance of the stations was very valuable, as the complete round was more than a 400 mile run for the SIOUX.

At present, under James Faughn, we are improving mooring components and developing the instrumentation and power source for the oceanographic use of these moored stations. A magnesium-seawater battery has been developed by Arthur Nelson that delivers a total power of 250 watt hours per pound of battery, neglecting the weight of the seawater electrolyte, versus the 15 watt hours per pound of the lead-acid cell, an improvement by a factor of 15

(although this battery is not rechargeable of course). This power is delivered at a relatively low rate. Instrumentation, recorder and lights have been designed to utilize it. The power source will be adequate for about three months as planned at present.

Installations of several of these oceanographic stations are to be made next month off the California Coast.

In the mechanical components, they will resemble the REDWING stations rather closely.

I will briefly describe the process of installation of a typical station (Figure 4). First over-the-side is a ball breaker fitted with flukes. This acts as a pilot and signals its arrival on the bottom by an implosion, which is picked up on the fathometer. The flukes will allow it to provide some added holding power. The ball breaker is lowered with a three-sixteenth inch cable pilot line a few fathom shorter than the desired final submergence of the upper float, say 200 feet. The pilot line is shackled to the main anchor, usually a railroad car wheel of about 700 pounds weight. Above this is another length of cable, which is longer than the eventual pennant. This is to prevent the stiff brittle main wire from dragging bottom in case of failure of the main float. The main wire is a one by seven high tensile steel Bethanized wire of about one-eighth inch diameter and 2300 pound breaking stress. It is attached to the one-quarter inch cable by a special clamp. All connections are insultated and no uninsulated metal is in contact through any other to seawater.

The main wire is 5000 to 15,000 feet long, depending on the depth, and is payed out rapidly over a metering sheave. Shortly before it is due to reach bottom the wire is stopped and the ship is maneuvered for a zero wire angle. When this has been accomplished, and the surface components are in readiness, the lowering is continued at a reduced rate until the ball breaks. This signal is connected through the intercom to the bridge, deck and winch. The winchman stops the winch immediately. The submerged float, consisting of a fitted and pressurized butane tank is connected to the main wire with a clamp. The strain is taken on the pennant and all is lowered away rapidly as the vessel falls off. The skiff is launched over the side from skids and the vessel stands clear.

Depending on depth the entire installation operation requires 15 to 45 minutes for an experienced crew.

If the ship is not maneuvered correctly or the installation is not lowered promptly after the ball breaker hits bottom, the submerged float will end up too deep or on the surface for we ordinarily are dealing with a tolerance of plus or minus 100 feet in 15,000, that is, less than one per cent, and the ship can drift over small bottom irregularities during any delay.

We usually have recovered the records and re-armed the stations by picking up the pennant at the break point, releasing the skiff and attaching a prepared replacement skiff. The replacement is launched over the side while the replaced skiff is brought aboard over a stern ramp. The records are recovered from this skiff and it is re-armed for installation at the next station. Properly carried out this pickup and replacement procedure requires less than five minutes and is done without losing way. Thus in servicing the moorings the vessel can make her rounds essentially at cruising speed.

We have installed skiffs in a state 6 sea and recovered in a state 7. The moorings have survived a state 8 sea, the highest sea state to which they have been exposed.

I have here a piece of the mooring wire, which is specially drawn for our use by the Bethlehem Steel Company.

The Captain of the SIOUX was astonished by the properties of this wire. After REDWING we attempted to recover some of the deep components of the moorings for examination but the SIOUX could not break them out at full turns astern. There is no opportunity to jerk on such a mooring and the ATF is not very effective astern. Ahead, she sailed them out easily. Nevertheless, the Skipper reputedly carried a pencil length of the wire about to show how small a wire could moor the SIOUX.

I have gone into the matter of these moorings in some detail because I want to impress on you that here is a small, practical, inexpensive system that <u>exists</u>, that we know quite a bit about, and that has been moored in depths of 99 per cent of the deep sea and, as it is now designed, probably will remain for considerably longer than half a year in most of the sea on the basis of weather, currents, ships' traffic, etc. In principle, the mooring can be made in any existing depth of the sea. Figure 5 shows the allowable depth of moorings for various ultimate strength of wires. This figure considers <u>only</u> the stresses involved in installation and provides for an anchor weight equal to that of the wire. You will note that the 285,000 psi wire that we use allows installation, in principle, to the greatest depth in the sea.

The basic components of this system, less instruments, cost about $850., less than a day's oceanographic ship time, and over half of this cost is that of the glass plastic skiff that we use.

What can be done with these?

Well, the application to oceanography and to related Naval environmental studies is obvious. From these stations we intend to record wide spacial and time series of temperature, depth of thermocline, wind direction, intensity and other measurements. Other laboratories will record sound background. We will have something of the equivalence of many oceanographic vessels taking data for us. They will be used to obtain data during periods of change such as ocean frontal passages, or upwelling. We are using them to maintain navigational control on surveys. We intend to use them even to obtain such things as serial water samples in deep water.

For the oceanographic purposes in the forseeable future, we intend to use the skiff exchange method of recovering the data rather than by telemetering, interrogation from the air or other advanced techniques.

What are the applications to other Navy problems?

Well, I probably speak from a sizeable store of ignorance on the subject, but I believe that the consideration of such installations in the ASW problem should go considerably beyond their utilization proposed in Project Nobska. As you know, Project Nobska suggested that vertical strings of contact mines be moored in the deep sea as an ASW weapon. This was before Scripps had reported on the development of the present mooring system.

If such a thoughtful group as Nobska could consider deep-moored <u>contact</u> mines practical as a submarine deterrent with a detection range of a submarine's beam, say 30 feet, which is certainly the absolute minimum detection radius; then <u>very short-range influence detection must be highly desirable from such stations</u>.

Let me sketch my line of thought.

As I understand the present ASW approach, it is founded upon certain expensive anchor points of rather limited number, i.e.: patrol planes, destroyers, SSK submarines, and bottom mounted detectors.

It is natural that with a relatively small number of expensive observing posts, the detection development strongly emphasizes range. Hence, the Navy has pushed the development of Lofar, explosive echoranging, and other long-range approaches. Certainly these long-range methods are vitally important, but every step in increasing range is not an unmixed blessing, for as we look for greater transparency of the oceans to some form of energy propagation, we open the windows for more of such energy entering the system and we become further concerned with background, jamming and saturation by multiple targets. It is no surprise that a pound or two of TNT exploding in the sound channel every minute can disrupt long-range detection over great distances, yet a freighter can sow thirty pounds a minute for a year.

These serious factors are the price of range. They can be overcome directly only by increased subtlety and complexity of the detecting equipment.

Under the present system, very short-range detection is of value only for the final acquisition of a target.

I propose the consideration of a surveillance barrier consisting of a series of simple, short-range detection, radio-reporting stations.

If we have the capability of setting up such a short-range surveillance barrier, there is much to commend it. It has the possibility of working against a low background, jamming the waterborne signal becomes a virtual impossibility, enemy destruction of an element of the system becomes relatively unimportant and can be made to reveal the attacker, and saturability pertains only to the weapon that backs the system.

Also a strong obvious show of surveillance is a strong deterrent.

Such a barrier would constitute a show of surveillance under any circumstances, but particularly if short-range active sonar were used, as the surveillance would be obvious even to submerged vessels.

Let us say that a short-range system can be developed, active or passive, with an assured range of only one mile, then a radio reporting surveillance barrier with a depth of four units (that is four units wide) could fence Europe from Greenland to Africa with 4000 stations. This might cost less than $10,000,000., and require less than 20 small vessels to maintain it.

Simple air-borne-sound location of aircraft is a compatible use of such a barrier.

In addition, I see no reason why such a barrier could not be tied in with submarine communication for operations of the Polaris type. Admittedly the use of a single moored transmitter is inacceptable as it probably reveals the submarine's position too closely. But if the Polaris submarine operated near to or within such a barrier with an IFF and coded signal this might well solve the Polaris communications problem.

Killer submarines and aircraft could use the barrier for air-to-sub communication, vectoring, and attack.

But these are problems for system analysis.

What I strongly urge is that we carefully review all of the short-range influences of a propelled submarine that have been considered in the past and discarded. EDD, induced field, short-range sonar, high frequency passive listening (i.e. the SHARK type of detector), UEP, and others should be reconsidered in relationship to a closely spaced deep sea barrier and in view of the background in the deep sea. Newly conceivable short-range influences also should be examined, nuclear resonant electromagnetic emmission, microwave distortion and radiation, for example.

Certainly all conditions of the deep sea, in addition to those influencing underwater sound, have an equally important place in the Navy's interest, for many reasons. In this case, if we can discover an influence with an assured range of 3 miles, one mile or even 100 feet, there is a strong possibility that we can go far in alleviating the serious threat of Soviet submarine attack.

It appears to me that in the submarine barrier problem, we are dealing with the old engineering problem of how many piers do we put under a bridge. That is, a surveillance system can take the form of the Golden Gate Bridge with a very few highly sophisticated, costly and vulnerable anchor points or it can take the form of a piling trestle with many simple components (or a balanced combination of these). I suggest that both have their advantages and disadvantages and that we should not overlook the piling trestle when we know how to drive the piling.

I feel that the mooring technique constitutes such a simple pile-driving method and, more immediately, a method of exploring the influences and deep-sea background with which such a surveillance barrier must operate.

This probably is not a very appealing approach, I am sure. It looks like hard work, grubby and inelegant. In comparison with the long-range detection systems it indeed looks like the piling trestle compared with the Golden Gate Bridge. But, to push this analogy a bit farther, I recall that in the investigations of the failure of a famous great bridge some years ago, it developed that the engineer had known, prior to the collapse, that the addition of piling and cable attachments would have saved the bridge, but the engineer thought that "these would detract from the dignity of the structure". To which one of the investigators, thumbing through some photographs of the resultant wreckage, dryly observed that he "didn't think that the bridge looked very dignified anyway!".

Inelegant as it may appear, I think we should thoroughly consider the shoring-up of our long-range detection span with such simple braces.

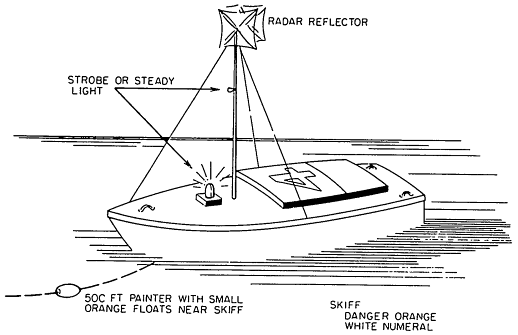

Fig. 1 - Deep Moored Instrument Skiff

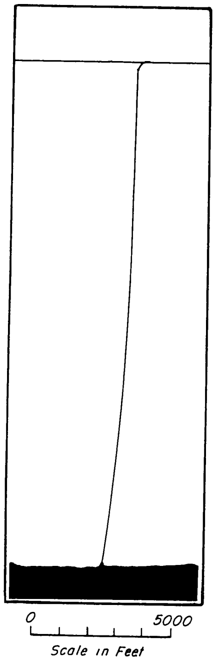

Figure 2

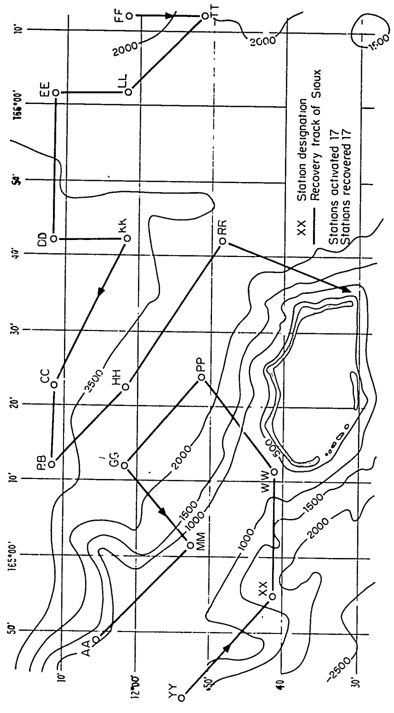

Fig. 3 - Skiff distribution for TEWA

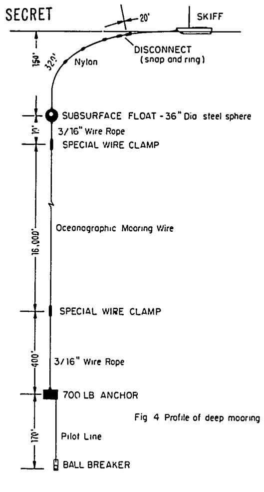

Fig. 4 - Profile of Deep Mooring

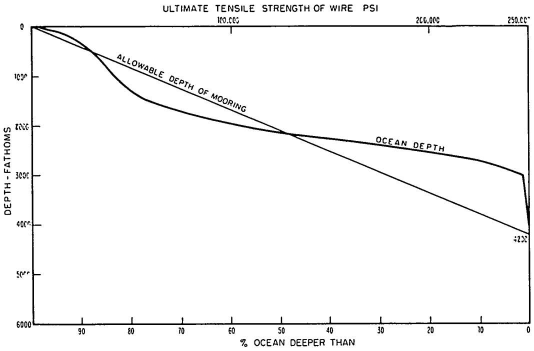

Fig. 5 - Allowable Depth of Mooring Versus Ultimate Tensile Strength of Wire

NUCLEAR CLOSED CYCLE GAS TURBINE POWER PLANT STUDY

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In the fall of 1955 the Power Branch of the Office of Naval Research initiated a design and feasibility study of highly advanced, light weight, mobile nuclear reactors. This study, which covered reactors having a fairly wide range of powers, was done without any specific application in mind but as a part of ONR's broad program of basic research in scientific fields having an important bearing on Navy problems. When preliminary results of this study were examined about a year ago, it was apparent that a light weight, high temperature reactor had possibilities, particularly as a heat source for a power plant for the propulsion of small ships. Concurrent discussions with the Office of the Chief of Naval Operations and the Bureau of Ships pointed up the need for a power plant of 5000 to 30, 000 SHP for the propulsion of small submarines and surface vessels of the escort class.

As a result of these discussions it was decided to select a specific application requirement having a high priority and, rather than continue with the broad study of advanced reactors as had been done to date, select a more conservative design that could be produced in the reasonably near future. The application selected was a reactor for a power plant for a very small submarine requiring 5000 SHP, or 15 MW of reactor heat, and being one that presented the greatest design challenge.

It was recognized that, while the reactor itself appeared promising, it would also be necessary to investigate a compatable power plant, that is one whose size and weight would result in a total propulsion system of acceptable weight and dimensions. For some time ONR had been aware of the possibilities of the closed cycle gas turbine, studies of its use with a fossil-fired heat source having already been made by the Bureau of Ships (1), and it was therefore decided to initiate design and feasibility studies of such a power plant for use with a nuclear heat source. This work was done by the author's company and a portion of our findings is reported here (2).

Note: Numbers in parentheses refer to references at end of text.

In setting up the power plant requirements, it was directed that heat be received from the reactor through an intermediate loop, but that cognizance should be taken of the long term possibility of the plant receiving its heat directly from the reactor. Plant output was to be 5000 SHP plus 85 KW of ship's service power and the heat available from the reactor was 15 MW at a temperature of 1400°F. Minimum size and weight were stressed as design requirements, size being qualified by the requirement that the plant fit in the hull of a 500 ton submarine, having a clear inner diameter of 13-1/2 feet and the weight of the complete propulsion plant, including all auxiliaries and reduction gear, not exceed 50,000 pounds or 10 pounds per horsepower.

The bare machinery set, with primary reduction gear but less auxiliaries, is shown in Figure 1. This machinery set is basically a five foot diameter cylinder, twelve feet long with an additional four feet in length added by the primary reduction gear. Weight of the machinery set as shown plus all operating auxiliaries is estimated at 42,000 lbs.

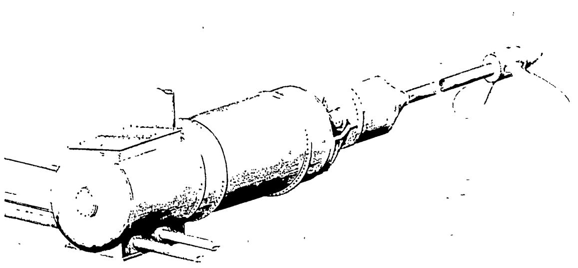

Fig. 1 - Artist's Concept of 5000 SHP Closed Cycle Gas Turbine Propulsion Plant

This power plant is designed to operate on a Brayton cycle with regeneration, using helium as the working fluid. A cycle without intercooling or reheat was chosen because of the requirement of a compact, light-weight power plant. While in theory intercooling and/or reheat would result in a higher efficiency and a greater output per unit weight of working fluid flowing, which would give a plant of smaller size, this does not prove to be the case in this specific design.

The working fluid in a closed cycle gas turbine power plant can be any fluid that is gaseous at normal temperatures and pressures. Due to the requirement that this power plant be installed in a confined space, materials that are toxic or explosive in air mixtures are excluded. All closed cycle gas turbine power plants built to date use air as the working fluid, however, use of air for this application has the disadvantage of resulting in large heat transfer surface requirements. Considering that the design objective is a power plant of minimum size and weight, a monatomic gas is to be preferred because the high ratio of specific heats results in a plant having a low pressure ratio and a high mean circuit density. A gas having a high specific heat at constant pressure is desirable because such a characteristic results in a low ratio of pumping power to heat transferred. Since the heat transfer surface represents the major bulk in a closed cycle gas turbine installation, all transfer being by forced convection, a low pumping power ratio results in minimum surface. On the other hand, a high value of specific heat means a large number of compressor and turbine stages, but since a monatomic gas having a high specific heat has a high acoustical velocity, and we are not stress-limited in turbomachinery design, this limitation is not serious.

A number of studies have been made of the influence of working fluid characteristics on the design of a closed cycle power plant, (3)(4) and of those gases that could be used in this installation, helium is the first choice because of its high gamma value, good heat transfer properties, inertness, nuclear and non-toxicogenic characteristics and the possibilities its use offers in future developments.

The disadvantage of helium is one of logistics, particularly offshore, where gas must be carried or transported to make up any losses from leakage or from opening some part of the plant to make necessary repairs at sea. Although considerable experience has been accumulated with helium in compressors, heat transfer apparatus and other power plant components and systems, we know of no specific experience with helium in turbomachinery having performance levels comparable with those required for this plant. Development will be necessary but should not involve insurmountable problems or excessive time. In the balance, the advantages to be gained by the use of helium as the working fluid in a plant of advanced design outweigh the disadvantages by a large margin.

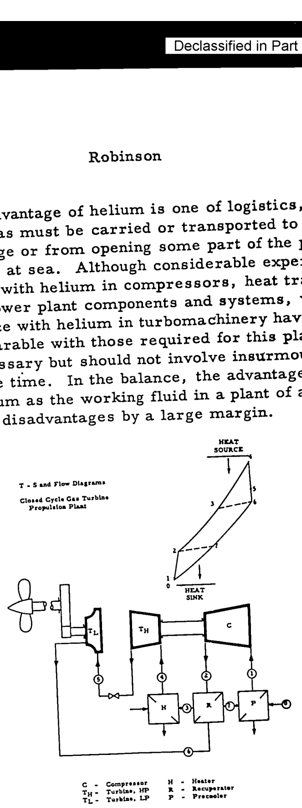

Fig. 2 - TS & Flow Diagram

A flow and TS diagram of the cycle are given in Figure 2. Maximum output of the plant is 5000 SHP and the heat source and sink are sized for this power. However, an output of 4000 gas horsepower, or 4000 horsepower at the turbine was selected as a "reference-design-point". Design conditions at this output are given in Table I.

TABLE I

"Reference Design Point" Design Parameters

Item	Value
Reference Design Point output at turbine blades	4000 HP gross
Sink Temperature, T_o	80°F
Compressor-inlet Temperature, T_1	90°F
Turbine-inlet Temperature, T_4	1300°F
Compressor Efficiency, ηc	84%
HP Turbine Efficiency, η_{eh}	87%
LP Turbine Efficiency, η_{el}	85%
Recuperator Effectiveness, η_r	90%
Pumping Power/Heat Transferred, w/q	2%
Cycle Efficiency, η_{th}	31%

For "reference-design-point" output of a propulsion plant set, it is desirable to select a gross horsepower that is somewhat lower than rated power, in order to optimize the power-turbine efficiency for part-load operation. This is because the U/C_o of the power turbine varies with load, in contrast to the essentially constant U/C_o of the solid-shaft closed cycle plant. After a series of successive approximations of precooler size at full power, 4000 gross horsepower (at the turbine rotor) was selected as a suitable value for reference-design-point output. This resulted in maximum plant efficiency at about 2500 SHP.

Performance at the reference-design-point was calculated on the basis of 90°F compressor-inlet temperature. This figure is not necessarily the condition at peak load on the precooler, which must have sufficient capacity to dissipate the unavailable energy at the maximum useful output of 5000 SHP. The compressor-inlet temperature may then be higher than the reference-design-point value as long as maximum shaft output can be obtained with the specified sea-water temperature, which was 85° for this condition.

It should be recognized that the temperature ratio of expansion in a closed cycle gas turbine is not dependent upon the sink temperature, where both efficiency and power output of a steam-turbine plant are. In a closed cycle it is only efficiency that is significantly affected by sink or compressor-inlet temperature, the power output being a function of pressure level and only to a very minor degree of the sink temperature.

Basic performance of this plant is given in Figure 3. It will be noted that helium flow and reactor output vary directly with system pressure while output is not quite linear due to fixed losses, improved internal performance at part-load and the variation of power turbine efficiency with load.

Figure 4 is another presentation of performance plotting plant efficiency vs. output with compressor-inlet temperature and system pressure as parameters. It will be noted that a fixed reactor output can be associated with a system pressure. The part-load efficiency is also shown in this figure, rising to a maximum at about 50% power, then falling off at lesser loads and equaling maximum power efficiency at about 20% output.

We believe the success of the closed cycle gas turbine as a propulsion plant depends a great deal on its arrangement. The arrangement should be such as to: result in minimum weight and volume, maintain alignment during operation in heavy seas, meet Navy shock and vibration-isolation requirements in a simple straightforward manner, have the minimum of piping and open-end shafts, and provide accessibility for normal maintenance and servicing. We have concluded that the best way of meeting these varied requirements is to design the machinery set as an integrated unit insofar as is possible, rather than as an assembly of turbomachinery and heat exchangers interconnected by ducts and shafting.

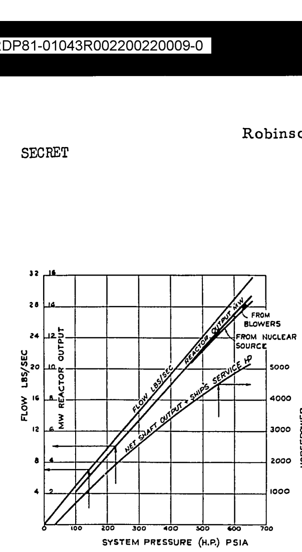

Fig. 3 - Estimated Plant Performance Output vs. System Pressure

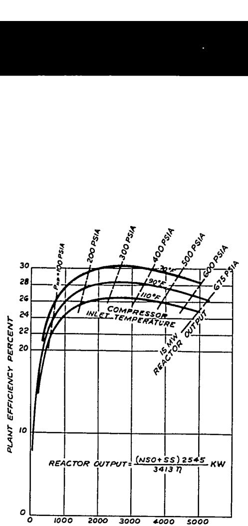

Fig. 4 - Estimated Plant Performance Efficiency vs. Output

A number of configurations were studied and the one finally decided upon is illustrated in Figure 5. Due to the fact that recuperator volume requirements are exceedingly small, resulting principally from the use of helium and compact heat transfer surface, it is possible to use a co-axial design wherein the recuperator surface is "wrapped around" the turbomachinery. In so doing, the plant assumes the form of a cylinder having no external piping other than that required to conduct the helium to and from the reactor heat exchanger, and two open-end shafts: the power turbine output shaft and a constant speed shaft for generator drive taken from the compressor end of the compressor-turbine set.

In this arrangement, the shell or containment vessel is only subjected to the low-pressure-system pressure. All high pressure

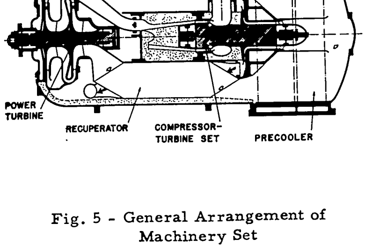

Fig. 5 - General Arrangement of
Machinery Set

gas within this structure is contained in recuperator passages, ducts, etc. Internal insulation is used so that the cylindrical pressure vessel is designed for low-pressure system pressure at a temperature slightly above ambient.

Accessibility of components is limited as it is necessary to remove the precooler, for example, to have access to the high-pressure compressor-turbine set. The general philosophy is that the machinery set would be removed from the vessel, in whole or in part, for overhaul, while in port.

The desirability of providing complete accessibility to all components upon which maintenance could logically be expected to be performed while at sea is a prime requirement. Assuming that such

maintenance comprises routine inspection of the lubrication and control-system components, cleaning of precooler tubes and water filters, and, in general, checking the functioning of power plant accessories, a "packaged" arrangement of the machinery set is entirely consistent with this requirement. It must be recognized that in general, a reduction in equipment life and reliability must be accepted as the price for high plant performance. However, design simplicity and elimination of unnecessary complications in a system is one of the most effective ways of improving reliability, which is achieved with the integrated system.

This design approach can be appreciated when you consider a similar plant assembled of the individual components, interconnected by shafting and piping and disposed so as to provide for complete individual accessibility. The plant would consist of three casings housing the three turbomachines and two casings housing the two heat exchangers, interconnected by six ducts and two pieces of shafting. There are five shaft seals in contrast to two required in the integrated plant. There are six pieces of ducting with twelve joints contrasted to the single duct with one joint in the integrated plant. In addition, the plant using individual pieces of apparatus poses problems in alignment, occupies a greater volume and is heavier. In contrast to the integrated design, certain casing must be designed for full system pressure and temperature where in the integrated design the casing is subjected to the lower system pressure only. The price that is paid for this integrated design is the necessity of partial disassembly to get at any piece of turbomachinery. However, experience with plants designed on these principles has shown that the maintenance problems are less with the integrated design. Figure 6 is such an example, comparing the machinery set of a 2000 KW electrical generating plant of 1940 vintage with one of integrated design currently being produced.

In designing an integrated machinery set close attention must be paid to the problems of assembly and disassembly. The approach used in this design has been to build the plant up from a number of bench assemblies as shown in the exploded view in Figure 7, the components and design details being as follows: a- The precooler subassembly which is of shell and tube design using extended surface finned tubing. Tube runs are essentially straight and can be cleaned by mechanical or chemical means. b- The center section, being the

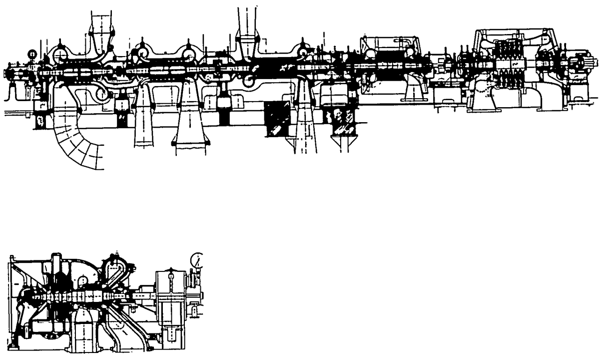

Fig. 6 - Comparison of Machinery Sets of AK36 and Tuco 52

backbone of the engine or the reference frame. c- The compressor-turbine sub-assembly, or the constant speed gas generator, which is an axial-radial compressor driven by an axial flow turbine. The final radial stage of the compressor is used to turn the gas 90° to enter. d- the recuperator sub-assembly comprising eight similar cartridges built up of pin-fin extended surface. These recuperator elements are assembled with a central duct incorporating the compressor diffuser, turbine housing and inlet and outlet ducts, to and from the reactor heat exchanger. e- A power turbine connecting duct fastens to the rear of this central duct to conduct helium from the high pressure to the low pressure turbine and from the low pressure turbine to the recuperator, after expansion. The assembly is completed with the power turbine sub-assembly and the whole en-

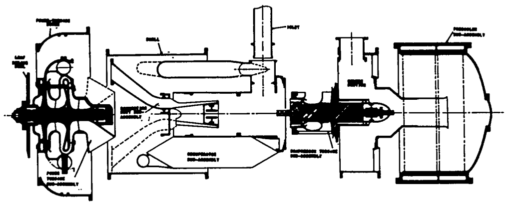

Fig. 7 - Exploded View of Machinery Set Sub-Assemblies

closed in a shell which would incorporate the power plant mounting brackets.

There are two unusual design features in this plant; the use of gas film bearings and a radial inflow reversing power turbine. The use of gas film bearings simplifies the construction considerably as it removes the necessity of a lubrication system and seals necessary to keep the lubricant from leaking into the gas stream. The use of a radial inflow power turbine solves one of the major problems present in the design of a gas turbine plant for ship propulsion, that is the problem of reversing. Use of the radial inflow turbine is possible with a closed cycle plant due to the low volume flow into the turbine, arising from the high pressure level of the plant. Reversing is accomplished by changing the angular position of the nozzle guide vanes with relation to the turbine wheel, as shown in Figure 8. With a wheel designed with a moderate degree of reaction, as would invariably be the case, astern efficiency is about 60% of that ahead.

The auxiliary systems required for operation of this propulsion plant consist of the sea-water circulating system, off-gas handling and control system and seal system.

Because of the high temperature at which heat is rejected from a plant of this type, cooling water flows are quite moderate being of the order of 1250 gpm for the complete system or one quarter gpm per SHP output. The system is quite straightforward, consisting of dual pumps and strainer assemblies drawing water from a sea chest, circulating it through the system and discharging it overboard. The precooler of the machinery set is designed so that one half can

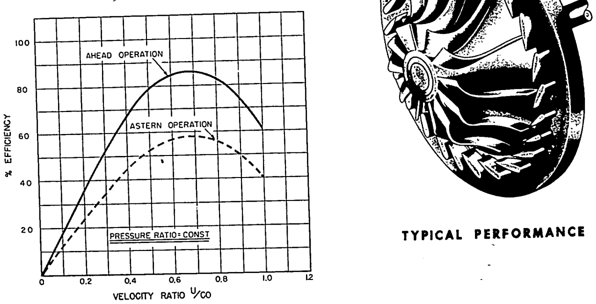

Fig. 8 - Radial Inflow Reversing Power Turbine

be shut off for servicing, leaving the other half in operation.

Power output of a closed cycle gas turbine plant is controlled by adding or withdrawing working fluid from the system to meet the then existing power demands. Working fluid not in circulation within the system must be stored external to the plant and an off-gas system is provided for this purpose. Figure 9 illustrates the off-gas and control system. Output is regulated by selecting a system pressure which will yield the output required. Depending upon whether a power increase or decrease is being called for, helium is introduced into the plant through an admission valve to the low pressure side of the system or withdrawn from the plant from the high pressure side of the system. When withdrawing helium it first passes through a heat exchanger where it is cooled, passes to a surge tank and then to a

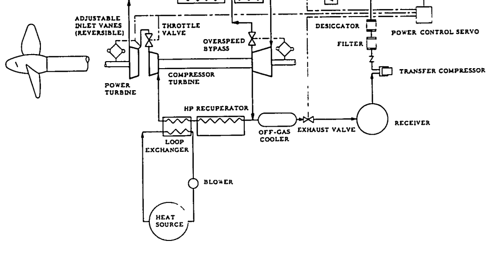

Fig. 9 - Off-gas and Control System

transfer compressor which transfers it to the accumulator for use in a subsequent demand for increased power. The plant is designed for a power rate change of 1-1/2% rated power per second or 75 HP per second. This is achieved by sizing the plant admission valve for a flow equivalent to this power change for an increase in power. Reducing power at this rate presents problems as the capacity of the transfer compressor controls the rate at which working fluid can be withdrawn from the system and the rate at which power can be reduced. In order to avoid the use of excessively large transfer compressors, advantage is taken of the characteristics of the power turbine for a reduction in power. Figure 10 is a qualitative presentation of power turbine performance, plotting turbine head, or power output vs. nozzle guide vane position at constant system pressure. Power output can be reduced, or the turbine reversed, by manipulation of the nozzle guide vane control at constant system pressure.

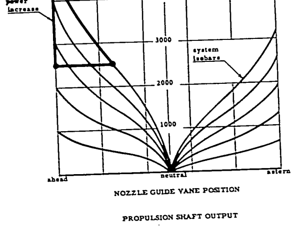

Fig. 10 - Power Turbine Performance

Transit operation can be accommodated in this manner and if permanent power reduction is demanded, working fluid can be withdrawn from the system by the transfer compressor, which is sized for a mean power reduction of 7.5 HP per second over the power range.

The rotating shaft seals of a closed cycle gas turbine plant have probably received closer scrutiny than any other item in the plant. We are of the opinion that successful solution to the problem consists of the development of an adequate seal system rather than the seal itself. We are of the opinion that the seal must be a wet contact seal, where in effect the seal functions to keep a seal lubricant and coolant out of the plant, rather than keep the gas in. Solubility of helium in and separation of helium from the seal fluid is an important consideration in the system design proposed which is described in detail in reference 2.

These auxiliary systems are illustrated in Figure 11 while Table II summarizes the principal characteristics of the plant just described.

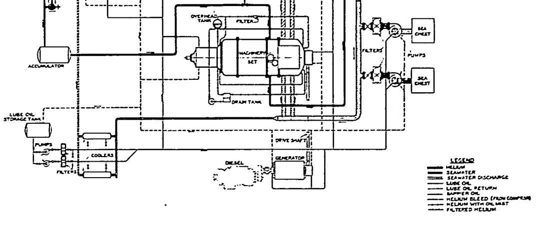

Fig. 11 - Auxiliary Systems

TABLE II

SUMMARY OF PLANT CHARACTERISTICS

Shaft Output	5000 SHP
Electrical Output(Ship's Services)	85 KW
Reactor Heat	15 MW
Heat Rate	9960 BTU/HP-Hr
Reverse Power	3185 SHP
Power Rate Change	75 HP/sec
Water Requirements - flow	1250 gpm
- head	18 ft.
Weight of Basic Machinery Set	22,300 Lbs.
Weight of Complete Plant (Including Primary Gear, Shafting & Auxiliaries)	42,000 Lbs.
Volume of Helium at SHP max at NTP	2710 Ft^3
Turbine Inlet, Pressure	640 psia
Temperature	1300°F
Compressor-Axial/Radial, Stages	8 + 1
HP Turbine-Axial, Stages	5
LP Turbine-Radial, Stages	2
Recuperator Surface (LP side)	4560 Ft^2
Precooler Surface (Gas side)	6200 Ft^2

The reactor study which prompted this power plant design was carried out by the Nuclear Development Corporation of America and included a liquid metal (NaK) cooled, intermediate - fast reactor and a helium cooled, beryllium moderated, intermediate reactor. Both reactor systems provide 15 MW of heat to the power plant working fluid through an intermediate exchanger, and shielding for both reactor systems are designed to meet current Navy rate requirements in the vessels in which they are installed.

An intermediate loop exchanger is a necessity with the liquid metal cooled reactor and this exchanger is contained within the primary shield system because of radiation from the activated coolant. While an intermediate loop exchanger is not required theoretically with the helium cooled reactor, its use was considered prudent in view of the application and the possibility of a fuel element failure which would release fission products to the gas stream. When the development of fuel elements has reached the point where the probability and seriousness of their failure is acceptable on a statistical basis and means are available for reducing the activity in a contaminated working fluid circuit, the loop exchanger can be dispensed with at an appreciable saving in size and weight. Plant performance will also be improved due to the higher gas temperature available.

The two reactor types chosen for study represent two possible paths to the high temperatures which are necessary for the achievement of a light weight power plant and for efficient operation of a gas turbine in particular, where temperature at the turbine must be 1300°F or higher.

The liquid metal cooled, intermediate - fast reactor is a concept which has been under study at NDA for some time. It has been designated as the LWMR (Light Weight Mobile Reactor) and incorporates many features which lead to a reactor of minimum size and weight. The core consists of fuel elements, coolant and structure. No moderator is used, which minimizes the volume of the active core region. In many respects, the core resembles the fast breeder reactors EBR-I and EBR-II as built by Argonne National Laboratory.

This small core size means that the effective radius of the shielding is reduced, hence the shield weight is reduced. In addition, most of the heavy lead gamma shield material has been used close to the reactor core while lighter lithium hydride neutron shield material has been used in the outer shielding layers. The combination of a small reactor core, heavy shielding material close to the core and lighter shielding material away from the core together with elimination of secondary shielding for the loop exchanger leads to a reactor system having a basic diameter of 14 feet and a weight estimated at 215,000 pounds. This together with the machinery set results in a propulsion plant up to the final gear reduction stage of 257,000 pounds. To this must be added the weight of a generator (s) and an emergency diesel engine drive, if required, which can easily total 20,000 pounds to give a total propulsion plant weight of approximately 280,000 pounds or slightly more than 55 pounds per horsepower.

The helium cooled, beryllium moderated, intermediate reactor was chosen as a second reactor type for this study because its development problems were less complex and it offered the eventual possibility of elimination of the intermediate loop exchanger. This reactor concept has been designated as the GCMR (Gas Cooled Mobile Reactor). The core consists of fuel elements, moderator, coolant and structure. Presence of the moderator increases the core size over that of the LWMR and hence leads to a larger diameter shield of greater weight.

Beryllium was chosen as the moderating material because of its known technology. However, the use of hydrided zirconium, as an example, is extremely attractive from the standpoint of reducing the core size, but further development is required before such materials can be used at GCMR temperatures.

The shield design for the GCMR is essentially the same as used for the LWMR but the larger core results in a shield having a basic diameter of 16 feet and a weight estimated at 318,000 pounds. This together with the machinery set results in a propulsion plant up to the final gear reduction stage of 360,000 pounds. Again, we must add to this the weight of a generator (s) and an emergency diesel engine drive, if required, to give a total propulsion plant weight of approximately 380,000 pounds or slightly more than 75 pounds per horsepower.

Elimination of the secondary loop exchanger in this system will result in a reduction in weight of the order of 8000 pounds. Use of a moderator having the characteristics of hydrided zirconium will result in a smaller core and shield and a reduction in weight of the order of 50,000 pounds. Therefore, as along term development the GCMR approaches the weight and size of the LWMR, although it is doubtful if it can ever meet it. However, the increased plant output resulting from the 100^{o} higher turbine temperature makes the plant superior on a specific weight basis.

Installation studies of these reactor systems and the closed cycle gas turbine power plant were made in the hull of a small submarine and a small surface vessel. An outline drawing of the LWMR system in these two hulls is shown in Figure 12. The small submarine is of a nominal 500 ton displacement having a hull diameter of 15 feet with a clear inner diameter of 13 1/2 feet. The small surface vessel is a Class 339 (WGT) Destroyer Escort hull. While it is recognized that this latter installation is not practical, the WGT was used only to establish the space available for a propulsion plant in a small surface vessel.

The submarine is powered with a single 5000 SHP propulsion plant which provides for normal operation over the full speed range, surfaced and submerged, as well as power for creep speed through an auxiliary motor drive. During operation at creep speed the complete propulsion plant gear train is immobilized to the propeller shaft and power is transmitted to the propeller shaft by the creep motor through a V-belt drive. Energy during this operation is provided by an auxiliary generator driven from the compressor-turbine set.

This same creep propulsion system is used during emergencies, energy being supplied by batteries when submerged and by an emergency Diesel generator set when surfaced.

The size of the small submarine hull and the necessity of providing for these alternate propulsion schemes dictated, to a large extent, the configuration and arrangement of the gas turbine plant described.

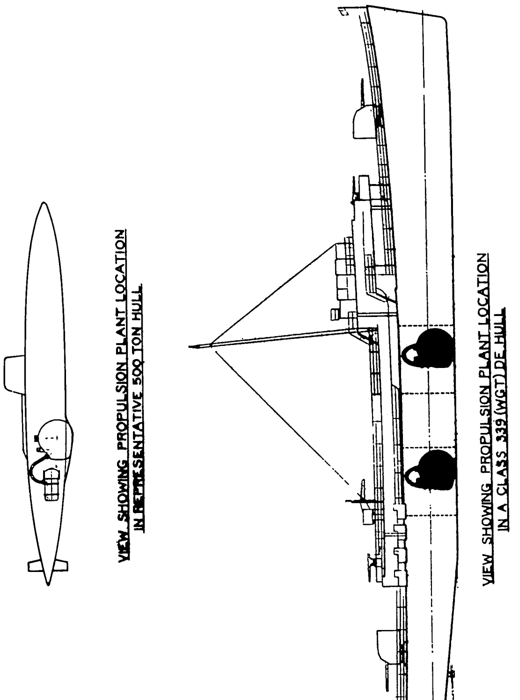

Figure 12

Installation in the surface vessel was more straightforward as there was ample space in hull and the necessity for a variety of alternate propulsion methods was not present, since two complete and separate propulsion plants were used.

It is recognized that the power plant design presented here represents a considerable departure from conventional Naval practice. However, in the nuclear power field such a departure is essential if small power plants of acceptable size and weight are to be made available.

This study has indicated the possibility of a "packaged power plant" of modest size and weight resulting, to a large extent, from the design philosophy which was followed. This design philosophy, with respect to the power plant, is comparable to that used in the design of a supercharged high output diesel engine while that used in the reactor design lies somewhere between that followed in the aircraft nuclear propulsion program and that of the present Naval reactor program. It remains to be determined whether this philosophy is appropriate to the missions which a small submarine or surface vessel would be called upon to perform and the time schedule under which such a propulsion system would have to be developed.

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JULIE AND GILDA

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U.S. Atlantic Fleet

This paper reviews the Navy's program in making operational an airborne ASW localization technique using explosive echo ranging. JULIE is the code name given to the technique when used with sonobuoys and fixed wing ASW aircraft. GILDA is the name given the technique when used with dipped or towed sonar from helicopters or airships.

It would be repetitive to elaborate in detail NEL's background work in explosive echo ranging since 1941. Woods Hole Oceanographic Institute has been using this technique for research since 1950, and perhaps before then. The Bureau of Aeronautics in 1953 began studies for its application in aircraft. The Naval Air Development Center at Johnsville in 1954 had further noted that only one "black box" amplifier was needed to be added to existing on-the-shelf components, and the resultant system would be ready for fleet use. It was not, however, until the NOBSKA conference in 1956 that the need of adapting explosive echo ranging to aircraft was given an impetus sufficient to result in funding and establishing projects.

During the past year, several Atlantic Fleet units have been busy in developing JULIE. Air Development Squadron ONE is now in the process of submitting their final recommendations to Commander Operational Development Force on tactics for interim JULIE. Two crews in Air Antisubmarine Squadron 36, the "Scatterwell Group", with Carrier based ASW aircraft, have had as their sole mission the tests on suitability of equipment, the development of interim tactics, and JULIE training requirements. Four special crews in Patrol Squadron 8 and 44 have respectively concentrated on JULIE in land planes and seaplanes. After review and analysis of the final reports from these units, Commander Naval Air Force, Atlantic Fleet will publish interim

Type Command tactics and Commander Antisubmarine Defense Force, Atlantic Fleet will publish interim Intertype ASW tactics.

Background discussion of JULIE is not complete without giving all due credit to the Canadians who have been in this business longer than we have; have procured their equipment, developed their tactics, and have an excellent crew training program. Direct and close liaison with their JULIE project personnel has saved us many hours in the prosecution of our work.

It is most satisfying to report that through the joint efforts of the Bureaus and offices in the Navy Department and of all the units above-mentioned, an accelerated explosive echo ranging program for aircraft has become today's reality.

As an introduction to the tactical employment of JULIE, a description of the equipment and a look at sample JULIE tapes is in order. Figure I portrays in block diagram the several components of the JULIE system.

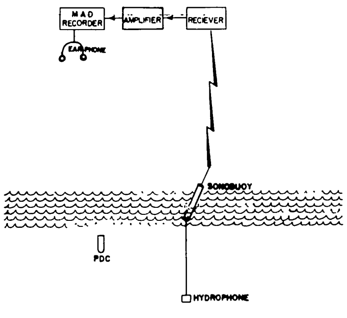

Fig. 1 - JULIE System Components

Here is both simplicity and usability of on-the-shelf equipment. The practice depth charge (PDC) is manufactured in two models. One with a hydrostat fuse set at 50 feet; the other with two hydrostats with selectable settings of 50 or 300 feet. The SSQ-2B sonobuoy has a 40-foot hydrophone and 5-8 mile radio link with aircraft flying at normal 350 foot tactical altitudes, with additional range up to 30 miles as the aircraft increases altitude. The amplifier filter control box is the only new piece of equipment required. Two pens on the present Magnetic Airborne Detection (MAD) recorder have been adapted for use in this system. Each pen records information from a selected sonobuoy channel. The JULIE operator measures ranges directly from the recorder tape. Through split headphones he also can listen to two sonobuoys binaurally. Components shown make up the <u>interim</u> JULIE system. When finally configured in 1959-60, Patrol aircraft will have a specially-designed recorder in lieu of the present MAD recorder.

An underwater explosion is an omni-directional sound source. The sonobuoy hydrophone is also omni-directional. As the pulse of energy from an explosion travels out and passes the sonobuoy, it is received by the hydrophone, transmitted to the aircraft receiver, amplified and displayed on the recorder as a sharp pulse. This is the initial pulse and the first event recorded on tape. Figure II is a schematic of a detonation from an explosive on a single buoy, and received on two channels.

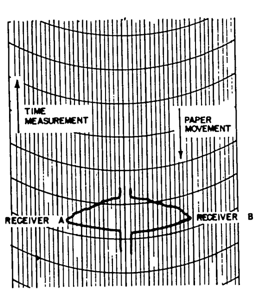

Fig. 2 - Sample JULIE Recorder Tape Detonation

If the explosive sound pulse hits a submarine, the return echo appears as in Figure III, with an appreciably larger echo both heard and recorded from target beam aspect than bow or stern aspect.

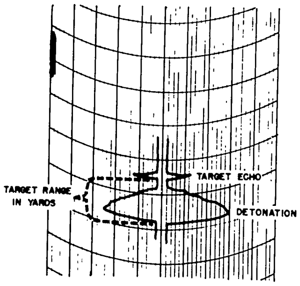

Fig. 3 - Sample JULIE Recorder Tape Target Echo

By a ruler calibrated in two-way travel of sound, or one-half speed of sound, the range of the target in yards is measured from the base of the detonation to the base of the return echo.

In deep water (2000 or more fathoms), generally a target echo is received before the bottom bounce echo, shown in Figure IV.

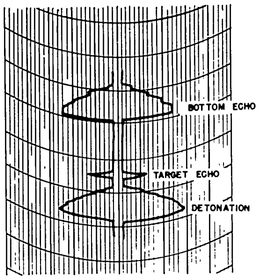

Fig. 4 - Sample JULIE Recorder Tape Bottom Echo

In shallow water, the JULIE operator must be "on his toes" to listen for a target echo and to perceive its recording in the maze of bottom bounce noise. Experience has shown that explosive echo ranging is satisfactory in shallow water up to 200 fathoms and in deep water beyond 2000 fathoms. In shallow water, echos are received generally after the several bottom reverberations have substantially decayed. In deep water, echos can be utilized after the detonation and before bottom reverberations. In between these depths the receipt of an echo becomes marginal due to the occlusion caused by the charge dropped at the buoy and the early receipt of the bottom reverberations.

The tactics I will review are best described as being sample, interim tactics. They have been tried and proven. As presented, they are not related, nor do they represent all the recommended steps necessary for localization and final submarine attack. This paper cannot begin to cover the technical data written on JULIE tactics. Rather, through a general presentation, JULIE'S potential is indicated.

The very reason for JULIE (and where she best performs) is her capability to localize an underwater target. The datum must first be found, usually by a disappearing radar contact, by ECM fix, or by submarine, surface ship, or helicopter sonar. Given datum, a representative localization pattern such as is shown in Figure V, is selected.

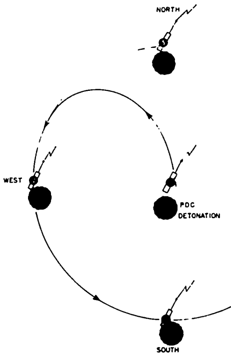

Fig. 5 - Sample JULIE Localization Tactics

A buoy is dropped on datum, with a smoke float and a deep-set PDC. Peripheral buoys are then planted in a circle whose radius is dependent on several factors: water depth, estimated sound range underwater; buoy inventory remaining on the plane; reliability of sonobuoys. While establishing the sonobuoy plant, the first detonation is recorded. The area within the planned circle is largely covered in this first charge. The pilot completes his circle, planting as many sonobuoys as required. He then continues flying the circle and "bombs" each buoy. The JULIE operator listens for distinct target echoes while visually monitoring the recorder tape. If no target echo is received, the pilot can elect to bomb each buoy again, or establish a new datum and repeat the process of dropping and bombing the planted buoys. In those few patrol aircraft presently equipped with two recorders--one for MAD and one for JULIE--the MAD

equipment is used as an additional means of detection while the pilot flies the sonobuoy pattern.

If a target echo is received from one of the buoys, the next tactical step involves the problem of rapidly fixing the target location and solving target ambiguity by a two-charge single buoy method. (Figure VI)

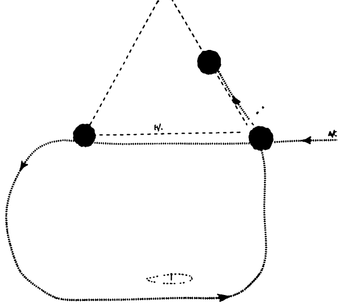

Fig. 6 - Sample JULIE 2-Charge Single Buoy Tactics

The pilot drops a charge at a given buoy and a second charge on a bearing, tangent to the localization circle of buoys, and at a best-estimated range from the buoy, usually 2000 yards. By dropping these charges, the JULIE operator is able to first measure a range from the buoy to the target, and then a range from the second charge to the target. The inter-section of the range curves will provide a fix and its image. The pilot then maneuvers to drop a third charge half-way between the buoy and one of the fixes. In Figure VI, the third charge will produce a range approximately one-half that obtained from charge one on the buoy, from which the pilot concludes that the third charge was in fact dropped between the buoy and the actual submarine.

Having fixed a target, the pilot is now ready to set up a two-buoy, single charge method to track and attack the target. (Figure VII).

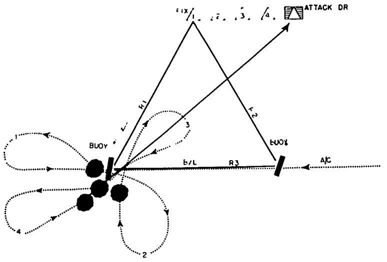

Fig. 7 - Sample JULIE Tracking and Attack Tactics

The pilot drops two buoys as accurately as possible to establish the desired base line. He then flies path #1 and bombs a buoy, both to measure the base line and measure the range to fix #1. He continues on successive flight paths, dropping charges each time he returns to the buoy, and obtaining indicated fixes on target. The buoy must always be between the charge and the submarine. When adequate target course and speed indication are obtained, an Attack DR is estimated and a final heading is taken to that point for weapon release.

Before leaving the discussion of tactics, consideration should be given to the use of MAD in the final attack phase. It is too well known in Antisubmarine Warfare how difficult and how extremely important it is to classify a target. Unfortunately, we cannot yet give JULIE a classification capability. It may be possible for an experienced operator to use beam, or bow and stern aspect to aid in classification. This remains for future study. We should then,

insure that the MAD equipment is used over the target. With the interim JULIE equipment now being provided, with a single dual-purpose MAD recorder, this presents a problem. Some 40 or more seconds are required to convert the recorder pens from their use with JULIE to their MAD function. This time is precious while approaching an attack DR position. Several solutions are seen. For patrol aircraft, the installation of a second MAD recorder for its designed function should be provided. For carrier based ASW aircraft, with no room for another recorder, MAD classification over the target could be made by a second plane, with the further addition of helicopter sonar gaining contact and tracking the target. Without an "assist" over the target, these planes "going it alone" will in all likelihood revert to MAD after the pilot is satisfied with the JULIE target course and speed, and conduct prescribed MAD tactics prior to weapon drop.

Thus far I have discussed JULIE'S background, her components, and her sample tactics. Part of JULIE'S history includes a period of time in which her capabilities were perhaps exaggerated. This technique was suggested in lavish terms as the answer to the long range detection problem for ASW. Time and experience have sobered the initial enthusiasm. We know today that we have a simple, yet excellent localization technique, with considerable capability when utilized by personnel who know how to best use the equipment. It is my purpose to present JULIE with her known capabilities. I must, then, consider both her potential, her weaknesses, and the problems we face.

What deep water ranges have been found by explosive echo ranging? In Southern waters off Florida and Guantanamo, 2500 yards, 500 yards, 7500 yards. However, in the water north of Norfolk, in the April to September season, ranges nearer 1500-3000 yards are most representative. In June and July, we may be fortunate to have 500-yard ranges, the sonar conditions are so poor. In the winter months, somewhat better conditions prevail. 4000-6000 yards is average, depending on water depth. You can see why this technique is not adaptable to search doctrine. So <u>much</u> depends on water depth and sonar conditions on a given day, in a given area; on weather as it affects the ocean surface during and after storms or high winds. As an aid to the aircrew, the Hydrographic Office is preparing predicted sonar range tables for various ocean areas and seasons of the year. A pilot and his JULIE crew face a new requirement in their ASW training: a working knowledge of varying ocean conditions so that range predictions can be made as part of the planning for the size of the sonobuoy localization pattern and number of sonobuoys required.

Figure VIII contains a combination of several factors determining the size of the localization pattern.

TIME LATE	SUBMARINE SPEED—6KTS
EER RANGE 2500YDS	
5 MIN	6000 YDS (7-8 S/B)
10MIN	6000 YDS (7-8 S/B)
20MIN	10000 YDS (12 S/B)
30MIN	12000 YDS (15 S/B)
EER RANGE 5000 YDS	
5MIN	4000 YDS (3 S/B)
10MIN	6000 YDS (4 S/B)
20MIN	7000 YDS (4 S/B)
30MIN	9000 YDS (6 S/B)

Fig. 8 - Radius of EER Sonobuoy Patterns

"Time late" to datum combined with predicted explosive echo ranging ranges (EER) determines the radius of the pattern required against a submarine at the speed shown. The number of sonobuoys to plant is further dependent on predicted sonar conditions. Several points on the chart are of particular importance. Submarine speed is one. Experienced JULIE crews to date have been able to satisfactorily localize and "keep hold" of a submarine at 6-10 kts. A submarine using evasive tactics at this speed is a challenge to the JULIE operator. It takes an appreciable number of seconds, in confined workspace and with cumbersome rule measuring, to take ranges from the tape and plot these on the chart. If the rate of expenditure of PDC's is high, for example, while constantly bombing a two-buoy pattern to track the target, the operator is busy indeed. On the other hand, there are many times when the data flow is dangerously too slow, particularly against a fast target. An example of this case is the time required to fly between buoys on an extended range circle. Aircraft inventory of PDC's is too small to permit indiscriminate and rapid-fire explosive echo ranging in this latter case. The careful matching of the sonobuoy pattern and the use of PDC's against the predicted target speed is most important.

Another important aspect of Figure VIII is the indication of the large number of sonobuoys required to make the JULIE technique effective. Here is both an aircraft stowage problem and a cost problem. A patrol plane carries 32 sonobuoys. A carrier-based ASW plane carries 16. If several localization patterns are required before a target is obtained, it is quite evident that JULIE-equipped aircraft can run out of stores long before the plane runs out of gasoline. These are todays problems and must be faced. This applies even more so to PDC stowage and usage. A patrol aircraft carries 60-70 charges; the carrier plane, 30-50 charges. Every pilot will always want to hold part of his supply in the event a target is found and an attack is possible. What of the cost? The SSQ-2B sonobuoy cost $125. A PDC costs about $30. An 8-buoy pattern will cost $1000 in sonobuoys and $240 for only one round of bombing by one plane. Multiply these figures many times over for the numbers of aircraft involved and numbers of submarine contacts to investigate. JULIE will be an expensive girl.

JULIE poses some additional problems which need solving. One of the most important is the need to design and manufacture sonobuoys and PDC's that can be relied upon to work. It is common knowledge, for example, that up to 12 sonobuoys may need to be expended for an effective 8-buoy pattern. During the past year, the SCATTERWELL GROUP dropped 851 buoys. 240 were duds. 70% were reliable. Vacuum testing of the buoy prior to flight has recently been found to increase buoy usability to approximately 90%. This helps. Mod 12 PDC's are unreliable at the 300-foot setting. About 40 seconds is normally required for the fall thru water to 300 feet. 50-75 seconds has been experienced before the detonation was recorded. An explosion depth varying from 400-600 feet is therefore indicated. On numerous occasions, a deep charge exploded so close to a charge dropped 20 seconds earlier that all data unusable and the ranging had to start all over again. $30 is a lot of money for little gained. A cheap, lightweight, reliable, and smaller PDC is a must.

A problem for research and development involves the occlusion experienced at detonation. This blanketed and therefore unrecorded area about the explosion has been estimated in some cases in the 300-foot PDC setting to extend to 1200 yards radius. A sonobuoy with Automatic Gain Control is being tested to reduce this problem.

A third major INTERIM JULIE problem involves the urgent need for an improved aircraft DRT system to complement the interm JULIE equipment now being provided.

A Gyro-stabilized compass and doppler speed input are needed. Without new navigation equipment, the pilot must plant his various sonobuoy patterns, making innumerable changes of heading, all on dead reckoning and still be expected to fix a target position with sufficient accuracy to drop a torpedo with a 500-yard acquisition range. This requires the utmost in crew training and coordination. Fortunately, planned equipment for fleet delivery in 1959-60 will include the needed new items.

One more point of interest concerns JULIE before I briefly discuss GILDA. The training program for JULIE crews is underway. The Special Devices Center is commencing delivery of mock-up trainers which utilize magnetic tape recordings for target echo recognition in conjunction with the MAD recorder. The Fleet Airborne Electronics Training Unit and the ASW Tactical School at Norfolk are preparing syllabi for classroom study of the theory and tactical application of explosive echo ranging. So much for classroom training. What of practical training with a submarine? Here is a discouraging area which poses a serious problem. It has been estimated that 6000 submarine hours will be required just to basically train Atlantic Fleet JULIE crews. By "basic" is meant a minimum of three 2-hour flights with the submarine at a known location and speed. A fourth advanced flight is made against an evading submarine. JULIE submarine requirements, added to submarine requirements for new and other fields of endeavor certainly point to the ever urgent need for additional submarines or fixed ping targets in the Fleet. Without this increase, JULIE crew training is likely to proceed at a snail's pace.

During the past years, the technique of explosive echo ranging has been applied experimentally to surface ships, submarines, airships and helicopters. Everyone in the act, and rightly so. Of particular interest to the Submarine Force is EER use as a method of finding range to a target held by a passive sonar at optimum listening depth. With sonar bearing and explosive range, a target fix can be relayed to patrol aircraft, thereby saving considerable "time late" to datum. This can further aid the aircraft in determining the optimum JULIE localization pattern. 30 mile ranges have been experienced under favorable conditions by submarines.

Experience to date with helicopters and dipped sonar has not been too promising. First tries resulted in explosive damage to the transducer. Later attempts by a second helicopter dropping a PDC 100 yards from the dipped sonar gained no greater range than was possible by the active sonar. Further helicopter work now awaits the modification of sonar equipment. GILDA with airships and their towed sonar has been successfuly tried under controlled target conditions. One extremely long range--8½ miles--was recorded. It is understood that Commander Fleet Air Wings Atlantic Fleet plans to request that CNO accelerate Project GILDA for airships so that further work can determine their capability under varying tactical and sonar conditions. With the airship sonar array having a beam directional in the vertical plane, it appears that bottom reverberation problems may be somewhat reduced. This is particularly important in water from 200 to 2000 fathoms. This part of the ocean is extremely difficult for successful echo ranging by JULIE equipment without AGC buoys.

All of us who labor in ASW are appreciative of the time, funds, and effort expended in developing JULIE to an operational system. We cannot, however, rest on our laurels. I have indicated major problems that need solving. Thanks to JULIE, and to forthcoming new passive detection equipment and weapon development; the airplane in the ASW team finds itself with a new major role to perform in submarine detection, localization and kill.

"PROJECT MONTE"

A. B. Focke, Chairman
Mine Advisory Committee
Washington, D. C.

Project MONTE was undertaken by the Mine Advisory Committee at the request of the Chief of Naval Research and the Chief of Naval Operations.

It's objectives were threefold:

1. To review the research and development program in mine countermeasures to determine our present capabilities.

2. To determine whether the present program was likely to achieve acceptable results, and

3. To recommend those actions which would result in the improvement of our mine countermeasures readiness.

To accomplish these objectives the work was divided into three phases:

The first began in the early spring with a very few workers preparing a bibliography and assembling the fullest possible library of useful documents.

The second phase lasted from mid June through mid August, during which time a group of about sixty-five of the outstanding past and present workers in the field were gathered at the U. S. Naval Postgraduate School in Monterey, California, to work over the assembled data, gather more and prepare the report material.

The third phase began immediately upon completion of the second and consisted of presenting the findings of the project to the Navy both in oral and written reports. Thus this paper is a part of this third phase.

At the outset of the summer work, it became apparent that it was absolutely necessary to set up boundary conditions within which the work was to be confined. The most important of these were:

First: The war situation which was most fully treated was chosen to be of the Korean type. This decision was based upon the assumption that if the home territories of either the USSR or the NATO countries become involved theaters, nuclear weapons will almost certainly be used and the effects of a mining campaign will become negligible. Thus the Korean peripheral type war is probably the biggest thing that will actually involve mine countermeasures as an important element. This type situation demands the maintenance of several task force organizations to cope with the probable hot spots throughout the world. Each of these task forces must include a mine countermeasures capability and it is this capability that "MONTE" strove to improve. We believe that if such task force capability is achieved and maintained there will automatically be a capability in being in home waters due to the requirements of rotation and training. It was our belief that this capability in being would be of the right size to fulfill the needs at home. Furthermore we believed that this same capability, expanded but kept mobile, would provide the most effective countermeasure system in a European theater.

Second: We confined our attention to those countermeasures actions which can be taken after the mine has left the mine layer and before it has exploded. Preventive countermeasures may be difficult or impossible in limited wars which are to remain limited and were therefore not considered.

Third: A complete lack of information on Russian mines beyond those recovered in Korea forced MONTE to base its studies on the mines recovered there, together with the trends in United States mine development. No new principles have appeared in US mines nor apparently in foreign ones. The importance of mixed mine fields was recognized and it was felt that any nation having a variety of mines available would make use of mixed fields. Thus the recent obsession with pressure actuated mines alone rather than as parts of a well planned field was considered unwarranted.

Fourth: Attention was given to three time periods and the results that could be hoped for in each. These were (1) to

April 1958, (2) to 1960 and finally to 1965.

As a preliminary and immediate action, we recommended the procurement of limited quantities of a specific list of materials which when supplied to and used by the operating forces would materially reduce the time required to clear a channel of enemy mines. In preparing this list we followed the policy of providing a duality in the basic nature of the equipments provided and a capability throughout the life of the mine from laying to destruction. The equipments fell into five general categories, mine watching, precise navigation, mine sweeping, mine hunting, and identification and destruction.

In all cases it was recommended that the equipments procured be used at once in realistic fleet exercises to acquaint the operating forces with the techniques required in using them and the increased capabilities they would ensure. We believe that effective use of these equipments in supplement to existing methods should increase the effectiveness of our mine countermeasures by as much as a factor of two and that if immediate action were taken this could be achieved by April 1958!

In addition to these recommendations for equipment procurement, we recommended the termination of several projects and the realignment of many others. A rough balance between proposed procurement and cancelled projects made us believe that our recommendations could be prosecuted within the current budget and personnel limitations.

In connection with the longer term program, MONTE made more than 150 detailed recommendations covering the many equipment developments, the information gathering projects, training and education programs, and the like. It is recommended the creation of a Mine Countermeasures Operations Experimental Group at the CNO level. It has prepared an accurate, detailed, technical summary of the mine countermeasures research and development program. The library of documents accumulated includes some 1200 items which have been fully indexed with a uniterm system. The first volume of the report, a summary, has been completed and distributed. The second volume which includes the detailed reports of each of the working groups is at the printers and the third volume, the bibliography is about to be distributed.

In general, MONTE concluded that thanks to that least expensive of major Naval functions, the research and development program, our mine countermeasures readiness is not in as bad shape as

many think and that the existing R&D program promises to provide a marked and continuing improvement throughout the coming years - <u>if it continues to be adequately supported and its results passed on to the fleet</u>.

Because of the theme of this conference, I should like to expand upon one phase of the work of MONTE. This is the area covered by the Environmental Factors Group.

In the entire field of mine warfare the natural environment plays a dominant role. Mine warfare exists only because it employs a weapon which utilizes this environment for purposes of ambuscade, while mine countermeasures, in locating and disposing of the weapon, is in effect the unmasking of the ambuscade.

Therefore, the environment must be taken into account in operations planning, actual operations, and during design and development of new equipments and techniques. Ignorance of or disregard for, the environment has resulted in numerous costly blunders ranging from the loss of men, ships and material during combat operations to the losses incurred in the development of worthless, expensive and complicated equipment.

Numerous examples exist of equipment which, after having performed satisfactorily in the laboratory or test basin, failed under natural conditions. World wide variety and seasonal variability of environmental conditions must be kept in sight. Satisfactory performance at Key West or Panama City, Florida, is not conclusive unless the device is specifically intended for use in those areas. Even the relative performance of two pieces of equipment determined at one locale may not be indicative of their relative performance at another locale.

Unfortunately, scientists and operating personnel tend to idealize and oversimplify the environment. Too many equipments are designed for the "Average Condition." Some harbors have relatively flat, sandy bottoms, with clear water and short, simple approaches from the 100 fathom curve. Often, however, they have boulders and rock terraces which will wreck a bottom drag, give false acoustic targets and high acoustic background, non-emergent seaweed which can acoustically conceal a mine, strong shear currents which can put a ship out of a narrow channel before the helmsman can react, mud bottoms which must constantly be dredged to maintain a channel, and minable approaches for hundreds of miles. The "environmental naivete" of many people in mine countermeasures is often shattered too late to do any good.

It is therefore important to determine carefully which natural environmental factors are signigicant for the equipments used in mine countermeasures systems, how this data may be obtained for points of tactical interest and how this data is to be presented to the operating forces.

Some of the principal sources of available environmental information are:

1. The Hydrographic-Oceanographic Data Sheets (HODS),
2. The Air Objective Folder (AOF),
3. The Harbor Defense Atlases (HDA),
4. The Inshore Survey Preliminary Reports,
5. The Sailing Directions,

(All from the U. S. Navy Hydrographic Office)

6. The National Intelligence Surveys (NIS) prepared for the Departments of Defense and State, and
7. Various Coast and Geodetic Survey publications.

These documents contain information of interest for many harbors, however, there is a marked lack of information on those harbors in which we are most likely to have to operate in the case of peripheral wars. It was found during the summer that the highest priority had been given to the acquisition of information on more US harbors and the lowest priority to getting information on neutral and USSR harbors! This seemed to MONTE to be completely backwards and a strong recommendation for a change was made.

A mine countermeasures program must be designed and operated with full regard to environmental factors and it is important that the effects of the environment on all elements of the mine countermeasures system be understood. There must be known the facilitating and limiting effects on the enemy mine designer and tactician, the mine layer, the mine itself, the target ship and on the implements of the mine countermeasures system itself.

To be effective the mine countermeasures planner must have a good understanding of the effects upon the operations of the enemy, the target ship and his own forces.

To indicate the scope of the environmental problem let me mention some of the major items which may be of importance. As I mention them I am sure you can think of ways in which they may be of significance:

First: On the nearby shores; Relief and Landmarks.

Second: In the atmosphere; Wind Direction and Velocity, Precipitation, Visibility, Cloud Cover, Storms.

Third: At or near the surface; Sea and Swell, Breakers and Ice, Flotsam and Debris, Acoustic Scattering.

Fourth: In the water; Depth, Tidal Range and Current, Temperature, Structure, Acoustic Attenuation, Ambient Noise, Visibility, Fouling, Salinity.

Fifth: At or near the bottom; Topography, Roughness, Penetrability, Electrical Resistivity, Magnetic Permeability, Acoustic Reverberation, Jetsam, Fouling.

Sixth: In the bottom; Composition and Structure, Acoustic Characteristics, Buried Jetsam.

In going over this list we can think of the effect of each item on the mine, the target and the countermeasure system.

As was stated earlier, we need these environmental data for foreign ports where peripheral wars are likely.

In presently friendly ports, NATO and SEATO cooperation can provide much information, and visiting US ships and NATO and SEATO craft can secure additional data.

In neutral ports, visiting US Naval vessels should be used, whenever possible, to observe and record bottom contours starting from the 100 fathom curve, take sonar observations of the bottom and bottom obstacles, measure water temperature as a function of depth, take bottom samples and so on, without overstepping the bounds of propriety. Mine craft visiting foreign neutral ports are in a special position, since they can use their mine hunting equipment as a part of their means of observation. The need for accurate plotting of position as the observations are made is obvious. Underwater swimmers can collect many valuable data. Swimmers who are also marine biologists, geologists, or archaeologists are familiar in foregin ports and have far greater access to important areas than do military personnel. Their reports should be solicited wherever possible, and the data made available to the Navy Hydrographic Office.

In enemy ports, foreign intelligence is the only direct means to obtain these data. The Office of Naval Intelligence should be alerted to this need.

Since the opportunity to collect such data in enemy ports does not often present itself, another approach is suggested. This is to institute a program of research into the oceanographic and environmental factors important to mine countermeasures, and to synthesize these factors into a harbor classification scheme.

It is quite possible that the geology, oceanography, and meteorology for harbors of one type are similar. If this should be found true in enough instances, it might then be possible to infer a great deal about an unknown harbor if it can be classified as to type.

Finally, I wish to express again the thanks of the Mine Advisory Committee to the many agencies which provided personnel to MONTE at considerable sacrifice to their own programs.

FUTURE MINE DEFENSE CAPABILITIES RELATED TO THE OCEAN AS THE OPERATING ENVIRONMENT

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INTRODUCTION

In this presentation we shall consider some of the more significant interactions between the "Ocean as the Operating Environment of the Navy" and the element of the Mine Defense Forces. Specific examples of environmental limitations imposed on some equipments and techniques will be discussed. Attention will be given to the safety of mine countermeasure vessels. Some discussion will be devoted to the unresolved problems relating to the environment. Finally, we shall delineate logical future actions related to environmental problems which, when implemented, will result in enhanced capability of the Fleet.

THREAT

The priority of effort given to the various problems obviously depends upon the nature of the threat facing us. The assumption seems to be fairly well justified that future all-out conflict is improbable and that limited wars of the Korean type are more likely. Conflicts waged on the coastlines of the major powers would not then be expected, but the waters adjacent to or important to the satellite nations would be the areas of action. In the "limited or peripheral war" concept, attention must be given to environmental problems on a world-wide scale.

The Russian mine threat is of greatest concern. It appears from ONI sources that their stockpile contains about a half million mines. Most of the mines are believed to be simple and of the moored type, but the Russians are believed to have, or at least to be familiar with, all influence types. While the sophisticated mines may compose only a minor part of the stockpile, their threat must be taken quite seriously. These mines are expected to show increased resistance to countermeasures. Their mechanisms will be expected to discriminate better between ship and sweep signatures and to become passive in the presence of a sweep. Designers will attempt to circumvent spurious actuations by the environment, and to develop some defense against hunting or watching.

Minehunting and watching are coming of age and assessment of their potential capabilities is fairly well realized. It can now be expected that trickery will be employed, either through circuit or physical characteristics to enable a mine to "conceal" itself from hunters and watchers, or by the use of counterfeits to confound their efforts. In the attempt to make mines indifferent to their environment, the Russian designer has a great advantage over this nation. His mines are designed as weapons against ships that create relatively large influence fields; ours must respond to the much smaller fields of submarines. Susceptibility to environmental disturbances decreases as the mines become coarser.

It is clear that the service environment of naval mines is an important factor in their design. It is equally true that the environment imposes a severe burden on the mine countermeasures forces by limiting the effectiveness of their best efforts. Let us consider some of the characteristics of the marine environment that present particular problems in mine countermeasures.

MINEHUNTING EFFECTIVENESS

The Minehunting effort comprises particular techniques of detection, location, classification, identification, and neutralization of mines. Sonars are heavily relied upon to provide capability in detection and location.

Figure 1 gives a concrete example of the effect of environment on the ability of the AN/UQS-1 to detect ground mines. In all three cases a hard, sandy bottom is assumed and the sonar is making a parallel search along tracks separated by a 70-yard lateral distance and thus the average mine is within theoretical range of the sonar on ten passes. Corresponding to a one word description of sonar conditions as excellent, average, or poor, a rough qualitative description of a typical accompanying environmental situation is given, together with an estimate of the sonar performance which can be achieved. Shoran is the navigational aid.

ENVIRONMENTAL CONTINUATION	SONAR CONDITIONS		
	EXCELLENT	AVERAGE	POOR
I. SEA	0 - 1	2	3
II. MEDIUM			
Gas, Thermal, Saline, and Biological Clouds or Layers	None	Light	Concentrated
DEPTH	70 Ft.	70 - 120 Ft.	120 Ft.
III. BOTTOM	Smooth	Rough	Very Rough
Accumulative Probability of Detection	.99	.90	.60
Single Pass Probability of Detection	.50	.35	.20

SONAR DETECTION PROBABILITY IN
VARIOUS ENVIRONMENTAL CONDITIONS

Figure 1

This capability deteriorates as inhomogeneities appear in the water, as bottom clutter increases, or as bottom solidarity is lost. Refraction of sound due to thermal layers and cells, absorption and scattering caused by turbidity, and unpredictable reflection depending on the sea state and bottom topography decrease the ability of the sonar to locate small targets.

The AN/UQS-1 is a descendent of the conventional ASW sonar where the design requirement of long range was a primary interest. Whereas range is desirable for minehunting applications, some compromise of range would be tolerated provided capability in addition to detection could be attained. The desired capability would be classification or possibly identification. This consideration has been the basis for the development of the SHADOW equipment. (1)

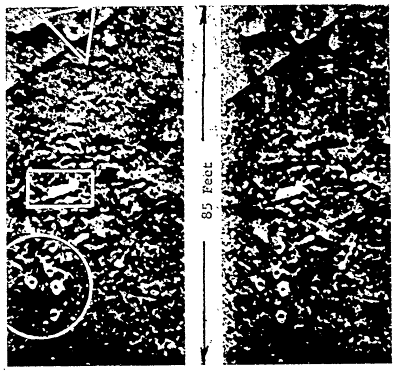

Fig. 2 - Shadowgraphs of Sea Bottom

Figure 2 illustrates the degree of definition achieved with the experimental device. It is a photograph of the viewing screen on two successive looks. It shows the bottom of a small harbor basin in which tests were conducted during the summer of 1957. A truck tire is seen within the triangle, a mine case within the rectangle, several passenger car tires within the circle; and the long straight line is a 3-inch fire hose.

THE ENVIRONMENT AND MINESWEEPING EFFECTIVENESS

The importance of the environment with regard to the effectiveness of minesweeping equipments depends on the influence field of concern. In our discussion we shall mention particular equipments and particular mines in examples of the problems that are fairly common to the particular influence concerned. The indication of effectiveness used here is a nominal swept path width. The variation of this quantity with the changing character of the environment indicates the complexity of this one aspect of the minesweeping problem.

Let us first examine a situation in acoustic minesweeping. The transmission of sound in water depends primarily on its frequency, on the water depth, and on the geology of the bottom. The transmission to longer ranges depends also on the velocity of sound in the water and the bottom. Seasonal changes in these velocities may thus change the transmission pattern but are not expected to be disturbing. Tidal variations in water depth are considered in acoustic sweeping because low frequency sound is transmitted better in deeper water, and also because some mines have automatic depth adjusting devices and become more sensitive with increased depth.

In Figure 3 the sweep is the A Mark 6(b) and the target is the acoustic mine Mark 25 Mod 1. The curve applies to a water depth of 50 to 70 feet. This curve shows the relationship between the swept path width and A_o, the observed transmission loss at 100 yards. Beyond this range the attenuation is about the same in the areas designated. The figure portrays a considerable part of the expected range of effectiveness of this sweep against this mine. As a result of environmental surveys in shipping channels to Panama City, Charleston, Chesapeake Bay, Delaware Bay, and Boston, the effectiveness is known to be about as indicated here. The widths of path are conservative and reflect the poorer transmission where significant variations in environment occur within the channel. Other acoustic generators and targets could be represented by curves of the same general character. It can be seen that the sweeping effectiveness in the Panama City channel is roughly twice that in the Boston channel. Where no environmental survey information exists, operational instructions are prepared on a basis of a swept path width of about 180 yards. It can be seen that, with this value as a guide, too much sweeping would be done in four of the areas and not enough in the Boston area. Herein lies the key to optimization of effort with a subsequent dividend of reduction in force requirement.

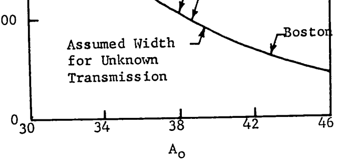

Fig. 3 - Acoustic Sweep Effectiveness versus Environment

Further refinement and optimization of effort is possible when the variation within any given channel is analyzed. Figure 4 shows the swept path width as a function of location within the

South channel approach to Chesapeake Bay. The swept path width changes by a factor of about four from one end of the channel to the other. We see that, without the benefit of a survey and using a 180-yard swept path width for instructions, we would have directed too much sweeping over three-fourths of the channel and too little over the remainder. With the survey data now available, optimization of effort can be attained through segmentation of channels as far as it is operationally practical.

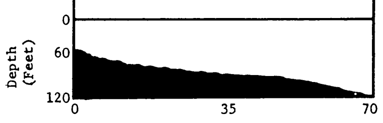

Fig. 4 - Acoustic Sweep Effectiveness in Chesapeake Bay South Channel Approach

In magnetic sweeping the environmental problem is somewhat different both in character and in scope. Except for the water depth, the environment affects only the sweeps that employ the sea and the bottom as conductors of electric current. The magnetic field of an electrode type sweep is produced partly by the cable-carried current and partly by the currents that are distributed through the sea from the electrodes. The distributed current fields have magnitudes determined by the electrical characteristics of the area. Let us now refer to Figure 5.(2)

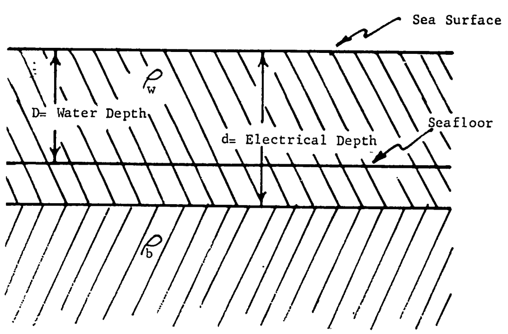

Fig. 5 - Assumed Sea - Seabottom Layers

To calculate the field values(3) it has been necessary to assume that the water and bottom form two homogeneous and electrically isotropic layers. The upper layer consists of the sea water and of surficial sediments which have at least approximately the same electrical resistivity as the water. The overall thickness of this layer is the electrical depth, d. The second layer is assumed to be infinitely thick and has electrical resistivity larger than that of the water. Fairly simple electrical survey techniques give the values of d and of the electrical reflection factor, $Q = \frac{\rho_b - \rho_w}{\rho_b + \rho_w}$.

The magnetic field values are calculated as functions of the quantities Q, d, D, and the characteristics of the electrode sweep. Such calculated values have been found trustworthy to ranges as great as 600 yards.

In Figure 6 the magnetic field at the sea floor has been plotted as a function of horizontal distance from a single electrode for a water depth of 60 feet. The curves were plotted for a current of 1000 amperes and for an electrical depth equal to the actual depth. The wide variation in the horizontal magnetic field strength is readily apparent.

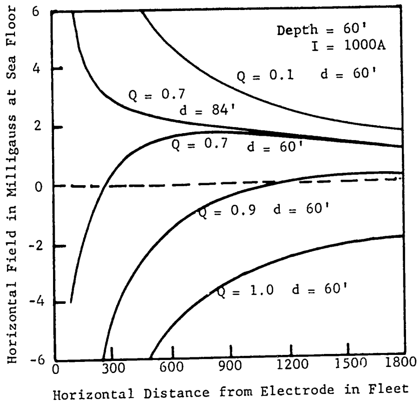

Fig. 6 - Magnetic Field for a Surface Electrode

In Figure 7 we have examined the effectiveness of an M Mark 5(a) sweep by plotting the width of the swept path as a function of the ratio between the electrical depth and the actual depth. The relationship of sweep current to mine sensitivity is 500 amperes per milligauss. We have assumed the case of a bottom having infinite resistance, and Q is therefore 1.0.

Fig. 7 - Magnetic Sweep Effectiveness versus Environment

The sweep is seen to be most effective for the d/D ratio of 1 and least effective for a ratio of 1.5. From actual survey data we know that conditions indicated here do exist. It is interesting to note that at Boston twice as much sweeping is required in the North channel as for the South channel.

Some comment as to sweeper safety is in order. A wide swept path as shown in the South channel at Boston implies as well a relatively strong magnetic field under the sweeper and a considerable risk if sensitive mines are present. This suggests, of course, that to use the full capability of the sweep would require precursor passes with reduced current to clear those mines over such an area that the sweeper could remain in swept waters.

We have seen that the environment determines to a great extent the effectiveness of electrode type magnetic sweeps and also of acoustic sweeps. In both cases the environment is passive, and its influence is fairly constant except for moderate seasonal changes. By sharp contrast when pressure mine mechanisms are considered, the sea becomes an active participant in a manner that may change day-to-day and even hour-to-hour.

Refer now to Figure 8 which illustrates the sweeping of pressure-magnetic combination mines under various conditions of sea state. The target is the German DM-1 mine, actuated by the 10,000-ton Guinea Pig as shown in the curves to the left and by the M Mark 5(a) sweep, in the curves to the right. The widths of path of these two sweeps are plotted against the quantity Y. Here Y is a quantity determined by the sea state and the sensitivity of the mechanism. The mine fires when it receives both a pressure look and a magnetic look within a prescribed time interval. When the waves are very small in height, the signature of either a target ship or a Guinea Pig sweep may cause the pressure look. Waves of slightly greater height may modulate such signatures sufficiently to prevent the occurrence of a look. This effect increases with increasing wave height, and the width of path of the Guinea Pig falls off as Y increases.

As the wave height increases, the trough of a wave of relatively long period simulates a ship signature and may cause a pressure look in the DM-1 mechanism. When such looks occur sufficiently frequently, the combination mechanisms can be swept profitably with magnetic gear alone. The four curves in the right hand side of the figure show how the average actuation width of an M Mark 5(a) sweep increases with Y when the mean wave period is 8, 10, 12, and 14 seconds. The intersections of the rising and the falling curves indicate the Y values at which the advantage passes between the Guinea Pig and the M Mark 5(a) sweep with different mean wave periods.

Figure 8 reveals the sometimes decisive nature of the environmental influence on mine countermeasures operations. It also depicts one of our most severe problems. The determination of Y must be based on records of swell and wave action as felt on the sea bottom. Swell recorders for this purpose are not yet available but are expected to be in use within the foreseeable future. However, much work must yet be done to realize the full potential of the swell recorder. We must at present anticipate recording the swell at a number of points in an area, since we lack means to predict the pressure fluctuations at any point on the basis of those observed at a remote point.

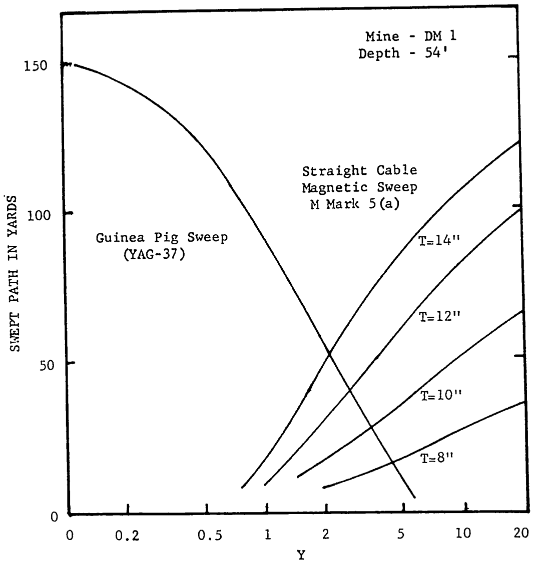

Fig. 8 - Comparison of Guinea Pig and M Mark 5(a) Sweep Effectiveness versus Environment (SWEEL)

Pierson of New York University, under contract to the Bureau of Ships, is giving attention to this problem of area prediction and to other aspects of a general study of ocean waves. Some work has been done and is now being continued at the Mine Defense Laboratory, concerned with the representation of ocean waves as power spectra. A new program recently initiated at Georgia Tech will, it is hoped, contribute to our understanding of ocean waves and to our ability to base area-wide estimates on limited point observations. Attainment of the objectives of all these efforts would place our utilization of the sea as a sweep on a level near that attained by our acoustic and magnetic devices. Even a moderate accomplishment of our objectives, in addition to the provision of a satisfactory swell recorder, would doubtless enable us to direct our sweeping efforts more effectively and thus to reduce the force requirements; at least until the Russians can place in operation a pressure mechanism that discriminates extremely well between long period swells and ship signatures.

HYDROGRAPHIC OFFICE ENVIRONMENTAL SURVEYS

Considerable effort has been expended by the Hydrographic Office with MDL and the Bureau of Ships support in the conduct of surveys of the mineable areas along the United States' coastline. It is felt that the data gathered are now sufficient for the preparation of generalized instructions in both hunting and sweeping. These instructions are written in such manner that qualified Fleet personnel may choose optimum procedures based upon particular environmental parameters that describe the operational area. In addition, for those areas surveyed, sweeper risk is now definitely known.

In view of a "limited war concept" and the need for environmental data for planning mine countermeasure operations, it is felt that further surveys of continental U. S. should be delayed until the more important mineable waterways throughout the world have been surveyed. It is realized that this undertaking is well beyond the capability of presently available Hydrographic Office forces, both to obtain and to reduce the required data; therefore, extreme discretion in establishing priority to new world areas is essential.

It is believed that future surveys will experience considerable gain when the Hydrographic Office can be provided with a single acoustic generator for the spectrum now being covered by four devices and a minehunting sonar equipment capable of classification of bottom objects and suitably housed as a bottom following device. Equipments are under development that may possibly fulfill these needs.

Inasmuch as it is unlikely that the Fleet will have survey information available when called upon to render mine countermeasure effort, it is necessary to provide them with equipments for quick "on-the-spot" environmental surveys. Such a survey presumably could be carried out simultaneously with the initial sweeping and hunting procedures. These equipments would consist of resistivity apparatus for determining the magnetic sweep index of effectiveness and the safety of the sweeper; an acoustic monitoring system to determine transmission characteristics and to assure safety of the sweep and that the acoustic sweep is operating properly; a swell recorder for observing bottom pressure fluctuations during countermeasure operations; and, the aforementioned minehunting devices.

There are within the mine defense program many problems that are fundamentally environmental and to which satisfactory answers could have tremendous impact on our future capabilities. I should like to discuss a few of these problems, since we invite you to help us solve them.

The first is Geological Prediction of environmental characteristics. Here, the objective would be to establish relationships, with sufficiently high confidence limits to warrant use, between the area geology and the parameters required to evaluate our sweeping influences. Existing geological information would then enable us to estimate sweep effectiveness and sweeper risk factors in many areas where our survey equipment would not be welcome. Such areas, of course, are among those most likely to be the scene of our mine countermeasures efforts. With this knowledge our present conservative estimates of effectiveness and risk could be established at higher levels. Thus, the actual force requirements could be reduced somewhat. Of course, the predicted values would be used only if more reliable values obtained in surveys were not available.

The first attempt to accomplish this objective was made in World War II by the Military Geology Unit of the Geological Survey(4) at the request of the Bureau of Ships. The specific effort was to find a correlation between the electrical parameters and the area geology and to determine the extent to which these parameters could be predicted. The results of the study indicated that where the major geological features such as composition, age, attitude, and ground water are known, resistivity of the sea bottom can generally be predicted as high or low; predictions of maximum possible

electrical depth are likely to be in error by 25 to 50 feet. It may be that a re-examination of this problem, with the additional data now available and our better understanding of the technologies, may lead to a more useful correlation. However, the need diminishes as additional surveys are made throughout the world.

A second area of interest is the phenomenon of Seiche. Seiche, by definition, is an oscillation of the surface of a lake or land-locked sea with a period varying from a few minutes to several hours. It is thought to be induced by local variations in atmospheric pressure. Such wave action, of satisfactory period, might serve us by sweeping the pressure mechanisms. There are perhaps many mineable areas throughout the world with land-water geometries such that either a natural or an artifical seiche might so serve. The exact characteristics required are unknown. This problem is at present being studied at MDL, both with regard to the areas where natural seiches are common and with concern for a technique for production of artifical seiches.

The most severe problems related to the production of seiches appear to be the power requirement and the geographical configuration of wave making devices. Low power requirements are anticipated when energy can be applied to the water mass at its resonant frequency -- such frequency must lie within the vulnerable range of the mechanism. When the land-water geometry requires energizing at non-resonant frequencies, energy requirements may be outside practical limits.

Two records of a natural seiche observed in Pensacola Bay, Florida, are shown in Figure 9. While the amplitude of the negative wave, approximately 2 inches, would satisfy mine requirements, the long periods of about 30 minutes would not because of the tide leak compensation in the mine mechanism.

A third area of interest, and I might say of despair, is that of sonar performance in thermo-layered waters. We do not now see much hope of attaining satisfactory transmission of sound through sea water for the minehunting range requirements under these conditions. The circumvention of this obstacle through the use of variable depth sonars and of bottom following devices appears to be the only solution to this problem.

A question has been raised, though not too seriously, of the prospects of an electro-optical approach to minehunting. Can the water layer be induced to change characteristics for a matter of micro-seconds or longer -- by shock, magnetics, or otherwise during which time electromagnetic energy may be propagated?

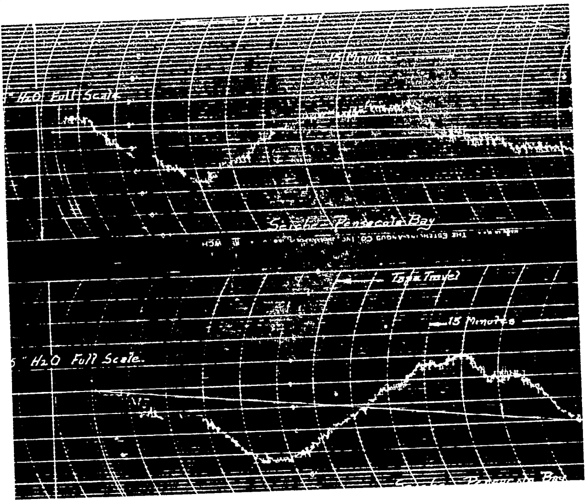

Fig. 9 - Natural Seiche in Pensacola Bay

A fourth problem is the relationship of atmospheric disturbances to countermeasures. The problem may be discussed with respect to both present and future mine mechanisms. A recent ONI report stated that an unknown number of mines were detonated during a severe thunderstorm along the Swedish coast at Stockholm on 6 August 1957, presumably by lightning. Whether this presumption is correct or not, the question has been posed frequently: what effects may lightning discharge, both to and from the sea, have on mine mechanisms? This is an area in which information is lacking but one of interest both to mine field planners and to countermeasures forces.

With regard to future mechanism design, it seems that the alternating magnetic effects of electrical storms could limit the feasibility of a mechanism actuated by the alternating magnetic fields of ships. Minesweeper ranging data of this influence indicate that, apart from general background problems, such mines could be a real threat to the wooden hulled mine countermeasure ships. A typical signature is presented in Figure 10. (5)

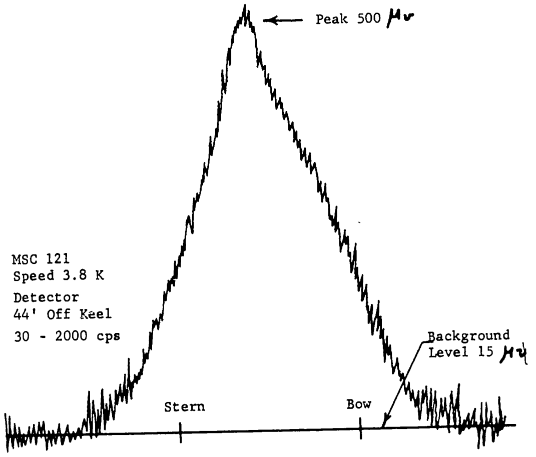

Fig. 10 - Typical AM Signature of Wooden Hull Minesweeper

For this ship, an MSC, the signal is in the 20 to 2000 cps band and peaked at 500 microvolts, 25 db above background. The signal appeared to be well localized, its amplitude being roughly proportional to the inverse cube of the distance from the ship.

There is little information available on the characteristics of AM signals due to weather. It may be found, after the background facts are known, that anti-environmental circuitry is difficult to build into the mechanism design. However, until these facts are known a valid assessment of the threat cannot be established.

We have seen that we can improve the effectiveness of our minesweeping efforts as much as four-fold (perhaps more in situations not considered here) when we have reliable environmental information as required. In the younger art of minehunting, which does not so readily adapt to its environment, we recognize both a great potential gain and a great need. There we have not been able to delineate our problems so clearly. In this task we need all the information and assistance that you gentlemen can offer us. Our lines of inquiry include the following:

a. As yet we do not know the optimum frequency for better location and better classification of mines on the bottom. We have used frequencies between 100 KC and 1.5 MC, but we really need to know the best frequency from the back scattering point of view, the distance point of view, and the classification point of view.

b. In addition, we need urgently to find some holes in the ocean structure which will allow us to locate and classify mines at distances much greater than we are able to reach at the present time. The LOFAR system detects submarines at great distances, but only in deep water. It is not adaptable to our problem of shallow water mine location because of its relatively great skip distances. Can we develop a comparable system operating at such frequencies that it can reach to great ranges in shallow water with less skip? Such is our need--in order that a moderate number of passes will enable us to cover a large area completely.

These, gentlemen, are among our major problems. We invite you to share in our efforts to solve them. We urge you to give thought to them and to share with us your knowledge, your ideas, and the references to literature or data that you may have in your files. Progress toward these apparently unattainable goals, coupled with optimum utilization of existing mine defense systems made possible through increased knowledge of our environment, will contribute increased efficiency and safety and thus extend our Future Mine Defense Capability.

The author is deeply indebted to many persons who contributed data, suggestions, and personal assistance to this effort. Among those I wish to particularly mention are: C. M. Richards, L. W. Owen, Jr., R. H. Forbus, H. G. Hamby, J. C. Anthony, J. Hagemann, G. C. Watkins, E. L. Sanderson, and F. D. Sisler of the Navy Mine Defense Laboratory.

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AMBIENT NOISE, ITS ORIGIN AND CHARACTERISTICS

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If a hydrophone is placed in the ocean and its self-noise is progressively reduced, there is a residue of noise which we may consider as coming from the ocean even in the absence of specifically identifiable noise by sources. This, we refer to as the ambient noise. In this paper we will outline the characteristics of this noise in the frequency range from 1 cycle to about 2 KC and will speculate about some of the possible origins of this noise. In spite of a considerable amount of work, we know relatively little about this noise and the paper will summarize all of the data available to us.

Technique

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Spectrum Level

Figure 1(1) shows a curve representing the thermal noise in the ocean at the average ambient temperature. This curve is essentially the acoustic analog of the black body radiation spectrum. Also, in Figure 1 are shown the Knudsen curves. These are based on a large body of World War II data and represent the average results of this data for the various conditions shown. It should be noted that the noise level increases with decreasing frequency (slope -5 db per octave) and also increases with increasing sea state.

Figure 2(1) shows the results of measurements with ship-hung (neutrally buoyant equipment), and Figure 3(1) similar results with bottomed equipment. The features of these curves which should be noted are the general agreement with the extrapolated Knudsen curves in the region above 100 cycles, the generally flat plateau from 10 to something a little less than 100 cycles, and the rapid increase below 10 cycles. It is also clear that the plateau shows less variation with sea state than in the region above 100 cycles. Please note that the "0" sea state level at 100 cycles is approximately -40 db. A number of observers have suggested a correlation with local wind speed which is more direct and definite than correlation with sea state.

Figure 4(11) shows the pressure level at 1 KC as a function of wind velocity and it is clear that there is a definite observable trend.

Figure 5(3) shows data from a different set of measurements with different instrumentation at 800 cycles.

Figure 6(11) gives the slope in db/octave as a function of wind speed for the spectrum between 100 cycles and 1 KC. The progressive flattening of the spectrum with increasing wind speed is apparent. The effect of a rain storm has been observed to be the same; a pronounced flattening of the spectrum above 100 cycles while the rain was falling. This observation was in shallow water.

Figure 7(11) shows the average spectrum level between 20 and 100 cycles as a function of wind velocity and it is clear that it is

AMBIENT NOISE, ITS ORIGIN AND CHARACTERISTICS

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Figure 7(11) shows the average spectrum level between 20 and 100 cycles as a function of wind velocity and it is clear that it is difficult to show much correlation although other data indicates a slight correlation with sea state. This data may be summarized by saying that with increasing wind velocity there is a pronounced increase in the spectrum level above 100 cycles with a flattening of the slope, but from 10 to 100 cycles the level of the plateau changes only slightly with sea state. Below 10 cycles there is little data to indicate correlation with wind speed or sea state although the latter parameter may be of some importance.

A few measurements have been made of the depth dependence of the ambient noise, and Figure 8(15) shows some data which was taken east of the Bahamas in very deep water. It will be noted that above 20 cycles there is scarcely any dependence with depth at all, but below 20 cycles there is an apparent increase as one approaches the surface as well as a bulge at the sound channel axis and perhaps at other depths. The effect near the surface probably represents the hydrodynamic pressure effects which one would expect when one is closer to the surface than one wave length of the swells on the surface. This effect has been observed in other data. The deep effects, particularly the bulge at the sound channel axis, were absent from a few measurements taken in the Tongue of the Ocean. This is a body of water some thousand fathoms deep enclosed almost completely by shoals and Bahama islands. This indicates, although there is not very much data, that the deep sound channel may contain some sound which is traveling around the ocean. Its level is not particularly high relative to that at other depths.

Figure 9(6) shows a histogram of frequency of various levels observed at 100 cycles with a bottomed hydrophone at San Juan, P.R. The mean level, some 20 odd db below a dyne, corresponds well with a sea state 2 to 3 observed during the period of measurement.

Figure 10(6), from a much smaller body of data, shows a similar histogram of noise levels at 100 cycles taken from a bottomed hydrophone in a deep lake in Idaho. The mean level of -41 db corresponds well to "0" sea state ambient noise at 100 cycles in the deep ocean. The lake was dead calm when these measurements were made.

Directivity

There is a small body of data bearing on the directivity of the ambient noise in the vertical plane. Two techniques have been used in the collection of this data. In the first method, the noise received at two hydrophones is cross correlated and the result plotted as a function of the hydrophone separation.

Figure 11(7) shows a block diagram of the correlation system. If one assumes that the noise sources are distant, that they have auto-correlation functions represented by their band widths, and that they are incoherent with each other, it is possible to compute theoretical curves for the correlation functions as a function of separation based upon various angular distributions of noise.

Figure 12(7) shows some data and, in particular, the upper half contains data taken with various horizontal separations of hydrophones in shallow water off Perranporth, England, looking out towards the Irish Sea. The theoretical curve was computed assuming omnidirectional noise and it appears to fit the data very well.

Figure 13(7) shows similar data taken with vertical separations at the same site. The various curves assume omnidirectional noise, sin θ, and $\sin^2\theta$. The best fitting curve is a mixture of the three as designated. This "best curve" is plotted in Figure 14; on which up is up and down is down. The pronounced up-down characteristic of the curves is extremely interesting as are the nulls just below the horizontal. The db scale should be divided by two.

Data has also been taken in deep water using the hydrophone array diagramed in Figure 15(14). In this case the data was analyzed both from a correlation point of view as described above and by treating the arrangement of hydrophones as a vertical array in the usual manner, using the same noise model as above. A sample of the data is shown in Figure 16. This was taken while the ship which had laid the array was proceeding away from it at a distance of about 12 miles. We believe that noise from the ship accounts for the thumbs between 60 and 80°, and for part of the extreme bulge on the sides of the bottom lobe. These features are absent from curves taken with the ship not under way. However, these thumbs serve to label the angles of distant propagation.

Figure 17 diagrams the various regions of propagation. Region "C", the horizontal angles, contains rays which leave the area and never reach the surface. Region "A" contains rays which must be reflected from the bottom at least once more steeply than the critical angle for reflection, and these rays are highly attenuated. Region "B", corresponding to the thumbs in Figure 16, provides the rays of distant reception. If the model used for interpreting the data is to be believed, and not all possible models have been examined, then the principal contribution to the noise seems to come from the up-down direction at the places where these measurements have been made: southeast of Bermuda and in the basin between St. Thomas and St. Croix, V.I. It is interesting to note that the excess in the upward direction corresponds fairly well with the assumption that the noise originates at or near the surface, propagates downwards and is partially reflected at the bottom. The data is insufficient for us to be sure of this.

Strange Noises

We are confining ourselves to the general character of the noise and will not discuss any of the numerous variety of impulsive and narrow band "strange noises" which have been observed in many areas. These noises do not seem to affect the general characteristics described above, or at any rate we do not have sufficient data to show that they do.

Theoretical Speculations

We do not have available any coherent theory of the origin or origins of the ambient noise, but only a number of ideas which may contribute, when more data is available, to an understanding of the noise. It has been suggested that much of the noise comes from distant shipping. We find it difficult to believe that this is generally the case. Inasmuch as the vertical directivity measurements and the deep lake measurements argue against this possibility. A simple computation indicates that it is not possible for the available shipping to put out sufficient noise energy to account for the observed levels. This computation assumes that the levels we have found everywhere we have looked so far are representative of the levels everywhere in the ocean. This does not, however, rule out the possibility that in many local areas of interest such as the shipping lanes, or regions near the shipping lanes, may be dominated by ship noise. The vertical directivity calls our attention to the surface and the correlation with local wind speed and correlation with sea state confirms this suspicion.

The circumstance of the plateau between 10 and 100 cycles is in itself interesting. It should be noted that the minimum phase velocity or surface waves, i.e., the point at which control of the waves goes from gravity to surface tension is at some 13 cycles. We do not know whether this is merely a coincidence, and have not, to date, been able to make a coherent theory based upon the surface waves. It is clear that they are important near the surface below 10 cycles. Unless some second order effect, for example that described by Longuet-Higgins, is invoked, one would expect surface wave produced noise of the hydrodynamic type to decrease markedly with depth.

There are a number of other phenomena in the near surface layers of the ocean which might provide sources of noise. Among these may be mentioned turbulence. However, one would not expect much acoustic radiation at the low velocities observed. Bubble phenomena would be expected to contribute at somewhat higher frequencies. In any case, unless turbulence and bubbles are pronounced at deeper depths than several hundred feet it is difficult to account for the observed depth independence.

We would like to mention two other possibilities which are even more speculative and less well founded than those discussed above. Although the thermal noise appropriate to the temperature of the ocean itself cannot account for the low frequency noise, we might argue that thermal noise generated at the center of the earth, at a considerably higher temperature, could propagate out to the crust, due to the low absorption for low frequency sound. Although the thermal spectrum would be rising with frequency, we know that the absorption is also rising with frequency and might have the dominant effect, producing a falling spectrum. It is difficult to make this theory quantitative because relatively little is known of the absorption coefficient in the earth for acoustic waves of the frequency here discussed.

The other speculative theory we may dub the "Gamow" or "once there was a loud noise in the ocean" theory. This suggests that the present spectrum and characteristics of the noise represent an equilibrium in which incoming sound reverberates for a considerable time due to the relatively low absorption. The spectrum is controlled by an interaction among absorption, reflection, and thermal effects, with second order terms in the acoustic equations providing for redistribution among frequencies.

Conclusion

The data on the ambient noise, although very sparse, is extremely interesting and hints at a number of pronounced properties which may lead us eventually to an understanding of the sources of the noise, and perhaps also to an ability to discriminate against the noise for purposes of detection.

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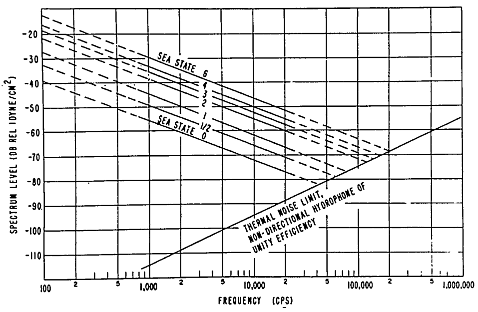
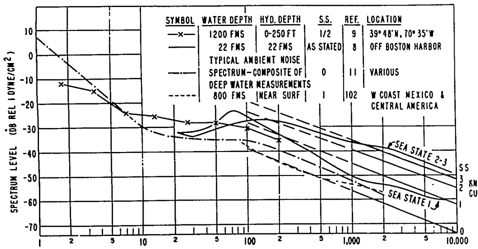


Figure 1



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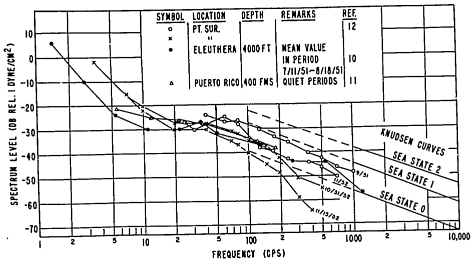

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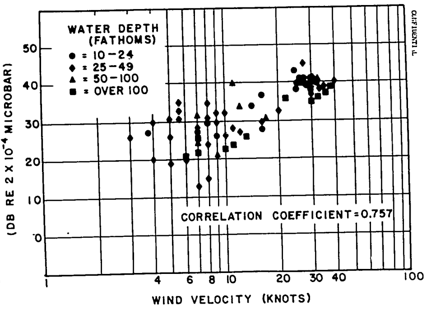

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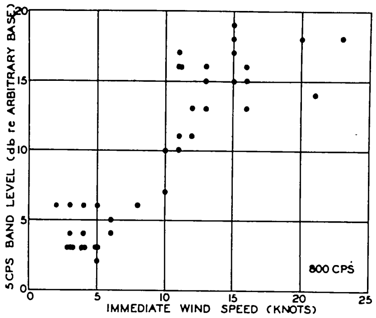

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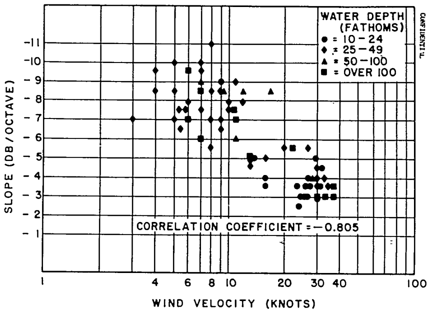

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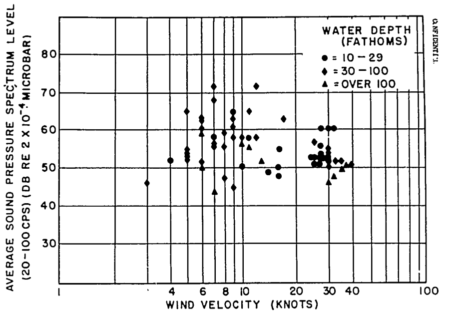

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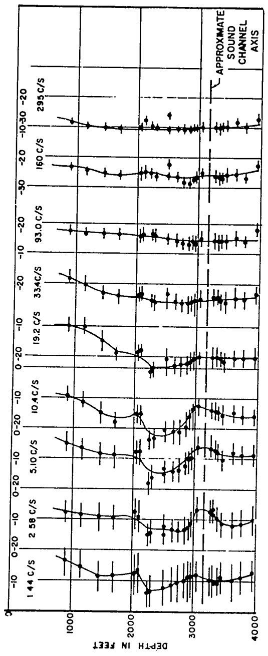
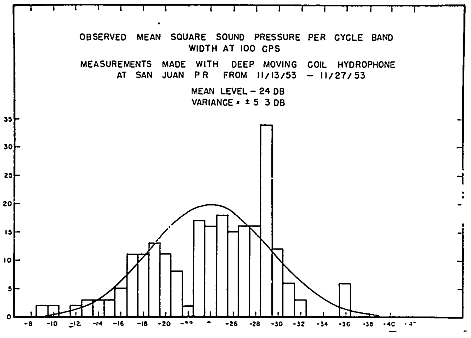


Fig. 8 - Ambient Noise Profile Site II



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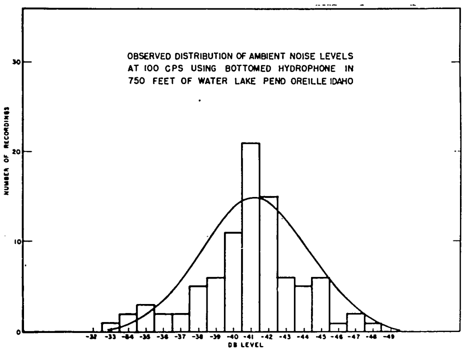

Figure 10

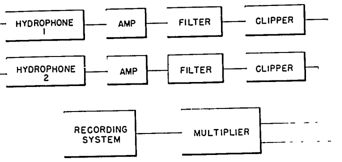

Fig. 11 - System to Measure Expectation Value of

$\cos\left(\frac{2\pi d}{\lambda}\sin\theta+\Phi\right)$

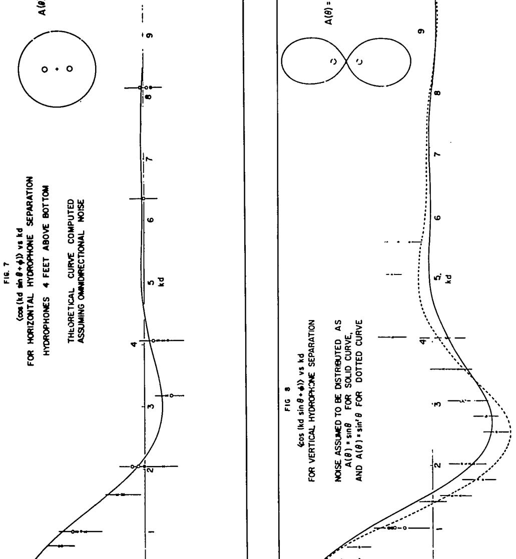

Figure 12

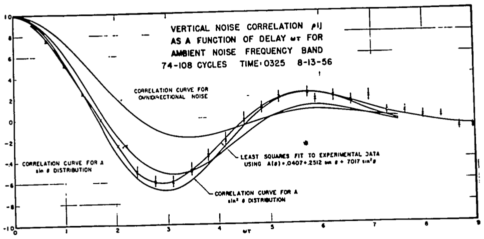

Figure 13

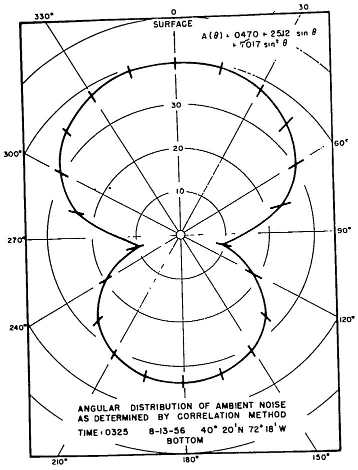

Figure 14

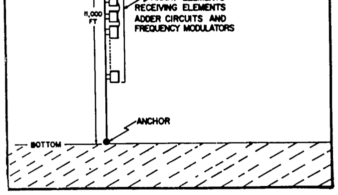

Figure 15

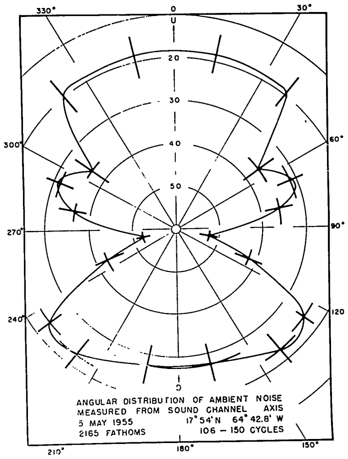

Figure 16

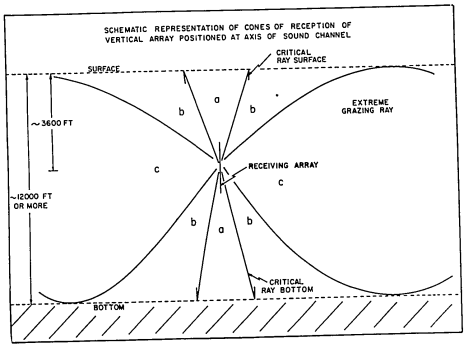

Figure 17

SOUND PROPAGATION MEASUREMENTS

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INTRODUCTION

Several contributors to naval science early recognized the value of high explosive economical and versatile instruments for underwater acoustics research. Many of these scientists were influenced in their choice by their previous experience in commercial seismography where explosives were well established as a routine tool in seismic prospecting for oil and in related geophysical research by the mid 1920's. Furthermore the thread of awareness of the potential of explosives as sound sources has gone very nearly full circle, since a number of the early commercial prospectors had gained their own early experience in seismography while devising systems for locating heavy enemy artillery by detecting seismic waves in the ground and sound waves in the air from the big guns of World War I.

Previous to these comparatively modern uses, explosions, usually gunpowder, have been employed off and on for well over a hundred years as sound sources both in air and under water. Thus several European scientists of the 17th century timed the passage of sound over a known distance from a gunpowder shot to measure the speed of sound in air, while Maury in 1854 fired gunpowder under water in an unsuccessful attempt to measure water depth by echo sounding. There are several other similar records prior to World War I.

So far as I am aware, the first extensive use of explosives under water for science or engineering was the program of radio-acoustic ranging carried out by engineers of

the U. S. Coast and Geodetic Survey during the 20's and 30's. They measured the travel time of acoustic waves from a dynamite shot at an echo-sounding survey ship to an anchored radio-sonobuoy and back by radio waves to the ship as a means of measuring distance to the buoy for precise navigation. The research attending their development led them to an appreciation of many of the effects subsequently studied extensively in naval underwater sound research (cf. Dyk and Swainson, 1953). Few people recognize the fact that this high precision navigational aid was used by many survey ships for several years.

Since 1937 Prof. Maurice Ewing and his co-workers have carried out extensive research with explosives at sea which led directly to SOFAR and made relatively easy the discoveries of acoustic peaking in the ocean and general appreciation of the possibilities of long range sound propagation at low frequencies. Similar research has led them and several other research groups to extensive findings about the structure of the earth's crust beneath the oceans, and within the continents as well. Likewise the work by the California Division of War Research under the leadership of Dr. Eckart employed explosives extensively in their studies of underwater sound propagation, as described in Volume 7 of the NDRC Summary Volumes, "The Principles of Underwater Sound".

The story of the past is all very well, and is exciting and inspiring to many of us in the present. However, explosives have remained a most durable instrument in naval science to the present day and show no indication of falling into disuse. I believe the reasons for this circumstance are significant and important to the research of the foreseeable future.

Explosives were relied on initially because the chemical reaction of a high order detonation releases so large an amount of energy in so short a time. Hence high peak power. A further advantage is the broad spectrum of an explosion. The shock wave of an explosion under water contains adequate energy for a wide range of acoustical problems for frequencies between a few cycles per second and, say, 100 kc/s. A third advantage is that the initial shock is very short, and for the higher frequencies is the only considerable radiated energy. At frequencies below a few kc/s subsequent oscillations of the gas globe send out pulses which can be either confusing (if you confuse easily) or can be a distinct advantage in some research. For example, the time interval between the peaks of the shock wave and the first bubble pulse is an excellent measure of the depth of detonation for a given weight and type of explosive.

The short, intense shock wave provides very high resolving power which has proven very useful in determining the exact transmission paths that are effective in both passive and active detection systems. As many of you know explosives have been used extensively in assessing passive detection paths in various parts of the ocean by a very simple technique of correlating pulse arrivals at short range where interpretation is unambiguous to longer ranges where identification of paths would otherwise be uncertain at best. Fig. 1 is an example of such a correlogram. It consists of a series of recordings of arrivals from a shallow shot to a shallow hydrophone at gradually increasing range. The records near the top are taken at so short a range that the paths may be certainly identified as associated with a direct transmission, single, double, triple, etc. reflections from the bottom or refractions in the outer part of the SOFAR channel. As the range increases the direct transmission path commonly deteriorates and consequently the first arrival weakens and disappears. At still longer range the first bottom reflection similarly disappears, and the second, third, and so on. From the manner and range of these disappearances in different parts of the spectrum we have been able to verify many theoretical predictions about acoustical transmissions, and we have been led to the discovery and understanding of new and important effects which, while not unsuspected in most instances, nevertheless were not properly appreciated at the outset.

Another example which illustrates the powerful resolution of explosion technique was a study of sound transmitted from deep water to the sloping side of an oceanic island. Here reception at a bottomed hydrophone had been observed to be approximately one-fourth as effective for steady state transmissions from one azimuth as another. By a simple extension of the correlation technique just described it was possible to show that in the "poor" direction a submerged hill acted as a screen to cut out exactly three-fourths of the total available transmission paths, whereas in the "good" direction there was no such difficulty. Examples of this sort are legion, both in naval science and basic research in submarine seismography (cf. Hersey and Officer, 1952; Officer, 1955; Rinehart, 1955; and Anderson et al., 1957).

The broad spectrum of the shock wave gives a peculiar advantage for certain aspects of acoustical transmission studies. It is commonplace to students of sound transmission to observe very large short term fluctuations in received pressure levels from continuous sinusoidal sources which result from interference between wave trains following different paths. This sort of fluctuation is virtually eliminated when levels from an explosion in the frequency band of interest are measured through a moderately broad band-pass filter. Thus explosives are time-saving as a statistical tool. This effect was demonstrated constantly during an extended sound transmission study where a single frequency source was towed from the same ship that dropped explosives. The shot results proved to represent an excellent smoothing of the continuous transmission data.

Such questions as the accuracy of our knowledge of the energy radiated by explosions and its reproducibility have often been raised. The question has been studied intensively by a number of groups interested in underwater explosions for ordnance purposes. They regard properly engineered explosives as being very reproducible indeed and our own experience with them at Woods Hole certainly indicates the same. Ordnance investigators have carefully investigated the scaling laws, have measured peak pressures and the shapes of pressure-time curves; further they have shown that the radiation from simple spherical charges or rectangular blocks which are short compared with the wave length can be predicted with quite adequate accuracy for acoustical research from a knowledge of a few straightforward characteristics of the individual explosive. The only qualification to this statement is with respect to small charges, say of the order of half a pound or less of certain explosives, notably TNT and C3. Thus spherical charges or rectangular blocks such as the various standard demolition blocks heavier than 0.5 lb. are acoustical instruments of known accuracy when properly employed.

Directional effects of explosives at range comparable to the dimensions of the charge are striking and moderately well known, and in addition the ordnance scientists know much about tricks of producing special pressure-time variations with shaped charges. However, the directionality of explosives at several thousand yards is just beginning to be appreciated and studied intensively. We have used a simplified theory of radiation from arrays of sources to predict the directionality of linear arrays of charges, and have demonstrated qualitative agreement in practical tests at sea. While it is too early to tell how useful such devices can be, nevertheless it is certainly practical to concentrate energy of an appreciable part of the spectrum in preferred directions for long range propagation, echo ranging, and reverberation studies.

Observational Techniques

As explosives have been used for more and more different purposes a rather special set of observational and analysis techniques have been developed. The interpretation of any analysis of shot data must take suitable account of the characteristics of the hydrophone, the filters and the recording system employed. When this has been done, meaningful results can be obtained. Examples of such analyses are discussed in detail by Johnson, Bradshaw and Hersey (1957) for a directional charge investigation and by Machlup and Hersey (1955) for special studies of the deep scattering layers of the open ocean.

The earliest recording of energy transmitted over long distances was on an photographic oscillogram or some sort of direct writing recorder. Recordings were compared with accurate timing so that apparent travel times or differences in travel time between recognizable events could be read. As we started to employ explosives for measuring the amplitudes of wave trains over different paths we first relied on measurements of peak amplitude. The folly of this procedure has long been recognized. Subsequently experiments with an analog computation of $\int p^2 dt$ over the desired pulse or pulse train gave consistent results and has been widely used for the past four or five years. Results from such analyses of magnetic tape-recorded signals have been shown to compare favorably with comparable measurements from pressure-time curves of shock waves at short range recorded by ordnance scientists by means of high speed photographing of oscilloscope traces (Weston, 1957; Hersey, 1957). In Fig. 2 are shown such comparisons from work of Weston at the Admiralty Research Laboratory and independent studies in this country.

When very short pulse arrivals are being studied the more complex analog computations can be substituted by calibrated recordings with a rectifier feeding a galvanometer, the response of which is slow compared with the pulse length. This method must be used with due caution as it is reliable only when this condition is satisfied.

A number of interesting investigations of transmission and scattering phenomena have been made by playing tape recordings of explosions to a sound spectrograph such as the Kay Electric Vibralyzer. Thus, as in Fig. 3, the upper limbs of the group velocity dispersion curves of the normal modes

familiar to students of shallow water transmission are beautifully displayed by a recording of a shot arrival to this instrument.

One of the important future problems of sound transmission is the accuracy of sonar data, which, in turn, requires that we know the long and short term stability of transmission paths. One proposal for such a study is to establish a suitable source and receiver well separated from one another, and transmit pulses from one to the other on a regular schedule for a year or more. Explosives would make an ideal sound source for this work except for the mechanical difficulty of placing successive charges reliably in the same place by a simple, economical method. The difficulty of identical repetition of explosive tests which this points up is perhaps the greatest shortcoming they have for work in open water. For such purposes we are seeking means of generating accurately timed, very intense short pulses. In this search various groups have tried spark sources, mechanical impulse sources, guns shot under water, and other schemes. All prove useful to a degree, but all so far have fallen orders of magnitude short of what is already available in the energy of a small block of TNT.

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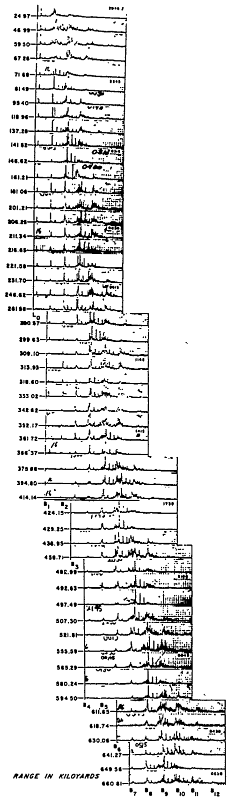

Fig. 1 - Correlogram of Shot Arrivals for a 330-Mile Transmission Run SE of Bermuda

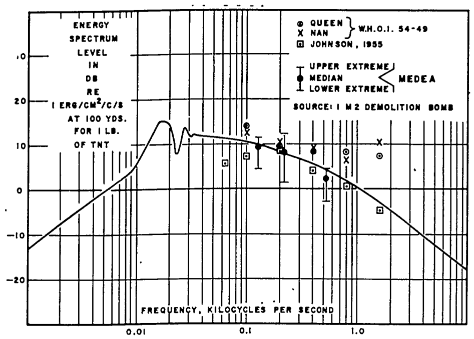

Fig. 2 - Shot Spectrum Inferred from Long-Range Transmission Compared With Short-Range Measurements.

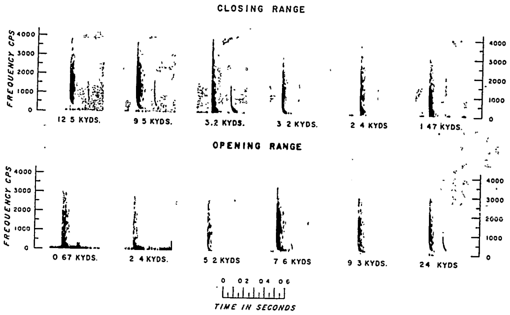

Fig. 3 - Sound Spectograms of Shallow Water Shot Arrivals

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