NAVAL RESEARCH REVIEWS

JUNE 1966

Linear Programming and Its Progeny

George B. Dantzig
Chairman, Operations Research Center
University of California, Berkeley

Vicennial Article

Origins and Influences

In the years following its conception in 1947 in connection with planning activities of the military, linear programming has come into wide use. In academic circles, mathematicians and economists have written books on the subject. Our purpose is to give a brief account of its origins and to point out those influences which brought about its development. Interestingly enough, in spite of its now known wide applicability to everyday problems, linear programming was unknown before 1947. Fourier may have been aware of its potential in 1823, and it is true that in the U.S.S.R., in 1939, Kantorovitch made proposals that were neglected there during a period that witnessed its discovery and rapid development elsewhere.

Influence of Military Planning

The following statement of M. K. Wood and M. A. Geisler is pertinent:

> *It was once possible for a Supreme Commander to plan operations personally. As the planning problem expanded in space, time, and general complexity, however, the inherent limitations in the capacity of any one man were encountered. Military histories are filled with instances of commanders who failed because they bogged down in details, not because they could not eventually have mastered the details, but because they could not master all the relevant details in the time available for decision. Gradually, as planning problems became more complex, the Supreme Commander came to be surrounded with a General Staff of specialists which supplemented the Chief in making decisions. The existence of a General Staff permitted the subdivision of the planning process and the assignment of experts to handle each part. The function of the Chief then became one of selecting objectives, co-ordinating, planning, and resolving conflicts between staff sections.*

World War II witnessed the development of staff planning on a gigantic scale in all parts of the U.S. military establishment and in such civilian counterparts as the War Production Board. A nation's military establishment, in wartime or in peace, is a complex of economic and military activities requiring almost unbelievably careful coordination in the implementation of plans produced in its many departments. If one such plan calls for equipment to be designed and produced, then the rate of ordering equipment has to be coordinated with the capabilities of the economy to relinquish men, material, and productive capacity from the civilian to the military sector. These development and support activities should dovetail into the military program itself. To be coordinated between the major activities are hundreds of personnel subtypes and thousands of supply subtypes.

During the war, the planning process itself became so intricate, lengthy, and multipurposed that a "snapshot" of the military staff at any one time showed it to be working on many different programs—some in early phases of development and based on earlier ground rules and facts. To cut the time of the planning process, a patchwork of several of these programs often was thrown together based on necessarily inconsistent facts and rules. To coordinate this work better, the Air Staff, for example, around 1943, created the program-monitoring function under Professor E. P. Learned of Harvard. The entire program was started off with a war plan in which were contained the wartime objectives. From this plan, by successive stages, the wartime program specifying unit deployment to combat theaters, training requirements of combat personnel and technical personnel, supply and maintenance, *etc.*, was computed. To obtain consistent programming, the ordering of the steps in the schedule was so arranged that the flow of information from echelon to echelon was only in one direction, and the timing of information availability was such that the portion of the program prepared at each step did not depend on any following step. Even with the most careful scheduling, it took about seven months to complete the process.

After the war, it became clear that efficient coordination of the energies of whole nations in the event of a total war would require scientific programming techniques. Undoubtedly, this need had occurred many times in the past, but this time there were two concurrent developments that had a profound influence: (a) the development of large-scale electronic computers and (b) the development of the inter-industry model proposed by Wassily Leontief.

The potential attraction of the inter-industry model was its simple linear structure. In some ways it was too simple. It was not dynamic, and it assumed that each industry had a unique technology which produced only one product. Another limitation of the model was that it was not possible to have alternative feasible programs.

It was necessary, therefore, to generalize the inter-industry approach. The result was the development of the linear-programming model. Intensive work began in June 1947 in an Air Force group under the Comptroller General Ed Rawlings that later was given the official title of Project SCOOP (Scientific Computation of Optimum Programs). Principals in the group included Marshall Wood, Murray Geisler, John Norton, and the author.

The simplex computational method for choosing the optimal feasible program was developed by the end of the summer of 1947. Interest in linear programming began to spread quite rapidly. During this period, the military sponsored work at the Bureau of Standards on electronic computers and on mathematical techniques for solving such models.

Early contacts with Tjalling Koopmans, of the Cowles Commission, who then was at the University of Chicago and who now is at Yale; and Robert Dorfman, then of the Air Force, now at Harvard; and the interest of such economists as Paul Samuelson, of the Massachusetts Institute of Technology, initiated an era of intense reexamination of classical economic theory based on the results and ideas of linear programming.

Early contact with John von Neumann at the Institute for Advanced Study gave fundamental insight into the mathematical theory and sparked the interest of A. W. Tucker of Princeton University and two of his former students, David

Gale and Harold Kuhn. With Office of Naval Research support, they attacked problems in linear inequality theory and game theory. Princeton became an academic focal point in these related fields.

It was the size of the military planning problem which made it evident in the immediate post-war period that even the best of future computing facilities would not be powerful enough to find an optimal solution to a general detailed military planning model. Accordingly, Project SCOOP modified its approach and, in the spring of 1948, proposed that there be developed special linear programming models, called "triangular models," whose structure and computational solution would closely parallel traditional stepwise staff procedure to provide a feasible, but not necessarily optimal, solution.

Since 1948, the military has been making more and more active use of mechanically computed programs. The triangular models are in constant use for the computation of detailed programs, while the general linear-programming models have been applied to smaller systems, such as (a) contract bidding; (b) balanced aircraft, crew training, and wing deployment schedules; (c) scheduling of maintenance overhaul cycles; (d) personnel assignment; and (e) airlift routing problems.

During the period from 1948 on, granting agencies—particularly the Office of Naval Research—began to support research seeking to develop efficient methods for finding optimal solutions to larger and larger planning systems.

The Influence of Economic Models

The current introduction of linear programming into economics appears to be an anachronism; it would seem more likely to have begun when economists first began to describe economic systems in mathematical terms. Indeed, a crude example of a linear-programming model can be found in the Tableau Economique of Quesnay around 1758; he attempted to interrelate the roles of the landloard, the peasant, and the artisan. We find that L. Walras proposed, in 1874, a very sophisticated mathematical model which had as part of its structure fixed technological coefficients such as are assumed in linear programming. Oddly enough, until the 1930's there was little in the way of exploitation of the linear-type model.

Of particular note is the effort during the 1930's of a group of Austrian and German economists who worked on generalizations of the linear technology of Walras. This work raised some questions that may have stimulated the mathematician Von Neumann, in his paper "A Model of General Economic Equilibrium," to formulate a dynamic linear-programming model in which he introduced alternative methods of producing given commodities singly or jointly. Von Neumann assumed (a) a constant rate of expansion of the economy and (b) a completely self-supporting economy. While the model did not contain any explicit objective, Von Neumann showed that market forces would maximize the expansion rate and proved a theorem that the maximum rate of expansion was equal to the interest rate on capital invested in production.

The inspiration of the general linear-programming model arose out of the practical planning needs of the military and the possibility of generalizing to this end the simple structure of the Leontief Model. From a purely formal standpoint, one could consider the Leontief Model as a simplification of the

Walrasian Model. Actually, theoretical economic models were a kind of ivory tower. According to Leontief:

> *One hundred and fifty years ago when Quesnay first published his famous schema, his contemporaries and disciples acclaimed it as the greatest discovery since Newton's laws. The idea of general interdependence among the various parts of the economic system has become by now the very foundation of economic analysis. Yet, when it comes to the practical application of this theoretical tool, modern economists must rely exactly as Quesnay did upon fictitious numerical examples.*

Leontief's great contribution (in the opinion of the author) was his construction of a quantitative model of the American economy for the purpose of tracing the impact of government policy and consumer trends upon a large number of industries which were imbedded in a highly complex series of interlocking relationships. To appreciate the difference between a purely formal mathematical model and an empirical model, it is well to remember that the acquisition of data for a real model requires an organization working many months, sometimes years. After the model has been put together, a second obstacle looms—the solution of a very large system of simultaneous linear equations. In the period 1936-1940 there were no electronic computers; the best that one could hope for in general would be to solve 20 equations in 20 unknowns. After this, there is still a third obstacle, the difficulty of "marketing" the results of such studies. From the onset, the undertaking initiated by Leontief represented a triple gamble.

As a result of the Great Depression and the advent of the New Deal, a serious attempt was made by the government to determine and then support certain activities which it was hoped would speed recovery. This brought about more intensive collections of statistics on costs of living, wages, national resources, productivity, *etc.* There was a need to organize and interpret this data in order to construct a mathematical model to describe the economy in quantitative terms.

From 1936 on, the scope, accuracy, and area of application of Leontief-type models were greatly extended by the Bureau of Labor Statistics. It was the work there by Duane Evans, Jerome Cornfield, and Marvin Hoffenberg that stimulated efforts toward seeking a mathematical generalization suitable for dynamic military applications.

A few words about the Leontief model itself are in order. The focal point of input-output analysis is an array of coefficients variously called the "input-output" matrix or "tableau economique." A column of this matrix represents the input requirements of various commodities for the production of one dollar's worth of a particular commodity. There is exactly one column for each commodity produced in the economy. Thus the production of a commodity corresponds to the concept of an activity in a linear-programming model. If the input factors appearing in a row of the matrix are multiplied by the corresponding buying industry's total output, the totals represent the distribution of the dollar value of purchases among the selling industries. Thus, the model makes it possible not only to determine each industry's rate of output to meet specified direct demand by civilians and the military, but also to trace the indirect effect on each industry of government expenditures in, say, military programs.

In 1947, T. C. Koopmans took the lead in bringing to the attention of economists the potentialities of the linear-programming models. His rapid development of the economic theory of such models was due to the insight he gained during the war with a special class of linear-programming models, called "transportation models," which he applied to Allied shipping problems. In 1949, he organized the historic Cowles Commission conference on "linear programming," which was attended by such well-known economists as K. Arrow, R. Dorfman, N. Georgescue-Roegen, L. Hurwicz, A. Lerner, J. Marschak, O. Morgenstern, S. Reiter, P. Samuelson, and H. Simon; such mathematicians as G. W. Brown, M. M. Flood, D. Gale, H. W. Kuhn, C. B. Tompkins, and A. W. Tucker; and by government statisticians, including W. D. Evans, M. A. Geisler, M. Hoffenberg, and M. K. Wood. The papers presented there were later collected into the book *Activity Analysis of Production and Allocation.*

The following is an interesting quotation from that book's introduction, written by Koopmans, the editor, which serves to characterize the linear-programming model:

> *The adjective in "linear model" relates only to (a) assumption of proportionality of inputs and outputs in each elementary productive activity and (b) the assumption that the result of simultaneously carrying out two or more activities is the sum of the results of the separate activities. In terms more familiar to the economist, these assumptions imply constant returns to scale in all parts of the technology. They do not imply linearity of the production function....Curvilinear production functions...can be obtained from the models...by admitting an infinite set of elementary activities....*
>
> *Neither should the assumption of constant returns to scale...be regarded as essential to the method... although new mathematical problems would have to be faced in the attempt to go beyond this assumption. More essential to the present approach is the introduction of...the elementary activity, the conceptual atom of technology into the basic postulates of the analysis. The problem of efficient production then becomes one of finding the proper rules for combining these building blocks. The term "activity analysis"...is designed to express this approach.*

The number of practical economic applications is continually growing. Linear programming is being used by economists to study in detail the economics of specific industries, such as metal working, petroleum refining, and iron and steel, and to yield long-range plans for electricity generation in an entire economy.

For a better appreciation of the economic implications, the reader is referred to *Linear Programming and Economic Analysis,* by Dorfman, Samuelson, and Solow, and *Economic Theory and Operations Analysis,* by W. J. Baumol.

Mathematical History

The linear-programming model, when translated into purely mathematical terms, requires a method for finding a solution to a system of simultaneous linear equations and linear inequalities which minimizes a linear form. This central mathematical problem was not known to be an important one until the advent of linear programming in 1947.

We are all familiar with methods for solving linear equation systems, which start with our first course in algebra. The literature of mathematics contains thousands of papers concerned with techniques for solving linear equation systems with the theory of matrix algebra (an allied topic), with linear approximation methods, *etc.* On the other hand, the study of linear inequality systems excited virtually no interest until the advent of game theory in 1944 and linear programming in 1947. For example, T. Motzkin, in 1936, in his doctoral thesis on linear inequalities, was able to cite after diligent research only some 30 references for the period 1900-1936 and about 42 in all. In the 1930's, four papers dealt with the building of a comprehensive theory of linear inequalities and with an appraisal of earlier works. These were by R. W. Stokes, Dines McCoy, H. Weyl, and T. Motzkin. As evidence that mathematicians were unaware of the importance of the problem of seeking a solution to an inequality system that also minimized a linear form, we may note that none of these papers made any mention of such a problem, although there had been earlier instances in the literature.

The famous mathematician Fourier, while not going into the subject deeply, appears to have been the first to study linear inequalities systematically and to point out their importance to mechanics and probability theory. He was interested in finding the least maximum deviation fit to a system of linear equations, which he reduced to the problem of finding the lowest point of a polyhedral set; he suggested a solution by a vertex-to-vertex descent to a minimum, which is the principle behind the simplex method used today. This is probably the earliest known instance of a linear-programming problem. Later, another famous mathematician, de la Vallee Poussin, considered the same problem and proposed a similar solution.

The Work of Kantorovitch

The Russian mathematician L. V. Kantorovitch has for a number of years been interested in the application of mathematics to programming problems. He published an extensive monograph in 1939 entitled "Mathematical Methods in the Organization and Planning of Production."

In his introduction, Kantorovitch states:

> *There are two ways of increasing efficiency of the work of a shop, an enterprise or a whole branch of industry. One way is by various improvements in technology, that is, new attachments for individual machines, changes in technological processes, and the discovery of new, better kinds of raw materials. The other way, thus far much less used, is by improvement in the organization of planning and production. Here are included such questions as the distribution of work among individual machines of the enterprise or among mechanisms, orders among enterprises, and the correct distribution of different kinds of raw materials, fuels and other factors.*

Kantorovitch should be credited with being the first to recognize that certain important broad classes of production problems had well-defined mathematical structures which, he believed, were amenable to practical numerical evaluation and could be numerically solved. If Kantorovitch's earlier efforts had been appreciated at the time they were first presented, it is possible that linear programming would be more advanced today. However, his early work in this field remained unknown both in the Soviet Union and elsewhere for nearly two decades while linear programming became a highly developed art. According to *The New York Times,*

> *The scholar, Professor L. V. Kantorovitch, said in a debate in 1959 that Soviet economists had been inspired by a fear of mathematics that left the Soviet Union far behind the United States in applications of mathematics to economic problems. It could have been a decade ahead.*

During the summer of 1947 Leonid Hurwicz, well-known econometrician associated with the Cowles Commission, worked with the author on techniques for solving linear-programming problems. This effort and some suggestions of T. C. Koopmans resulted in the "simplex method." The obvious idea of moving along edges from one vertex of a convex polyhedron to the next (which underlies the simplex method) was rejected earlier on intuitive grounds as inefficient. In a different geometry it seemed efficient, and so, fortunately, it was tested and is now accepted as the standard solution procedure.

The Work of Von Neumann

Credit for laying the mathematical foundations of this field goes to John von Neumann more than to any other man. During his lifetime, he was generally regarded as the world's foremost mathematician. He played a leading role in many fields. Perhaps in the long run his stimulation of electronic-computer development during World War II will prove to be his most significant contribution. In 1944, John von Neumann and Oskar Morgenstern published their monumental work on the theory of games, a branch of mathematics that aims to analyze problems of conflict by use of models termed "games." A theory of games was first broached in 1921 by Emile Borel and was first established in 1928 by Von Neumann with his famous "Minimax Theorem." The significance of this effort for us is that game theory, like linear programming, has its mathematical foundation in linear inequality theory.

Von Neumann, at the first meeting with the author in October 1947, was able immediately to translate basic theorems in game theory into their equivalent statements for systems of linear inequalities. He introduced and stressed the fundamental importance of duality and conjectured the equivalence of games and linear-programming problems. Later, he made several proposals for the numerical solution of linear-programming and game problems.

New computational techniques and variations of older techniques are continuously being developed in the United States and abroad. The well-known econometrician Ragnar Frisch at the University of Oslo has done extensive research work on his "multiplex method." Investigations in Great Britain have been spearheaded by S. Vajda and M. Beale. A number of important variants of the simplex method have been proposed by C. Lemke, W. Orchard-Hays, E. M. L. Beale, P. Wolff, and others.

Electronic Computer Codes

A special variant of the simplex method that was developed for the transportation problems was first coded in 1950 for the National Bureau of Standards SEAC computer. The general simplex method was coded in 1951 under the general direction of A. Orden of the Air Force and A. J. Hoffman of the Bureau of Standards (later, Hoffman was with ONR and IBM). In 1952, W. Orchard-Hays of the RAND Corporation worked out a simplex code for the IBM-C.P.C. and later for the IBM 701, 704, *etc.* His code turned out to be practical for commercial applications. As a result, the use of electronic computers by business and industry grew by leaps and bounds. Many of the digital computers which are commercially available provide, as part of their soft ware, codes of the simplex technique. In fact, computer companies are now spending close to a

—Continued on page 23

Deep-Sea Search for a Lost H-Bomb

For 228 hours between mid-February and early April 1966, the deep submersible ALVIN searched the steep, rugged floor of the Mediterranean Sea off the coast of Palomares, Spain, for an H-bomb ejected by a disabled U.S. bomber. During this period, the vehicle's three pilots—William O. Rainnie, Marvin J. McCamis, and Valentine P. Wilson, all of the Woods Hole Oceanographic Institution—working two at a time, put the craft through a series of unprecedented maneuvers while completing 34 dives to depths as great as 3000 feet. The average length of each dive was 7 hours, and the longest dive lasted 11 hours—the day ALVIN first located the bomb.

Accompanying ALVIN in the urgent quest was the ALUMINAUT, a 50-foot long privately owned aluminum submersible, which operated on this mission under contract with the Navy. The MIZAR, the Naval Research Laboratory's oceanographic research ship, provided navigational guidance for the submersibles. (The MIZAR also played a prominent role in the search for the THRESHER; see *Naval Research Reviews,* June 1965.) A special transponder attached to the hulls of ALVIN and the ALUMINAUT emitted signals which MIZAR picked up and processed by computer to maintain a constant fix on the positions of the submarines. By means of undersea telephone links, the MIZAR could guide the submarines to any spot on the ocean bottom, doing so in about the same way a control-tower "talks" an airplane down in a thick fog.

ALVIN is operated by the Woods Hole Oceanographic Institution for the Office of Naval Research for the purpose of carrying out a broad program of oceanographic research and performing special Navy missions at depths as great as 6000 feet. The vessel, which was built by the Applied Sciences Division of Litton Industries, Minneapolis, Minnesota, is 22 feet long, has a top speed of 3 knots, a cruising speed of 1.5 knots, and a range of 15-20 miles. The pressure sphere, which is 7 feet in diameter, accommodates 2 pilots and one observer and instrumentation and life-support equipment sufficient to sustain the crew for 24 hours or more. Four viewing ports permit observation ahead of and behind the vehicle. The vessel is driven by 3 propellers—2 small "lift" propellers, one on each side of the craft, which are rotatable so as to direct the thrust up or down, ahead or astern; and a large propeller, located at the stern, which can be turned from side to side to steer the vehicle in the manner of an outboard motor on a conventional small boat.

ALVIN was in the final phase of an overhaul following her successful shakedown period and was being readied for an ocean-engineering task in the Tongue of the Ocean, when the call was received to go to Spain. On February 2, the craft was flown across the Atlantic, and on February 14, it made its first dive in search of the bomb.

ALVIN found the bomb on March 15 by following a track which its pilots believed had been made by the bomb as it tumbled down a steep slope of the ocean floor to a resting place at a depth of 2500 feet. On this dive, the pilots were McCamis and Wilson. The ALUMINAUT, which is larger than ALVIN and can stay submerged longer, was sent down to stand by as a marker until the MIZAR could pinpoint the position by means of its special navigational equipment. After the MIZAR had guided the ALUMINAUT to the general vicinity of ALVIN, the pilots of the two submersibles communicated by voice, effecting the first deep "inner space" rendezvous of submersibles.

The next day, ALVIN carried to the bottom, in the claw of its mechanical arm, a 3/8-inch polypropylene line, to the end of which was attached an anchor fluke. ALVIN drilled the fluke into the bottom by spinning the claw. It was the first time such a task had been performed by a submersible.

The recovery operation began when MIZAR dropped to the bottom an anchor and a specially constructed steel work table to which lines and grappling hooks were attached. The surface ship was able to place the anchor and table within 75 feet of the bomb. ALVIN then grasped the parachute in its claw and pulled it as clear of the bomb as possible, laying it out on the ocean floor. Next, the little submarine took one of the lines in its claw and firmly entangled its grappling hooks among the parachute shroud lines. This had to be done carefully to avoid entangling the arm itself in the shroud lines. If the arm had become entangled, it could have been jettisoned, but the loss would have virtually ended ALVIN's usefulness to the recovery operation.

The anchor and work table, to which the parachute and bomb were now attached, were raised slowly by the MIZAR. Unfortunately, just as the load came free of the bottom muck, the lifting line broke, and the bomb tumbled away down the slope, dragging the parachute with it.

The search was begun anew. By now the pilots had become familiar with the terrain and were able to maneuver with more assurance, which, in conjunction with the MIZAR guidance system, enabled them to return to the original site quite readily. Once again, they spotted a track that could have been made by the bomb as it rolled farther down the slope. After traversing the area to which this track led, they came upon the parachute at a depth of 2800 feet. However, they could not determine if the bomb was underneath it. The pilots who made this second sighting were Rainnie and McCamis. The ALUMINAUT again descended and rendezvoused with ALVIN to serve as a marker. The next day, ALVIN returned and placed an electronic beacon on the parachute to guide the lowering of the recovery device, which, on this occasion, was a motorized maneuverable work "table" outfitted with television and other equipment required for the retrieval of objects from the ocean bottom. The device, called CURV, for Controlled Underwater Recovery Vehicle, was designed and operated by the Naval Ordnance Test Station, Pasadena, California.

When CURV had reached a position directly over the parachute, a grapnel with a line attached was hooked into the parachute shrouds. PETREL, the support vessel for CURV, then took a strain on the line to pull enough of the parachute away to enable ALVIN's pilots to observe the bomb and thus make certain it had not separated from the parachute and tumbled to a greater depth. Some of the tensest moments of the entire search now were experienced by Wilson and McCamis, who were at ALVIN's controls. The strain on the parachute shrouds had stirred up the bottom silt considerably, reducing visibility from about 25 or 30 feet, to which the pilots had become accustomed at that depth, to about zero. Cautiously, they edged into the cloud of silt, peering intently into the reflected glare of the spotlight beam. Suddenly, immediately in front of them, they confronted the parachute, part of which billowed above the ocean floor like a circus tent and part of which, apparently, had rolled up

—Continued on inside back cover

Fourth of a series of articles highlighting oceanographic institutions that receive support in large measure from the Office of Naval Research.

OCEANOGRAPHIC INSTITUTIONS

The Department of Oceanography of Texas A&M University

Willis E. Pequegnat
Acting Head, Department of Oceanography
Texas A&M University

It was inevitable that training in both oceanography and meteorology would some day be introduced into one or more of the public institutions of Texas. The State has over 600 miles of coastline on the Gulf of Mexico, into which have been scoured a dozen or so deep-water ports that handle an enormous amount of freight. And the Gulf itself is a bountiful storehouse of natural resources. Its broad continental shelf holds immense quantities of oil and gas, and there are promising indications that its continental slope and possibly the abyss may be even more productive; its waters supply the raw materials for major chemical industries, sustain a fishery of substantial proportions, spawn violent storms, and supply moisture that may be transported hundreds of miles inland.

It was inevitable that such training should have come to be centered at Texas A&M University. In fact, even today, visitors on the campus frequently express wonderment that a landlocked institution would have nutured a large department of oceanography. The reason it did so is to be found in the academic nature and public orientation of the institution itself. Service to the community and to the State are its hallmark. The land-grant colleges have been designed to respond effectively to the agricultural and other economic needs of their region, and Texas A&M is the land-grant school of Texas. In the thirties and forties those who quickened the tempo of economic exploitation of the Gulf encountered problems that had to be answered by oceanographers and meteorologists. Offshore towers and marine pipelines were found to be vulnerable to attack by wind and wave, man-made harbors and coastal installations had to be protected from storm surges, and fisheries people raised questions to which only trained biologists could find answers. Interestingly enough, Texas A&M became the first shcool on the Gulf Coast to establish a department of oceanography—not to make it possible to meet some of these needs for the first time, but because it had already been doing so for several years. A large cadre of biologists, chemists, engineers, and geologists were already supplying answers to industrial problems through the instrumentality of the Texas A&M Research Foundation. But some problems defied easy solution, and it became apparent that specially trained personnel were needed and that extended research was called for. It was a natural step, therefore, for these people to urge the Board of Directors of the then Agricultural and Mechanical College of Texas to authorize development of an academic department of oceanography. In January 1949, swayed by a cogent memorandum from A. A. Jakkula, then director of the Research Foundation, the Board authorized appointment of a five-man department. For reasons consistent with tradition and need, oceanography gained a formal foothold in Texas.

By September 1949, D. F. Leipper had arrived to serve as head of the department and to fill as well the role of meteorologist. J. G. Mackin became the biological oceanographer; D. W. Hood, who was completing a doctorate in biochemistry at A&M, took charge of chemical oceanography; and A. Price became the first geological oceanographer. A little later, R. O. Reid arrived to direct physical oceanography and ocean engineering, and in 1952, W. Saucier was brought in to develop a curriculum in meteorology. Thus was born a department of oceanography and meteorology.

The Department Today

Early in 1964, D. F. Leipper resigned as department head in order to devote himself more effectively to teaching and research. In anticipation of a major change in the administrative position of the department within the University structure, W. E. Pequegnat was prevailed upon to assume the headship of the department until this change had been effected. Later in 1964, the Texas Commission on Higher Education granted A&M's petition to create a College of Geosciences that would administer separate departments of oceanography, meteorology, geophysics, and geology and geography. This entity became operational in September 1965, when H. R. Byers assumed his role as first dean of the college. Near midyear of 1966, R. Geyer will assume headship of the again separate department of oceanography.

Thus organized, we are fast approaching the end of the second decade of the department's history. But the few years yet to pass before this milestone is reached are likely to be extremely productive ones. The oceanography staff at A&M has always been heavily involved in and dedicated to the graduate teaching function. No one could have predicted in 1950 that a decade later Texas A&M University would be granting annually about one-third of all M.S. and Ph.D. degrees in oceanography in the United States. Today, we have about 70 graduate students, which nearly equals the total degrees in oceanography granted by the department since its beginning. We have just revised our curriculum, instituted a serious search for additional staff members, and tightened our admission standards. This year, out of a substantial number of applications, only one student in ten can expect to be offered full admission to our graduate program.

Obtaining adequate financial support is the overriding problem connected with the building of a well-rounded program in oceanography. This problem has never been more critical than today. Students are seeking admittance to the study of oceanography in increasing numbers, and research costs are rising at a steady rate. Early in the department's history, the Office of Naval Research began supporting selected components of staff research. As time went on, ONR became the largest single source of funds for the department. Other groups have provided substantial support, including the State of Texas, the National Science Foundation, Atomic Energy Commission, Office of Saline Water, and

Corps of Engineers, but it is clear that the comprehensive coverage of ONR's support has permitted the shaping of an oceanographic program much more effectively than could ever have been accomplished through grants to individuals. Through this support, the department has been able to build a balanced and comprehensive educational program and to support the research needed to keep it vital.

A&M has graduated through a series of ships to its present vessel, the 180-foot ALAMINOS, which is well equipped for deep-sea research of varied types. As nice as this vessel is, we are looking forward with keen anticipation to receipt of one of the Navy's AGORs in the late 1960's, for this will be the first time that A&M will have worked with a ship designed from the keel up for oceanography. This ship will not arrive a moment too soon, because our scientists now are using the ALAMINOS to the fullest extent of its capabilities.

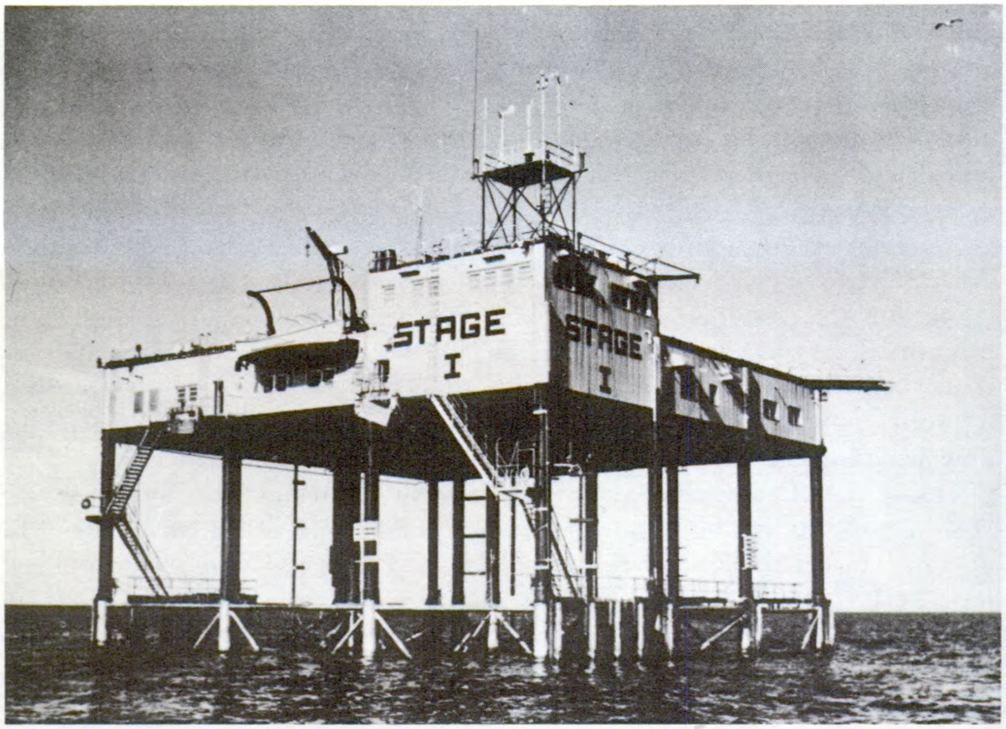
Texas A&M has responded to these tangible expressions of faith in the development of its oceanography program by filling some of the Navy's needs for advisory, instructional, and research services. For years, members of the staff have served willingly as consultants on several of the Navy's scientific and defense panels. Then, too, beginning in 1964, the department agreed to accept three Navy officers for postgraduate training; one of them is LCDR Don Walsh, who, in 1960, descended in the bathyscaph TRIESTE to a depth of 35,800 feet in the Pacific Ocean. We are pleased to note that next year a dozen or so officers will be studying with us under this mutually beneficial arrangement.

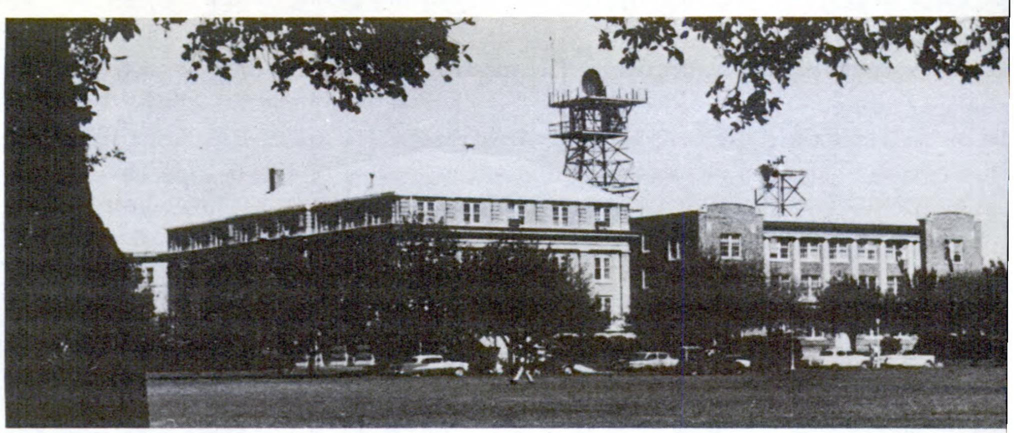
Research Efforts

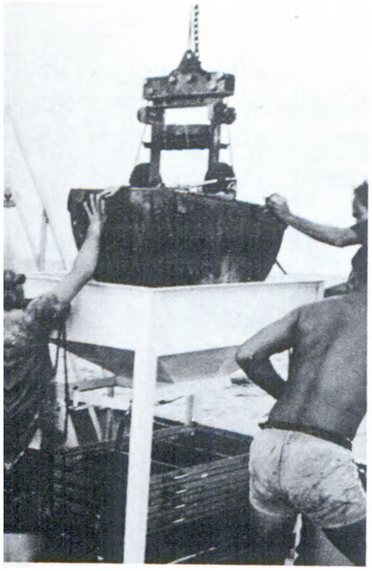
Because oceanography is multidisciplinary, it encompasses a wide variety of research activities. Investigators at A&M have covered the gamut from the air-sea interface to the abyss, from the analysis of complex molecules and C^{14} dating to quasi-synoptic surveys of the Gulf and modifications of tsunamis as they encounter shallow water. It is only possible here to touch upon a few of these investigations and then only in outline form.

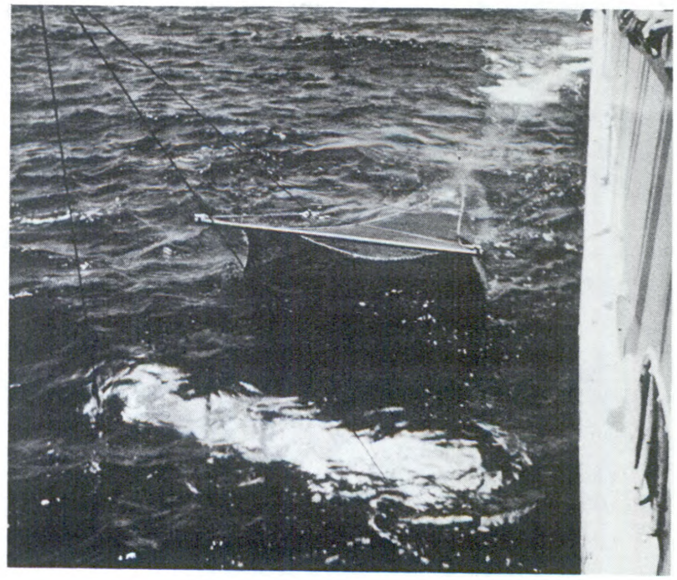
Marine Geophysics

Marine geophysicists are interested particularly in the origin of the Gulf of Mexico and in its relationship to the surrounding continental masses. Even at this time, the origin of the deep basin is a source of controversy, and very little is known about the relationship of Gulf structures to the tectonic activities that have occurred on the North American continent. There are three schools of thought regarding the origin of the deep basin: (1) that it is oceanic in nature, has always been oceanic, and the great amount of sediment being delivered to it explains the present shallower-than-oceanic depth; (2) that the deep basin was originally a land mass that has been faulted down to its present depth, that the surrounding scarps (Sigsbee, Campeche, and West Florida) are fault scarps; and (3) that the Gulf represents a slowly widening rift or tension gap between North and Central America and the Caribbean block. J. Antoine's studies, some of which have been carried out cooperatively with Lamont Geological Observatory personnel, indicate that the deep basin of the Gulf has always been oceanic. This view is substantiated particularly by seismic refraction data that reveal


STAGE
I
STAGE
I





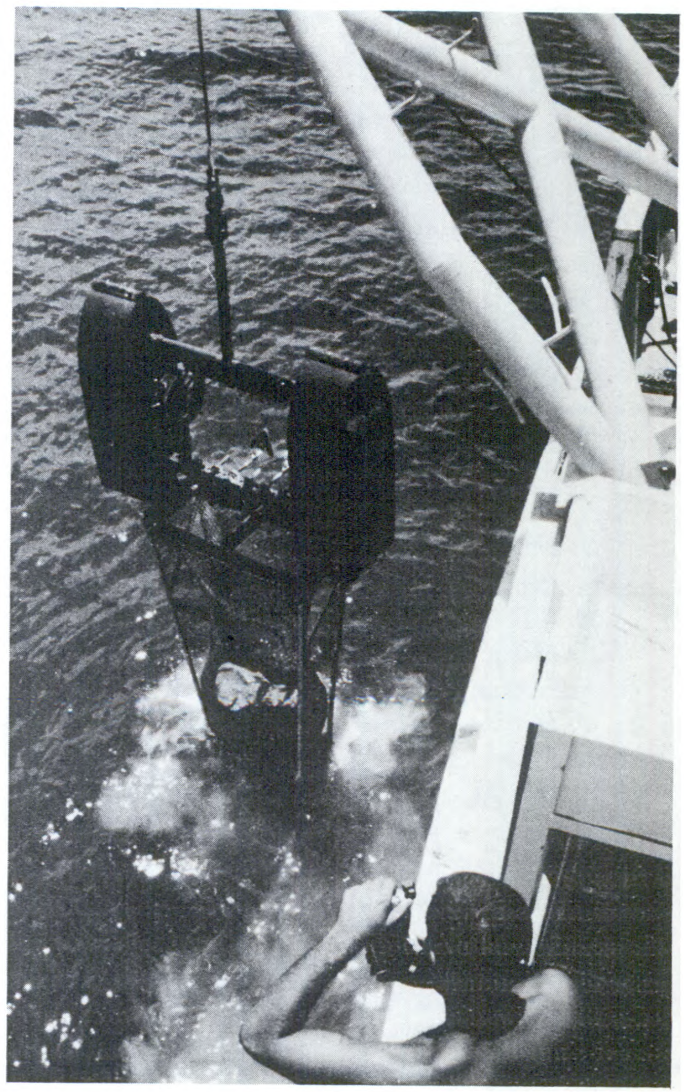


ṡacing page –

ıge I, an instrumented tower uti- Texas A&M for research about ɛs off the coast of Panama City, The water depth here is ap- ately 100 feet.

The research ship ALAMINOS berth in Galveston Harbor.

Goodwin (right) and Bizzell lhich presently accommodate the activities of the Departments of graphy and Meteorology.



ɒage –

ɥft: A grab sample is discharged ɛ abyss into a hopper-separator ɾvery of species as small or smal- n one millimeter in length.

ɒight: A mid-water trawl is for sampling large zooplankton ı at depths between 1000 and ɛters. The depressor vane that ɲe net to dive rapidly is already ıe surface.

lhe abyssal dredge returns from ɔm of the Gulf with a sample.

the mantle to be at oceanic depths, which tends to rule out the possibility that this area is a foundering continental mass.

Two years ago Antoine and W.Bryant discovered a linear ridge system on the continental slope parallel to the east coast of Mexico. They believe that this system of parallel ridges is related to the heavy sedimentary load on top of the volcanics in western Mexico. The resulting lateral pressure gradient could have folded the Tertiary sediments both to the east and west. This is apparently the case on land, where similar ridges exist, but generally in a highly eroded state. Since the submarine ridges have been protected from erosional processes, they may provide more definitive data on origins than those on land.

Antoine believes that the continental margin of Texas and Louisiana, where east-west trending ridges have been found, is being built out into deep water by the accumulation of sediments that produce a pressure gradient in the underlying salt, tending to "plasticize" it and to produce a seaward flow in the bed. This could result in the formation of a progressive ridge system that would result in the out-building of the continental margin.

Our work south of the Florida Panhandle has resulted in the discovery of a basin south of the shoreline that suggests the Gulf Coast Geosyncline extends this far east. There is also evidence that the salt intrusions characteristic of the western Gulf exist also in the offshore Florida area.

Current and Circulation Studies

In early years, K. Hidaka, during a period when he was on the department staff, made substantial contributions to theoretical studies of coastal currents and related upwelling and to our knowledge of the general circulation of the Pacific Ocean. D. F. Leipper was a pioneer in studies of the surface circulation in the Gulf. As is well known, the surface circulation in the Gulf begins with, and its dynamics seem critically dependent on, the Yucatan Current. The latter is that segment of the Gulf Stream system which enters the Gulf of Mexico through the Yucatan Strait. J. Cochrane began an intensive study of this current in late 1959. He found it to exhibit marked seasonal variations, being strongest and most concentrated in late spring and weakest in November. When it is strong, the current penetrates well into the Gulf toward the Mississippi Delta. When weak, on the other hand, it turns abruptly toward the east and joins the roots of the Florida Current. Cochrane also found evidence for upwelling in two low-temperature bands in the Yucatan region. Both have marked seasonal characteristics. One band appears to be related to dynamic effects of the Yucatan Current. The second, which occurs along the northern Yucatan coast, seems to result from the effects of trade winds blowing parallel to the north Yucatan coast.

Because of the importance of equatorial currents to fisheries, the Bureau of Commercial Fisheries, in 1963, instigated the International Cooperative Investigation of the Tropical Atlantic. Texas A&M cooperated with Argentina to make cruises to the region off northeastern Brazil both in 1963 and 1964. Cochrane studied the origins of the Equatorial Undercurrent, which he found appears first on the equator as a confluence of a current from west northwest and a series of branches of the Guiana Current. It first appears about 40°W.

One of the obstacles to understanding the physical processes that occur in a body of water, even in one as small as the Gulf, is the difficulty of obtaining measurements of physical parameters in small-scale time series. In 1962, H. J. McLellan, now a member of ONR's Ocean Science and Technology Group (see his article in this issue), and W. D. Nowlin, aboard A&M's research vessel HIDALGO, undertook the first rapid, large-scale survey of the waters of the Gulf to be made with one ship since the 1932 cruise of the MABEL TAYLOR. The results of this cruise, during which 126 hydrographic stations were made over the entire Gulf in a few weeks, provide the first gross characterization of these waters for the winter season. Analysis of the deep-water data reveal (1) horizontal uniformity of temperature and salinity, (2) marked but unexplained lateral gradients of dissolved oxygen, and (3) a sill depth in Yucatan Strait between 1650 and 1900 meters. An analysis of the shallow-water data will be published in the near future. Moreover, it is anticipated that a summer cruise for the same purpose will be undertaken in 1967.

Hurricane Studies

When severe hurricane Hilda crossed the Gulf of Mexico in 1964, D. F. Leipper acquired the first systematic set of oceanographic observations immediately after passage of such a storm over deep water. One striking observation revealed a decrease in surface temperature of more than 6°C along the hurricane path. There was much evidence of a broad pattern of mixing, upwelling, and downwelling of the affected waters. Vertical displacement of isotherms of as much as 60 meters occurred near the center. A theoretical description of upwelling and mixing induced in a stratified, rotating ocean by an intense hurricane has been completed by J. O'Brien. His mathematical models appear to approximate observed conditions very closely and thus offer some tentative explanations of the mechanisms involved. He finds that the initial response of the ocean to hurricane passage results in a thickening of the upper water layer at the storm's center. After several hours, significant velocity divergence develops, and the warm central waters are displaced, permitting strong upwelling. An interesting conclusion is drawn from the model, *viz.,* that under conditions extant in the Gulf, the region of upwelled water will remain intact for several weeks after the hurricane's passage.

In 1965, by a stroke of fortune, Leipper was able to make temperature measurements in the northeast Gulf just two weeks prior to the passage of hurricane Betsy. Observations were repeated immediately after the hurricane, revealing oceanic effects differing from those after Hilda. For instance, the temperature drops were not as great, and upwelling occurred on both sides of the hurricane path. The differences appear to be related to Betsy's higher speed of propagation and large eye width.

Establishment of an Environmental Research Facility

In late 1960, Texas A&M launched an investigation of the feasibility of establishing a marine environmental studies program based on offshore oil platforms in the northwestern Gulf of Mexico. By 1961, a decision had been reached to begin such a program and to establish it on two Navy-owned towers off Panama City, Florida, that had just been declared surplus to the needs of the Bureau of Ships. R. D. Gaul took charge of this project, the prime aim of which was to establish an automatic measurement and data-gathering, -telemetry, -recording, and -reduction system capable of supplying air-sea environmental information essential to a variety of special research projects. Early in the development of this project it became apparent that proper interpretation of tower-derived data required information on general environmental conditions farther offshore. Hence, by 1963 regular hydrographic observations over the northeast Gulf shelf were initiated in cooperation with the Gulf Coast Research Laboratory.

This project has been quite successful. All of the major technical problems associated with data acquisition and handling have been solved. The processing of data collected by the automated system has become virtually routine. Data are transferred from the serial PCM/FM format on telemetry tape recorded in the field to a blocked parellel/serial format compatible with computer characteristics. All field tapes are processed through the IBM 7094 to storage tapes at a rate 32 times faster than the data are recorded in the field.

Off-tower field studies indicate to date that the usual shelf circulation in the northeastern Gulf is driven by flow farther offshore and beneath the surface isothermal layer. The shape of the bottom, especially in the region of De Soto Canyon (a feature that cuts the shelf south of Mobile), seems to exert a strong influence on surface, as well as subsurface, circulation. Several new problems have been defined as a result of the routine work conducted on the towers. For instance, it appears from temperature data taken along transects over the northeast shelf that internal waves may be generated at the break between shelf and slope. There are indications that standing waves from about 10 to 20 miles in length may be set up only to decay rapidly offshore.

Having served their purpose well, it is anticipated that the Panama City investigations will be phased out by the summer of 1966.

Biology from the Gulf to the Antarctic

The instrumented towers have served the needs of other types of investigations as well. In 1964, S. Z. El-Sayed launched a major study of primary production in the waters adjacent to the platforms. These studies, which are based on the C^{14} technique, promise to contribute much to our understanding of the chemical and physical factors that control the food manufacture of the phytoplankton and to give us more profound discernment of the phenomena that account for seasonal and year-to-year variations in the magnitude of this photosynthetic production, which, as is well known, undergirds the majority of food webs in the marine environment. For several years, El-Sayed has been pursuing similar studies in conjunction with the Argentine Hydrographic Office in waters stretching from Tierra del Fuego to the Bellingshausen Sea. Here, he has added a link to the food web by attempting to correlate the magnitude of zooplankton populations with phytoplankton synthesis.

Also in 1964, W. E. Pequegnat launched a comprehensive study of marine fouling in conjunction with the data-gathering capacities of the towers. Bottom-to-surface arrays of artificial substrates have been installed 2, 11, and 25 miles offshore and harvested at intervals ranging from two weeks to one year. Comprehensive laboratory analysis of these floats not only has revealed significant differences between inshore and offshore fouling communities but also has turned up a rash of organisms not previously known to inhabit the Gulf of Mexico. An interesting sidelight of this study is that the nature of the fouling community between shore and 25 miles offshore changes markedly with major fluctuations in the strength of the Yucatan Current.

As part of a study of the bottom fauna in the abyss of the Gulf, Pequegnat and G. Rowe have discovered fragments of iron-rich rock in the eastern section that support some extremely rare sessile animals, all of which measure a few millimeters in length. The presence of these small animals attached to the rock indicates that the rock lies exposed, *i.e.,* free of pelagic muds—a fact that is difficult to account for without postulating the existence of rather high-velocity bottom currents at depths of about 11,000 feet in the eastern Gulf. Recent preliminary attempts to prove the existence of these currents have yielded sufficiently encouraging results to warrant a special study of this phenomenon.

Long-Wave Modification Studies

The development of mathematical techniques to augment the prediction of storm-surge damage has forged ahead with the advent of computers. The complexity and generality of the individual investigations has increased with computer capacity. At present, numerical experiments involving two spatial coordinates and time are conducted with the IBM 7094.

The earliest such studies at A&M were undertaken by R. O. Reid and B. W. Wilson. Reid's initial work employed the method of characteristics to analyze the storm tide in the Narragansett Bay system, whereas Wilson used a statistical dynamic approach to the storm surge in New York Bay. Current research is concerned with the phenomenon of tsunami waves near islands and a study of the modes of motion present in large basins.

One may consider that a tsunami has four major elements—generation, propagation, modification, and run-up. Reid and D. Vastano are interested presently in the modification phase that results when a tsunami commences to interact with an island root. The objective of this research, which employs a special polar coordinate system adapted to giving an accurate rendition of the island on a numerical grid, is the development of a technique for numerically modeling the interaction. From this it should be possible to investigate the role of diffraction in bringing about tsunami modification.

Reid and T. Royer now are investigating the normal modes of oscillation of large enclosed bodies of water. This study may reveal the radial and angular motions and their periods which occur in a body of water under the influence of the earth's rotation. Again, a numerical technique is employed to calculate these modes of motion for representative depth profiles. It is expected that this work will help solve some of the forced-surge phenomena that occur in the Gulf of Mexico.

A Look to the Future

In a very strict sense, not all of the brief sampling of research projects mentioned above were supported wholly by ONR. The business of supporting oceanographic research today presents a difficult accounting problem. The key word in the first sentence is "wholly," for it points clearly to the extremely

—Continued on inside back cover

The Seven Seas*

Hugh J. McLellan
Ocean Science and Technology Group
Office of Naval Research

What does the expression, "the seven seas," mean? Surely many heroes of old, real and fictional, sailed the seven seas. We know present-day heroes who would, with authority, list the seven (different seven for each hero, but all authoritative). The fact is, most would list seas that were unknown when the expression first became prevalent. It appears that to the ancients, "seven" often meant "many" just as "seven times seven" meant "about as many as there ever might be." Words mean different things to different people at different times. Take "oceanography." A few years ago, oceanographers were pretty well agreed as to what it meant. Now, everyone uses the word and, as a result, its meaning is stretched all out of shape. For example, skin diving and marine engineering often are confused with oceanography.

Instead of the seven seas, an oceanographer is more likely today to speak of the "world ocean" (*das Weltsmeer*), but he does know about seven if allowed criteria other than geography in subdivision. Let me sketch my impression of these seven seas.

The Physicist's Sea

The physicist's sea must be measured: hence, it has a surface area of 361.06×10^6 km², a volume of 1370×10^6 km³, a mean depth of 3795 meters, and a maximum depth of 10,863 meters. Its salt content ranges locally from 20 to 40 grams per kilogram, with a mean of 34.72 parts per thousand, a median value of 34.69 parts per thousand, and a sharply peaked frequency distribution. Its temperature ranges from $-2°$ to over 30°C, and the potential temperature (*in situ* value less effect of adiabatic compression) has a mean of 3.52° and a median of 2.1°. There are regions of sharp vertical and horizontal thermal gradients, which are often also regions of interesting dynamical processes. These waters are subjected to pressure ranging from atmospheric to 1000 atmospheres, or 10^9 dynes/cm². Density is a function of temperature, salinity, and pressure. Density ranges from 1.02 gm/cm³ to about 1.08 gm/cm³. Water with the mean salinity, mean potential temperature, and located at half the mean depth would have a density of 1.036 gm/cm³.

As indicated, this ocean is neither homogeneous nor incompressible. Mathematical models applying these simplifications do not adequately explain many observed phenomena; one is forced to use non-linear differential equations of second order. Furthermore, this ocean is on a rotating earth, and scales of motion are such that coriolis acceleration hardly ever can be neglected.

---

*A slightly modified version of the paper presented on April 15, 1966, at the Institute of Environmental Sciences' Annual Technical Meeting, held in San Diego, California. Reprinted from *The Journal of Environmental Sciences* (a publication of the Institute), April 1966.

Sea level is not level but perturbed by tides, wind waves, swell, wind setup, and mass adjustment to established currents. Any piece of ocean large enough to be of much interest is sufficiently large that exchange coefficients are not single-valued, as they are in the laboratory. Exchange of momentum, heat, *etc.* is largely turbulent exchange and is governed by the scale of the phenomena, shear, stability, *etc.* Motion can be detected in all scales from molecular up to the dimensions of intercontinental distances. Some are ordered and probably can be predicted from the dynamics and boundary conditions, but it is clear that much of the movement never will be predictable except in a statistical sense. The physicist, if he does not turn away to more tractable problems, must wrestle with the problem in its complexity.

Light in the blue-green region penetrates weakly, with an extinction distance in the clearest water of 67 meters. At other wavelengths it is very greatly attenuated, and longer wavelength electromagnetic radiation cannot be propagated efficiently as far as one wavelength. Compressional (acoustic) waves are the only efficient means of communicating intelligence through the ocean.

The Chemist's Sea

Here is 97 percent of the world's water, which is only slightly like the standard laboratory reagent. Here is a vast reaction vessel in which a multitude of reactions are proceeding at different rates at different places.

The major constituents, besides water, are present in the ocean in relatively constant proportions so that for many purposes we can quantify their concentration as a single variable (salinity), yet there are uncertainties in the equation of state that we write for seawater as a two-constituent (water and salt) system. Several of the minor constituents are nutrients which are removed from surface waters by plant growth and replenished belo v by decay, being brought again to the region of growth by upwelling and vertical mixing. Other trace elements whose roles in organic production are not as well understood enter the system and are concentrated by organisms or scavenged by particulate material that ends up in the sediments.

Dissolved gases are equilibrated at the atmospheric interface. Oxygen may be further enriched in the upper levels by photosynthesis, and it is depleted throughout the column by respiration and decay of organic debris. The concentration of dissolved oxygen below the surface layer decreases with the time that the water has been out of contact with the air. There is a large range in observed concentrations; indeed, some isolated basins, such as the Black Sea and the Carioco Trench, have become anoxic and are regions of sulphide production where the chemistry is vastly different from that of the majority of the ocean.

Carbon dioxide is utilized in photosynthesis and renewed in respiration but forms part of a complex balance in the carbonate system. Dissolved CO_2, bicarbonate ions, and carbonate ions are all present, and the balance shifts in such a way as to effectively buffer the solution at a pH close to 8. Also involved in this system is equilibration across the air-sea interface, precipitation of carbonates in the shells of animals, dissolution of carbonates from the sediments, and, in some regions, inorganic precipitation of calcium carbonate.

Recent work has shown the presence of quantities of dissolved organics throughout the ocean in a wide variety of species. While occurring mainly in solution, they can form aggregates which may serve as particulate food for small animals. Also, polar molecules seem to form organic film around inorganic particles and to inhibit both their sinking and their dissolution.

The Geologist's Sea

The most interesting part of this sea is the bottom. Before ways were devised for looking at the bottom and below it, geologists only could speculate on the processes that shaped the earth's crust from a small fraction of the evidence arbitrarily selected from the dry parts. Exploration has shown the ocean basins to be quite different crustal features than continents and to display an amazing variety of topography. Here are ridges, trenches, and mountains formed by crustal deformation and volcanism that are comparatively free from the erosion that blurs sub-aerial features. At the same time, great canyons cut in the continents' edge and jumbled sediments attest to the mechanisms of flow and slumping that violently reshape the ocean floor.

Here, the whole process of sedimentation can be observed. The water circulation enriches certain surface areas so that biological productivity is unusually high. Microorganisms with calcareous or silicious tests live and die in great numbers, and their remains rain down slowly on the sea bed to form carpets of sediment. Their ecology can be studied, and piece by piece the paleontologist can put together the recent history of our planet.

Observing techniques have only recently been developed or are still under development. Once a technique becomes available, it can be used freely throughout the ocean without regard to political boundaries or property rights, which often are an obstacle to its use on land. Some measurements even prove to be easier to make at sea than on land. There is a lot of sea and much to be learned, but more and more of our geologists are turning to the problem.

The Biologist's Sea

This is where the life is. This is probably where it all began. In one system of classification of animals, all 17 phyla are found in the sea, and five of them are exclusively marine. Of 47 classes of invertebrates, 21 are exclusively marine, while only three are exclusively non-marine.

Among the primary producers—the plants—the situation is otherwise. The variety in the sea is very limited compared with that on the land. The primitive forms are very highly developed, and production is limited to the lighted surface layers. Productivity varies widely, but when conditions are favorable—*i.e.,* when dissolved nutrients and vital trace elements are present in sufficient concentration and when temperature and illumination are within the required range—explosive growth takes place.

This is the beginning of a complex chain according to which simple animals live on the plants or organic detritus and, in turn, form food for other animals till we have life at all depths and virtually everywhere in the ocean.

Although it is a region of mass mortalities, and the life processes sometimes appear wasteful, it is by and large a friendly environment. Temperature ranges are small and, because water has such a high specific heat, fluctuations occur slowly. The water itself circulates the food supply, and the buffering mechanism maintains a constant pH. Support provided by the fluid makes the requirements for skeletal support less stringent, and the ionic strength of the solution facilitates osmotic regulation.

This is an exciting place for the biologist – there are still new life forms to be discovered and new ways of life to be understood. Just recently, the possibility that dissolved organics may be aggregated to form suitable food for certain animals was discovered. This presents a whole new loop for the food chain and may answer perplexing questions regarding the support of animal life.

The Engineer's Sea

The engineer who is concerned with building systems in the sea or systems to be used in the sea faces problems that can be classified under the following headings: statics, dynamics, chemistry, and location.

To withstand the great ambient pressures, instruments must be placed in pressure vessels, which impose stringent requirements on weight, size, and shape. The alternative is to use free-flooding systems, whose components will, themselves, stand the pressure, but this is not always practicable. Electrical connections must be made to exclude the conducting sea water, and pressure cases must have foolproof penetrations, because any failure tends to be catastrophic.

The waters are almost everywhere in motion – sometimes ordered, as in steady currents and tides, and sometimes violent and disordered, as in surface waves. Thus, they are always imparting energy to structures introduced into the sea. The problems of designing equipment to meet these conditions are intensified by real limitations in knowledge of the energetics and very limited ability to predict them.

The chemical reactions which ensue when structural materials are introduced into the sea are not well understood. Pressure and dissolved oxygen seem to exert profound influence upon the corrosion of materials. Often the inclusion of a small component with slightly different properties completely changes the reaction rates of processes that deteriorate structures. Any structure introduced into the sea presents a surface for the attachment of organisms and a resultant biochemical interface that may quickly deteriorate the structure. Such attachment also changes the dynamic response of equipment to oceanic motion.

Coupled to these problems is the problem of location. First, where are you or your equipment located in the ocean? Then, how are you located relative to your equipment? Finally, how are two pieces of equipment not rigidly attached located relative to one another? Although many ingenious techniques have been tried. it must be stated flatly that satisfactory answers to these questions cannot today be generated.

The Acoustician's Sea

No more efficient method than sound has been found for transmitting intelligence through the ocean; so there has grown up a large group of specialists in submarine acoustics.

Their sea is a chemical solution, which is evidenced by the absorption of acoustic energy many times as great as simple theory predicts at the low frequencies generally used. It is stratified with respect to salinity and temperature (and, hence, sound speed), so that sound beams are severely refracted. This condition both interferes with the use of acoustic systems and permits efficient long-range propagation in certain modes.

It is a medium in motion, where internal waves, turbulence, and associated inhomogeneities give rise to fluctuating propagation losses and limit the signal coherence—hence the effective gain of transducer arrays.

The geology influences acoustics because different sediment types and varying microrelief of the sea floor change its characteristics as a reflector of pressure waves.

It is also a biological environment, with large organisms presenting acoustic targets that seem to masquerade as submarines, and with biological noise makers that sometimes transform the "silent sea" into an impossible medium for acoustic signalling. Small organisms scatter sound and, as they mass together and migrate vertically in response to changing light conditions, form scattering layers that are sometimes mistaken for the ocean bottom when they show up on echo sounders. Because they are distributed through the water, living organisms contribute to the problem of volume reverberation, imposing limitations on sonar systems.

The Poet's Sea

With the possible exception of a sunset, nothing visual can stir man's mind like the sea. A sunset at sea is the ultimate. From the shore, the rise and fall of the tides, the endless shoreward progression of waves, the irresistible erosion of the land into the sea, and the mystery of the varied jetsam give the poet new insight into his place in the scheme of things.

From a ship, even in quiet weather, the sea can appear vast, mysterious, and terrifying. So quickly it can be aroused to fury and make man in his frail craft feel as inconspicuous as he really is in the cosmic scheme.

These, then, are the seven seas. As stated earlier, they are really only one sea (*das Weltsmeer*) to the oceanographer. It is bounded only by land and air and joins, rather than separates, nations. The study of this ocean is a large task—large enough for all who wish to engage themselves in it. International cooperation is becoming extremely common and will persist unless forbidden and policed by politicians. Jealousies can and do exist between scientists in a single nation because of fiscal competition, but mutual respect and desire for cooperation are the rule among workers from different nations.

More than 750 scientists, industrialists, and Naval officers took part in the Third Annual Navy Symposium on Military Oceanography, which was held at the Naval Training Center, San Diego, May 11-13. The purpose of the meeting was to facilitate the exchange of the latest information on such subjects as military operations in shallow water, oceanographic prediction, warfare applications, oceanographic engineering and technology, and marine sciences research. Sponsors of the classified sessions were the Naval Oceanographic Office, Office of the Chief of Naval Operations, Office of Naval Research, Bureau of Naval Weapons, Bureau of Ships, Bureau of Yards and Docks, and twelve Naval laboratories. The Navy Electronics Laboratory was the host organization.

Linear Programming—Continued from page 6
half million dollars on soft-ware development of a complete linear-programming system which is free to customers who buy or rent their equipment.

Extensions of Linear Programming

If we distinguish, as indeed we must, between those types of generalizations in mathematics that have led to existence proofs and those that have led to constructive solutions of practical problems, then current developments mark the beginning of several important constructive generalizations of linear-programming concepts to allied fields. These are:

• *Network Theory.* A remarkable property of one very special class of linear programs, namely, the transportation or the equivalent network flow problem, is that their solutions are always in integers. This has been a key fact linking certain combinatorial problems found in mathematical topology with certain continuous problems of network theory. The field has many contributors. Of special mention is the work of Kuhn (for finding a permutation of ones in a matrix composed of zeros and ones) and the related work of Ford and Fulkerson of RAND (for network flows).

• *Nonlinear Programming.* A natural extension of linear programming occurs when the linear part of the inequality constraints and the objective are replaced by convex functions. Early work by Barankin and Dorfman centered about a quadratic objective and culminated in an elegant procedure developed independently by Beale, Houthakker, and Wolfe. Wolfe showed how a minor variant of the simplex procedure could be used to solve such problems. Duality concepts first proposed by Von Neumann have been successfully extended to certain classes of nonlinear programs. As a result of these investigations, a new uniform procedure has been developed which solves linear programs, quadratic programs, and general matrix games. The research of C. Lemke and Howson, H. Scarf, and the joint work of R. Cottle and the author should be mentioned. Large-scale systems with mixed linear and nonlinear parts are of great practical importance in industry today, and interest in this field is growing rapidly.

• *Integer Programming.* Important classes of nonlinear, nonconvex, discrete, combinatorial problems can be shown to be formally reducible to a linear-programming problem with the additional restriction that some or all of the variables must be integer valued. The linear-programming approach was used in 1954 by Fulkerson and Johnson and the author to construct an optimal tour for a salesman visiting Washington, D.C., and 48 State capitals of the United States. Our theory was incomplete, however. The foundations for a rigorous theory were first developed by Ralph Gomory in 1958 under an Office of Naval Research contract with Princeton. Many important planning problems are integer programming problems. The best location of warehouses, the optimal routing of a fleet of supply ships, optimal provisioning under space and weight limitations, the optimal sequencing of jobs on machines, the assignment of crews to meet an airline routing schedule, and optimal ways to cut out patterns from stock materials are some examples.

• *Programming under Uncertainty.* It has been pointed out that programming under uncertainty cannot be usefully stated as a single problem. One important class is a multistage one in which the technological matrix of input-output coefficients is assumed known and the values of the constant terms uncertain, but the joint probability distribution of their possible values is assumed to be known. Research in this field is still in its infancy, and practical planners will continue to resort for some time to heuristic schemes to cover stochastic events.

Large-scale System Development

Of all the progeny of linear programming, perhaps the most fruitful development at the present time is that of techniques for solving linear programs with special structures. Many groups have been developing linear-programming models of their firms for over a decade. As the years go by, the trend is toward larger and more comprehensive corporate models. These are multistaged and dynamic and exhibit a hierarchal structure. Although many proposals have been made, little in the way of practical codes was developed to handle such problems until recently.

In 1959, Philip Wolfe and the author proposed the decomposition principle, an approach which decomposes a model into smaller parts which can be independently optimized. The solutions of each of the parts are treated as proposals which are modified to be consistent with total system resources and demands. Several companies, such as C.E.I.R., Mathematica, and Bonner-and-Moore, which specialize in developing computer programs, have written decomposition codes. In one application, that of the National Biscuit Company, a system of nearly a million variables and thirty-two thousand equations has been successfully solved.

Industrial Applications of Linear Programming

The history of the first years of linear programming would be incomplete without a brief survey of its use in business and industry. These applications began in 1951 but have had such a remarkable growth that the commercial offspring has overtaken its military parent.

Linear programming has been serving industrial users in several ways. First, it has provided a novel view of operations; second, it induced research in the mathematical analysis of the structure of industrial systems; and third, it has become an important tool for business and industrial management for improving the efficiency of their operations. Thus, the application of linear programming to a business or industrial problem has required the mathematical formulation of the problem and an explicit statement of the desired objectives. In may instances, such rigorous thinking about business problems has clarified aspects of management decision-making which previously had remained hidden in a haze of verbal arguments. As a partial consequence, some industrial firms have started educational programs for their managerial personnel in which the importance of the definition of objectives and constraints on business policies is being emphasized. Moreover, scheduling industrial production traditionally has been based on intuition and experience, a few rules, and the use of visual aids, as has scheduling in the military. Linear programming has induced extensive research in developing quantitative models of industrial systems for the purpose of scheduling production. Of course, many complicated systems have not as yet been quantified, but sketches of conceptual models have stimulated widespread interest.

The first and most fruitful industrial applications of linear programming have been to the scheduling of petroleum refineries. As noted earlier, Charnes, Cooper, and Mellon started their pioneering work in this field in 1951. Two books have been written on the subject, one by Gifford Symonds and another by Alan Manne. So intense has been the development that a survey by Garvin, Crandall, John, and Spellman in 1957 showed that there are applications by the oil industry in every phase of its activities from exploration, production, and refining to final distribution and sales.

The food-processing industry is perhaps the second most active user of linear programming. In 1953, a major producer first used it to determine shipping schedules for catsup from six plants to 70 warehouses.

In the iron and steel industry, linear programming has been used for the evaluation of various iron ores and of the pelletization of low-grade ores. Additions to coke ovens and shop loading of rolling mills have provided additional applications. A linear-programming model of an integrated steel mill has been developed. The British steel industry has used linear programming to decide what products their rolling mills should make in order to maximize profit.

Metalworking industries use linear programming for shop loading and for deciding whether to make a part in a shop or to buy it outside. Paper mills use it to decrease trim losses and to decide which of their several mills should be assigned to respond to an order for paper.

The optimal routing of messages in a communication network, contract-award determinations, and the routing of aircraft and ships are problems that were first considered for application of linear-programming methods by the military but that are now applied in industry.

One overall measure of the use of linear programming and its extensions is the dollars spent on computer time in the United States. This is known to run in the millions.

A Few Words About the Future

One of the most startling developments in recent years is the penetration of the electronic computer and mathematics into almost every phase of human activity.

If there is a library, then someone is at work representing (inside the memory of a computer) the book number, its title, its shelf location, who has it on loan, the date due, the author, its call number, its cross references, its frequency of use, and so on. A library is like a population that does not bury its dead. Out of this rather straightforward effort of getting some of the present information about a library into a more manipulatable form will emerge the "information storage and retrieval system" of tomorrow, in which the old physical book and printed paper page may well become a relic like an ancient scroll.

Wherever one finds a system for processing insurance premiums, for keeping track of bank deposits and withdrawals, for recording airline reservations, or for any other type of inventory control, someone is at work simulating such a system in an electronic computer and forging the links whereby the real world supplies information to the computers and the orders of the computer are translated into real actions.

It is correct to regard much of what has been done so far as a vast *tooling up*, a preparation for new ways to do old tasks. It is the exponential improvement in electronic hardware, the availability of new machine languages and special machine programs that now permit the practical implementation of these ideas. We are witnessing an accelerated trend toward automation of simple human control tasks.

Operations research refers to the science of decision and its application. In its broad sense, the word "cybernetics," the science of control, may be used in its place. This science is directed toward those tasks that humans have not yet delegated to machines. Tasks involving human energy and (as we have seen) those involving simple human control already have been conceded to machines even though they have not been taken over fully by them. It is the automation of higher order human decision processes that is the last citadel.

At the lowest level of these higher order tasks is the human ability to recognize patterns in sight, sound, touch, smell, and taste. Although these tasks may elicit simple responses (such as turn the wheel to the right or left), human presence is needed because a complex mental recognition process is involved. It would be easy to get a machine to mechanically separate returned Coke and Pepsi bottles if it were smart enough to recognize which is which.

At the next level of complexity is the human ability to observe and to adapt to physical movement; for example, to observe a dial or a car's angle to the road direction and to manipulate certain controls to change the physical movement in some preferred way. Here, again, it is easy to get a machine to make the physical movement of the controls if the machine is smart enough to adapt to trends in the observed movements as changes are made in the controls.

Although pattern recogniztion is by no means a solved problem, banks do have machines that recognize account numbers on checks, and machines do exist that give change for a dollar bill but not for a blank piece of paper. Automatic feed-back controls in simple situations have been known for a long time. The governor invented by Watt to control the speed of a steam engine is such a device. Closed-loop controls that rely on computers to analyze input data are now a reality in certain large-scale operations, such as oil refineries, chemical plants, and power-distribution systems.

At still a higher level of complexity are those decision processes that involve many alternative courses of action. An industrial complex may have at its disposal many types of equipment and a variety of raw materials and personnel skills. The complex could manufacture a vast variety of products by means of many alternative process sequences. If the wrong decisions are made in the scheduling of the various processes, labor and machines are idle, through-put is reduced, and in-process inventories are increased. If the wrong decisions are made in raw-material selection, the procedure for manufacture, or the choice of final product, labor and machines are overworked, expensive materials are purchased when cheap ones will do, and unwanted products are dumped on the market.

In the last two decades, great strides have been made to effectively use electronic computers as part of the planning process. As we have noted already, a pioneering effort of this kind was first initiated by the military around 1947 in Project SCOOP. Part of the ramifications of that project included a 400-sector inter-industry model of the national economy. Except for the preparation of input data, the calculation of various planning programs was completely mechanized. The size of systems handled was truly enormous. A program typically stated by month (for 36 months) the level of each type of activity for thousands of activity types. The balanced flows of some tens of thousands of input and output items (necessary to support these activities) were also stated as a function of time. As ground rules, appropriations, or international conditions changed, these programs were recalculated rapidly again and again.

This early pioneering effort at mechanization of the planning process showed that it was possible to describe in mathematical terms the interdependence of various activities, such as training, the work of a combat unit, an engine overhaul, steps in an industrial process, and the shipment of goods from various places of origin to numerous destinations. The approach, as we saw earlier, is to make each activity *elementary enough* so that its inputs and outputs are proportional to the level of the activity. The resulting mathematical system is one of linear inequalities called a linear program. By incorporating this mathematical approach, planning staffs have been relieved of much drudgery and have been able to concentrate more and more on overall objectives.

True optimization is the revolutionary contribution of modern research to decision processes. In the entire history of mankind, a great gulf has always existed between man's aspirations and his actions. He may have wished to state his wants in terms of objectives, but there were so many possible different ways to go about it, each with its own good and bad, that it was impossible to compare them and to say which was the best. Man invariably turned to a leader, a manager, a governor, or a commanding officer, whose "experience" and "mature judgement" would point the way. Inevitably, "the way" became the new objective. *This substitution of the means for the objective* is the history of mankind. The slogan "the end justifies the means" perhaps could be better stated as "the end might conceivably justify the means if one could ever remember what the original objective was."

Because man did not have the ability to select the best among infinite alternatives, his planning was characterized by many ground rules and policies dictated by men with "mature judgement." It seemed impossible, therefore, that planning could ever be done by computer without constantly stopping the machine to await decisions from the experts. The habits of centuries are not easily overcome, but planning staffs freed from the drudgery of computing one or possibly two alternatives now are beginning to express themselves in terms of overall objectives and to ask the computers to find them the "best."

As the power of computing machinery has increased and the power of methods proposed by mathematicians has grown, the achievement of optimal solutions to large-scale complex planning problems has become a reality.

The mathematical systems developed for planning in industry and the military are truly among the largest in the world. Typical problems run from 300 to 800 equations. In Europe, the new code "Ophelia" is designed to solve practical problems involving as many as 4000 equations. In all cases, the number of possible activities (variables) run in the thousands. We have already mentioned a new method, called the decomposition principle, for handling extremely large systems.

Let us now turn to cybernetics developments in the U.S.S.R. In 1939, Leonid Kantorovitch proposed that mathematical methods be applied to planning problems. As we pointed out earlier, for one and a half decades his work was unknown to the Western world as well as in Russia (Communist policy had shelved it as dangerous). In 1959, the Supreme Soviet decreed cybernetics top priority. Scientific circles in Russia, as a result, have begun a vast tooling up. Computers are not as plentiful there as they are in the United States, but this does not prevent education on their design nor work on the development of machine languages nor work on the design of complex control systems. It is stated by one authority that there are *ten times* as many engineers and mathematicians working on control theory in the U.S.S.R. as in the United States.

It is reported that Russians feel that through their efforts in cybernetics they will outdistance the productivity of the Western world. According to economists who have studied developments there, the Soviets feel that the weak point of their planning system lies at the middle management level, the factory managers. This group apparently is unable to exercise initiative and modify its given production plans. On the other hand, their top management (at industrial and governmental levels) appears to be the equal of ours. The same is true at their lower management levels. Their hope is to replace middle-management planning with a highly flexible scheme which they believe is inherently superior to ours.

We should not dismiss too quickly their idea of overtaking us. It should be noted that, historically, it has been difficult to change the direction of large-scale enterprises once they have gathered momentum. These momentums have been the underlying cause of our business cycles and depressions. It would thus appear that timely, balanced, optimal programs encompassing a broad spectrum of enterprises could have enormous payoffs. They believe that excellent detailed planning and rapid flow of information could avoid these problems completely. Soviet Academician Vasili Nemchinov sums it up this way:

> *The Communist system alone gives sufficient room to apply the combination of mathematics and cybernetics to the national economy. Only under the system of public ownership is it possible to introduce into the economy a single automated electronic system of planning. In a private enterprise system the use of cybernetics is restricted by the framework of companies, corporations, and syndicates.*

Whether computers and programming can accomplish this miracle of putting the Soviet Union ahead of everyone else is, therefore, a challenging question. We have seen that every step necessary to fulfill this aim has already been service-tested on a large scale in this country, particularly in military planning and in industry. We have seen the rapid improvements in computer technology and how computers are penetrating into record keeping and process control so that input data can be made available instantly to the planning system and the results of the computation can be prepared in a form for necessary feed-back action.

Can computers be programmed to solve the truly immense systems characteristic of a national economy, particularly dynamic systems involving optimization? Here again we note that by use of the decomposition principle of linear programs, systems of the order of 3×10^4 equations and 10^6 variables have already been solved. Ponder the statement made by the Russian, Malkov: "Half of the mathematicians in the Moscow Computing Center are working on decomposition problems." Even if total system optimization is presently

—Continued on page 29

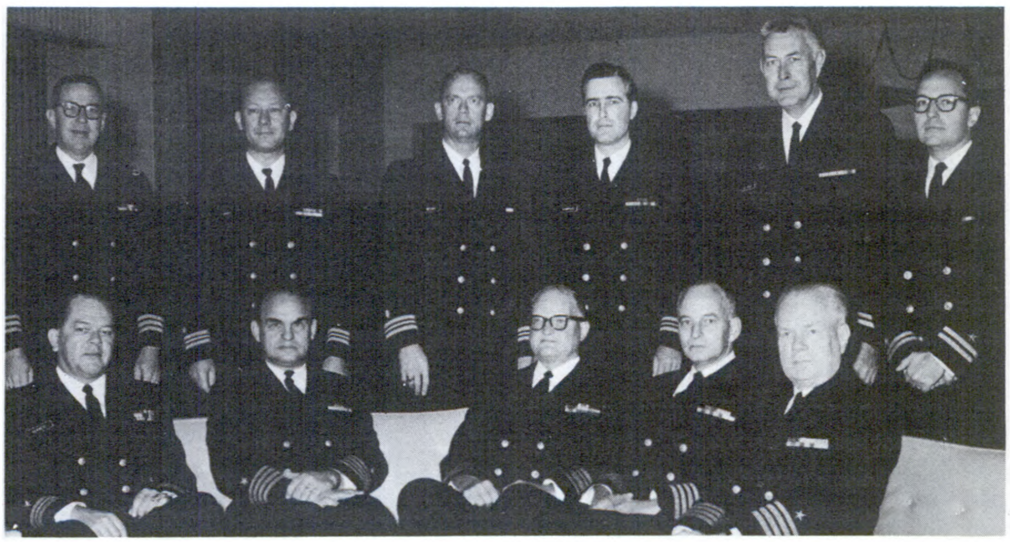
On the Naval Research Reserve

TWELFTH NAVAL DISTRICT REPORTS

Commanding Officers Conference

A conference of commanding officers of Research Reserve companies in the 12th Naval District was held in December 1965 at NAS, Alameda, California. All eight companies in the district were represented.

The agenda covered topics on the Naval Reserve, particular emphasis being given to the Research Reserve within the overall program. Attendees felt that the cross fertilization of ideas made possible by this group meeting would produce beneficial results in individual company activities.



Representatives of the eight companies in the 12th Naval District who participated in the Commanding Officers Conference. From left to right, seated, LCDR Thomas J. Kennedy, Research Program Officer, 12th Naval District; CAPT Carl A. Hering, Commanding Officer, NRRC 12-8; RADM Carl E. Watson, District Commandant's Representative; CAPT Richard W. Smith, Commanding Officer, NRRC 12-5; and CAPT Julius W. Jockusch, Commanding Officer, ONR Branch Office, San Francisco. From left to right, standing, CDR Bernard G. Olsen, Executive Officer, NRRC 12-2; LCDR Martin Gross, Commanding Officer, NRRC 12-9; LCDR Emerson L. Besch, Commanding Officer, NRRC 12-6; LCDR James T. Nawrocki, Commanding Officer, NRRC 12-3; LT Wayne E. Biehler, Commanding Officer, NRRC 12-4; and LT Norman T. Allen, Executive Officer, NRRC 12-1.

Linear Programming—Continued from page 28

impossible—*and it is*—there are all kinds of schemes involving partial aggregation that permit near-optimal solutions.

We are witnessing a computer revolution in which nearly all tasks of man—be they manual labor or simple control, pattern recognition or complex higher order decision making—all are being reduced to mathematical terms and their solution delegated to computers. It is in the latter development that linear programming (and its extensions) is playing a key role.

Week-end Seminar Held at Davis

A symposium on the Engineering and Scientific Applications of Ionizing Radiation was sponsored by NRRC 12-6, University of California, Davis, on June 18 and 19, 1966. The seminar chairman was LCDR Margaret L. Fuller, USNR, special assistant to the commanding officer, NRRC 12-6. Naval Reserve officers of the 11th, 12th, and 13th Naval Districts were in attendance.

Special guests introduced by LCDR Emerson L. Besch, USNR, Commanding Officer, NRRC 12-6, included CAPT J. F. Sunley, USNR, Commanding Officer, USN&MCRTC, Sacramento, and LCDR T. J. Kennedy, USNR, Research Program Officer, 12th Naval District.

The seminar provided an opportunity for Naval Reserve officers interested in ionizing radiation to hear addresses by a distinguished group of scientists actively engaged in research in this field. The four sessions were chaired by CAPT Raymond M. Keefer, USNR, CAPT Wilbur L. Parker, USNR, CAPT Arthur H. Smith, USNR, and CDR H. Michael Reisenauer, USNR, all members of NRRC 12-6.

Introductory lectures on the physical aspects of, and the biological effects of, ionizing radiation were followed by a talk on radiation safety and management of radiation by a member of the Office of Environmental Health and Safety, University of California, Davis. The major portion of the symposium was devoted to a discussion of the research projects at the University. The specific topics covered were radiobiological research, ionizing radiation hazards of high altitude and space, Project Plowshare, cyclotron research, ionizing radiation in the food chain, and ionizing radiation as applied to fresh fruits and vegetables. Visits were made to the Radiobiology Research Laboratory, the Low Energy Nuclear Research Laboratory, and the Co^{60} Food Preservation Laboratory.

Considering the comfortably warm mid-June climate of Davis, the officers attending the seminar were pleased with the presentation on "Stability of Flavor and Quality in Wines," which was the highlight of the social hour and dinner on June 18.

Polaris Missile Symposium

One hundred Naval Reserve officers participated last month in a most informative and interesting two-day Polaris Symposium sponsored by Naval Reserve Research Company 12-3, which meets regularly at Stanford University.

NRRC 12-3's Commanding Officer, LCDR J. T. Nawrocki, USNR, greeted the officers on May 14 at Lockheed Missiles and Space Company in Sunnyvale, where a comprehensive briefing of the Polaris concept, history, and future was presented. On the second day of the symposium, the group met at Mare Island Naval Shipyard in Vallejo for a tour of a Polaris submarine and a briefing on the vehicle.

The chairman of the symposium, which was classified, was LCDR T. J. Kowall, USNR, Executive Officer of NRRC 12-3. LCDR K. N. Arnold, USNR, a member of the Naval Reserve unit, served as chairman for the first day's meeting.

Berkeley Chemist Selected for Promotion to Captain

CDR James A. Bassham, USNR, of Naval Research Reserve Company 12-5, Berkeley, California, was among the 11 Research Reserve line officers selected for promotion to captain by the Promotion Board, which met last January. At almost the same time that the board was meeting, CDR Bassham was serving as chairman of the Thirteenth Annual Research Reserve Seminar on "Man's Conquest of the Sea," which was held at the Naval Station, Treasure Island, San Francisco, from January 24 to February 4.

CDR Bassham

CDR Bassham's active military service includes duty as radar officer with L.S.T. Flotilla 35 in the Pacific during World War II and as a member of a special research team with the Office of Naval Research, San Francisco, during the Korean War.

He is a graduate of the University of California at Berkeley, where he received his B.S. degree (1945) and Ph.D. degree (1949) in chemistry. His principal scientific work has been in the field of photosynthesis. He is coauthor (with Melvin Calvin) of two books: "The Path of Carbon in Photosynthesis" and "The Photosynthesis of Carbon Compounds." His publications in scientific journals number about 75. A description of earlier work on photosynthesis in which he participated can be found in his article "The Path of Carbon in Photosynthesis," which appeared in the June 1962 issue of *Scientific American*. An article on "Use of Controlled Photosynthesis for Maintenance of Gaseous Environment," by Dr. Bassham, appeared in the October 1954 issue of *Naval Research Reviews*. In 1956-57, he held a National Science Foundation Senior Postdoctoral Fellowship, spending the year at the University of Oxford. From 1957 to 1959, he served as Lecturer in Chemistry at Berkeley. His present position is Research Chemist and Associate Director of the Laboratory of Chemical Biodynamics at the University of California, Berkeley.

* * *

Medical Officer Promoted

RADM Conard

CAPT Robert A. Conard, USNR, a member of Naval Reserve Research Company 3-9, Upton, Long Island, New York, has been promoted to the rank of rear admiral, Medical Corps. In civilian life, Dr. Conard serves with the Medical Department at Brookhaven National Laboratory.

RADM Conard received his medical degree in 1941 from the Medical College of South Carolina and spent 14 years in the Navy as a medical officer. During World War II, he served on a cruiser in the South Pacific. Since then, he has specialized in the field of nuclear medicine. He has participated in numerous studies on the effects of radiation, both in the laboratory and in association with the nuclear bomb testing programs in Nevada and the Pacific.

In 1955, he joined the staff of the Medical Research Center at Brookhaven, where he has continued studies on the medical effects of radiation. Admiral Conrad is in charge of the medical team that goes to the Marshall Islands annually to conduct medical surveys of the Marshallese people who were accidentally exposed to radioactive fallout following a bomb test in 1954. He has been involved in extensive studies on the effects of fallout radiation on these people since the accident occurred.

Promotion Selections

Two thousand and thirty three Naval Reserve line officers were selected for promotion to lieutenant commander by the Fiscal Year 1966 Reserve Selection Boards. Among those selected were 42 Research Reservists, who are listed below:

FOR LIEUTENANT COMMANDER

	NRRC		*NRRC*
Allen, Norman T.	12-1	Klein, Melvin A.	3-4
Amsler, William E., Jr.	3-8	Langworthy, James B.	5-9
Anderson, Benny A.	3-5	Lederman, Peter B.	3-1
Andrews, Charles H.	8-4	Marra, Bruce L.	4-3
Baker, Robert P.	8-7	Martin, Albert J.	5-9
Baldwin, Robert C.	4-4	Maycock, Paul D.	8-12
Barr, Edward S.	11-5	McLean, Charles R.	4-7
Bayles, John J.	11-8	Messenger, Ward P.	1-1
Biehler, Wayne E.	12-4	Miller, Max K.	8-5
Busharis, John G.	3-2	Mischitelli, Ralph P.	3-7
Caplan, Paul E.	11-2	Morrison, Robert L.	3-14
Conti, Peter S.	11-2	Parke, John S.	9-15
Gerdon, Paul J.	5-8	Peavy, Wesley R.	5-10
Gilman, Walter L.	3-14	Phillips, Lawrence D.	9-3
Gleason, Burton J.	9-5	Pitt, Woodrow W., Jr.	6-3
Haskew, Eugene S.	6-18	Rutledge, Delbert L.	5-10
Heckler, George F.	1-2	Snedeker, Earl K., Jr.	4-1
Hill, Ernest H.	3-7	Touchton, Charles F., III	5-10
Hohman, Glenn W.	3-2	Townsend, Bobby N.	8-4
Hollien, Harry F.	6-4	Williams, James M.	8-9
Hough, Hugh V.	8-4	Van Horn, George A.	4-4

Date of Rank		*Designator*	*Year of Birth*		*Education*	
Earliest	7-2-53	1105:28	Earliest	1920	Doctors	4
		1315:1	Latest	1936	Masters	7
Latest	7-1-61	1355:1	Median	1932	Bachelors	31
		1405:9				
Median	6-1-60	1515:2				
		1615:1				

U.S. GOVERNMENT PRINTING OFFICE : 1966 O—220-666

Deep-Sea Search—Continued from page 8

around the bomb, encasing it like a mummy. Realizing that if ALVIN became enfolded in the parachute, they probably would be unable to free themselves, the pilots turned sharply away, relying on the vehicle's quick response to its controls to avoid entrapment. The parachute did entangle itself in CURV, but not seriously enough to hamper the lifting operation, which was then begun. Both CURV and the bomb were hoisted successfully to the surface and deposited aboard the PETREL.

Throughout the entire operation, ALVIN functioned with only minor mechanical breakdowns and received no damage—a performance which is a credit largely to the thorough overhaul given the craft by Woods Hole engineers last fall following the summer test series. ALVIN now is at Woods Hole being checked over carefully in preparation for deep-ocean engineering and oceanographic research to be undertaken in the Bermuda and Bahama areas this summer.

Texas A&M University—Continued from page 17

helpful way in which ONR has been able to provide support to oceanographic institutions. Most cruises of our research vessel are truly joint ventures, involving in one way or another funds provided by the university, ONR, NSF, AEC, and other sources. But it has been more often true than not that ONR support has provided the broadest coverage, even though the actual dollars expended are no more for ONR than for, say, NSF. Both the administration and the scientists are appreciative of this fact.

At this writing, the future of oceanography appears to be brighter than in any time of its history. Better instruments now are available and even better ones are on the drawing boards; well-trained students are entering the field in increasing numbers; industry again is showing interest in supporting the academic aspects of the discipline; and, at Texas A&M University in particular, the oceanographic staff shows promise of expanding sufficiently to make it possible for professors to pay greater heed to their private research. At the same time, we must be prepared to see the cost of pursuing oceanography continue to rise for some years to come. In a field in which certain expendable tools of the art are reckoned in hundreds of dollars, and a dive in a deep submersible requires thousands of dollars, we cannot expect to offer instruction at the usual cost-per-unit basis.

In our opinion, government agencies and private industry that will contribute to the support of oceanography can look to ONR for guidance in planning programs for the effective spending of funds in this growing science.

Michelson Hall, a $14-million science and mathematics building is now under construction at the Naval Academy, Annapolis, Maryland. The building is named in honor of the Academy's most famous scientist-graduate, who became the first person to measure accurately the speed of light and the first American to receive the Nobel Prize in physics.

The science building is the key structure in a $55-million Academy modernization program, scheduled for completion in 1971, involving the remodeling of many existing buildings, relocation of industrial facilities, re-routing of road networks, and new plazas, pedestrian areas, and entrances.

IN THIS ISSUE

VOL. XIX NO. 6

NAVAL RESEARCH REVIEWS publishes highlights of research conducted by Navy laboratories and contractors and describes important Naval experimental facilities. Manuscripts submitted for publication, correspondence concerning prospective articles, and changes of address, should be directed to Code 740, Office of Naval Research, Washington, D.C., 20390. The magazine is listed for sale by the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C., 20402. Subscription price: $1.50 per year in the U.S. and Canada; $2.00 per year, foreign; $0.15 per individual copy. The issuance of this periodical approved in accordance with Dept. of the Navy publications and printing regulations.

EDITOR: Richard D. Olson

NAVSO P-510

Rear Admiral J. K. Leydon addresses members and friends of the Office of Naval Research during its Vicennial Banquet, which was held in Washington on the evening of May 4. Directly in front of the admiral, facing the camera, is the traditional birthday cake, and at his left is Mrs. John S. Foster, Jr., wife of the Director of Defense Research and Engineering, Office of the Secretary of Defense. The banquet featured the presentation of the Captain Robert Dexter Conrad Award to Rear Admiral Levering Smith, Director, Special Projects Office, and an address by the Honorable Paul H. Nitze, Secretary of the Navy. Earlier in the day, ONR held its Vicennial Convocation, in which a number of distinguished scientists and Naval officers participated.