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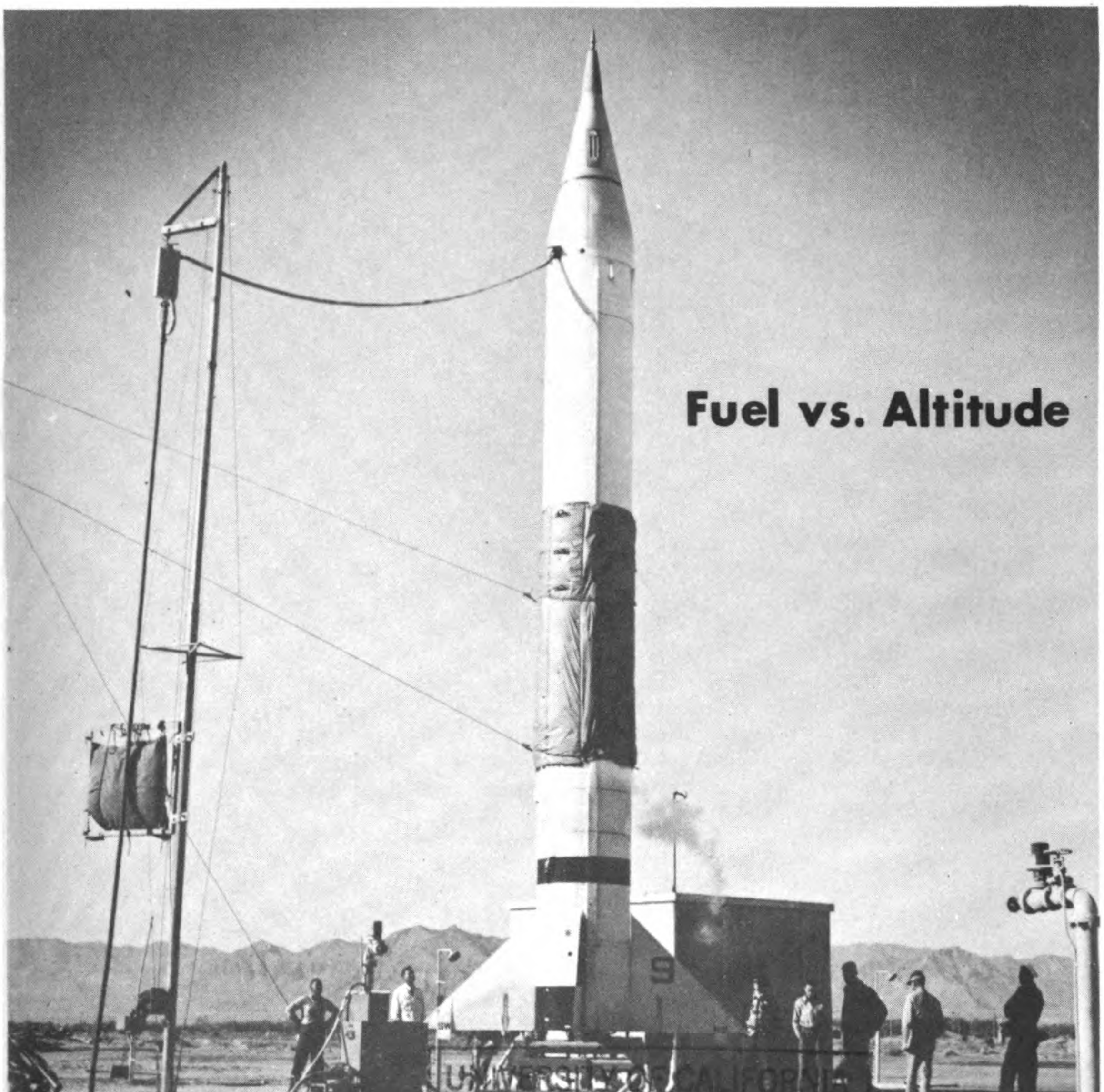
RESEARCH REVIEWS



Fuel vs. Altitude

NAVEXOS P-510

DEPARTMENT OF THE NAVY
WASHINGTON, D. C.

ON THE COVER: Excess oxygen escaping from a VIKING before take-off, in spite of padding. The better the balance between fuel and oxidizer, the greater the likelihood of both burning out together, and the higher the rocket will go. For an engineering solution to this problem, see page 12.

Research Reviews endeavors to report briefly highlights of technical progress in research by Navy laboratories and contractors and the development of important naval research facilities. Articles which meet these broad criteria and possess a good degree of readability are welcomed. Manuscripts and changes of address should be sent to Code 740, Office of Naval Research, Washington, D. C.

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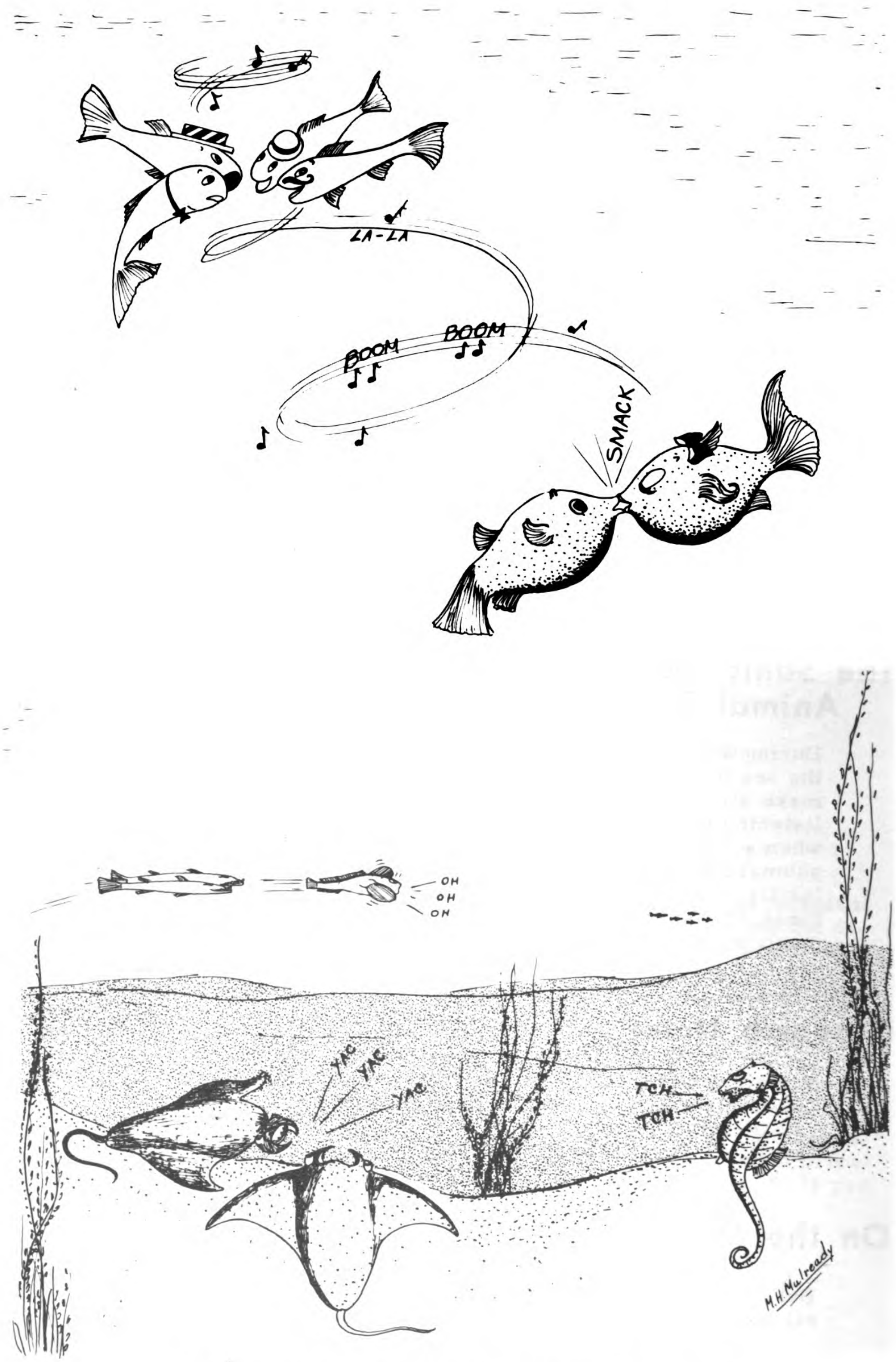

Decibels in the Depths. See article on Page 13.

Effects of Ultrasound on Tobacco Mosaic Virus

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Sound that is too high for human hearing has few applications but these few are impressive and promise others. Among the most fascinating is the production of superior vaccines by ultrasonic techniques. A whole new area of medical research has been opened by this development, which may have as its long-term result a drastic reduction in the number and kinds of diseases plaguing mankind.

It all began twenty years ago when Wendell M. Stanley, a young biochemist on the staff of the University of California, earned himself a Nobel prize by showing that viruses could be crystallized.* These tiny, elusive particles which are responsible for so much mischief in our daily lives are even too small to be observed under an ordinary microscope and can only be seen in an electron microscope. Like other living organisms, they are able to multiply but probably only when in contact with living cells. Stanley's work really dealt, therefore, with that mysterious borderland between living and dead matter and paved the way for the spectacular progress which has since been made in this field. His specific contribution was the isolation from a large number of tobacco leaves, attacked by so-called mosaic disease, of a crystalline substance which proved to be highly infectious. This was clearly the contagious agent.

Tobacco mosaic virus has several features which make it very desirable for scientific investigations. It can be readily grown in tobacco plants and is obtained in the pure state by comparatively simple methods. It exists in relatively high concentrations in the plant and can be further concentrated during purification. In addition, the virus is extremely stable by comparison with many other viruses, very homogeneous in size and shape and comparatively large. Furthermore, it retains its ability to infect susceptible plants over long periods. Since all viruses have certain common properties, studies with tobacco mosaic virus have yielded information applicable to viruses in general.

Tobacco mosaic virus is rod-like in shape. The basic infectious virus unit is generally conceded to be 280 millimicrons long and 15 millimicrons in diameter. This means that approximately 90,750 virus particles laid end-to-end would span an inch. Theoretically, one such entity is sufficient to cause infection in a susceptible plant. In a period of ten days to two weeks after infection, the diseased plant contains literally millions of the basic infective units, all of which are descendants of the initial invader. Only the barest beginnings have been made in determining how such myriads of infectious units arise from one of a few progenitors. It seems certain that reproduction does not occur by means of any usual or well-known mechanism, such as simple division.

*Stanley, W., Isolation of a Crystalline Protein Possessing the Properties of Tobacco Mosaic Virus, Science 81, 644-45 (June 28, 1935).

There is evidence, however, that viruses in general reproduce by some complex physicochemical process. The activities of cells infected by the virus seem to be redirected so that virus particles are produced rather than the normal cell constituents.

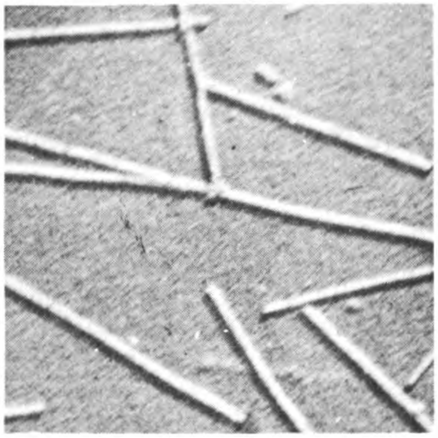
One outstanding characteristic of tobacco mosaic virus is its ability to build end-to-end or linear aggregates of the basic unit. Under some circumstances this tendency becomes very pronounced. Thus, five or six or more single virus particles may aggregate linearly to form a long filamentous structure, as shown in Fig. 1A. Fig. 1C shows the basic or monomeric form of the virus prior to end-to-end aggregation which results in polymeric forms.

The ability of the virus to aggregate linearly has caused considerable speculation with regard to the polymerization process and with regard to the strength of the forces necessary to cause the separate virus entities to bind themselves together in this fashion. Some workers have stated that "the joints formed by end-to-end union of particles appeared to be as strong mechanically as other positions along the rods."

It is known that sound fields of sufficient intensity will break or disintegrate bacteria and other microorganisms. Accordingly, we decided to try using sound fields to determine the strength of forces of end-to-end aggregation as compared with the intrinsic forces involved in maintaining the monomeric form of tobacco mosaic virus as a unit.

For this purpose, sound waves vibrating at a frequency of 7,000,000 cycles per second were employed. These and all other sound waves oscillating at a frequency greater than 20,000 vibrations per second are generally termed ultrasonic vibrations. Such vibrations were produced by means of an oscillating quartz crystal. When, under the proper conditions, a quartz crystal is excited by an electrical impulse, it vibrates at a frequency which is dependent on its thickness. As the thickness of the quartz decreases, the number of vibrations per second increases. In this case, a wafer-thin crystal was used. Tobacco mosaic virus was exposed to vibrations produced by this crystal, and the effects on the virus were determined by viewing it in an electron microscope after exposure to ultrasonic waves.

Though not difficult, a rather detailed and time-consuming process is necessary in order to obtain the purified virus suspension used in this study. All viruses must be grown or cultured on suitable living tissue or cellular material. In no case can a virus be cultured on synthetic material. Tobacco mosaic virus is ordinarily grown in tobacco plants from which it is subsequently extracted and purified for research purposes. In extracting the virus, diseased tobacco plants were harvested and frozen. The leaves were then ground in an ordinary food grinder and the resulting pulp was squeezed through four layers of cheesecloth. By this process, a dark brown juice was obtained. The juice was then centrifuged for a short time at sufficient speed to separate finely ground particles of plant leaves from the liquid portion of the juice containing the virus. At this point, the only tasks remaining were to separate the virus from the plant juice and from any small remaining particles of plant debris not separated by the initial centrifugation.



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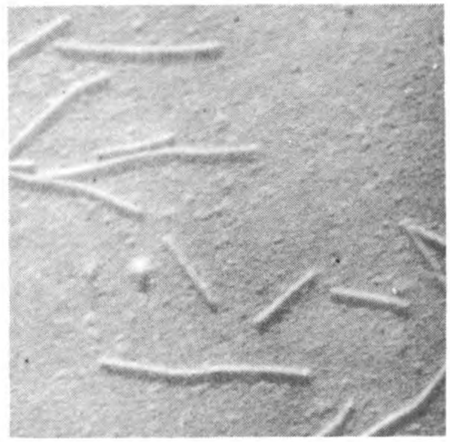

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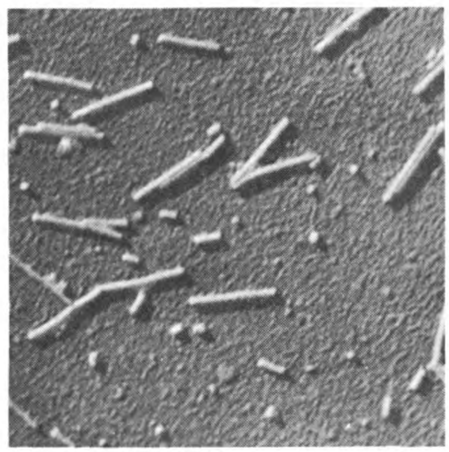

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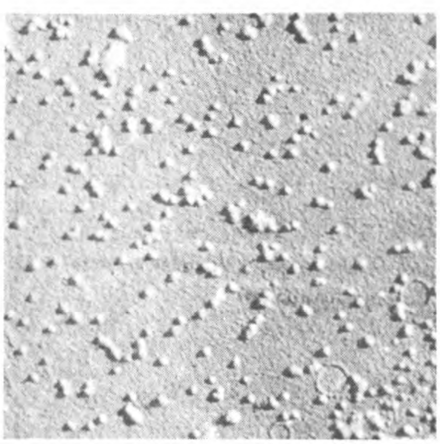

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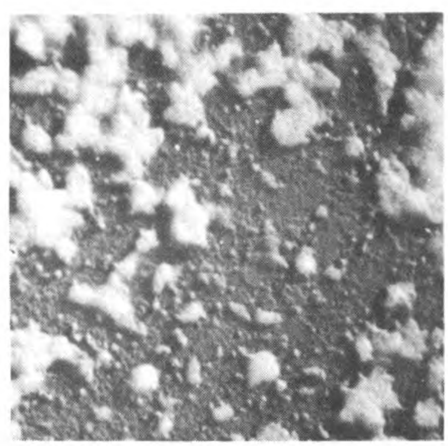

F

Fig. 1. Electron Micrographs of Tobacco Mosaic Virus, 35,100 x

All viruses are so small that they do not settle out of liquids on standing. It becomes necessary, therefore, to force them out of suspension. This is done by employing centrifuges which rotate at very high speeds. Tobacco mosaic virus is quite readily pulled out of suspension by spinning at speeds sufficient to produce forces 40,000 times that of gravity.

The action of ultrasonic waves is complex, and the extent to which tobacco mosaic virus is affected by them depends on several factors. The more important of these are wave amplitude and exposure time. Various workers have shown that frequency is far less critical than amplitude.

Linearly aggregated virus suspensions, as well as suspensions composed only of single virus units, were exposed to sound. Progressive increases in the ultrasonic power were employed to determine in a stepwise manner the effect of sound on the virus.

In the case of linearly aggregated virus, it was readily shown that ultrasonic waves effected a marked decrease in the linear aggregation accompanied by a simultaneous increase in the number of basic units 280 millimicrons long. This effect was produced at comparatively low ultrasonic power levels. As the power was increased, an increasing number of fractures at the joints formed by end-to-end union of particles was observed. With a further increase in the ultrasonic power level, aggregated and unaggregated virus particles were fragmented further. Finally, at very intense power levels, the virus was highly disintegrated. Numerous very small particles were produced, as shown in Fig. 1E.

The results of the exposure of tobacco mosaic virus to increasing ultrasonic power levels is shown graphically in Fig. 2A, 2B, 2C, and 2D on the next page. This graph does not show the effects of ultrasound on the virus at maximum power levels. In addition to the increase in the number of basic units, as revealed by the graph, another effect can be seen. The graph shows a progressive increase in particles 175 to 205 millimicrons long. In Fig. 2A, these particles comprise 1.7 percent of the total; in Fig. 1D, 9.5 percent. On an over-all basis, 38 percent of the fragmented virus produced by ultrasonic treatment consists of particles 175 to 205 millimicrons in length. This is a highly significant fraction and suggests a weak spot in the physical structure of the virus rod.

Fig. 1A to 1F are electron micrographs which show the progressive decrease in linear aggregates of tobacco mosaic virus with an increase in ultrasonic power level. Particle-size measurements of 110 of the type of virus fragments seen in Fig. 1E were made. There were 34 particles, 20 to 30 millimicrons long, 67 of which were 30 to 40 millimicrons in length, and only seven, 40 to 50 millimicrons long.

The mechanism by which sound fields produce their effect on biological material is of some interest. All of the disintegrating effects of sound fields are apparently due to a phenomenon known as cavitation. This phenomenon consists of the production of small voids in a liquid exposed to sound fields of sufficient intensity. The voids are created

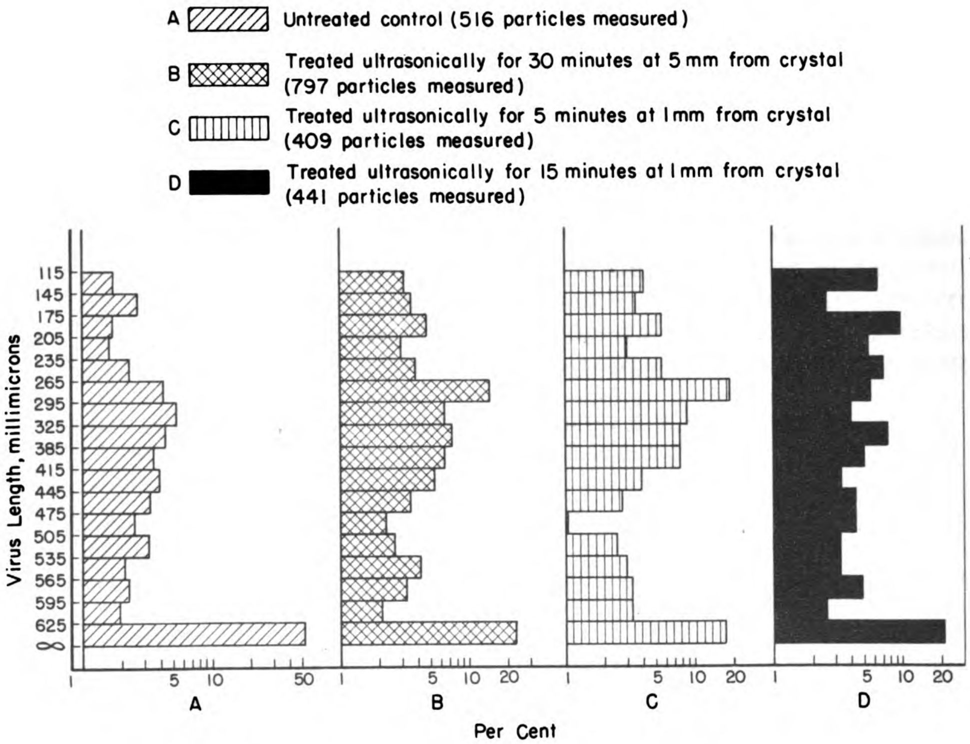

Fig. 2. Tobacco Mosaic Virus Length Distribution from Electron Micrographs

by large differences in pressure in the sound field. As the voids are produced, gases dissolved in the ultrasonically treated liquid rush in and partially fill the voids. Subsequently the voids collapse or implode rapidly with the production of enormous pressures and accelerations of liquid particles. These large forces and perhaps others are responsible for the effects of cavitation on biological material. As the intensity and amount of cavitation is increased, the effects on various substances become more pronounced.

There can be little doubt that cavitation is not the only factor responsible for fragmentation of tobacco mosaic virus in ultrasonic fields. Particularly where extreme fragmentation of the type seen in Fig. 1E occurs, a liquid temperature of approximately 65°C is required. It appears, therefore, that heat in combination with the cavitational forces produced in an intense sound field may be jointly responsible for the effects shown in Fig. 1E. These data indicate that, at comparatively low ultrasonic power levels, end-to-end virus aggregates fracture into predominantly basic virus units. It can be postulated, therefore, that the forces that bind together the basic units to form linear aggregates are collectively much weaker than the intrinsic forces holding the virus together as an entity. These investigations also show that there is a probable weak spot or area in the virus at a point 175 to 205 millimicrons from one end. Since intense energy fields are required to disrupt the virus to the extent shown in Fig. 1E, it also follows that the basic unit of tobacco mosaic must be a closely knit physical structure as compared with many other biological entities. This is not surprising, since, in virtually all respects, tobacco mosaic virus has shown itself to be very stable.

In conjunction with ultrasonic exposures and subsequent electron-microscope studies, determinations of the effect of ultrasonic rupture on the infectivity of the virus were made.

To assay the effect of ultrasound on the infectivity of the virus, Scotia beans were used. When the primary leaves of this plant are rubbed with suspensions of tobacco mosaic virus, small brown necrotic lesions appear at points where the virus has invaded the tissues of the leaf. As in bacterial plate counts, it is assumed that each lesion arises from a single infectious virus unit. By the use of this technique, it is possible to determine the infectivity of a virus suspension and to compare this with the infectivity of other suspensions.

After exposure of a virus suspension to ultrasound, a small amount of the suspension was rubbed on the surface of the uppermost leaves of Scotia beans just after they had unfolded. An unexposed sample of the virus having the same concentration was applied to the leaves of other Scotia bean plants to serve as a control. Employing this method, all virus suspensions exposed to ultrasound were assayed to determine the effect of the sound field on the infectivity of the virus.

In general, as the ultrasonic power input was increased, the infectivity of tobacco mosaic virus decreased in the case of unaggregated basic units. At very low vibrational amplitudes, there was little or no effect on the virus. Exposure to higher vibrational amplitudes produced a larger percentage of particles shorter than 280 millimicrons. Since the 280 millimicron-length particle is the basic infectious unit, a break in its physical structure makes it no longer infective.

After producing a significant increase in the output energy of the 7-megacycle ultrasonic transducer, infectivity studies were made of virus suspensions exposed to more intense ultrasonic fields. Under such conditions, the infectivity was reduced drastically, in some cases as much as 95 percent. This was associated with extreme fragmentation of the basic virus units, as shown in Fig. 1E.

Tobacco mosaic virus is a nucleoprotein. When injected into the animal body, protein and protein-linked substances are antigenic and elicit the production of antibodies. When brought together in a test tube, an antigen will react with its corresponding antibodies, or, to a less marked degree, with antibodies produced against similar substances. The antigen-antibody reaction is highly specific and, in addition, extremely sensitive. The specificity of the antigen-antibody reaction is believed to be based on the complementary chemical configuration of antigen and antibody.

Fragmentation of tobacco mosaic virus to the extent shown in Fig. 1E was very marked, and it seemed reasonable to suppose that chemical groups not exposed at the surface of intact tobacco mosaic virus might have been exposed by the ultrasonic fragmentation process. This posed the question of the antigenic relation between this material and intact virus, and the following serological studies were made.

Two rabbits were injected in the ear vein with intact tobacco mosaic virus. Two other rabbits were injected in the same manner with fragmented virus. Each of the rabbits received successive injections of 0.1, 0.2, 0.4, 0.8, and 1.0 ml of antigen. Injections were made three days apart in every case.

Ten ml of blood were taken from each animal seven days after the final injection using the heart-puncture technique. The blood sera were prepared by a standard method and refrigerated. The sera from animals injected with like materials were pooled and used throughout the serological tests.

Prior to serological studies, the concentration of the fragmented and intact virus suspensions was determined by Kjeldahl analysis for protein nitrogen. Complement-fixation studies were undertaken first. Complement fixation is a very sensitive serological test which determines the specificity of reaction between given antigens and antibodies. Antibodies produced in response to the injection of a particular antigen will react strongly with that antigen. Antibodies produced against a similar antigen will also react, but not so strongly. It is possible to determine visually the degree of specificity of the antigen-antibody reaction.

In the first complement-fixation tests, intact tobacco mosaic virus was reacted with its specific antibodies which were contained in the sera of rabbits injected with the virus. Likewise, complement-fixation tests were run with disintegrated virus and antibodies to it.

Cross complement-fixation studies were then conducted. Intact tobacco mosaic virus was allowed to react with antibodies to fragmented virus, and fragmented virus was allowed to react with antibodies to intact tobacco mosaic virus.

The results of these rather complex reactions must, of course, be further verified, but tentatively they indicate that there were not any marked differences antigenically between whole and disintegrated tobacco mosaic virus. The results of the studies also showed that disintegrated tobacco mosaic virus is as good an antigen as the intact virus. Thus, it appears that ultrasonic disintegration did not alter markedly the antigenic specificity.

Based on these results, it would seem logical to apply ultrasonic techniques to pathogenic bacteria in an attempt to isolate those antigenic materials which, when injected into the human or animal body, affect the production of disease-resisting antibodies. Preliminary results of such work might indicate that ultrasonic techniques have considerable promise in the production of superior vaccines. These findings represent, therefore, one of the numerous instances wherein research may lead to practical, useful end products while contributing at the same time to fundamental knowledge.

On November 12 it was announced that the TERRIER, a slender, needle-nosed, ground-to-air guided missile, had been successfully launched—and had destroyed targets—from the deck of the venerable old battleship MISSISSIPPI.

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Solving Production and Inventory Problems

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Imagine that you are manufacturing a certain product and are faced with the problem of keeping ample supplies of it in various warehouses to meet demand. How would you go about determining the "best" pattern of production and shipments? The combination of common sense and trial and error, usually referred to as "judgment" can help you to make good decisions, but to find the best solution is a more formidable problem. In the fall of 1952, a research team* at the Carnegie Institute of Technology set out to find the answer. They chose as the subject of their study a paint-manufacturing company. The following description of its operations at the time the study began will point out the problems encountered. The balance of the article is concerned with the method which is being used to solve them.

Plant facilities included a factory warehouse and a group of about 25 district warehouses (and stores) supplied by the factory. A wide variety of items were manufactured. There were some 500 different types of paints, and each type was sold in a number of can sizes. In all, about 1500 items were regularly manufactured and stocked. Additional items were made on special order. Although a relatively small number of items made up a large part of the total gallonage, maintenance of a full line of products was an important objective.

Most of the items were subject to wide seasonal fluctuations in sales. Sales in the peak summer months, for example, were three to four times as large as in the late autumn months. The company tried to solve the production problem thereby created by producing small-size cans during the off-season. The time required to manufacture the paint was relatively short—a few days to two weeks in the factory, and a day or two in shipment. Most of the warehouses received shipments weekly or oftener. Emergency orders were shipped as soon as the paint was available, while normal replenishment orders were shipped at regular intervals.

Production planning and control were based largely on orders received from the branch warehouses. As orders were received, they were checked against factory-warehouse inventory levels to determine outages. These were summarized at the beginning of each month and the most serious cases handled first. Some color and chemical sequences of paint manufacture were more economical than others, and these were followed where possible. The actual scheduling was a dual function of the foreman and scheduler. The overall objective for a given month was to eliminate all shortages that existed at the beginning of the month.

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*Professors C. C. Holt, H. A. Simon, F. Modigliani, R. Schlaifer, and the author.

The principal problem arose from the fact that the attempt to carry sufficient stocks of each individual item at the factory and warehouses seemed to build up excessive total inventories. One technique for coping with this situation was the use of several types of priority orders on the factory. There was also some interest in the possibility of ameliorating the situation by centralizing information on stocks and sales at all levels; an informal policy of this type had paid off during a previous shortage period.

The company was also interested in the possibilities of stabilizing production throughout the year. Employees tended to reduce their effort in the off-season in an attempt to spread out the work. A definite policy of level production might remove this fear and improve efficiency. It might also reduce the amount of premium costs associated with overtime payments during the peak season.

The task of designing an inventory and production-control system involves more than a determination of general policies. Policies, to be effective, must be related specifically to the decisions that are made by executives at the several levels of the organization. The inventory and production-control decisions that were selected for intensive study in the paint company were:

1. Decisions to order from the factory specified quantities of specified items,
2. decisions to make a shipment of a specified collection of items to a warehouse at a specified time,
3. decisions about the operating rate of the factory—the aggregate production, size of work force, overtime operation, etc.,
4. scheduling decisions determining which items are to be produced when, and in what quantities, by the factory.

Since these decisions must be made repeatedly, it is important that the method of arriving at them be relatively simple. It may even be necessary to sacrifice some accuracy in order to obtain methods which can be readily applied by operating personnel. The frequency with which these decisions should be made is in itself problematic. It is also necessary that certain costs be taken into account, particularly the following:

1. Costs of holding inventories and costs of stock runouts,
2. costs of shipments,
3. costs of manufacturing that depend on the order in which individual items are scheduled for production, and upon batch sizes, and
4. costs depending on the rate at which the factory operates—size of labor force, overtime, and changes in rate of operation.

Even without a detailed analysis of this cost structure, certain implications are evident. Inventories are held to prevent stock runouts, to avoid the high costs of manufacturing uneconomically small batches, and to permit stocks to be accumulated during seasons of light demand for sales during seasons of heavy demand. Some balance must be maintained, however, between the costs and losses associated with each one of these factors and the corresponding cost of holding inventories.

Further complicating any decisions in this area is the uncertainty of the future. Since no crystal ball exists to predict future sales, there will be errors in any forecasts. It is, therefore, imperative that any practical method of arriving at decisions have "built in" some way of adjusting to past forecast errors and providing for future forecast errors.

The factory, district warehouses, and retailers form a five-stage system. Between each pair of "stages" is a pool of inventory: raw-material inventory, factory-warehouse inventory, district-warehouse inventory, and dealer's inventory. In the long run, the quantities that pass through each stage are determined by the quantity passing through the final stage, the quantity sold. However, in the short run the rates at which quantities flow through a particular stage can vary independently of the rate at which they are flowing through other stages.

The central problem in such a cascaded system is that it can be set into oscillation by fluctuations in the rate of flow at the final stage that have not been foreseen and provided for. Furthermore, such oscillations can even be greatly amplified by the reactions that take place in the earlier stages of the system. For example, assume a sudden increase in the sales of a particular type of paint. Dealers will increase their orders not only to meet the increased demand but also to replenish their depleted inventories. The inventory of this line held at each warehouse is determined by the individual warehouse managers and the inventory at the factory warehouse by the factory manager. If the quantity at a given warehouse is low, that particular warehouse is soon out of stock. This will often result in lost sales while more paint is being secured from the factory. If the inventory at the factory is low, there may not be sufficient paint on hand to fill the orders of the branch warehouses. If the item is out of stock, more paint of this type will have to be produced as soon as possible. Since this production will have to be made on immediately available equipment, the production cost may be considerably increased. Rescheduling of other products will be necessary which in turn will result in other items being out of stock with further lost sales, and the whole cycle repeated with another item causing the system disturbance.

The overall research strategy was first to determine desirable policies to handle each of the four types of decisions required in the system, namely: warehouse orders, warehouse shipments, factory operating rate and factory schedule. Secondly, these separate decision rules were to be fitted together to minimize the total costs of the system. Thirdly, provision had to be made for coping with problems arising in the application of the new decision procedures. Fourthly, the procedures developed had to be tested by a specific application.

Decision rules obtained by this approach are applicable to a wide class of situations and problems. Testing the rules in an actual operating company provides a basis for confidence that would otherwise be lacking. It also provides valuable background information for use in applying these rules to other situations.

One important characteristic of this research strategy is that of assigning explicit numerical values to all costs and relevant variables.

Admittedly such quantification is often necessarily crude, particularly where such intangibles as morale and customer satisfaction are concerned. However, judgmental decision-making, through its subjective weighing of various factors, faces the same problem. Despite its difficulties the explicit quantitative weighing of factors is helpful in focusing attention on the essentials of a problem. The most important reason for explicit quantification is that it makes available for use a large body of mathematical and statistical techniques.

It is seldom if ever feasible to deal with a problem in complete detail. Therefore, strategic simplification is necessary. Explicit quantification is a great aid in deciding which simplifications are justified and which are not.

As mentioned before, the goal of the program was to find explicit solutions of decision-making problems in the form of decision rules. These rules would be of the form "when such and such a situation occurs, do thus and so." Optimum lot-size rules are examples. In arriving at such rules the relevant costs, forecasts, and relationships are all taken into account. Once the decision rule is established, a decision can be readily obtained by making a simple calculation using current data. The utility of this type of rule is clear when a large number of decisions have to be made on a routine basis. For example, where there are a large number of different products, simple "order-point" inventory rules are extremely useful.

However, it should not be inferred that decision rules eliminate the need for judgment on the part of the decision-maker. Instead, his judgment is required to determine what factors are relevant in making the decision so that the appropriate decision rule can be selected for the case at hand.

Given unlimited cleverness, it would undoubtedly be desirable to develop methods for making all the production and inventory decisions simultaneously and in proper relation to each other. However, there are complex interactions between these decisions. For example, shipment decisions cannot be made optimally without consideration of the specific effects of the shipment schedule upon factory operations. The present state of the art is such as to make a global approach completely unfeasible. The alternative approach taken in this study involves two steps:

1. Working out policies to govern each of the four kinds of decisions enumerated above, taking general account of the impact of one decision upon the others, but not attempting to deal with all simultaneously in detail.
2. testing the system so evolved for the mutual compatibility of its parts. That is, making certain that the decisions relating to one part of the system do not nullify the decision policies of another. For example, if order points and order quantities are established for individual items, these will determine the aggregate demands of the warehouses upon the factory. For the parts of the system to be compatible, these aggregate demands must not exceed the quantities that the factory, in terms of its own decision procedures, is prepared to supply.

To a certain extent problems of compatibility can be anticipated and avoided by making sure, in dissecting the system into its component decisions, that as few of the built-in interrelationships as possible are cut apart. The decision rules should be so designed that reactions at each stage of the system take account, so far as possible, of what is going on at other stages. For example, information about warehouse inventories or even dealers' inventories may be of great value in setting factory rates so as to minimize manufacturing costs.

The foregoing has outlined the nature of the production and inventory-control problems in a paint company, the decisions that have to be made, and the general methods and techniques which are being used in making a research attack on these decision-making problems. In the course of describing the problems, the various relevant costs were listed.

One additional cost not previously mentioned must also be kept in mind when decision-making methods are being evolved. That is the administrative cost of employing these methods in making decisions. Perhaps this can best be said by stating the overall objective of our research in the area of production and inventory control, namely: good decisions at low administrative costs. Obviously, even if there are savings to be realized through new techniques of dealing with production and inventory problems, the cost of actually using these techniques must be low enough so as not to outweigh the savings realized.

Propellant-Level Sensors for Viking Rockets

One of the multitude of problems involved in flying rockets is to get the amounts of the two propellants—fuel and oxidizer—balanced so that both will be completely consumed at the end of powered flight. They practically never are. The consequent loss in efficiency due to the weight of the left-over propellant—called outage—may cut the optimum altitude by as much as 30 percent. Take Viking 11, for instance. With no outage it might have reached 180 miles; actually it only got up to 158 miles. The outage was only 3.5 percent, yet it weighed some 400 pounds.

NRL's rocket engineers have recently developed mercury manometer-tube sensors which automatically measure the mass-level of both propellants. They worked satisfactorily in recent Viking flights. The next task is to link the sensors with a servo mechanism whereby the proportions of the propellant masses at any time will determine the setting of a flow control valve which would simultaneously exhaust both propellants.

The sensor and control system will add some weight to the rocket, of course. But the added weight of a 30 pound unit, or less, may save 300 to 600 pounds of unused fuel.

A control system of this type may also be adapted for long-range ballistic guided missiles. Thereby, both the efficiency and effectiveness of defense weapons of this category would be markedly increased.

The Sonic Marine Animal Problem

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Five days after Pearl Harbor the U.S.S. PERMIT made the following entry: "0810. Sound picked up unusual noise ... could see nothing through periscope on that bearing. This noise sounded like hammering on steel in a non-rhythmic fashion accompanied by porpoise noises. Headed for sound. At times could be heard through 360°."

Within a week the U.S.S. TARPON reported "Noises which sounded as if the deck grating over the boat storage had been lifted and dropped three times. Shortly thereafter, sound heard echo-ranging from two ships bearing in the direction of the Gulf (Albay, P.I.), but no propeller noise was heard. Nothing was in sight through the periscope."

At 2030 on Christmas Eve the U.S.S. SALMON "heard screws dead ahead but this was up moon and clearly visible and there was nothing in sight."

Listeners on other submarines described unidentifiable contacts running the gamut of sound from mild beeping, clicking, creaking, harsh croaking, crackling, whistling, grunting, hammering, moaning and mewing, to the staccato tapping as of a stick rapidly and steadily drawn along a picket fence, of coal rolling down a metal chute, fat frying in a pan, and the dragging of heavy chains. Again and again during the early months of the war "false propeller and echo-ranging noises" were intercepted in areas where there were no other ships. These obscure observations were recorded in strictly SECRET Submarine War Patrol Reports.

During the summer of 1954, however, press releases throughout the country carried such factual headlines as "Fish Talk," "Scientists Listen to Fish Voices," and "Scientist Likens Noises of Fish to Those of Humans." That underwater acoustical phenomena could change in years from the category of unexplained, highly classified data to authenticated newspaper copy was made possible to a large extent by the intensive post-war research on marine sound producers, spurred on by communications and other acoustic difficulties in World War II.

Early in 1942 other reports like those of the PERMIT, TARPON, and SALMON crossed the decks of Navy trouble shooters. The underwater listening systems installed by the Coast Artillery at strategic points to give warning of approaching enemy craft were at times disrupted by unaccountable sounds. In one such case, serious variation in noise levels in waters adjacent to Fort Monroe was noted each day during the important dawn and dusk listening periods. This time schedule of "strangely loud background noise" offered a valuable clue: it occurred in early spring, when members of the croaker family are known to tune up.

With the war progressing rapidly there was little opportunity for detailed experimentation; however, preliminary observations on water noise conditions were undertaken by the Naval Ordnance Laboratory and the National Defense Research Council. These included arrangements, made by the Oceanographer of the Mine Warfare Operational Research Group, for representatives from NOL to carry on tests at the John G. Shedd Aquarium in Chicago and at the U. S. Fish and Wildlife Station at Beaufort, N. C. Resulting data on 33 species at the Shedd Aquarium and five species at the Beaufort Laboratory demonstrated that much of the questionable underwater sound might well be made by fishes. Extensive analyses of an almost continuous crackling background noise likewise identified snapping shrimp as serious offenders on southern Atlantic and Pacific coasts. Exploratory hydrophones were employed at such key points as Cape May, Miami outward to the Bahamas, Pearl Harbor, Ellice Islands, Noumea, Guadalcanal, and the Russell Islands. It was evident that marine animal sounds are widespread and can be a source of significantly high background.

While investigators were learning more and more about the possible frequency and intensity of such sounds, other significant episodes occurred. It was rumored that mines planted inside the Great Barrier Reef of Australia by enemy raiders had been exploded by sonic fishes. The noise made by a single toadfish was measured on the North Carolina coast, and it was apparently loud enough to detonate the type of acoustic mine then being readied by our Navy for use in the Pacific. A double-actuation mechanism had to be developed for protection against such biological sound interference.

At this time Japan was also suffering from the interference of marine animals with communications. Underwater noises, at times resembling enemy activity, troubled their submarines and set up so much racket they threatened the effectiveness of controlled defensive minefields. Although the Japanese Hydrographic Office assigned top scientists to study the "extraordinary phenomena of noisy sound which were said then to be observed almost periodically," the survey results were stated tersely: "Causes still unknown." Not until late 1944 did a prominent ichthyologist from Tokyo Imperial University ascertain the biological source of the troublesome sounds. Transcriptions of the 84 disc recordings on which his decision was based were brought back from Japan by CDR Charles J. Fish, USNR, in 1946 and have been studied by the author.

Even though American scientists beat the Japanese by two years in recognizing biological interference, data were not immediately available to explain the existing records or to predict when and where they might again be encountered. For this, the methods of sound production by different species, the character of the sounds, regional and seasonal variation, and the conditions under which they are produced would have to be ascertained. Indeed, in 1942 so little was understood of the noise-making propensities of marine animals that "a list of all known (world-wide) forms of marine life producing subsurface sound" prepared by the United States National Museum for the Navy included only 14 families of fishes and 17 families of crustaceans. Collected data on their sonic activity were mostly in broad descriptive terms like "nasal whine," "loud grunt," or "hoarse croak." Much was mere hearsay. Magnitudes and frequency spectra of the various sounds had not been measured.

Thus, in accordance with recommendations of the Chief of the Office of Naval Research to the Pacific Science Conference in 1946, basic research on underwater biological sound was incorporated in the program of the Pacific Oceanic Biology Project, then being initiated under contract with ONR. Intensive review of available literature in many languages added 31 families of fishes to the original USNM list of soundmakers in central and western Pacific waters, bringing the total of alleged sonic families to 42. Inasmuch as most families include many different members, it was immediately evident that potential sonic species might number thousands. Accumulated data on geographical, seasonal, and vertical distribution were gathered for each species as a basis for predicting the expected occurrence of its sounds.

The second stage of the investigations has involved actual experimentation with individual fishes. Field observations and theorizing are valuable, but the time had now come to determine the precise character of the underwater sounds including when and especially why they are produced. Between 1949 and 1954, 62 species of temperate coastal fishes, 105 subtropical and tropical fishes, 20 crustaceans, and two species of marine mammals have been auditioned by the present Oceanic Biology Project, operated by the Narragansett Marine Laboratory (NML) under contract with the Geophysics Branch of ONR. Potential soundmakers were impounded in open water or in laboratory tanks at the NML, Bermuda Government Aquarium, Bermuda Biological Station and the Lerner Marine Laboratory at Bimini, B.W.I. The animals were subjected, wherever possible, to a series of carefully controlled situations and stimulations as a means of evaluating their sonic habits. Hydrophones and tape recorders monitored the reactions of specimens when introduced into new surroundings as well as after acclimation, when fed, annoyed, frightened, crowded, drawn into competition, or otherwise artificially stimulated. Frequency spectra of sounds thus recorded have been obtained and permanent records have been added to a Reference File which will eventually include, it is hoped, the characteristic sounds of all important marine species.

In every case the particular anatomical sound mechanism has been dissected and studied. Although fish have no organs developed solely for sound production, nature has been ingenious in modifying various body parts to take over this additional function. Often the hydrostatic organ which enables certain fishes to keep in equilibrium with varying pressures of surrounding water, called the air bladder or swim bladder, becomes a sort of resonator or sound-box. Sometimes muscles are embedded in the air bladder and, by contraction, set up vibrations of walls and gaseous contents, with resultant sound; sometimes slender muscles connecting the bladder with modified vertebrae vibrate like violin strings. Thus may be explained the muffled grunts of rock hinds, sustained resonant rumbling of Nassau groupers, growling of trunkfish, drumming of croakers, and tom-tom-like beating of sea catfish.

Other fishes scrape skeletal bones against each other to produce sound. The very abundant sculpins of northern waters produce dull droning, buzzing, or long continued rumbling sounds (like generator hum) by articulating bones of the pelvic girdle; the giant-sized ocean sunfish grates its teeth in the manner of pigs or other ruminants. Puffers and burrfishes manage long bursts of nasal croaking by rubbing together their upper and lower "plates," and the sharp whining swish and chirp of filefishes also originate in the mouth—in this case facilitated by special transverse grooves on the upper incisors. Each species of fish has a characteristic sound, or series of sounds, which maintains a constant frequency pattern through repeated outbursts. Although individuals of different sizes vary somewhat in the principal frequencies exhibited, the general spectra is strikingly similar for all members of the same species. So distinctive in nature are these sounds, as a result of range limitation, harmonic quality, duration, repetition rate, etc., that the subsurface listener can soon learn to differentiate by ear the various sources in an unknown population.

A statement of maximum sound pressure for any species, however, cannot yet be ventured, for experiment has shown that the peak performance of a fish's soundmaking apparatus seldom occurs. The insistent mating call of a 203-mm toadfish repeatedly reaches 122 db in open water, whereas in the laboratory its most aggravated growl, produced by the same air-bladder mechanism, has not exceeded 118 db. Certainly the specially developed drumming muscles of the gray squeteague are capable of louder sounds than the 109.69-db croak—the loudest so far measured—of a 475-mm experimental specimen. Magnitude seems to be directly proportional to intensity of stimulation as well as to size of soundmaker.

Experimental results indicate that the majority of species may use sound voluntarily as a means of communication, particularly to implement breeding, as an expression of fright, as a measure of defense or offense, as a response to environmental changes, or as a means of orientation. Involuntarily biological sound occurs under certain other stimulation. Fish noise of mechanical origin, as well, must be looked for by the subsurface listener. Commonly such noise is associated with feeding, hence dentition and diet of the local fauna are clues to its possible source; e.g., the activity of rays is marked by loud crackling as their pavement-like teeth crush shells on the bottom, and hydrophones in shallow water populated by cunners may pick up constant clicking and chirping, which are chewing sounds.

Although the use of organic soundmaking mechanisms is usually voluntary and purposeful, experiments have proved conclusively that the majority of sonic marine forms respond only to definite external or internal stimuli and remain silent at other times. Thus, between early June and July in waters close to the Quonset Point Naval Air Station, hydrophones pick up a continuous chorus of loud boat-whistle-like sounds (pressures measured to 122.27 db for a single blast, repeated at half second intervals), whereas none of these contacts are intercepted at any other time of year. This is the identical noise that troubled U. S. Navy personnel planning for the use of acoustic mines in World War II. Had they known the comparative brevity of the "broadcasting" season and the fact that the toadfish-producer occurs only in very shallow water, this noise might have been considered an acceptable risk.

The period of greatest soundmaking is synchronized with the breeding cycle in many other fishes as well. Since spawning habits of most common species are known, the biologist can usually predict with considerable accuracy dates and locations of fish concentrations. This is valuable knowledge because, although the sound of an individual may be insignificant, the combined output of a school results in considerable volume. For instance, one drumfish croak may never reach 114 db at close range or be attenuated over 50 feet, but a nocturnal chorus of spawners has been shown to raise the general background level of a large bay at least 114 db over the audible frequency range. The characteristic drumming, aptly likened to a pneumatic drill working in concrete, may preclude the possibility of detecting slowly moving submarines by overall sonic means. Fortunately for Navy purposes, croaker noise and that of many other fishes is restricted to a comparatively low and narrow frequency band. Experiments indicate that the sounds of the majority of North Atlantic coastal species may be almost eliminated by filters without losing ships' signals.

The effect of mass broadcast is well demonstrated by the snapping shrimp, which makes its characteristic sound with the great claw. Although in this investigation a single snap made by a specimen less than three inches from the hydrophone has never reached 120 db, the din from a natural bed of these shrimp has often registered 120 db three feet away. It is a continuous crackle of both sonic and supersonic frequencies, interfering chiefly with supersonic listening. Experience has shown supersonic listening ranges for surface vessels to be reduced as much as 40 percent, and the sound of torpedoes and cavitating submarines to be seriously masked. Again the biologist becomes an important consultant; he advises that both snapping shrimp and the equally noisy squilla (with the accompanying crackle) may be expected in any body of water with coral, rock, stone, or shell bottom, in a worldwide geographical range between 35°N and 35°S, but rarely if ever in depths of more than 30 fathoms.

Whereas the occurrence of shrimp noise and much coastal fish noise is more or less predictable in fixed localities, the type of animal interference which accounts for most of the false propeller noise, phantom echo-ranging pings, and squealing heard by sonarmen can occur almost anywhere, at any time. The apparent producers are porpoises and whales, who range throughout the oceans of the world. When the members of this project charted the Submarine War Patrol Reports they found that the distribution of observed sound concentrations approximates the known seasonal distribution of marine mammals. Being inquisitive and gregarious, it is not remarkable that these animals were attracted to submarines and at times followed along for considerable distances, sounding off with "voices" distinguishable throughout the entire audible frequency range.

Field experience has demonstrated that fish sound also may be expected in deep water, even though sounds from concentrations close to shore are more noticeable. Large groupers hooked at 300 to 400 meters in the Bahamas have the same soundmaking ability as their booming shallow water relatives, and ocean sunfish taken far offshore gnash their teeth and grunt loudly. That some members of the grouper family reach a weight of nearly 700 pounds, and sunfish 2000 pounds, suggest that unexpected bursts might be quite disconcerting to a sonarman!

Nor is marine animal sound limited by the calendar. Except in those cases where sonic activity is definitely associated with the breeding season, it is logical to expect characteristic sounds anywhere and at any time within the geographical range of each sonic species. Seasonal and regional data are requisite, therefore, in any attempt to predict underwater background of biological origin within a particular area.

One of the most important results of the present investigation has been finding that routine field scanning, as practiced in the past, cannot evaluate the possible animal-sound interference. Even the most loquacious species are usually silenced by the approach of a vessel; large schools of grunts regularly ceased their croaking as they swam past our skiff lying quietly over a Bimini coral reef. Only by means of a wire-encased hydrophone suspended from a distant buoy have good field observations been accomplished, and then only after long periods of waiting. Fishes, like most other animals, take evasive action when confronted by strange contacts; made wary by even mild disturbance, they seek inconspicuous escape and an obscure hiding place in which to remain motionless and silent. Thus, to determine the character and magnitude of underwater background levels in any particular region, seasonal and diurnal field recordings must be supplemented by measurement of the sound output of every local species. It must be assumed that any one or all will contribute when properly stimulated. And adequate stimulation must be expected since biological sound is associated with almost every phase of colony life.

Although a basic approach has been taken by this project, i.e., an understanding of the character and significance of underwater sound of biological origin, the resultant sound recordings, frequency ranges, patterns and pressures of individual sounds, and data on the circumstances associated with their production may have immediate practical application in Navy problems. For instance, recordings may be useful for indoctrination of sonarmen, to familiarize them with expected animal interference; biological data, which shows what sonic forms may be expected, in what numbers and in what seasons, can facilitate prediction of sound conditions and physical data, which spots sound levels and frequency ranges, may help determine design and operation of various acoustic gear.

Intensive study of underwater animal sound was suggested by the experience of sonarmen at sea, and will continue to be sparked by the cooperation of field observers. The author will welcome information on the observations of others and suggestions for further expension of present research.

Research Notes

Miniature Gyro-Compass Ready for Fleet Use

The world's smallest nautical gyro-compass—light enough to be carried by Naval or civilian craft—has been developed by the Navy in cooperation with the Marine Division of the Sperry Gyroscope Company. It will permit small craft to navigate with direct reading true-north accuracy for the first time.

The Navy anticipates widespread use of the new instrument in the fleet, where it may replace the magnetic compass, which must be corrected at each reading to obtain true-north accuracy because of the earth's magnetic influence which varies at different latitudes.

The miniature gyro-compass has been designated the Mark 22. In rugged tests conducted by the Navy, it has proved its accuracy during sharp, fast turns of speeding boats, in adverse sea conditions, and in beachhead operations. Its development brings nearer reality a Naval goal to improve beachhead operations, by equipping landing craft and other vehicles with gyro-compasses to assure precise maneuvers and pinpoint landings in combined-arms assaults.

Occupying less than one-half cubic foot of space, the nine-pound Mark 22 compares favorably in performance with present-day 900-pound master gyros which stand four feet high. It fits easily on a shelf close to the steering station, so that a steering repeater system is unnecessary. Repeaters can be run from the Mark 22, however. Also, its extreme simplicity permits operation by personnel without specialized gyro-compass training, and its design simplifies easy replacement in the field of complete units or components as required.

The ruggedness and reliability of the Mark 22 have been obtained through a combination of new design elements with a new small, high-speed gyro and miniaturized controls which make it seek true-north.

The small, lower-priced gyro-compass also is expected to provide better navigation for civilian craft, such as tow boats, work boats, fishing schooners, and pleasure craft, as well as an economical secondary source of ship-course information for larger freighters and ocean liners.

Research Reviews Is Now For Sale

Attention is invited to the note on the inside front cover. Research Reviews is now for sale—by the Superintendent of Public Documents, not by ONR.

The publication will continue to be distributed free-of-charge to U. S. Government addressees, and to contractors doing research for the Navy.

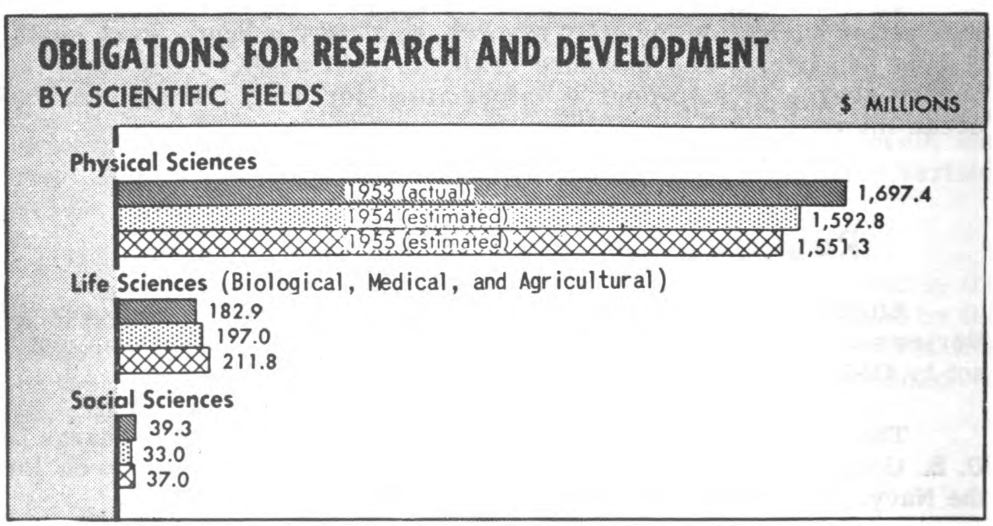
Government to Spend Two Billion Dollars on Research in 1955

In fiscal year 1955 Federal agencies will obligate an estimated $1.99 billion for research and development activities, about 10 percent less than the $2.23 billion obligated in fiscal year 1954, according to the report, Federal Funds for Science, III. The Federal Research and Development Budget, Fiscal Years 1953, 1954, and 1955, issued by the National Science Foundation.

The major decreases occurred in obligations for research and development plant and facilities, $158 million in 1955 compared with $227 million in 1954; and applied research and development, $1,669 million in 1955 with $1,703 million in 1954. Obligations for basic research in the sciences were expected to increase during the year from $120 million in 1954 to $131 million in 1955. These figures exclude approximately $176 million (1954) and $35 million (1955) of research and development funds available to the Office of the Secretary of Defense that were not allocated to specific programs at the time of writing.

About 87 cents of each dollar obligated by the Federal Government for scientific research and development went to the physical sciences; 11 cents went to the life sciences (biological, medical, agricultural); and 2 cents to the social sciences. Research and development for national security accounted for about 85 percent of the Federal science expenditures, and the remaining 15 percent was divided among all other functions of government, including agriculture, health, welfare, transportation, communications, and development of natural resources.

More than 20 Federal agencies reported on their expenditures and obligations for science. Seven agencies accounted for more than 98 percent of the total funds. The Department of Defense was responsible for about 75 percent of the funds. The other six agencies were: Atomic Energy Commission; National Advisory Committee for Aeronautics; Department of Health, Education, and Welfare; Department of Agriculture; Department of Interior, and Department of Commerce.



The North Pacific Was Once Warmer

The first evidence that latitudes north of the tropics were once covered by warmer water than at present has been obtained by the University of California's Scripps Institution of Oceanography. Cores of bottom sediments 28 feet long from two locations at the approximate latitude of Portland, Oregon, showed that beneath 10 to 15 feet of the typical buff clay of the ocean bottom were layers of white calcareous ooze.

Jeffrey D. Frautschy, geologist, who directed coring operations on the two-ship expedition, says that the ooze is composed of the shells of foraminifera, primitive animals of a type common to surface waters of present-day tropical areas. "Finding a deposit of this material at a depth of 14,000 feet, where the water temperature is now less than 35 degrees Fahrenheit, is unusual," Frautschy says, "because water this cold contains large volumes of dissolved carbon dioxide gas which is very effective in dissolving small calcareous shells before they have time to be covered up by the accumulating sediment."

"In order for such small, soluble particles to survive this long exposure, water temperature at the time of deposition must have been several degrees higher than at present. Previous evidence collected farther south suggests that during Tertiary time, about 40 million years ago, northern Pacific bottom water temperatures were in the range of 50 to 60 degrees Fahrenheit."

The cores were taken on a two-ship expedition under the direction of Russell W. Raitt, Associate Professor of Geophysics. The region explored lies about 1,000 miles west of California. It is marked by large-scale geographical features that trend in an east-west direction rather than in a northwest-southeast direction as do the mountain chains and the valleys of the adjacent mainland. Two great escarpments, or cliffs, divide the area into separate geological provinces. Each province has a characteristic depth range and type of topography. The evidence of a warmer climate is further confirmed by fossils found in marine rocks now uplifted and exposed along the shores of the North Pacific.

The chief purpose of the expedition was to determine whether the escarpments dividing the provinces have their origins in deep-seated vertical crustal displacement or are only near-surface features. This was done by measuring the travel time of sound through the sea floor. Preliminary results fail to indicate any gross differences between the crustal structure in this area and in other parts of the deep Pacific, but distinctions may show up with further study of the records obtained.

Correction

We fumbled editorially in preparing for publication Miss Miriam N. Swaffield's article on The Polaroid Color Translating Microscope which appeared in the September issue. The photomicrograph on the bottom of page 5 shows normal guinea pig cells; none were cancerous as indicated in the accompanying text. Our apologies to a conscientious author who does not wish to overstate the capabilities of Polaroid's remarkable instrument.

On the Naval Research Reserve

BuPers Approves Brookhaven Seminar

The establishment of the Nuclear Physics Seminar at Brookhaven National Laboratory as an annual event of ONR has been approved by the Bureau of Personnel. The first such seminar is scheduled to convene on 29 May, 1955 with an overall quota of 96 officers distributed as follows:

First Naval District	6
Third Naval District	12
Fourth Naval District	12
Fifth Naval District	4
PRNC	8
Sixth Naval District	6
Eighth Naval District	6
Ninth Naval District	12
BuShips and BuMed	30
Total	96

The quota of thirty made available for the use of programs sponsored by BuShips and BuMed is within the capacity of the laboratory to accommodate and train and is in excess of the current requirements of the Research Reserves Program. It is believed that those portions of the seminar devoted to nuclear power and to radioactive isotopes will provide training of value to members of these two other Special Programs.

Personnel attending the seminar are required to have obtained Secret Clearance and satisfactory completion of Navy Correspondence Course "Nucleonics for The Navy" or evidence of employment in some phase of nuclear energy including administration.

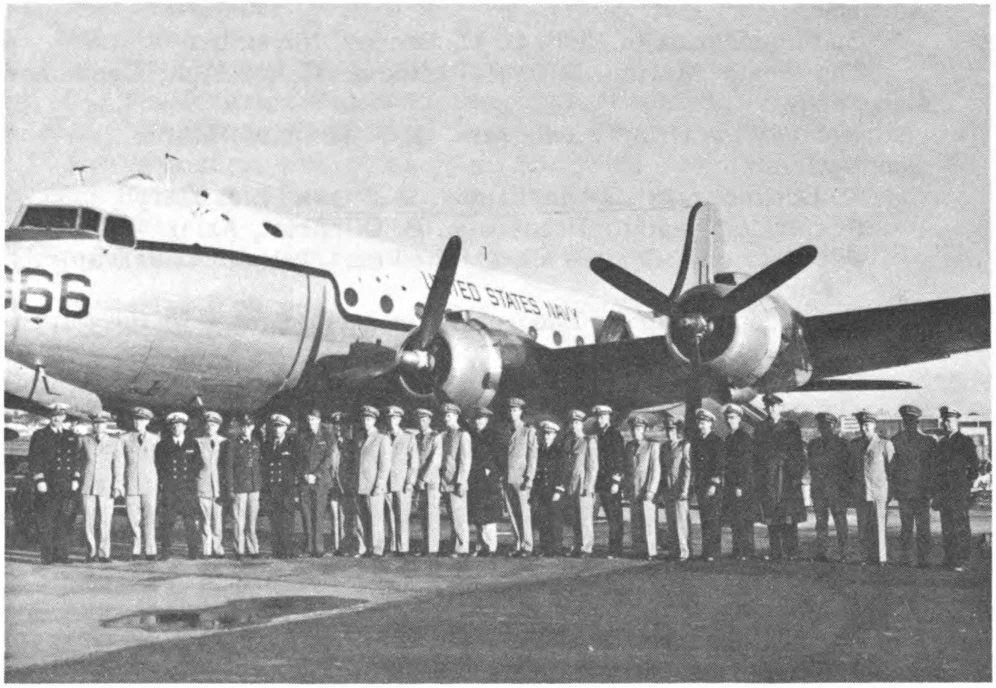
Research Panels Making Progress

The following Reservists on Appropriate Duty Orders have submitted research reports to ONR:

LCDR John R. Maloney, USNR, NRRC 9-13
LCDR Bergene Kawin, MSC, USNR - S1

These reports have been reviewed by the Biological Sciences Division of ONR and are considered to be excellent pieces of research. The experiments were properly designed to establish the validity of the results sought. These studies have contributed important information on two major problems of the Navy.

Reservists Visit Key West



Pictured above are the reservists from NRRC 9-8, 9-9 and 9-7, who made a trip to the Advanced Undersea Weapons School at the U. S. Naval Base, Key West, Florida on 29-31 October. While there, they attended lectures and discussions on current Navy studies on anti-submarine problems and visited the submarine USS ARCHERFISH.

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New Company Activated

NRRC 12-9 was officially activated by the Commandant of the 12th Naval District at the U. S. Navy Radiological Defense Laboratory, San Francisco Naval Shipyard, Hunters Pt., San Francisco on 9 November 1954. CDR William Plum has been designated Commanding Officer of this company. Other officers appointed are LCDR R. L. Stetson, USNR, Executive Officer, and LT E. L. Alten, USNR, Training Officer.

CAPT R. A. Hinners, director of the Radiological Laboratory, will serve as sponsor for the company. Dr. Paul Tompkins, Scientific Director at the Laboratory, will be Technical Advisor and CDR A. O. Dorrity will be Military Adviser. The main speaker at the Activation meeting was LCDR Hamilton B. Joslin, USNR, Research Reserve Program Officer of the 12th & 13th Naval Districts.

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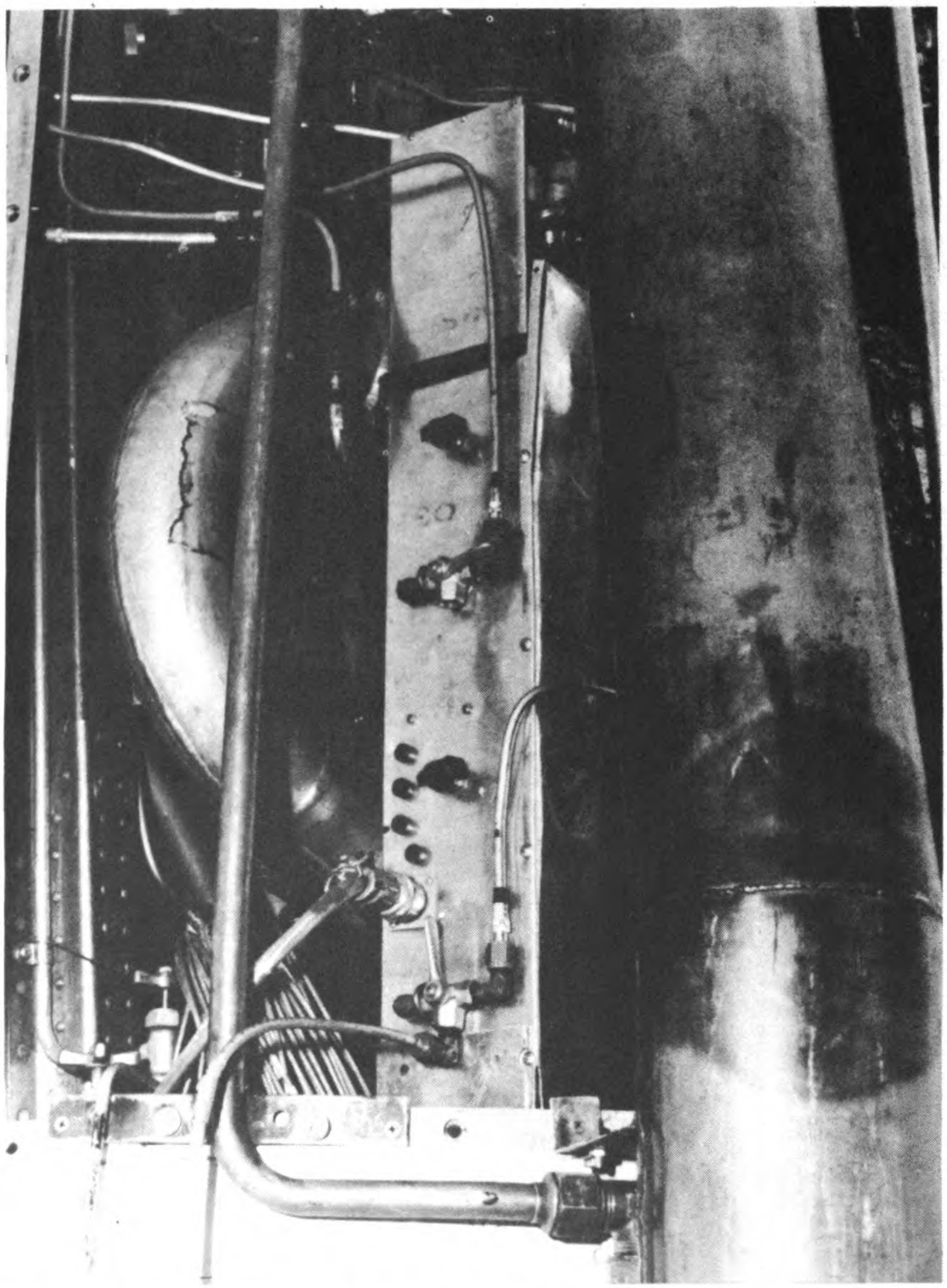
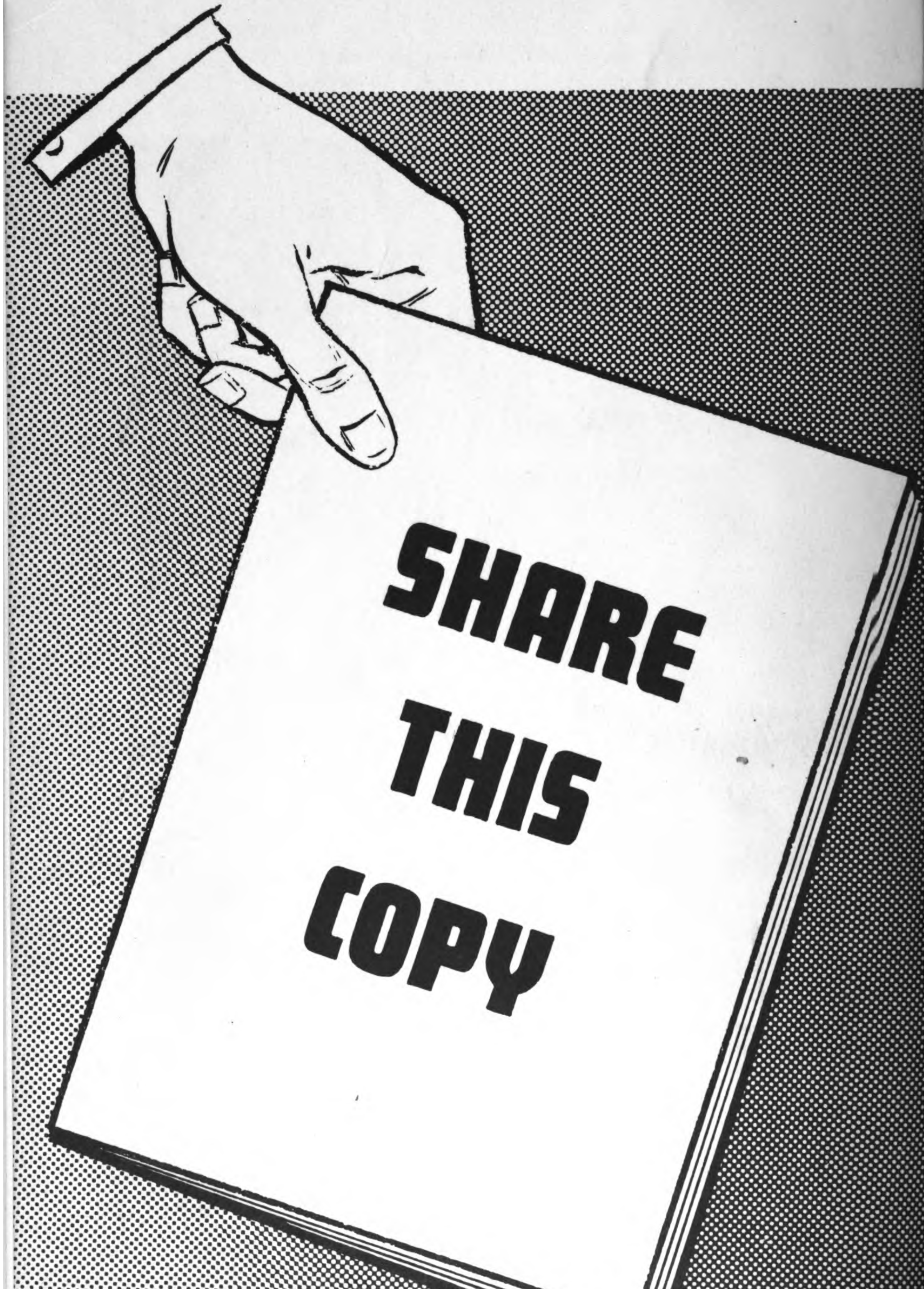


Rectangular Two-Fuel Sensor Unit in Viking 10. See Page 12.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