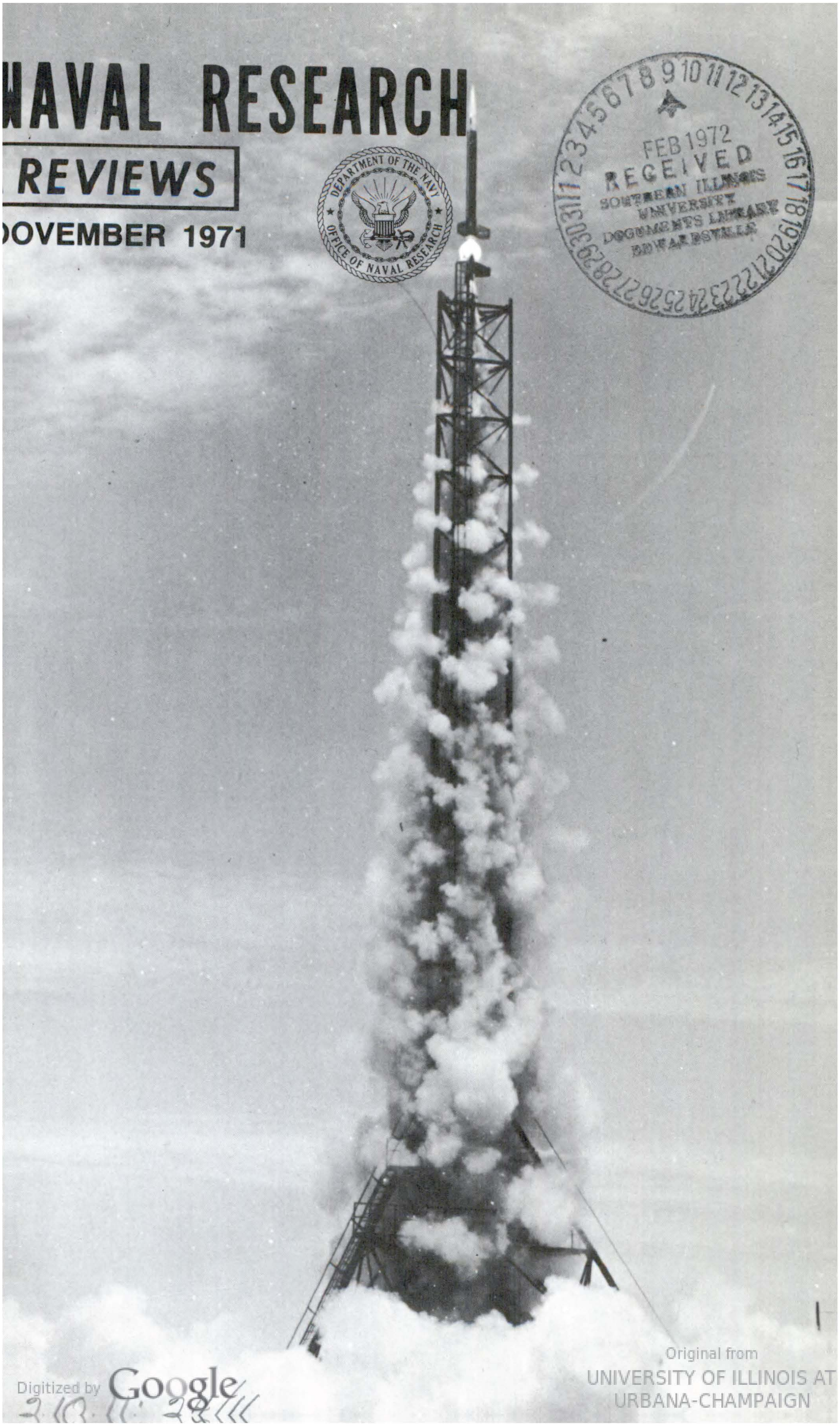
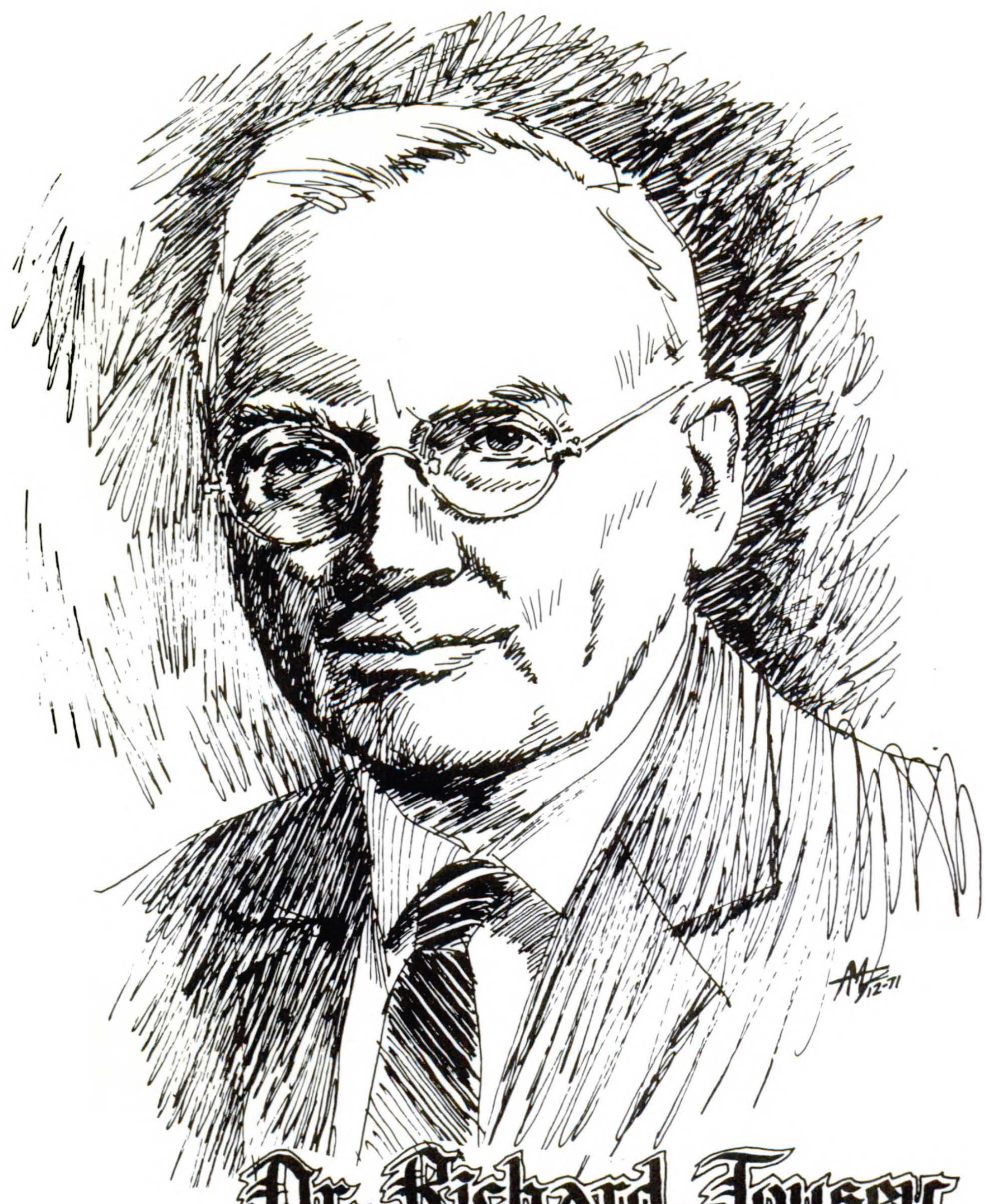
NAVAL RESEARCH REVIEWS

NOVEMBER 1971





Dr. Richard Tousey

Dr. Tousey came to the Optics Division of the Naval Research Laboratory in 1941 where he began a program of upper atmosphere research, coupled with research on vision. His early work on the brightness of the sky and the visibility of stars was conducted from high-flying aircraft. Since rocket research began in 1946 he has been in charge of a program of spectroscopic work from rockets, satellites, and manned orbiting solar observatories, concentrating on the solar spectrum in the extreme ultraviolet. His work resulted in many firsts which include the extension of the solar spectrum into the ultraviolet and the determination of the profile of the solar Lyman-alpha line of hydrogen. He guided NRL research on the visibility of earth satellites, and was a member of the Science Program Committee of Project Vanguard. Today Dr. Tousey is head of the Rocket Spectroscopy Branch of the Space Science Division at NRL. Dr. Tousey, who is a member of the National Academy of Science, has received the Navy Award for Distinguished Service in Science and the Meritorious Civilian Service Award.

Rocket Astronomy*

Herbert Friedman
Naval Research Laboratory

It is a quarter century since the news that captured V-2 rockets would be fired from the White Sands Missile Range presaged the coming of the Space Age. Several groups were organized at a number of institutions such as the Naval Research Laboratory (NRL), the Applied Physics Laboratory (APL) of the Johns Hopkins University, the Watson Laboratories of the Air Material Command, the Evans Signal Laboratory of the Army Signal Corps, and the Universities of Michigan, Princeton, and Harvard to develop programs of upper air research. At the Naval Research Laboratory, a broad-gauged set of atmospheric, cosmic ray, and astronomical observations was initiated. Dr. E. O. Hulburt, then Superintendent of the Physical Optics Division, believed a quick and simple approach could be taken to explore the solar ultraviolet spectrum below the wavelength limit set by ozone absorption. He suggested to Dr. Richard Tousey that it might be worth sacrificing a small Hilger quartz spectrograph which had already accumulated a respectable lifetime of scientific research dating back to its use in the Arctic during the Second International Polar Year, 1932-33.

Dr. Tousey picked up the challenge, but he and Dr. Hulburt quickly realized that the simple approach wouldn't suffice. To compensate for the uncontrolled spin and precession of the rocket, the conventional slit of a concave grating spectrograph was replaced by a fisheye lithium fluoride lens. The film had to be modified by putting a fluorescent coating on the front to provide ultraviolet sensitivity and a conductive coating on the back to avoid static sparking when the film was rolled in vacuum. Many important contributions were made to the development of a flight instrument in roughly three months. John Strong and Wilbur Perry at the Johns Hopkins University prepared the grating so as to minimize stray light. The 2-millimeter lithium fluoride spheres were polished under the supervision of A. J. Devlin at the Naval Gun Factory's Optical Shop, and Walter Baird Associates designed and built the basic hardware.

When the spectrograph was first flown in the nose of a V-2 rocket on June 28, 1946, the result was catastrophic. The rocket returned to earth, nose down, in streamlined flight and buried itself in an enormous crater some 80 feet in diameter and 30 feet deep. Several weeks of digging recovered just a small heap of unidentifiable debris, as though the rocket had vaporized on impact.

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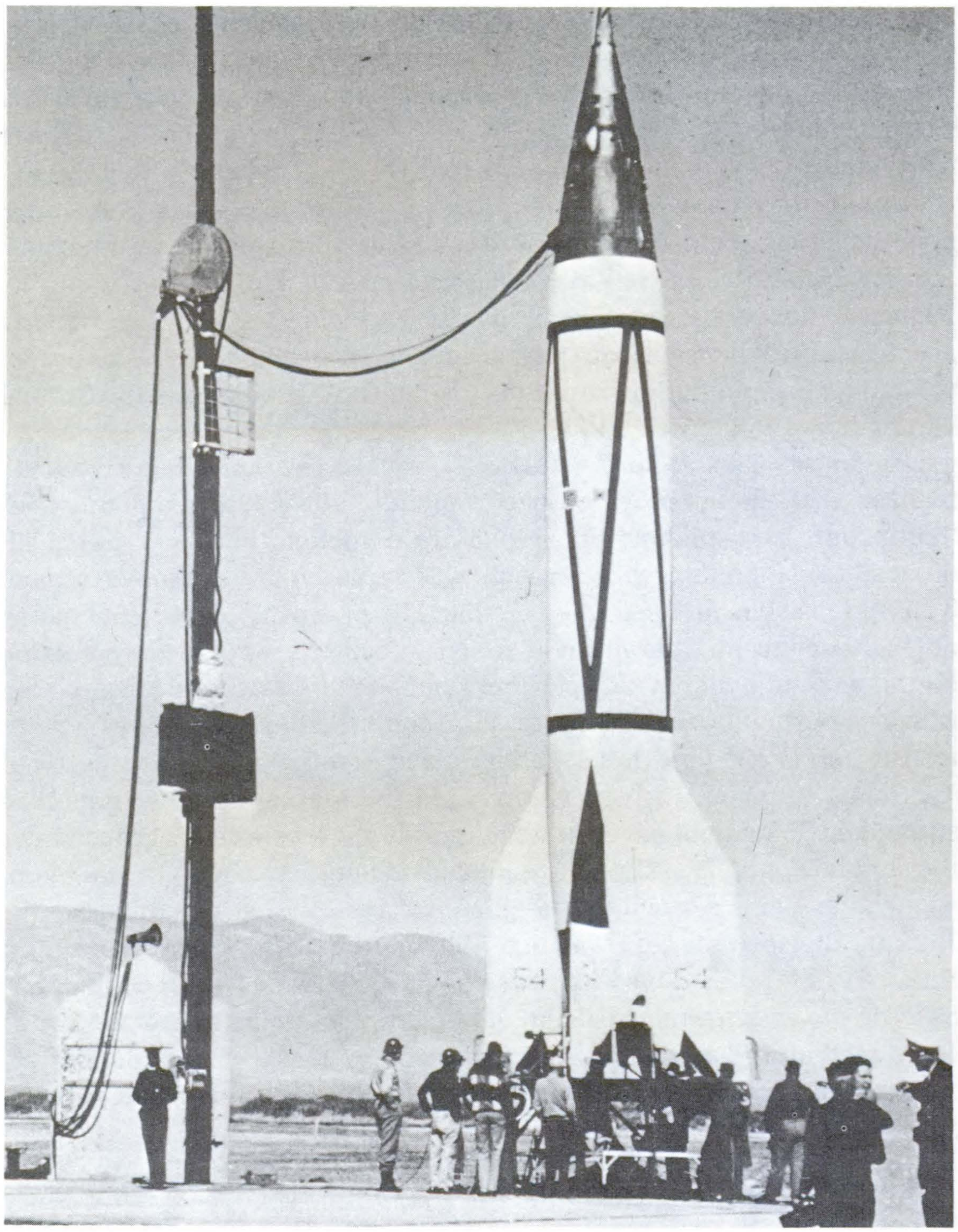
*Paper presented September 1, 1971 at the conference on "Education in and History of Modern Astronomy," which will be published in *Annals of the New York Academy of Sciences* (in press), The New York Academy of Sciences, 1972:Reprinted by permission.

Following that sad lesson, it was decided to mount the spectrograph in a tail fin and to sever the tail section from the body of the rocket before reentry. The fins would be expected to float down relatively gently. The V-2 itself, with its streamlining destroyed, would also tumble erratically to earth. On October 10, 1946 this arrangement was flown and the spectrograph was recovered in excellent condition. The series of spectral exposures extended to progressively shorter wavelengths with increasing altitude and, at the 55 km peak, reached all the way to 2300 A.



The launching of a V-2 rocket

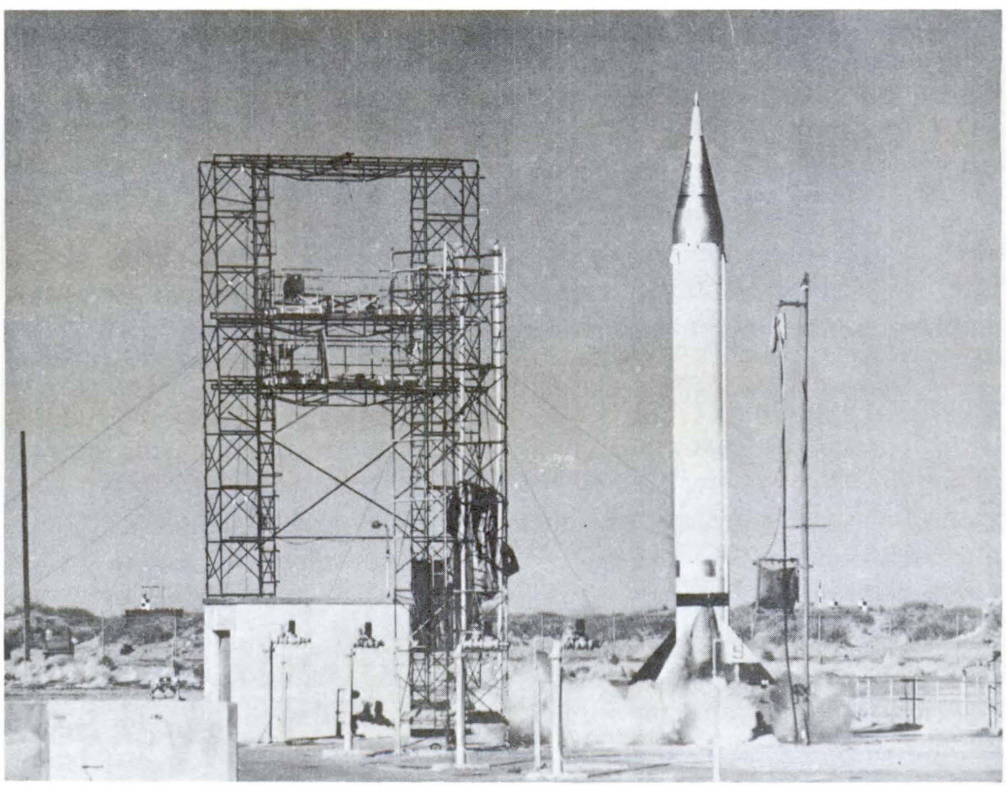
The NRL group was not alone in these first efforts to conduct solar astronomy from space. J. J. Hopfield and H. E. Clearman, Jr. at the Johns Hopkins University APL succeeded barely six months later. One of our most distinguished ground-based astronomers, Jesse L. Greenstein, was among the pioneers. His first rocket disaster, however, was sufficiently traumatic to drive him back to the Yerkes Observatory. The October 10, 1946 flight marked the beginning of a continuing program of solar studies that eventually unfolded the entire spectrum to its X-ray limit with high resolution. In 1946, the Air Force Cambridge Research Laboratories (AFCRL) entered the V-2 program and immediately supported a sophisticated pointing control development at the University of Colorado under Dr. W. B. Pietenpol. This two-axis stabilized spar became the standard platform for all solar rocket observations as soon as it became available in 1952. This device provided great increase in observing time that immediately made it possible to reach into the extreme ultraviolet with the limited exposure times available in a rocket flight.

The eventual accomplishments of high resolution solar spectroscopy were not obvious, even granted the first successes of the V-2 program, and the author and his colleagues sought simpler photometric devices to probe the extreme ultraviolet and X-ray regions of the spectrum. Theorists, notably B. Edlen, had predicted X-ray emission from the solar corona and, as far back as the early 1930's, Vegard and Hulburt had suggested solar X-rays as a source of ionization of the E region of the ionosphere. T. A. Burnight at NRL included film packs with X-ray-transparent windows in the early V-2 flights and reported blackening which he attributed to X-ray exposure.

The approach that I pursued in 1948 was to develop narrow-band Geiger counters based on selected gas ionization thresholds and filter materials. A collection of detectors covering the bands 1-8A, 1050-1350A, and 1450-1600A was flown on a V-2 in September 1949. As the rocket rose, signals from hydrogen Lyman-alpha (1216A) came in strongly at about 75 km, followed by X-rays (1-8A) above 85 km and the Schumann continuum (centered near 1450A) above 90 km. In one simple set of measurements we thus confirmed the role of Lyman-alpha in producing the ionospheric D region, the importance of solar X-rays in controlling the E layer, and the departure from photochemical equilibrium of the dissociation of molecular oxygen, so that the molecular form persisted well into F_2 region.

Our first success led us to attempt much more ambitious payloads in follow-on V-2 experiments, but our beginners' luck deserted us. A 1950 V-2 exploded on the pad before our eyes, producing the biggest bonfire we had ever seen. At about the same time, rapid progress was being made in the development of the Viking rocket which had a gimbaled engine to permit guidance by changes in thrust direction. In 1951, a Viking was scheduled to fly with additional stabilization derived from spin jets. We were privileged to be assigned a major portion of the payload space for a collection of some 30 ultraviolet and X-ray photometers. The flight program called for eliminating the roll and pointing the large assembly of detectors continuously at the sun. Unfortunately, the stabilization worked well only up to about 50 km. Then the rocket began to spin and at 100 km, it spun so fast that the instrumentation was torn from its mountings.

The frustrations of V-2 and Viking failures led us to look more and more seriously at the Aerobee rocket, whose development had been initiated by James A. Van Allen in recognition of the need for a simpler rocket designed purely for research purposes. The early Aerobee, however, seemed unattractive for astronomical research since it was limited to a maximum altitude of about 90 km. Still we felt that it would be useful for solar Lyman-alpha and hard X-ray studies and there were a number available. Although some 20 Aerobees had been contracted for, most scientists were looking to the powerful Viking for their experiments, and Aerobees were essentially free for the asking. Our request for three Aerobees to carry duplicate sets of payloads was honored with little question. All three flights worked nearly perfectly and provided



The launching of Viking-9

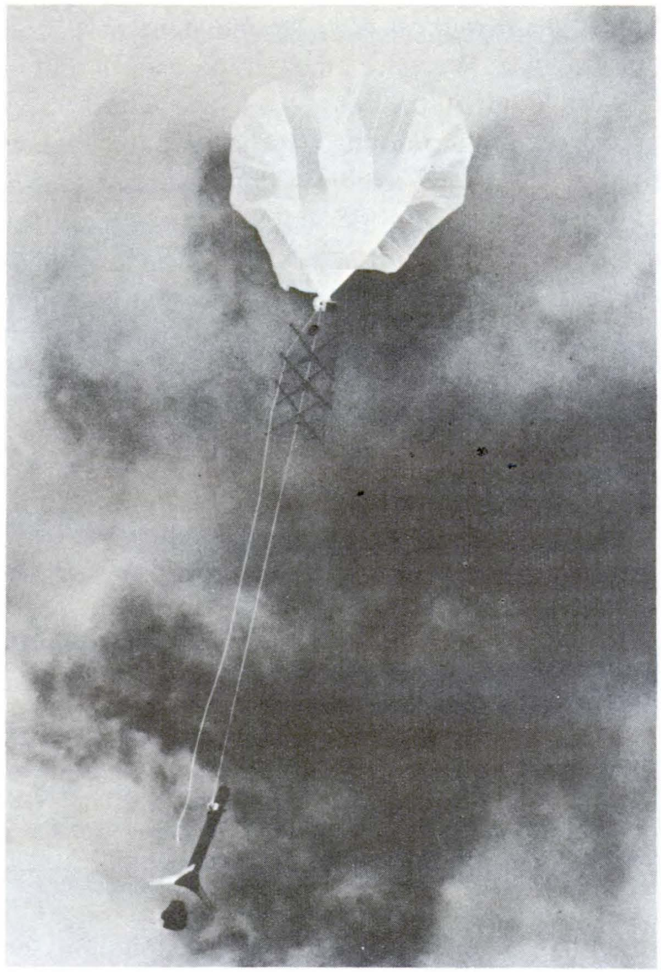
interesting new data on Lyman-alpha and X-rays as well as the ozone absorption minimum near 2100A. Our colleagues began to show more interest in Aerobees, especially when a simple extension of the fuel tank section increased their height capability to beyond 130 km.

With these stretched Aerobees, we began the extension of rocket astronomy to stars beyond the sun. The step was enormous, for the light from all the stars combined amounted to only a billionth of the light from the sun, and we had no rocket stabilizer for pointing at specific stars. Because of the rapid spin and precession, we opened the detectors' fields of view to 20 degrees permitting us to see at least the brighter ultraviolet stars transit in a fraction of a second. Our first attempt in 1955 gave us a major surprise. We were amazed to observe that, as the rocket exceeded the 90-km level, all the counters sensitive to Lyman-alpha were chocked by an overwhelming flood of radiation. At wavelengths longer that Lyman-alpha, the Milky Way showed up strongly. Our next step was to repeat the observations with finer collimation, which we obtained by bundling short lengths of hypodermic needles so as to yield a field of view about 3-degrees wide. In 1957, this second generation stellar astronomy payload revealed many stars and produced a contour map of the Lyman-alpha glow. It then became clear that the glow was localized and that we were observing solar Lyman-alpha resonantly scattered from a geocoronal cloud of hydrogen that envelops the earth. By 1959 we were flying 4-inch and 6-inch mirror telescopes with narrow band ultraviolet detectors at their foci. As these telescope photometers swept the sky, early-type stars down to 5th and 6th magnitude could be detected and, in a typical flight, some 200 stars would appear in the telemetry record. From such primitive beginnings the stage was set to initiate NASA's elaborate Orbiting Astronomical Observatory (OAO) program in 1960.

Our earliest observations of solar ultraviolet and X-rays were motivated as much by a desire to understand solar control of the ionosphere as by our interest in solar astronomy. The fluxes we observed from a quiet sun could explain the D region as a product of solar Lyman-alpha ionization of the trace constituent nitric oxide, and the E region could be attributed largely to soft X-rays (8-100A) that ionize all of the atmospheric constituents. When we examined the phenomenon of radio fadeout during a solar flare, we came convinced that it could not be a simple enhancement of Lyman-alpha, leading to greater D-region ionization and the consequent absorption of short radio waves. It was necessary to invoke a flux of X-rays of wavelengths as short as 1A and capable of penetrating the atmosphere to the level of 60 km. We were thus led to search for intense X-ray emission accompanying solar flares.

In 1956 we had not adequate resources for studying a transient event as unpredictable as a solar flare. A "push-button" type of rocketry was needed, which could send a stand-by payload aloft at a moment's notice.

V-2's, Vikings, and Aerobees all used liquid propellants which could not be stored in a rocket in the launching tower for more than a few hours. The only solid-propellant vehicle available was the Deacon, with a 6 inch diameter, 9 foot long motor that could barely carry it to 37 km when launched from the ground. However, if the Deacon were first carried to 24 km by a balloon, it could be ignited at that altitude and could climb to well above 100 km. This combination of rocket and balloon was called the "Rockoon."



The Rockoon, combination of rocket and balloon

To probe the solar flare problem, we organized an expedition called "Operation San Diego High." Our base was the Navy LSD, USS COLONIAL, and from its decks about 350 miles out to sea off the coast of southern California we flew 10 Rockoons. Early in the morning of each day, we launched a 150,000 cubic foot polyethylene balloon with a Deacon rocket dangling below it. The ship had to cruise with the breeze at the same speed so that the balloon stood straight up at launch. About 1-1/2 hours later, the balloon would be floating at 24 km and racing westward at 30 knots with the prevailing upper air winds. A teletype link to the High Altitude Observatory at Boulder and to Sacramento Peak Observatory gave us warning of the start of a flare (which rises to maximum in only a few minutes). We could fire the Rockoon by radio command and it would streak above the absorbing atmosphere to measure the solar ultraviolet and X-ray flash of the flare.

In all of this expedition one technical problem gave us by far the most anguish. No suitable igniter was available for use on a solid propellant rocket in the near vacuum of 24 km. The standard Deacon igniter failed on the first two launches. I drafted Dr. James E. Kupperian, Jr. of our team to assume the role of Chief Gunner's Mate. In his teen years he had acquired considerable expertise with making gun powder from the ingredients in his chemical set. With this background experience, he proceeded to develop a high-altitude Rockoon igniter and, after one more failure, we had a string of successful ignitions.

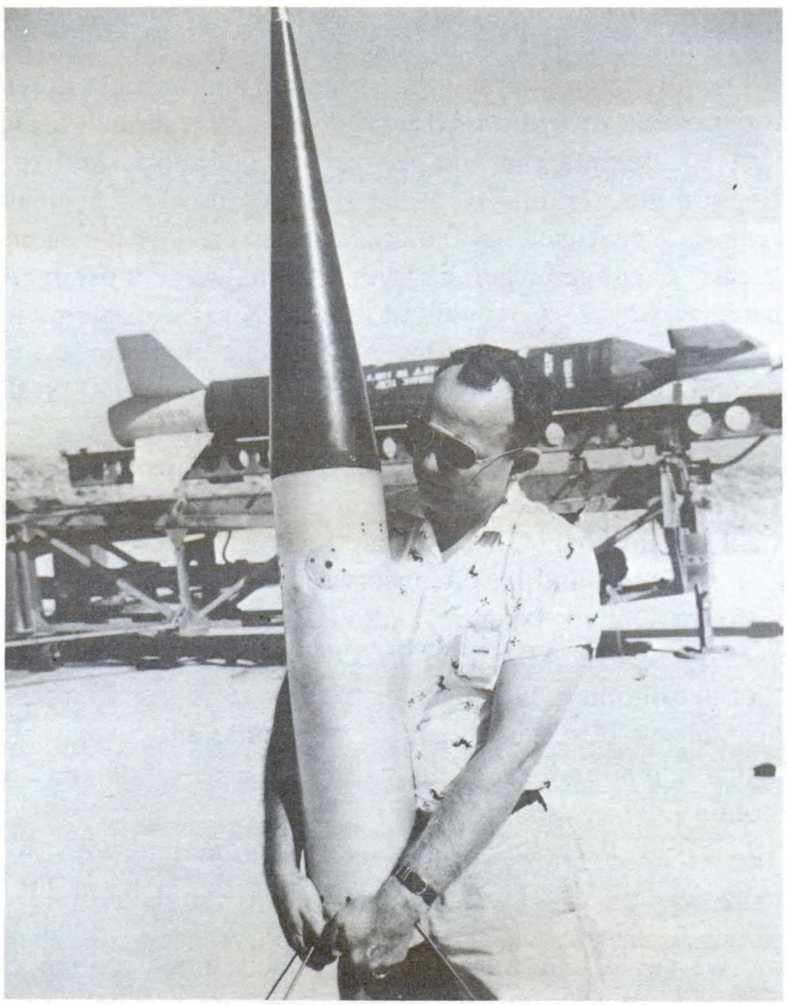
From a scientific standpoint, however, the results were disappointing until we came to our last Rockoon. The procedure had been to launch a Rockoon each morning and let it float until a flare was reported. If a flare did not occur, the rocket had to be ignited and brought down at the end of the day so as to avoid drifting out of our prescribed firing zone. For the first 9 attempts the sun refused to cooperate and remained disappointingly quite. On our 10th and last try, however, it finally produced a weak flare that gave us the crucial answer. The X-ray emission was very greatly enhanced whereas Lyman-alpha was almost unchanged. This confirmation of the association of intense X-ray emission with solar flares has since become one of the most fascinating subjects of solar astronomy, and the NASA Orbiting Solar Observatory (OSO) series has produced a wealth of detailed flare X-ray spectra.

The first use of rocket astronomy during an eclipse took place on October 12, 1958 when the path of a total eclipse crossed the South Pacific. An International Geophysical Year (IGY) expedition was organized to make ground-based observations from a tiny coral atoll, Puka Puka, in the Danger Islands, and to launch a series of rockets from the helicopter deck of the USS POINT DEFIANCE, LSD 31. The goal of the rocket astronomers was to isolate discrete X-ray sources on the disk of the sun by observing their occultations, and to establish the residual Lyman-alpha and X-ray fluxes from the chromosphere and the corona at totality.

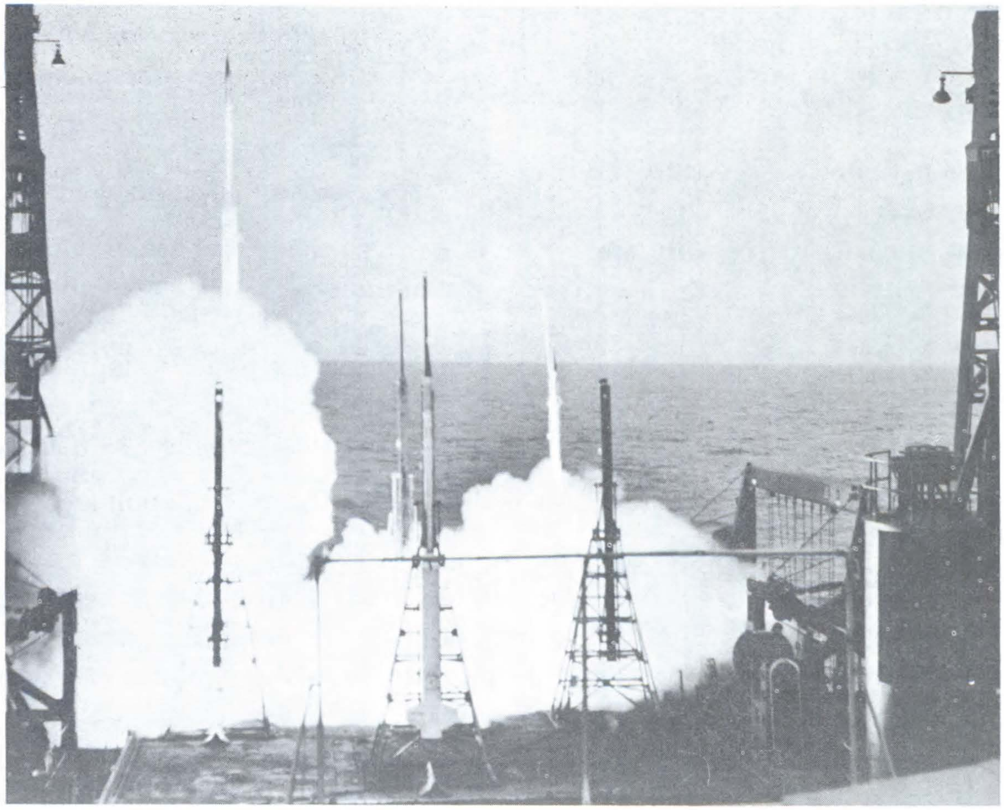
In the 1957 IGY flare studies, we had experimented with two-stage solid rockets, substituting a Nike booster for the balloon lift of the Rockoon system. Such two-stage rockets were truly "push-button" systems and we could plan to launch a precisely timed sequence as the eclipse progressed. Six rockets were placed on the small helicopter deck about 20 feet apart. They were mounted on simple tripods welded to

1/4-inch steel deckplate that served as the blast deflector. Since the Nike booster is comparable to a 1000-pound bomb, we had some nightmares of the good ship Point Defiance going to the bottom when we exploded the first Nike. Apart from that, our major problem was dampness. We had to enclose the instrumented sections in makeshift waterproof sleeves of vinyl plastic filled with drying compound. These had to be removed shortly before firing. Because the rocket had to be precisely aimed through the eclipse shadow, we used a gyro-stabilizer to delay the firing signal until the rolling ship was horizontal to plus-or-minus 1/4 degree.

As the eclipse progressed, the first four shoots went off without a hitch, but when the button was pushed for the fifth rocket, nothing happened. The previous four blasts had loosened the external pull-away plug that carried the starting signal to the rockets. While we watched with baited breath, Don Brousseau of the NRL group raced up the ladder



William R. Nichols carrying instrument section for Nike-Deacon solar flare experiment



Six rockets were placed on the small helicopter deck about 20 feet apart. They were mounted on simple tripods welded to 1/4-inch steel deckplate that served as the blast deflector.

to the helicopter deck, climbed the tripod frame, and reinserted the loose plug in the rocket. He then dashed for the nearest gun tub and huddled behind the armor-plate protection while the rocket was fired no more than 50 feet away.

The eclipse rocket astronomy mission gave us clear confirmation of the association of soft X-ray emission with plages. At totality, Lyman-alpha was essentially totally eclipsed but the residual X-ray flux from the extended corona was 13 percent of the uneclipsed flux.

It seemed to me that no subsequent eclipse expedition could match the high adventure of 1958 in the Danger Islands. But the experience of Dr. Guenter Brueckner and his NRL colleagues on the occasion of the March 1970 Eclipse was certainly very unique. Because of the rare circumstances that the totality zone included the rocket range at Wallops Island on the Atlantic Coast, a great effort of numerous rocket astronomers was organized for the event. The NRL rocket carried a high resolution spectrograph to photograph the chromospheric ultraviolet spectrum and worked perfectly, but the water recovery system failed. The instrument section plunged to the bottom of the ocean at a depth of 6,000 feet. It would have been appropriate to shed tears and give up, but Brueckner persisted in attempting salvage, and he was given encouraging support by the National Aeronautics and Space Administration and the U.S. Navy.

An undersea recovery device, CURV III (Controlled Underwater Recovery Vehicle), that could search the bottom with TV eyes and sonar and maneuver to graffle an object as large as the Aerobee instrument section with its large claws was flown from the West Coast and delivered to a Navy salvage vessel at Norfolk. The point of impact was precisely located from radar data and CURV III began its search of the area nearly two weeks after Eclipse Day. To compound the difficulties, the sea floor was strewn with debris from the area's previous use as a firing range, and there was substantial risk of grappling with a live shell on the bottom. However, the rocket was found within 200 yards of its radar-designated impact point, and was brought to the surface. One of the magnesium film cassettes was crushed and so badly corroded that there was no hope for its film, but the second, which had been Teflon coated on the interior surfaces, was in excellent condition. Despite its seawater exposure, the film was successfully developed following carefully prescribed instructions from Kodak and the spectral images were brought out so well that the scientific objectives of the experiment were in a large measure achieved.

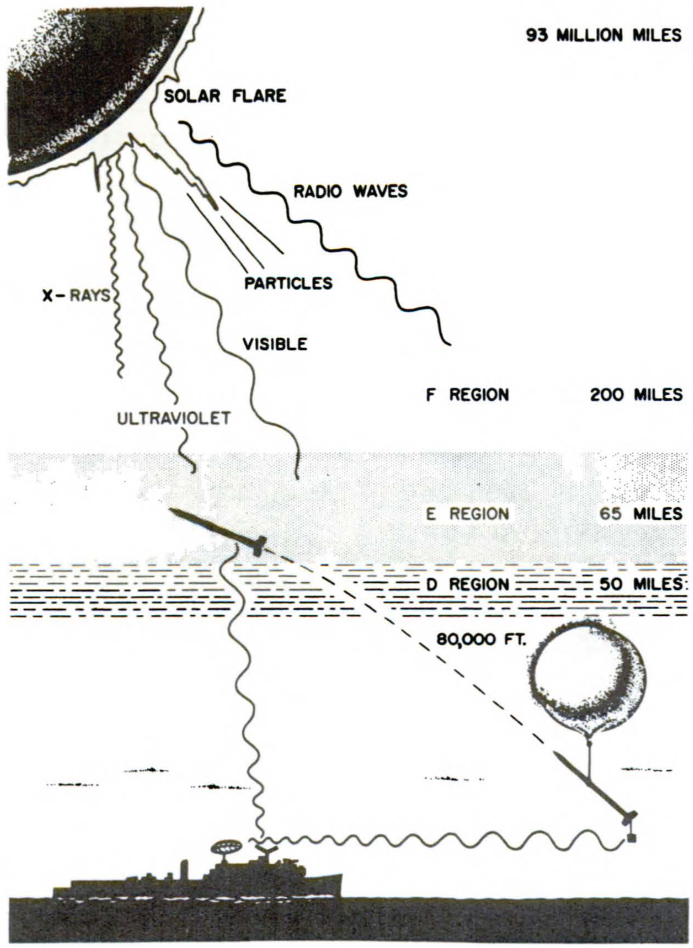
The development of galactic and extragalactic X-ray astronomy can be traced back to some clues that were observed as early as 1956 in the Rockoon-flare program. One of the detectors in the X-ray instrumentation package was a sodium iodide scintillation counter sensitive to the range from 30-200 kev. Two of our flights during non-flare conditions revealed a component of hard X-rays which increased with altitude in such a way to be clearly distinguishable from secondary radiation generated within the atmosphere by cosmic rays. Dr. Kupperian and I suspected that this broad sky background of X-rays was extra-terrestrial and we reported the results to the International Astronomical Union Assembly in Moscow in 1958. I later discussed with Fred Hoyle the possibility that the observed X-rays could be evidence in support of the "hot" universe version of the continuous creation cosmology, in which the newly created neutrons disintegrated into energetic electrons and protons. The resulting hot (10^9K), intergalactic gas would be expected to produce bremsstrahlung X-rays, but the observed flux was approximately 50 times less than we calculated. In subsequent years, the hard X-ray background spectrum has been found to follow a power law and its isotropy is well established. The primitive results of the 1956 Rockoon flight fit very well on the now-established spectral curve. The accepted theoretical explanation, however, is that the X-rays are produced by inverse Compton scattering of cosmic ray electrons on the cosmological 3°K microwave background.

Many of our contemporary astronomers believe that the history of X-ray astronomy is a prime example of serendipity (discovery by pure chance). The early hint of a substantial extra-terrestrial X-ray flux led us to think seriously of X-ray astronomy as early as 1957 when we began to fly detectors specifically to search for X-ray sources. The Crab Nebula was guessed to be one of the most likely discrete sources and if the stabilization system for the Aerobee had been developed in those early years, the Crab undoubtedly would have been targeted for X-ray observations. Evidence for discrete source X-ray emission had to wait for the 1962 Aerobee flight of Riccardo Giacconi and his colleagues, because he was the first to devote the full space of his payload to the X-ray search. His principal objective was a search for X-ray fluorescence of the lunar surface, but he and Bruno Rossi and their associates were very conscious of the prospect of finding celestial X-rays from sources other than the moon.

Shortly after the discovery of X-ray emission from the general direction of the galactic center by Giacconi and his colleagues, the NRL group identified two sources, one of which lay in the direction of the Crab Nebula. It was thought that this source might be a neutron star remnant of the Supernova of 1054 A.D. It was therefore crucial to determine whether the emission was indeed associated with a starlike object, or was distributed over the volume of the nebula. If the July 7, 1964 occultation of the Crab by the moon could be observed from a rocket instrumented with X-ray detectors, a direct measurement of size could be obtained. In the spring of 1964 we decided to attempt this measurement, which would require that the rocket be launched and stabilized to point the X-ray counters steadily at the Crab for precisely those few minutes during which the occultation of the central region would occur. By the date of the occultation the Automatic Control System (ACS) for the Aerobee was still considered developmental and had failed to function properly on six preceding attempts. Fortunately however, for this very special once-in-nine-years occultation of the Crab, it performed perfectly. The answer to the question of size was that least 90 percent of the X-ray flux was produced in the nebula in much the same pattern as the optical and radio emission. The possibility that perhaps 10 percent of the emission could come from a central star was not positively answered until the discovery five years later of the X-ray pulsar in the Crab source.

The above examples of some of the events that mark the early history of rocket astronomy have been drawn largely from my personal experiences and close associations. They represent only a fragmentary account of a much larger story, that would include the pioneering work of a considerable number of my contemporaries. Magnificent satellite observatories, such as the Large Space Telescope (LST) and High Energy

Astrophysical Observatory (HEAO) that are planned for the future will soon relegate the stories I have told here to the status of pre-history, but I doubt that any future space astronomer will enjoy an experience comparable to the individual sense of high adventure and exhilaration of the "do-it-yourself" years of rocket astronomy.



Graphic Representation of a Rockoon launching timed to a solar flare

About the Author

Dr. Herbert Friedman of the Naval Research Laboratory is one of the nation's outstanding astrophysicists. His work in rocket astronomy has led to many important discoveries. Since 1949 when Dr. Friedman conducted his first experiments with V-2 rockets, he has participated in over 100 rocket and satellite launchings. These experiments have traced the solar cycle variations of X-ray and ultraviolet radiations from the sun, produced the first X-ray and ultra-violet photographs of the sun, led to the discovery of the hydrogen geocorona and measured the ultra-violet fluxes of early-type stars. Among Dr. Friedman's many awards are the Rockerfeller Public Service Award and the President's National Medal of Science.

Fundamental Limitations to Oceanic and Atmospheric Prediction*

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Predictability and the Growth Rate of Errors

A fundamental scientific question regarding any physical system whose state undergoes continual fluctuations concerns the extent to which the present and past states determine the future. A closely related question concerns the extent to which future states, even if formally determined by the present and past, can be discovered in advance by any procedure which man can hope to carry out. When the system under consideration is the ocean or the atmosphere, the questions acquire practical importance, since they relate to the extent to which the state of the sea or the weather can be predicted.

If we disregard for the moment the possibility that a particular physical system may not be completely deterministic, we may nevertheless find that we cannot predict its behavior perfectly because we cannot observe the present state with complete precision, or we cannot formulate the physical laws as perfect forecasting rules. In the case of the ocean and the atmosphere both of these shortcomings are present. For the most part they are not due to errors in observation nor to lack of knowledge of the laws, but result simply from omission. The systems are so intricate that no conceivable observing system can detect every detail, nor can any forecasting system, even with the help of the most giant computer, take the influence of every detail into consideration. The atmosphere and the ocean are presumably not completely deterministic, but any additional lack of predictability on this account is completely overshadowed by the effects just noted.

As a point of departure for our treatment of the predictability problem, we consider the behavior of the *difference* between two conceivable states of a system, each state varying with time according to the same set of governing laws. Since one important case arises when one state is the true state of the system, while the other is the state as it has been observed or predicted to be, so that the difference is the error in observation or prediction, it is convenient to refer more generally to the difference

*Paper presented at the 8th Navy Symposium on Military, Oceanography, Monterey, California, May 1971.

between any two states as an error. We are thus concerned with the typical rate of growth or decay of errors as time progresses.

Consider for the moment a hypothetical deterministic system where the governing laws may be formulated as perfect forecasting rules, so that errors in forecasting will arise only from errors in observing the initial state. We may then distinguish among three possible situations.

First, if the system is such that different states tend to evolve toward the same state as time progresses, *i.e.*, if errors tend to diminish, it is not necessary to observe the present state at all in order to make a good forecast. A number of periodically forced systems are of this sort. To a fair approximation, the oceanic tidal motions fit this category: prediction of next week's tides does not require us to observe today's.

A second case occurs when errors show no systematic tendency either to grow or decay. In this event we must observe the present state (or some past state), but having done so we can forecast at virtually any range into the future with no greater error in prediction than the original error in observation. Certain laboratory models of atmospheric flow fall into this category, including those which are undergoing the phenomenon of "vacillation," with regular periodic changes in the streamline pattern.

Finally, if the errors tend to amplify, the forecast will fail at sufficiently long range if the initial observations are anything less than perfect. Refinement of the observations will extend the range of predictability, but not to infinity. If we have some idea of how accurately the system may be observed, the principal quantity which we must also know, in order to estimate the degree of predictability at various ranges, is the typical growth rate of errors. It appears virtually certain that the atmosphere is a system of this sort.

More precisely, the state of the atmosphere does possess periodically forced components, notably the "normal" diurnal and annual variations, which are predictable an arbitrary number of days or years in advance. Superposed upon these variations there are nevertheless important nonperiodic fluctuations, including the motions of migratory cyclones and anticyclones, which do not appear to be predictable at very long range. The same is presumably true of such oceanic phenomena as meanders in the Guld Stream: it is certainly true of oceanic conditions which are caused largely by interaction with the atmosphere.

As with many real physical systems, the laws governing the ocean and the atmosphere cannot actually be formulated as perfect forecasting rules. An additional source of error in forecasting is therefore present. If the rules have been poorly formulated, the continual accumulation of errors from this cause may be so rapid as to obscure altogether any amplification of those errors which already exist. If, on the other hand, it becomes possible some day to formulate the laws with rather high precision, the rate of accumulation of errors resulting from applying the *assumed laws* rather than the exact laws to the assumed state will never become very large. Meanwhile, the amplification resulting from applying the laws to the *assumed state* rather than the exact state will become larger and larger as the assumed state departs more and more from the exact state. Thus the actual growth rate of the total error will soon be for practical purposes the rate at which distinct states governed by the sane laws depart from one another, *i.e.*, the quantity which in the preceding paragraphs we chose to call the growth rate of errors. It therefore appears that we can gain considerable quantitative information regarding predictability, even for systems where the governing laws can never by perfectly formulated, by considering only the rate at which errors would typically grow if the laws were perfectly formulated.

Growth Rates in the Atmosphere and the Ocean

Studies performed within the past few years have shed considerable light upon the growth rate of errors in the atmosphere. Among the most recent pertinent studies is one by Smagorinsky (1969), who simulated the behavior of the atmosphere with a large numerical model, and one of ours (Lorenz 1969b), which considered the observed behavior of naturally occurring atmospheric analogues. These studies concur in the result that errors of small amplitude, in scales of motion large enough to be resolved by conventional numerical-prediction grids or weather maps, tend to double in magnitude in about three days. Once the errors acquire considerable amplitude they grow less rapidly, ultimately becoming no larger than the difference between randomly chosen states of the atmosphere.

Taken at face value, these results would suggest that with anticipated improvements in our observational network we may some day be able to predict the locations and intensities of migratory cyclones and anticyclones up to two weeks in advance. Meaningful prediction a month in advance of anything other than gross averages would seem to be precluded, however, for many years to come.

We are not aware of investigations of this sort dealing with the predictability of the ocean. Certainly world-wide oceanic conditions have never been observed with anything like the completeness needed to say whether the state at one specified time resembles the state at another: analogue studies are therefore precluded. Numerical modeling of oceanic circulation is still in a rudimentary stage, compared to atmospheric modeling. The task is complicated by the variable depth, and the barricading effect of the continents, not to mention the wind stress on the surface.

Noting that the range at which the behavior of a cyclone is in principle predictable is at least comparable to the typical time during which a cyclone maintains identity as a system, we may postulate that the predictability range of a particular oceanic system is comparable to the typical life span of such a system. Much study is needed, however, before we can be sure that this assumption is justified.

In the remainder of this discussion we shall therefore restrict our remarks mainly to the atmosphere. It should nevertheless be evident that some of the qualitative statements are applicable to the ocean.

Unanswered Questions

The total motion of the atmosphere may be resolved into superposed motions of many different scales. The various scales do not act independently of one another: the properly formulated equations governing the larger scales contain terms representing the influence of the smaller ones. The vertical transports of momentum, heat, and moisture by systems as small as cumulus clouds, and the consequent alteration of the large scale distributions of these quantities, are among the more obvious examples of interactions of one scale with another.

Errors in observation or prediction are simply differences between two possible states of the atmosphere. It follows that a full treatment of the behavior of errors in the larger scales of motion must include an appraisal of the possible effect of errors in the smaller scales.

Neither the numerical simulation of the atmosphere by Smagorinsky (1969) nor our investigation of analogues is capable of making such an appraisal. In Smagorinsky's study the state of the atmosphere is represented by the values of the various meteorological quantities at a grid of points, with neighboring points separated by a few hundred kilometers. The expected influence upon the larger scales of motion of scales too small to be resolved by the grid is parameterized in terms of the larger scales themselves. However, the small-scale features present at any particular time constitute only a statistical sample of those features which could conceivably be present at that time, and the possible deviation of the influence at that time from the expected influence is not taken into account.

Since our study is based upon observed atmospheric behavior, the influence of the small-scale features is automatically included, but again the state of the atmosphere is represented by numbers at grid points, whence unresolved small-scale features cannot be taken into account in deciding whether or not two states qualify as analogues. There is therefore no way of determining to what extent the observed error growth is attributable to prior errors in the smaller scales.

Under present-day operational forecasting procedures, except in the case of very-short-range local forecasts, the errors in observing or predicting the smaller scales are entirely errors of omission; these scales are for practical purposes unobserved. The errors in these scales, such as the differences between true states where these scales are present and observed states where they are absent, are therefore large, even initially. These initial small-scale errors will lead soon afterward to detectable large-scale errors; the latter will not only continue to accumulate but will also proceed to grow, just as if they had been present initially. It thus appears that small-scale errors alone place a limit upon the range of useful predictability of the larger scales.

It might appear that this range could some day be increased, when a workable procedure for observing the smaller scales is discovered. However, small-scale errors differ from large-scale errors in that their typical growth rate is much more rapid. An error in representing a thunderstorm, for example, presumably grows at least as rapidly as the thunderstorm itself, doubling in perhaps twenty minutes rather than three days. If the small-scale errors could somehow be made small in amplitude initially, they would soon afterward become large, whence the enormous effort needed to observe the small scales would add only an hour or so to the range of predictability. This hour might represent a great gain for very-short-range forecasting, but at a range of a day or more the gain would be insignificant.

The preceding considerations are not restricted to the atmosphere. They apply equally well to any fluid system whose motion is sufficiently turbulent.

In an attempt to treat the interactions among scales quantitatively, we have worked with an ideal two-dimensional fluid (Lorenz 1969a). We found that errors in the smallest scales had very little direct effect upon errors in the largest scales, but that they very rapidly led to errors in slightly larger scales. These in turn brought about errors in still larger scales, until ultimately the largest scales were affected. Using numerical values of velocities representing those occurring in the atmosphere, we found that systems cyclone scale were predictable less than a week in advance, while the very largest scales became unpredictable after about seventeen days.

There are various features of this study which force us to discuss it under the heading of "unanswered questions." First of all, the dependent variables in the equations which were solved represented statistical properties of ensembles of errors, and, in order to reduce the set of equations to a closed system, a closure assumption was needed. The assumption used was to the effect that quadratic functions of the errors were independent of quadratic functions of the basic states upon which they were superposed. This assumption is perhaps suspect because of its resemblance to the discredited quasi-normal approximation. More specifically, the equations resulting from it contained only spectral densities as dependent variables, so that an error in a given scale of motion, once established, was effectively indistinguishable from any other error of the same magnitude in the same scale. In reality it seems possible that initial errors in a small scale might produce, in slightly larger scales, errors of a rather specialized form which would be ineffective in producing errors in still larger scales. The study also used a special procedure for handling the nonlinearity in the equations, which could have caused the errors to grow too rapidly.

These considerations indicate that it has not been completely established that errors propagate rapidly up the scale, from small scale to large, in any real fluid system. With regard to the atmosphere a number of further questions require answering. What is the effect of the full three-dimensionality of the smaller scales of atmospheric motion? What is the effect of the presence of the various phases of water? Finally, what additional predictability might be present as the result of a "spectral gap" somewhere between the thunderstorm scale and the cyclone scales? Answers to some of these questions are expected to follow from research currently in progress.

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About the Author

Dr. Lorenz is Professor of Meterology at MIT. His field of work is dynamic meterology especially in the areas of general circulation of the atmosphere and atmospheric predictability.

NRL Develops Improved Satellite Navigation System

Before the era of artificial earth satellites, the accuracy of deep-water navigation had not improved beyond that available from celestial techniques, according to a recent NRL Progress Report.

The Naval Research Laboratory has now developed an experimental passive ranging system which can be used to provide continuous navigation fixes from low or medium altitude satellites, and which may be used to synchronize the navigator's clock with the satellite clock to an extreme accuracy. The new system has been labeled Time Navigation (Timation).

On the Naval Research Reserve

NRRC 11-5, San Diego Wins National Award

Rear Admiral C. O. Holmquist, USN, Chief of Naval Research, announced that this year's winner of the Research Reserve for General Excellence was NRRC 11-5, San Diego, California. CDR Wade E. Selph, USNR, was in command of NRRC 11-5 during Fiscal Year 1971. Presentation of the award is planned for early 1972.

The award is given to the company deemed most outstanding from nominations submitted by Commandants of the Continental Naval Districts. The winner, from 77 Research Reserve Units in competition, was selected by a panel composed of the following officers:

CAPT W. F. V. Bennett, USN
Director, Naval Applications and Analysis Division
Office of Naval Research

CAPT J. E. O'Neil, USNR
Director, Naval Reserve Programs Division
Bureau of Naval Personnel

CAPT R. E. Bondy, USNR
Director, Naval Reserve Plans Division
Office of the Assistant Deputy Chief of Naval Operations (Naval Reserve)

Among the notable accomplishments of NRRC 11-5 for Fiscal Year 1971 were the following:

Inspection Grade	3.772
Ready Reserve Status	100 %
Satisfactory Federal Year Completion	100 %
Drill Attendance	91.6%
ACDUTRA Participation	73.3%
Correspondence Course Completion	40 %
Training Grade	3.63
Presented Research Reserve Seminar on "Remote Sensing," 3-14 August 1970	

Members of the panel commented favorably on the records of the other companies entered in the competition. These companies were as follows:

1-2	Providence, Rhode Island
3-9	Upton, Long Island, New York
4-4	State College, Pennsylvania
5-9	Naval Research Laboratory, Washington, D.C.
6-9	Athens, Georgia
8-4	Houston, Texas
9-21	Denver, Colorado
12-6	Davis, California
13-1	Seattle, Washington

NRL Formula Promises Cure for Marine Environment Electrical Failures

A new material developed by Naval Research Laboratory chemists here holds promise for curing that age old plague to mariners,—electrical and electronics failure due to salt air and salt water corrosion.

Although a source of some annoyance and expense to private boatmen, the problem has been particularly acute for maritime shippers and the Navy, where ships and aircraft experience electrical leakage through insulation after long-term exposure to the marine atmosphere and repeated changes in temperature.

In a recent scientific progress report, H. R. Baker and R. N. Bolster of NRL's Chemistry Division showed that this new material rapidly displaced moisture from insulator surfaces, increasing their resistivity more than twice as fast as most of the other water-displacing agents previously evaluated. This now makes possible the rapid restoration of equipment wet by condensation or flooding.

The dry, water-repellent film left by this material on the treated equipment not only prevents electrical leakage upon subsequent exposure to moisture but also protects metal parts against corrosion.

The reliability of equipment chronically affected by moisture can thus be improved by the remedial application of this material. The water-displacing action results from the use of butyl alcohol in the solvent blend.

The protective film is composed of a paraffin wax, ethylene-vinyl acetate copolymer, and an amino-acid salt corrosion inhibitor. Although the film is solid, it remains soft enough so that it has a minimal effect on electrical contacts.

While modern electrical and electronic equipment is being made with improved materials to resist adverse environmental conditions, the trend toward compactness and complexity not only makes them more susceptible to insulation failures, but renders them even more difficult and expensive to trouble-shoot and repair. The use of the NRL-developed surface treatment should aid considerably in the maintenance and restoration of sophisticated and complex electronic equipment.

Research Notes

Aries Expedition

A volcanic seamount, now submerged 4,800 feet below the surface of the ocean between the Hawaiian Islands and Japan, probably stood as a land mass millions of years ago.

Several hundred miles northwest of Midway Island in the Pacific, scientists charted one of the largest flat-topped sub-marine mountains or guyots, ever discovered in the world ocean.

Investigators at Scripps Institution of Oceanography, University of California, San Diego, listed these and other discoveries on the return of the 209-foot, 1,362-ton research vessel *Thomas Washington* from the Aries Expedition.

During 11 months of work sponsored by the Office of Naval Research, the National Science Foundation, and the State of California, the *Thomas Washington* logged more than 53,000 miles in the western Pacific between Antarctica in the south and Japan in the north.

Dr. Bruce A. Taft, assistant professor of oceanography at Scripps, coordinated plans for the entire expedition and acted as chief scientist for two of the eight legs.

Plankton-Current Correlations

After the vessel departed San Diego last November for Wellington, New Zealand, *via* Papeete, Tahiti, she sailed southward for 3,000 miles as scientists investigated the plankton populations within and bordering the equatorial currents.

In these operations, multiple nets were towed at as many as ten depths at once. This technique, which was developed at Scripps, gives reliable estimates of the vertical distribution of the plankton organisms.

In general, the scientists sought to learn about the relationships of oceanic plants and animals to the currents in the equatorial belt and to find out why the equatorial current are fertile whereas the currents to the south are extremely poor in marine life.

Studies by Dr. Elizabeth Venrick during the expedition showed that the southern part of the tropical belt was not as barren as it first appears to be. The plant plankton, upon which the marine food chain depends, was concentrated not in the surface layer as would be expected, but, instead, at more than 500 feet of depth. A broad east-west belt of water south of the equator was found to contain types of plankton that are known, on the basis of earlier expeditions, to come from the far western part of the ocean. This seems to contradict the notion that currents typically flow toward the west in this particular zone, 10 to 20 degrees South. The ship proceeded westward, making two more transects of this anomalous zone and establishing that its characteristic fauna does extend continuously, east-west.

Water Circulation

The *Thomas Washington* logged 8,500 miles between New Zealand and Antarctica during studies of the circulation of the waters carried out by measuring their characteristics and velocity. During these studies, measurements of temperature, salinity, oxygen, and nutrients were made from the surface to the ocean floor at 60 positions. These measurements traced the outflow of water from the Ross Sea into the open Antarctic Ocean and will attempt to estimate the contribution of the Ross Sea water to the heat budget of the ocean-atmosphere system. The warmer waters enter the ice-covered Ross Sea from the open Antarctic and are cooled. They they flow back out again near the bottom, rather than at the surface.

Seventeen free-vehicle instrument drops were made and all recovered. Five of these were drops of baited cameras taking photographs of fish. The other drops were current meters designed to measure the velocity near the ocean bottom.

Zooplankton net hauls were made at 20 stations, and at three locations samples were taken for determination of tritium, carbon dioxide, oxygen isotopes, alkalinity, radium, and various gases.

Plankton Communities

During March, earlier studies of the structure of planktonic communities in the vast south central gyre of the Pacific were continued to investigate grazing habits of herbivores, the manner in which marine plants take up nutrients, and the competition among marine predators and among their prey.

In a different oceanic region such as the California Current, the immigration into and emigration out of the Current by marine organisms is an important factor. This inward-outward movement is at a minimum in a relatively stable area like the gyre, a factor making it easier for scientists to study the interactions between competitors and between predators and prey.

Similar studies of planktonic communities were also studied on the last leg of the expedition, in the central North Pacific gyre, between Honolulu and San Diego. In addition, the scientists collected a variety of marine animals—fish, squid, plankton—to analyze the body content of lead, mercury, DDT, PCB, and other pollutants.

Oceanic Mixing Processes

Measures were taken of the variation of salinity and temperature at various stations along the track of the ship. Such measurements were taken on a scale as small as an inch and through the greater part of the ocean depths.

These small-scale measurements form the "imprint" of the mixing processes taking place in the ocean; that is, they are a measurement of the way that frictional stresses are transmitted through the ocean and the mechanisms by which the deeper waters are mixed upward into surface layers, bringing along nutrients to the top. Measuring such mixing processes provides a method for determining how carbon dioxide and other elements are diffused into the ocean.

Pacific Equatorial Undercurrent

Investigations focused on the Equatorial Undercurrent in the central Pacific. The Equatorial Undercurrent is a strong (up to 3.5 knots) eastward-flowing subsurface current which is found in a narrow band 250 miles wide along the equator in all oceans.

A study of the distribution of temperature and salinity in the vicinity of Jarvis Island was carried out. Jarvis Island lies 40 miles south of the equator at 160° W and is located in the strong flow of the Undercurrent.

The Jarvis Island survey provided a description of the effect of the island on the flow of the Undercurrent and the change in water properties from one side of the island to the other. The character of the mixing processes around the island will be deduced from these data. It is possible that higher productivity sometimes observed behind islands may be accounted for by increased mixing of the waters produced by the island's disturbance of the large-scale flow. These measurements will clarify these mixing processes.

At 150°W, where the Pacific Equatorial Undercurrent was discovered in 1952, moorings with current meters were installed which were then picked up by R/V *George Wallace Melville* in September. These moorings, which were in place for five months, will provide a long record of velocity variations in the Undercurrent and the deep water underneath the Undercurrent. Measurements from the ship at the time the moorings were put in showed that the Undercurrent at 100 meters had a speed of 3.5 knots, and the Undercurrent extended all the way up to the surface. The unusual "surfacing" of the Undercurrent is thought to be due to the decreased strength of the Trade Winds during this month.

Kuroshio, A Deep Boundary Current

Studied also was the Kuroshio, a deep boundary current that flows south of Japan and is analogous to the Guld Stream in the Atlantic Ocean. The behavior of the Kuroshio is unique in that occasionally there are very large shifts of the current away from the coast that persist for many years. On this leg an intensive study of the path of the Kuroshio was made to determine the detailed behavior of the current as it flowed along the Japan coast.

Temperature measurements down to 450 meters were used to fix the position of the current. These path data, in conjunction with velocity measurements near the sea bottom, will be used to determine the factors that control the position of the current. The shipboard measurements indicate that the Kuroshio extends all of the way down to the sea bottom (a vertical distance of over 4,000 meters). At one location the average speed of the Kuroshio at the bottom was over 0.05 knots, which is very fast for a deep current.

Volcanic Seamounts

A vast outpouring of volcanic matter on the sea floor 140 million years ago in a 3-million-square-mile area between the Hawaiian Islands and Japan was indicated in geological studies of the submarine Mid-Pacific Mountains. Approximately 40 dredging operations on nearly 20 seamounts revealed coral reefs atop submerged volcanic peaks.

By studying fossil material taken from the reefs, the age of the reefs and an idea about when the peaks became submerged was obtained. Knowing the age of the reefs puts a restriction on the age of the crust of the sea floor, for the reefs are younger than the volcanic seamounts on which they rest.

Throughout the large area crossed, the reefs, or atolls, were found to be about the same age. Perhaps this is an indication of a vast outpouring of lava on the sea floor at the same time throughout the area.

It was impressive when one dredge haul on a seamount 4,800 feet below the surface brought up round, smooth cobbles up to eight inches in diameter.

Although the seamount is now submerged, finding the cobbles leads us to the conclusion that the volcanic peak at one time millions of years ago stood as a land mass above the surface of the ocean.

Guyot Discovered

In late July and all of August the *Thomas Washington* logged almost 10,000 miles of survey track from Yokohama to Honolulu in conducting geological and geophysical investigations in the region of the southern Emperor Seamounts and the Hess Rise.

The most spectacular discovery during this leg of Aries was the charting, in the southern Emperors, of one of the largest guyots so far discovered in the world ocean. This guyot lies 700 miles northwest of Midway Island and had previously been shown on charts as several shallow soundings.

But survey work by the ship revealed a single large guyot 70 miles long and 45 miles across, rising 15,000 feet from the surrounding sea floor to within 1,500 feet of the surface. Dredging on the top of this guyot produced samples of coral reef debris that proved this had at one time been a coral atoll or perhaps an island similar to Kwajalein Atoll in the Marshall Islands.

Buoy Servicing

In early September, under the direction of David D. Muus, the *Thomas Washington* recovered one buoy and serviced three others located approximately 1,000 miles north of the Hawaiian Islands. These unmanned, moored buoys were placed as part of Scripps's North Pacific Study, an investigation of air-sea interaction.

Helium Speech Processing Goals Met

Research on gradient microphones, speech processors, diver communication, and speech intelligibility have paid off according to the participants of a joint ONR/BuMed workshop (NR 197-003) held at the Naval Submarine Medical Research Laboratory, 18-20 August 1971.

Data presented at the workshop indicated that a satisfactory gradient microphone, developed by LTV Advanced Technology under an ONR contract, has been fabricated for use at high pressure and within a reverberant helmet. Speech unscramblers were described and demonstrated by several manufacturers of helium speech processors. Weight, size, and dollar cost varied over a wide range but very high intelligibility levels were attained. Independent evaluations of these processing systems at simulated depths have been conducted with ONR support at the University of Florida and the Naval Ship R&D Laboratory, Panama City, and the suitability of these systems for Navy operations has been verified. Research continues in the above areas, micro-miniaturization proceeds, and efforts to meet the requirement for communication between divers at 4000 yards have been initiated. It is evident from this workshop that an acceptable system for speech at great depths is near at hand.

NRL Breakthrough in Sound and Light Wave Application

Scientists at the Naval Research Laboratory (NRL) have developed a technique for investigating and measuring the properties of strengthened glass by a method using the combination of light and high frequency sound (ultrasonic) waves.

Glass can be made stronger by chemical stressing of its surface which consists of permetting big ions to diffuse into the glass surface. This is called "ion stuffing." Until now, there has been no known method for measuring this type of induced surface stressing.

The NRL measuring technique consists of first inducing surface acoustic waves on glass samples which sets up molecular corrogations in the glass surface. Then a laser beam is scattered from these associated small amplitude surface corrogations to measure the speed at which they travel down the surface. The resultant data are used to measure the strength of the glass surface.

Scientists in the Acoustics Division say the technique will be of great value for the nondestructive rapid determination of glass strength and in the study of the strengthening mechanism itself. It can also serve as a monitoring method to determine how glass is changed as well as a research tool in the chemical treatment of glass.

Requests for joint efforts already have been received from groups at the National Bureau of Standards and the Naval Ordnance Laboratory where programs in the chemical strengthening of glass are already under way.

Study on Sonarmen Reporting of False Targets

A major factor in sonar detection appears to be the criteria which a sonar operator uses to decide whether or not to report an initial contact, that could be a false target. On the one hand, he does not want to report a contact that would result in his ship taking unnecessary action. On the other hand, he is concerned about the consequences of failing to report an initial contact that proves to be a real target. There is evidence that his decision takes into account the particular operational situation in which his ship is involved and how serious might be the consequences of reporting a possible false contact or failing to report a real one, in that specific situation. The effect of this type of subjective judgment is under study by Dr. Robert Mackie of Human Factors Research, Inc. supported by the Office of Naval Research in a program designed to evaluate sonar detection performance.

The first phase of the study was a survey of both sonarmen and their officer supervisors utilizing scenarios of various types of operational situations, such as ASW exercises, non-ASW peacetime exercises and wartime operations. The results showed that both groups were in agreement concerning the certainty threshold that is desired for reporting a contact, the consequences of missing a real target and the cost of delay in reporting. There was little agreement, however, in ranking operational situations according to the severity of the consequences of reporting false contacts. Generally sonar operators expressed caution in reporting initial contacts while officers favored less caution, even though more false contacts would be reported. Both groups agreed that a more accurate reporting of the sonarman's confidence or certainty when he announces an initial contact would be very useful to the bridge.

During the next phase, detection experiments will be conducted to determine the relationship between subjective judgments and detection performance. A study with similar objectives, but utilizing a different sonar simulation, is under way by Mr. Edward Rizy, of the Raytheon Company.

Results of both research studies will be useful for improving sonar contact reporting procedure, determining information feedback requirements for sonar operators and developing performance aids.

Semi-Automatic Plotting of Shallow Water, Bottom Topography

Scientists D. T. Hodder and P. B. Chandler of North American Rockwell Space Divi-
sion have developed a technique for semi-automatic plotting of shallow water, bottom
opography from aerial multispectral photography. This research is being conducted under
n ONR contract. The initial investigation basically defined the depth-film density rela-
ionships under a limited range of sediment conditions. Film density measurements were
nade from multispectral photos with a scanning microdensitometer and the data digitized
or computer input. A computer program was developed to statistically merge the digitized
hotographic data from successive flights over the same target site. This program uses
ocal surface fits to produce the complete contour map. The local surfaces are obtained by
inear regression techniques and then joined into the complete contour map by smoothing
nd blending. The various digitized photographic density inputs are handled in this fashion,
tored in a rectangular array, statistically combined and contoured using the original
lgorithm. These results indicate that the system can be improved to the point where it
ill be fully automatic. Such a system could be an integral part of a surveillance-recon-
aissance system for coastal areas and for amphibious, mine, shallow water and riverine
perations.

Ferro-Cement Hull Construction

A few ounces of an inexpensive chemical is all it takes to double the strength, stiffness, and corrosion resistance of a cement-hull boat, University of California engineers have found while investigating the properties of ferro-cement under an Office of Naval Research contract.

About a dollar's worth of chromium trioxide (CrO_3) added to the cement mix water can increase hull strength 59 per cent in ferro-cement boats, according to R. Brady Williamson, associate professor of structural engineering and structural mechanics on the Berkeley campus.

Ferro-cement, a combination of steel mesh (such as chicken wire or hardware cloth) and cement mortar, has come into popular use for homemade boat hulls and other strong, lightweight, thin-shell construction.

In standard ferro-cement boat construction, galvanized steel mesh (mesh coated with zinc) is stretched over plain steel reinforcing bars to form the boat hull. Next, cement mortar is impregnated into the frame and a thin layer spread over the surface.

While testing the strength of ferro-cement in the Structual Engineering Laboratory at Berkeley, Williamson and graduate student Kenneth A. Christensen discovered that fresh ferro-cement mortar developed bubbles, weakening it and making it susceptible to corrosion.

Further study revealed the bubbles were caused by hydrogen gas which formed whereever the fresh mortar joined the galvanized mesh to the plain reinforcing bars. The dissimilar metals reacted in the presence of the fresh mortar, giving off hydrogen gas.

The use of galvanized mesh is highly desirable in boat construction because of its corrosion-resistant characteristics. Galvanized reinforcing bars, however, are not practical because dissimilarities in the metals might still exist even if both the mesh and the bars were galvanized.

A solution to the problem was suggested by two other professors in the College of Engineering at Berkeley, Boris Bresler, a concrete structures specialist, and Israel Cornet, a corrosion expert and also an ONR contractor.

Although neither man had ever worked with ferro-cement, they recognized the problem as one they had studied in other research. They were sure chromium trioxide would neutralize the reaction.

Further tests showed that not only did chromium trioxide inhibit hydrogen gas from forming, but it also made the ferro-cement stronger than before.

Christensen put the laboratory findings to work under real conditions on a 37-foot ferro-cement sloop he was building. Based on laboratory calculations that approximately two ounces of chromium trioxide should be added for every 50 gallons of cement mix water, he added 3.4 ounces of the chemical to the 85 gallons of mix water he needed for the hull—an additional cost of $1.74. Test panels showed the result to be bubble-free ferro-cement.

Williamson and Christensen, discovered the bubbles when they made horizontal, thin-layer test panels, panels that allowed the bubbles to come to the surface.

In actual boat building practice, the layers of mortar and mesh over the plain steel would usually be of sufficient depth to suppress emergence of the hydrogen gas at the surface, and the more-or-less vertical surface would increase the suppressive force of the mortar.

As a result, the gas bubbles are trapped along the reinforcing bars, causing a poor bond to form and increasing the chance that salt water might reach the ungalvanized steel, and cause destructive corrosion.

The fact that the gas has been trapped is the reason the problem has apparently gone unknown until now, the two say, and they speculate that the weakening condition caused by the hydrogen gas has probably affected most ferro-cement projects where galvanized mesh and plain steel have been used together.

Ceramic Oxide Materials for Improved High Power Laser Hosts

Research on ceramics as high power laser hosts have been in progress fifteen months at the General Electric Research and Development Center. It is being conducted by Drs. C. Greskovich and K. Woods under an ONR contract funded by ARPA. The need exists for high performance lasers for range finders, target illuminators, *etc*. Current lasers for such applications are based on neodymium in either crystalline (yttrium iron garnet) or silicate glass hosts. These do not sustain the high average pulsed power levels desired. A ceramic oxide host, "Yttralox," has been shown to possess potential for achieving this mode of operation. This material (90% yttrium oxide and 10% thorium oxide in solid solution) (undoped with Nd^{3+}) was developed by the General Electric Company in a company funded project. These materials of very near theoretical density were doped with small amounts of neodymium 3^{+} ions and were shown to be capable of sustaining lasing action. It was clear from prelininary work that the microstructure and processing of material was much less than optimum, *i.e.*, lasing behavior and fabrication could not be achieved in a reliable and reproducible manner. This contract was directed at increasing optical quality of Yttralox ceramics for use as a laser host, and at achieving reproducible fabricability of the optically ultra-clear materials needed. The work was backed up by several ONR contracts on scientific understanding of ceramic processing. High purity Yttralox powders were optimized as to chemical homogeneity and particle size and shape. Calcined powders were analyzed as to their sinterability in order to make bodies which are essentially pore free. Microstructure development and origin of pores was followed by microscopic techniques to control refractive index. Active and passive measurements were made on these greatly improved materials to evaluate their laser potential. Five rods were prepared and submitted to ONR for evaluation at NRL. The optical quality was markedly improved by optimizing the ceramic processing route used. Two of these rods have been lased repeatedly and are thoroughly described in the first annual report produced under the subject contract. The other three rods have not been tested for their lasing behavior but should perform as well or better than the first two based on recent total light scattering measurements done at G. E. These materials are remarkable: they are polycrystalline rods (*i.e.*, ceramic bodies) over three inches in length with optical clarity good enough to view scenes feet away and also with the capability of sustaining lasing action. The results of this contract may stand as a benchmark in demonstrating how control of development of microstructure and flaws during processing very markedly influences properties of high quality engineering materials.

Interferometer Development

Under an ONR contract with University of California, Berkeley, a millimeter wavelength interferometer of great stability, sensitivity and resolution has been evolved. This important instrumentation advance is a result of application of modern noise, correlation and antenna data processing techniques to design and operations of an interferometer operating at extremely-high-frequencies. Each element, the precise antenna dishes, lines equalizers, wide-band correlation and computer interface circuit was generated with total system gain phase and electric line length stabilities in mind. University of California scientists are using the device to map out brightness distributions in water-vapor and other discrete lines of our galaxy, as well as the planets. Naval interests include precision tracking and feature identification of air and surface targets.

NRL Using Holography in Study of Dendrite Morphology

Naval Research Laboratory scientists reported that holographic interferometry is well suited to studies of the growth of dendrites, the branched, tree-like crystals which play an important role in the solidification of metal alloys.

According to a recent NRL Progress Report, the image reconstructed from a hologram of a dentritically freezing system can be thoroughly searched, examined, and measured in detail.

Transient dendritic growth forms, appearing at any location within the specimen, can be focused upon and examined interferometrically at leisure. A holographic technique has been used here to study the shapes of dendrites growing in certain transparent organic materials having solidification behavior similar to that of metals.

Because of its importance in the study of physical metallurgy, work is continuing on this effort at NRL.

Navy Reports Progress in Termite Research

Navy research on how to destroy termite colonies completely without the use of insecticides is making progress, but scientists are hampered by the discovery that termites breed more profusely and are more wily than they anticipated.

The immediate target is the Formosan termite which heavily infests Hawaii where they are extensive naval installations. This species has also found its way to the continental United States. Although specialized construction techniques together with the use of resistant materials or chemical barriers substantially reduce infestation, they are not completely effective and usually increase the cost of construction.

Insecticides, aside from their potential danger to the environment, are limited in their effectiveness against the Formosan termite. It has been found that these termites are in many cases able to reinfest a structure after an insecticide treatment. Moreover, the termite will wall off sections of the colony where insecticides are applied so that the entire colony cannot be eliminated.

The technique under development by the University of Hawaii under a contract with the Office of Naval Research is to introduce a deadly disease capable of reaching epidemic proportions among the termites in a colony. Initial experiments have utilized the nematode DD-136. This is a parasite which has been found to be highly infectious to all stages and castes of the termite family.

The nematode takes approximately seven days to kill the termite, which allows ample time for diseased insect to travel throughout the colony and spread the infection. In this way, it is hoped to create an insect epidemic among the termites.

Initial field experiments have demonstrated that it is practical to trap large numbers of termites, infect them with the parasite and re-introduce them into the colony. An insect epidemic, however, has not yet taken hold partly due to the discovery that the colonies are very extensive, numbering into the millions of individual termites.

In addition, in some colonies the termites are able to recognize that certain of their fellow termites have become diseased and then proceed to collect them and wall them off, limiting the spread of the infection. For some reason this "quarantine" action takes place in some colonies but not in others.

Further experiments are aimed at adjusting the threshold of dosage of the nematode required to assure the complete spread of the disease. Other biological materials, such as certain bacteria fungi, are also being studied. While these fungi are highly infectious to the termites, they do not spread in the lightless termite galleries. Strains that thrive in the dark are being sought.

U.S. GOVERNMENT PRINTING OFFICE : 1972 O - 465-881

ONR Ionospheric Research Satellite

At approximately 0540 PST on 17 October 1971 the ONR-001 High Altitude Ionospheric Research Experimental Package was successfully launched into a 400 nmi circular polar orbit from the Air Force Western Test Range, Vanderberg AFB, California.

The package was one of four DOD experimental packages placed in orbit by the Air Force Space Experiment Support Program (SESP) launch No. 71-2. The launch vehicle consisted of a long tank Thor-Agena Rocket with three solid state strap-on auxillary boosters.

The ONR-001 experiment contains a wide array of electron, proton and alpha particle detectory with wide dynamic ranges for both energies and densities. These detectors will measure the energetic particles precipitating into the earth's atmosphere. In addition the experiment contains in Earth Reflecting Ionospheric Sounder (ERIS) which will measure the changes in ionospheric electron concentration produced by the precipitating particles.

The natural ionospheric events caused by precipitating particles are the aurora and the polar cap absorption (PCA) events. Both of these disturbances cause radio and radar propagation problems and require investigation for the reason. More importantly though is the fact that the PCA event can be used to simulate the ionospheric effects produced by a high altitude nuclear explosion. Such explosions can cause very serious and long lasting communications blackout at VLF through HF.

Some problems were encountered with low temperatures on the particle detectors and with high noise levels on the ERIS receivers. All temperatures had increased to nominal predicted levels by November fifth and the ERIS noise problem went away with the termination of the SAMSO-002 experiment. We now have a very successful experiment in progress. The ONR-001 experiment is expected to have a useful life of from six months to one year.

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

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NAVSO P-510

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