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NAVAL RESEARCH REVIEWS

FEBRUARY 1964

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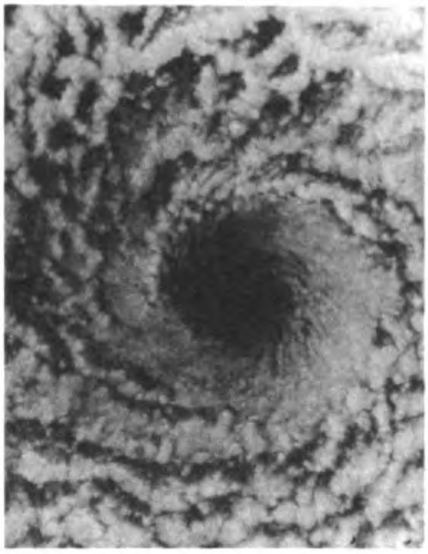

Perfect Storm Vortex

At about ten o'clock on the morning of October 1, 1962, CAPT Lachlan MacLeary, an Air Force pilot, took off from Edwards Air Force Base, California, in a U-2 aircraft on a special mission conducted for the Department of Defense by Arthur D. Little, Inc., Cambridge, Mass. The objective was to make measurements of the infrared radiance properties of clouds by means of a grating spectrograph and a 16-millimeter time-lapse motion picture camera.

At the preflight briefing, CAPT MacLeary was told of the possibility of finding clouds over Arizona; but as he reached his assigned flight altitude—65,000 feet—he saw none in that direction. In fact, the only clouds in view anywhere comprised a band of "low stratus" clouds extending seaward from the coast. So the pilot turned southwest to fly over Los Angeles and out to sea over these clouds.

Shortly after crossing the coast, CAPT MacLeary saw an unusual disturbance in the clouds over the Santa Barbara Channel, where no severe weather had been expected. "A miniature hurricane," he reported by radio. He then flew directly over the eye at 65,000 feet and photographed it with the time-lapse camera over a period of about 1-1/2 minutes. One of these pictures of the vortex—perhaps the most perfectly formed storm center ever to be photographed—appears on the front cover.

An analysis made of the sequence of photographs indicates that the projection of the eye of the vortex at sea level had a major diameter of about 4.4 kilometers and a minor diameter of 3.1 km. These figures were based on the 15.6 km. length of San Nicolas Island, a portion of which appeared in one of the photographs. Estimates of the cloud heights in and around the vortex were not made.

The existence of the vortex apparently went unnoticed by local weathermen. However, as far as is known, no severe weather occurred in conjunction with the disturbance.

The study of infrared radiance properties of clouds is being supported by the Advanced Research Projects Agency through the Office of Naval Research.

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The X-Ray Sources in Scorpius and the Crab Nebula*

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The exploration of stars, galaxies, and other celestial entities by means of x-ray detectors flown in rockets high above the earth's atmosphere has opened up an entirely new chapter of astrophysics. The approach, a recent offshoot of "x-ray astronomy," which began with x-ray observations of the sun, may enable astrophysicists to locate a number of the sources of x-rays reaching the earth from space and to obtain some information about the processes which lead to the production of these rays.

Although efforts to detect x-rays from the night sky had begun as far back as 1956, in the NRL Aerobee program, no positive indications of x-ray emission from the galaxy were obtained until about two years ago, and not until last April 29 was a detector providing a narrow field of view carried aloft.

Scientists have hypothesized that x-rays are produced near the centers of galaxies or in galactic halos as the result of interactions between high-energy protons and electrons and the thin gases of the galaxies. They have suggested also that the rays may emanate from stellar coronas, flare stars, and the remnants of supernovae (such as the Crab Nebula), and from other very hot matter in the sky—but with what intensity and from precisely what locations, they have not known.

The experiment in x-ray astronomy conducted last April 29, and others similar to it that are expected to be conducted in the future, may help resolve some of these uncertainties. On April 29, the Naval Research Laboratory launched an Aerobee rocket into the sky over New Mexico carrying a detector equipped with a hexagonal honeycomb collimator that narrowed the "field of view" to 10 degrees. The instrument, a large-area (about 86 square centimeters) proportional counter, was carried to an altitude of 130 miles—80 miles above the height at which most of the x-rays of interest (1.5 to 10 kev, or 1-8A) begin to be absorbed by the earth's atmosphere. As the rocket spun and precessed, the x-ray detector, which was mounted in the side of the rocket, "viewed" the entire sky above the horizon in the course of 4 minutes of flight between altitudes of 50 and 130 miles. In all of the sky, there appeared only two clearly defined x-ray objects—a very strong source in the Scorpius region and a weaker source in the Crab Nebula.

The X-Ray Source in Scorpius

Eight different times during the rocket flight, the gyrations of the rocket caused the x-ray detector to sweep across the Scorpius source, and each time its signal was clearly evident in the telemetered counting rate. Even though the

* A slightly modified version of the paper presented by Dr. Herbert Friedman to the 115th meeting of the American Astronomical Society, Washington, D.C., December 27, 1963.

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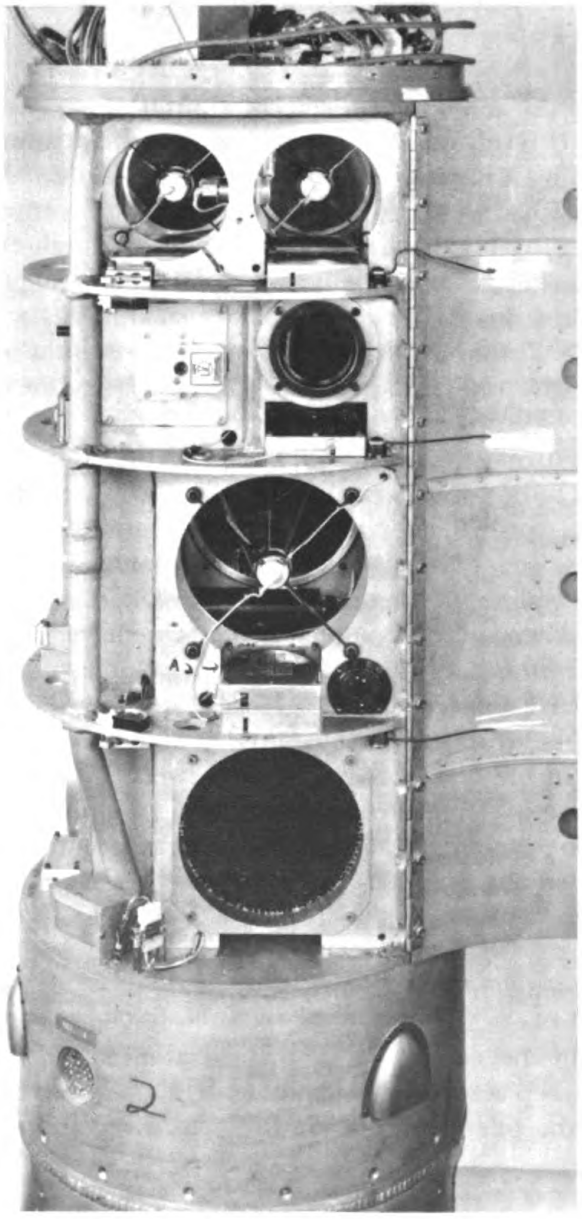
detector viewed a 10-degree field, the pattern of signals was symmetrically distributed about a point in the region between Nu-Scorpii and Chi-Scorpii. The measurements are consistent with a point source, or star, but do not rule out a more extended source, one as broad as 2 degrees.

The position of the x-ray source was at 16 hr. 15 min. right ascension and -15 degrees declination. No unusual stars or optically prominent features are present in this region of the sky. One possible hypothesis is that the x-rays come from an invisible cloud of extremely hot gas, of the order of a million degrees centigrade, but how such a hot gas cloud might arise in this region is not at all obvious. A second possibility is that the source is a neutron star. According to theory, neutron stars are extremely hot, very dense objects having cores consisting entirely of neutrons. Their existence was predicted several decades ago, but it has not yet been verified by observation.



Instrument payload flown in NRL Aerobee rocket on April 29,1963. The x-ray detector is shown in the lower section.

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Neutron Stars

That stars may evolve to a stage in which their cores are composed purely of neutrons was first proposed in 1934 by W. Baade and F. Zwicky and later subjected to more detailed theoretical treatment by J. R. Oppenheimer and V. M. Volkoff. Such stars could be brilliant x-ray sources and yet be invisible at optical wavelengths. No optical evidence has yet been produced for the existence of neutron stars.

The densest objects observable with optical telescopes are the white dwarf stars, which have somewhat less than solar mass and a radius comparable to the earth's. It used to be thought that white dwarfs were the products of supernova explosions, but they are so common (about 10 percent of the stars in the solar neighborhood) that they must clearly evolve from some more usual processes than the supernovae that occur roughly once every 50 to 300 years. It has been proposed that under the extraordinary conditions of pre-supernova explosion, the core of a massive star can be crushed to a density more than a million times as great as that of a white dwarf. In the final collapse of the supernova, the outer shell of gas explodes into space leaving the compact core of neutrons, weighing as much as the sun but at a density of 10- to 100-billion tons per cubic inch, with a central temperature of several billion degrees centrigrade. This super dense neutron star would measure only 5-10 miles in diameter, but its surface temperature may reach 10^7 degrees. A normal yellow star, such as the sun, having a surface temperature of 6000 degrees, radiates almost all of its energy in the visible range of wavelengths. A blue star might have surface temperatures of 100,000 degrees and radiate most of its energy in the far ultraviolet, but a neutron star with a 10-million degree surface would radiate nearly all its energy in the form of x-rays and be invisible even if it were as close to the sun as the next nearest star in the sky.

Dr. Hong-Yee Chiu (Columbia University and Goddard Institute for Space Studies) has recently made some computations of neutron-star numbers and brightness. Assuming a galaxy 10-billion years old and an average supernova rate of 1 per 200 years, the galaxy should now contain 10^8 neutron stars. Of these, one should have a surface temperature of about 10-million degrees and a life of about 100 years. Its x-ray emission would appear most intense in the range 1 to 10 A, where the rocket's counter detected the source in Scorpius. In fact, its emission would be intense enough to supply the measured flux even if the star were 30,000 light years from the earth, almost at the edge of the galaxy.

Chiu's calculations show that there might be 100 neutron stars within the Milky Way galaxy with surface temperatures of about a million degrees and lifetimes of 10,000 years, but their x-rays would be most intense at longer wavelengths, near 100 A, which are absorbed over relatively short distances of interstellar space.

The strong x-ray source in Scorpius may therefore be a neutron star, undetected by any ground-based astronomical technique. Theory predicts that there is probably only one star of the strength measured in Scorpius within the entire Milky Way galaxy. To lend credence to this hypothesis, it will be necessary to establish that the observed source is in fact a point source, a star. X-ray telescopes must be designed so as to have sufficient resolution to distinguish between a star and a gas cloud. When the location of the source is ac-

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curately pinpointed, a search could be made with the Palomar telescope for a very faint and unusually blue star.

The x-ray source in Scorpius is a new class of object to be added to the list of strange astronomical radio-optical sources discovered in the past few years. These include the eleven recently identified "quasi-stars," such as 3-C-48, 3-C-273, and 3-C-295. Their spectra show very large red-shifts,* which if attributed to recession velocities would place the "stars" at distances of 2- to 5-billion light years. Two of these "stars" appear to be 100 times brighter than our entire Milky Way galaxy if their distances are correctly established. The red-shifts, on the other hand, could be gravitational shifts† characteristic of neutron stars situated within our own galaxy. It can be argued, however, that the residual gaseous envelope of a neutron star would be too thin to radiate visible light detectable much beyond our own solar system. Alternative hypotheses propose: (1) super-massive stars 100 to a million times as massive as the sun in a collapsing phase; (2) chain-reacting supernova explosions in dense elliptical galaxies; or (3) an excited gas cloud in intergalactic space with a diameter of hundreds of light years and a mass equal to a billion suns. The x-ray source in Scorpius differs from these visibly bright and radio bright "quasi-stellar" sources in that it is neither visible nor has it been identified with any radio emission.

The X-Ray Source of the Crab Nebula

The weaker x-ray source observed by the NRL group was the Crab Nebula. Its x-ray intensity was about one-eighth that of the Scorpius source.

High-energy (relativistic) electrons gyrating in a magnetic field radiate a continuous spectrum of electromagnetic radiation (synchrotron radiation) from radio wavelengths to a short wavelength limit determined by the maximum electron energy. The spectrum is relatively flat, or uniform throughout, and the radiation is polarized. The Crab Nebula is one of the strongest radio sources, and its visible light is highly polarized. To account for the radio emission requires electrons with energies up to 100 million electron volts, but to explain the visible emission requires still higher energies in the range of cosmic rays, up to 200 billion electron volts, and a magnetic field strength of 10^{-3} gauss (galactic field = 10^{-6} gauss). To produce the x-rays (1-8 A) observed by the NRL rocket would require electron energies as high as 10^{14} electron volts. However, when the measured visible spectrum of the Crab Nebula is extrapolated to x-ray wavelengths, it falls short of the measured x-ray flux by several orders of magnitude. Clearly, the observed x-rays cannot be synchrotron radiation. We suggest that the x-rays are a thermal emission, as in the Scorpius case, from the neutron star remnant of the supernova explosion of 1054 A.D., which formed the Crab Nebula.

*The term "red shift" refers to light produced in some distant celestial objects that appears red because the objects are moving away from the earth, therefore causing an increase in the wavelength of the light. For example, if a sodium lamp could be seen from earth on an object characterized by red shift, it would appear red instead of yellow.

†There are two kinds of red shift. One is the doppler shift, which is an increase in wavelength which occurs because the object is moving away from the earth. The other is a gravitational shift, which occurs if the object is very dense, as a neutron star would be; the radiation must travel "uphill," or against gravity, to such an extent that it loses energy and thus increases in wavelength.

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There are many puzzling features of the Crab Nebula. Theory estimates that the original supernova involved the release of 10^{51} ergs of energy. The nebula now fills one cubic parsec of space and the total energy contained in electrons and the magnetic fields is about 10^{48} ergs. It seems rather surprising that after 1000 years only one-thousandth of the original energy has disappeared.

Baade discovered in 1942 that "light ripples" run through the Crab and that they occur somehwat irregularly, about three times a year. The ripples move outward at about 1/10th the speed of light and disappear a short distance away from the central star. This phenomenon suggests an active source still operating at the center of the nebula. In fact, the luminous moving concentrations indicate that there may be periods of several years when the central star is violently active.

Over the past two millenia, galactic supernova have definitely been observed in A.D. 185, 369, 1006, 1054, 1572, and 1604. The last three are the Crab, Tycho Brake's star, and Kepler's supernova. The earlier cases are documented in the Chinese chronicles, and the location of the 1006 supernova was placed on the far edge of Scorpius from the newly discovered x-ray source. Dr. Donald Morton of Princeton University has informed us that still another supernova is on record in the Chinese chronicles as having reached a brightness comparable to the quarter moon in 827 A.D. and that its location was not far from that of the Scorpius x-ray source. Thus the possibility exists that neutron stars were formed during each of these events.

Isotropic X-Rays from the Galaxy

In studies of x-ray sources and their intensities, it is obviously important to establish accurately the level of the total, or isotropic, x-ray flux reaching the earth from space—distinguishing between what is truly galactic or extra-galactic and what is produced in the earth's high atmosphere through the action of trapped energetic particles. By comparing x-ray signals recorded in a rocket looking upward with those looking toward the earth, the NRL group made a determination of the average intensity of x-rays coming from the overhead sky. If this flux is truly a galactic or extra-galactic emission, important cosmological deductions can be made. For example, Burbidge and Gould have shown that if x-ray emission comparable to the Scorpius flux is produced in most galaxies, the net flux reaching the earth from all galaxies would be isotropic and of the magnitude of the background radiation observed by NRL. The hot universe model* of the steady state theory proposed by Hoyle and Gold requires that matter be created continuously and that it be in the form of neutrons. The neutrons would decay to protons with the emission of high-energy electrons that would heat the intergalactic gas to 10^{9}°C. and produce x-rays. The background x-ray intensity observed by NRL, however, is about a hundredfold weaker than predicted by this theory.

A clue to the presence of energetic particles capable of producing x-rays in the high atmosphere is the characteristic blue glow emitted by positive ions of molecular nitrogen, N_2^+. This blue glow is the most intense emission of aurorae

*According to the hot universe model, galaxies are regions of local cooling in a hot, intergalactic gas. Condensation occurs as the result of the pressure of the external hot gas at the surface of the cooler region. Once higher densities are produced, gravitation becomes a dominating force.

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and gives a quantitative measure of the electron energy dumped into the auroral region. In the mid-latitude night sky the N_2^+ emission is too faint to be measured and only an upper limit can be set, based on the minimum glow detectable against the starlight background. This limit would indicate an electron flux capable of producing x-ray bremsstrahlung comparable to the sky background x-ray emission observed by NRL. We therefore cannot yet eliminate atmospheric x-rays as a possible explanation for the isotropic flux.

Other Observations of Galactic X-Ray Emission

Observations of galactic x-ray emission have also been reported by Giaconni, Gursky, Paolini, and Rossi of American Science and Engineering Corporation and Massachusetts Institute of Technology. Their 1962 experiment, originally designed to observe x-ray emission from the moon, used a Geiger counter without any collimation to define the field of view narrowly. As a result, they observed a very broad signal, about 100 degrees wide, and concluded that it was probably associated with the galactic center. A repeat experiment one year later under essentially identical conditions gave similar results. To quote from their recent publication, "Our experiments reveal a main source close to the center of the galaxy, but apparently not quite coincident with it."

The stronger source detected by the NRL group is on the northern border of the Scorpius constellation. Its position is identified to within about one degree and it is approximately 20 degrees from the galactic center. During the NRL flight, the galactic center was below the horizon and invisible from the rocket. Because the detector used by Giaconni *et al.* had such a broad field of view, the NRL source in Scorpius must have contributed to its signal. However, since their field of view also included the galactic center, it cannot be excluded that a portion of their observed response did, in fact, come from that region, as they have suggested.

Although the observations of galactic x-rays made by NRL have revealed only two prominent sources, it is undoubtedly true that many weaker sources exist below the range of detectability of the sensors that were used. It is entirely possible that the development of much more sensitive detectors and of x-ray telescopes for use in rockets will reveal a great many weaker sources now buried in the noise of the isotropic background radiation. With the longer counting times available from orbiting astronomical observatories, it should be possible to increase the efficiency of detection with the square root of the available time of measurement.

SPACE SCIENCE AWARD

One of the authors of the article above, Dr. Herbert Friedman, was presented the Space Science Award by the American Institute of Aeronautics and Astronautics (AIAA) in New York City in January. Dr. Friedman was selected for the award for his investigations of planetary atmospheres, which involved studies of the properties of solar ultraviolet and x-radiation and the effects of this radiation on the various regions of the ionosphere.

Dr. Friedman is Superintendent of the Atmosphere and Astrophysics Division of the Naval Research Laboratory and Chief Scientist of the E. O. Hulburt Center for Space Research.

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Seismic Crustal Studies in the Arctic Ocean Basin

LT Jaap W. Boosman, USNR
Geography Branch
Office of Naval Research

During the months of October and November 1963, the University of Wisconsin, University of Minnesota, and Columbia University's Lamont Geological Observatory successfully conducted the most intensive seismic crustal study ever attempted in the Arctic Ocean Basin. The program, fully supported by ONR's Arctic Research Laboratory and the icebreakers USS STATEN ISLAND and USCGC NORTHWIND, was carried out under joint sponsorship of the Office of Naval Research and the Air Force Office of Scientific Research. Preliminary indications are that the data obtained will contribute significantly to the understanding of the nature, thickness, and structure of the earth's crust underlying the Arctic Ocean, as well as of the character of the structural transition from continental land masses to oceanic basins.

The Arctic Ocean with its approximately 8.5 million square kilometers of surface represents the smallest yet least understood ocean area of the world. Some of the most perplexing and still unsolved mysteries confronting arctic scientists pertain to the fundamental geologic and geophysical characteristics of the ocean floor. The earth's interior is characterized by a thin surface crust overlying a thick layer of denser and more elastic material, commonly referred to as the mantle, which extends roughly halfway to the earth's center. The crustal material, which is separated from the underlying mantle by the Mohorovicic Discontinuity, or "Moho," ranges in thickness from about 4 to 70 kilometers, being thickest beneath continental land masses and thinnest beneath the major ocean basins of the world.

Because of its position between the continental land masses of North America and Eurasia, the crust underlying the Arctic Ocean Basin is considered by many scientists to be the keystone in the structure of Northern Hemisphere geology, making its study fundamental to a better understanding of intercontinental lithologic and tectonic relationships. In an attempt to gain further knowledge of the nature, thickness, and structure of the earth's crust underlying the Arctic Ocean Basin, as well as to determine the nature of the structural transition from the North American continent to the Basin, the Geography Branch of the Office of Naval Research has in recent years supported an intensive program of arctic geophysics that has included diverse studies in geomagnetism, gravity, ocean-bottom heat flow, and seismology.

During the summer of 1961 a seismic study of the Arctic Continental Shelf was inaugurated off the northern coast of Alaska. In addition to demonstrating the feasibility of conducting seismic refraction investigations in the Arctic Ocean Basin, this initial study revealed that a typically continental seismic structure underlies the Basin north of Alaska—the crustal thicknesses recorded (up to 55 kilometers) being much greater than one normally expects to find in true ocean basins. The seismic refraction technique involves measuring the

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travel times of elastic waves generated by explosive charges and propagated through rock layers in the crust and upper mantle. A seismic profile representative of underlying geology and crustal structure is obtained by firing charges at one site and recording the elastic waves generated by the charges at another site, then repeating the process at predetermined intervals along a desired azimuth.

In recent years it has been well demonstrated that seismic refraction techniques may be successfully employed in the detection and monitoring of thermonuclear explosions, provided that sufficient information concerning travel-times and attenuation of elastic waves in the propagating medium between test and monitoring stations is available. In view of the political significance of such an application and considering the geographic location of the Arctic Ocean Basin between two of the world's greatest political powers, gaining an understanding of the crustal characteristics of this region becomes of utmost importance.

In an effort to reduce gaps in this knowledge the Office of Naval Research and the Air Force Office of Scientific Research jointly sponsored a cooperative crustal seismic program that was conducted during October and November of 1963 in the Beaufort and Chukchi Seas within a 400 kilometer radius of Point Barrow, Alaska. The program, employing proven seismic-refraction techniques, was conducted by scientists from the University of Wisconsin's Geophysical and Polar Research Center, Lamont Geological Observatory of Columbia University, and the University of Minnesota. It was operationally supported by ONR's Arctic Research Laboratory at Barrow, Alaska, and the icebreakers USS STATEN ISLAND (AGB-5) and USCGC NORTHWIND (WAGB-282), which were made available to the program by the Navy and Coast Guard.

Preliminary research plans called for at least two detailed crustal profiles to be measured along azimuths radiating seaward from Point Barrow. The profiles were to be obtained by firing explosive charges at sea from the STATEN ISLAND and recording the waves that they generated both at sea aboard the NORTHWIND and ashore along linear seismometer arrays established in the vicinity of Barrow. One profile was to traverse the Chukchi Sea to a point approximately 350 kilometers west of Point Barrow; it was expected to rest wholly over the continental shelf. The second profile, which was to extend a similar distance into the deeper Beaufort Sea north of Point Barrow, would traverse an area believed to be of true oceanic character. (See chart page 9.)

Final preparations for the program were underway by early summer. While two temporary field stations and a 15-kilometer seismic geophone array were being established on the tundra along the arctic coast 30 miles south of Barrow, more than 100 tons of explosives and scientific equipment were loaded aboard the STATEN ISLAND at Seattle prior to the ship's departure for arctic operations on July 20. By this time the NORTHWIND was already in arctic waters engaged in scientific studies for the U.S. Navy Oceanographic Office in the Laptev and East Siberian Seas.

Final field and laboratory preparations were completed in late September, and project activities formally commenced as scheduled on October 1 as the two assisting icebreakers rendezvoused at Barrow for final planning conferences among commanding officers CAPT J. P. Martin of the NORTHWIND and CDR J. J. Metschel of the STATEN ISLAND, senior project scientists

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A temporary field station is established on tundra along the Arctic coast near Barrow, Alaska. This site served as one of two land-based recording stations located along a 15-kilometer geophone array.

Part of geophone array is installed 30 miles south of Barrow. Cable is reeled off rear of sled drawn by a "weasel."

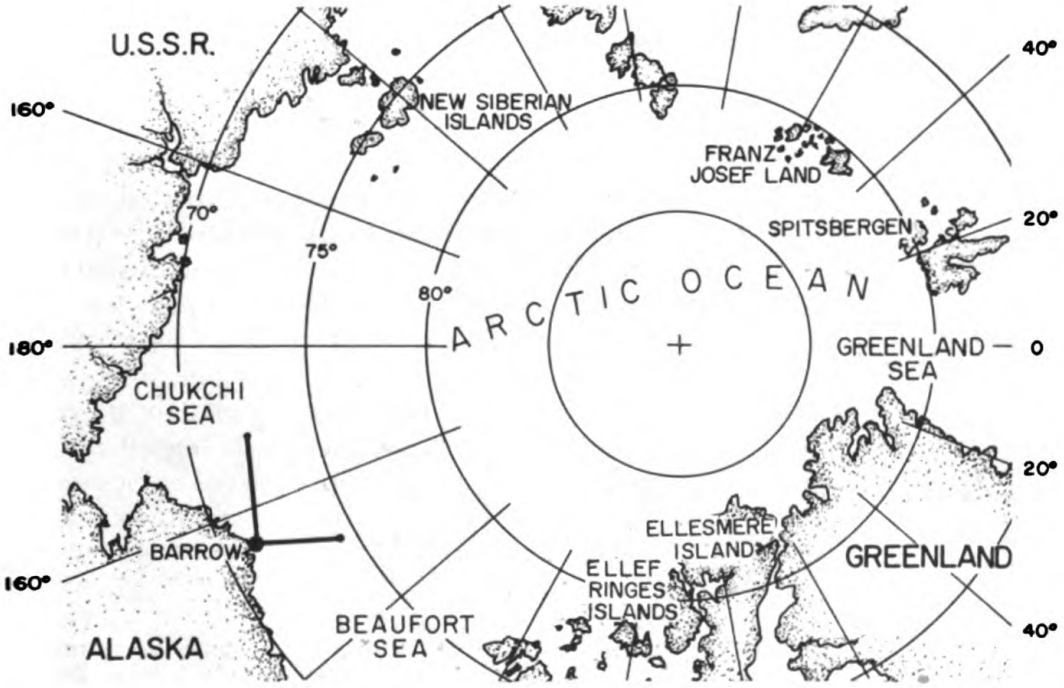

Chart of Arctic Ocean Basin and surrounding land showing location of refraction profiles obtained in the Beaufort and Chukchi seas in 1963. Profiles are indicated by the two lines extending into ocean from Barrow.

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A package of explosives weighing 2400 pounds is armed prior to launching into open water from fantail of USS STATEN ISLAND. When heavy ice was encountered, the launching procedure illustrated below and on the opposite page was followed.

An explosive charge is prepared for firing from the USS STATEN ISLAND in area in which sea is covered by heavy ice. See caption at right.

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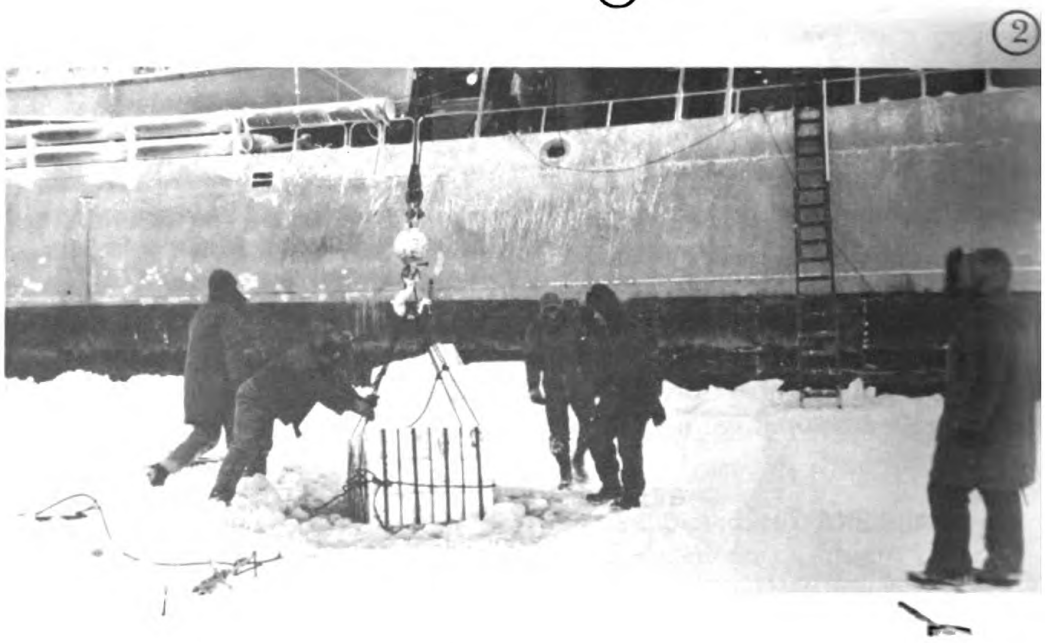

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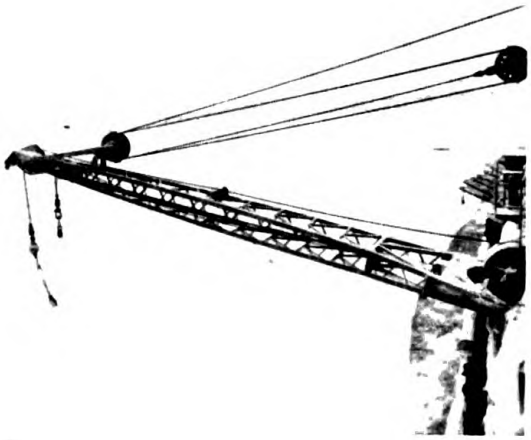
The USCGC NORTHWIND, which served as a recording station during seismic crustal study.

1, Explosives are lowered to pack ice adjacent to ship. 2, Package is placed in hole in ice opened for this purpose by a small charge. 3, Demolition team arms explosives prior to suspending charge by rope at desired depth below ice. 4, Demolition cable is payed out as ship moves off to a safe distance prior to firing of charge.



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Dr. R. P. Meyer and Dr. N. A. Ostenso of the University of Wisconsin and Dr. K. Hunkins of Columbia University, and Mr. M. C. Brewer, Director of the Arctic Research Laboratory. At this time it was decided to complete the Beaufort Sea profile first, because of rapidly deteriorating ice and shooting conditions to the north. Just as scientific personnel and remaining project equipment were being loaded aboard ship, both icebreakers received orders to depart immediately on a brief Fleet exercise. For project personnel awaiting the return of the ships at the Arctic Research Laboratory, the delay did not prove uneventful; on October 3 they witnessed the most severe arctic storm ever to hit this north Alaskan coastal area in its entire recorded and legendary history (see research note on page 21). In view of the destruction inflicted upon the area, the crustal seismic project was fortunate to suffer only minor materiel damages, all of which were quickly repaired.

Research activities resumed on October 10, with the return of the STATEN ISLAND and NORTHWIND. As the NORTHWIND steamed toward a recording position on the north end of the proposed profile in the vicinity of 74°N. and 152°W., the STATEN ISLAND positioned hydrophones and began traveling toward the NORTHWIND firing charges enroute.

Scientific activities were once again curtailed when on October 14 one of the STATEN ISLAND's two helicopters crashed. The plane was on an ice-reconnaissance mission about 7 miles from the ship when, apparently, its tail rotar failed to function properly, causing it to crash through the light pack ice. Killed in the tragic mishap were the ship's commanding officer, CDR J. J. Metschel, and the pilot, ENS J. L. Wood. The loss of those well-liked and outstanding officers was felt deeply by all ship and project personnel.

As the STATEN ISLAND continued to move northward toward the NORTHWIND, extremely heavy ice was encountered, rendering the normal procedure of launching explosive charges from the fantail impossible (see photo on page 10). An alternate plan—slower but more reliable—was therefore put into effect. It required the ship to anchor to a heavy ice flow and fire charges suspended in the water from the pack ice. Upon completion of the Beaufort Sea profile, both ships returned to Barrow, arriving October 29, to prepare for further studies in the Chukchi Sea. During the preceding three-week period of operations excellent data were obtained at all recording sites from a total of 45 shots fired at intervals ranging from 0.8 to 16 kilometers along the profile.

Between the 1st and 13th of November a second seismic refraction profile was completed across the Chukchi Shelf. This line extended from Barrow to a point 400 kilometers to the west. Operational procedures similar to those followed in obtaining the Beaufort Sea profile were employed as the NORTHWIND first established a recording station at the far end of the proposed profile, in the vicinity of 72°N. and 168°W., and then the STATEN ISLAND moved toward her, firing charges while closing range. Research and operational activities during this period were seriously hampered by very heavy ice, strong and unpredictable currents, deteriorating weather, and an almost complete absence of daylight. In spite of these adversities, scientific and ship personnel were able to fire successfully 57 shots on the Chukchi Shelf, including single charges up to 2400 pounds in weight. In addition, a number of smaller charges were fired to obtain reflection profiles of upper sedimentary layers of the ocean

—Continued on page 23

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The Problem of Jet Fuel Contamination

J. A. Krynitsky
Fuels Branch, Chemistry Division
Naval Research Laboratory

In the early days of jet aircraft, there was a widespread belief that jets would run on anything that burns and that fuel quality factors would be at a minimum. With ever increasing refinements to both the engines and the airframes, this is no longer true, and fuel specifications have become increasingly restrictive. As a result, jet fuels are now being checked more thoroughly than aviation gasolines.

Today we are on the verge of imposing even stricter requirements which relate to the elimination of contaminating material. The contaminants of concern are water, particulate matter, microbes, and surfactants (surface-active agents).

Strange as it may seem, these materials did not present great difficulties for aircraft powered by reciprocating engines. The reasons become apparent when we examine both the volumes of fuel handled and the nature of the fuels. A large reciprocating engine burns about 100 gallons per hour of aviation gasoline, whereas a modern jet engine can burn in excess of 1000 gallons per hour of jet fuel. Therefore, we must handle much greater volumes of fuel and operate fueling systems at much higher throughput rates. Whereas a fueling rate of 100 gallons per minute is sufficient for most gasoline-powered aircraft, it is not uncommon to fuel jet aircraft at the rate of 600 gallons per minute. Further, jet fuels have both a higher viscosity and a greater specific gravity than aviation gasoline. Both of these factors make removal of contaminants through normal settling and other means more difficult. A rule of thumb is that aviation gasoline should be settled in storage tanks for one-half hour for each foot of depth and jet fuels at least two hours for each foot of depth.

Problems Arising from Contaminated Fuel

Water and particulate matter can act either singly or in combination to cause a variety of fuel troubles. Aircraft fuel filters may be fouled by the formation of ice or by the accumulation of solids. Precision fitted moving parts found in fuel controls can be easily jammed and damaged by particulate matter. Fuel-quantity gages and flow dividers malfunction when contaminated by foreign material. While all of these problems are important in their own right, a much more serious problem has recently come into being—the corrosion of integral wing fuel tanks.

The wing tank corrosion problem arose with the advent of the so-called "wet wing" aircraft, in which the wing is used as the fuel tank. The problem was first noted a little over 4 years ago in military aircraft stationed in tropical climates, but later it was found to exist in other climates in other large aircraft, both military and civilian.

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Examination of a problem tank usually reveals the presence of a brown slimy substance and/or particulate matter in combination with water. Figure 1 is a photograph illustrating contamination in a wing fuel tank. In extreme cases, the slime takes on the appearance of a mat-like sludge which covers the lower surfaces of the tank. Removal of surface deposits frequently shows that the topcoating (protective organic coating applied to the interior of aluminum wing tanks) has failed and that the aluminum has become pockmarked with corrosion. The areas of corrosion are usually directly related to the location and concentration of contaminating deposits and are most severe in those regions where water settles and collects.

In some cases, an insidious pitting corrosion takes place (Figure 2). Because the surface effects produced by this type of corrosion are small, a true appreciation of damage can only be obtained after removing the topcoating and grinding out the corroded pits. In at least one instance, the first sign of trouble occurred when the operator noticed fuel starting to leak through a wing surface. In another, corrosion was so severe that the aircraft had to be taken out of service and returned at reduced load to the factory for re-work. Reliable sources have estimated that 15 percent of the larger jet-powered military and commercial aircraft in operation today have suffered significant wing-tank corrosion damage.

Analyses of corroded areas have revealed, besides aluminum products, the presence of iron oxides, alkali metal salts, and silica. Water removed from sump areas of aircraft has frequently shown high concentrations of salt and other minerals to be present. Studies of the slime materials and water have also revealed the presence of microorganisms. We shall now consider each of these contaminants individually.

Fuel Contaminants

Water - All hydrocarbon fuels contain some water, which may be either entirely in solution or partly dissolved and partly free. The amount of water which can be dissolved in fuel depends both on the fuel composition and on the temperature. When a water-saturated fuel is cooled, some of the dissolved water "precipitates" as free water in the form of a very fine cloud. There is a rapid exchange of water between that dissolved in the fuel and that contained in the overlying atmosphere. Consequently, dehydrated fuels tend to pick up water from the atmosphere, and saturated fuels may lose water. The tendency is for fuel to lose water while a plane is climbing and to pick up water when the plane lands. As a rule of thumb, on warm humid days a large aircraft can pick up a pint to a quart of water per vent per descent.

Water of condensation is rather pure and, at best, only slightly corrosive to aluminum, whereas extraneous water may be saline or brackish and often is very corrosive.

Normally, extraneous free water is removed from fuels throughout various stages of storage and transfer by settling in tanks and through the use of filter-separator units. The detection of saline and mineral waters in aircraft tanks is *prima facie* evidence that somewhere a breakdown in the system has occurred.

Particulate Matter - By and large, oxides of iron comprise the bulk of the particulate matter found in fuels. This follows from the fact that iron is the most common material used in the construction of fuel-handling and transportation systems.

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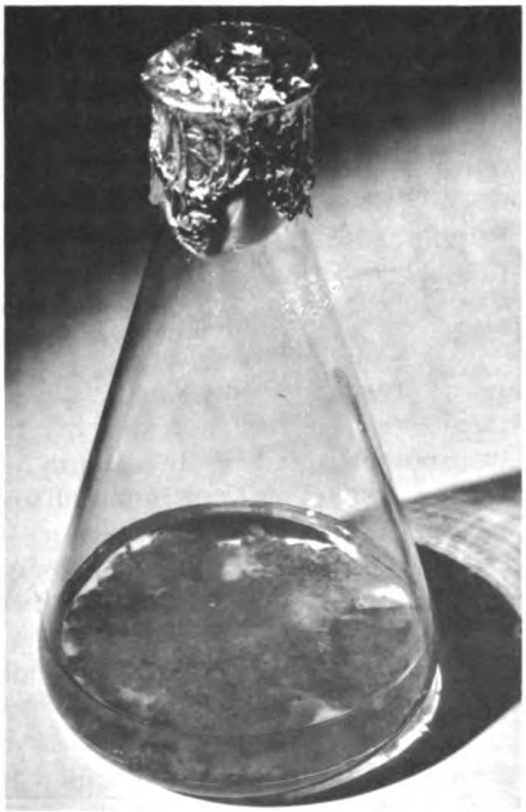
Figure 1 - Contamination in a fuel tank

Figure 2 - Magnified view of corrosion damage

Figure 3 - Fungal mat growing at a fuel-water interface



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Solids are removed from fuels by settling in storage and by the use of efficient filters during transfers. As in the case of finding saline water in tanks, the finding of iron oxide in aircraft tanks also is evidence that fuel delivery systems are not functioning properly.

Iron rust is believed to play an important part in the corrosion phenomenon. It has the ability to hold free water on its surface and is known to accelerate the development of certain bacteria in fuel systems. Its tendency to become firmly attached to topcoating materials is believed to be instrumental in causing perforation of topcoatings.

Microorganisms - At first the finding of microbial growth in aircraft fuel tanks came as a shock to most people. Subsequently, it has been found that not only do these organisms exist in fuel environments, but also that they can actually utilize hydrocarbons as an energy source in their metabolisms. Today, more than 100 forms of "bugs" have been identified with fuel systems. These include numerous species of bacteria, fungi, and yeasts. (Figures 3 and 4). Contrary to first expectations, most of these creatures are not exotic, but are microorganisms commonly found in soils, water, and even air throughout large areas of the world. Dr. Dorthea E. Klemme of the Naval Research Laboratory has shown fungi to be present in many aircraft and fuel storage tanks. She has found that one species predominates, and has identified it as a brown hormodendron fungus. (Figure 4).

Probably, microbes are introduced into tanks during fueling, if the fuel is contaminated with free water or particulate matter. Studies at NRL and other laboratories have shown that maximum growth appears to be concentrated at fuel/water interfaces and that an aqueous phase must be present for active growth to occur.

Most persons associated with the problem of wing-tank corrosion agree that microorganisms must constitute an important part of the picture. It is certain that organic acids and other metabolic products are capable of corroding metals. Laboratory studies have demonstrated that topcoatings can be degraded by attached microbes and that the underlying metal can become corroded. In addition to acid-producing abilities, the moisture-holding properties of fungal mats and concentration cell formation may also induce corrosion.

Surfactants - These are surface-active agents which disperse particulate matter and water in fuels and make their removal more difficult. The presence of surfactants in fuels has been recognized only in the last 2 to 3 years. Minute concentrations of such materials may prevent separation of suspended water and solids during normal settling periods. Further, it has been shown that certain surfactants can cumulatively collect in filter separator units and, after a comparatively short throughput of fuel, can effectively poison these units and render them ineffective for removing suspended water and particulate matter from fuels. Surfactant concentrations as low as 0.5 parts per million have been known to "disarm" filter-separator units in this fashion.

Surfactants can arise from the refining processes or may enter fuels as contaminants from other products handled in a distribution system. Common examples of materials produced during refining are the sodium sulfonates and naphthenates.

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Control Method

From what has been described, it is evident that for effective control of corrosion in wing tanks, it is necessary to ensure the absence of free saline or brackish waters, particulate matter, and of microbial growths. If we could deliver exclusively clean, dry fuel, aircraft problems would be reduced considerably. Not only would direct problems be minimized but, indirectly, problems associated

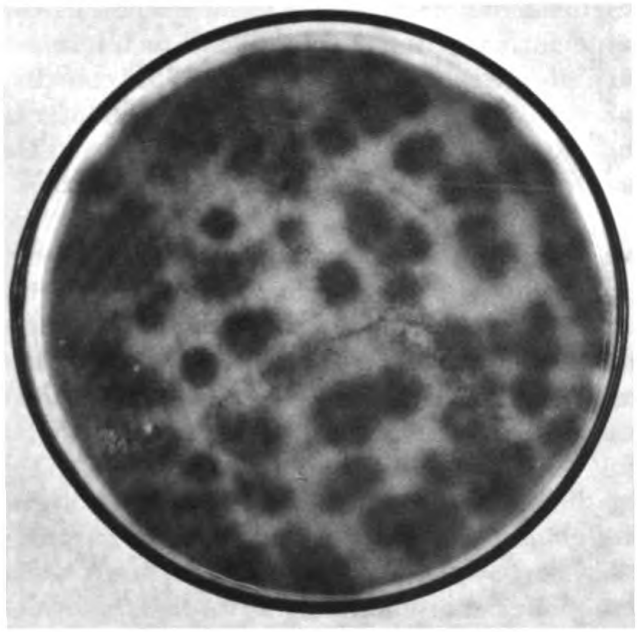
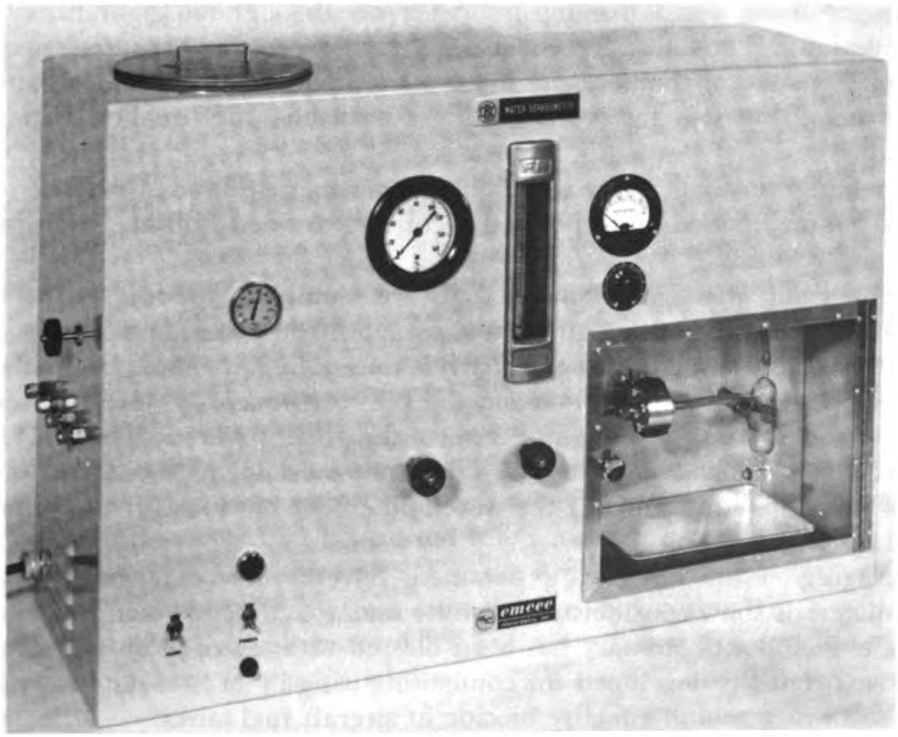


Figure 4 – Colonies of brown *Hormodendron* fungus

Figure 5 – Water Separometer



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with microbiological growth would also be alleviated, because microorganisms require free water containing certain minerals to grow actively.

Therefore, the control of surfactants becomes all-important to the delivery of clean, dry fuel; for, as has already been mentioned, trace quantities of such materials can undo the beneficial effects of settling and can destroy the capacity of filter-separator units to remove both free water and particulate matter.

Practical detection of trace surfactants in fuels has posed an interesting and challenging problem to the industry, because ordinary physical and chemical methods appeared to lack sufficient sensitivity to detect and to differentiate between them. The Naval Research Laboratory played a leading role in the development of a highly sensitive performance test which is based on a miniature fuel-handling system. Industry adopted the NRL method, and the coordinating Research Council, Inc. (a cooperative petroleum and aviation industry group), together with this Laboratory, have carried out further developments and refinements. The final apparatus, known as the Water Separometer, is shown in Figure 5.

The Water Separometer is a small-volume apparatus in which a water-fuel emulsion is prepared and metered through a cell containing a standardized "Fiberglas" coalescer. The effluent is analyzed for entrained water by light transmission. A water separation index, modified (WSIM), which has a 0-100 scale, rates the ease with which a given fuel releases the dispersed emulsified water; the higher the numerical rating, the cleaner the fuel is relative to surfactant materials.

The importance of controlling the wing tank corrosion problem through control of surfactants has been brought out in practice as well as theory. Investigations of problems at several Air Force and Naval bases have shown that frequently surfactants, as detected by the Separometer method, were the basic cause of the difficulties experienced. By tracing the source of these materials and eliminating them from the fuels, dramatic improvements were obtained.

The Separometer test is coming into wide use throughout the industry for monitoring jet fuel qualities. Recent surveys have shown that because refineries have been apprised of the necessity for producing quality fuels, and because a tool for measuring this factor has become available, fuel quality is indeed improving.

Total reliance on fuel quality is not enough. Proper equipment must be used and must be maintained and operated according to good housekeeping practices.

However, even when good quality fuels are handled according to the best practices, breakdowns may occur. Thus, contamination may find its way into aircraft tanks, and problems, particularly those of a microbiological nature, may develop. Therefore, we may need even further protective measures. Currently, the two most promising approaches being pursued are: (1) the development of topcoating materials which are inert to microbial and other forms of contamination and (2) the development of biocides for use in fuels and fuel systems.

Encouraging results are being obtained. Several new experimental topcoating materials show considerable promise and are currently being evaluated in aircraft. Finally, the military has been blessed with a stroke of serendipity: an additive originally developed for combatting icing in jet fuel systems is proving to be a practical and effective biocide in aircraft fuel tanks.

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INVENTIONS

Avoiding Failures of a Rocket's Steering Mechanism

Control of the direction of thrust of modern rockets is achieved by means of a guidance system and a device called a "jetevator" that is attached to the rocket nozzle. The jetevator, which is regulated by the guidance system, has moveable elements that protrude into the exhaust-gas flow. Upon ignition of the liquid or solid propellant fuel of the rocket, the gases produced by the burning fuel escape rearward, out through the nozzle, giving the rocket its thrust. By slight deflections of these gases, effected by movements of the elements of the jetevator, the rocket is kept on the desired flight path.

Obviously, perfect operation of the jetevator is essential if the rocket is to reach its intended destination. Too often, however, jetevators have not operated properly, causing many rockets to veer far off course. One explanation for these failures is that present-day high-energy propellants contain large quantities of aluminum, much of which is present in the exhaust gases. Because the jetevator acts as a heat sink, the alumina, in the form of a vapor or a highly dispersed liquid, condenses and adheres to the inner surface of the steering mechanism, sometimes causing the moving parts to bind.

To avoid malfunctions of this kind, Mr. F. R. Barnet of the Bureau of Weapons conceived the idea of placing a graphite seal between the nozzle and the jetevator. This sealing ring would not only serve to lubricate the inner surface of the jetevator, permitting it to move freely at all times, but it would also prevent the build-up of alumina on the inner surface. Deposits of alumina large enough to affect the operation of the jetevator would not occur because the relatively soft layer of graphite would receive the particles, preventing them from accumulating in such a way as to cause binding of the moving parts.

A patent covering the "Jetevator System Design," No. 3,102,390, was issued to Mr. Barnet on September 3, 1963.

Dr. David H. Lewis and the Phonocardiac Catheter

In the article "Detector of Heart Defects," which appeared in this section of the December 1963 issue of *Naval Research Reviews,* one of the three inventors of the phonocardiac catheter described in the article was incorrectly identified as a Navy electronic engineer. This man, David H. Lewis, is actually a physician.

The phonocardiac catheter is an instrument that provides a means of monitoring very accurately any unusual sounds made by the heart to facilitate determinations of the exact sources of heart defects. It is a long tube less than 1/10th of an inch in diameter that is inserted into a vein or artery and then pushed along the passageway until its tip reaches the heart. The tip is specially designed to originate signals representing sound waves emanating from within the heart. These signals are then amplified and transmitted to a recording instrument outside, where they are analyzed.

— Continued on back cover (inside).

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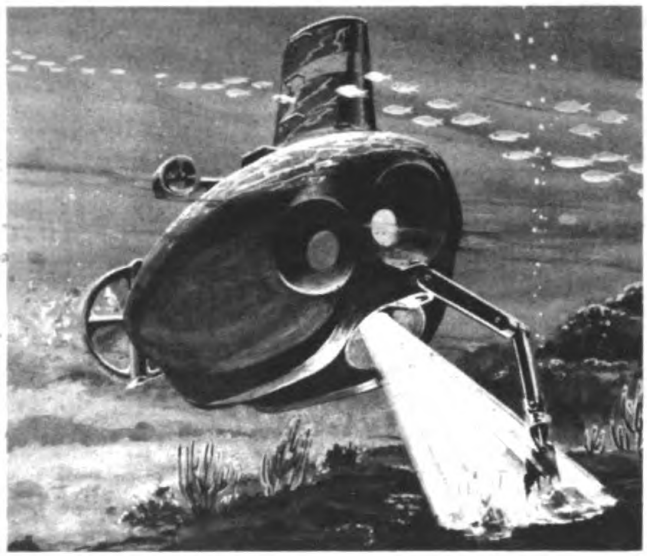

RESEARCH NOTES

Artist's concept of ALVIN.

ALVIN's Pressure Sphere Tested

Last December and January tests were made of the pressure sphere built for ALVIN, a two-man research submarine that will be able to descend to an ocean depth of 6,000 feet. The sphere has an outside diameter of 6 feet, 10 inches, which is about the same as the outside diameter of the sphere of the Navy's bathyscaph TRIESTE; however, the latter is suspended from a 50-foot buoyancy hull. The walls of the sphere of the new vehicle will be 1-1/4 inches thick as compared with 4 to 7 inches for the bathyscaph.

Two pressure spheres were prepared for testing. The first sphere was cycled at 3300 pounds per square inch for 500 cycles while 380 strain gauges registered the effects. The gauges showed that at no time was 50 percent of the yield strength of the material exceeded. Furthermore, no sign of leakage was found. The second sphere—the one which will actually be installed in ALVIN—was tested at the pressure which exists at the depth at which the sub is designed to operate. After testing of the second sphere, the first sphere was tested again, this time with the objective of intentionally collapsing it or at least subjecting it to the maximum pressure the testing tank could produce so as to determine the collapse pressure.

ALVIN is expected to undergo its first deep-sea tests early next summer.

One of the chief objects of study of the new craft will be the continental shelf along the eastern seaboard of the United States. Another may well concern the acoustic characteristics of the sea—the vehicle serving as a quiet, deep-riding, mobile station for this work. ALVIN will also be used to inspect man-made structures and equipment placed on the ocean bottom. Several physical oceanographic investigations are being considered, too—for example, of currents, turbulence, internal waves, and variations in temperature and salinity. The sub may also be used to study the natural resources of the eastern fishing banks.

ALVIN is being built by Litton Industries, Inc., for the Woods Hole Oceanographic Institution. The submarine will be operated by Woods Hole as part of a research program supported by the Office of Naval Research.

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Main street of camp at Barrow after storm.

Point Barrow's Worst Storm

The most severe storm in the entire recorded and legendary history of Point Barrow, Alaska, hit that coastal area last October 3. For 24 hours, a gusty wind that reached speeds as high as 80 knots blew in from the ocean. The tides rose some 10 feet above normal and combined with breakers 10 to 12 feet high to create havoc with the Point Barrow camp complex and the Eskimo village of Barrow to the south. Although no lives were lost as a result of the storm, many buildings, supplies, pieces of equipment, and utilities were seriously damaged.

The Arctic Research Laboratory, which is located at Point Barrow, was damaged only slightly, but all scientific programs had to be halted for several days following the storm (see "Seismic Crustal Studies in the Arctic Ocean Basin," this issue). ARL is owned by the Office of Naval Research and operated by the University of Alaska.

One of the most serious consequences of the storm was the loss of the area's local supply of fresh water—a nearby fresh-water lagoon. The lagoon was completely flooded with sea water. Now fresh water has to be hauled across the tundra by tractor train from a fresh-water lake about 6-1/2 miles away.

The camp at Point Barrow. Fresh-water lagoon that was flooded by sea water lies just beyond camp.

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Glass for Submarine Hulls

A hollow glass sphere that has been prepared for testing.

In its search for new materials for deep-diving submarines, the Navy's David Taylor Model Basin is giving careful consideration to glass.

As part of its studies of this material, the Model Basin recently conducted hydrostatic tests of hollow glass cylinders and spheres (about the size of basketballs). It was found that common glass, which has unusually high compressive strength and relatively low weight, has considerable potential as a structural material for deep-submergence submarine hulls. Through these tests, the Model Basin has verified earlier calculations which indicated that spheres of glass and several other brittle materials (such as aluminum oxide and boron carbide) have an outstanding strength-to-weight advantage over any other type hull material.

Another desirable characteristic of glass for deep-diving underwater craft is transparency. It would be extremely advantageous if glass could be used, for example, as hull material for oceanographic research vehicles.

Project MAC

The Massachusetts Institute of Technology has been participating since last spring in a major National program of research on advanced computer systems and their exploitation. The effort is now being sponsored by a $2,220,000 contract awarded by the Office of Naval Research on behalf of the Advanced Research Projects Agency of the Department of Defense.

The research is being carried out under the project name "MAC," an acronym derived from two titles: "Machine-Aided Cognition," which expresses the project objective, and "Multiple Access Computers," which describes its major tool. The broad goal of the project is the experimental investigation of new ways in which on-line use of computers can aid people in their creative work – whether research, engineering, design, management, or education. Thus, an essential part of the project is the evolutionary development of a large, time-shared computer system that is easily and independently accessible to many people and truly responsive to their individual needs. The keynote is ease of access, both physical and intellectual, which must apply to the information stored in the computer system as well as to the computer's information processing capability.

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The present MAC computer installation includes a specially modified IBM 7094 computer and a Digital Equipment Corporation PDP-1 computer. The IBM 7094 computer is the central part of the time-sharing system. Currently, primary terminals of the system are 40 Model 35 Teletypes capable of 100 word-per-minute operation. The present capacity is 10 users.

The director of Project MAC is Dr. Robert M. Fano, Ford Professor of Engineering and Professor of Electrical Communications at M.I.T.

Determining the Capacity of Ports to Handle Cargo

How much cargo and how many military personnel can be shipped in and out of any marine port in the United States under varying conditions in both peacetime and wartime? No one really knows the many answers to this question, because the job of calculating them is so complex. Nevertheless, the problem is under study and a method of solving it is being developed. The research, which is being conducted for the Office of Naval Research by a group at the University of California at Los Angeles, involves an analysis of all elements of operations within the marine port-complex. This work is expected ultimately to lead to the development of a computerized port-complex model which can be used to determine the overall capacity of any port to handle cargo and personnel.

Cooperating in the investigation are Naval officer students of the Transportation Management Course given at the U.S. Naval School, Oakland, Calif. These officers are collecting, organizing, and analyzing data peculiar to Navy cargo movements through the Freight Terminal Department of the Naval Supply Center, Oakland.

Seismic Crustal Studies—Continued from page 12

floor. On November 13, after six weeks of arduous operations, the 1963 Arctic Basin Crustal Seismic Program was completed as both ships returned to Barrow to offload project personnel and equipment before leaving arctic waters.

Thus concluded one of the most extensive and complex research efforts ever conducted in the Arctic Ocean Basin. It involved participation of more than 20 scientists from four major universities; use of three temporary field stations established on the remote arctic tundra; the movement of more than 200 tons of project equipment, instruments, and supplies; constant communication and coordination between scientific parties hundreds of kilometers apart; and the full-time operational support of two icebreakers. Despite the many hardships and disappointments encountered, including among others the tragic loss of two lives, bow damage to both vessels, total loss of a STATEN ISLAND helicopter and the NORTHWIND's rudder, and a complete breakdown of the NORTHWIND's heating and water distillation plants, the program was completed successfully with all scientific objectives achieved.

Although the results of this study are now only in an early stage of analysis, data substantiate the tentative conclusions derived from the 1961 studies—namely, that large crustal thicknesses up to 55 kilometers exist in the Arctic Ocean Basin north of Alaska and that the region in general is underlaid by a material that has a typically continental seismic structure.

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ON THE NAVAL RESEARCH RESERVE

Group Active Duty for Training

As Spring nears, some Research Reserve companies plan group active duty for training. This interesting and enjoyable type of training is generally scheduled over a weekend – Friday, Saturday and Sunday. No pay or allowances are given, but officers attending earn a retirement point for each day of attendance.

Three excellent seminars that present opportunities for group active duty for training have been scheduled. They and their locations are as follows:

HOUSTON, TEXAS

NRRC 8-4, Houston, Texas, is sponsoring a weekend seminar on April 3rd, 4th and 5th at the Manned Space Craft Center, NASA.

TULLAHOMA, TENNESSEE

NRRC 6-18, Nashville, Tennessee, is planning a weekend seminar at Arnold Engineering Development Center, Tullahoma, Tennessee, on April 10th, 11th and 12th.

DAHLGREN, VIRGINIA

NRRC 5-12, Dahlgren, Virginia, will conduct a weekend seminar on May 22nd, 23rd and 24th at the Naval Weapons Laboratory.

Report of National Naval Reserve Policy Board, 1963

Recommendations of the National Naval Reserve Policy Board and the action taken by the Secretary of the Navy or the Chief of Naval Operations, as appropriate, have been published by OPNAV NOTICE 5420 dated November 18, 1963. The complete National Policy Board Report is available at Naval Reserve Training Centers or Naval District Headquarters. Listed below are briefs of two recommendations which may be of particular interest to Research Reservists.

RECOMMENDATION NO. 8

SUBJECT: Increased allowance of stationkeepers and support personnel.

It was recommended that prompt action be taken to provide an adequate number of active duty personnel at all levels for effective support of the Naval Reserve program.

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The Chief of Naval Operations recommended approval, stating that the need for adequate support is basic to a successful Reserve program. It was further stated that within present allowances every effort has been made and will continue to be made to maintain Naval Reserve training activities at manning levels commensurate with those of other shore activities.

SECNAV ACTION: Approved.

RECOMMENDATION NO. 22

SUBJECT: Officers should be aware of their mobilization billets.

It was recommended that all Naval Reserve officers assigned mobilization billets be informed of the nature of their assignment. It was felt that the most effective way for an officer to ensure progressive professional growth in his Naval Reserve career planning is to know the general area of his mobilization assignment or, as a minimum, the type command and specialty in which he would serve on mobilization.

CNO ACTION: The Chief of Naval Operations approved in principle this recommendation, but deferred implementation subject to a determination of its feasibility with respect to the capability of the Naval Reserve Manpower Center.

"Naval Research Reviews" Distribution Increased

Starting with the February issue of *Naval Research Reviews*, the number of copies provided to Research Reserve companies will be increased almost twofold. At the present time, 600 copies of this publication are received for distribution to Research Reserve companies; this number has been increased by 500 copies for a total of about 1100 copies. With a membership of approximately 2400 officers in the program this will provide approximately 1 copy for every 2 members.

Inventions – Continued from page 19

Dr. Lewis' contribution to the development of this instrument was made while he was assigned to the Aviation Medical Acceleration Laboratory as a Medical Corps officer. Later he became associated with the Philadelphia General Hospital, where from 1958 to 1963 he conducted research on the circulatory physiology of the heart, utilizing the new instrument, under the auspices of the Office of Naval Research. Dr. A. M. Moghadam, the pediatric cardiologist who employed the phonocardiac catheter to aid in saving the life of a young girl last August, a brief account of which is given in *Naval Research Reviews*, December 1963, had been assisting Dr. Lewis in conducting this ONR-sponsored research since its inception. When Dr. Lewis left the Philadelphia General Hospital last year, Dr. Moghadam became the principal investigator under the ONR contract.

Dr. Lewis also worked in conjunction with another ONR contractor at the American Electronics Laboratory in further refining this unique device.

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EDITOR: Richard D. Olson

This striking storm vortex was photographed from an altitude of 65,000 feet off the coast of California by the pilot of a U-2 aircraft on a flight made as part of a study of the infrared radiance properties of clouds. A brief account of the flight and an interpretation of the disturbance are given on the front cover (inside).

NAVEXOS P-510

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