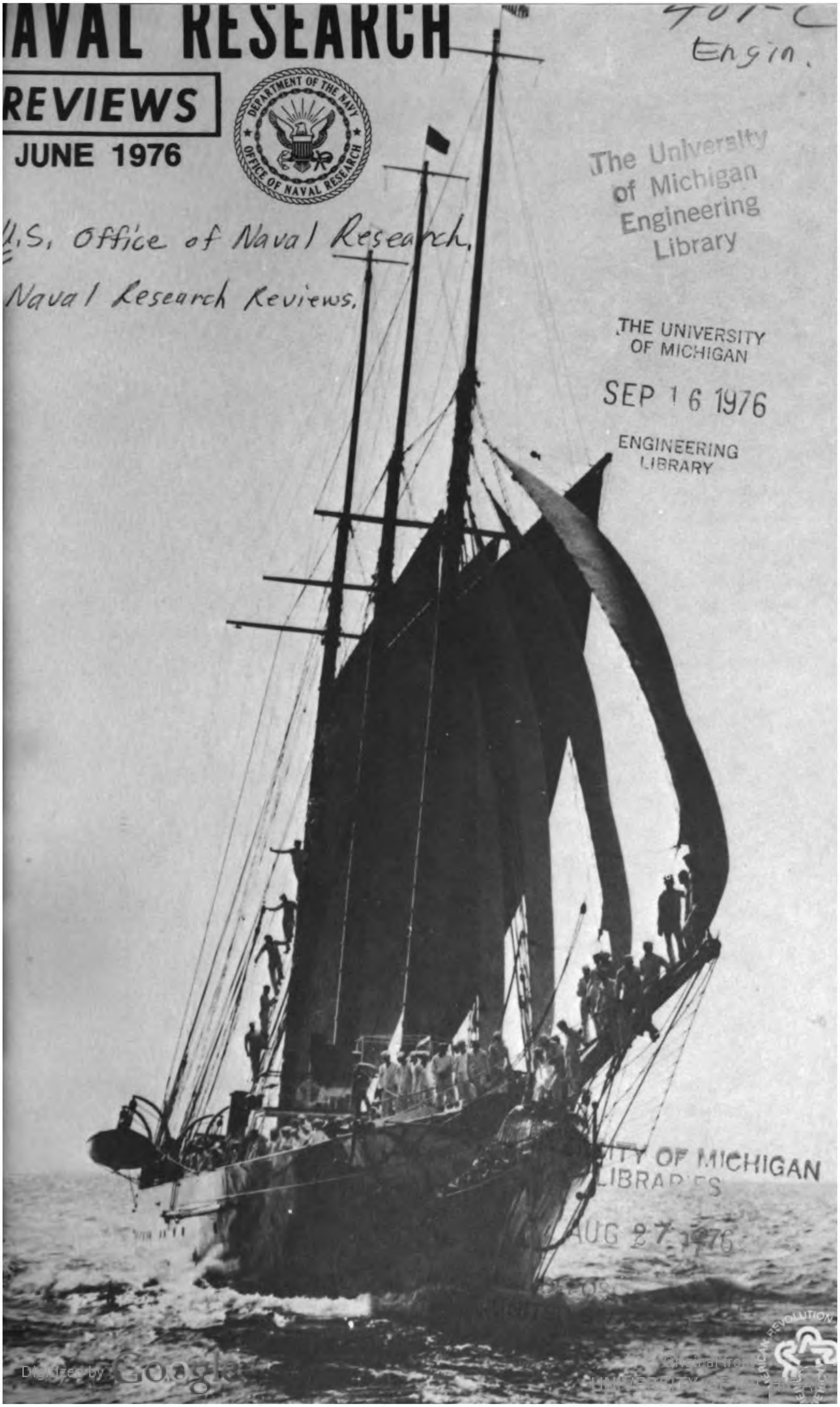
NAVAL RESEARCH REVIEWS

JUNE 1976

DEPARTMENT OF THE NAVY · OFFICE OF NAVAL RESEARCH

U.S. Office of Naval Research.
Naval Research Reviews.



PROFILES IN SCIENCE

Professor Sheila Widnall

Sheila Widnall is a Professor of Aeronautics and Astronautics at the Massachusetts Institute of Technology, specializing in the field of Fluid Dynamics. She received her doctorate in 1964 from MIT for a thesis on unsteady and steady loads on fully wetted and supercavitating hydrofoils of finite span. This work was supported under the fundamental hydromechanics program of the Navy. Her other research activities have included studies of aerodynamic noise mechanisms of helicopters and fundamental studies of the structure and stability of flows containing concentrated vortices; she has made several very important contributions to this field. In 1974, she served as the first Director of University Research for the U.S. Department of Transportation. At present, she is working under ONR sponsorship on the development of a three-dimensional lifting surface theory for wings with leading edge vortices. Professor Widnall is a member of the (AIAA) American Institute of Aeronautics and Astronautics and a member of its Board of Directors. She served as an associate editor of the AIAA Journal of Aircraft and a member of the AIAA Aeroacoustics Panel.

Numerical Models for Synoptic Analysis/Prediction of Currents and Temperature/Salinity Structure in the Oceans

T. Laevastu, S. Larson and K. Rabe*
Naval Environmental Prediction Research Facility

The Intention of Synoptic Numerical Modeling

It could be postulated that the aim of numerical modeling is based on Laplace's remark that "Given the initial position and velocity of every particle in the universe at any particular instant and given all forces at work in Nature, a super-intelligence could calculate with precision the entire history and future of the cosmos." Even if our theories regarding the behavior of Nature were sufficient to describe all the processes at work in the ocean, we cannot completely describe the initial state of the ocean (i.e., the motions and forces acting within and upon the ocean at a given instant) with available observations. This task is especially hampered by the fact that the horizontal dimensions of dominant dynamic processes in the ocean are relatively small – roughly 100 km (or one tenth the dimensions of similar processes in the atmosphere). Real time (synoptic) modeling of the ocean could be carried out if one could approximate the initial conditions by applying major driving forces, such as winds and tide generation forces, to an ocean initially at rest with the correct distribution of temperature and salinity. The resulting motions could then be calculated until quasi-equilibrium conditions between the driving forces and the resulting motion and distributions are achieved. The above procedure of initialization is one of the basic requirements which must be satisfied by any synoptic ocean analysis/forecasting model.

While the problem of synoptic forecasts of ocean conditions is a very difficult one, the need for such predictions has been well established. For example, a detailed salinity/temperature structure is required for accurate prediction of sonar ranges and other applications of sound propagation employed by the Navy. Also, a knowledge of the synoptic behavior of currents, especially tidal currents, is required for navigation

*Dr. Laevastu and colleagues are world famous for their systematic investigations of upper ocean processes over the past twenty years. At the Environmental Prediction Research Facility, Monterey, California they have concentrated on developing models of upper ocean variability of applied problems.

in coastal waters, for search and rescue purposes, for mooring of various recording devices, for predicting the fate of pollutants, and for coastal construction.

Although some knowledge of average (climatological) current conditions has been and still is of some use, modern technological advancements often require much greater accuracy of current analyses and prediction than is possible to obtain from climatological information alone. Furthermore, the great short-term variability of currents and other conditions in near-surface layers of the ocean has been fully recognized in the last decade. Whereas it was earlier believed accurate to describe, for example, a northward surface current with such values as 10 ± 2 cm/sec, it has now been recognized that it would be more correct to indicate such a current with numbers such as 2 ± 10 cm/sec, with a negative value indicating southward current.

To obtain information on currents in coastal areas requires weeks or months of measurement (recording). However, severe or anomalous conditions, which are of most interest especially for pollution and coastal construction, usually do not occur during the measurement period. Thus synoptic analysis/prediction of ocean conditions and processes with numerical means has become a necessity.

Numerical ocean modeling with a predictive capability comparable to that of synoptic numerical weather prediction has been attempted with various types of models, such as statistical-empirical models for the prediction of a single parameter (e.g., mixed layer depth) as well as relatively complete primitive equation models. In this condensed review we will deal mainly with the Hydrodynamical-Numerical (HN) models which are essentially primitive equation models and have reproduced verifiable synoptic conditions and processes. As it is not possible to review and reference all the voluminous amounts of literature mainly in the form of technical reports in this short general review, no references are given.

Hydrodynamical-Numerical (HN) Models and Their Basic Characteristics

A variety of numerical models have been developed which attempt to reproduce and predict currents and sea level and state the parameters of temperature and salinity. Among these are excellent research models for the investigation of long term general circulation in the oceans. Other essentially atmospheric models have been applied to the oceans. None of these are suitable for synoptic ocean analysis and prediction.

The type of numerical models which, according to our experience, are most suitable for synoptic modeling (numerical analysis/prediction) are the Hydrodynamical-Numerical (HN) models developed initially by Walter Hansen at the University of Hamburg in the early 1950's when the first practically usable computers became generally available. There are now, several slightly different versions of the HN models in general use, the most common being the Hansen, Leendertse and Heaps types.

Any synoptic ocean analysis/prediction model should include tides, for in many areas the tides are the main component of velocity at any instant in time. Furthermore, as the vertical motions in the ocean are nearly absent, the changes of thickness of internal layers and sea level changes can be computed with the continuity equation. The atmospheric driving forces (mainly surface wind and pressure) must be included in the oceanic models on a synoptic time scale.

The basic equations in HN models are the equations of motion in the horizontal and the continuity equation. The equations of motion can be in linear form or can include the field acceleration (convective) terms. The latter are important if the grid size is small (less than a few kilometers). The bottom friction term, as well as internal friction in multilayer and multilevel models, is usually in nonlinear quadratic form with a constant friction coefficient.

The HN models can be used in multilayer form whereby the layers are considered vertically integrated and the depth (thickness) changes of the initially specified layer boundaries are computed. The model can also be run in multilevel mode where the depth of the level remains unchanged.

The most commonly used computational grids in finite difference formulation are so-called staggered grids, as shown in Figure 1. The initial depths (and/or layer thickness) are prescribed at u and v points where the velocity is computed. The sea level and layer thickness changes are computed at z points.

A finite element formulation has been tested in the HN model, but no obvious advantages have been found and at times even more computer time has been needed for a solution with the finite element method than with the conventionally used finite difference method. Due to the need to apply Courant-Friedrich-Lewy stability criterion in finite difference method, the time step for computation becomes short indeed if grid size is small and maximum depth in the computation area is large.

As the numerical model gives current vectors at each grid point in short time steps, it is possible to compute the advection and diffusion of conservative properties, such as salinity. Several satisfactory finite-difference formulations have been devised and tested for this purpose. It is also possible to treat non-conservative properties such as temperature and pollutants by including source and sink and decay terms in these formulas. With respect to sea level predictions, the models are started from "rest" as the initial conditions at any moment of time are

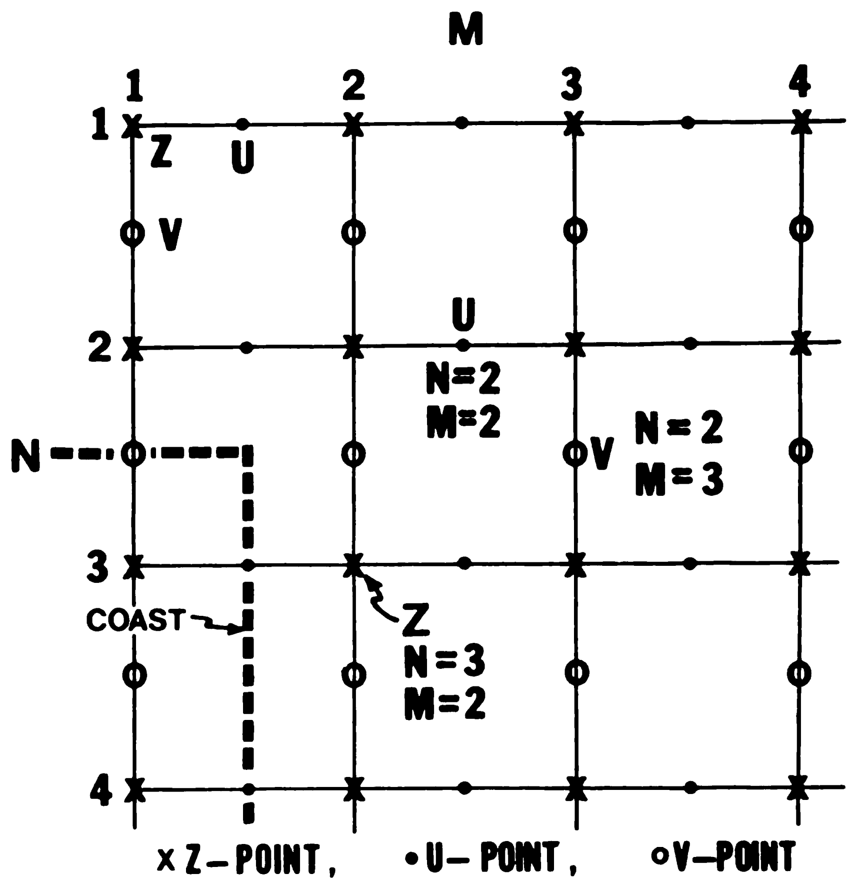


Figure 1 — The staggered grid of Hansen type HN model

not known with sufficient accuracy. The initial temperature and salinity distribution usually is prescribed from climatological means.

The tides are prescribed with available harmonic constants at one or more open boundaries and wind is introduced in a time-varying mode at each grid point. The open boundaries of the model area must be prescribed or left open for in and outflow in case more than one open boundary exists in the computation area. The initial application of the HN models was for semiclosed seas and estuaries, which usually had only one or two separated open boundaries which could be easily prescribed with respect to sea level, tides and external surges, and/currents. However it became necessary to apply the HN model to coastal areas with three open boundaries or to any area in the ocean with four open boundaries. Generally no boundary values were available and considerable effort has been spent to find a satisfactory treatment of multiple open boundaries. Although no fully satisfactory theoretical method exists at present, several rational approaches have proven useful and have yielded reasonable results. The tidal elevations are introduced in each time step at one of the open boundaries, superimposed at times on permanent flow if the latter is known and prescribed. The other two or three boundaries are left open either with a method called radiation boundary condition or with the variables computed up to the boundaries. In the latter case, at some boundaries, use must be made of a previous value of either elevation or one of the velocity components outside of the boundary. In this case the missing variable, either velocity component or elevation, outside the boundary is taken to be the boundary value at the previous time step. Furthermore a slightly higher horizontal viscosity coefficient can be used in open boundary regions.

However, best results from a small-mesh open boundary model can be obtained if computations are made first for a large area with a coarse grid. The boundary values for small-mesh models are then taken from the larger model runs and interpolated to smaller mesh; this is often called a "telescoping technique".

A third method for the description of multiple open boundaries is possible if sea level recordings are available from one or more points within the computation area. In this case, a transfer function between these recording points and points at the open boundary can be determined by statistical means and used in prescribing the boundary conditions.

The "permanent flow" (large scale gradient or thermohaline current) can also be prescribed in a small area model. This can be done either by describing known currents at a boundary and running the model until equilibrium has been established, whereafter the boundary values are extracted and introduced into the model in a later run when tides and winds are also applied. A second approach for prescribing "permanent flow" is to prescribe a longitudinal or transversal slope at the boundaries. This slope can be computed from Torricelli's theorem. If large eddies or external surges are known to move into the area, they too must be prescribed. The eddies, which can be generated within the the computation area by coastal topography or by bathymetry, are well generated by the model as numerous experiences have shown.

The initial distribution of variables is not known because an initial analysis cannot be made for the ocean as it is made for the atmosphere; the computations are started with the ocean in rest and must be carried out for a period of several hours to a day or more, dependent on grid and area size, before realistic synoptic conditions are simulated. For the description of the tidal domain only 25 to 60 hours real time computations are made after the model has reached realistic synoptic state due to the large computer core and time requirements of HN models.

Finally, it should be borne in mind that the models have to be adapted and tuned to each specific location and application followed by a demonstration of true predictive capability.

Past Application, Verification, and Present State of HN Models

The HN type of numerical models have proven themselves, mainly because of their accuracy and general purpose as well as specific applicability to a variety of research and applied problems.

Wide use has been made of HN models in Europe and lately also in the U.S. The principal use of these models can be divided into four categories. The first category of HN model application is for routine operational use, such as sea level (storm surges and actual depth) and current predictions, such as in the North Sea or in any other area. Also in this category can be counted the potential use of the model for temperature and salinity structure analysis/prediction for Antisubmarine Warfare purposes.

The second category of more routine application of HN models is for water quality control, including pollution transport and flushing problems. An example of the application of the model on the distribution of pollutants from instantaneous point source is shown in Figure 2. The use of HN models for search and rescue in locating the drift of liferafts, ships, and other objects can be included in the second category. In the above mentioned applications the selected computational area is fixed and continuous testing and improvement of the model takes place in the same area and program.

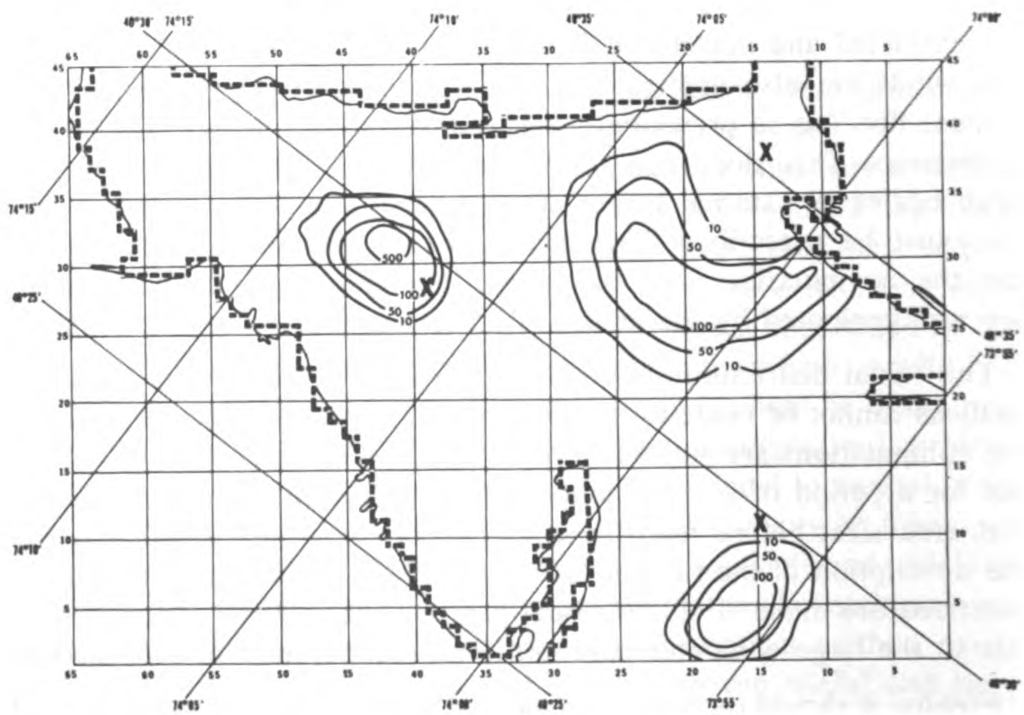


Figure 2 – Concentration of pollutants in Lower Bay of New York after 7 hours of instantaneous release (10,000 units at points marked with X) as computed with HN model.

In the third category of application, the models are used to simulate currents, tides and related parameters which are otherwise not available from previous observations, and the measurement of which is impractical. An example of this type of application is shown in Figure 3 with an extract from a model run off the east coast of Florida. One of the main objectives of this study was to investigate the effects of channels in submerged reefs on the exchange of coastal water with offshore (Gulf Stream) water and to study the effects of winds on the near coast. Into the same third area of application can be counted the use of HN models for obtaining data on currents, sand transport, etc., for coastal construction, deep sea moorings and other "one shot" requirements. All these possible and potential applications have, however, not been fully utilized in the U.S. up to the present time.

The fourth category of application of HN models is for research purposes, including further testing and development of the model, and for the investigation of areas where the driving forces and disturbances are of importance such as the "Wirkungspunkte" (points of influence) method, which has great potential for the design of observation networks in the ocean. The method of "Wirkungspunkte", first developed and employed by Hansen, allows the determination of the areas in the ocean that are at relative rest and those that are in unrest and where monitoring can be effectively carried out. This method has many further

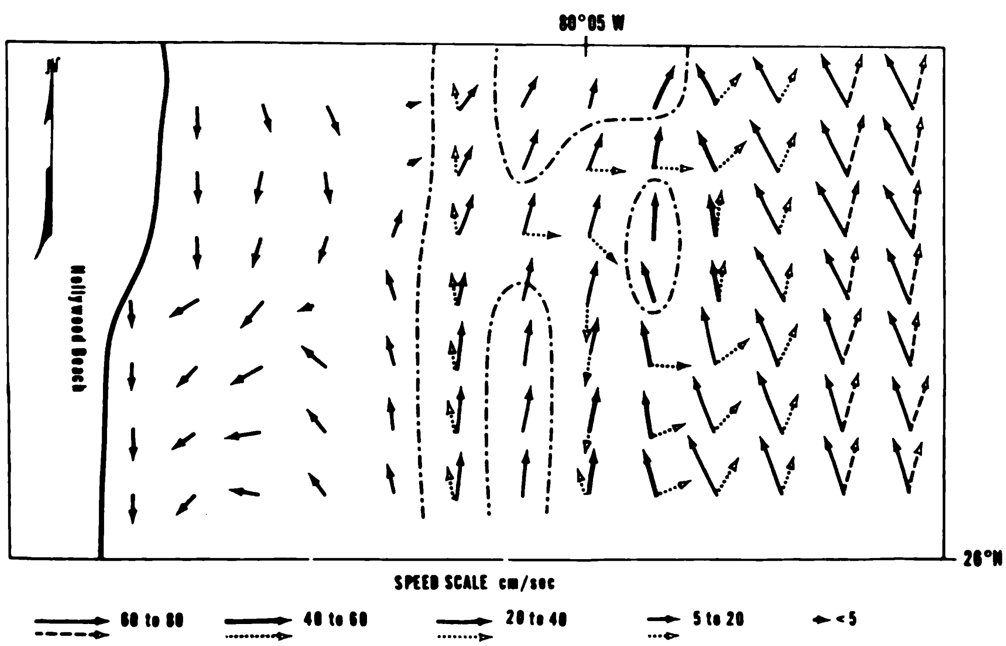


Figure 3 — Computed surface (full arrows) and below thermocline (dotted arrows) currents off Hollywood Beach, Florida, 2 hours after high water, wind from NNE, 8 m/sec. Currents computed with a two-layer Hydrodynamical-Numerical (HN) model, grid size 300 m.

possibilities of applications, such as on the problems and study of climatic changes in respect to oceanic feedback.

The verification and tuning of each application of HN model is usually done via sea level (e.g., tides or storm surge) verification. As the continuity equation and equations of motion, but not the vorticity and/or vertical motion equations, are used in the model, it follows that, if level changes verify well, the currents which produce the convergence/divergence and sea level change must also be correct in the same space and time scale. The verification of sea level is usually done with tide gage data from points within the area which were not used for boundary specification. It is also desirable to verify the currents, if current recordings are available (which is rarely the case). An example of this type of verification is shown in Figure 4.

The application of a two-layer HN model to the Strait of Gibraltar is shown in Figure 5 as an example of currents at a given instance in a specified tidal phase. Figure 6 shows the sea level and top of thermocline topography in the same location. This study indicated that the relatively short but pronounced internal waves in the Strait of Gibraltar were caused by the "hydraulic jump" over the sill separating the Mediterranean from the Atlantic.

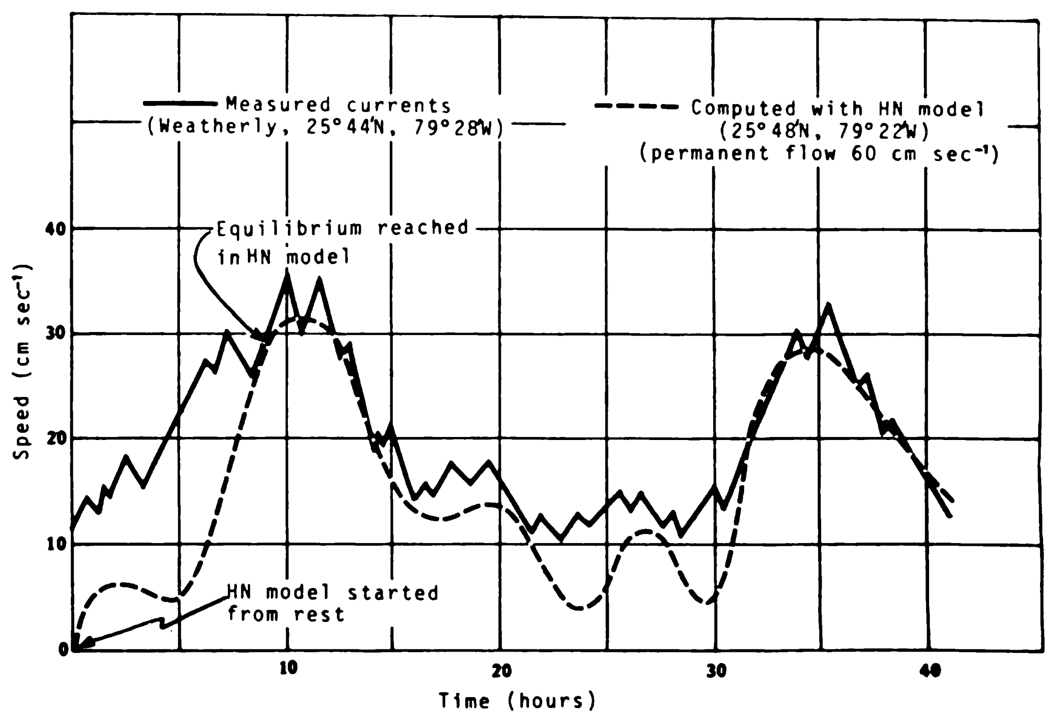


Figure 4 — Comparison of computed and observed currents in the Strait of Florida, near the island slope of Bahamas.

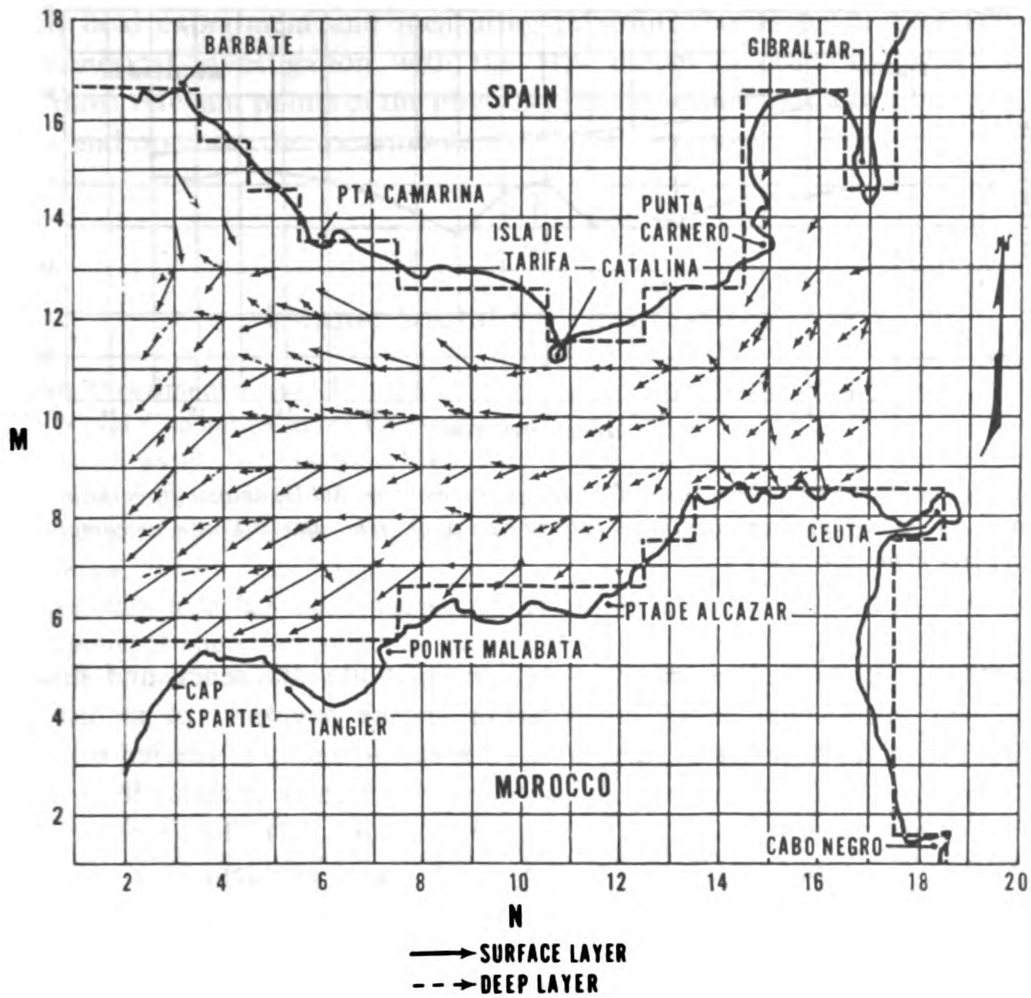


Figure 5 – Surface and deep layer currents in the Strait of Gibraltar at low water at Tarifa.

Some Numerical Modeling Problems Awaiting Better Solutions and Potential Future Applications

Because man does not possess complete knowledge of the intricate behavior of Mother Nature, we cannot expect any model to yield complete and perfect results. Thus there are still many problems with HN models which require better solutions, a few of which are briefly listed below: (1) There is a need to improve the multiple open boundary treatment, especially in cases where several HN models are run along the coast with overlapping boundaries. (2) The multilevel and multilayer models should be combined into a single three-dimensional model. This is essentially a computer programming and program optimization problem. (3) The treatment of internal friction in three-dimensional models needs to be improved and tested. (4) Further

216-194 O - 76 - 2

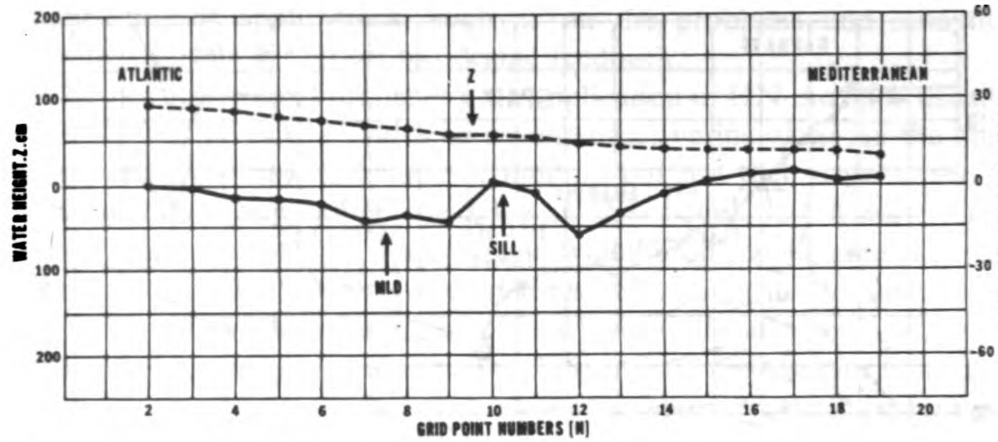


Figure 6 – Surface tide and depth of the top of thermocline (MLD) change from the mean along the axis of the Strait of Gibraltar two hours after high water at Tarifa, as computed with HN model (see Figure 5).

comparative work is needed in comparing finite difference and finite element approaches. (5) The criterion on the necessity of including convective terms must be further developed. (6) Study is needed on the treatment of "vanishing layers," a problem which is peculiar to ocean models and does not occur in atmospheric models. (7) The search must continue for a better solution to the variable grid problem. And, above all, (8) much more verification of the model applications in various conditions is required.

The need for a comprehensive treatise of HN methods and models has become apparent, both for study and training – especially from an operational applications point of view. Such a manual needs to include the theoretical background, numerical formulations, and model descriptions as well as the empirical approaches used in handling the problems listed in the previous paragraph.

There is a need for close collaboration between descriptive oceanographers who provide the measurements for boundaries or for verification, the meteorologists who provide the required meteorological driving forces, and those who develop and apply the HN model.

A need for further study of turbulence from a Lagrangian point of view is also required, especially in connection with pollution and sediment transport problems.

Finally, the method of "Wirkungspunkte" in connection with the HN model promises many further applications, both in science and engineering. As one can determine with this method the areas from which disturbances (caused by driving forces at these locations or external to them) can propagate into various areas of interest, one can thus determine the areas where field observations and recordings should be made. Thus each field experiment and measuring program should be preceded by a numerical investigation with the HN model in order to ascertain the most relevant points of the physics of the system in order to efficiently plan and organize the measurements and observations.

Unique Sound Imaging System

An experimental model of a unique sound imaging system has been built at the Naval Coastal Systems Laboratory.

Known as the Ahead Search Classify Sonar, the device is equipped with a complex acoustic lens which was designed with the aid of a computer using optical lens optimization programs. It is the largest compound sonic lens in existence.

Although light has been imaged for centuries, it wasn't until 1936 that the technique of sound imaging was discovered. Since the early 1940s, the Navy has been interested in imaging with sound and has experimented with it on various projects, with only limited success thus far.

The main problem is that sound at very high frequencies is attenuated rapidly as it propagates through seawater, limiting operation to ranges of 10 meters or less unless frequencies below 1 MHz are used. If lower frequencies are used, picture quality is degraded because of poor resolution. To overcome these constraints, the large lens was developed with the ability to focus on objects at ranges between 10 and 150 meters and provide a visual picture on a television like display.

Henry Warner, research physicist in the High Resolution Sonar Division of the Coastal Technology Department, originated the concept of the Ahead Search Classify sonar some two and a half years ago.

Warner's objective was to develop a practical underwater acoustic viewing system for use by the Navy in searching for and identifying objects on or near the sea floor. The compound lens which he developed has six elements and is designed like a zoom lens, with one of the elements movable so that focusing is possible without moving the whole lens. Also, the multiple elements allow the image to be corrected over the required field of view.

According to Warner, the whole concept was to devise equipment which would provide imaging capability under water comparable to a television camera but which would use sound rather than light to minimize the effects of turbidity and scattering on image quality.

If the initial tests are successful, Warner envisions usage of the device in a towed body to search the sea bottom, from a self-propelled submersible, or as part of a fixed installation to examine ship bottoms. Also, a vital contribution will be to people doing underwater work in undersea habitats, wellheads, underwater mining, etc.

Winter Thunderstorms in Japan—A Hazard to Aviation

E. T. Pierce*
Stanford Research Institute, Menlo Park, California

Introduction

If a meteorologist accepts an assignment overseas one of the unexpected benefits is to experience bizarre weather features quite alien to his previous experience. ONR assignments are no exception in this regard, and it was during my spell as the initial member of the ONR Scientific Liaison Group at the U.S. Embassy in Tokyo (1), that I first encountered the anomalous winter thunderstorms of Japan. In particular, those of the Hokuriku coast are so extraordinary as to verge on the eccentric.

The coast of the main island (Honshu) of Japan, facing the Sea of Japan, has three main sections. The southern section runs approximately West to East from 131°E, 34.5°N, to Wakasa Bay (136°E, 35.5°N); the northern forms a great arc from Toyama Bay (137.5 °E, 37°N) to the tip of the Aomori Prefecture (140.5°E, 41.5°N). The intermediate section—the Hokuriku Coast—although small in extent represents a definite interruption to the general trend of the Japan Sea coastline. The Hokuriku coast stretches from Wakasa Bay to include the Noto peninsula (tip at 137°E, 37.5°N) forming one arm of Toyama Bay; the direction is roughly southwest to northeast.

Almost all localities in temperate regions of the Northern Hemisphere experience only one seasonal maximum in thunderstorm activity; this is usually in August. However, along the Hokuriku coast there is also a secondary maximum in December. This is quite apparent in the data tabulated below for four stations (2).

Average Number of Thunderstorm Days

	Month											
	1	2	3	4	5	6	7	8	9	10	11	12
Tsuruga	1.1	0.8	0.7	1.0	1.2	1.9	3.3	4.1	2.6	0.8	1.1	2.1
Fukui	1.4	0.6	0.9	1.0	0.9	2.1	2.4	3.5	2.1	1.1	1.1	2.1
Kanazawa	1.9	0.7	0.9	1.0	1.2	1.5	2.4	3.0	2.2	1.8	2.3	2.2
Fushiki	1.0	0.5	0.7	0.9	1.3	1.4	2.6	3.3	2.2	1.2	1.7	1.7

*Dr. Pierce, a Staff Scientist at Stanford Research Institute, Menlo Park, California, has been supported by ONR for many years and has special interests in atmospheric electricity.

Thus the first abnormality of the Hokuriku winter storms is in their very occurrence.

Meteorological Features

The abnormality is not confined to occurrence. Some of the meteorological characteristics listed below are also unusual:

(a) The storms form in an orderly, regular manner near the coast when there is cold air above. The instability initiating the storms may be assisted by warm ocean currents and by lifting originating at the land-sea boundary. However, the systematic organized character of the storms is entirely different from that of most thunderstorms.

(b) The cloud tops seldom extend above 15,000 ft. The usual range of cloud top heights is 10,000 to 15,000 ft. this is much lower than for a typical thundercloud.

(c) Severe turbulence and icing conditions are very rare within the Hokuriku thunderclouds.

(d) Cold rain or—more commonly—wet snow, often falling in successive showers, usually accompanies the storms.

(e) After thunder occurs the storm produces heavier snow. There is a local belief that an especially violent snow "gush" follows very soon after a thunderclap.

Electrical Features

The electrical characteristics are in many aspects even more extraordinary than the meteorology; this is indicated in some of the items below:

(f) The occurrence of lightning is almost always detected by hearing thunder rather than by seeing a flash. This is understandable given the local climatic conditions. During a winter (December through February) month the mean temperature is under 3°C (37°F); the monthly precipitation exceeds 280 mm (11 inches); and there is less than one clear day per month. Given this climatic rigor most people will stay indoors as much as possible, and even if they are outside, the poor visibility precludes the easy observation of a lightning flash.

(g) The storms produce very few lightning discharges (thunder rolls); three or four is typical. The flashes are well separated in time often by as much as 20 minutes.

(h) The individual thunder rolls are very protracted.

(i) Flashes are often triggered by the intrusion of aircraft into the cloud.

(j) There is some evidence (3) that the main positive charge center in the storms lies below the negative center. This is entirely the opposite of the polarity arrangement usual in thunderclouds (4).

(k) There is also evidence (3) that the discharges that reach the ground contain only one stroke and almost always bring down positive electricity. By contrast something less than 10% of the flashes in conventional thunderstorms carry positive charge to the earth (4).

(ℓ) When a flash to earth occurs in a winter Hokoriku storm its effects are much more severe than those for summer discharges to ground in the same area. This is illustrated by the statistical data for lightning damage to transmission lines in the Komatsu district of the Hokoriku Electric Power Company (2). The monthly order, in terms of decreasing number of damage incidents, is August, December, January, July, November, etc. Thus in spite of the low flashing rate in the winter storms, the total number of discharges is much less in winter than in summer, the damage incidence is comparable. The obvious conclusion is that the winter flashes are very severe.

Discussion

The Hokuriku winter storms are extraordinary. Nevertheless, all the existing evidence concerning them has a substantial self-consistency. The thunderclouds seem to be quasi-stratiform—of very considerable horizontal extent but of very limited thickness. The cloud electrification is probably such that the upper portions carry a net negative charge while the lower layers are positively charged.

There is presently some agreement that within a conventional thundercloud the general electric fields are perhaps 50 kV/m, but there are localized regions of intensified field where the fields are on the order of hundreds of kV/m (5). It is within these "hotspots" that natural lightning is initiated, and the hotspots themselves result from the convective inhomogeneities inevitable in a boiling cumulonimbus. Turbulence in the Hokoriku storms is slight; thus the hotspots of high field rarely occur naturally. However, when a large conductor, such as an aircraft, intrudes into the cloud the field intensification it creates is sufficient to artificially initiate or "trigger" a lightning flash.

Once the flash has been initiated it apparently extends laterally to considerable distances as is indicated by the long duration of the thunder roll. The entire positive charge may pass to earth thus accounting for the severity of the discharge. It is tempting to draw an analogy with the giant electrically positive flashes observed by Berger on Monte San Salvatore in Switzerland (6).

The Hokoriku winter storms offer some exceptional opportunities for experimentalists. Obviously, the unusual features of charge polarities both for the clouds and for the flashes to earth need to be better confirmed. Measurements indicating whether or not the positive discharges to ground are indeed of particular severity would be very desirable.

to Komatsu Airport, and landed safely although much damage had been suffered by the aircraft; this damage included the complete disruption of a radome.

Two phenomena of long-standing interest in atmospheric electricity could be very advantageously studied in the Hokoriku storms. These are the "rain-gush" (or perhaps "snow-gush" in Hokoriku), and triggered lightning. The rain-gush is the term describing the increased precipitation widely believed to follow soon after a lightning-flash (7). Several physical mechanisms have been advanced for its cause, but it is difficult to differentiate between these mechanisms, and indeed even to establish the reality of the gush effect, by observations of normal thunderclouds. This is because, for conventional storms, the radar returns (indicative of the location and size of precipitation elements) fluctuate so quickly, and lightning flashes occur in so rapid a succession, that data interpretation is seldom unambiguous. However, the Hokoriku storms with their ordered structure and very low flashing rate, are exceptionally suitable for a definitive investigation of the rain gush.

Triggered lightning can occur when an aircraft, or—especially—a large rocket, enters an electrified cloud. The most famous triggered lightning incident was at the launch of Apollo 12; this, and other instances of triggered lightning, have been discussed in previous issues of *Naval Research Reviews* (8-10). Triggered lightning is of growing concern in operations involving aircraft and rockets, and may be of significance in future activities such as the Space Shuttle Program. Many efforts have been made to trigger lightning by firing rockets into thunderclouds (5), but evaluation of the success of these efforts has not been easy, primarily because with conventional storms there has always been a good chance that natural triggering was about to operate at the same time that the artificial triggering was attempted. The Hokoriku clouds are, however, only marginally thunderclouds; they exist—electrically primed—for long periods between the triggerings that result in lightning. Under these circumstances, triggered lightning experiments have a high probability of being productive.

Finally, the Hokuriku storms are already well recognized as a hazard in aircraft operation. The Japanese domestic carrier All Nippon Airways (ANA) provides service to the Hokuriku coast from other areas of Japan. ANA regards the winter storms as an operational problem because of aircraft triggered lightning, extremely intense flashes, and a very low natural flashing rate so that avoidance techniques based on the prior occurrence of lightning are relatively ineffective.

December 12, 1967, was the worst day on record; it produced two serious incidents. In the afternoon (1518 JST) a Friendship-27 of ANA, making its first approach to Fukui Airport, was struck by lightning while at a height of 4,000 ft. The flash continued to ground and there destroyed the airport homing beacon. The flight was therefore diverted

Komatsu air facilities are used jointly by civil aircraft and aircraft of the Japan Self Defense Forces (JSDF). On the morning (1100 JST) of December 12, 1967, a JSDF F-104 fighter was struck by lightning. The pilot lost control and baled out. Unfortunately, the F-104 crashed in the downtown area of Kanazawa a city of some 300,000 people. Much damage was done, 4 people were killed, and 23 injured.

References

1. Profiles in Science, *Naval Research Reviews*, **28(10)** (October 1975).
2. Winter Flight Operation Manuals for Toyama, Fukui, and Komatsu Airports, All Nippon Airways (1968).
3. T. Takeuchi, M. Nakano, M. Nagatani, and H. Nakada, *Jour. Met. Soc. Japan*, **51,** 494 (1973)
4. M. A. Uman, *Lightning* (McGraw-Hill Book Co., 1969).
5. G. A. Dawson, D. M. Fuquay, and H. W. Kasemir, Chapter 17 in *Weather and Climate Modification*, W. N. Hess, editor (John Wiley, New York, 1974).
6. K. Berger, *Jour. Franklin Inst.*, **283,** 478 (1967).
7. C. B. Moore, B. Vonnegut, E. A. Vrablik, and D. A. McCaig, *Jour. Atmos. Sci.*, **21,** 646 (1964).
8. M. Brook, C. R. Holmes, and C. B. Moore, *Naval Research Reviews*, **23(4),** 1 (April 1970).
9. E. T. Pierce, *Naval Research Reviews*, **25(3),** 14 (March 1972).
10. R. D. Hill, *Naval Research Reviews*, **28(10),** 1 (October 1975).

Technique Improves Carbon Fiber Materials

A Naval Research Laboratory chemist has developed and patented a technique that increases the tensile strength of carbon fibers used in laboratory and commercial materials.

Dr. Victor R. Deitz, credited with the invention, said carbon fiber materials improved by this technique are useful in aircraft and aerospace applications, as well as in ordnance systems.

In the technique, carbon fibers are immersed at ambient temperatures in liquid bromine or bromine dissolved in a non-reactive solvent, within a chemical resistant container for a period of time. The bromine is then removed by flushing the carbon fibers with an inert gas. The removed bromine may be recovered and reused. The addition and removal of the bromine reorients the elementary fibriles within the fibers to more stable configurations and, thus, the tensile strength of the treated fibers is increased.

Queen of the Oceanographic Fleet*

The Vema, Columbia University's famed research ship, recently passed her millionth mile near Australia, in her search for clues to the earth's origin and evolution.

Vema's continuous scientific voyages over 22 years constitute science's longest and most productive exploration of the oceans. No other oceanographic research vessel has probed, profiled or photographed more of the ocean floor. The Office of Naval Research and the National Science Foundation have supported much of Vema's work during these years.

In a cablegram prepared for transmission to the ship, her scientists and crew, Columbia President William J. McGill praised the "extraordinary new knowledge" and "major discoveries" that have come from her voyages. In another cable, Dr. Manik Talwani, director of the Lamont-Doherty Geological Observatory, which operates Vema, called her "a leader in exploration of the oceans and what lies beneath them," adding: "The data gathered by Vema have enhanced understanding of the physical earth as it is today, as it was millions of years ago, and as it may be in the distant future."

At sea all but several weeks a year, when she is being outfitted for her next voyage, Vema has been called both "the hardest working research vessel afloat" and "queen of the oceanographic fleet." Among her many distinctions, Vema has:

- gathered nearly half the extant data on the ocean floor, giving Columbia scientists the largest collection of ocean sediment cores and the most extensive collection of marine geophysical data anywhere.
- pioneered the development of many of the technical means of getting those data, including seismic refraction and reflection instruments, gravity measurements, deep-sea photography and coring.
- discovered and mapped the world-circling mid-ocean ridges, which led to a revival of the theory of continental drift.
- provided marine geophysical information that confirmed the theory of global plate tectonics, moving the earth sciences into new exploration of the earth's inner dynamics.

Once a privately owned, three-masted schooner, Vema sailed on her maiden voyage in 1923 from Copenhagen where she had been designed by Burmeister and Wein. Christened "Hussar," her name was changed by shipping magnate George Vetlesen, who acquired her in the 1930s and compounded the name Vema from the first two letters of his last name and his wife's first name, Maud. Vema was one of the finest

*Press release from Columbia, University, New York, New York.

and fastest transatlantic yachts; setting an unofficial record for a crossing under sail, she went from Montauk Point, N.Y., to Bishop Rock, England, in 1934 in 10 days, 10 hours.

After service as a floating training barracks during World War II and several years of near-ruinous neglect on a Staten Island mudflat, Vema was rescued in 1953. Columbia scientists chartered her for an expedition to the Caribbean and Gulf of Mexico during which the ocean bottom was analyzed and charted.

Acquired by Columbia that year, Vema was overhauled from engine to hull and superstructure and refitted with electronic devices, underwater cameras, depth-recording devices and related oceanographic equipment. In 1966, she became the first civilian vessel permanently equipped to navigate by artificial satellite. Henry C. Kohler, a native Nova Scotian, has been master of the vessel for 18 years.

During 32 scientific voyages, Vema scientists have developed a battery of precision tools and techniques, including seismic refraction and reflection instrumentation and improved depth recording devices, for studying the ocean floor and what lies beneath it. The scientists have perfected undersea photography and have adapted gravity measuring devices and magnetometers for use on surface vessels that allow inferences to be made regarding the rocks many miles below the sea surface.

Use of these procedures and instruments has enabled Columbia scientists to accumulate enough data to draw maps of the ocean floor, understand processes of marine sedimentation and define the age and structure of ocean basins and underwater landscapes.

One of the most striking features of those landscapes, Columbia scientists reported in 1957, is a ridge of two-mile-high underwater mountains that circle the world in an almost unbroken chain 45,000 miles long. During later explorations, Vema scientists found that the crest of the ridge is nearly devoid of sediment, that the flow of heat from inside the earth is more intense there than at any other point on the globe and that symmetrical patterns of magnetism exist in the rock on either side of the crest.

From studying data on seismology and ocean-floor magnetism retrieved by Vema, Columbia geophysicists confirmed that the earth's crust is composed of several large plates, 60 miles thick, which continually move in relation to one another at rates of a few inches a year. Their new edges are formed by magma welling up from fissures in mid-ocean ridges; old edges disappear again into the earth's mantle along deep underwater trenches. To describe the process, Columbia scientists coined the now-common phrase, "the new global tectonics."

Today, Vema continues to map the mountains and valleys of the once seemingly flat oceans and trace instrumented ocean buoys that demonstrate the interactions of ocean currents and the effects of ocean pollution. Her scientists explore continental margins to determine their age and thickness of sediments, in the process, aiding in the discovery of undersea oil and natural gas reserves. The scientists unravel the history of world climate changes from deep-sea sediment cores.

One of the smallest deep-water oceanographic research vessels afloat – 202 feet long with a displacement of 734 tons – every square inch of space is utilized. Vema is equipped to perform a number of scientific tasks simultaneously. While cruising, her instruments record water depths, ocean-floor structure, variations in the earth's gravitation, and the history of the earth's magnetic field locked in sea-floor rock. Seismic profilers scan underwater sediments and crustal rock; periodic measurements are made of ocean-water temperature and salinity. At preplanned intervals and sites, special tools punch columns of sediment from the ocean bottom – some as long as 100 feet – and dredge samples of the earth's submarine crust.

In addition to these ongoing studies, each leg of a Vema voyage is assigned one or more special missions. The millionth-mile leg investigated evolutionary oddities of one branch of the mid-ocean ridge system – the Southeast Indian Ocean Ridge. Unlike other sections of the world-circling mountain range, portions of this ridge have grown in a unique and curious asymmetric fashion. Columbia scientists suspect that forces below the ridge, acting deep within the earth's mantle, are actually causing a large section of this mountain range to collapse to unusual depths. They hope to confirm the theory through dredging, heat-flow measurements and seismic studies.

Vema as she appears today

On the Research Reserve

Shallow Water ASW

Naval Reserve Research Laboratory 622 (NRRL-622) in Seattle, Washington has recently completed a study of shallow water antisubmarine warfare (ASW). Shallow water, for purposes of this study, is defined as ocean areas with depths less than 400 meters. The study includes data on the submarine threat; special problems in the applications of sensors, platforms, and tactics; and description of the shallow water ASW environment in key areas of the world.

The purposes of the study were to provide training for mobilization for members of NRRL-622 and to provide general support to the Acoustics Division, Naval Research Laboratory. The officers of NRRL-622 were selected for their special skills in the area of ASW and include engineers and scientists drawn from industries and universities in the Northwest. NRRL-622 was established in August 1974 as part of a major reorganization of the Research Reserve which was intended to strengthen ties to the Fleet and to develop improved mobilization capability.

The study details the mission of the Soviet Navy in the Mediterranean, the Caribbean, and the North Atlantic. It emphasizes the problems of detecting submarines which are transiting shallow water areas or remaining in these areas to escape detection. The study summarizes the technical literature on the capabilities and limitations of existing operational submarine detection systems when they are applied in shallow water areas. Such shallow water areas present special problems for ASW operations, including high ambient noise levels, complex layering of waters of varying characteristics, reverberation from the sea bottom and surface, and exposure of ASW forces to land based air attack. Another section of the report deals with new techniques for submarine detection that may have special advantages when applied in shallow water areas.

NRRL-622 is presently considering options for continued efforts in the area of shallow water ASW. The Unit is pleased with the support it received from Naval Research Laboratory (NRL) on this project which demonstrated the feasibility of cooperation between NRL and its reserve components.

Clinch River Breeder Reactor

The Clinch River Breeder Reactor Project currently being planned for a site near Oak Ridge, Tennessee, promises to bridge the gap between present day electrical generation technology and that of the 21st century. This was the message conveyed in a seminar sponsored by Office of Naval Research Headquarters Unit 208 in Oak Ridge.

In the three day session, the seminar covered numerous energy alternatives including those most often touted as being capable of replacing nuclear power as alternative energy producers. These presentations, centered about the overall U.S. energy requirements through the year 2000, pointed out the seriousness of the energy question and made it clear that there are no energy alternatives. In order to avoid economically depressing energy shortages in the near term, every available energy resource will have to be utilized to the maximum extent practicable. This means that the current domestic energy supplies, coal and uranium, will require rapid expansion and sources for future energy supplies, solar and geothermal primarily, will have to provide a considerable amount of power by the turn of the century. Other 21st century energy sources, central station solar and fusion, must continue development as the ultimate power sources.

There is a fly in the ointment, however. Coal mining capabilities are not unlimited and carry environmental penalties. Uranium of the type used in current nuclear plants cannot last for more than a few more decades. Natural gas is no longer being discovered as rapidly as it is being depleted. Domestic oil supplies, even including the vast oil finds of the Alaskan North Slope, are declining and there is no prospect of improvement. Hydroelectric power has already been utilized to nearly the full capability. The 21st century energy supplies are yet many decades from realization. All of this points to a gap, one which could result in severe economic effects.

Those involved in the Liquid Metal Fast Breeder Reactor (LMFBR) program believe the LMFBR can effectively and safely fill this gap. John M. Haffey, Project Management Director of Information provided the case for LMFBR in his address to nearly 100 seminar participants. Of every 100 pounds of uranium-mined, 99.3 pounds are the isotope Uranium-238 and only seven-tenths of one pound is the isotope Uranium-235. "Unfortunately" said Haffey, "the only form of uranium that can sustain a fission reaction is the seven-tenths of one pound - the Uranium-235." The breeder, though, can produce more fuel than it consumes by converting Uranium-238 to Plutonium-239. The Plutonium can then be used to fuel conventional nuclear power plants. For nuclear power plants, this means extending the effective fuel supply from several decades to several centuries.

The Clinch River Breeder Reactor Plant is expected to begin construction by July 1977. But first, the project must satisfy an independent board of scientists that it is indeed safe. There are several interventions which contest this point, bringing out concerns about the liquid sodium to be used as a coolant, the possibility of a core disruptive accident, the plutonium which would be produced and about the plant's impact on the environment. "I firmly believe the breeder is quite safe" was the way Ann Hansen, a nuclear safety engineer assigned to the LMFBR project put it. She and David K. Goeser, Manager, Lead Reactor Manufacturer Safety and Reliability Division of Westinghours discussed the licensing and operational and safety aspects respectively.

Hansen indicated that there are two totally independent systems which would operate automatically to shutdown the nuclear reactor in the event of any abnormal functioning of the plant. There are also several independent systems which are capable of removing decay-heat once the reactor has been shutdown. She discounted any accident similar to the fire that occured at TVA's Browns Ferry Nuclear Plant.

Goeser discussed the technical aspects of the LMFBR design. This design includes an intermediate sodium system which physically separates the reactor sodium cooling system and the water system used to drive the turbine-generator. There is considerable concern about the reaction which can take place when water and sodium come into contact. While a leak in a steam generator could result in a violent chemical reaction between water and sodium, such an incident could not affect the reactor and therefore is an economic rather than a nuclear safety problem. For the purposes of design, it is assumed that such an interaction will occur. It should be pointed out that liquid sodium coolant is not a new concept but has been used for many years in reactor applications. In fact, a sodium cooled reactor, the Experimental Breeder Reactor No. 1, produced the first electricity from nuclear power.

Another of the concerns discussed at length was the core disruptive accident. Goeser indicated that safeguards in the form of shutdown systems, redundant heat removal systems, and redundant fail-safe core control systems makes such an accident highly improbable.

W. D. Burch, Director, LMFBR Fuel Reprocessing Program for Oak Ridge National Laboratories concluded the meeting with a discussion on the Breeder Fuel Cycle. The long term storage required for plutonium is not considered a problem since the plutonium is needed for fuel for conventional reactors. Other high level wastes will be produced but satisfactory storage is available and ongoing studies of vaults in salt formations is well-advanced. The concerns about the possible diversion of plutonium are being studied carefully and there is little doubt that satisfactory safeguards can be made available when it becomes necessary.

The meeting was well attended with units from Tennessee, Virginia, Maryland, Georgia, Alabama, and Washington, D.C. represented. Also present were members of the press, Sierra Club, general public and the active naval community including Captain J. E. McNish, Special Assistant for submarines to the Assistant Secretary of the Navy for Research and Development and Captain J. N. Green, Office of Naval Research Assistant Chief for Technology.

Research Notes

Experiments in Remote Sensing

The Naval Coastal Systems Laboratory has completed a series of experiments in aerial remote sensing using a system furnished under contract by the Experimental Research Institute of Michigan.

The objective of the experiments was to evaluate passive multispectral techniques in a coastal environment. Data from the experiments will define parameters for an experimental remote sensing system for military applications. Such a system would utilize spectral information in the scene under observation by equipment operated in airplanes or satellites.

In operation, a telescope scans the area below the aircraft. A radiation detector converts the focused beam of radiation to an electrical signal. As the aircraft moves forward, subsequent line scans form a continuous strip image of the terrain below. The signals are then applied to a recognition processor where certain features are identified and form elements in a recognition map.

Aside from a host of military applications, remote sensing has numerous civilian applications; for example, classification of crops, detection of crop diseases, ice surveillance, land use studies, water pollution indices, urban studies, and geological mapping.

A Revolutionary Development in Rotating Bearings*

The Swing-Pad Bearing, a new basic form of a lubricated rotating bearing invented at the David W. Taylor Naval Ship Research and Development Center, is expected to have significant impact on the design of machinery for future ships. Improved performance and increased dependability of machinery based on this bearing concept should extend ship availability and effectiveness. Development of water-lubricated machinery based on the use of the Swing-Pad Bearing will reduce pollution and conserve energy.

Unlike conventional lubricated rotating bearings whose performances have been advanced only by improved lubricants and bearing materials, the Swing-Pad Bearing embodies a totally new approach. Performance results, based on prototype experiments, conform:

- Successful operation at load/speed conditions under which conventional lubricated rotating bearings fail (Figures 1 and 2).
- Exceptional performance with low viscosity lubricants (Figures 3 and 4).
- Decrease in chance of failure from overheating. These operating characteristics signal major improvements in performance, endurance, and weight of conventional machinery arrangements; in practical hardware for new machinery concepts; and in the use of low viscosity fluids such as water for bearing lubricants.

*Reprint from press release from Naval Ship Research and Development Center, Bethesda, Md.

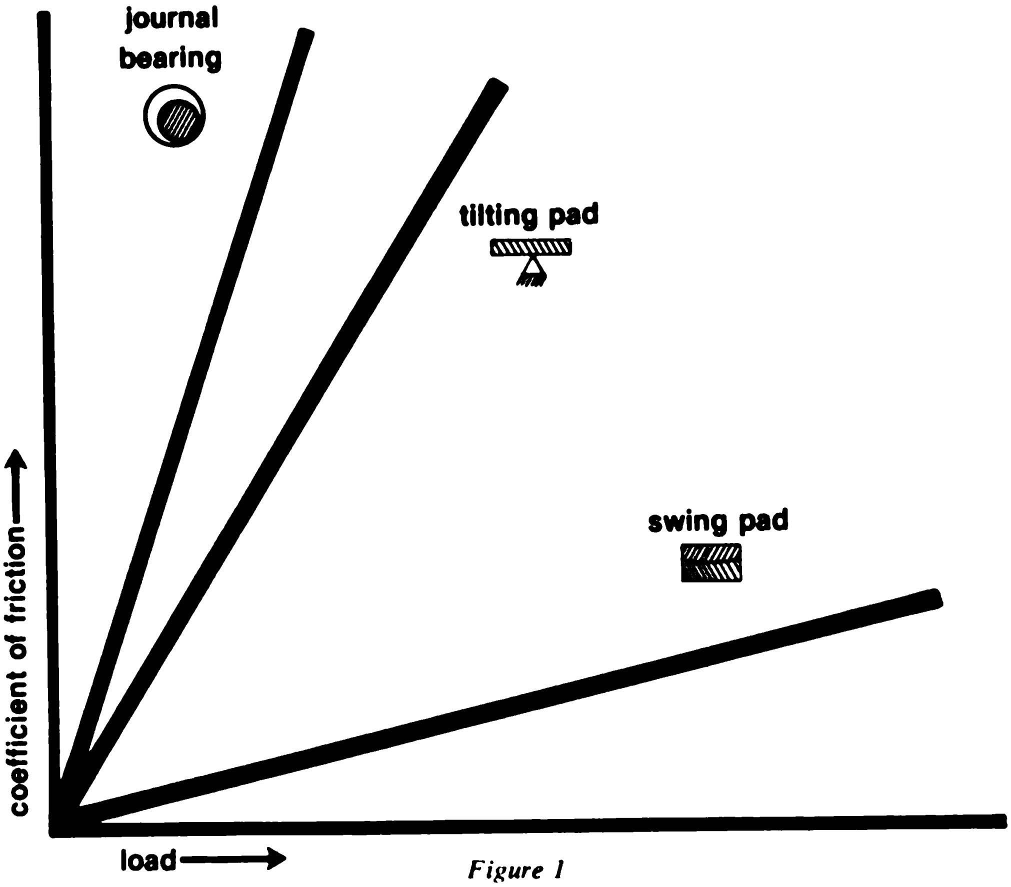


Figure 1

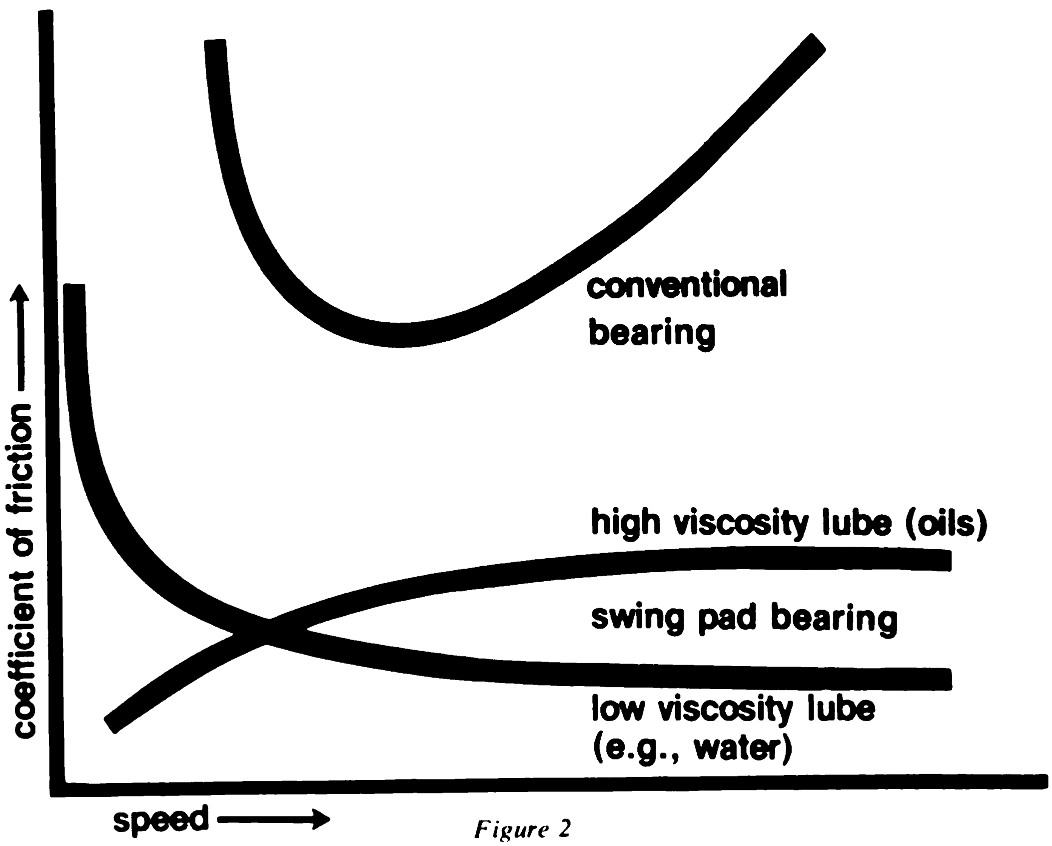


Figure 2

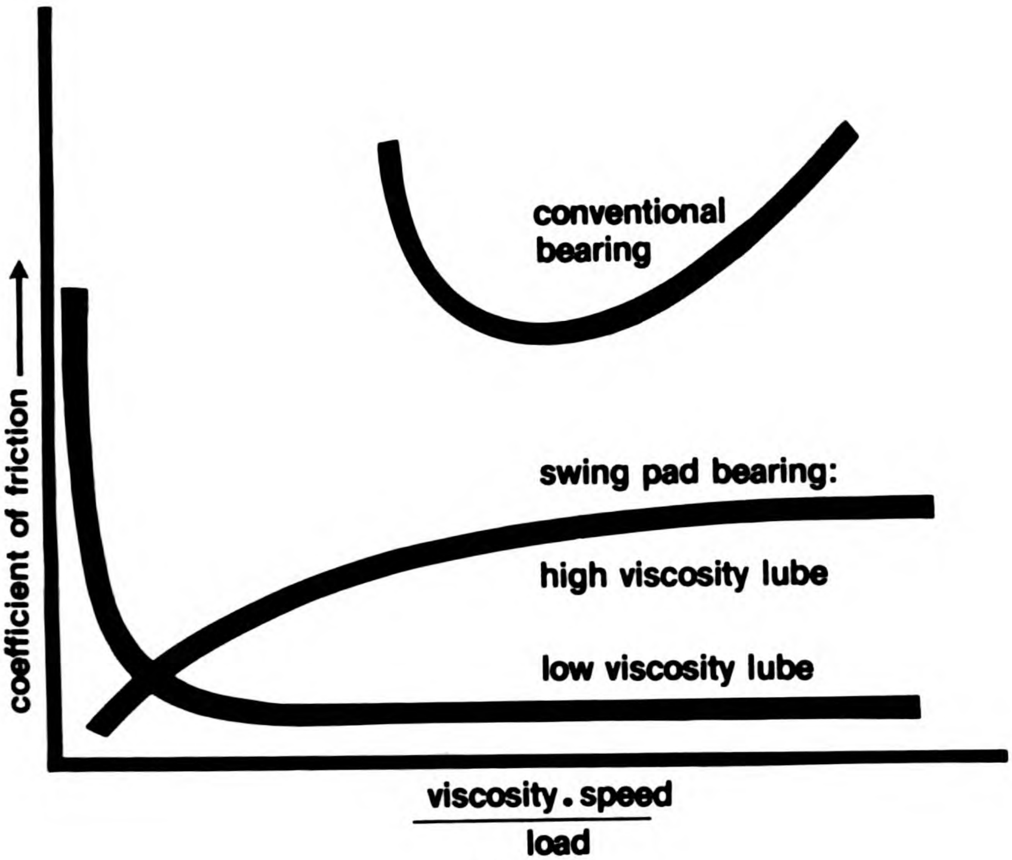


Figure 3

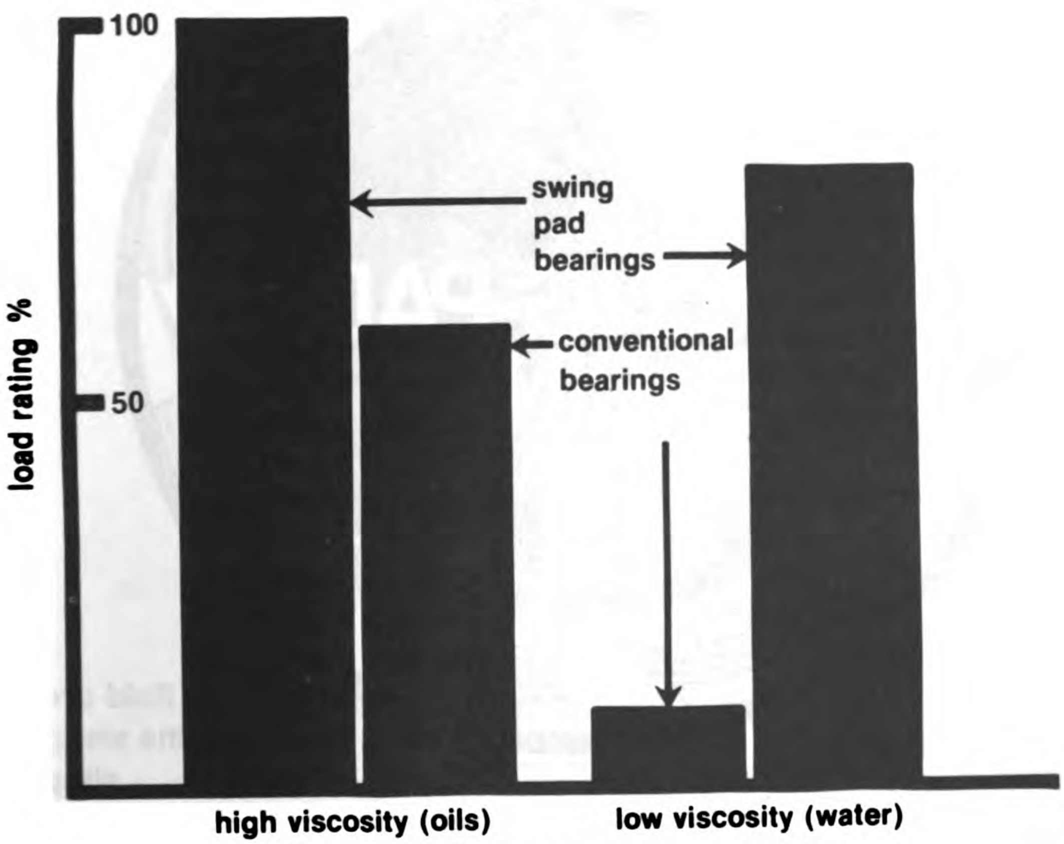
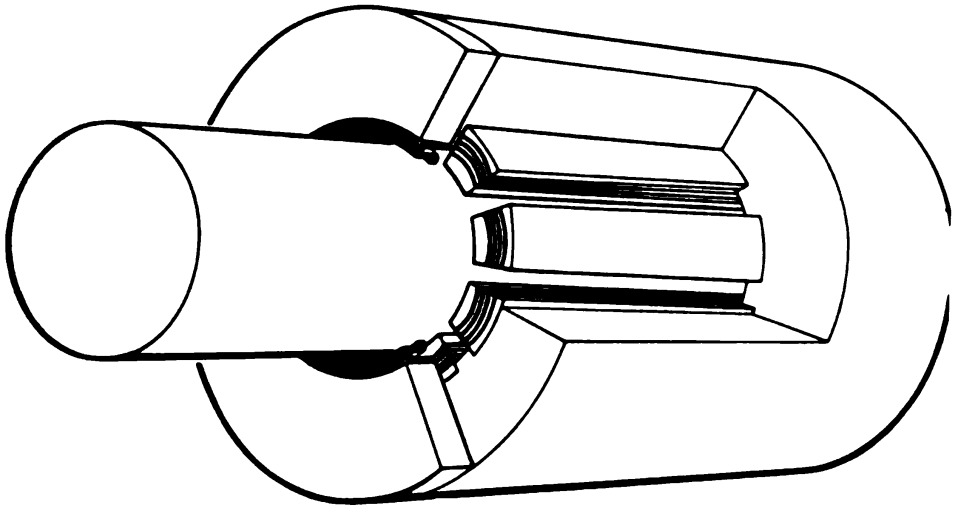


Figure 4

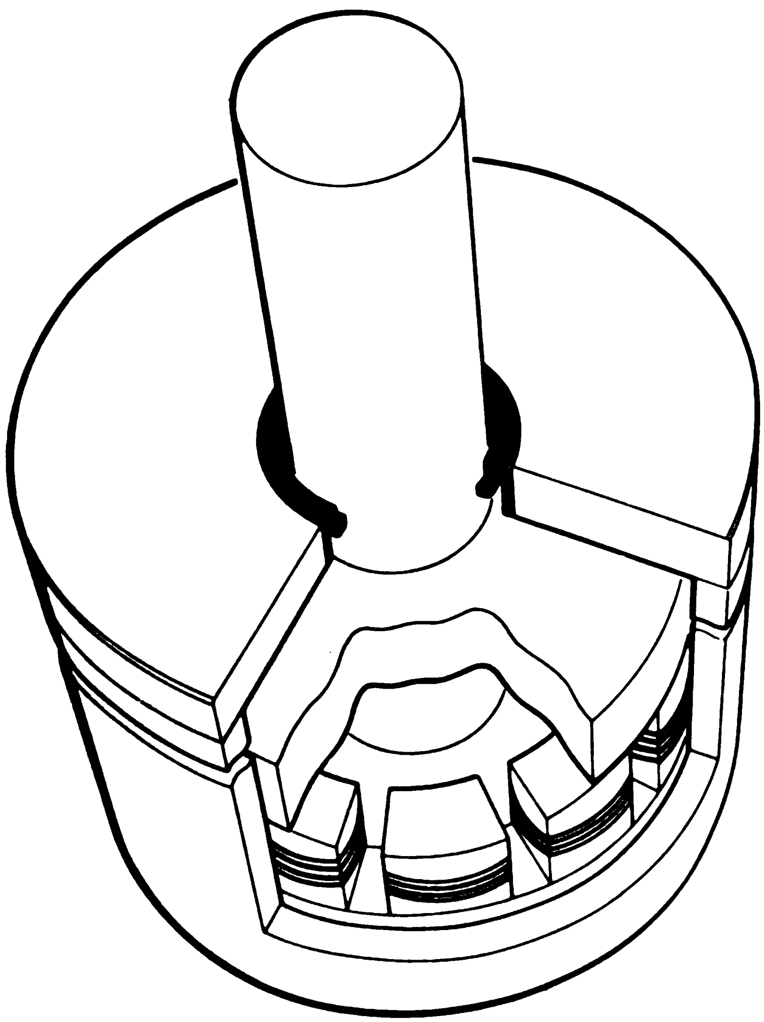
Most lubricated rotating bearings, including the Swing-Pad Bearing, are hydrodynamic fluid-film bearings in which fluid-film pressure is required to maintain separation between moving parts. Generated by the relative motion of the parts, a fluid wedge is formed into which the lubricating fluid is drawn by the viscous friction force exerted by the moving surface. The fluid-film thickness must be sufficient to prevent asperities on the mating surfaces from touching. Thick films are favored by high speeds, light loads, high fluid viscosity, and by bearing geometry favorable to fluid wedge formation.

The novelty of the Swing-Pad Bearing form is that the friction force itself is used to deflect the bearing surface to produce the converging wedge. The stationary bearing surface is segmented. Each segment is a "pad." These pads are supported by curved segments of laminated elastomer with the center of the curvature located above the pad bearing surface. The laminated elastomer, stiff in compression and soft in shear, will support the bearing load and allow the pads to displace around the center of the curvature, swinging their surfaces to admit lubricant at the leading edges. This forms a load-carrying wedge of fluid. The pads displace through a motion resembling a swing. The construction is simple, rugged, and inexpensive (Figure 5).

Figure 5



Journal Bearing



Thrust Bearing

Figure 6

bearing load will resist this motion. Moment directions are opposite, and the pad surface will stabilize when these moments are in equilibrium. Increasing loads increase the friction forces. A wedge shape converging in the direction of motion is always maintained regardless of load intensity.

The Swing-Pad Bearing form can be designed in a journal version, a thrust version, and a combination thereof. The pad bearing surface is the conventional bearing surface used in other forms of rotating bearings (Figure 6).

The Navy-developed Swing-Pad Bearing carries a U.S. Patent Number 3,930,691 of 6 January 1976.

The location of the swing center is of paramount importance. The bearing friction force on the pad bearing surface will swing the surface. The applied

Blood Research Investigation Initiated

At the University of Michigan, Dr. David Aminoff has recently begun a unique undertaking—the conversion of type A red blood cells to type O by bacterial enzymes. His expertise in blood cell surface carbohydrate chemistry has made this a possibility. His approach is to remove the surface antigens which cause blood transfusion reactions from red cells. His goal is to purify the appropriate enzymes in bulk and develop his method for commercial use. Similar approaches to removing B group antigens would produce blood suitable for transfusing into high-blood-loss trauma patients without the need for time consuming cross-matching. This work is jointly supported by the Office of Naval Research and the Naval Medical Research and Development Command.

The offending A group antigen is the carbohydrate α-N-acetylgalactosamine, which is selectively removed by α-N-acetylgalactosaminidase (called Azyme) produced by the bacterium *Clostridium perfringens*. A recently acquired preparative instrument, the LKB Multiphor 2117 flat-bed isoelectric focusing apparatus will make it possible to separate this particular enzyme from the many carbohydrases secreted by the bacterium. A particularly troublesome carbohydrase contaminant of earlier preparations removed red cell sialic acid, which results in the cells being removed from the circulation by the liver. The role of sialic acid in the maturation and removal of circulating red cells is another area of interest in Dr. Aminoff's laboratory. Current preparations of Azyme have been shown to result in: (a) no hemolysis of the red cells; (b) the destruction of the A activity; (c) the revelation of H activity (the carbohydrate antigen on O cells which underlies A and B activity); and (d) the solubilization of N-acetylhexosamine, presumably the α-N-acetylgalactosamine. In addition to achieving these goals on a larger scale, Dr. Aminoff will test enzyme-treated, isotopically-labeled A cells for viability in autologous donor pigs or other animals with A activity.

U. S. GOVERNMENT PRINTING OFFICE : 1976 O - 216-194

Dr. Hoogstraal Admitted to the Zoological Society of London

Dr. Harry Hoogstraal, senior civilian scientist at U.S. Naval Medical Research Unit No. 3 in Cairo, Egypt, and the 1971 recipient of the Robert Dexter Conrad Award was admitted to the Zoological Society of London as an Honorary Fellow.

The letter of invitation from Lord Zuckerman is quoted below in part:

> "The Council of the Zoological Society of London, under the Presidency of H.R.H. The Prince Philip, Duke of Edinburgh, at its meeting in December, unanimously resolved to invite you to accept admission to the Society as an Honorary Fellow.
>
> Our Royal Charter, first granted to the Society in 1829, lays upon the Society the duty of advancing zoology and animal physiology, and in furtherance of the work, enpowers the Council to admit as Honorary Fellows "eminent persons who have distinguished themselves as zoologists". The number of members may not at any time exceed 25. This is the highest honour of its kind which the Society can bestow, and I need hardly say how honoured we should be if you would agree to accept this invitation."

Dr. Hoogstraal is recognized internationally for his research on ticks and mites, with particular reference to their role as human disease vectors. He is also a recipient of the Department of Defense Distinguished Civilian Service Award and numerous professional honors and awards.

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 730, 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: $6.50 per year in the U.S. and Canada; $8.15 per year, foreign; $0.55 per individual copy. The issuance of this periodical approved in accordance with Dept. of the Navy publications and printing regulations.

Editor: WILLIAM J. LESCURE

NAVSO P-510

Associate Editors:

A. R. LAUFER, ONR PASADENA

A. R. DAWE, ONR CHICAGO

A. L. POWELL, ONR BOSTON

D. A. PATTERSON, NAVAL RESEARCH LABORATORY

IN THIS ISSUE

VOL. XXIX, NO. 6

Cover Caption

Vema in 1942 when she was a picket boat for the Coast Guard

DEPARTMENT OF THE NAVY
OFFICE OF NAVAL RESEARCH
ARLINGTON, VA. 22217

OFFICIAL BUSINESS

PENALTY FOR PRIVATE USE, $300.

POSTAGE AND FEES PAID
DEPARTMENT OF THE NAVY
DoD-316

U.S.MAIL

CONTROLLED CIRCULATION RATE