SCIENCE and the SEA

VOLUME II
1969

U. S. NAVAL OCEANOGRAPHIC OFFICE

SP-132

SCIENCE and the SEA

VOLUME II

1970

U. S. NAVAL OCEANOGRAPHIC OFFICE

For sale by authorized Sales Agents of the U.S. Naval Oceanographic Office,
Washington, D.C. 20390; also by
the Superintendent of Documents, U.S. Government Printing Office,
Washington, D.C. 20402 - Price $1.00

FOREWORD

Science and the Sea, a collection of selected Pilot Chart Articles, was first published in 1966 as a means of acquainting teachers and students alike with some of the more practical aspects of the familiarization with the sea as regards to oceanography, hydrography, and navigation. Since then, the publication, now designated as Volume I, has been widely distributed and has thus received the acclaim of readers in many walks of life. As proof of the great interest generated by Volume I, numerous requests have been made for a further compilation of similar articles.

Volume II of *Science and the Sea*, the second in this proposed series, features ten additional articles covering a wide range of oceanographic, hydrographic, and navigational subjects. The articles included were originally prepared for presentation on the reverse sides of issues of the *Pilot Chart of the North Atlantic Ocean* and the *Pilot Chart of the North Pacific Ocean*. These charts are published monthly by the U.S. Naval Oceanographic Office to provide mariners with a graphic synopsis of oceanographic, hydrographic, navigational, and meteorological conditions that prevail in those waters.

Volume I of the booklet may still be procured by ordering from the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402. Price 75 cents.

A. S. SLATTERY
Captain, U.S. Navy

TABLE OF CONTENTS

GEOLOGICAL OCEANOGRAPHY

By Andries Van de Ree
Maritime Safety Division
U. S. Naval Oceanographic Office

Geological Oceanography is the application of the science of Geology to the ocean basins. As such, it is directed toward all aspects of geology. It includes the investigation and analysis of the topography and the composition of the ocean floor, the study of volcanism, magnetics, gravity, seismism, heat flow.

In the last two decades great strides have been made in our knowledge of the ocean floor and its sediment layers. Three factors have contributed to the advancement in this field. Firstly, instrumentation has progressed rapidly, giving us better tools for exploration—improved echo sounders, more accurate electronic position finding systems, gravity meters operating on surface ships, new acoustic devices, electronic computers, and submersibles of various sizes. Secondly, the U.S. Navy, in cooperation with others, has begun surveying accurately the unknown part of the ocean floor to publish bathymetric (deep measuring) charts urgently needed by nuclear submarines capable of diving to great depths. Thirdly, in the last few years the government has made additional resources available for both theoretical and applied ocean research.

The ocean floor, covering approximately 72 percent of the earth's surface, is divided into areas with the following common features:

1. The continental shelves, the relatively shallow areas bordering the continents and a few large islands.
2. The continental slopes and rises which usually extend from the outer margin of the shelves to the deep sea floor.
3. The deep sea floor, the domain with great depths where abyssal plains are interspersed with great mountains, extensive ridges, deep basins, valleys, canyons, troughs and trenches.

Before discussing each of these areas and some of the other fields comprising Geological Oceanography separately, a background is provided for the lay reader.

HISTORICAL DEVELOPMENT

For centuries, geology, as a physical science, was explored by scientists who occupied themselves almost entirely with charting the land and investigating basic geological principles. Geological Oceanography was neglected until the latter part of the eighteenth century when James Cook led a scientific expedition which not only measured the ocean depths, but took many temperature observations from 1772 to 1775. Soundings of real oceanographic importance were taken in 1840 when Sir James Clark Ross obtained soundings of more than 2,600 fathoms in the Antarctic.

In those days, soundings were made with a hemp line. Lowering and raising the lead to take a deep-sea sounding took hours. An improvement in sounding was introduced in the middle of the nineteenth century by Lt. Matthew Fontaine Maury, U.S.N., using a cannon shot attached to a ball of twine, which ran out rapidly. When the bottom was reached, the twine was cut and the depth determined from the length of twine remaining in the ball on board. However, this method did not produce a bottom sample, so that one of Maury's co-workers, Midshipman Brooke, U.S.N., invented an automatic device for detaching the extra weight from the sounding lead when it hit bottom, with the result that a lighter line could be used to raise the lead. Lt. Maury issued a bathymetric chart of a part of the North Atlantic containing fewer than 200 soundings.

In 1882, the U.S. Commission of Fish and Fisheries launched the *Albatross*, the first ship ever built in this country for oceanographic research. Under the leadership of Agassiz, the ship took more deep-sea soundings than any other vessel up to that time.

An important innovation in sounding was introduced by Thomson (Lord Kelvin) in 1874 by using piano wire for sounding line instead of hemp or twine.

In the early twentieth century, a real boon to the progress of oceanographic research was the development of the echo sounder. It was a major breakthrough in increasing our knowledge of the relief of the ocean floor. In 1923, the U.S. Coast and Geodetic Survey used the first echo sounder on the *Guide*, and from 1925 to 1927 the *Meteor* of the German Atlantic expedition made an extensive investigation and obtained numerous echo soundings in the middle and southern part of the Atlantic Ocean, providing the scientific community with detailed profiles of the ocean floor in the explored area. Comparing these profiles with those available from the continents, it was found that irregularities in the ocean bottom in some areas are as great as those on land. Echo-sounding lines of the U.S. Navy, the Coast and Geodetic Survey, and others proved that in other oceans, irregularities are also common.

Shallow areas of the ocean floor are being explored by geologists by swimming with scuba gear, which consists of one or more cylinders of compressed air strapped to the back and a tube leading to the mouth for breathing.

Another means of increasing our knowledge was the development of the deep-sea camera. In 1893, Boutan took underwater pictures off the Mediterranean coast of France, but it was not until 1938 that Ewing and his group started to experiment with cameras which could be used on the deep-ocean floor. Since then, many pictures have been taken aiding the scientist in the examination of the sea floor and the study of the sediment types. A team of scientists of the U.S. Naval Research Laboratory has taken pictures of the ocean floor where the submarine *Thresher* disappeared about 260 miles east of Boston. The photographs proved, without doubt, the fateful end of the submarine.

To transmit data rapidly, the research vessel *Geronimo*, operating in the Equatorial Atlantic Ocean in September 1963, sent oceanographic information directly to the National Oceanographic Data Center, Washington, D. C. via the *Syncom* satellite.

The *Oceanographer* and the *Discoverer*, oceanographic survey ships of the U.S. Coast and Geodetic Survey, are equipped with automatic data processing systems to provide readings of shipboard instruments and perform calculations for ships' laboratories simultaneously. Similar systems reflecting the latest state of the art have also been installed on the latest U.S. Navy oceanographic research ships.

Fortunately for the advancement of marine geology, other avenues of exploration were brought into play. In 1930, Otis Barton constructed a diving sphere, called the "bathysphere", which was lowered into the ocean by a wire. A more recent vintage of the diving sphere is the bathyscaph *Trieste*, which descended to a depth of 5,966 fathoms in the Challenger Deep in the Pacific Ocean.

Submersibles to explore the oceans by close observations are being developed in ever-increasing numbers. One of the latest experiments was the descent of the manned submersible *Sealab II*, 57 feet long and 12 feet in diameter, to a depth of 210 feet off San Diego, California. A group of men lived and worked under pressure for several days, occasionally outside the submersible. Pioneering to habitate the ocean floor has begun.

Another attack on the secrets surrounding the deep-sea floor is the Mohole Project, which has the objective of piercing the earth's crust and reaching the earth's mantle. To accomplish this goal, technical know-how should provide the tools to drill through some 15,000 feet of rock in a location where the ocean is about three miles deep.

Preliminary investigations were conducted by the drilling barge *Cuss I*, which drilled a number of holes, the deepest being 601 feet into the ocean bottom in water about two miles deep. The tests showed that for drilling purposes, the platform should be kept at a horizontal distance from the drill hole not to exceed five percent of the depth. This requirement was satisfied by measuring by sonar the distances from the platform to sonar buoys moored on the ocean bottom, feeding these data into a computer which regulated the direction and pitch of the platform's propellers to keep its position within allowable limits.

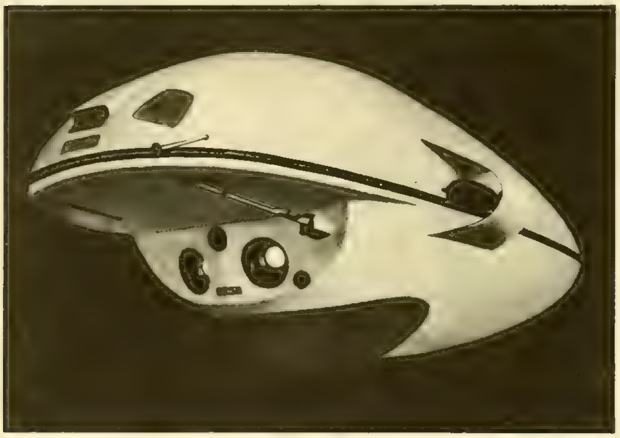


Figure 1. Submersible DEEPSTAR-4000, capable of diving to 4000 foot depths for periods up to 24 hours. Built by Westinghouse Electric Corporation.

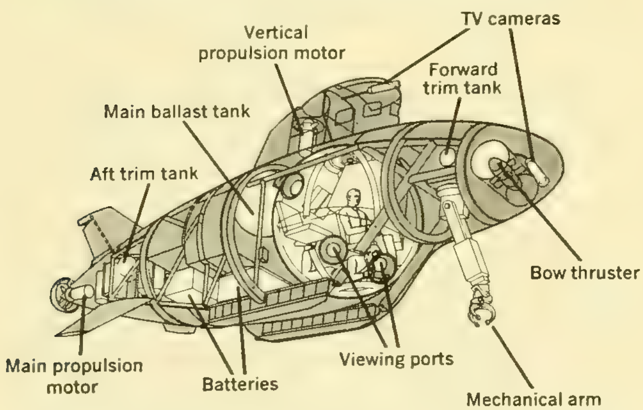


Figure 2. Cutaway drawing of submersible STAR III equipped with external mechanical arm that has interchangeable "hands".
Courtesy General Dynamics Corporation.

THE CONTINENTAL SHELF

The Continental Shelf is the shallow platform adjacent to the continents or some large islands, stretching out from the shore to a depth where a marked increase of slope to greater depths is noted. Its special feature, the shallowness, dampens the swell which rolls in from the deeper parts of the ocean, and makes the establishment of harbors along its edge feasible. Because most of the fish in the ocean is on the shelf, fishermen have been busily engaged in this area.

This platform has been better explored and surveyed than the remainder of the ocean floor because of the shelf's importance to the mariner who avoids the shoals and obstructions, and uses soundings and bottom samples as aids to navigation. However, investigation of the shelf is an endless task, because tectonic activity frequently changes the bottom contours considerably as was experienced when the U.S. Coast and Geodetic Survey took soundings in an area in Alaska affected by the earthquake occurring in 1963. Moreover, erosion and deposition cause alteration in the bottom relief.

In recent years the shelf has gained added importance for the large amount of minerals found on and beneath its floor. In 1946 the United States took possession of the mineral rights on the continental shelf adjacent to its shores; the 100-fathom curve was defined as its outer limit.

In many other parts of the world, however, the outer limit of the shelf, where a marked increase in slope is noted, lies at a different depth. According to F. P. Shepard, the average slope of the shelf in the world is 0° 7′, its average width is about 42 miles, and the average depth of the outer margin is 72 fathoms. It has been estimated that the shelves cover about 7.6 percent of the earth's surface.

Formerly, the shelf was believed to be always a gentle sloping plain, but this is only true in specific locations. Often the shelf is hilly with many irregularities. An example of shelves with a rough bottom is found adjacent to the land masses which had been covered by glaciers. Deep depressions, such as the fjords in Norway and British Columbia, or deep troughs, such as the Gulf of St. Lawrence and the Straits of Juan de Fuca, penetrate far into the land, and often extend across the shelves, but with shallower depths seawards. Those deep bays frequently have many basins containing muddy sediments combined with gravel and sand. Many banks, rising close to sea level, extend along the outer shelf and are covered by sand and gravel, among which are the Grand Banks of Newfoundland and Georges Bank off New England. They furnish the best fishing grounds in the world. Numerous hills, mostly mantled with rock or covered with boulders or gravel, are sometimes located on the inner shelf.

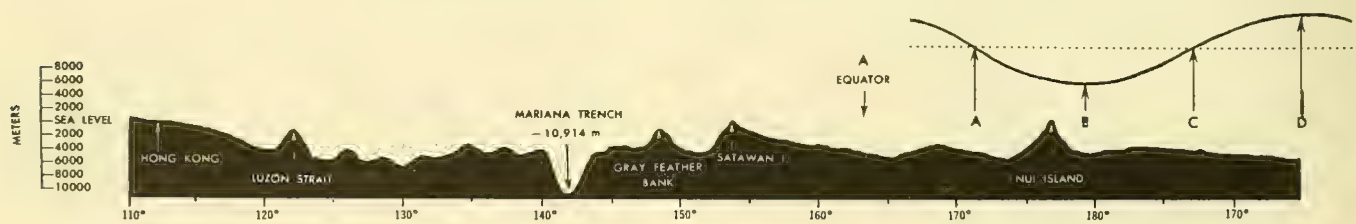
Shelves with a smoother bottom are those with elongated sand banks and depressions. This bottom relief is found on the shelf adjoining the shore of New Jersey and resembles the topography on land, the plains with their sand ridges. These shelves are mostly covered with sand or a combination of mud and sand. In areas subject to severe storms or strong tidal currents, such as the North Sea or off Nantucket, elongated banks are shifting constantly and have to be sounded frequently to warn the mariner of changing conditions. A narrow shelf which is subjected to strong currents is found on the east coast of Florida and off Cape Hatteras.

On the Pacific coast the shelves located off young mountain ranges are mostly narrow and deeper than the average or are lacking entirely. An interesting example of a missing shelf is on the west coast of South America where the land declines with a 5-degree slope from the crest of the Andes Mountains to the bottom of a trench offshore.

The shelves which are the widest and the shallowest are found off river deltas and in areas where coral growth is plentiful. On the northern coast of Siberia, where large rivers carry loads of sediments, the shelves are the widest in the world. Wide shelves can also be found at the mouth of the Amazon River, in the Yellow and Bering Seas, in the Gulf of Siam, in the Persian Gulf, and in the Bay of Bengal. Shelves where coral growth is extensive are found off Australia. The shelf off Queensland is about 170 miles wide and very shallow. The Great Barrier Reef of active coral growth lies on its outer part.

Interesting features in the bottom relief of the shelf are the submarine valleys. They are sometimes loaded with sediments but others which are scoured by tidal currents can be easily detected, as is the case of the valleys off the coast of Brittany.

A discontinuous submarine valley lying slightly below the surrounding area is located between Java, Sumatra, Malay Peninsula, and Borneo. Hurd Deep with a depth of 94 fathoms and the Ouessant



Trough with a depth of 105 fathoms in the English Channel are discontinuous submarine valleys presumably cut out by the strong tidal currents prevailing.

The most common sediments found on the shelf are sand, mud, and gravel-pebbles, cobbles and boulders. In addition, rare sediments are bombs, ash, or pumice of volcanic matter; seaweed and other marine plants; oysters mostly found in brackish water; and sponges which grow on the shelf in tropical areas.

The depth of the sediment layer varies in different locations. Off the east coast of the United States, the thickness of the sediments under the shelf is about 17,000 feet. According to G. E. Murray, the coastal plain and inner shelf at the Gulf Coast of the United States and Mexico have a great wedge of sedimentary strata which thickens to about 6.5 nautical miles under the present coast line.

The lowering of the sea level that happened during the ice periods when a greater part of the continents was covered with ice masses seems to be the main factor to explain many of the present conditions of the continental shelves. Formerly, it was believed that the shelves were cut by wave action at present sea level. However, most shelves join the coast without great cliffs and have outer limits that are too deep to be caused by wave action.

Proof of the former subsidence of the sea level may be found by the presence of coarse sand, presumably deposited when the sea level was lower, on the outer shelf and by the existence of river channels which have been found across the North Sea and the English Channel. According to R. A. Daly, the sea level was lowered about 246 feet during the periods of maximum ice advance.

As one-half of the ice on the continents has melted so far, an increase in the world temperature will eventually flood the coastal plains around the world. It has been observed that the sea level throughout the world is rising about 2½ inches in a hundred years because of the melting of glaciers.

THE CONTINENTAL SLOPE

The area between the continental shelf and the deep-ocean floor is marked by steep slopes. The steep upper part is called the continental slope; the lower part with gentler slope has been named the continental rise or deep-sea fan. According to Shepard the steepness of the slope from the shelf outer margin to a depth of 1,000 fathoms averages 4°17′. The greatest gradient has been found in the Bartlett Trough off Santiago, Cuba, with a slope of 45 degrees.

Although most continental slopes are continuous, others are interrupted by continental borderlands, areas with terraces or basins. These borderlands are at greater depths than the valleys of the continental shelves but at lesser depths than the deep-sea floor.

It is believed that the continental slopes were originally formed by fracturing of the earth's crust. The numerous earthquakes appearing on or near the continental slopes substantiate this belief. Renewal of fracturing and submarine landslides causing sediment-laden density currents to flow near the bottom prevent the accumulation of large sediment deposits on the slope.

After submarine cables were laid across the ocean, it was found that breaks appeared in them on the continental slopes. These breaks are believed to be caused by landslides, the sediment on the slope becoming liquified, or turbidity currents flowing along the bottom.

Submarine Canyons

The winding V-shaped depressions with many branches that extend down most continental slopes are similar to the canyons on land are called submarine canyons.

One hundred years ago the assumption was made that submarine canyons were old river valleys, that had subsided below the sea level. Since the canyons extend often to the bottom of the continental slope, this theory has been abolished. Several geologists believe that the principal cause of the existence of the canyons is fracturing of the sea floor. The winding nature of the canyons with its branches prompted other scientists to find a different explanation. The opinion has now been widely accepted that submarine canyons were cut by the turbidity currents flowing near the bottom.

Marginal Plateaus

Separated from the continental shelf by a section of the continental slope, the marginal plateaus are areas with a shelf-like appearance. Often the surface is irregular in profile such as those of the marginal plateaus off Recife and Rio de Janeiro, Brazil, and west of Angola. The Blake Plateau located off the east coast of the United States is rather flat with depths ranging between 400 and 600 fathoms. The bottom consists of rock or a similar substance which is difficult to core. There are many explanations for the existence of this plateau. One opinion suggests that due to slow subsidence during many centuries, the latter shelf sank to lower levels, but sediment deposits did not build up because of the powerful current of the Gulf Stream.

The Continental Rise

The sediment-covered plains bordering the continental slope are called the deep-sea fan or the continental rise. Its main features are the gentle slope and smooth bottom. In most areas the continental rise is bordered by the abyssal plains; in others, for example off California, the beginning of the abyssal hills marks the lower limit of the continental rise.

THE DEEP-OCEAN FLOOR

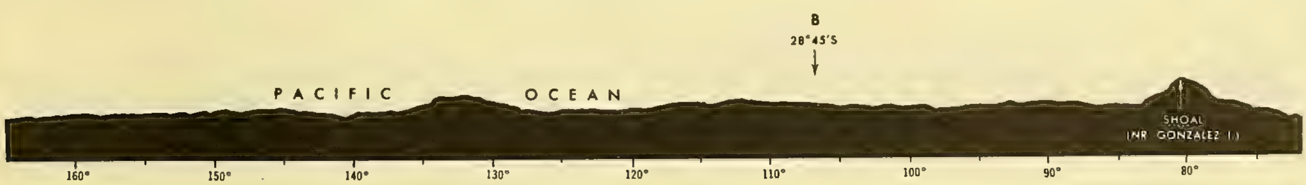
The deep-ocean floor, a part of the earth's surface, consists mostly of a sediment layer on top of the earth's crust superimposed on the earth's mantle. Inside the earth's mantle is the core.

The earth's mantle has a volume about 10 times greater than the combined volume of the core and the crust. Its inner surface, the core-mantle discontinuity, lies about halfway between the center and the surface of the earth, and its outer surface, the crust-mantle discontinuity, also called "Mohorovicic Discontinuity", lies about 6.5 nautical miles under the ocean basins and between 19 and 27 nautical miles under the continents.

The earth's crust is divided into a top layer of lighter rocks, mainly granite and granodiorite, called "sial" for silicon and aluminum, and a much thicker bottom layer of heavy rocks, both peridotite and basalt with peridotite of even greater density underneath, known as "sima" for silicon and magnesium. The layers forming the earth's crust are not evenly distributed over the earth's surface, but at the margins of the continents the sial layer becomes thinner to seaward or stops entirely. In the Pacific Ocean, the sima layer is exposed over vast regions; in the Atlantic and Indian Oceans, however, a thin stratum of sial covers the floor.

By topographic features the deep-ocean floor can be divided into two regions: the oceanic ridges and rises, and the abyssal floor subdivided into the abyssal plains and the abyssal hills.

A mid-oceanic ridge is an elongated elevation on the sea floor with steep irregular slopes in the middle of the oceans. Bottom-water temperatures taken in the east and west basins of the Atlantic by early oceanographic expeditions ascertained that the shallow area in the middle of the ocean, previously discovered by soundings, was a ridge, named Mid-Atlantic Ridge. It extends from Iceland to a southerly latitude of about 57 degrees. Points on the ridge are almost equidistant from the outer edges of the continental slopes on both sides of the Atlantic. The highest part of the ridge rises about 2,000 fathoms above the deep basins on the sides to about 1,000 fathoms below the sea level. The highest peaks in the ridge project above water, and form islands as the Azores, St. Paul Rocks, Ascension, and Tristan da Cunha. The ridge is intersected by an important break, called "Romanche Furrow", just northward of the equator.



The tectonic features of the Mid-Atlantic Ridge seem to be a part of a 40,000 mile long world-encircling belt which passes through the South Atlantic, around the Cape of Good Hope into the Indian Ocean, around Australia, up the Eastern Pacific, through the Arctic Basin and the Norwegian Sea. South of the Azores, this ridge is very complex with many mountains and valleys. In the South Atlantic, the ridge has a layer of sediments from about 300 to 650 feet thick, but in other zones sediments are sparse or entirely lacking.

Some elongated valleys extend down the slopes of the Atlantic basins with steep sides and flat floors that are 10 to 100 fathoms lower than the surrounding area. These depressions are from about three to five miles wide. Terraces like plateaus are found on both sides of the Mid-Atlantic Ridge.

Oceanic rises are elongated elevations with gentle smooth slopes having continuous layers of oceanic sediments. The lack of terrigenous sediments and the sharp change in slope at the base of such rises indicate that the turbidity currents have not affected these areas.

In 1947 an expedition of the Woods Hole Oceanographic Institution made the important discovery that large areas of the deep-ocean floor in the North Atlantic are flat, almost level plains with a bottom gradient of less than 1:1000. These plains are called abyssal plains and have been found on the deep-sea floor throughout the world mostly at the base of the continental rises.

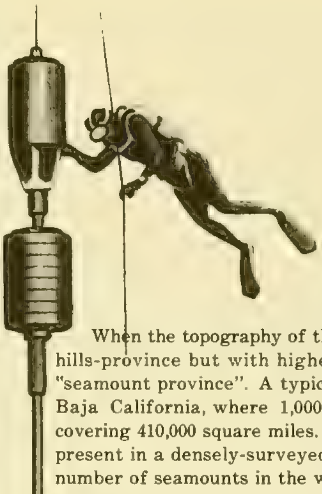
Current opinion suggests that these plains were produced by the deposition of coarse sand and shallow-water fossils carried by turbidity currents fanning out on the sea floor. These plains only exist in areas where the turbidity currents are not blocked by the bottom relief. Since turbidity currents cannot pass island arcs and trenches, the Pacific has fewer abyssal plains than the Atlantic. Abyssal plains have been observed also in marginal seas, such as the Western Mediterranean, the Gulf of Mexico, and the Caribbean.

Although many soundings have been made over the deep-sea floor with standard echo-sounding apparatus, large errors in these instruments made a study of the abyssal plains next to impossible. To make a more effective study of these plains feasible, a Precision Depth Recorder (P.D.R.) was developed in 1954. A more accurate curve of the bottom relief was obtained on an 18-inch-wide fathogram by recording depths in a 400-fathom range. For example, a depth of 3,745 fathoms will be shown when the fathogram records depths between 3,600 and 4,000 fathoms. Even at such great depths a slight variation can be easily observed on the fathogram. An accuracy of the P.D.R. and Precision Graphic Recorder of 1 fathom in 3,000 has been achieved.

An additional improvement in sounding occurred with the development of a high-resolution narrow-beam echo-sounder, electronically stabilized, so that the return echo represents the accurate depth under the ship. The reception of echoes from surrounding slopes has been greatly reduced.

Deep-sea channels at the seaward end of submarine canyons, cut out in the continental slope, often extend across the boundary in the abyssal plains. On the seaward side of most abyssal plains, adjoining areas are covered by abyssal hills. These hills vary in height between 50 and 200 fathoms and are between two and six miles wide. They are most numerous in the Pacific, where they cover most of the floor. If an area is almost completely covered by hills, it is called an abyssal-hills-province. Abyssal hills are found in abundance in basins separated from land areas by trenches, ridges, or rises. Two strips of abyssal hills run parallel to the Mid-Atlantic Ridge for nearly its entire length. The Western Atlantic Abyssal-Hills Province, southeast of Bermuda, is over 500 miles wide.

A seamount, mostly of volcanic nature, is an isolated circular or elliptical elevation on the ocean floor, rising at least 500 fathoms above its surroundings and having comparatively steep slopes. Soundings, taken with a Precision Depth Recorder over seamounts often show craters on their tops.



Resembling a huge underwater spear, this corer, used to extract samples of the sea bottom, is checked by a scuba diver.

When the topography of the ocean floor is similar to the abyssal-hills-province but with higher peaks, the area is designated as a "seamount province". A typical seamount province can be found in Baja California, where 1,000 seamounts are located in a region covering 410,000 square miles. Considering the number of seamounts present in a densely-surveyed area, it has been estimated that the number of seamounts in the whole Pacific Basin may reach roughly 10,000.

Seamounts having flat tops are called "guyots" or "tablemounts". To find an explanation for the flat-top appearance of the guyot, a topographic survey was made with echo sounders of five tablemounts, followed by dredging and coring for rocks and sediments. The results suggested that the tops of the guyots have once been at or near sea level, when erosion took place, but have sunk on account of subsiding of the ocean floor and the guyots, or the rising of the sea level.

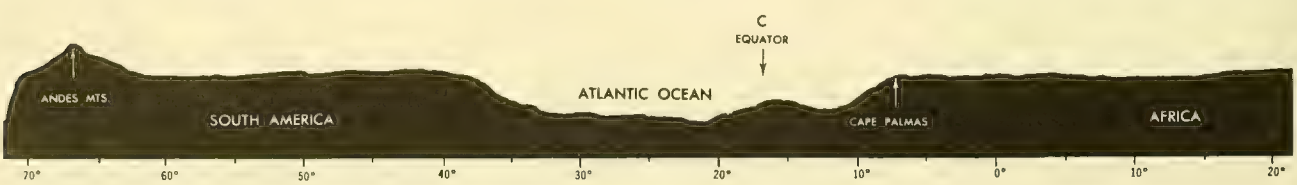
Although seamounts and guyots are present in the Atlantic, greater numbers are known to exist in the Pacific. Guyots, fewer in number than the seamounts, appear in three linear groups—the Emperor Seamount Chain, south of Kamchatka; the Marcus-Necker Ridge, west of Hawaii; and the region stretching out from the Marianas to the Marshall Islands. Furthermore, 10 guyots, close together, in the Gulf of Alaska, seem to be forming parallel lines. Other guyots exist as isolated mountains.

Trenches are long and narrow depressions with steep sides in the ocean floor. These trenches attain the greatest depths of the ocean, and are often adjacent to island chains with active volcanoes and earthquake activity, while others border the coast of Mexico, Central and South America.

For many years the Mindanao Trench off the Philippines was thought to be the deepest, but soundings have disproved this belief; greater depths have been found in the Tonga Trench of the South Pacific Ocean, the Mariana Trench and the Kuril Trench.

The Middle-America Trench, extending from the southern end of the Gulf of California almost to Panama, has been explored most thoroughly. It was found, after producing a contour map of the area, that the floor was flat in part for several miles across and was V-shaped elsewhere. A thick layer of sediment was found underneath the flat floor, while the V-shaped floor was free of sediment. Several submarine canyons cut the landward wall of the trench, and a group of basins with varied depths up to 3,700 fathoms and some hills, presumably submarine volcanoes, are spread out on the floor.

Many scientists indicated the connection between the trenches, and earthquakes and volcanoes. It is generally believed that the trenches are surface expressions (faulting of the crust) of large-scale processes acting deep within the earth. Along the trenches earthquakes are more frequent than in any other region in the world. Near the trenches tremors are of shallow origin, but farther landward the earthquakes originate at greater depths and their origins reach depths exceeding 200 miles when on a line 200 miles removed from the trench. This phenomenon has been observed for all trenches of the world. If the origins of the earthquakes farther landward do not increase in depths, the trenches are lacking.



Features prevalent beneath the sea.

Many trenches located in regions with earthquake activity are paralleled by linear groups of volcanoes. In the same manner, the Aleutians, the Kurils, and the Marianas are arc-shaped island chains located on the concave side of the arcuate trenches.

In the sea floor of the northeastern Pacific, H. W. Menard found four great parallel fractured zones with an average width of sixty miles between 1950 and 1953. The Mendocino Fracture Zone, the northernmost, extending westward from Cape Mendocino for a distance of more than 1,400 miles, stands out for its steep slope, called "sea scarp", which in places is over 10,000 feet high. Menard also discovered many smoothly sloping areas extending to the deep-sea floor around some island masses, which he called archipelagic aprons, presumably caused by lava flows originating from the islands.

Depressions, resembling canyons, have been found in the abyssal floor. They often have steep walls and flat floors. East of Newfoundland four of these depressions have been discovered, which are part of a continuous canyon extending for a length of 1,500 miles from Greenland to the Southeast Newfoundland Ridge. Other ocean canyons have been found in the equatorial Atlantic and in the Hikurangi Trench.

Oceanic islands, mostly limited in area and volcanic in character, rise from the ocean floor far from the continents. Large continental islands, such as Iceland, Greenland, and New Zealand are not in this category. Japan and the Aleutians are in a borderline class. Oceanic islands are either a part of a chain or are isolated. Older oceanic islands in the tropics are often surrounded by reefs, and the volcanic base may be covered by limestone. Oceanic islands, which appear to be isolated, are sometimes the highest peaks of oceanic ridges such as in the Atlantic, South Pacific and Indian Oceans.

Volcanic oceanic islands in the Pacific Ocean are often located in linear groups, such as the Hawaiian, Society and Marquesan Islands. These islands and their ridges are built of lava, and rise from submarine ridges, which may be caused by faulting. When volcanoes are spaced far apart as those in Tubuai (Austral) Islands Group, their lava output has not been large enough to build a ridge between them.

A ring-shaped reef lying at or near sea level enclosing a lagoon is called an atoll. Most of them rise from the ocean floor, but others are found on the continental shelves. Kwajalein in the Marshall Islands, the largest existing atoll, covers about 840 square miles. Most atolls on the ocean floor have probably been produced by coral growth on top of truncated volcanoes. Basalt, a volcanic rock, has been obtained from the slopes of some atolls in the Marshall Islands.

SEDIMENTS ON THE OCEAN FLOOR

Since the Challenger Expedition (1872-1876), cores of bottom samples have been extracted from the ocean floor. In the beginning cores were only one foot long, but after the development of the piston corer, cores up to 70 feet have been raised.

According to calculations made by P. Kuenen, the average thickness of the sediment layer in the ocean basins should be about two miles. However, observations made with sound waves indicate that the depth of the sediment layer in the Atlantic averages about 3,200 feet, and in the Pacific about 1,600 feet. E. L. Hamilton suggested that the lower parts of the sediment layer have become solidified into consolidated sediments. When sound waves are used to measure the sediment layer, they are reflected by the interface between the consolidated and the unconsolidated sediment layers. Sediment thickness has now been measured along 150,000 miles of track.

Sediment types can be arranged according to their origins—terrigenous, biogenous, halmyrogenous, and cosmogenous. Terrigenous sediments originate from the continents, and are the results either of mechanical and chemical breaking down of the rocks or of volcanic activity. These particles in minute size can be widely distributed by ocean currents over the whole ocean floor and can be found in red deep-sea clay. If these particles are of different sizes, such as gravel and stones, they originate from moraines and were transported by icebergs over the ocean areas. Terrigenous sediments

356-697 O - 69 - 2

may be deposited also by dust, which is carried far into the oceans by the wind. For example, the dust originating from the Sahara Desert has been found in the bottom sediments west of the Cape Verde Islands. Sediments of volcanic origin, the fine ash from subaerial eruptions, may be transported by the wind over wide areas. Biogenous sediments are of organic origin, and are divided into two types—the remains of animals and plants living on the ocean floor, or the remains of animal and plant plankton. Halmyrogenous sediments are new direct formations of minerals which are deposited when the water is over-saturated with soluble material. Deposits of iron and manganese oxides on the ocean floor belong in this category. Cosmogenous sediments originate from outer space and consist of small balls about 0.2 mm in diameter of magnetic iron or silica.

Since 1947 M. Ewing and his co-workers of the Lamont Geological Observatory have raised more than 3,000 cores from sediments in all oceans and adjacent seas during 44 oceanographic expeditions. The study of these cores taken from the bottom of the deep-sea floor revealed that deposits of the glacial periods were present in these sediments. Layers of gravel and stones, deposited by drifting icebergs during the periods of the ice ages, alternate with layers deposited during warmer stages of the climate. After investigating numerous cores, it was concluded that of the four ice periods the first one, called the Nebraskan Glacial period, started about 1,500,000 years ago, the beginning of the Pleistocene, the last epoch of geologic time. Using the radio-carbon method of dating, the last two major maxima of ice ages were fixed at about 60,000 and 18,000 years ago.

Sand has been found to cover large parts of the ocean floor. There was a general belief that these parts were great submergences and that these areas had been located close to the surface. After long cores had been obtained from these regions, it was observed that the sand layers are imbedded in layers of deep-sea deposits. From the map made by David Ericson, it was learned that these sandy areas stretch out from the coast in great sea fans and must have been transported by density currents.

MAGNETIC MEASUREMENTS

Because of the universal use of the magnetic compass for many centuries, systematic magnetic measurements at sea were already conducted during the voyage of Joao de Castro from 1538 to 1541.

After the introduction of iron and steel ships, accurate magnetic measurements at sea could no longer be taken except in non-magnetic ships, specially constructed for this purpose. An example of a non-magnetic vessel was the *Carnegie*, which conducted magnetic measurements from 1909 to 1929.

Recently the United States Navy has been carrying out "Project Magnet", covering almost the whole ocean area, using aircraft as well as ships. These measurements are essential to comprehend the whole magnetic field, which is to be divided into parts of internal and external origin. Complicated equipment is necessary to conduct these observations.

Much geological information can be obtained from a much simpler device towed behind a ship or aircraft, measuring the total magnetic force, which is influenced by the magnetic properties of the different types of rock lying beneath the ocean floor.

One of the first attempts to make a detailed magnetic map of an extensive ocean area was based on the survey conducted by the Scripps Institution of Oceanography, in conjunction with the U. S. Coast and Geodetic Survey, off the west coast of the United States. The results showed major structural trends of which there is little or no indication in the topography.

GRAVITY MEASUREMENTS

A body suspended above the earth's surface when free to move will travel towards the earth with an acceleration mainly dependent upon the attractive force of the earth and the centrifugal force caused by the earth's rotation. From the many observations with a pendulum taken on land to determine this acceleration, it was found that the gravitational pull varies in different locations on the earth's surface. One of the reasons causing this phenomenon is the unequal distribution of the earth's masses containing various materials.

To acquire a more complete picture of the location of these masses, gravity measurements at sea became a necessity. However, gravity observations taken with a pendulum required a stable platform. To satisfy this condition, the steamship *Fram* of the Nansen Polar Expedition (1893-1896) took observations when the ship was

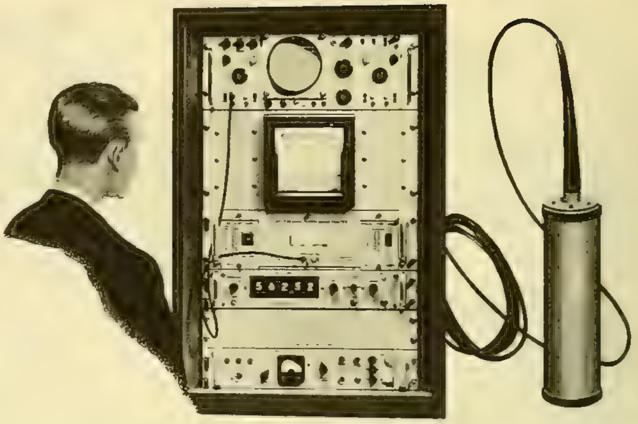


Figure 3. Sensor streamed behind the ship and magnetometer on board are used for taking magnetic measurements.

fast in the ice. Later on, F. A. Vening Meinesz perfected the pendulum apparatus and conducted many observations around the globe from submerged submarines. In recent years J. Lamar Worzel of Lamont Geological Observatory has made many investigations in this field.

During the International Geophysical Year, instrumentation had improved so much that gravity meters installed on surface ships of more than 1,000 tons displacement provided sufficiently accurate measurements under reasonably favorable sea conditions. However, a correction has to be applied to oceanic gravity measurements for depth of water to determine the relative heaviness of material underlying the ocean floor.

From the many gravity measurements in the ocean it was learned that the oceanic crust as a whole is probably balanced against the continents. However, local variations in the corrected gravity measurements are caused by density variations beneath the sea bed. Therefore, gravity surveys are useful for making reconnaissance to locate features which cannot be detected otherwise.

Deficient gravity (negative anomaly) has been found above the ocean trenches caused, presumably, by a thin crust underneath. Seismic shooting, however, indicated that the crust underneath the trenches is relatively thick. Further investigation will, no doubt, resolve these differences of opinion

A lack of balance and changes in level have been observed on the coasts of the Hudson Bay, which have been rising because the layer of ice diminishes throughout the years; the Atlantic Coast, however, has been sinking through the build-up of deltas and shelves deposited by sediments transported by the rivers.

SEISMIC MEASUREMENTS

Our knowledge of the structure and thickness of the sediment and rock layers of the deep-sea floor has been advanced considerably by seismic measurements. The methods are based upon the measurement of the time required for sound waves to travel from the place of origin, where the vibration is created, to a receiving station. If the path and travel time are known, the speed of travel of the sound waves can be computed. Because many experiments by laboratories have given estimates of the sound velocities in various rocks and unconsolidated sediments, a reasonable guess can be made about the type of texture in a layer traversed by the sound waves.

If the underocean faces between the bottom layers are good reflectors, and the speed of sound in these strata are known, a measurement of the time needed for sound waves to travel through each layer and back by reflection indicates the thickness of each layer.

Because conventional echo sounders operate on relatively-high sonic frequencies which cannot penetrate far into water-saturated sediments, a sounding apparatus, called "Sonoprobe", has been developed transmitting low-frequency sound waves. Penetration through a sediment layer up to 300 feet, returning an echo from the underlying rock floor, has been achieved by sound waves produced by this device. However, an expert has to control continually the proper output of sound into the water to detect minor reflections from the rock lying beneath the sediment.

Sonic waves caused by explosions are capable of penetrating to depths of thousands of feet and have been the major tools for subsurface exploration. Because the powerful sound is accompanied by many echoes, only large thicknesses of the bottom layers can be determined. Using this reflecting-wave method, W. Weibull found that the thickness of the sediment layer varied and attained two miles in some places of the deep-sea floor.

Besides the above reflecting-wave methods, systems to study the ocean floor by means of refraction waves have been used since 1937. In the beginning explosions were set off at the ocean bottom, and the produced waves were received from a group of seismographs lowered to the same level. This costly and time-consuming method was abolished and now a method is in use setting off explosions from one moving ship at regular intervals and receiving the sound waves on seismographs placed on a stationary ship. By recording the travel times of the sound waves caused by these explosions, the number and thickness of the layers of sediment and rock can be estimated, as well as the speed of sound in each layer—See Fig. 4.

About two years ago the Coast Guard cutter *Woodrush* had been aiding the University of Wisconsin in explosion seismology experiments in the Great Lakes to determine the thickness and topography of the earth's crust to points some twenty miles deep or to the so-called "Moho" discontinuity. Many shots using explosives weighing up to 20,000 pounds were expended.

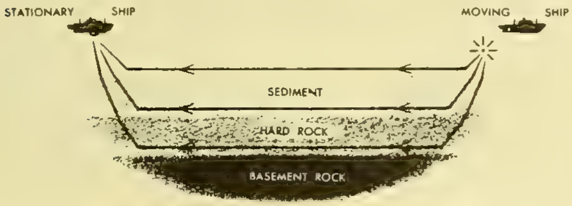


Figure 4

HEAT FLOW MEASUREMENTS

Heat flow from the interior of the earth was first considered to be the heat of a cooling molten core. It was assumed that the earth was not more than 80 million years old, or the inner part of the earth would have lost all its heat. However, with the discovery of radioactive substances in crustal rocks and their heat producing qualities, it was found that the interior could maintain a high temperature for billions of years.

Heat-flow measurements through the sea floor have been made in later years with a cylindrical probe about 15 feet long and about one inch in diameter. On top of the probe is attached the recorder placed in a pressure-tight case.

To save time, an instrument has been developed in which the temperature gradient is measured by an attachment to a corer. By measuring the temperature difference between the top and bottom of the core and determining in the laboratory the conductivity of the sediments in the core, the heat flow can be ascertained for a unit area in a unit of time. Contrary to the former belief, that heat flow was less from the ocean floor than from the continent, it appeared to be actually slightly greater. The heat flow in the Pacific floor was determined to average about 40 calories per square centimeter per year, which equals about the heat flow from the continents.

CONCLUSION

Although the investigation and analysis of the ocean deep has solved many mysteries, we have to make many assumptions and guesses regarding the conditions on and below the ocean floor. Greater exploration is needed to give us a better understanding of the evolution of the earth and a greater knowledge of the ocean bottom, so that we may exploit its resources.

With the growing awareness of the importance of oceanographic research, Geological Oceanography, using improved instrumentation and employing a greater number of scientists, will progress rapidly to meet the demands of mankind.

OCEAN WAVES

By Willard J. Pierson, Jr.

Their variety and complexity is bewildering and vexing to designers of ships, radar, and sonar—but their energy spectra are being unraveled by tricky analyses of new records from the sea

Prehistoric man in his childlike simplicity probably threw stones into placid pools of water and watched with keen and uncomplicated pleasure as ridges and depressions on the surface radiated from the satisfying splash in ever-widening circles. More than a century ago hydrodynamicists, perhaps with a more sophisticated sense of pleasure, developed the mathematics for analyzing ideal periodic and aperiodic waves in a fluid bounded by a free surface. Today those who study real waves on water—for pleasure or for profit—must combine the mathematical methods of time-series analysis with those for analyzing nonlinear oscillations, and both of these with elaborate statistical methods, to describe and predict the wave-torn configuration of the sea surface.

These mathematical procedures are formidable. But they have not deterred studies of ocean waves. On the contrary, the number of investigators has been growing rapidly. And it increasingly includes not only oceanographers, but designers and operators of ships, hydrofoil craft, submarines, harbor and other coastal installations, offshore drilling platforms, and similar structures—and still others whose prime concerns are radar return from the sea surface, or the ambient noise background against which underwater sonar systems must operate. A few of the practical reasons for studying ocean waves are suggested in Fig. 1.

Investigators of ocean waves are not all motivated by either practical reasons or mathematics. To some the challenge lies in the art of making difficult measurements. And precision instruments, now being used instead of scattered visual observations to record waves at sea, also have played an increasingly prominent role in recent progress.

What accounts for the need for such an impressive arsenal of observational and analytical tools? Two things—the internal complexity and diversity of waves, and the many ways they can combine to create that confused, chaotic, worldwide geometric entity called the surface of the sea.

The surface of the sea is a mess

At any instant, this surface covering three-quarters of the earth exhibits an amazingly complex and thoroughly random shape. Its geometric irregularities span horizontal distances ranging from centimeters or less to thousands of kilometers, a range of 9 orders of magnitude. Irregularities in the vertical direction are much less, however; they span several tens of meters at most.

The complex pattern created by intersecting waves is not static. It changes endlessly through time, and it never repeats itself exactly in totality. But individual elements of the total pattern—individual kinds and groups of waves—do repeat themselves; they are periodic, over a tremendous range in time. The periods of the smallest "capillary" ripples, for instance, so important in radar work at sea, are less than a second, while a single cyclic oscillation in worldwide sea level sometimes takes geologic ages to complete. Few periods of ordinary wave motions on water, however, exceed several hours and most are much less.

Small wonder, in the face of this chaos extending over such long spans of space and time, that many scientists and engineers came to feel prior to the last war that real ocean waves—unlike the ideal waves of classical hydrodynamic theory—lay beyond the bounds of possible understanding. Yet in the last 15 years, under the stimulus initially provided by the need for knowledge of sea and surf conditions during World War II, we have partly broken through the "chaos" barrier to a reasonably clear understanding of the behavior of several kinds of waves. We even can—and routinely do—forecast the heights, periods, distribution, and travel paths of the dominant kind of ocean waves, those generated by turbulent fluctuations in the wind. Such forecasts are even accurate, sometimes!

Does this mean we truly understand ocean waves? Of course not, no more than the weather forecaster truly understands the dynamics of the atmosphere. To understand waves fully we must know how they begin, how they travel, how they interact with other waves, with the air above, and with the water and bottom below. And we must know how they die. We know none of these to our satisfaction, but we do know enough to draw clear distinctions among various kinds of waves.

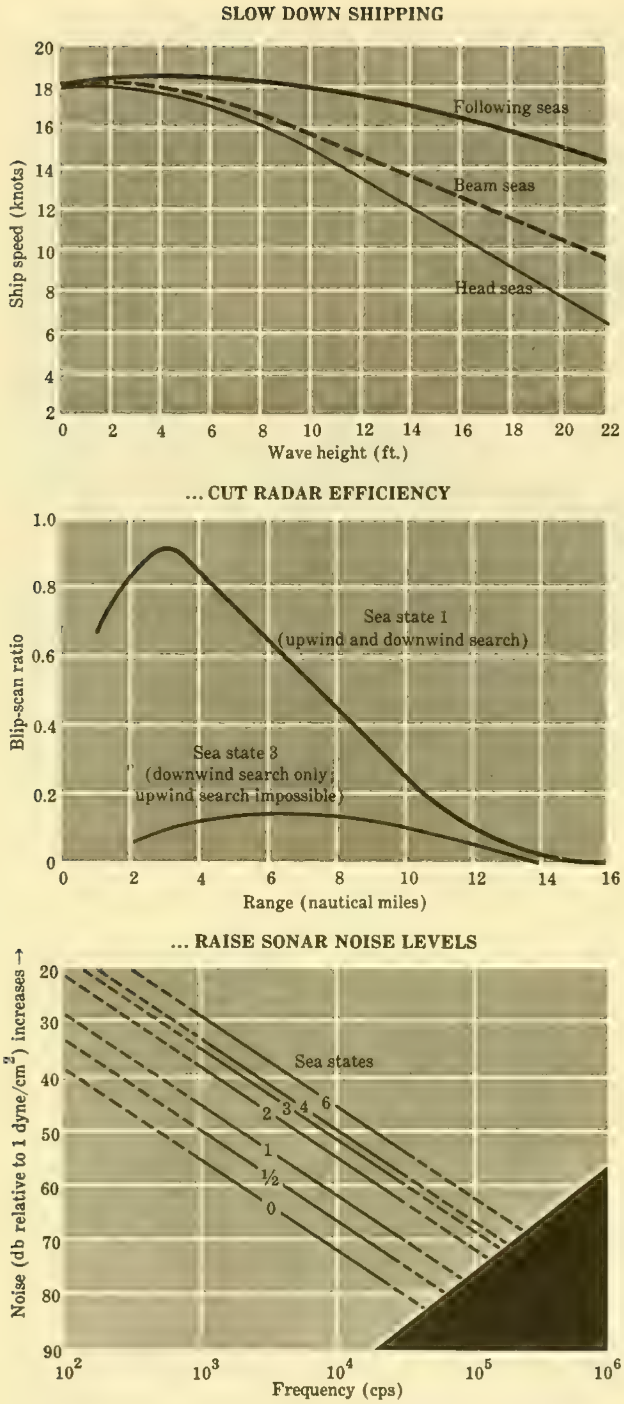


Fig. 1. Lowered ship speeds reflect not only added drag imposed by higher waves but also voluntary reductions made to ease strain on vessel, cargo, or passengers. Radar efficiency, expressed by blip-scan ratio, and deep-water sonar noise background both vary with sea state (defined in the margin).

The family tree of ocean waves

Waves *on* water differ fundamentally from waves *in* water. Internal waves of various kinds develop below the surface at the stable interface between water layers of differing densities. They are difficult to study because they can only be detected by the way temperature or salinity of the water changes across the interface (Fig. 2) and by the slicks of smooth appearing water that they create at the sea surface, as they travel along at depth. Although their periods are long in relation to their length—internal waves, in other words, move very slowly compared to other waves—their height can easily reach 50 or 60 ft. They are a quite interesting and important class of waves; one line of informed speculation concerning the loss of the US nuclear submarine *Thresher* invoked their influence, for example. But waves *on* water are our prime concern here.

In order of decreasing wavelength, waves on water include the tides, seiches and storm surges, tsunamis, wind waves and swell, and the diminutive capillary waves. Each of these could justifiably claim our attention.

The tides, for instance, with their typical heights of 2-10 ft (up to 50 ft in extreme cases, as at the Bay of Fundy) and their clocklike regularity at most places, may someday be as important in power generation as they long have been in determining ship-arrival and departure times.

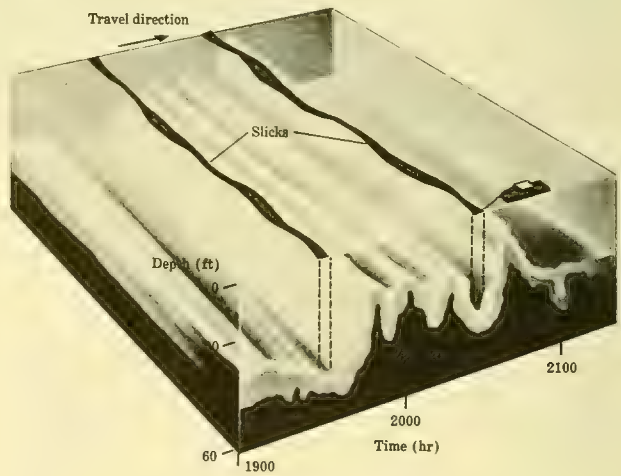


Fig. 2. Internal waves with varying heights and periods, generally moving at speeds less than 1 knot, form between subsurface water layers whose densities differ because of differences in temperature and/or salinity. They are usually detected by oscillations in the depth of isotherms, as shown, as one water mass replaces another along an undulating boundary; but their presence at depth frequently can be inferred by "slicks" of smooth water visible at the surface, located above the trailing slope of larger internal waves.

Sea State Code	Wave Height (ft)
0	0
1	0-1/3
2	1/3 - 2/3
3	1 2/3 - 4
4	4-8
5	8-13
6	13-20
7	20-30
8	30-45
9	>45

9 orders of magnitude.

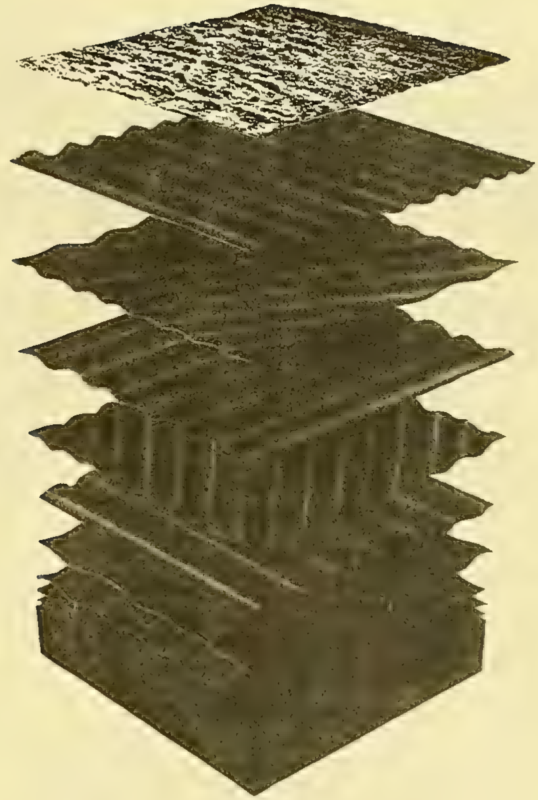


Fig. 3. The infinitely complex, real sea surface is closely approximated in wave studies by a model surface which, as shown, is made up of a large number of randomly superimposed, simple harmonic, progressive sine waves—each having its own amplitude, direction of travel, and frequency.

Seiches and storm surges—generated either by hurricanes, tropical cyclones, or, in the right circumstances, by frontal squall lines—are also of more than passing practical interest. The heights of these sporadically occurring wind-driven waves can easily reach 10 ft or more in harbors; they differ from each other primarily in that the seiche is a storm surge which, because it occurs in a landlocked lake or partially inclosed harbor, enters into a standing-wave oscillation that persists after the generating wind dies down. The effects of both on coastal and harbor installations on occasion compare with those of the less frequent but more spectacular tsunamis, which are generated by some of the seismic disturbances that occur in ocean areas.

Tsunamis are the most awesome waves on the surface of the sea. The modest 1-2 ft heights that characterize them in the open sea rapidly piles up to nearly vertical walls of onrushing water—as much as 100 ft high—along coast lines and beaches of appropriate configuration near their area of generation, in the Kamchatka Peninsula, the Aleutian Islands, the Kuriles and the South Pacific.

In the family of ocean waves the smallest are the capillary waves. They have sharp troughs that point downward into the water, in contrast to ordinary wind-driven waves which have sharp crests that point up into the air. This difference in form is a consequence of the capillary's very short wavelengths; below wavelengths of about 2.44 cm, waves on water show puzzling nonlinear properties, which are somehow related to the large local curvature of the water surface. Under these conditions the effect of water's surface tension in controlling the wave's form and height becomes more important than the factors of gravity and water depth that are the controlling parameters for other waves raised on the sea by winds.

It's these other wind waves whose wavelengths range up to thousands of feet, however, that make ships heave, pitch, roll, surge, sway and yaw that limit ship speed; and that routinely travel as "swell" thousands of miles out of the storm areas in which they are born, across the oceans, to break with mostly gentle but unending and deadly erosional efficiency on the shores. Let's concentrate on them.

Birth and development of wind waves

If wind waves were perfectly periodic, simple harmonic progressive waves with infinitely long crests—as shown in the lower part of Fig. 3—or if this standard assumption of classical wave theory were even approximately true, they would have been understood for more than a century. But wind effects on the sea surface are not this simple, because turbulance and viscosity in both sea and air introduce complex nonlinear effects.

Wind turbulance creates a moving pattern of minute fluctuations in air pressure over the water; these can generate the initial tiny ripples that eventually become fully developed waves. Viscosity and turbulence also create a distribution of pressure differences in the air that is out of phase with the waves, and these pressure differences feed in the energy needed to grow bigger waves.

Measuring the amount of energy fed into waves by the wind is a severe and unsolved instrumentation problem. However, we can attain one important practical end—forecasting sea states—by treating the character of the sea surface statistically, after the energy being fed into the waves equals the energy dissipated by breaking at the wave crests, so the waves are no longer growing. This point of dynamic equilibrium—where the sea is said to be "fully developed"—limits the height wind waves can achieve, even under forcing conditions of strong winds in severe storm areas. Classical hydrodynamic theory, although it cannot really explain this limiting process, nevertheless is useful in appreciating what seems to be going on physically.

Wind waves limited by blowing their tops

The ideally organized motion of water particles beneath a regular train of waves, moving in water deep enough so bottom effects don't enter the picture, is shown in Fig. 4. Perhaps surprisingly, the water particles do not move *en masse* with the waves above them which carry the wind-supplied energy from one parcel of the ocean to another. It's fortunate that they don't. If you recall standing inshore of the breakers along a beach, where, after breaking, the water particles do move *en masse*, you'll realize instantly that no ship could sail if a 10-ft wave on the open sea, for example, represented a wall of water that high moving along with the waves.

Instead of traveling with the waves, the particles move in nearly stationary circular orbits which lie in the vertical plane. Orbits of particles at the surface have a diameter equal to the height of the wave from crest to trough. Below the surface, orbits grow smaller with increasing depth, by a factor of about 1/2 for a depth equal to 1/9th the wavelength, 1/4 for a depth equal to 2/9ths the wavelength, and so on. Water particle motion effectively is nil for all practical purposes, such as submarine operation, at a depth of about 1/2 wavelength.

All water particles in the long-crested deep-water waves of Fig. 4, whatever their depth and regardless of their orbital diameter, complete one orbit in the same period taken by the wave itself to advance one wavelength. But the particles don't all reach the same points in their orbits—the top for instance—at the same instant. Rather, like the valves in an engine opening and closing at just the right instant in the combustion cycle, the water particles phase in and out of the appropriate positions in their respective orbits so as to fill the wave form as it progresses laterally.

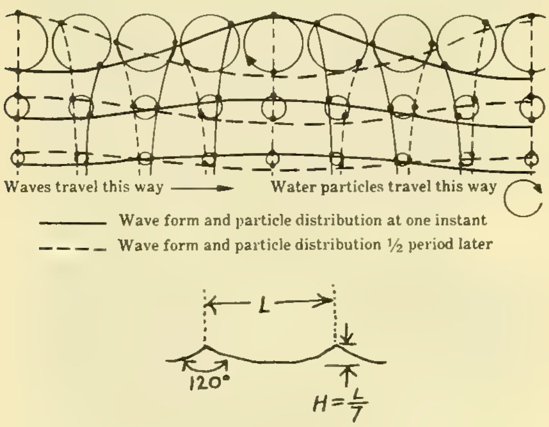


Fig. 4. Instead of traveling with the waves, the water particles themselves move in nearly stationary orbits whose diameters decrease exponentially with depth beneath the surface. Each particle cycles into the appropriate position in its orbit so as to sustain the wave form as it progresses, carrying energy across the sea.

The energy spectrum of the sea

The ideal wave train pictured in Fig. 4 has infinitely long crests that are somewhat more narrow, and equally long troughs that are a bit wider than those of a sinusoidal wave; its form more nearly approaches the curve called a trochoid. And as wind-generated waves grow steeper their form departs even more from the sinusoidal ideal.

No one has ever seen—and no one ever will see—a sea that behaves in the classical way just outlined, not even for a finite time over a finite area of the ocean. Yet for many years attempts were made to force real waves to fit this restrictive oversimplified theoretical model, at least locally.

But actual waves on the surface of the sea are irregular, aperiodic, and short crested. The realization that the classical theoretical structure was untenable came gradually. Some features of real waves were discovered, written up in classified reports, and so successfully buried they had to be rediscovered by others several times before the knowledge became available to those studying ocean waves.

The essential feature of wind waves, and of their swell progeny which usually have distinctive frequencies (see Fig. 5), is that in practice they must be studied in terms of probabilistic models and measured and analyzed by statistical techniques. To do this nowa-days, we use an extremely useful but still not fully accurate model of the waves that describes their fluctuation in height at any point in terms of a statstically invariant Gaussian (i.e., normally distributed) function of time. Such functions were studied originally in communications theory to evaluate noise variation as a function of time.

When the function that describes the fluctuating height of waves (the "noise") at a fixed point is generalized to cover many points over the sea surface, we obtain a function—a model of the sea surface—that closely approximates reality. This model sea surface is a characteristically short-crested, Gaussian surface that *moves* in a convincing way through time.

SEA AND SWELL DIFFER CLEARLY...SOMETIMES

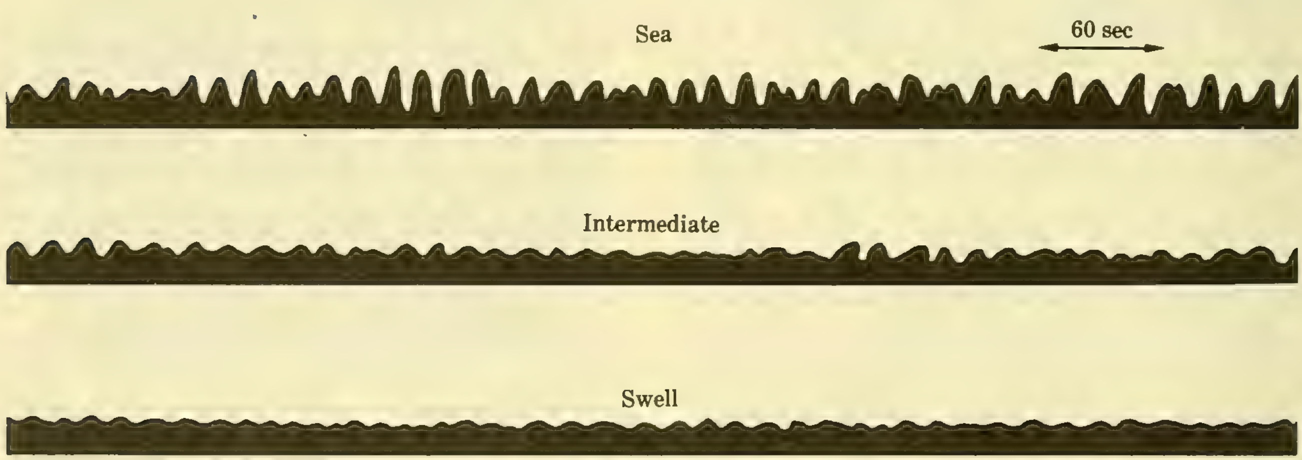


Fig. 5. Waves still in the area of the winds that generated them—"sea"—are typically but not always higher, more sharply peaked, more disorderly, and shorter-period than waves—"swell"—that have traveled out of their generating area.

Such a surface can be easily understood from Fig. 3. It's made up of a large number of randomly superimposed, simple harmonic, progressive sine waves of different amplitudes, each traveling in a different direction and each having a different frequency.

Here's another way to think about this all-important concept, let's step back to the physical picture of waves for a moment. As the wind blows and as the waves grow, turbulent variations and varying amounts of internal eddy viscosity—as well as the interaction of one wave with another—set an individual limit to the growth of each individual component wave train in the developing sea. They do this by initiating the energy-dissipating, breaking, or "white-cap" process, whenever a momentarily high crest reaches an unstable configuration. (In the classical theory, this occurs when the height-to-length ratio of waves in a train reaches the critical value of 1/7th at which point in a wave's development its crest is sharply peaked, as shown in the margin. But on the real ocean this limiting value is not known.) Thus, the total energy present in all of the waves on a developing sea progressively distributes itself over a range of frequencies, each frequency characterizing a particular wave train. As the waves continue to grow and as new trains continually develop, this range extends more and more to shorter frequency—or longer period—waves. In brief, a *spectrum* of ocean waves is formed (Fig. 6), in which—for any given wind velocity and for fully developed waves—the energy distribution over the band of wave frequencies from 0.4×10^{-1} to 3 cps is distinctive.

Spectral filters and wave forecasts

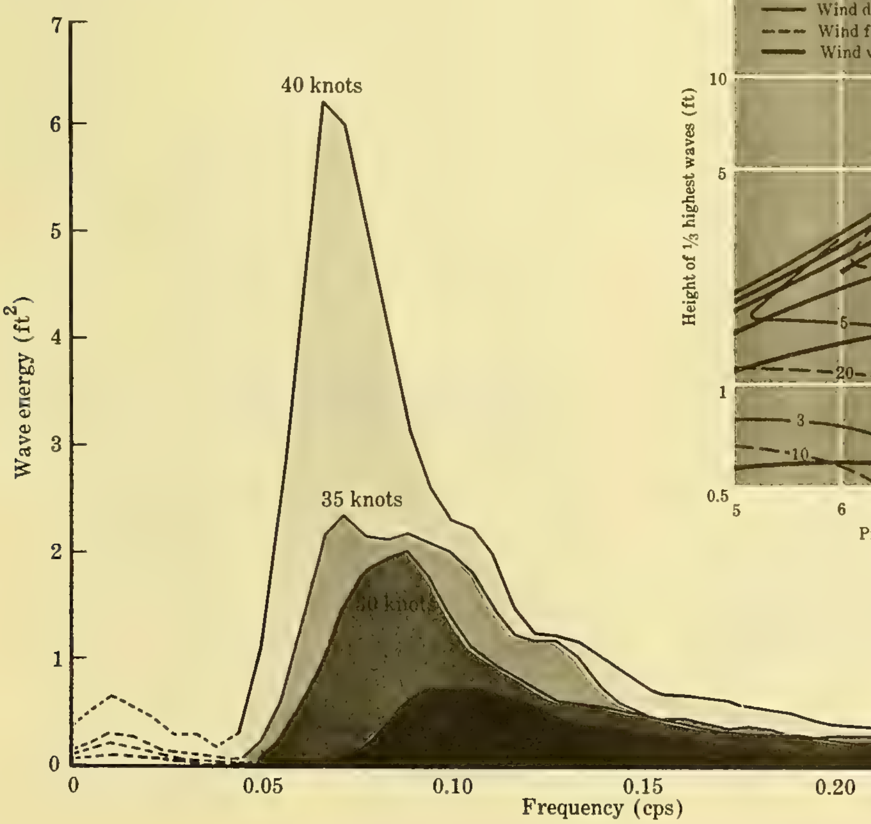
This spectrum enables us to resolve the total variance of the mean-square sea-surface elevation (the "energy," or total area under spectral curves such as in Fig. 6) into contributions traveling in different directions and having different frequencies. Or put another way, if the waves on the sea surface are put through a filter—either in recording or in subsequent analysis—so that only those waves traveling in a small range of directions and occupying a small band of frequencies are left on the model "sea surface," we can specify this fraction or component of the variance.

The problem of finding an adequate way to estimate the spectrum of a statistically invariant Gaussian process is not simple. And it arises in many fields besides ocean waves such as turbulence, seismic analysis, electronics, and weather prediction. Happily, it was solved in 1949, by John Tukey of Princeton.

Once the problem was solved, we were able to develop ways to forecast swell quantitatively; we were able to analyze rather fragmentary wave data and discover the many different spectra that occur in nature; and we could predict with some sophistication the effects of wave refraction in shallow water.

The idea of spectral filtering just mentioned comes up in still another important way, in connection with operational wave-and-swell forecasting. About 10 years ago, for example, Gerhard Neumann of New York University found it was possible to derive a theoretical expression for the characteristic frequency spectrum of wind waves from thousands of visual wave observations made with a stop watch. This theoretical spectral equation gave no information about different directions of wave travel. It depended on only two variables: (1) the wind velocity; and (2) either the distance over water that the wind blew with constant velocity and direction, also called the "fetch," or the duration of the wind. And it provided a moderately accurate way to forecast the spectrum of *waves* in deep water as a function of the past history of the weather over the ocean. Fig. 7 summarizes some of the salient features of this prediction system. It forecasts—among other things—the average of the heights of the one-third-highest waves that will be running, and an average wave period.

Fig. 6. When wind-generated ocean waves reach maximum height their energy, which is proportional to their mean-square height, is distributed over a narrow frequency band that varies with the wind velocity, as shown. Such distinctive energy spectra underlie wave-forecasting systems.



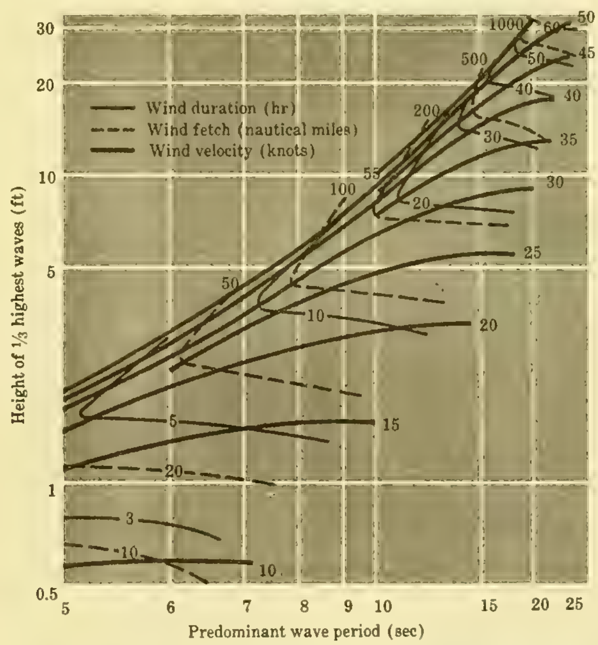


Fig. 7. Salient features of the wave forecasting system in current use by the U. S. Navy are shown on this diagram. Forecast is a function of the weather over the ocean and depends on only two variables—wind velocity, and either the fetch or the duration of the wind. Intersection of either of the latter curves with the appropriate wind velocity curve yields forecast information shown.

Swell, on the other hand could only be forecast in this scheme by means of mathematical filters. These slowly tuned through the spectrum of the wind-born sea as a function of the dimensions of the storm source, the strength of the winds in the source, and the distance from the source of the point for which the swell forecast was to be made.

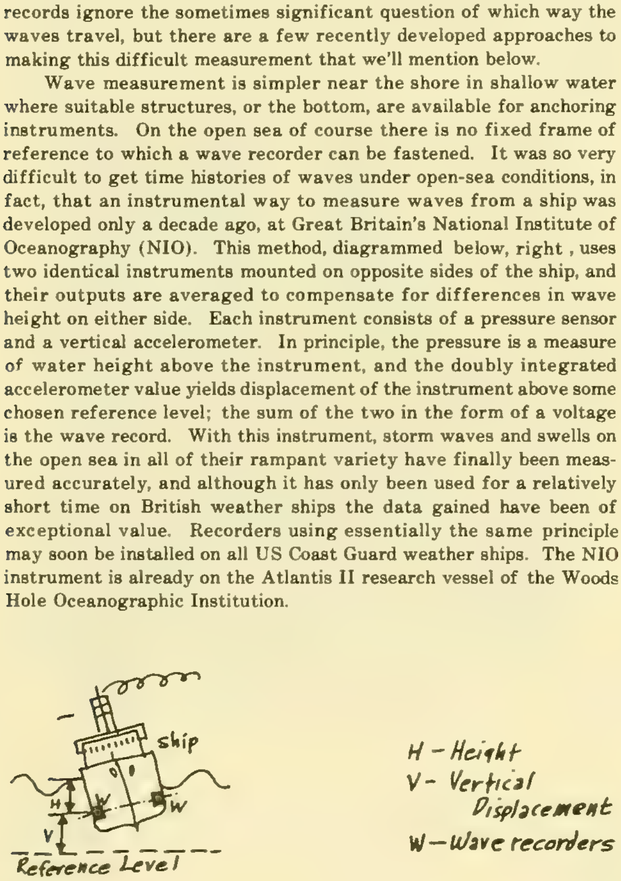
These approaches to forecasting waves and swell were built into an operational forecasting system—by Neumann, R. W. James, and me—that is in current use by the US Navy and most other maritime agencies.

In the effort to develop better ways to predict waves and swell many different spectral forms and other procedures have been proposed. Large areas of disagreement developed among oceanographers concerning the precise form of the wave spectrum of a "fully developed" sea for a particular wind speed. But more recent data appear to be resolving these disagreements. Improved calibration of wave-recording instruments—of all things—has brought the formerly widely divergent results of different investigators into closer agreement. And formerly overlooked considerations of how the wind speed varies with height seem to account for most remaining discrepancies. The forecasting rules developed by Neumann, James, and myself will have to be corrected in the light of recent results. But they were surprisingly close to reality in most respects, especially considering how "primitive" the hand-held stop-watch data were, upon which they were based.

Lots of new ways to measure waves

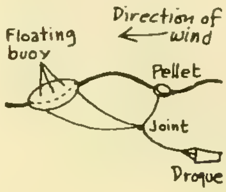
Study of wave spectra for all purposes will be helped a good deal by more measurements, of higher accuracy, of real waves in the ocean. In general, waves are recorded on graphs like those of Fig. 5, which show the varying height of the water surface at a fixed point as a function of time; needed analyses are performed later. Such records ignore the sometimes significant question of which way the waves travel, but there are a few recently developed approaches to making this difficult measurement that we'll mention below.

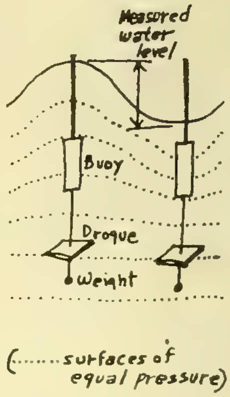
Wave measurement is simpler near the shore in shallow water where suitable structures, or the bottom, are available for anchoring instruments. On the open sea of course there is no fixed frame of reference to which a wave recorder can be fastened. It was so very difficult to get time histories of waves under open-sea conditions, in fact, that an instrumental way to measure waves from a ship was developed only a decade ago, at Great Britain's National Institute of Oceanography (NIO). This method, diagrammed below, right , uses two identical instruments mounted on opposite sides of the ship, and their outputs are averaged to compensate for differences in wave height on either side. Each instrument consists of a pressure sensor and a vertical accelerometer. In principle, the pressure is a measure of water height above the instrument, and the doubly integrated accelerometer value yields displacement of the instrument above some chosen reference level; the sum of the two in the form of a voltage is the wave record. With this instrument, storm waves and swells on the open sea in all of their rampant variety have finally been measured accurately, and although it has only been used for a relatively short time on British weather ships the data gained have been of exceptional value. Recorders using essentially the same principle may soon be installed on all US Coast Guard weather ships. The NIO instrument is already on the Atlantis II research vessel of the Woods Hole Oceanographic Institution.



Ship-borne Wave Recorder

Other methods for measuring waves at sea do not use a ship's hull as an anchor and reference point—instead they use as a reference the quiet water that lies below the depths agitated by waves. One such method suspends from a buoy, a large flat plate (or "drogue") that is designed to respond to the passage of the waves with as little lift as possible. To the buoy is attached a measuring pole (see marginal sketch) against which wave fluctuations are recorded either mechanically or electrically. Such methods are generally unsatisfactory and quite costly.





Pole and Drogue type Wave Recorder

The problem of high cost in obtaining large numbers of nondirectional wave records may be eased by a floating-buoy device—dubbed the "Splashnik"—recently developed at the David Taylor Model Basin in Washington, D. C. Said to cost about $150, the device converts the output of a vertical accelerometer mounted on a raft, with a transmitter, to an FM signal whose frequency varies with acceleration; it transmits the signal to a nearby ship where the familiar double integration to get wave height is performed.

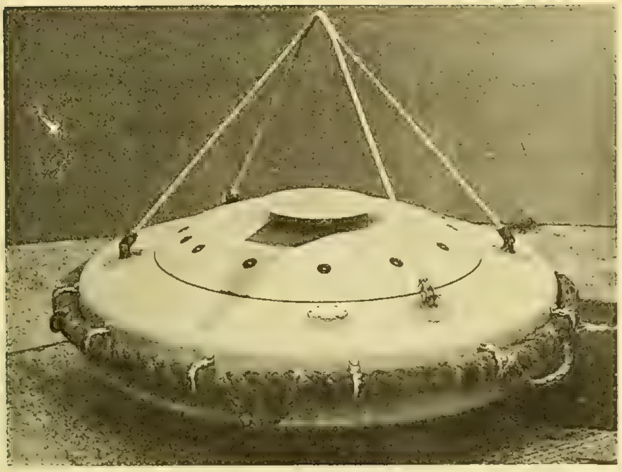
Another new and promising way to measure waves on the deep sea is to use a highly stable platform, like the Scripps Institution of Oceanography's new "ship-on-end"—dubbed FLIP. Any wave recording device would work well on FLIP. In recent trials in waves 40 ft high, FLIP moved a remarkably small 6 in. ! Anyone who's spent any time at sea will appreciate what this means.

Nondirectional devices on stable platforms like this could be used in suitably spaced arrays to yield useful data about wave directions, if such platforms cost less. Using wave recorders in this way would be similar in principle to using antenna arrays for direction-finding in radio astronomy.

Waves on the open sea with lengths shorter than one thousand feet or so also can be measured by stereophotogrammetry. With a long ship and cameras pointed horizontally at each end, the profiles of several waves can be measured. Aircraft can also obtain stereowave photographs, and these can be used—though at the cost of much time in stereoanalysis and computation—to get the *directional* wave spectrum.

A more direct approach to getting directional information on waves in a wind sea, developed at the British NIO, uses a single floating buoy (Fig. 8) that's kept in constant alignment with the wind by means of an attached pellet and drogue, as sketched in the margin. Inside the buoy are an accelerometer and two gyroscopes and associated electronics. The assemblage gives data on pitch, roll, and heave (or vertical displacement) of the buoy, from which some features of the angular (azimuthal) distribution of energy in each frequency band of the wave spectrum can be derived.

Regardless of the direction taken by waves and swell on the open sea, their ultimate fate is certain. Sooner or later either they die at sea, as the poorly understood processes which dissipate their energy operate to destroy them, or they reach one of the world's coastlines. There, frequently, they expend their energy in one last sometimes destructive burst before they die.



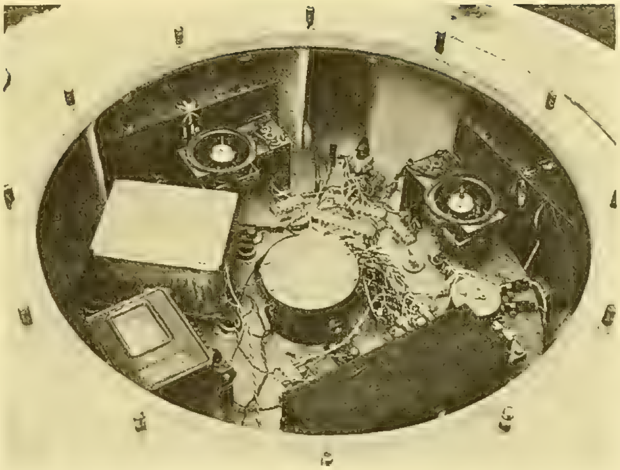


Fig. 8. British National Institute of Oceanography developed this floating buoy that carries an accelerometer and two gyroscopes. Instruments give data on pitch, roll, and vertical displacement of buoy, from which directional wave spectra can be derived.

To all things there comes a time

As wind waves and swell finally approach a coast and the depth of water decreases, the water particles in orbital motion far beneath the waves begin to "feel bottom." Orbits closer to the bottom of the wave structure gradually flatten into ellipses, and the forward-backward motion of particles becomes greater than the wave's height at the surface. As these changes occur along a gently shoaling bottom, both the group and the phase velocity of the waves decrease. Waves in shallower water are more retarded than the waves just behind them that are still in somewhat deeper water; as a consequence wavelengths also decrease, but wave periods remain the same. Differences in depth along the coast account for differences in the amount of retardation experienced by a wave along its length. This in turn causes the waves to refract as they approach the shore—waves of lower frequency, such as swell, refracting more than waves of higher frequency—as shown in Fig. 9.

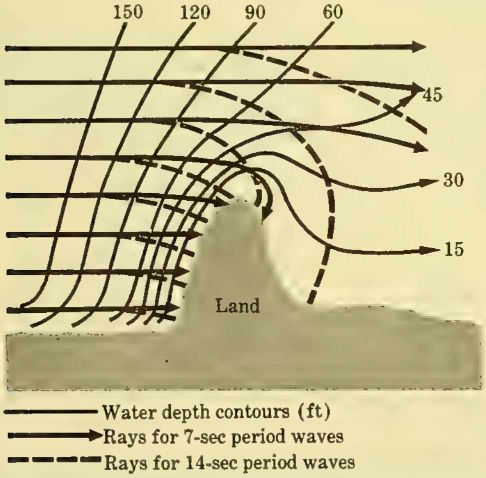


Fig. 9. Differences in water depth along a coast cause waves to refract, as shown here by rays showing direction that waves travel Lower frequency waves such as swell refract more than the waves of higher frequency, complicating the picture of how energy is distributed along coast.

Like the frequency or period, the all-important amount of energy being transported shoreward by the waves at all stages of their progress also remains approximately constant. To conserve energy as their velocities decrease, the waves must grow higher and steeper—until turbulence in the surf and the final plunge up the beach dissipate the energy completely. This is the energy that coastal engineers must contend with.

Just how much of the wave energy in deep water is ultimately destroyed by breaking at a beach, how much by whitecaps and turbulence in deep water, and how much by friction against the bottom in shallow water is not known. Barber and Tucker of NIO estimate, however, that a run-of-the-mill ocean swell—perhaps 2 m high in deep water—contains 5×10^6 ergs of energy per cm^2 of sea surface. If the period of this swell is 10 sec, its group velocity in deep water is about 7.8 m/sec, which means that the swell is transmitting energy at the rate of 3.9×10^9 ergs/sec for *each* cm of length along the crest. When this swell reaches a coast this energy is nearly all spent in turbulence in the surf or breaker zone. It amounts to approximately 40 kw along every meter of shoreline. And how many meters are there along the shorelines of the world?

SURVIVAL at SEA

356-697 O - 69 - 3

By John W. Chanslor
Maritime Safety Division
U. S. Naval Oceanographic Office

The powerful and unrelenting sea, though peaceful at times, is the inevitable enemy of all who venture upon it. It follows, then, that those who "go down to the sea in ships" and have accepted this calling should undertake sufficient survival study to assure that what was once their home will not become their coffin.

Survival in the sea depends upon four things: knowledge, equipment available, self control, and training. Without these four prerequisites, one's chance of survival at sea would depend on the severity of the situation. Many mariners have been lost at sea simply because they lacked sufficient training to know how to survive.

It is the intent of this article to bring to the fore again, a few of the basic principles of survival.

PRE-ABANDONMENT

In peacetime abandonment at sea is rare. Consequently, few mariners today have been through this experience. Shifting cargo, hull damage, machinery casualties, collisions, fire, and groundings, however, are rather common. When any of these occur, abandonment may be the ultimate consequence.

The order to abandon ship is an irrevocable decision, made usually under conditions of uncertainty, where all action directed toward saving the ship ceases. The success of abandonment is highly dependent upon the point in time when it is actually begun.

Instances have been reported of premature abandonment. As an example, one of these involved a Liberty ship which developed cracks in the main deck during a North Atlantic gale. The ship was hove to in order to ease the strain of pitching and rolling. She remained in this condition for nearly three days. The weather moderated on the third day and the ship proceeded to the nearest port. On the fourth day a weather report, indicating further heavy gales, was received and the Master decided to abandon ship. The entire crew was rescued within a short period of time after abandonment. The ship remained afloat and finally beached itself on one of the Hebrides Islands. Although not conclusive, the circumstances tend to suggest that the Master, in all probability, could have reached port safely.

ABANDONING SHIP

As with most problems, there is a proper way in which one should endeavor to abandon ship. The span of time between the Commanding Officer's decision to abandon ship and the actual time of departure is a most important one. In addition, it is also a period of possible confusion and mental strain. If the time element is sufficient, certain preparations can be made before the actual time of abandonment. Of course, this would include having the radio operator send out the required distress message. If a reply is received, the fact should be made known to each boat and raft. A final check on the position of the ship together with the range and bearing to nearest land is vital information each life craft should have. Other items such as a pilot chart, navigational chart, sextant, chronometer, radio, plotting equipment, almanac, compass, flash light, and navigational tables should be placed in some of the life craft.

Reaching an exposed deck is frequently difficult. Survivors of sinkings have reported that some of their shipmates went down with the ship because of the confusion attending the disaster. In many instances, the compartments in which the men were trapped were not actually cut off completely, only partially. These lives were lost due to the development of habit and lack of foresight.

When a man reports on board a new ship he usually learns the easiest way from his bunk to his duty station and automatically uses it in both directions, watch after watch. Thus, the habit of using the same route day after day becomes so strong that in time of emergency he finds it difficult, if not impossible, to utilize an alternate avenue of escape. A collision or explosion may flood a compartment through which the usual route passes, or knock out a ladder that is customarily used. Every mariner should, therefore, thoroughly know his ship. This familiarity can best be accomplished by drills held at different times of the day and night. Those who know all escape routes have an advantage that may mean the difference between being trapped in a sinking vessel or getting away.

Topsides training in the methods of abandoning ship can be given in conjunction with these drills. The following points should be frequently stressed:

1. Whenever possible, men should abandon ship fully clothed but without shoes. This principle applies equally well for any latitude.
2. When habitually used passageways and hatches are blocked or cut off, individuals who know all escape routes have a far better chance of reaching an exposed deck.
3. If there is a choice, men should leave by the windward side of a sinking vessel, and from either the bow or stern, whichever is lowest in the water.
4. If the ship is listing, men should leave by the side lowest in the water.
5. Jumping from the deck of a sinking ship with a high freeboard introduces difficulties which do not appear when men abandon ship by means of a ladder, cargo net, or line, etc. If at all possible, men should leave by climbing down rather than jumping over the side. The chance of landing on debris is great.
6. If one must jump, he should do so feet first, with the legs together, the body erect, and life preserver securely fastened.
7. When jumping from a ship that is entirely surrounded by burning oil, it is best to jump to windward, feet first. Grab the nose and cover the mouth with one hand and cover the eyes with the other. A very deep breath should be taken prior to the jump. The inherently buoyant life preserver and shoes should be discarded. The CO_2 inflatable preserver should be kept on, but uninflated. Clothing should be worn, however, as a protection against flames and debris. The survivor should swim as long as he can under the surface of the water. When it is necessary to come up for another breath, the swimmer should look up, extend his arms above his head and pull them in a wide vigorous sweep which will aid him in coming to the surface. His hands and arms then should make wide sweeping movements across the surface to splash the water, thus driving away the flames momentarily, forcing the upper part of the body above the surface and allowing the man time to breathe. As he comes to the surface, he should endeavor to turn his back to the wind before the next breath is taken. After the breath is taken, he submerges again, feet first (Standing Dive). This technique should be repeated until he is clear of the burning oil.
8. When a man reaches the water after abandoning ship, he should attempt to get away from the ship by swimming his fastest and most powerful stroke. He should put from 150 to 200 yards between himself and the ship before he stops to rest.
9. In time of war or national emergency, the following lesson may be well to remember. On many occasions during World War II, the enemy strafed survivors from sinkings. In this manner many men lost their lives not knowing that six to ten feet of water would have saved them. This depth of water will not stop the bullets, but it will deflect them away, giving the survivor another chance. Five seconds is about the maximum length of time a modern aircraft can hold a small traget in his gunsights. Conversely, it is rather easy for a swimmer to hold his breath for 15 seconds.

After a group of survivors have successfully reached the water, their chances for eventual rescue will be improved greatly if a basic pattern of behavior is followed. These elements are:

1. When a man has reached a point between 150 and 200 yards from his ship, he then should start making his way to one of the life craft.
2. He should conserve as much energy as safely possible, as an unforseen emergency may arise calling for a large expenditure.
3. If explosions are occurring, a survivor should swim on his back with head and chest as far out of the water as possible.
4. A survivor should remember that team work is required for successful recovery and that his shipmates are not opponents in this struggle.
5. For the maximum number to survive, a group of survivors should establish a definite chain of command. A capable leader is a prerequisite for high morale. He will see that available supplies are properly cared for, that lookout duties

are assigned, and that signaling gear is available and properly used.

6. Life craft should be lashed together so that the group will not scatter.

Once a crew has completed abandonment and is distributed among the life craft, under most conditions, rescue is reasonably certain. Research shows that due to the close teamwork between rescue commands, ships, and planes most survivors are picked up quite swiftly—many times within only a few hours.

USE OF CLOTHING AS A FLOATING AID

The most important piece of abandon ship equipment is the life preserver. When properly adjusted, it will support a man even though he is unconscious. A survivor should not abandon hope, however, if he finds himself in the sea without one. For, one may be improvised from the very clothing he is wearing.

To inflate a shirt or jumper, all buttons should be buttoned and knots tied in the collar and cuffs. The shirt tails should be tied around the waist. When this has been accomplished take a deep breath of air, submerge, and expel the breath into the shirt between the second and third button holes. Properly inflated one's shirt becomes a good floating aid.

Trousers, though, will make an even better buoy than the shirt or jumper. After the trousers have been removed, tie a single overhand knot as close to the end of each leg as possible and secure the fly. Then take one side of the waist in each hand and bring them up and over the head from behind the body. This traps a good pocket of air in each leg. To completely fill the trousers with air,

submerge and blow air in the opening. The waist is then gathered together in one hand, resulting in a good pair of water wings.

Thus, a survivor should never discard his clothing, for in addition to a floating aid, it can be very useful in other ways. It will serve as his protection against sunburn, windburn, cold, and of course, be needed upon rescue.

SWIMMING

An unexpected ship roll coupled with a second of carelessness, together with a slick deck, and a mariner is very likely to cease standing and start swimming.

The first act of survival, a man overboard should concern himself with,is to immediately endeavor to swim away from the ship's screws. Although an alert Watch Officer will swing the stern of his ship away from a man overboard, he may be completely unaware of the situation at the time. Momentum, luckily, is in one's favor if he falls overboard, as it will usually carry him within a short distance of the safety zone from the propellers. His first sprint, then, will be but a short one.

After a man is safely clear of the propellers and his ship has passed him by, he should conserve his energy. Unless a life ring or buoy is seen in the near proximity, he should just float. If he is not wearing a life preserver an improvised one from his clothing, as previously mentioned, should suffice until recovery.

One of the latest methods recommended for endurance is the "Jellyfish Float." It has been designed to sustain a person who finds himself in the water without *any* floating aid. The physical attitude assumed actually has some resemblance to that of a jellyfish. Its success depends on the person's ability to control his breathing.

To assume the Jellyfish Float position, slide the arms down along the legs until they are suspended toward the bottom. Do not bend the knees, but let the legs hang freely and relaxed. Take a deep breath and allow your face to submerge below the surface. Remain in this relaxed position until another breath is required.

When more air is needed, just move the hands up and forward below the water surface. Then press the hands down and back (as in a Butterfly Breast Stroke), exhaling. During the stroke lift and turn the head to one side. Upon reaching the surface, inhale through the mouth.

If a swimmer takes a deep breath, he will float at the surface in this manner. However, should he drop too deep on returning to the floating position, a scissors or flutter kick will return him to the surface.

Unless one is seen going overboard, or unless he is shortly missed, another facet of survival appears, i.e., immersion hypothermia—the term for subnormal body temperature resulting from the loss of heat when a human is immersed in cold water.

Body temperature control depends upon the balance one's body is able to maintain between heat loss and heat production. Production of heat is accomplished by the conversion of food to energy. The principal conductor of heat throughout the human body is blood. And, primary heat loss is at the skin surface. If the vital organs do not maintain their heat, they will cease to function. During the process of slow body cooling, the amount of blood in the vessels of the extremities is gradually reduced and circulation is slowed. As body cooling is increased, circulation slowly ceases in the hands and feet. Eventually, the heat produced by the internal organs is not sufficient to maintain required temperature and death occurs.

The following estimate of survival from immersion hypothermia is based upon the temperature of the water and the length of time exposed. It is believed to be approximately correct, but considerable deviations should be expected among individuals. Some men have lived in cold water many hours longer than the indicated figures. Thus, a search for survivors should not be called off because the table shows they may have succumbed.

Water Temperature (°F.)	(°C.)	Duration at Survival
32	0	Less than one hour
40	4	½ to 3 hours
50	10	1 to 6 hours
60	16	2 to 24 hours
70	21	3 to 40 hours
80	27	indefinite

Survivors whose body temperature have been lowered to levels which can be fatal should be rewarmed rapidly. The proper methods of treatment will be found in medical and survival books carried aboard most ships. Basically, treatment consists of the following:

The survivor should be undressed immediately and placed in a hot bath of about 120°F. for 10 minutes. Although this may be painful to him if he is conscious, it is the recommended method to insure survival. After the bath, the survivor should be dried with a towel and placed in warm blankets. If his temperature does not rise, he should again be placed in a hot bath until his temperature reaches 93°F. At this point, his temperature should continue to rise and a more gradual rewarming is suggested.

If a shower must be used in lieu of a bath, the survivor should be wrapped in towels, keeping them thoroughly saturated with water between 120° to 125°F.

Survivors who are conscious when rescued from cold water will often survive without the aid of a warm bath if they are dried and placed in warm blankets. Massaging is to be avoided under all conditions.

LIFE CRAFT AND SURVIVAL

After a survivor has reached one of his ship's life craft, he is almost assured of survival and rescue. Lifeboats and rafts of the Navy, Merchant Marine, and Coast Guard have been adequately supplied with sufficient survival equipment to cope with emergencies at sea. All one normally must do is to learn what this equipment is and how to properly use it. Of course, this should be done long before an emergency arises.

Assuming that the emergency message was properly sent by your ship prior to abandonment, help from one of our many Rescue Coordination Centers should be on the way by the time you reach one of the life craft. Rescue Coordination Centers, operated by the Navy, Air Force, and Coast Guard, are always on the ready. Upon the receipt of an SOS or Mayday, they immediately begin to effect assistance and recovery.

Thus, one's stay in a life craft will ordinarily be but a short one. However, if the SOS was not sent for some reason, or if the position in it was in error, then a prolonged stay in your lifeboat or liferaft may be required. Under these conditions survival is still likely.

Command aboard a life craft is assigned by the Commanding Officer of the ship. If the assigned life craft commander is not present, the next senior should then assume command. His responsibilities are great, for chance of survival is greatly enhanced by his ability to assume responsibility, maintain morale, enforce discipline, assign jobs, take charge of rations, and deal with emergencies.

Generally, it is best to remain near the position of abandonment until reasonable hope of rescue craft arrival has to be abandoned. The sea anchor should be rigged, put into use immediately, and left out for two or three days.

When departure from the scene is decided upon, the course set should be in accordance with the prevailing winds and currents shown on the Pilot Chart. It is rather useless and disheartening to attempt to sail or row any great distance against contrary winds and currents.

During times of weather too heavy in which to safely sail, the sea anchor should again be put into use. When this is necessary, remember that it should always be veered to lie in a trough when the life craft is at the wave crest. The length of line to the sea anchor should not coincide with the length of the sea, or the boat and sea anchor will both be in wave crests at the same time and the drag effect will be lost just when it is needed most. As the boat will be making some sternway, the rudder should be unshipped to prevent damage. If it is possible to rig a small sail fore and aft it will act as a weather vane and tend to keep the boat's head into the wind and sea. When, for any reason, this isn't possible, one set of oars should be manned in readiness to keep the boat headed into the approaching sea.

When rescue becomes a possibility and a ship or aircraft is seen by the lookout, the signaling equipment becomes an all-important item.

It is most difficult to spot life craft from an aircraft above 3,000 feet. If a sea is running, it is also quite difficult to see life craft from a surface ship.

Experience has shown that the signaling mirror is a very effective signaling device. It takes considerable concentration to use it properly, but the small pocket-size mirror is capable of reflecting sunlight so that it can be observed from a distance of 8 to 10 miles. The mirror is tricky to use; but if instructions accompanying it are closely followed, it should not be too difficult. Signals should be continued until it is positive the rescue craft can not lose sight of you. In a liferaft with a sea running, this literally means on top of you. If rescue is to be made by aircraft, however, be careful not to flash the mirror in the pilot's eyes—especially when he is making a landing approach. Pyrotechnic signals should probably not be used until rescue craft are actually seen. For, beyond 2 to 4 miles they are not likely to be observed.

The most commonly used night signal is the flashlight. This is a very effective device and a waterproof model is standard equipment in nearly all life craft. The only note of caution here is to conserve the batteries as much as possible, using it only when really necessary.

The dye marker is a good aid to discovery during daylight. It consists of a can of fluorescein dye powder, the contents of which are sprinkled on the water surface. The yellow-green dye should be visible from the air for a period of 4 hours at a distance of 10 miles, at an altitude of 3,000 feet. Rough seas will shorten its longevity, however.

Another very useful item in a life craft is the tarpaulin. A brightly colored one may be used to attract attention. It is also a survivor's best aid in collecting water.

In tropical waters one's greatest hazard from exposure is dehydration. This is usually the principal cause of exhaustion and death of those adrift in life craft. Under favorable conditions a man can survive without water from 8 to 10 days, on the average. Without food, but supplied with adequate water, he may live for 30 days or more. Thus, when the water supply is limited, available water should be used efficiently. Dampen your clothes with sea water during the hottest hours of the day. Keep exertion to a minimum and sleep when possible. If you have no water you should not eat, as the amount of food the body can assimilate depends upon the amount of water available. This is one of the reasons emergency rations are purposely made bland. Others are that well-seasoned foods induce thirst and highly palatable ones, under extreme conditions, may make rationing difficult. Life craft rations are a compromise between an adequate diet and a limited supply of water, being high in carbohydrates and low in proteins, thus yielding maximum calories with a minimum demand on the kidneys.

Water will be your most important need. When it is in short supply and cannot be replaced by chemical or mechanical means, but only by chance rain, use it efficiently. Men on short water rations during an extended survival period have usually experimented with some substitute for water; i.e., the drinking of sea water in moderate quantities, juice expressed from the flesh of fish, etc. However, the fact still remains that under survival conditions at sea, unless means for chemically or physically separating the salts from sea water are available, the only safe fluid to drink is rain. For, sea water is inimical to the human body and will shorten rather than prolong survival time. It aggravates thirst and increases water loss by drawing body fluids from the kidneys and intestines, resulting eventually in serious convulsions and delirium.

As previously mentioned, the tarpaulin, sail, or poncho will be a great aid in collecting rain water. Plans for its exact use should be made in advance, keeping in mind that these sheets may be difficult to handle in the high winds and rough seas that accompany a squall. Watch the clouds and be ready for any chance shower. If the paulin is encrusted with dried salt, wash it in sea water. If the shower appears to be a light one, every available drop should be collected by first wetting the canvas with sea water, so that fresh water will not be absorbed by the fabric. The amount of salt water contaminating the rain water will be negligible, but the amount of fresh water lost through absorption, if the cloth is not first wet, will be considerable. In a driving rain, water can be collected by holding a canvas or any flat surface at an angle.

Store rain water in any available receptacle; even the bladders of inflatable life jackets have been successfully used. The human body can store water very well and, therefore, one should drink all he can when water is plentiful. Little of the water taken in quantity when one is dehydrated is lost through perspiration or excessive urination. Rain water, however, does not always satisfy the thirst as it lacks minerals and is tasteless. It has been recommended it be mixed with a little sea water, coffee, or tea solubles; or that some of the hard candy from the emergency food kit be dissolved in it for taste.

FOOD

If fresh water is available to the survivor, there is little cause for him to starve. One pound of body fat will provide your system with an equivalent of two good meals. The rate at which body fat can be converted to heat and energy is dependent upon air temperature, physical activity, and mental state. It follows then that longevity can be extended by relaxing mind and body, and reducing exposure to extreme temperature.

In addition to this stored energy, food may be gleaned from the inexhaustible sea. For, desolate though it may seem, the sea is far richer in various types of food than an equal amount of land. Small fish will usually gather in the shadow of life craft. These should first be caught for bait. Or, clumps of seaweed will usually yield small crabs and shrimp. In using a dip net to catch bait, hold it under the water and scoop upward. If a fishing kit is not available, hooks can be improvised from insignia pins, pencil clips, shoe nails, fish or bird bones, pocket knives, or pieces of wood. Line may be obtained from shoe laces, shroud lines, or thread from clothing. A fishing line with a breaking strength of over 100 pounds can be made by utilizing a yard length of canvas ravelings. The canvas should be dry, as wet canvas is quite difficult to unravel. With 8 or 10 strands held between the thumb and forefinger of each hand, twist the strands clockwise, while passing the right hand around the left in a counter-clockwise movement. This will form a section of the fishing cord. When approximately 18 inches of cord have been completed, cut off the strands at two-inch intervals, feeding in a new strand each time an end is reached. Continue this process until about 50 feet of cord is complete.

Various sizes of cord may be made in this manner. A line of two strands will have a breaking strength of approximately 20 pounds.

A spear may be made by lashing a knife to an oar. As light is known to attract fish at night, shine the flashlight on the water. Or, use the signaling mirror to reflect moonlight on the water. While actually fishing, do not make the line fast to the life craft or person, as large or dangerous fish can pull one overboard or upset a raft. Captured fish and/or bright objects should not be left dangling over the side for similar reasons.

Water fowl have been a source of food for many survivors. Several have reported them as having a musty odor and fishy flavor. All sea birds are edible and nourishing, however. They are apparently drawn to rafts and boats out of curiosity, by the small fish attracted by the life craft, but mostly because they afford a place to perch. Some survival reports mention the tendency of sea birds to roost on the life craft during the early morning and late evening hours.

If activity in the life craft is restricted, sea birds apparently have little fear of man and will land on or near more frequently. After they have landed, wait until the wings are folded before trying to grab them. If they tend to shy away, they may be caught in the following manner: Make one end of a line fast to the craft. Tie a simple overhand knot in the bight of the line. Place some bait within the knot loop and pull the bitter end of the line when the bird is standing within the loop. Sea birds can also be caught by trolling a baited fishhook or baited toggle of metal or wood. In many cases, the ease with which they have frequently been caught has resulted in their being a more dependable source of food than fish.

In addition to food, birds can be very useful to survivors in other ways. A streamer or fly can be made with the feathers. They may be skinned (cutting down the back) and a cap, ear muffs, scarf, or shoe lining fashioned from the downy breast feathers. Fishing spinners can be made from the long bill plates, and even the bones can be utilized for making fishhooks and skewers.

INDICATIONS OF LAND

A lookout should carefully watch for signs of land. Fixed cumulus clouds in an otherwise clear sky, or in a sky where the other clouds are moving, usually indicates land beyond the horizon. This type of cloud will form over high or mountainous land. Smaller clouds may hang, a little to the lee side, of atolls and small islands. On the under side of these, "lagoon glare" may often be seen. This greenish tint is caused by the reflection of sunlight from the shallow water of a lagoon, or of coral reefs. Actually, the reflection of light from any surface such as shallow water, sand, snow, or ice may be reflected in the sky or on clouds and is an indication of land.

The flight line of birds is another good indication of land. During the day, they are in search of food and their direction of flight is meaningless. However, as most sea birds roost ashore, their evening and morning flights to and from their roosts are an excellent indication.

During times of restricted visibility, there are still other indications one should keep in mind. These are the odors and sounds of the shore. The odor of burning wood is known to carry a great distance. Mud flats and the musty smell of mangrove swamps may be similarly noticed. Normally, the sound of surf is heard long before it can be seen. Continued bird cries from one direction may indicate their roosting place.

Long before Captain Cook visited the Pacific Islands, Polynesian navigators found their way home by watching wave forms or a certain joining of the waves.

Consecutive swells travel parallel to each other, with the prevailing wind, until they reach an island and then bend around it. These swells, their distortion, and the resulting refraction, form the wave patterns utilized as a navigational aid. (Figure 1).

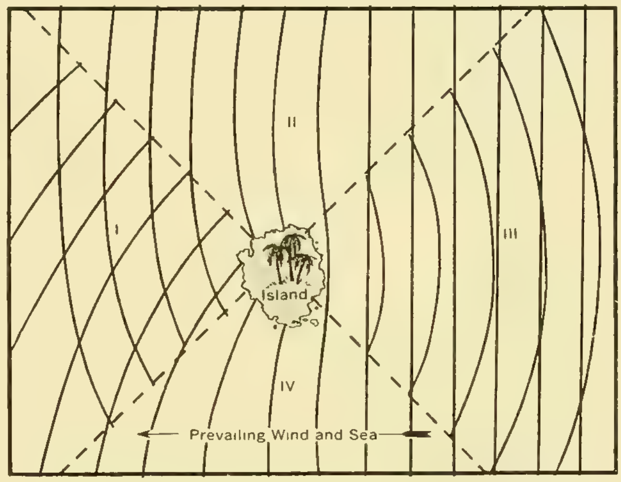


Figure 1

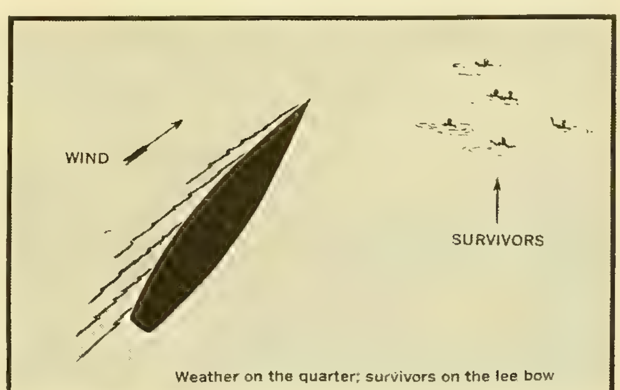
Suppose a survivor notices a wave pattern similar to that shown in quadrant III. That is, with the reflected waves coming back against the main swell. Land will then be in the general direction from which the reflected waves are coming. Consequently, one should head in this general direction, keeping a lookout for the choppy interference lines that form about 90° apart with the island at the apex. When this line is seen change course to sail parallel to it in order to reach the island.

On the other hand, if a wave pattern similar to that shown in quadrant I is noticed, land is in the direction from which the waves are coming. Similarly, as in quadrant III, a survivor should sail in this general direction, keeping a lookout for the choppy line previously mentioned and follow it to land.

Quadrants II and IV are most difficult to recognize. About the only way one can detect these two sections is that the swells will not be perpendicular to the direction of the prevailing wind. This condition is noticeable, however. When it is detected, sail approximately parallel to the swell until the choppy intersection lines are seen and then follow them to land.

Navigation has been a well-developed art in Micronesia since early times, with this type of wave pattern navigation forming a major part.

RESCUE TIPS



Weather on the quarter; survivors on the lee bow

Figure 2

In peacetime, with a calm sea, a rescuing ship has few problems in recovering survivors. One merely lowers away the ship's small boat, scoops the survivors from the sea and into the boat, then hoists the boat along with any survivors too weak to climb back aboard the ship. Unfortunately, the years of world peace are too few. And, wind and sea conditions conducive to small boat launching are not encountered with the frequency often desired. Thus, getting a survivor aboard ship can, at times, be quite difficult.

There is no single method or official doctrine applicable for approaching survivors under all conditions. Here the judgement and knowledge of the captain must be relied upon. A proven technique for recovering swimmers and men in life preservers, often considered as standard procedure, follows: The rescuing ship is positioned slightly up-wind from the survivors and allowed to drift, with engines stopped, down to them. (Figure 2.) In heavy seas, the weather should be kept on the quarter and the survivors on the lee bow. This practice reduces rolling, thus decreasing danger to the survivors as well as the rescuing personnel. If, however, a lifeboat or raft is to be approached, they will drift faster than the ship and the ship must, therefore, be positioned down-wind, letting the raft or boat drift down upon her. This method has the advantage of bringing the survivors to the ship. But, it also has various hazards and disadvantages. In heavy seas, the ship will be rolling and survivors must be taken aboard quickly. Additional care must be taken to assure against capsizing lifeboats and crushing personnel against the side of the rolling ship.

Another successful method is for the ship to steam past the survivors with a small amount of way on. As the vessel passes them a heaving line with a ring buoy attached is thrown to them. The ship then circles the survivors, stops, and makes the rescue. The ring buoy, or similar piece of flotsam, should be painted yellow or orange to make them more visible. With this method, the line floats and does not require the accuracy that a standard heaving line with a monkey fist attached does, as survivors can swim to the line.

Many times a survivor is so weakened by the cold water, or by the length of time he has been battling the sea, that he is unable to grasp a line passed to him. When this situation is met, a trained swimmer must be put over the side with a line to secure to the survivor. After the line is made fast to the survivor, the swimmer accompanies him back to the ship. No man should be ordered over the side and into the water to assist in rescue operations unless he is wearing an exposure suit and has a line attached to him from the ship. Further, he should be a skilled swimmer, well versed in rescue techniques. Otherwise, he may himself become a man who needs to be rescued.

In numerous survival incidents the moment of rescue has been attended by various dangers. These are usually brought about by underestimating sea conditions or lubberly handling. Rescuers with the best of intentions failed to realize the weakness and helplessness of survivors. Thus, just as many were thanking God for rescue, they suddenly faced their worst moments. Exposure and dehydration are the two greatest hazards of survival at sea. These two are closely followed, however, by the hazards accompanying rescue.

Survivors making shore landings have found it difficult to estimate the height and force of surf. Those being picked up at sea have faced equal hazards. On occasion, they have had to jump overboard to avoid being hit by the rescuing ship. Others have been battered and bruised trying to fend themselves off the side of the ship. It is not easy to climb up a rope ladder on a small ship. On a large one that is rolling in rough weather, it becomes very difficult.

Following AMVER, probably the next major item assisting in SAR is the versatile helicopter. This aircraft can perform rescues while hovering above the water. Or, if of the amphibious type, it can land in a rough sea only a few feet from those in peril.

On 3 January 1944, Commander Frank A. Erickson, U. S. Coast Guard, climbed into the cockpit of a small Sikorsky R-5 helicopter. His new and untried assignment revolutionized rescue techniques and earned him the distinction of flying the first helicopter mercy mission. Hampered by a severe storm, Commander Erickson flew his blood plasma-loaded craft from New York to Sandy Hook, where the U. S. S. *TURNER* had exploded. His efforts and success helped save the lives of more than 100 sailors and marked the beginning of helicopter mercy and rescue operations. Helicopters have since helped save thousands of lives.

In answer to how far a helicopter can now fly without stopping, on 6 March 1965, the U. S. Navy flew a twin-engine Sikorsky SH-3A non-stop from San Diego, California to Jacksonville, Florida. To commence this record-breaking flight of 1,348 miles, the helicopter took off from the carrier *HORNET* and landed 15 hours and 52 minutes later on the carrier *FRANKLIN D. ROOSEVELT*. The U. S. Navy has assigned this type helicopter primarily to anti-submarine warfare as combined hunter-killers. Although it averaged 133.3 mph on the above-mentioned flight, in February 1962, it set a world speed record of 210.6 mph.

MAN OVERBOARD

As previously mentioned, there is no one standard rescue procedure, due to the many variables. If the man overboard is in sight, however, a good recovery approach, and perhaps the fastest, can be made using continuous full rudder in one direction. (Figure 3). The stern should be swung away from the man in the water.

The bridge is not normally aware there is a man overboard, however, until the ship has passed him by. The initial turn is still made toward the side to which the man fell in hopes of moving the stern away. If visual contact can be maintained, a turn similar to that shown in Figure 3 promises to bring him back on board in the shortest time.

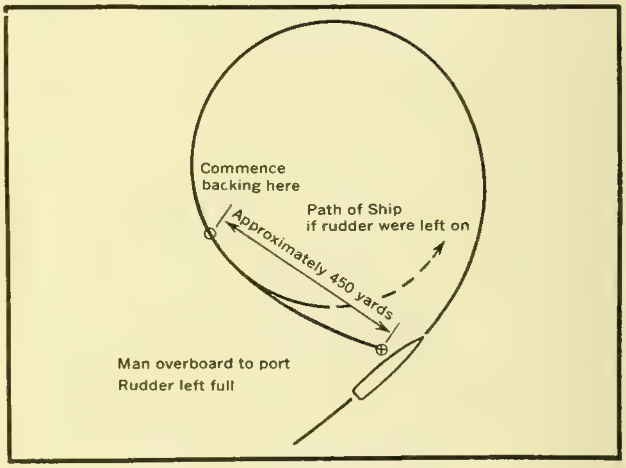


Figure 3

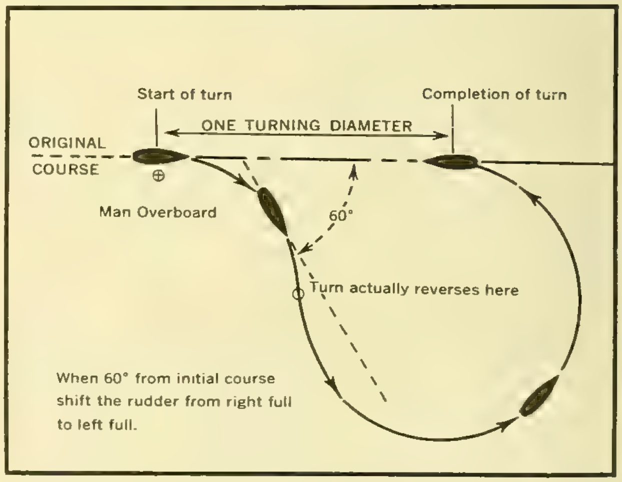
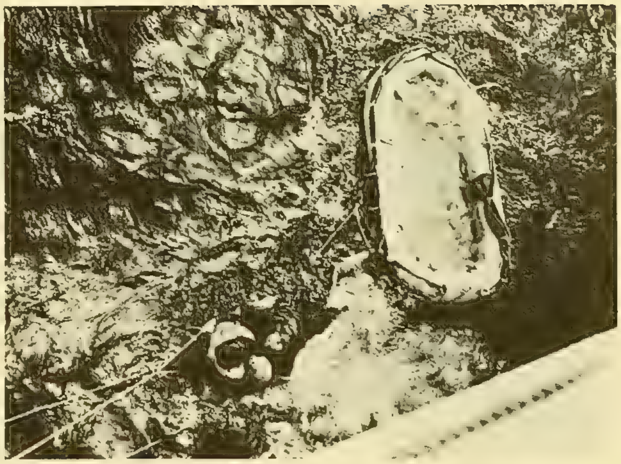


Figure 4

If visibility is restricted, a turn developed in 1942 by Commander John A. Williamson, USNR should be considered when the "man overboard" alarm is sounded. The Williamson Turn (Figure 4) not only turns the stern of the ship away from the man overboard, but also returns the ship to the approximate area where the man fell.

To execute this maneuver continue the initial Full Rudder until 60° from the original heading, then ordering the helm shifted. The 60° is about right for most ships. However, different ship types may require from 30° to 80° change. The exact amount can be learned only by trial and error during "dry runs". The ships heading will normally just reach 90° from the original heading as it commences to swing in the opposite direction. The turning should be continued until the reciprocal of the original course is reached. When the turn is completed, a ship should be heading back down her original track approximately one turning diameter from the point where the turn commenced. Thus, a careful search can be made back along the former track—the advantage of the Williamson Turn.



U. S. Coast Guard official photographs

SHARKS

The history of attacks by sharks dates back to the beginning of written records. Displayed on the side of a vase, that is believed to have been painted approximately 725 B. C., are drawings of a sailor being devoured by a shark-like fish.

Shortly after the New World was discovered, the Spaniards began to call the shark *tiburon*. While sailing with Vasco de Gama around Africa, Antonio Pigafetta wrote that "the tiburon have teeth of a terrible kind and eat people when they find them in the sea".

Pliny the Elder knew of the shark and referred to him as the dog fish. The word *shark* made its debut to our vocabulary in the middle of the sixteenth century when an English sea captain placed one on exhibit in London. Although not known for sure, it is generally believed that English sailors picked up the German word *schurke*, meaning villain. At any rate, the word seems to apply quite well, for the shark is truely a villain.

Considerable controversy still apparently exists among mariners as well as some ichthyologists regarding shark attacks. Prior to World War II there was very little accurate information available on the subject of sharks. Some of our survival manuals flatly stated that sharks were cowards and would not attack an uninjured man. Authenticated reports and observations made during the war, however, proved beyond doubt that some sharks will attack.

Further, the insurance offered by shark repellent isn't too promising. Some articles refer to it as absolute protection while others imply it is rather useless. The truth, however, is somewhere between these two extremes. The present day shark repellent consists of a packet of copper acetate and nigrosine dye. But, it has been demonstrated to have no inhibiting effect on the behavior of the species of sharks that inhabit the Caribbean Sea and Pacific Ocean. Therefore, the safest solution against shark attack is to get in one of the available life craft as soon as possible.

A survivor of a Pacific Ocean aircraft ditching, in which sharks killed two men, said that using the repellent was "like feeding them orange juice." Shark repellent loses effectiveness with age and should be in powder form. When it has hydrolyzed into cake form, it will not release the chemicals intended to provide the protection. Although not 100 per cent effective, repellent is the only weapon we currently have against hungry sharks. Hence, one should keep his repellent fresh and his powder dry.

Other than repellent, there are other measures one may take to enhance his safety.

While in the water:

1. Keep a sharp lookout for sharks.
2. Stay quiet and conserve as much energy as possible.
3. If swimming is required, do so with strong regular strokes Frantic irregular movements should be avoided.
4. When threatened by a shark, try feinting toward it. With some luck, it may scare him off.
5. Loud noises have also been successful. With the hand cupped, regularly slap the water surface. Another method reported to frighten away sharks is to put one's head under water and shout. One of the earliest accounts of this procedure working was of three survivors from a German submarine sunk off the west coast of Africa in 1943. They were attacked and bitten by sharks, but by submerging their heads below the surface of the water and "roaring", they succeeded in frightening the sharks away.
6. Do not swim directly away from a shark, but rather face him and try to outmaneuver him.
7. If a group of survivors are threatened, form a circle, facing outward, and around any previously injured men.
8. As a last resort, use your knife in self defense.

While aboard a life craft:

1. When sharks are known to be nearby, do not fish.
2. Do not clean any previously caught fish nor throw any waste overboard while sharks are in the vicinity.
3. If a firearm has been salvaged, shoot to kill. Shots close enough to the water to produce heavy concussion may ward off further attacks.
4. Before going into the water, check for sharks under the life craft.
5. If a shark threatens your raft, try jabbing his gills, snout, or eyes, with anything available.
6. Any burials at sea should be conducted at night.

The likelihood of shark attack is a very real concern to any mariner who finds himself in the water following a marine disaster. For there is no longer any question that sharks will attack and that a grave danger exists to anyone exposed to them.

By and large, when sharks are successful in their attack they leave no evidence. Consequently, the number of missing swimmers who may have succumbed to them cannot even be estimated.

To make a bad situation worse, sharks are found in all oceans and seas of the world. They may even ascend river mouths. All have voracious appetites. They are guided to their food by scent, sound, and sight. Further, they frequently travel in packs and feed at all hours of the day and night.

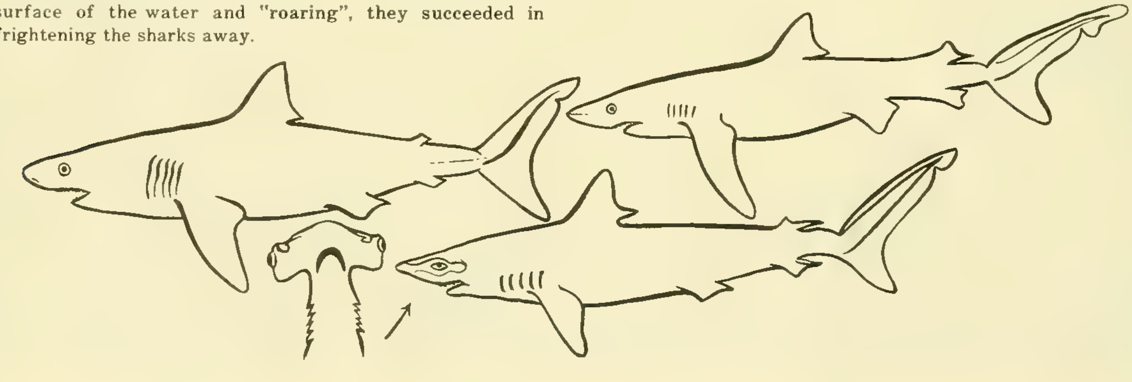
A shark's sense of smell is developed quite highly and it is generally believed that the presence of blood in the water tends to excite them. They are also very sensitive to sound vibrations transmitted through the water. Underwater explosions are known to draw them in search for food. Abnormal impulses, as those of a hooked fish, a dying animal, or a poorly-coordinated swimmer will draw sharks from a much greater distance than the scent of blood. This is the reason a swimmer should swim with powerful and even strokes.

It has been the general belief of many mariners that a shark must turn on its side or back to bite. This is not quite true, for though a shark may turn partially on his side, he doesn't have to. When a shark lunges forward in attack, he invariably arrives mouth first, with the entire front end displayed as mouth. It is possible for him to bite a man from most any position.

Sharks may hunt for food and attack singly. The majority of survival accounts mention the presence of more than one. This is because once a shark finds a victim he is almost immediately joined by others in the same proximity.

A most inconceivable aspect of a shark bite is the high percentage of survivors that have been bitten who reported feeling no pain from the bite at the time.

Two conclusions may be drawn concerning *tiburon:* One can never be certain what he will do, and the more we learn about him, the less we find we really know.



NAVIGATIONAL HINTS

By J. N. Spinning
Maritime Safety Division
U. S. Naval Oceanographic Office

INTRODUCTION

A primary function of the U. S. Naval Oceanographic Office is the improvement of its products used for navigating safely the vessels of the United States Navy, the mercantile marine, and others engaged in water-borne endeavors. The fulfillment of this function is a continuing and ever expanding task as new knowledge of the worlds of inner and outer space is acquired.

The era of modern navigation is generally considered to have been ushered in by Captain James Cook of the British Royal Navy during his three historic voyages of discovery into the Pacific Ocean between 1768 and 1779. This new era fostered the first steps in the transition of navigation from an *art* to a *science*. Today, with nuclear-powered vessels laden with highly sophisticated electronic navigation equipment and with experimental positioning satellites orbiting brightly in outer space, one might be tempted to say the transition is all but complete. Yet, we are all aware that the toll taken by groundings, collisions, and other marine casualties continues to rise in spite of all our electronic gadgetry. It thus appears that some of the old *art*, the *seamen's sense*, is still very much needed by twentieth century mariners.

There are many excellent works on navigation principles and techniques, such as the *American Practical Navigator* (Bowditch), where the navigator can find complete descriptions and solutions to about every known system of navigation. All too often, however, many of the little hints making up part of the *art* are buried so deeply within the text that they are overlooked. This article explores a few of these hints in an effort to stir new interest in them or even, perhaps, bring them to light for the first time.

DEPTHS-SHOALS-CURRENTS

The most important features of any chart are the soundings and depth curves by which the main characteristics of the bottom configuration are represented. The origin of the hand lead, the oldest known means of measuring depths, is lost in antiquity, but mention of soundings have been found in Egyptian records dating back several millenniums before Christ. An interesting account of the use of soundings and the danger they foretold is found in the twenty-seventh chapter of *Acts of the Apostles*.

The present day mariner faces many of the same problems of his ancient predecessors when navigating off a strange and relatively unsurveyed coast. As the lead or echo sounder can only give the depth under or near the keel, there is no way to forecast the depth ahead for any substantial distance.

With this point in mind, the navigator should carefully examine each chart he uses. If there are no fathom lines shown on the chart, it is probably due to insufficient data or a highly irregular bottom relief. A coast so shown should be given a wide berth. The same caution is to be exercised in areas where only isolated soundings, especially when those marked "doubtful sounding" or those enclosed in a dotted ring are shown. Invariably, the rule to be followed is:—*consider a coast to be foul unless it is shown to be clear.* The only positive way of determining that every pinnacle and obstruction has been found in an area is for survey vessels to wire-drag the area to a predetermined depth. Unfortunately, very few areas of the world have been surveyed so carefully.

What constitutes a safe sounding will vary with different vessels, so that no hard and fast rule can be laid down. Generally, however, when only scattered sounding data are shown on the chart, particularly along rocky coastlines, 10 fathoms should be regarded as a caution against the possible near approach to shallower water. When operating off a coast known to be well surveyed or when navigating inshore waters, as a useful aid, sketch in red ink or pencil a depth curve on the chart somewhat greater than the maximum possible draft of the vessel. This will provide the navigator with a meaningful danger line. The 10-fathom curve, if charted, can be traced with blue ink or pencil, or sketched in, and serve as a warning line.

Charts made from surveys conducted by the Oceanographic Office are reduced to a plane of reference, with due regard to tides, which present the hydrography in its least favorable aspect. The datum planes most often used are mean low water, mean low water springs, and mean lower low water. The datum of charts based upon those of other nations is that of the original authority.

Even with the charted soundings reduced to the lowest practicable plane of reference for the area, it should be remembered that local conditions will at times cause the actual water level to be lower than the chart datum.

A change in wave formation is often an indication of shoaling as waves close up and heighten when running from deep to shoal water. A deeply laden vessel, especially during heavy weather, should, when possible, avoid transiting areas of abrupt changes in depths, as the seas running from the deeper water will follow the bottom rise and become sharper.

In tidal estuaries, without marked irregularities of bottom, the maximum current velocity will occur at about half tide. The surface current is usually greater than that near the bottom, a condition which may enter into the navigation calculations of light and deep draft vessels.

ECHO-SOUNDING

Submarine topography is becoming increasingly important to the mariner as a means of navigation. With the development of the modern sonic sounding equipment found on most naval vessels and many merchant ships, it is possible to record depths up to 6,000 fathoms with an error of approximately one fathom. These sounding devices have made the profile of the ocean floor potentially the most universally accessible aid to navigation yet envisioned. Recent hydrographic surveys have given special prominence to this work and, as adequate bathymetric charts become available. navigation by underwater features may become as common as coastal piloting. Few bathymetric charts have been developed, however, for full reliance in navigation.

The standard velocity of sound waves as calibrated for all American-made equipment is 4,800 feet per second. Although the true velocity varies with local values of temperature, water pressure, and salinity, the difference is not considered important except in highly technical research work. It is the policy of the Oceanographic Office to chart all soundings on the basis of this standard value. Soundings obtained by equipment not calibrated to the American standard will *not* agree with the depths shown on H. O. Charts.

Echo sounding equipment, like any aid, is subject to errors if the navigator is not fully familiar with equipment operating characteristics and limitations. The routine checks outlined in the instruction manual should be carefully conducted at least once a watch.

The phenomenon known as "phantom bottom" has caused considerable confusion among many navigators. The phantom bottom appears on the trace as a bank between 125 and 375 fathoms below the surface and is only detected during daylight hours. The exact reasons for the occurrence of this phantom bottom return are not definitely known, but it has been experienced in most parts of the world. One theory offered is that concentrations of marine life descend to this area during daylight hours and then rise nearer the surface during the night. The navigator can often rule out these false returns by carefully checking them against known charted depths.

Excessive underwater turbulence which aerates the water can distort the outgoing signal (sound waves) to the point of preventing any echo from being received. Usually, this condition is only a problem when the vessel is rolling or pitching in heavy seas, backing down, or steaming in column formation.

Another cause of significant error is fluctuation of the current supply driving the depth-indicator motor. The accuracy of soundings is directly related to the revolutions per minute of this motor which normally operates on a 60-cycle supply. A change of one cycle, say 61 cycles, would cause an error of about 33 fathoms in a recorded depth of 2,000 fathoms. The navigator should be alert for this problem at all times.

NIGHT VISION HORIZON

During World War II, with our submarine forces operating along hostile shores for prolonged periods of time, an urgent need arose for fixing position without revealing presence to the enemy. The use of electronic aids was too risky in most cases and had to be forsaken in favor of celestial observations taken late at night.

Confronted with this situation, the submariners soon developed a highly reliable skill of observing stars against a night-vision horizon. The technique requires some preparation which at first may seem somewhat foreign to the surface mariner, but its usefulness should not be overlooked.

The observer's eyes must be completely "dark adapted." Proper dark adaptation can best be accomplished by wearing red goggles for at least 30 minutes prior to going on the bridge for observations. Once on the bridge, and in complete darkness, the observer must spend an additional 20 minutes further adapting his eyes to the sky and horizon. Great care should be taken not to look at any light or to use binoculars, because, by so doing, dark adaptation can be instantly lost and the entire time-consuming procedure would have to be repeated.

When the observer can see the horizon, he should send for a reliable assistant. The assistant brings the sextant, hack chronometer, and a flashlight fitted with a red lens emitting only a very dim light. It is also advisable for the assistant to dark adapt his eyes.

Once on the bridge, the assistant hands the observer the sextant set at the approximate altitude of the first star to be observed. He then stations himself behind the observer, back to back, illuminates his hack chronometer and waits for the "Mark!"

Navigator and assistant, having completely "dark adapted" their eyes, prepare to take round of sights against a Night Vision Horizon. Dark adaption can be instantly lost by looking at any artificial light source.

The observer holds the sextant *upside down,* pointed at the star, and brings the horizon up to the star. Next, the sextant is reversed and the star is adjusted to the horizon in the normal manner. During the observation it is extremely important that the observer *does not* look directly at the horizon. Instead, he should look up about 20°, keeping both eyes open and dim the star with a filter until it can scarcely be seen. When the observer is ready to "Mark", both eyes are closed for about 5 seconds. The eyes are then opened wide and the sight taken when in focus.

After the first sight is taken, the observer must be careful not to look at any light source until he has taken all the other sights he needs. The sights may then be worked by any method suitable to the observer.

SIGHT ERROR COMPENSATION

When possible, the navigator should take star sights both north and south of the zenith as this will tend to eliminate all systematic errors from the results. For example, one navigator might consistently bring his stars down too low, while another might tend to keep his too high; the horizon might be abnormally elevated or depressed; the actual refraction might be somewhat different than tabulated; or the sextant error allowed for incorrectly.

If the total effect of these errors makes the altitude too high, a northern star will give a latitude too far north and a southern star too far south.

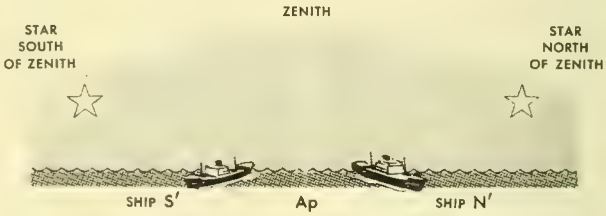


Figure 1. Sum of navigator's systematic errors result in observed altitudes that are too high.

In figure 1, the sum of the systematic errors, in each case, gives altitudes that are too high which result in apparent positions for the ship at N′ in the case of the northern star and at S′ for the southern star. The actual position lies about halfway between N′ and S′, at Ap.

In figure 2, the sum of the systematic errors gives altitudes that are too low. The actual position, however, still lies at Ap, about halfway between the apparent positions, N′ and S′.

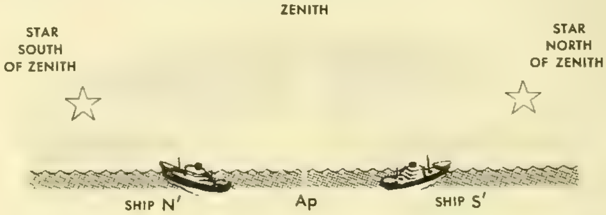


Figure 2. Sum of navigator's systematic errors result in observed altitudes that are too low.

LATITUDE BY MERIDIAN ALTITUDE BELOW THE POLE

Polaris is probably the most useful of all the stars in the higher northern latitudes and provides the mariner with his latitude, under reasonably favorable conditions, at any hour of the night. There is also another excellent, but seldom used, method of obtaining a much-desired latitude. This method involves finding the altitude of a circumpolar star when it is on the observer's meridian below the pole. While the method can be used in both the higher northern and southern latitudes, it is especially useful in the southern hemisphere where no guardian of the south celestial pole, such as Polaris, is available.

A circumpolar star is by definition a star which revolves around the elevated pole without setting. This situation occurs when the polar distance of the star is less than the observer's latitude and both have the same name.

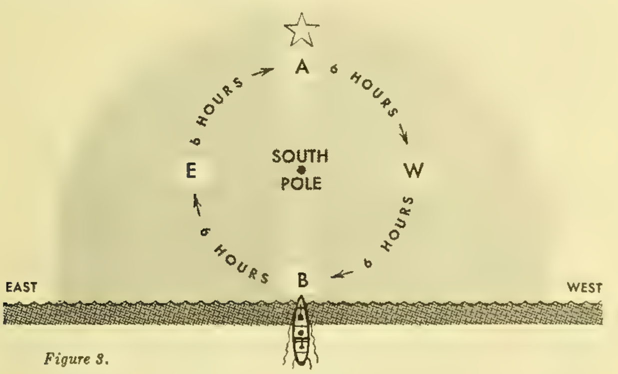


Figure 3.

In figure 3, AWBE is the diurnal circle of a circumpolar star in the southern hemisphere. Line AB is the observer's meridian. At A the star is on the observer's meridian, bears south and has reached its highest altitude. During the next six hours, the star will fall towards the west. Then, continuing to fall, the bearing will curve eastward for six hours until the star reaches point B. At B the star is again on the observer's meridian, bears south, and has reached its lowest altitude. From point B the star will rise towards the eastward for six hours, then while still climbing, it will curve westward completing one day's revolution when it again reaches point A.

To find the latitude, subtract the star's declination as tabulated in the Nautical Almanac for the appropriate date from 90°. The result is the star's polar distance. Add, to the polar distance, the corrected observed altitude when the star was at point B; the sum equals the latitude. The following example demonstrates the ease of the process.

On July 4, 1965, after several days of squally overcast weather, conditions improved and the navigator observed Achernar close to being on his meridian below the pole. A series of observations were taken and finally a low reading of 20°12.1′ was obtained. Knowing the height of eye was 44 feet and having no instrument correction, the navigator laid out the work:

MERIDIAN ALTITUDE OF ACHERNAR BELOW POLE

OBSERVED ALTITUDE	20° 12.1′	DECLINATION JULY 4	(—) 57° 24.5′ S
ALTITUDE CORRECTION	(—) 02.6′		(+) 90° 00.0′
HEIGHT OF EYE	(—) 06.5′		
TRUE ALTITUDE	20° 03.0′	POLAR DISTANCE	32° 35.5′ S
		TRUE ALTITUDE	20° 03.0′ S
		LATITUDE	52° 38.5′ S

NOTE: Corrections obtained from Nautical Almanac

FIX RELIABILITY

The pinpoint fix, whether obtained by stars, cross bearings of terrestrial objects, radio bearings or other means, is always a source of confidence to the navigator in that he knows his exact position at a specific time. Unfortunately, this single point is often very elusive and a round of stars or bearings leaves the navigator with a triangle or square for a fix. Some interesting hints about the latter merit review.

First, let us look at the case of star sights. As previously mentioned, a systematic error is often introduced in the observation of stars. Based on the assumption that this error is equal for each star, a very reasonable assumption, it becomes apparent that we can improve the fix reliability by properly adjusting the various lines of position.

Proper adjustment means that each line of position must be moved equally in distance and direction, either all towards or away, from the bearings of the observed bodies. When this is done, the navigator many times is able to completely close the triangle or square. The amount of adjustment necessary is found by trial and error. Occasionally, the actual position will be found to be outside the original fix shape altogether.

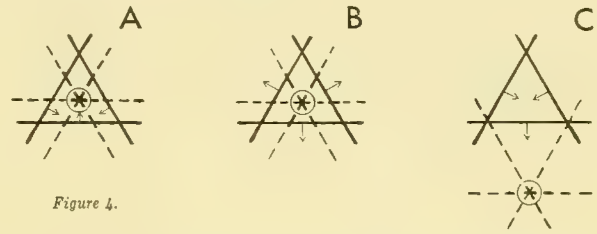


Figure 4.

In figure 4, the solid lines represent the position lines of 3 stars after being advanced to a common time. The bearings of the observed bodies are indicated by the small arrows. The dashed lines represent the new lines of position after the navigator has shifted them equally towards the bearings, figure 4, (A) and (C), or away (B), in order to make them cross at a common point. Looking at (A) and (B), it is at once apparent the actual position does lie within the original triangle. In (C), however, it is obvious that the lines will cross only at some point outside the original triangle. The value of placing the small arrows on the various position lines, to indicate bearing, cannot be over emphasized.

The desirability of taking stars to the north and south of the zenith has already been discussed. If, in addition, it is possible to take sights to the east and west of the observer, the best possible indication of fix reliability is obtained. In figure 5, the position lines of 4 stars are shown, with their bearings lying in the direction of the arrows. Looking at (A) and (B), it is again apparent that the actual position lies within the square and that the fix is reliable in both latitude and longitude. In (C), however, the latitude is reliable but the longitude is doubtful.

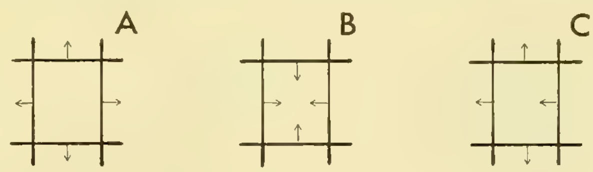


Figure 5.

Before looking at the problems of reliability of terrestrial fixes, let it be stated with the utmost emphasis that whenever three or more charted objects are available, a fix should consist of a *minimum* of three cross bearings. Even if the compass error is known, there is no check that a two bearing fix has been properly plotted on the chart. The third bearing will make any error in plotting immediately apparent. Frequently, a round of bearings, properly observed and plotted on an accurate chart, still do not cross at a common point. There is only one answer under these circumstances and that is *compass error.* This unknown compass error will affect each bearing by the same amount. By trial and error, the navigator can shift all the bearings clockwise, then counterclockwise until the bearing lines do cross at a common point. Often the vessel's actual position will be outside the original triangle. The navigator has not only accurately determined his position, but has also obtained the compass error which equals the number of degrees necessary to adjust the bearings. This hint is based on two important factors: one, that the chart is accurate, and two, that the bearings were accurately taken within a few seconds of each other.

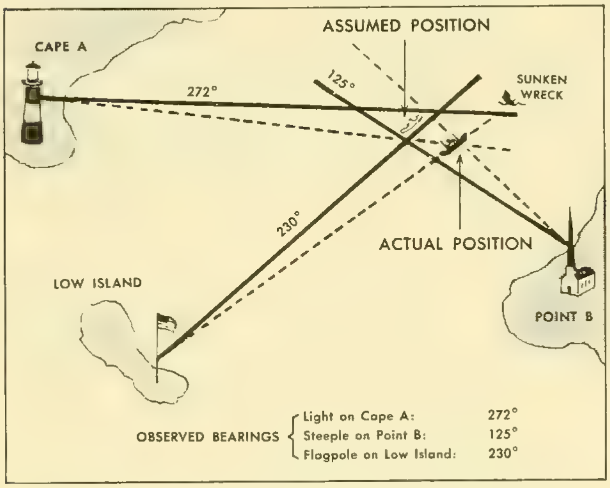


Figure 6. When possible, at least three cross bearings should always be taken in obtaining a fix. If the bearing lines do not cross compass error may exist.

In figure 6, the solid lines represent the observed bearings of three fixed objects on an accurate large scale chart. The navigator had properly observed and laid off the bearings and realized that the triangle formed was the result of unknown compass error. After a few minutes of juggling the bearings, equally clockwise and counter-clockwise, the navigator found that by adding 4° to each bearing that the lines of position crossed outside the original triangle. (the dashed lines.) The four degree adjustment revealed a previously unknown error of 4°E. in the compass.

SPECIAL CASE

There is a special case to be guarded against in the selection of terrestrial objects to be used in the cross bearing fix. A geometrical peculiarity which should be recalled is that through any three points not in a straight line, a complete circle can always be drawn, and only one. Now, if by chance the vessel itself is on or near this circle, a seemingly perfect fix can always be obtained. This situation is possible as compass error will in no way prevent the lines of bearing from crossing at a common point.

COMPASS ALIGNMENT

The true fore and aft alignment of the lubber's line on the standard compass and pelorus is relatively quick and easy to determine. This is accomplished by comparing the relative bearing of a distant object with that obtained by careful measurement on the chart when the vessel is alongside the dock and its true heading is known. The correct alignment of the lubber's line on the steering compass, as a rule, is more difficult to ascertain. Some mariners take for granted that the alignment is correct and fail to check it. This situation, however, should always be investigated when first reporting aboard for duty and after yard repair or lay up.

Cases have been recorded where the lubber's line of the steering compass was off the longitudinal axis by 5 or 6 degrees. While azimuths reveal errors of the compass card, they do not disclose the error of a misaligned compass bowl. When the steering compass is so located that it is difficult or impossible to line up with the jack-staff, the error in alignment, if any, may be very closely determined by the following method:

Ascertain the deviation on the four cardinal points by careful comparison with the standard compass or pelorus. Assign a (+) when the deviation is easterly or a (—) when westerly. Add the four figures together algebraically retaining the sign of the larger sum. Next, divide the result of the addition by 4. The remainder thus obtained is known as coefficient A and, if the compass is well made, is due for the most part to a misaligned compass bowl. When coefficient A is (+), the lubber's line should be moved to the right the number of degrees indicated or if (—) moved to the left.

CALCULATION FOR DETERMINING COEFFICIENT A

DEVIATION HEADING NORTH	—14°	DEVIATION HEADING SOUTH	+ 8°
DEVIATION HEADING EAST	—18°	DEVIATION HEADING WEST	+12°
TOTALS	—32°		+20°

$$\begin{array}{r} -32^\circ \\ +20^\circ \\ 4\,\overline{\smash{)}\,-12^\circ} \\ \text{COEFFICIENT A} \quad -\ 3^\circ \end{array}$$

In the above example, the lubber's line should be moved 3° to the left to place it on the longitudinal axis of the vessel.

MECHANICAL DEFECTS

The compass, like any precision instrument, is subject to various mechanical defects which can easily go undetected for some time. Most common among these are broken or blunted pivot points, punctures or roughness of the jewelled cap, card not moving freely in the bowl, and excessive weight on the card itself.

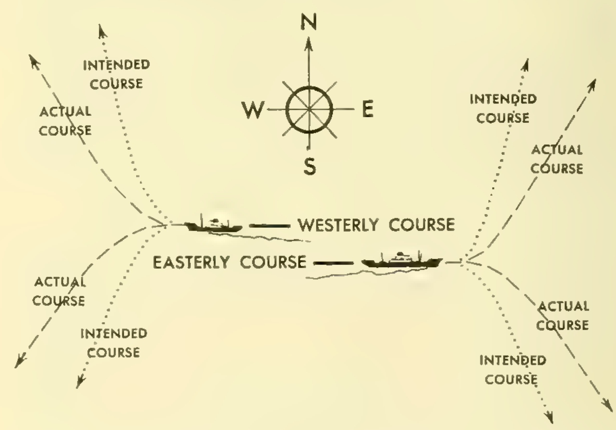
The mariner, with the aid of a small magnet, can quickly check his compass for defects of this nature by the following simple procedure:

Note the compass heading, then using the small magnet draw the north point of the compass card about 15° to the right. Next, remove the magnet and record the heading when the card comes to rest. Repeat the process this time drawing the card about 15° to the left. If the card comes to rest each time on the original heading, the compass is free of the mechanical defects mentioned. A final heading differing from the original indicates one or more defects are present and that repair is needed.

RETAINED MAGNETISM

A change in course after a vessel has been steaming or lying on the same heading for some time is always attended by compass error. This error is caused by the retained magnetism induced while the vessel was on that heading. The exact amount of error can only be determined by observation, but can be expected to throw the vessel in the direction of the last course. The general rules regarding the error to be expected are:

1. After steering for some time on westerly courses, expect:
   (a) Westerly error if you turn north;
   (b) Easterly error if you turn south.
2. After steering for some time on easterly courses, expect:
   (a) Easterly error if you turn north;
   (b) Westerly error if you turn south.



Retained magnetism induced in a vessel after lying or steaming on the same course for some time always causes the compass to hold back in the direction of the last course.

LOCAL MAGNETIC DISTURBANCE

There are a few locations in the world where the charts show areas, usually very small in extent and located in relatively shallow water, where local magnetic disturbance of the compass is caused by magnetic mineral deposits on the bottom. Although numerous reports have been received concerning local magnetic disturbances, it is often impractical to definitely establish whether the cause was external to the vessel. Therefore, only the most probable of these reports are shown on the charts subject to later verification or disproval.

Since magnetic force diminishes rapidly with distance, a magnetic center in the visible land would have to be of unprecedented intensity to affect the compass of a vessel ½ mile from it. Mariners may note a temporary deflection of the compass when very close to another vessel, a large mass of iron or steel or when passing over a wreck in shallow water. The influence radius in such cases, however, will be very small. If the compass continues to show erratic behavior the cause is probably within the vessel itself. In most cases, the trouble is attributable to some source of artificial disturbing influence, such as swinging booms, change in location of iron or steel gear near the compass, or defective electrical wiring in the bridge area. The ordinary phenomena of static electricity will not cause any noticeable deflection of the compass. Severe magnetic storms, often associated with sun spots or auroral displays, cause no more than a degree or so of deflection. Flashes of lightning, however, have been known to derange many compasses to the point of requiring complete readjustment.

Regardless of how well the gyro is operating or how well adjusted the compass may be, routine observations, to detect abnormal deviation, should be made once every watch and after a course change of 15° or more.

RADIO DIRECTION FINDERS

Due to the reliance placed on radio bearings in fixing a vessel's position, especially during periods of low visibility when celestial observations are unobtainable, the shipboard radio direction finder deserves the same care and consideration the navigator gives his sextant and the compass. Like these instruments, the direction finder has certain errors which can be minimized greatly by the skill and sound judgment of the operator. In order to obtain the maximum built-in potential of the equipment, it is essential that the navigator take every opportunity available to use the direction finder in good weather when results can be checked by other means. By so doing, the reliability of fixes obtained during adverse conditions can be more accurately ascertained.

Discussions on radio direction finders often refer to the effect of coastal refraction (land effect) stating that errors may be expected when radio bearings are taken by ships so located that the line of sight to the radiobeacon passes over land or along the shore. Extensive observations, however, seem to indicate that when the vessel is well off the shore this error is negligible. Bearings secured entirely over water areas are, of course, more desirable as any question of the coastal refraction error is thus eliminated.

Radio bearings taken on commercial entertainment broadcasting stations, on the other hand, should be viewed with extreme caution. The mariner must consider that the operating frequencies of such stations (550 to 1600 kcs), as compared with marine or aeronautical radiobeacons which operate well below 550 kcs, will require materially different calibration curves or compensation adjustment. Several other factors affecting reliability of bearings taken on such stations are:—the published position of the station may be that of the studio and not the transmitter site; the position coordinates have not been adjusted to the datum of the nautical chart being used; the transmitter may be located well inland, causing excessive coastal refraction error; and that the station may be synchronized with other stations, making identification of the transmitter impossible.

The navigator, considering all the foregoing limitations, may still be able to use certain commercial stations to good advantage. This can only be determined by carefully checking positions obtained from an individual station when the vessel's position is accurately known by other means.

The radio direction finder, like the compass, should be checked for deviation after changes in its surroundings have taken place and on a routine basis. It should be remembered that the compensated sets are just as vulnerable to changes in the position of ship's gear as are the non-compensated sets.

Each year the Oceanographic Office receives many inquiries asking why a certain aeronautical radiobeacon or light is not charted when it can be heard or seen for many miles at sea.

The Office welcomes all such inquiries and thoroughly investigates each one. The mariner should bear in mind, however, that these aids are placed for the maximum use of aircraft and not for surface vessels, a factor which must be carefully considered before placing these aids on a nautical chart. Many aeronautical radio aids and lights are moved from one area to another as seasonal wind and weather patterns change. The fact that such a relocation has taken place is not always made known immediately to maritime interests. The aeronautical radio aids listed in H. O. Publications 117A and 117B meet or surpass what the Oceanographic Office considers the minimum requirements for safe surface use. The aeronautical lights listed in the various volumes of Light Lists also meet this criterion.

SOUND SIGNAL CAUTION

The whistle, horn and bell serve as the principle means of communications for vessels to indicate or learn *presence* and *intent* or *fact.* The transitory nature sound transmitted by these devices has a significant bearing on their reliability as a navigational aid and a communications link. As now used, the various coded signals indicate not only presence but type of vessel (such as tug with tow, sail, or power-driven) and nature of the vessel's activity (such as underway, at anchor, backing down, or approaching a bend). There is a great deal of evidence to indicate that the failure to correctly hear or respond to sound signals is a major contributing factor in ship collisions.

A study of the testimony given following numerous collisions, resulting in damage in excess of one million dollars, occurring in good visibility under inland rules, reveals that the significant factor bringing about many of these collisions was the watch officer's belief that he had heard a signal other than that actually sounded. Inland rules require not only *establishment of intent,* but also *agreement* by the vessel signalled. With such a built-in safety factor in the rules, collision must then be the result of either human failure or overconfidence.

Let us look at the cause of one collision; where the main ingredient responsible has been experienced by almost every watch officer. A vessel approaching another desired to take the starboard side of the channel for a port-to-port passing situation and so indicated this by sounding one short blast. The blast, however, amounted to little more than a wisp of steam and a rather sick gasping cough barely audible on the vessel's own forecastle head. The watch officer, realizing that the approaching vessel could not possibly have heard the signal, sounded another short blast. This second blast was very clear and audible. Unfortunately, the watch officer on the signalled vessel observed the wisp of steam from the first attempt, but due to noise on deck had concluded that he had just not heard it. Then, both seeing and hearing the second short blast, he assumed that the other vessel had sounded two short blasts, answered in kind, and altered his course into a costly collision.

Overconfidence in the old saying "seeing is believing" certainly spoiled his day! The officer initiating the signals also lacked good judgment in sounding the second blast so soon after his first unsuccessful attempt. There appears to be a definite reluctance on the part of many watch officers to sound the danger signal, as required by the inland rules, when the intentions of the other vessel are in doubt. This reluctance probably stems from the desire not to unduly alarm the master, but the sounding of four or more short rapid blasts to indicate uncertainty is much less alarming than maneuvering a vessel on assumption and guesswork.

RADAR LANDFALL

One of the more hazardous situations confronting the mariner involves the approach to land during poor visibility, especially after several days of overcast weather conditions when sights of doubtful value have been obtained and uncertain currents encountered.

The situation is further aggravated when the approach course makes a small angle with the coastline; where, due to depth of water, soundings are of little avail, and there are offshore shoals and reefs to be avoided. The mariner's main objective in this situation will be to identify, without any doubt, some feature and determine the vessel's position relative to it.

Charts are constructed with the emphasis placed on depicting the most prominent visual features for identification, such as conspicuous spires, domes, tanks, towers and so on. While these objects may be excellent visual landmarks, they may be extremely poor radar contacts, particularly if previous radar experience in the area is lacking.

356-697 O - 69 - 4

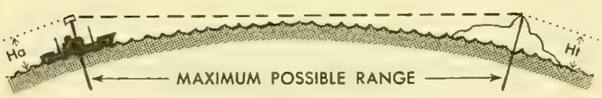
Preparation is therefore very desirable when approaching land in poor visibility with the aid of radar, so that the mariner may make a sound prediction of what should be seen and when. To do this, he must acquire a thorough understanding of the capabilities and limitations of his radar equipment, knowledge of the meteorological factors, either favorable or unfavorable, which will cause anomalous wave propagation, and some means of determining the distance off at which features of various heights will begin to appear above the radar horizon.

Radars operate in the frequencies that are essentially line-of-sight, but due to barometric pressure, relative humidity, and temperature gradient variations the waves are subject to some bending, either up or down, under certain atmospheric conditions.

The normal radar horizon is approximately 15 percent greater than the visual horizon at the same height. The approximate distance at which a feature will be on the horizon of the radar set is found by adding the distance of the radar horizon of the antenna to that of the feature, or can be computed by the formula:—

$$D=1.23\sqrt{Ha}+1.23\sqrt{Ht}$$

D = distance in nautical miles
Ha = height of antenna, in feet
Ht = height of target (feature), in feet



Radar horizon is 15% greater than visual horizon.

The following table gives the approximate distance to the radar horizon for a standard 3-cm radar under normal conditions for various heights of either Ha or Ht.

APPROXIMATE DISTANCE TO RADAR HORIZON

HEIGHT (ft.) Ha or Ht	DISTANCE OF RADAR HORIZON (N. M.)	HEIGHT (ft.) Ha or Ht	DISTANCE OF RADAR HORIZON (N. M.)
18	5	215	18
24	6	240	19
32	7	265	20
42	8	320	22
54	9	380	24
66	10	445	26
80	11	520	28
95	12	595	30
111	13	680	32
130	14	770	34
150	15	860	36
170	16	960	38
190	17	1060	40

(3-cm radar and normal conditions)

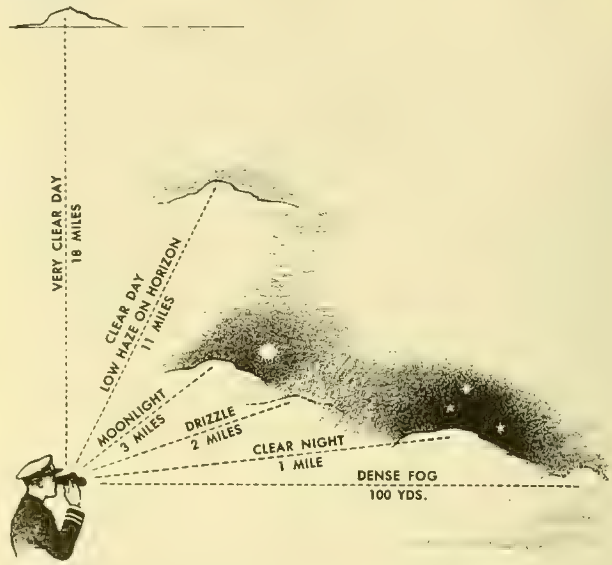
Inspection of the above table would indicate to the mariner whose radar antenna was 60 feet above the water, that a coastal bluff 80 feet high would not be visible on his radar scope until the vessel was within a maximum range 20.5 miles and the chances are that the bluff would have to rise above this maximum radar horizon distance before the reflected echo was strong enough to show upon the radar scope. The knowledge of the probable distances at which various objects can be expected to appear on radar will greatly assist in the accurate identification of various landfall targets. A more graphic means of showing target range can be had by constructing a simple curve on a piece of graph paper using the height of the mariner's own antenna based on the above table.

As with all other aids to navigation, the use of radar in good weather to check out target identification, ranges and skill of the operator will return valuable dividends when visual identification is not possible.

Regardless of how simple and direct the radar presentation may appear, it is essential that the navigator continue to employ all normal navigational techniques when in coastal waters. The navigator cannot afford the luxury of not maintaining a good dead reckoning position plot, a sharp eye on the soundings and awareness of the effects of set and drift conditions upon the vessel.

ICEBERG DETECTION

While any suggested signs, warnings or proposed methods of detecting the proximity of icebergs may prove of great assistance, they can be but supplementary to the eyes of an alert lookout. The old phrase that *the only sure sign of an iceberg is to see it* is still a very valid one. Over reliance in any other means could be extremely dangerous.



Distance at which a lookout can sight icebergs under various atmospheric conditions.

The distance at which a lookout can sight a berg varies, of course, with the state of visibility, height of eye and height of berg. On a very clear day a lookout stationed 70 feet above the water could sight a large berg up to 18 miles; in clear weather, with low-lying haze on the horizon, the top of a berg at 9 to 11 miles; in light fog or drizzling rain at 1 to 3 miles; and in dense fog about 100 yards. In light fog the lookout could sight a berg sooner if aloft, but in dense fog a position in the bow would be best. On a clear starlit night, a lookout will not sight a berg more than one-fourth of a mile away. If the bearing is known, however, this distance could be increased to one mile, with the aid of binoculars, by picking up the occasional spots of light as the swells break against it. On a bright moonlit night, a berg could probably be sighted up to 3 miles away.

As a general rule, there is no appreciable change in the air temperature near a berg nor in the water temperature surrounding it.

The presence of growlers and other pieces of detached ice usually indicates that a berg is in the vicinity and probably to windward. As growlers can cause considerable damage to a vessel, it is always best to pass a known berg on its windward side, especially at night or in low visibility.

The use of radar to detect the presence of bergs and growlers is certainly helpful, but often a large berg that has been sighted visually will not appear on the radar scope. This is probably due to the berg having a very smooth sloping side or because of sub-refraction which often occurs in ice areas. Many times, a berg detected by radar will disappear *again* from the scope as the relative positions of the berg and the ship change.

The detection of growlers by radar is even less certain. The echoes returned by these small bergs, which show only a few feet above the surface, are difficult to distinguish from strong sea clutter on the scope.

The following table shows the approximate maximum range that bergs can be detected by a 3-cm radar with the antenna located 50 feet above the water:

	HEIGHT ABOVE WATER	RANGE (N.M.)
Large icebergs	40—50 feet	12
Medium-sized icebergs	10—20 feet	9
Growlers	6—10 feet	2

PIN POINT ANCHORING

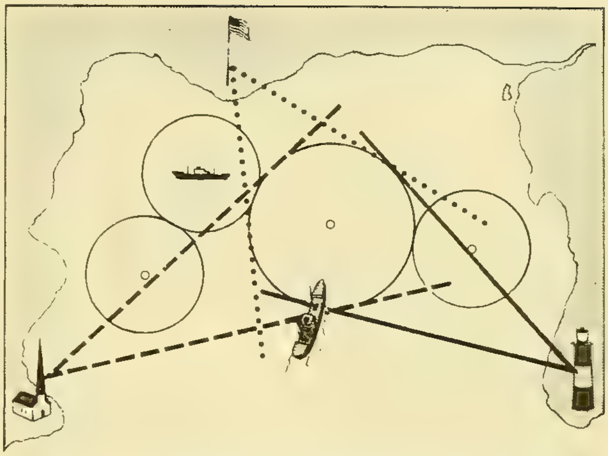
The following method of instantaneous plotting of a ship's position approaching and anchoring in an assigned berth has been found to be valuable in crowded anchorages.

A chart, preferably an anchorage chart of the area is prepared in the following manner:

Three or four prominent points or objects, preferably good radar targets, which give a coverage of the entire anchorage area as well as furnishing the widest possible angles of bearing are selected. From these selected points lines of position are drawn at 1-degree intervals covering the entire anchorage area, using a different colored ink for the lines drawn from each point or object. The bearing lines are extended beyond the anchorage area and the true bearing from the objects or targets marked on the extremities of the lines. Upon assignment of an anchorage berth, range lines in any desired increments are laid down in arcs with pencil from the selected points to the assigned berth. The prepared chart is now ready for use, overlaid with inked lines of position from the selected objects for bearing purposes and penciled arcs in the vicinity of the assigned berth for ranging purposes.

As the vessel approaches the assigned berth instantaneous fixes may be obtained, as rapidly and frequently as desired, merely by noting the bearings as the observer at the bearing circle gives them to the navigator at the prepared chart. The navigator simply marks the ship's position where the bearing lines cross. The radar ranges are also given at the same time as a further check on the ship's position. By setting a universal drafting machine or parallel rules on the ship's course line and placing same on latest fix any course changes are immediately apparent. A further refinement could be made by placing red-penciled range rings in increments of 100 yards from the center of the assigned anchorage berth in order to rapidly read off the remaining distance to the berth.

This method requires a navigation staff normally found on board a naval vessel. It may, however, be useful to the merchant navigator when assigned to a congested anchorage berth. It could also be used by a vessel regularly running a congested channel or restricted maneuvering area for obtaining positions, requiring only a minimum amount of time in the chartroom.



Simplified chart shows only bearing limits passing through desired anchorage. In practice, bearing lines at 1-degree intervals would be drawn from selected landmarks in different colors and marked at their extremities. Range circles, at suitable scale, would be drawn from center of anchorage to indicate distance remaining.

CONCLUSION

When one stops to consider that the *art* and *science* of navigation are a coalescence of astronomy, cartography, mathematics, geography, history and man's unquenchable desire to explore the unknown, it is easy to see that the skillful mariner must have a tremendous reservoir of facts, hints and common sense to fulfill his mission. The Oceanographic Office endeavors to assist the mariner in every possible field of safe navigation and solicits the mariner's comments and suggestions for the improvement of its products in a mutually beneficial program of maritime safety.

FISHERIES VESSELS AND GEAR

By J. N. Spinning
Maritime Safety Division,
U. S. Naval Oceanographic Office

The unprecedented expansion of fishing fleets throughout the world and the development of new fisheries and harvesting techniques are matters of ever-increasing importance to every watch officer. As encounters with the vessels, men, and gear competing for this rich protein supply become more frequent, the need for mutual safety will become more demanding. To adequately meet this demand watch officers need more than a seamanlike curiosity of those with whom they share the sea. This article explores the dominating factors which create, develop, and sustain a fishery, and fashion its tools of harvest

Today, there are well over one million vessels actively engaged in the time-honored fishing profession. Vessels range in size from the large factory mother ship down to the most primitive native canoe Each vessel, however, regardless of size, shape or means of propulsion, shares one common goal: to catch fish as efficiently as the circumstances permit.

The type of fishery and means of harvest play a significant role in the design and equipment of every fishing vessel. Although only a few vessels are so specialized that they can engage in just one fishery, most vessels are limited to one harvesting technique, or perhaps two for different seasons.

For generations prior to the Second World War, fishermen working from small vessels were content to fish the waters contiguous to their home ports. Relatively few ventured far from their native shores. World War II saw large numbers of fishing craft lost, destroyed, or rendered unseaworthy due to deterioration and neglect Faced with a hungry post-war population and a meager fleet, the fishing industry embarked on an urgent program of rehabilitation and expansion.

Stimulated by government, and aided by far-reaching technological advances in science, food processing, and harvesting techniques, the industry has made tremendous strides toward meeting the world's need for fish. This fact can readily be appreciated when we note that the total world catch has more than doubled during the past 15 years. Figures from the *Yearbook of Fishery Statistics*, now considered the most reliable source of what, where, and how much is caught, reveal that 217 countries, territories and island groups caught a total of 51.6 million metric tons of fish and other marine animals during 1964. The *Yearbook* also shows that of these 217, only 42 had catches over 100,000 tons and that they accounted for 95 percent of the catch. Only 12 countries had catches in excess of one million tons.

The following table shows the relative standings of the 12 major fishing nations based on the metric tons landed during 1964.

WORLD STANDING 1964

Position	Country	Metric Tons (Million)	Position	Country	Metric Tons (Million)
1	Peru	9,130,700	7	India	1,320,300
2	Japan	6,334,700	8	South & West Africa	1,254,500
3	Mainland China	5,800,000*	9	Canada	1,210,700
4	Soviet Union	4,475,800	10	Spain	1,196.600
5	United States	2,638,000	11	Chile	1,160,900
6	Norway	1,608,100	12	Denmark & Faroe Islands	1,010,200

*Estimated

CLASSES AND METHODS

Fish are classified as either pelagic or demersal. Pelagic fish are those species that live at or near the surface; included in this group are salmon, tuna, menhaden, mackerel, and herring. Demersal fish are those varieties that live at or near the bottom; included in this group are haddock, cod, rosefish, pollock, flounder, and all types of shellfish.

While there are virtually endless variations in the methods of harvesting fish, they can all be listed under one of three major groups: *direct attack*, *snaring* or *luring*. Direct attack embraces all techniques using such gear as harpoons, spears, dredges, rakes or tongs. Snaring covers all methods of making the catch by nets such as trawl nets, gill nets, purse seines, ring nets, or pound nets. Luring includes all forms of bait fishing where the fish or crustacean is enticed to bite a hook or crawl into a trap.

One fishing community may prefer one particular technique for harvesting the crop while a different method is favored elsewhere. The vital factors of capital to finance the operation, local market conditions, abundance of fish, and type of grounds all play key roles in the ultimate choice.

FOOD CYCLE

Relatively few of the more than 40,000 species of fish exist in sufficient concentrations to make commerical harvesting economically feasible. A large concentration of fish requires a proportionately large food reservoir. It follows, therefore, that commercial fisheries can develop only in those areas where the physical properties of the sea can support ample organic growth.

The food cycle is predatory in nature. It begins with tiny surface plants called *phytoplankton* using the sun's energy, through photosynthesis, to build organic tissue from dissolved inorganic materials in the sea. This involved process can only take place in the light-penetrated surface layers called the *euphotic zone*. These tiny phytoplankton serve to feed a multitude of small animals called *zooplankton*. Zooplankton provide the main source of nourishment for small pelagic fish which in turn fall prey to larger species of pelagic and demersal fish.

This food cycle tends to be long and inefficient when there is little change in the water layers within the euphotic zone. As the rate of surface water replenishment increases, due to upwelling and mixing of moving water masses, the abundance of marine life increases. Upwelling is caused primarily by water from the lower depths rising to replace the surface water which has moved away from the shore. This surface movement is due to the action of the prevailing alongshore and offshore winds coupled with the normal deflection caused by the earth's rotation. The resultant exchange of nutrients stimulates vigorous organic activity. It is in the areas of greatest upwelling and mixing that most of the commercial crop is harvested.

TRAWLERS

A frequent error made by watch officers, and lookouts alike, is the assumption that every fishing vessel sighted is a trawler. The basis for this assumption undoubtedly stems from the large number of actual encounters and the fact that they appear in all sizes and shapes. Trawlers may be broadly classed as either side or stern trawlers. Each class has definite characteristics which make accurate identification a simple matter regardless of size.

The key feature to side trawler identification is the pair of heavy A-frames they all carry. These A-frames, each fitted with a block, are mounted on one or both sides, with one located well forward and the other aft. A large winch is mounted on deck forward of the wheelhouse to handle the trawl warps. Once the trawl is streamed these warps are secured to a special towing block on the vessel's quarter. Trawling speeds vary from 2 to 5 knots.

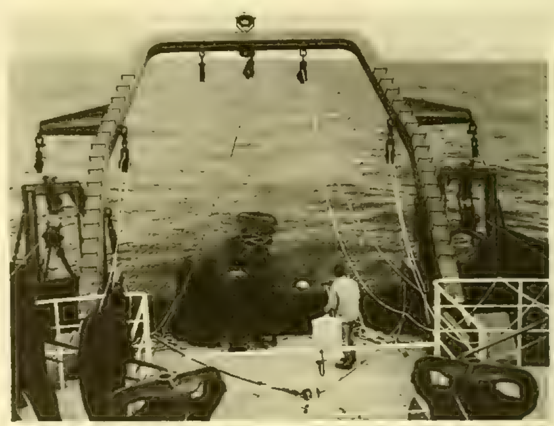
A typical North Atlantic side trawler is shown in figure 1. This 195-foot trawler, built by Brooke Marine Limited of Lowestoft, England, is arranged to trawl from the starboard side only, providing for spacious Officer's quarters on the port side. The vessel has an iced fish hold capacity of 18,200 cu. ft., a loaded speed of 14 knots, and a complement of 26 men.

Accompanying the trend toward stern trawler construction has been the increased interest in, and use of, mid-water trawling gear. Mid-water trawls permit vessels to fish either on the sea bed for demersal species or at any desired height above it for pelagic varieties. To accommodate this dual capability with one trawl requires some modification of the conventional otter board trawl. Many design concepts have been developed and tried with varying degrees of success. One promising design, however, is the versatile Grouselle trawl from France, shown in figure 3.

The Grouselle trawl has a trapezoidal-shaped opening with two triangular fillets between the wings and start of the cod end, a head line, and ground line. The float equipped head line trails behind the ground line which takes most of the strain during trawling. The head line is trailed as fish tend to dive in their attempt to escape the approaching net, an important consideration in mid-water work.

Figure 1 — *Photo—Brooke Marine Limited*

Figure 2



In recent years the trend in new trawler construction has been toward building stern trawlers rather than the conventional side types. Most stern trawlers over 150 feet in length are equipped with fish processing machinery, and excellent refrigeration or freezing facilities. Located near the stern, which often has a trawl slipway, is either a swinging gantry or a fixed gantry for handling the trawl warps.

On those vessels having the trawl slipway, the catch is hauled directly aboard via the slipway to the working deck where the fish are eviscerated and washed before being sent to the processing rooms. Stern trawlers without the slipway bring the catch over the stern by means of the hydraulically-operated gantry.

The 130-foot stern trawler *Seahorse*, built by Brooke Marine Ltd., is shown in figure 2. The design incorporates a soft nose stem, well flared bow, and a transom type stern with hydraulically powered gantry. This vessel has a 9,500 cu. ft. fish hold capacity, a loaded speed of 10.5 knots, and carries a crew of 18.

The Grouselle trawl

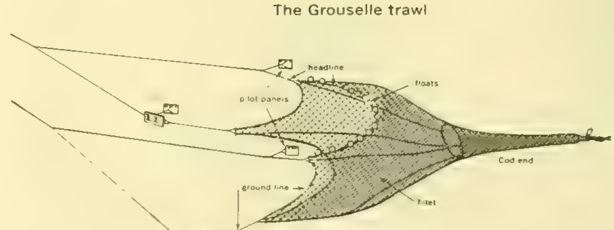


Figure 3

From the outboard ends of the head line, two upper lines are run to the towing warps well forward of the otter boards. A "Pilot" panel is secured to each upper line close to the point where it leaves the head line. These "Pilot" panels provide the necessary outward divergence to keep the net's mouth fully open in both a horizontal and and vertical plane.

Stabilization of the otter boards, which would have a tendency to capsize during mid-water trawling, is accomplished by securing a "Pilot" panel to each board. These stabilizing panels are secured by eye-bolts and assume a position during trawling outside of, and slightly higher than, the otter boards.

Prior to the development of special gear, such as the Grouselle trawl, mid-water trawls required towing warps six to seven times as long as the desired fishing depth. These extremely long warps made net handling slow and difficult. Now, with the aid of "Pilot" panels which cause rapid plunging as warp is paid-out or rising as taken in, towing warps no longer than needed for normal bottom work may be used for mid-water fishing as well.

Trawling has for many years been a dominant harvesting technique employed by the North Sea, Barents Sea, Iceland and Grand Banks fisheries. In the Pacific Ocean, both the Japanese and Russians operate large well-equipped trawler fleets off the Aleutian Islands and around the Sea of Okhotsk. Trawler operations require a substantial capital outlay which has held back development of important new fisheries in many of the less advanced nations. This situation, however, can be expected to continually improve as the world protein shortage forces these nations to look to the sea for survival.

PAREJA TRAWLING

The pareja trawl, or pair trawl, constitutes another major harvesting technique in which a net is towed over the bottom. Pareja trawling requires the services of two vessels steaming or sailing abeam of each other with the net towed between them. Spanish pareja vessels are a familiar sight in the waters between Morocco and the Irish coast including the Bay of Biscay.

Since pareja trawls are towed between two vessels, they do not need the heavy otter boards and associated gear to keep the net's mouth open. The resultant rig, being much lighter, also reduces net buffeting and damage to the catch. Pareja-caught fish, therefore, arrive at market centers in better condition than those caught by otter trawls. Less towing power and larger nets are additional advantages derived from the lighter rigs.

Figure 4 The 85-foot Spanish pareja vessel Ala-Izan (Fig. 4) was built by Hall, Russell and Co., Ltd. of Aberdeen, Scotland. This vessel is typical of the older vintage pareja craft still working.

A pair of pareja vessels, after streaming the net, take up station abeam of each other at a range of one-half to three-quarters of a mile apart. Towing speed is about 2 knots. As resistance on the trawl increases during harvest, this range is slowly closed until both vessels are close aboard at the end of towing period. Crews then take turns hauling in the net and stowing fish. Because of the close range involved during trawl recovery operations, fishing is usually limited to daylight hours. At no time should any vessel attempt to pass between a pair of pareja vessels engaged in fishing.

Pair fishing is also widely practiced by Chinese fishermen in the China and Yellow Seas using the traditional sailing junk with no power save the wind.

During the past few years, however, there has been an extensive modernization program underway in Hong Kong sponsored by the Fisheries Division of the Colony's Department of Agriculture and Fisheries. Through a development loan fund, fishermen are encouraged to put auxiliary power into their sampans and junks to increase their catching capability. Experiments have shown that catches made by powered craft are considerably higher than those made by similar craft without power. Increased catches and better marketing controls enable fishermen to pay back their loans and enjoy a better standard of living. Officials estimate that 65 percent of the Colony's more than 9,000 fishing vessels now have auxiliary power as a result of this program.

The fishing junk, with or without auxiliary power, is characterized by its two masts, low poop, and heavy windlass as compared with three and four masted cargo/passenger varieties.

Figure 5 Fishing junk

LONG-LINE FISHING

Small open boat long-lining, as once practiced extensively by the famed Grand Banks dorymen, has all but vanished from the list of principal harvesting techniques. Decline of this man-against-the-sea epic can be attributed to increased trawler activity, and a growing shortage of dedicated seamen willing to endure the hardships and loneliness of dory work.

Today, most commercially important long-lining is conducted directly from medium-sized, well-equipped, power-driven vessels. Lining does not dictate vessel design, therefore, a wide array of vessels are found within the various fisheries with no distinctive characteristic readily evident. Rather, it is the gear itself which reveals the most intelligence to an observer. Lining falls into two categories; subsurface and bottom.

Subsurface long-lining as pursued by Japanese offshore tuna liners is probably the most active and ambitious effort to be found in any fishery.

In essence, a long-line is merely a series of individual baskets of line joined together to form a continuous fishing rig up to 15 miles or more in length. Each basket, the basic unit of gear, contains from 600 to 2,000 feet of line.

In subsurface lining a main line, usually of nylon or wire construction, is suspended horizontally at the desired depth by means of glass buoyed float lines. Tuna main lines, for example, are set so that hooks will be between 50 and 300 feet below the surface depending upon species to be caught. In addition to the glass floats, a flagged bamboo pole marker is secured to each float line. These flagged markers serve to indicate direction of lay and to warn approaching vessels of the rig's presence.

At intervals along the main line, are fastened branch lines called *droppers*. The length of these droppers and the number used per unit of gear varies with different fisheries. Each, however, consists of a nylon or cotton section, a swivel, and a wire leader secured to a baited hook.

After the liner has set all her gear, she returns to the starting point and commences to work her way back along the rig. The main line is hauled aboard by a power-driven line-hauler. Once aboard, catch is removed, hooks rebaited, and gear reset.

Subsurface long-lining has proved highly successful for harvesting albacore, yellowfin, bluefin, and bigeye tuna. Identification of this gear is very simple due to the long string of glass floats on the surface, and the flagged markers.

Bottom long-line operating procedures are quite similar to those of subsurface lining. Instead, however, of suspending the main line, it is anchored to the bottom. Flagged bamboo pole markers are again used to mark the course and also the anchor sites. Glass floats are not required. Line hauling and baiting routines are carried out in the same fashion described for subsurface rigs. Bottom lining is the principal harvesting method used by the large halibut fishery off the United States Pacific coast. Figure 6 depicts a typical subsurface and bottom long-line rig.

A. Subsurface long-line rig B. Bottom long-line rig

Figure 6

DRIFTERS

Drifters, once the very heart of the British, Scandanavian and European pelagic fishing industry, have steadily declined in number over the past 20 years. Norwegian fishermen, for example, are substituting purse seines for drift nets with excellent results. In fact, Norwegian purse seiners harvested 400,000 tons of fish during 1964 in the North Sea alone. This was about one-half the total catch. Many British drifters have been converted to near-water trawlers, and now engage in demersal or pelagic fishing, depending on season and abundance of fish. Regardless, however, of their diminishing strength, drifters still contribute substantially to the total annual catch.

Drifters usually operate in fleets within 10 to 60 miles of their base port. Throughout the season, base ports must be shifted as fish migrations dictate but are always adjacent to the grounds being worked. Actual fishing operations are conducted only between dusk and dawn. During this period, a concentration of drifters present a formidable navigational hazard to any vessel wishing to transit the area. Radio navigational warnings are occasionally broadcast when concentrations of drifters are unusually large. If possible, the prudent watch officer should alter his course and go around the fleet. Timely action will not only prevent possible loss of an expensive net, but will save incalculable strain on the nervous systems of all concerned.

The 75-foot vessel Fragrant Rose (Fig. 7) was built by Herd and Mackenzie Limited of Buckie, Scotland. This craft is rigged as a drift net herring fisher

North Sea vessels average between 60 and 100 feet in length and are either steam or diesel-powered. Designed to bring in fresh fish, they operate on short trips and have limited accommodations for crew or provisions. Once nets are out, a small triangular or gaff-rigged mizzen sail is set to increase stability and keep vessel's head into the wind. A pivoted derrick boom and large capstan are located well forward for handling the catch. To reduce rolling, this pivoted boom is normally lowered and cradled on the wheelhouse roof when not in service.

Photo—Herd and Mackenzie Limited

Atlantic long-liner

Photo—U S Fish and Wildlife Service

Pacific halibut long-liner

The general migratory patterns of commercially sought pelagic species in the North Sea region are well documented by long experience. Individual vessels, however, still face the problem of precise location at a specific time. Although an important question in any fishery, it is more manifest in the case of drifters. For once the net is out, drift net fishing becomes the most passive form of all harvesting techniques. A catch depends solely on the fortuitous encounter with the net by a school. In selecting their grounds, fishermen rely heavily on past success, visual sightings, observation of bird activity, and more recently, on fish-finder sonar equipment.

The drift net can be described as a floating meshed wall. It is maintained in a vertical plane by floats secured to its head line and weights to its bottom line. Small buoys are spaced at intervals along the messenger line to indicate direction of lay and presence to surface observers. British drift nets average 60 yards in length and 10 to 15 yards in depth. A single drifter will *shoot* up to 100 or more nets, each joined to the next, forming a continuous wall of netting 3 miles long. After shooting her nets, the drifter rides moored to the downwind end until dawn when hauling commences. Mesh size is such that fish swimming into the net get partially through before becoming hopelessly entangled and held by their gills. Because nets are fairly close to the surface and hence visible to schools, all fishing must be done at night.

The foregoing resume of drift net fishing, of course, outlines the technique at its highest state of development. Drifting, however, is practiced at various stages of refinement throughout the world. Since power is not essential to the operation, many less advanced nations also utilize this harvesting method successfully using sailing craft and even canoes.

PURSE SEINES

Purse seines are the most productive harvesting implements employed by the pelagic fisheries. Unlike the passive drifting technique, purse seining is both active and aggressive with new schools continually being ferreted out. A typical purse seine is 2,000 to 3,000 feet long and 100 to 300 feet deep. The net is hung vertically in a circular fashion suspended between a surface float line and a weighted foot line. At intervals along the foot line are fastened seine rings, or eyes, through which a purse line is rove. Once a school has been encircled, the purse line is hauled-in on a power winch thus pursing or closing off the bottom escape route. Net sides are then hauled aboard the vessel, or into seine boats, until only the heavier bunt section remains. This procedure concentrates fish into one portion of the net where they can easily be brailed out.

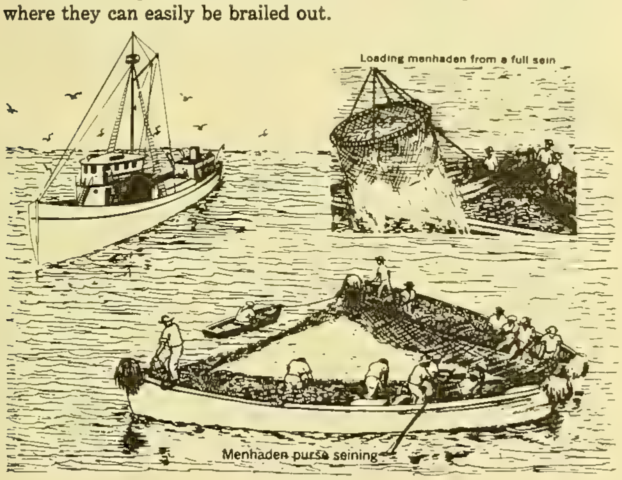


Figure 8

Purse seining as carried out on the United States Atlantic and Gulf coasts is centered around the menhaden fishery. More pounds of menhaden than any other single species are harvested annually by American fishermen. The 1964 crop was about 1.5 billion pounds. Menhaden are an extremely oily fish and except for the roe, which is prepared as a salted, frozen or canned product, are not a table fare. The meat is generally made into fertilizer and the oil used for industrial purposes. Some more highly refined menhaden meal is used in manufacturing animal and poultry feeds.

A menhaden purse seiner does not shoot the net herself. After a school has been sighted, a striker boat is dispatched to follow the fish while the purse boats carrying the net are launched. Using the striker boat as a guide, the purse boats quickly proceed to a point ahead of the school. There they separate, each carrying half of the net, and circle around behind the school. Meanwhile, the striker boat takes up station to tend the cork line during net retrieval. Encirclement completed, net ends are joined together. Pursing is accomplished by throwing a tom weight overboard to which both ends of purse line have been attached. Purse boat crews then commence hauling in excess net by hand to concentrate fish in the bunt section. The seiner maneuvers alongside and brails fish aboard. Figure 8 shows a menhaden purse seine set with purse boats hauling in net readying catch for brailing.

Purse seining is the predominant harvesting technique employed by the eastern Pacific tuna, salmon and herring fisheries. Nets in these fisheries are normally set directly from the seiner with the assistance of a small skiff. Nets are stored on large drums or turntables located aft to speed shooting time. When a school is sighted, the seiner maneuvers to a favorable position and sets one end of net into the water. The skiff tends this end and keeps it in position. The seiner then proceeds on a circular course to surround the school. After completing the set, net ends are joined and net pursed by a deck winch aboard the seiner. Figure 9 shows a West Coast drum seiner.

Figure 9 *Photo—U S Fish and Wildlife Service*

MADI VALAI

A very unusual and interesting net is the *madi valai,* or vertically-hauled net, used by fishermen off the Madras coast of India. Madi valai nets are worked in conjunction with weed lures designed to congregate fish over a particluar point. The lures, called *kambi,* are secured to a line having a float at one end and a stone anchor at the other. Water currents acting on the float stream the kambi line out in an inclined plane. Four catamaran type canoes, each handling one of the hauling lines, are paddled into position. Crews lower the madi valai horizontally to the desired depth. Next, they position the net under the kambi line and haul it rapidly to the surface by hand. Both demersal and pelagic species are harvested in this fashion.

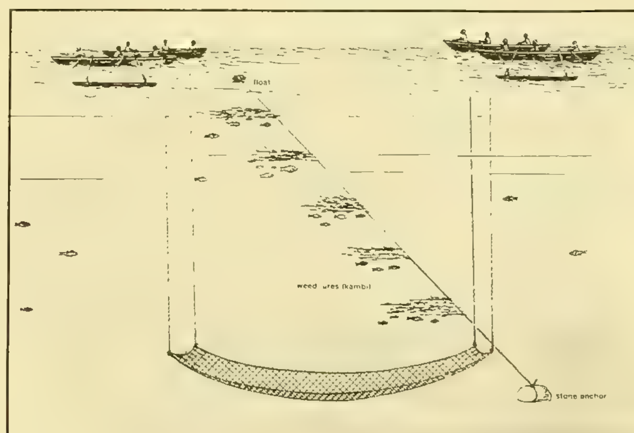


Figure 10 Madi Valai

SHRIMP FISHERIES

Coastal regions along the South Atlantic and Gulf coasts of the United States are richly endowed with excellent shrimp resources. This fishery furnishes more food, employs more people and supports a larger packing industry than any other in this geographical area. American shrimp fleets also travel far afield, with vessels working off Mexico, Honduras, Nicaragua, and Panama. Recently, vast new shrimping grounds were discovered off French Guiana. Some authorities believe the area contains the largest unexploited grounds in the Western Hemisphere. Estimates of the potential production capability have been set at 100,000,000 pounds annually. A new processing plant with dockside facilities has been erected at Cayenne, French Guiana, to handle the harvest. This plant will process 40,000 pounds of shrimp tails daily, and ship them in frozen form to the United States.

Mexico has a highly-developed shrimp fishery on both her Pacific and Gulf coasts. Over 1,000 vessels participate in harvesting the Pacific crop, with 300 craft working from Mazaltan, Mexico, alone. The east coast fishery is concentrated in the Gulf of Campeche. A substantial percentage of Mexico's rich harvest is imported by the United States.

Australia, Pakistan, Kuwait, and Nigeria are but a few of the many nations displaying considerable interest in developing commercially profitable shrimp fisheries. Any successful fishery must enjoy an abundant supply of raw material, adequate processing and storage facilities, good transportation connections, and the all important markets, domestic or foreign. Pakistan, for example, has a fairly abundant supply of shrimp but lacks sufficient local markets and distribution facilities. With the aid of modern freezing plants, however, Pakistan has been able to develop a good export trade.

Australia has a young and very promising shrimp fishery under development. Authorities, anxious to both expand and conserve the fishery, have embarked on a detailed research program to learn more about the migration, mating, and feeding habits of shrimp. Through such research and close cooperation with the industry, they hope to achieve maximum production potential without exploiting the crop beyond safe levels.

Shrimp live on the sea floor and are limited in their distribution to areas having muddy or sandy bottoms. With the exception of the Royal Red shrimp, which occur in depths between 175 to 300 fathoms, they are normally harvested in depths under 50 fathoms. Most shrimp caught are in their first year of life. Relatively few ever reach a full two year class. This indicates that a severe natural mortality rate sets in after the yearlings spawn. It soon becomes evident that a highly developed fishery cannot be sustained by a single year class without proper crop management.

Figure 11 Shrimp trawler

American shrimp fishermen harvest three major species in the southern fishery, which also embraces the Campeche grounds, white shrimp, pink shrimp, and brown shrimp. White shrimp are normally found in bays and inshore waters under 15 fathoms in depth. Fishing for this species is conducted during the day using conventional otter trawls having an average mouth opening of 80 to 100 feet. Pink and brown shrimp are usually taken in depths of 25 fathoms or more. Fishing for these two types is better at night. Vessels engaged in pink and brown shrimp fishing use double-rig trawls. Each trawl is 40 to 45 feet across the mouth, and is towed from an outrigger boom, one on each side of the vessel. To avoid fouling rigs, one trawl trails 150 feet behind the other. Double-rig trawls provide better catches, are easier to handle, are safer, and suffer less damage than the large, single type.

Before either trawl is streamed a small try-net, with a 10-foot mouth, is put over to determine if sufficient shrimp are present to make a drag worthwhile. Trawling times vary, but average between 2 and 3 hours. In addition to the shrimp that are harvested, considerable trash is picked up. This trash consists of fish, crab, shells, sponges, and other unwanted material. After the trawl is dumped on deck, the shrimp are removed from the trash, beheaded, and packed in crushed ice. The trash is thrown overboard again as no profitable means of processing it at sea has yet been found.

TUNAS

Tuna fish, or tunny as they are called in many fisheries, are truly an international resource, migrating over vast expanses of the tropical and subtropical seas. Although tuna fishing is pursued by most maritime nations bordering these waters, Japan and the United States harvest 90 percent of the world crop. France, Spain, and Peru also have very active tuna fisheries. While Japan's fleets range worldwide, the United States effort is concentrated in the eastern Pacific region, and around Hawaii. American tuna clippers from west coast ports fish from Canada to Peru, occasionally over 500 miles offshore.

Over a dozen species of tunas are taken by the various world fisheries, the five most important being: albacore, yellowfin, bluefin, bigeye, and skipjack. Albacore possess the whitest meat hence are the most valuable of all catches.

Harvesting techniques and paraphernalia vary widely. Around the Japanese archipelago, live-bait fishing is used for albacore and skipjack. Japan's offshore fleets employ long-line methods. American landings are almost entirely by purse seines. In the Bay of Biscay, French and Spanish vessels traditionally troll for tuna. Mediterranean fishermen still rely heavily on weirs and pound nets for their share of the harvest.

Since both long-line and purse seine fishing have already been covered, no additional discussion of those techniques, with regards to tuna, will be made.

Vessels engaging in live-bait tuna fishing must stop after leaving port and fish for small sardines, anchovies or smelts. This bait is kept alive in large deck tanks by circulating sea water until needed. Large clippers carry up to 15 tons of bait per voyage.

Schools are generally sighted by an experienced lookout stationed aloft. Some vessels have expanded their spotting capability by carrying a small seaplane, or by hiring free lance pilots working from coastal airfields for this chore. Once a school has been intercepted, the clipper is positioned and live-bait is thrown overboard to keep the school around. All available hands turn to during the ensuing period of intense fishing activity to fully exploit the school.

The crew fish from low-railed platforms secured to hull outside the gunwales. Fishing rigs consist of a barbless hook covered with feathers called a *striker* or *jig* connected by a short stout line to a bamboo pole. Excited by the live-bait, the tunas become so voracious they seize anything in sight. Upon striking the jig, the tuna is quickly pulled from the water and swung over the fisherman's shoulder, and deposited on deck. When fish run large, two, three or even four men will work together, each with a separate rod connected by means of a swivel to a single hook line.

TUNNYMEN

Tunnymen and tuna fishers in European waters bear no resemblance to the more spacious, elaborately equipped, Pacific tuna clippers. Vessels engaged in this important fishery off the French and Spanish Biscay coast are in the main, either powered craft called pinnaces, or large sailing and auxiliary powered yawls and ketches. The latter are usually under full sail presenting a picturesque sight with their brightly colored sails and hull. The number of these vessels still working, however, is small.

Sailing tunnymen range from 65 to 85 feet in length, carry a crew of eight and fish up to 500 miles from their home ports. The key features of sailing tunnymen are their fishing tangons (rods), fish drying racks, and absence of a wheelhouse. The two tangons are about 50 feet long with slightly curved ends. They are stepped by the mainmast, and are a common feature on pinnaces as well.

Each tangon carries 6 to 8 lines which trail astern of the vessel. Additional lines may also be trailed from each quarter. To these lines are fastened a brass or iron hook covered with horsehair. Once aboard, fish are gutted, cleaned, and hung to dry on rectangular framework racks located on deck. Voyages average 14 days on tunnymen without refrigeration and 21 days for those having such equipment.

Powered tunny pinnaces operate much closer to their home ports, often returning each night with their catch. During the winter months many of them fish for sardines along the coast. Vessels range from 45 to 60 feet in length. The tangons are stepped near the mast which is located aft between the engine room and stern. When not in use both tangons are lowered and swung forward to rest atop the wheelhouse roof.

SALMON

Figure 12

Wall carvings discovered in French caves bear witness that salmon were a popular food resource over 12,000 years ago. Time has not altered the salmon's standing, for today this fish still ranks high on the list of most valuable catches. During the space flight of *Gemini 4*, astronaut and seafood connoiseur James McDivitt had salmon on his flight menu. The 238 calorie portion was freeze-dried, compressed and dehydrated, all of which illustrates the remarkable versatility achieved in the processing of this fish. Before eating, the astronaut reconstituted his salmon dinner merely by adding water.

The Atlantic fishery is very small with salmon now considered more a game fish than a commercial crop. Once abundant, the great decline of the Atlantic stock is due chiefly to negligence. Impassable dams, overfishing with nets, industrial pollution and mass destruction of seaward-bound young in the water diversions to factories and power-plants being the prime causes.

The heart of the salmon fishery is located in the eastern Pacific Ocean, stretching from Alaska to southern California. There are five species taken in this prime area. These five, plus a sixth, are also found off northern Japan and eastern Russia. The world's major commercial effort is made in these two regions.

The life-cycle of the Pacific salmon is a most interesting one and plays a dominant role in the operation of this fishery. Females deposit their eggs in the gravel beds of small fresh water streams or lakes which empty into rivers leading to the open sea. After these eggs are fertilized by the males, each pair of spawned-out adults die. All Pacific salmon die after their single spawning season, while the Atlantic species generally return to sea. Throughout the winter, the eggs develop with young hatching in early spring. For about two months, the young salmon, called *fry*, live on the yolk sac which remains attached to their belly. Once this supply becomes exhausted, the fry push their way up through the gravel and become free-swimmers. Pink and chum salmon begin their seaward migration almost immediately, but the other species generally remain in fresh water from 1 to 4 years before migrating to sea. Salmon remain at sea from 2 to 5 years, depending on species and latitude, before returning to the streams of their birth. Very little is known about their sea years other than they scatter widely, and tend to stay in cold water.

The salmon crop is thus available to the fishery for only a short period of time over its entire life span. Fish not harvested during the returning migration are lost to the fishery forever, as they will all die after spawning. Too many spawners on the grounds can be just as detrimental to reproduction as too few. It soon becomes apparent that to sustain the species, yet exploit the crop to maximum safe levels, all fish over the number needed to reproduce the run should be harvested. The problem of determining the number of spawners needed is highly complex, and must be calculated for each individual stream. Additional spawning grounds can often be made available by the construction of fish ladders around obstructions, such as dams and waterfalls.

Salmon are harvested by a wide range of gear with purse seines, gill nets, and pound traps accounting for the largest shares. Trolling also is widely used in some areas. A typical troller is shown in figure 12. These vessels range from 25 to 60 feet in length and employ outriggers to keep lines clear of the vessel. In general, the fishing season is from late summer to early winter.

WEIRS, POUND NETS AND TRAPS

In coastal waters, natural estuaries, inlets and rivers, watch officers should always consider the possible danger to safe navigation presented by weirs, pound nets and fish traps.

A weir is an enclosure formed by fences of stakes entwined with branches and brush. This type of fishing gear has been used since the earliest days of civilization. Weir openings are usually placed some distance offshore, in a channel, or between islands to take advantage of the natural course taken by migrating schools. Long leaders running from shore to the weir's mouth aid in deflecting fish into the trap.

The main body is a circular or heart-shaped configuration formed by driving poles of various sizes into the sea floor. Brush is then closely interwoven between these poles to make the trap escape-proof. One or more brush leaders generally extend from shore to a point about 6 feet inside the mouth. Mouth openings are just large enough to permit fishermen to bring their dories into the trap. Once inside, they close off the mouth by means of a small drop net. A seine net, rigged in the pocket or crib, is used to concentrate catch for brailing. A typical Maine sardine weir is pictured in figure 13.

Dotting the Malayan shoreline is a very interesting variation of the weir called a *kelong*. These kelongs are fashioned from imported Indonesian nebong palm poles. Located offshore, in depths up to seven fathoms, they consist of two rows of pole barriers terminating at a trap end. Erected directly over the trap end is a sheltered platform where the fishermen live and work. A net is rigged inside the trap and is hauled periodically during the night by means of hand-operated winches on the platform. Fish are attracted to the kelong by the light from oil lamps which are placed close to the water's surface after dark. As there are no refigeration facilities on the kelong, catches are taken ashore each morning.

Pound nets are similar in many respects to the brush weirs. In their simplest design, they consist of three parts: (1) the leader, (2) the heart or wings, and (3) the crib. The name "pound" refers to the impounding of fish within the trap. The leader is a wall of netting up to 1,000 feet long supported by poles placed at intervals along the

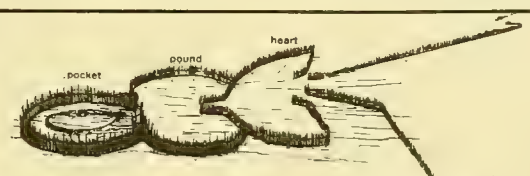


Figure 13 Sardine weir

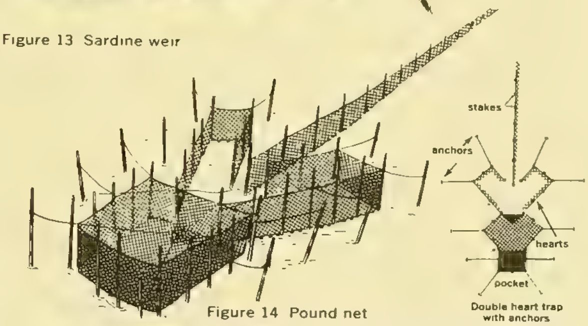


Figure 14 Pound net

route. At the offshore end of the leader, lies the heart, a net enclosure about 75 feet across. From the heart, fish enter the crib through the gate. Cribs are usually about twice the size of the heart and are made of much smaller netting. The crib section has a net bottom which, when raised, permits fish to be brailed directly from net to tender.

Fixed and floating traps may have more than one heart and crib, but are basically the same design concept.

OYSTERS

The oyster fishery is the oldest of all the known world fisheries. Primitive peoples in the earliest days of civilization harvested this food resource long before they learned to fish or hunt. Large shell mounds called *kitchen middens* have been found scattered along the coasts of Africa, Australia, Europe, and America. The size of these mounds indicate the great importance oysters played in the survival of these early inhabitants. Today, the oysterman is a true farmer carefully tending and cultivating vast underwater tracts. The economic importance is readily appreciated when we find that these submarine farms often return higher incomes than the best land farms do.

Oysters are a class of mollusks which have their bodies enclosed in a two-valve shell. They have no head and lack the muscular locomotive foot which other members of this group, such as clams, possess. Unable to see, hear or move, the oyster must lie motionless on the sea floor or attached to some underwater object. To offset the lack of vision and hearing, the oyster has developed a remarkable chemical sense. Tiny tentacles protrude beyond the edge of the mantle when the shell is open to taste the water, and detect light changes. A sudden change in light, or the presence of a toxic material in the water will cause the tentacles to contract. The stimulus of this action is passed through the mantle to the adductor muscle and the shell is closed. A tightly closed shell is the oyster's only means of defense.

LOBSTER FISHERIES

The delicacy of lobster meat and their high value per pound are valid barometers of the importance of this fishery. Disregarding minor specie differences, lobsters can be broadly classed as either true lobsters or spiny lobsters. The key distinguishing features of the true or Maine lobster are their large heavy crushing claws, stiff tail fan and smooth dark green body shell. This class is concentrated along the New England and Canadian coast.

Spiny lobsters have a much broarder range of distribution being found in the warmer coastal waters throughout the world. As the name implies, the legs and body shell are covered with short spines. Lacking the large crushing claws of the true lobster, only the tail section of the spiny lobster is worth processing.

South Africa is the world's largest spiny lobster producer. Australia, New Zealand, Japan and the West Indies also harvest a large crop of spiny lobsters annually, many of which are exported in frozen form. Commercial harvesting of all lobsters centers around the use of pots or traps. Although a wide variety of sizes, shapes and construction materials are to be found, the principle remains the same.

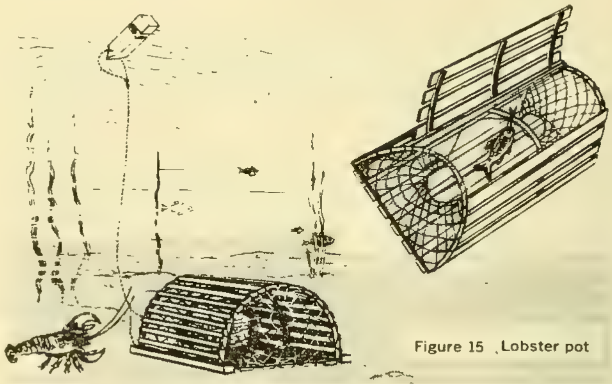


Figure 15 Lobster pot

A typical New England trap consists of an oblong lath box weighted with brick or stone and having one or two funnel-shaped openings. Bait, in the form of decaying fish, is hung inside the trap and acts to lure the lobsters in. While the bait last, the lobsters seem content to stay, but once gone, they are often able to escape the trap. For this reason, traps are hauled daily, if possible.

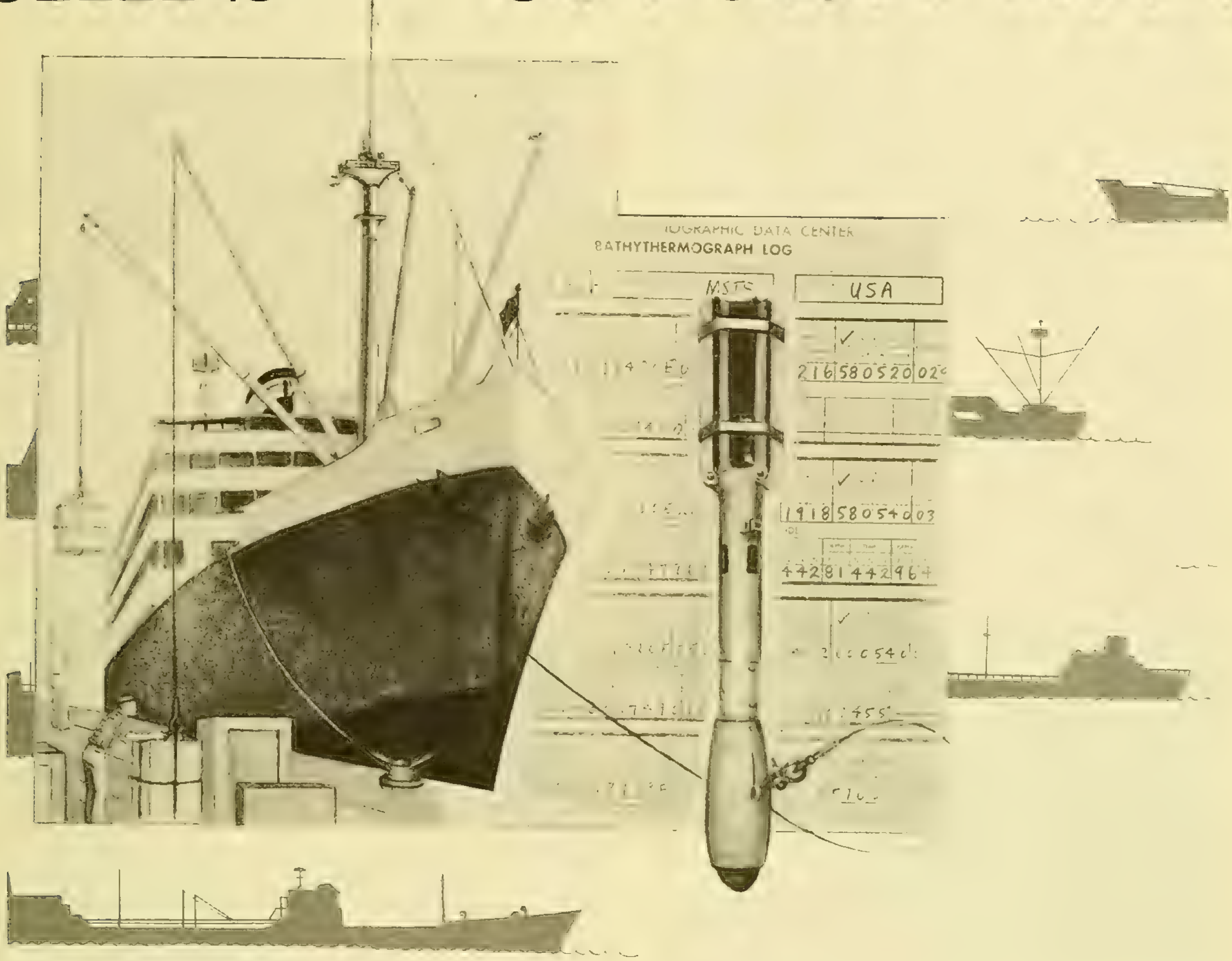
Most lobsters are caught in less than 30 fathoms of water. Buoys bearing the distinctive colored marking of the owner, are secured by warps to the traps, making identification easy. A single lobsterman can usually handle 100 traps under normal conditions.

CONCLUSION

It has been established that fishing is as old as man himself and that the paraphernalia employed to harvest the crop is infinite. The development of any commercial fishery is dependent upon a sustained demand, the physical properties of the sea, an abundant resource, a means of gathering, a mode of transport, and adequate storage. Regardless of how primitive or how sophisticated the endeavor, it is predicated on one of three basic techniques: direct attack, snaring, or luring. Further, each fishery requires either special vessels, gear or both to fulfill its mission. Finally, and perhaps most important, for any fishery to survive at a profitable level, some form of intelligent conservation program must be inaugurated.

Armed with this basic understanding of fishery operations, professional seamen can be expected to do more to make all encounters with the vessels, men and gear of this industry safe.

SHIPS OF OPPORTUNITY



By F. W. Fricker
Maritime Safety Division
U. S. Naval Oceanographic Office

During the past year or more, a number of scientific and maritime-oriented news media have made repeated references to the term "ships-of-opportunity". They were, of course, referring generally to those instruments of a unique method being recently employed by a number of agencies to conduct scientific research in the open ocean; the ships of the merchant marine.

The sudden surge of publicity in this regard was undoubtedly stimulated by two recent incidents which captured the imagination of the scientific press, aroused the interest of marine scientists, and attracted the attention of a segment, at least, of the U. S. Congress. Early in 1965 the U. S. Naval Oceanographic Office revealed plans to employ ships of commercial lines to gather oceanographic data, and the Office of Naval Research announced the successful completion of their PROJECT NEPTUNE. Although the primary objectives of the two projects were unrelated, the ships designated for participation became unofficially, yet appropriately, known as "ships-of-opportunity".

The origin of this, perhaps unusual, sobriquet is obscure. It can, however, be traced as far back as 1959 when additional ocean-going platforms were sought to assist naval units in support of a project the Navy calls ASWEPS (Antisubmarine Warfare Environmental Prediction Services). The project involved the development of thermal structure forecasting techniques in support of antisubmarine warfare operations, and was logically assigned to the Naval Oceanographic Office. That Office initiated a reporting system which consisted of a network of ships in the western North Atlantic Ocean. In addition to the conventional survey ships, all properly equipped naval vessels were directed to participate in the program. These units were later joined by U. S. Coast Guard vessels and ships of the Canadian Navy.

In order to increase the number of participating ships in the network, the Military Sea Transportation Service (MSTS)was requested to cooperate. That agency responded by making their large fleet available for the purpose, and their worldwide operations permitted a wide choice of platforms from which to fashion a more formidable network.

It is not clear to which category in this succession the title became attached, but due to the limitations imposed by schedules, routes, etc. of the latter group it can be surmised that MSTS ships were the first to be called "ships-of-opportunity".

The majority of the newcomers to the program were civilian-manned. Some were, for all practical purposes, purely merchant ships, being attached to the parent service by virtue of a charter. It is not surprising, therefore, that today the term has come to mean only those scheduled commercial and MSTS ships selected through expediency to perform oceanographic research. This context was further strengthened by the forementioned PROJECT NEPTUNE, sponsored by the Office of Naval Research primarily to demonstrate the feasibility of using merchant ships to collect biological samples in the vast reaches of the oceans.

In addition to being a name used to identify participating vessels, however, the title "ships-of-opportunity" is now thought of as embracing the entire concept of merchant ship utilization for oceanographic research purposes. The main feature of this unique means of obtaining scientific data that distinguishes it from regular programs is the specification that the acquisition thereof is not to interfere with the primary mission of the vessels involved. While this element naturally imposes certain limitations on the type of research that can be conducted, experience has shown that a number of worthwhile programs can be tailored to fit the restrictions imposed by the fixed route, high speed, and shipboard routine characteristic of merchant ship operations. Perhaps more importantly, the preciseness of berth liner schedules and their steadfast adherence to known routes present the scientific community with an unprecedented opportunity to plan and conduct a variety of research over the sea-lanes of the world. Indeed, it is this very singularity of purpose peculiar to merchant ships which provides the researchers with a simplex base from which to plan and outfit an expedition.

Because of the variety of studies involved in oceanographic research, ships-of-opportunity can mean different things to different people. Depending upon the aspirations of sponsoring groups, the types of research conducted in this manner and the techniques employed can vary from ship to ship. One or more programs can be conducted from a single ship, utilizing gear supplied by the researcher, or ship's equipment. The observations can be made by scientists embarked for the purpose or by previously indoctrinated members of the ship's personnel. Moreover, the data collected could be immediately processed and recorded in mobile laboratories temporarily deck-loaded or codified and radioed to specified receiving stations. Undoubtedly, other variations can be introduced to meet the requirements of many research projects.

The obvious flexibility of research activities permitted under this program is one of its more attractive aspects. It offers, at least, limited oceanic research capabilities to the many institutions now engaged in oceanographic work. It could provide them, at least theoretically, with an additional means of acquiring the special data they desire, and lessen their dependence upon other research facilities for needed information. As a companion benefit, any large usage of ships-of-opportunity would lighten the tremendous burden of routine survey and data collection responsibilities now imposed on our harried research vessels.

Probably the most attractive aspect of using ships-of-opportunity as oceanographic platforms is the relatively low cost per scientific observation that can be realized. This feature is afforded by the fact that the vessel's operating costs are covered by the steamship company responsible whether or not any research is conducted aboard. By comparison, all costs involved in the operation of a special research or survey ship must figure into the average cost-per-observation, and as a result, that cost is considerably higher. Another significant monetary saving is that which could be realized if scientific institutions were relieved of the outlay of funding the design, construction, and maintenance of numerous oceanographic research vessels. Under the ships-of-opportunity concept, these costs are defrayed by the merchant ship owners and operators. About the only financial responsibility to be met by the scientific community would be in designing, procuring and maintaining the scientific equipment used; transporting it to the ships; and paying the usual ocean freight charges, passenger expenses, and whatever shipboard labor costs that are incurred.

BORN OF NECESSITY

The concept of utilizing unconventional ships for oceanic data collection grew out of the need to augment the nation's research capabilities. The last two decades have witnessed a fantastic increase of scientific interest in the marine environment, as well as technological enthusiasm in exploiting oceanic resources. The increase has been understandably accompanied by a growing demand for field data. In addition to the extensive government sponsored programs, such as ASWEPS, many private institutions, both large and small, have become increasingly involved in oceanographic research. As their programs expand, new avenues of study come into focus which require precise field data for development; data which can only be provided by ocean-going platforms.

The demand for similar facilities is further heightened by the recently awakened interest in the marine environment by a growing number of scientists in so-called "non-oceanographic" fields, such as aquatic biology and biomedical physics.

For the most part, the burden of data collection in the open ocean has fallen to our comparatively small fleet of specialized research ships. In spite of several recent additions, augmentation of that fleet has not been proportionate to the demands for its service. Future increases in the size of the fleet will be limited due to existing budgetary restrictions. If we, as a nation, are to realize the anticipated development of our oceanographic programs, we must keep pace with the expanding requirements of its many components. The ships-of-opportunity program appears to offer one of the more likely means of attaining that goal.

NOT A NEW IDEA

Although the title "ships-of-opportunity" is a relatively new one, the concept of using the deck of a merchant ship from which to perform scientific experiments dates back to antiquity. Many of the early students of astronomy availed themselves of the observations made aboard trading vessels. Prior to the American Revolution, Benjamin Franklin took advantage of time spent upon merchant ships to personally investigate the Gulf Stream. One can well imagine the cooperative enthusiasm that this personable genius inspired among the ship's crew. His studies resulted in the printing of a chart showing the width, course, and speed of that current which was remarkably accurate for its time. Furthermore, his sampling and study of the "phosphorescent waters" led him to support the then revolutionary theory that the phenomenon was organically induced.

The exploits of Matthew Fontaine Maury are well known. Probably no scientist has ever utilized the observations made by mariners with greater results. Without the aid of a single survey vessel, his systematic examination and analyses of meteorological and hydrographic data recorded in myriad log books led to the genesis of a series of wind and current charts which were to revolutionize the world's trade routes. His "Abstract Logs", conceived and prepared by Maury to enable mariners to tabulate their observations, were the forerunner of the forms used by today's cooperating observers.

Perhaps even the work of Nathaniel Bowditch can also be included in this recap for although his computations were solely the result of his remarkable mind, Captain Bowditch availed himself of his crew's willingness to learn and thus was able to gear his classic navigational solutions to the intellect of the average seaman.

The U. S. Weather Bureau has utilized the ships-of-opportunity concept for more than 60 years in fostering the growth of a network of cooperative weather reporting ships. Today, the synoptic data received from their network, which includes many foreign flag vessels, enables the Weather Bureau to broadcast advisories and transmit weather charts by facsimile.

The direction and speed of ocean currents shown on Pilot Charts and in Current Atlases, particularly those not associated with the general circulation and those influenced by tidal action, have been determined over the years largely from drift and set information submitted by cooperating mariners.

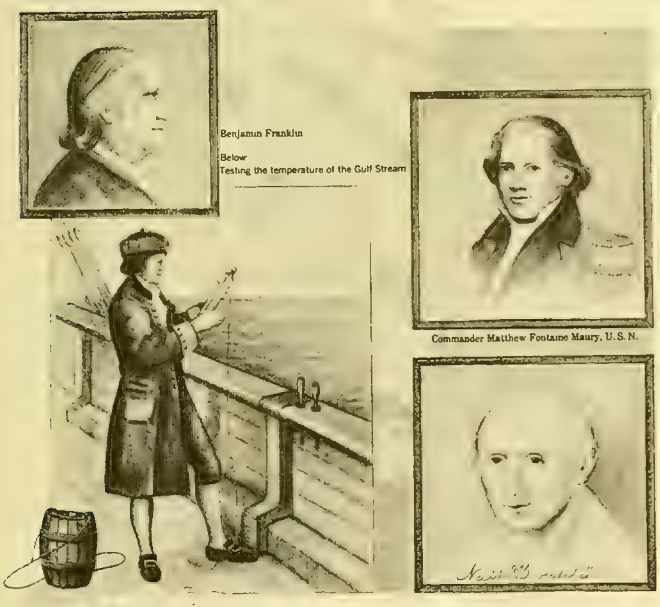
Thus, the research work begun by the far-seeing marine scientists of the past, made possible only by the cooperation of the mariners themselves, has provided us today with a sound background upon which to model and extend a productive ships-of-opportunity program. With a heritage such as this, the introduction of the scientist and his tools aboard modern merchantmen should prove of no hardship to the traditionally adaptable merchant seaman.

ASWEPS

In addition to the commercial and academic applications of synoptic oceanographic data, there is another, and perhaps more urgent, requirement. Scientists have long been aware that Sonar transmission can be deflected by water layers of differing temperatures, salinities, and/or densities, a phenomenon which affords submarines a distinct advantage over their surface adversaries. To reduce this advantage in favor of our antisubmarine forces, the U. S. Navy, under the coordination of its Oceanographic Office, established the Antisubmarine Warfare Environmental Prediction Services (ASWEPS) in 1959. The program was, and still is, experimental, its main purpose being to develop techniques in forecasting the ever-changing thermal structure of the sea. The area of the ASWEPS experiment was initially restricted to the western North Atlantic Ocean, but it has gradually been extended to include the eastern North Atlantic Ocean, Mediterranean Sea, and the Pacific Ocean.

At the outset, it was determined that ASWEPS development depended, to a large extent, on the regular receipt of oceanographic data, temperature-versus-depth information being the single most important environmental parameter required. To help meet this important temperature profile requirement, the Naval Oceanographic Office set up a network of reporting ships which consisted of the approximately 500 U. S. Navy ships that had previously been equipped to make bathythermograph (BT) observations. They were directed to make BT observations 4 times each day and transmit the results to the Naval Oceanographic Office for analysis. A composite of the data received has been used, as planned, for the preparation of synoptic sea surface temperature, sonic layer depth, and vertical gradient charts which are transmitted to the fleet and others by facsimile broadcast, similar to weather charts, or by radio message. These data have also been applied to the development of thermal structure forecasting techniques.

It was soon evident that the quantity and distribution of the data being reported was inadequate to provide the synoptic picture desired. Accordingly, a program was established to fill the data gap by utilizing various ships-of-opportunity, in this case, any vessels with a BT capability that were willing to participate. The first agency to cooperate in the program was the U. S. Coast Guard, but shortly thereafter the Bureau of Commercial Fisheries, the U. S. Coast and Geodetic Survey, various private institutions, and foreign governments were also cooperating.



Benjamin Franklin

Below
Testing the temperature of the Gulf Stream

Commander Matthew Fontaine Maury, U.S.N.

To increase the efficiency of the reporting network, a study was conducted to determine the feasibility of installing BT equipments on Civil Service manned ships of the Military Sea Transportation Service The study, begun in May 1959, proved extremely successful. Four MSTS passenger ships and one MSTS cargo ship operating routinely between New York and northern Europe were equipped with a BT-collecting capability. The Civil Service crews in these ships obtained and transmitted BT observations twice daily, when operating outside the 100-fathom curve, without any deleterious effect on the ship's primary mission. These ships increased the area of BT coverage by collecting their data along the sea lanes to and from Europe, thereby providing a dependable data input in areas where Fleet ships seldom operated.

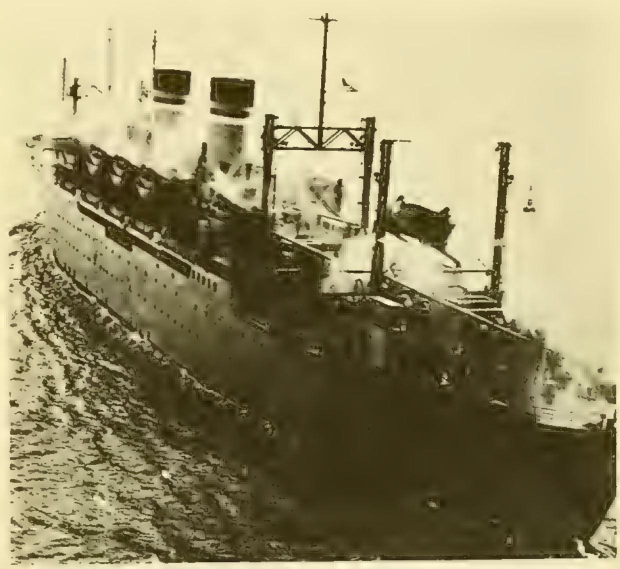
As a result of the success of this venture, additional MSTS ships in both the Atlantic and Pacific Oceans have been BT equipped. As of July 1 of this year 28 MSTS ships were regularly collecting and reporting BT data.

Various other governmental agencies and educational institutions operating survey vessels throughout the world were invited to participate in the program. Most of the organizations contacted responded favorably and are cooperating faithfully.

To effectively accomodate the expanding activities of ASWEPS, additional analysis groups were established. In October 1962, a Regional Analysis Group was initiated under the auspices of Naval Weather Service at Fleet Weather Central, Guam. Then, in January 1964, the Pilot ASWEPS (PASWEPS) Centre was established in London by the British Admiralty (now Hydrographic Department, Ministry of Defence). This year, additional analysis centers have been established in Rota, Spain; Pearl Harbor, Hawaii; and Alameda, California.

The initiation of the analysis system at Guam precipitated the idea of soliciting the cooperation of all friendly nations operating BT-equipped ships in the western North Pacific. As a result, BT data is now being received from Australian, British, Hong Kong, Japanese, Korean, and New Zealand ships operating in that area.

Nations operating Ocean Station Vessels in the eastern North Atlantic PASWEPS area regularly transmit reports to the central in London. These participating countries, besides the United Kingdom, include Denmark, the Netherlands, Norway, and France.



In May 1959 the USNS GEN. WILLIAM O. DARBY was BT-equipped and commenced reporting into synoptic network.

Despite the apparent size of the growing network, the amount of BT data received daily remained inadequate for conclusive analyses of the sea's thermal structure. Pursuant to the primary objective of the program, the search for potential BT data platforms continued. For all practical purposes, the only extensive source of ocean-going platforms that remained untapped for oceanographic data collection was that of the commercial maritime industry.

More than 18,000 commercial vessels of over 1,000 gross tons now ply the world's oceans, 900 of which fly the American flag and many more are American owned. While the concept of utilizing these vessels for oceanographic data collection had been discussed for years, little or no organized effort had been made to exploit this source.

A study was initiated by this Office to determine what improvement could be made in the synoptic data distribution by utilizing these ships-of-opportunity. By simulating a plot of selected merchant ships embarked on scheduled voyages and assuming that they were reporting BT data at prescribed intervals, a marked improvement in the distribution of synoptic data was theoretically achieved throughout the network.

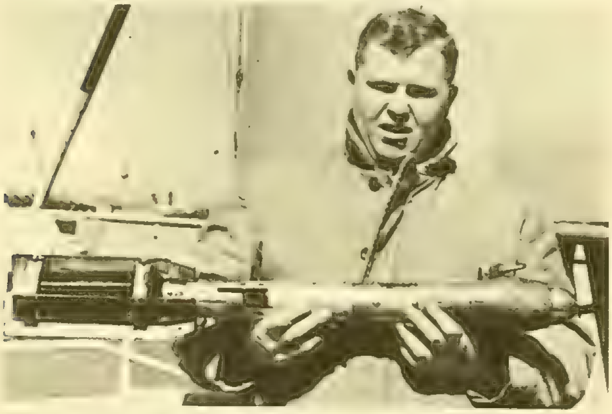
Encouraged by the results of the study, the Naval Oceanographic Office issued a proposal through the American Merchant Marine Institute for commercial steamship companies to participate in a pilot project to determine the feasibility of employing commercial ships for the acquisition of BT data. The pilot project would involve the outfitting, training, and evaluation of five or six commercial ships. It was specified that participation in the BT program was not to interfere with the primary mission of the ship.

The proposal, still valid, states that participation entails the installation of a 515 pound hoist on the port or starboard quarter of the ship the precise location being determined by the shipowner. The hoist drum is designed to hold 3,000 feet of 3/32-inch stainless steel wire rope. Further installation includes a 10-foot retractable boom which is fastened to the rail adjacent to the hoist. A supply of 2 bathythermographs, each a torpedo-shaped mechanical instrument weighing about 40 pounds, will be maintained aboard ship. All costs related to the installation, fabrication, supply, and calibration of the equipment are borne by the U. S. Navy.

Since the project is predicated on the ship's personnel operating the equipment, a representative of the Naval Oceanographic Office boards each ship to indoctrinate the crew in the program and explains the methods of recording, interpreting, and transmitting the BT data. A minimum of three days deep sea steaming time is required for training.

The procedure to be followed by the crew members assigned is quite simple. BT observations can be taken at speeds up to 16 knots. An observation is to be made twice daily at 0800-0900 and 1600-1700 local time when the ship is operating north of the Equator in depths greater than 100 fathoms. The launching and retrieving operation requires 2 men for a total of approximately 10 minutes. A glass slide, inserted in the BT prior to each observation, is etched with a permanent trace of temperature versus depth. Upon retrieval, the slide is placed in a viewer, the data recorded in a BT log book, and a coded message drafted. Logging the information and drafting the message requires about 10 minutes. The coded message (BATHY) is similar to a weather message and is transmitted to an appropriate analysis center during a normal radio watch as soon as possible after the observation is made. Accumulated BT log sheets and slides are mailed to the National Oceanographic Data Center, Washington, D. C., upon each return to the continental United States.

The maritime industry's response to the proposal was immediate. The first sucessful contract for the utilization of ships of a commercial line in the BATHY network was inaugurated on 1 February 1965 and soon thereafter the SS *African Rainbow* became the first of a new class of ships-of-opportunity. As of July 1, 1966, eight additional ships have been integrated into the ASWEPS system, and are reporting BT data as part of their daily routine.

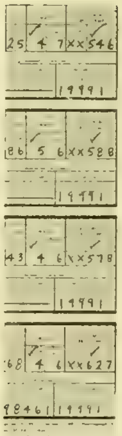


NAVOCEANO representative, holding the torpedo shaped bathythermograph, travelled aboard the AFRICAN RAINBOW from New York to the Canary Islands to collect data and train the ship's personnel on the proper operation of this device.

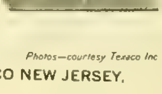
THE NEAR SURFACE REFERENCE TEMPERATURE SYSTEM

The procedure of taking and recording sea water temperatures is practically as traditional aboard ship as relieving the watch. The measurement is an important part of the weather reports submitted by weather reporting ships. It is a routine entry in the engineering log book. Survey vessels use sea surface temperature as a reference value in bathythermograph observations. Ship's officers are requested to include it when reporting on observed phenomenon to this Office. In short, the temperature of the sea has long been of scientific importance.

Sea surface temperature observations, when regularly received from a dense network of reporting platforms, can be used to construct sea surface temperature charts which have a number of important applications. In addition to the military aspect, surface temperature charts are now being utilized by the fishing industry to predict the shoaling behavior of certain popular fish, such as tuna and salmon.



BT log sheet and slide



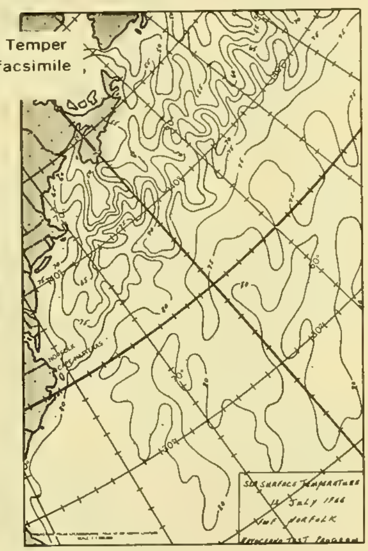
Photos—courtesy Texaco Inc

Crewmen taking BT measurements aboard the TEXACO NEW JERSEY.

As an example of this application, the U. S. Bureau of Commercial Fisheries publishes such a chart showing a 15-day synopsis of surface temperatures along the west coast of the United States.

Unfortunately, the majority of surface temperature measurements reported by ships are generally obtained from the ship's intake thermometer, an instrument of questionable value for measuring sea surface temperatures. The World Meteorological Organization, Commission for Instruments and Methods of Observation (1957), concluded that "intake temperatures suffer from lack of proper location of the thermometer, from unsatisfactory thermometers, and from crudeness (sic) of reading or timing".

To improve the quality of reported sea surface temperatures, the Naval Oceanographic Office conducted extensive tests in the laboratory and in the field to determine the effectiveness of various sea surface temperature measuring devices. The tests consisted of a comparative analysis of the classical devices and a newly developed device now commonly known as the Near Surface Reference Temperature (NSRT) System. The new device consists of a thermistor probe installed in the intake and electrically connected to a temperature indicating meter on the bridge. (See below.) Instantaneous measurements of surface temperatures can be obtained by merely depressing a button, thus permitting the watch officer to make the reading. The intake probe and meter readout proved especially promising from the standpoint of dependability, accuracy, and convenience.



Typical synoptic Sea Surface Temperature Chart as received by facsimile broadcast.

NSRT—Near Surface Reference Temperature meter and thermistor probe.

In late 1964, the U. S. Naval Oceanographic Office, in connection with ASWEPS, invited the U. S. Weather Bureau, Coast Guard, MSTS, and the Fleet to install and operate 125 systems. Upon completion of this pilot program, installations will have been accomplished on proportionate numbers of Coast Guard vessels, cargo and tank vessels of the MSTS, destroyers and aircraft carriers of the Fleet, commercial ships participating in the U. S. Weather Bureau cooperative weather reporting program, and several oceanographic research vessels. This wide variety of sea-going platforms is truly representative of the modern concept of ships-of-opportunity.

Experience gained in connection with the NSRT program will be used as the basis for further standardization of equipment and techniques. Meanwhile, shipboard personnel will appreciate the NSRT's capability for accuracy and the ease with which the observation can be made.

In addition to the observations required by the synoptic network, selected ships-of-opportunity having the necessary sounding equipment have been requested to record the depth and thickness of the *Deep Scattering Layers* wherever encountered. The data thus accumulated is forwarded to the Naval Research Laboratory for analysis in conjunction with their continuing studies of that biological-induced phenomenon.

PROJECT NEPTUNE

On October 19, 1964, the 8,000 ton American Mail Lines freighter, the SS *Java Mail*, departed Seattle, Washington, bound for Yokohama, Hong Kong, and other ports in the Pacific and Far East. From all appearances, the ship was embarked on a routine voyage. She was laden with a cargo consigned for another continent, and her officers and crew went about their work just as they had on many previous voyages. On this occasion, however, a Navy trailer van was lashed to the after deck and a six-man scientific party was berthed in the ship's cabins. Quite incidental to her task of delivering her cargo to foreign ports, the *Java Mail* was participating in the U. S. Navy's PROJECT NEPTUNE.

PROJECT NEPTUNE was executed to determine the feasibility of collecting biological oceanographic research data from a merchant ship without interferring with the routine of the ship's operation. By this singular demonstration, the Office of Naval Research, sponsor of the undertaking, hoped to establish the practicability of the concept of a fleet of "research ships-of-opportunity" (RSO's), specifically, ships of the American Merchant Marine. The project was the culmination of NRL's long standing desire to prove that concept and brought together the interests and resources of the General Motors Defense Research Laboratory which developed special sampling devices for the experiments; the Naval Missile Center at Point Mugu, California, which provided the laboratory van; and the American Mail Lines, which arranged for the *Java Mail* to serve as the first experimental RSO. In addition, PROJECT NEPTUNE received considerable encouragement from members of the staff of Congressional committees concerned with oceanography, particularly the House Committee on Merchant Marine and Fisheries.

This particular variation of the ships-of-opportunity concept features the deployment of a mobile laboratory with a team of onboard scientists to perform all of the duties connected with the scientific mission. The latter element is to enforce the "not-to-interfere" principle of the original idea. The mobile laboratories designed for RSO's could be stored at central or regional depots. When needed, any appropriate group of scientists could rent, lease, or charter one or more from the depot and arrange to have them transported to the port where the selected RSO is docked. The laboratory unit would then be hoisted aboard the ship and either fastened to the deck or placed in a hold, as appropriate. When necessary, the unit would draw upon ship's power and utilities, although, preferably, each laboratory would be a self-contained unit, independently powered. The scientists and technicians accompanying the laboratory would utilize the tourist accomodations of the host ship.

Demonstrating as many of these basic conditions as possible, the *Java Mail* proceeded upon her scheduled voyage. During its Pacific crossing, the vessel served as a platform for a variety of oceanographic investigations. Plankton samples were taken with a "jet-net", a bullet-shaped pod specially designed to collect undamaged specimens at the surface of the ocean while being towed at a relatively high speed. The vessel's main injection was used to take plankton samples and record sea water temperatures. Three times a day the group obtained bathythermograph data to a depth of 1,500 feet utilizing an experimental high-speed expendable bathythermograph. A thermistor was towed astern which measured water temperature continuously. Continuous atmospheric samples were taken recording radiations and other values. Water analyses were made to ascertain salinity, chemical composition, and oxygen content. Disposable radio transmitters were put into the sea and tracked periodically. Finally, drift bottles were cast overboard every eight hours.

The results of all tests and samplings were quite encouraging. By the time the *Java Mail* arrived at Hong Kong, all scientists aboard were completely convinced that the project was a great success and that the use of a merchant vessel for oceanographic work was entirely feasible.

On 22 January 1965, the House of Representatives Subcommittee on Oceanography of the Committee on Merchant Marine and Fisheries met in Washington, D. C. The purpose of the meeting was to bring together the oceanographic interests of the government and industry to hear, first hand, the results of PROJECT NEPTUNE and to evaluate, generally, the ships-of-opportunity program. At adjournment one thing was apparent: the nation's legislative, scientific, and industrial leaders involved in oceanography were in complete accord that the ships-of-opportunity concept was sound.

In July 1965, a further experiment in PROJECT NEPTUNE was carried out in the Atlantic Ocean, utilizing the SS *Export Champion* of the American Export-Isbrandtsen Lines on its New York-Rota-Genoa run. A mobile laboratory was transported to the departure point, in this case, New York Harbor, secured aboard with the aid of Naval Oceanographic Office and General Motors technicians, and in less than 48 hours the vessel sailed with an operating unit of five persons embarked. During the voyage, two types of expendable BTs were successfully streamed, the BT data acquired being sent to Fleet Weather Central, Rota, Spain. General Motors had installed a device that directly digitized the input onto a radio-teletype tape, to the dismay of FWC, Rota, which had not expected a merchant vessel to possess this capability. The high-speed net tow (jet-net) was damaged during the Atlantic crossing by being pulled against the ship's side by propeller action. It was rebuilt in Rota and successfully operated on the Rota-Genoa run. The continuous recording water temperature probe unit (NSRT) installed by NAVOCEANO operated successfully throughout the cruise.

PROJECT NEPTUNE, Atlantic, was considered by project officials to be a definite success in demonstrating that oceanographic units can be quickly mounted aboard merchant ships with little in-port installation time and no shake-down, and that the basic sensors can operate at 19 knots across an entire ocean without interfering with a ship's normal operating procedure.

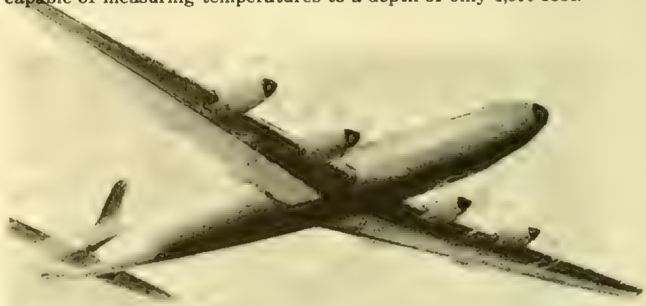
In another experiment, the Department of Interior's Bureau of Commercial Fisheries instigated a 14-month test project utilizing the Matson Navigation Company's SS *Californian* as a ship-of-opportunity. Using an expendable device, crew members of the *Californian* obtain temperature data every 6 hours to a depth of 1,500 feet along its track from Honolulu to San Francisco. These data are of interest to oceanographers in general and of vital concern to the Bureau of Commercial Fisheries in its study of the seasonal and year-to-year variations of the California Current region. Here, in an area that was once an opulent sardine fishery, large quantities of albacore, salmon, mackeral, bluefin tuna, and game fishes are taken each year, and major resources such as anchovy and hake exist untapped. Proper monitoring of the environment will be an important element in assuring that these resources may be utilized now, yet maintained for future generations to exploit. The success of this experiment will undoubtedly encourage a further and more extensive use of ships-of-opportunity for fishery research.

DISCUSSION

The cumulative successes achieved during these modest experiments with unorthodox research platforms has assuredly earned a place for the merchant ship in all future programming of the nation's oceanographic effort. Even at this relatively early stage of development, the theory that ships-of-opportunity can greatly expand our oceanic research capabilities has been soundly proven. A post analysis of their accomplishments thus far shows that valuable raw data concerning the sea's thermal structure can be provided by these ships over large portions of the oceans. Viable specimens of surface organisms can be taken at relatively high speeds with the prototype jet-net, and surface waters can be analyzed for almost any parameter known. The most surprising aspect of the several programs attempted is that this much has been achieved, for the most part, with "on-the-shelf", practically obsolete, instrumentation.

Because of the lack of more sophiscated instrumentation, the ships-of-opportunity programs are, at the present time, severely restricted in the types of observations they can make. In the case of the bathythermograph program, expansion of the network utilizing ships-of-opportunity has one serious limitation. A ship must slow to approximately 12 to 16 knots for 15 to 20 minutes while streaming a bathythermograph. The number of American Flag commercial ships operating at the low speeds acceptable for mechanical BT observing is at present very small and decreasing steadily each year. Furthermore, available MSTS platforms will have been exhausted in the near future. Therefore, if the Naval Oceanographic Office is to continue to engage in a vigorous BATHY Network expansion program, a capability must be developed to enable vessels to make BT observations at speeds up to 30 knots. Accordingly, utilization of an expendable BT system is being planned for ships-of-opportunity beginning in Fiscal Year 1968. This system should make the entire American Flag fleet of approximately 900 ships available as potential synoptic network participants.

In spite of the amazing successes in recovering biological samples at high speed, there are no readily available instruments that can duplicate the feat at any significant depth. The Near Surface Reference Temperature (NSRT) System, now being installed on many participating ships, will provide a vast improvement in a synopsis of surface temperatures throughout a given network of ships. The system is, however, still in an experimental stage which will preclude, for the present, mass production of the instruments involved. The expendable bathythermographs, types of which several manufacturers have introduced, are, at the present time, capable of measuring temperatures to a depth of only 1,500 feet.



Para-Buoy.

Airborne instruments such as the ART (Airborne Radiation Thermometer) and the AXBT (Airborne Expendable Bathythermograph) have been developed and employed on an experimental basis, adding the element of great mobility to the synoptic coverage of the oceans. Here again, the high cost of instrumentation may prohibit the immediate use of large numbers of aircraft for observational purposes.

It is generally conceded by all concerned that inadequacies exist in the synoptic type oceanographic data currently available for both research and development and operational analyses and forecasting. They can be summarized as follows:

(a) Insufficient number of observations.
(b) Inadequate distribution of data points.
(c) Variations in instruments, exposure, and observational procedure.
(d) Crude and inaccurate instrumentation.
(e) Limitations in acquiring certain required observations.
(f) Locating error in navigation.

Some of these inadequacies will eventually be resolved as a result of instrumentation development now underway and planned. When available, new instruments will result in greater accuracy of observation and permit acquisition of additional required parameters such as salinity and sound velocity of the marine environment at greater and greater depths. Standardization of instruments such as the NSRT and the expendable BT will refine the quality of data by improving instrument exposure and observational procedure. Eventually, the use of navigational satellites will reduce the data positioning problem.

With the possible exception of moored oceanographic platforms (buoys) still being developed, and the planned employment of aircraft for synoptic observations, none of the above efforts is directed toward solving the problem of inadequate data distribution. The efforts directed toward enhancing data accuracy and sensing additional elements may, in fact, deter solving the data distribution dilemma for at least the immediate future, because of the great unit cost often related to instrumentation development. As an example, the STD (salinity-temperature-depth) System being developed under the ASWEPS program will provide more data, with greater accuracy and at greater depths than now possible. Because of the relatively high cost plus installation and upkeep, however, the output from this instrument development will be limited to four data points in the North Atlantic for, at least, the near future. Present plans for utilization of the expendable BT's indicate that about 32 platforms will be outfitted and approximately 22,500 units expended during 1966. Here again, the expendable BT's will replace the mechanical BT on Fleet ships with no significant improvement in data distribution.

The data location or navigation problem is an inherent limiting factor in any ships-of-opportunity program. Most of the commercial ships available for this program employ LORAN A for navigation. Under normal operations at sea, LORAN is utilized only within several hundred miles of the coast, so that in mid-ocean greater errors than the optimum are common. From all indications, even new construction has made few provisions for precise positioning devices. It is also doubtful that commercial ships will convert to navigational satellite systems to any great degree in the next decade.

A program involving the development of highly accurate (and highly expensive) oceanographic instrumentation for employment on platforms which cannot provide companion accuracy in data location may not be realistic.

Therefore, the ships-of-opportunity program over the next few years must concentrate on synoptic data distribution. This is not meant to imply that ultimate data accuracy and instrument sophistication is not required. In the immediate future, while instrument availability and costs of sophisticated instrumentation are limiting to mass distribution, considerable advantage can be gained in developmental forecasting by utilizing less refined (and less expensive) gear to obtain wide data distribution at frequent intervals. Implementation of this concept will undoubtedly see a greater and greater expansion of the commercial fleet of ships-of-opportunity.

Once the necessary instruments become available in the quantity desired, the number of potential ships-of-opportunity can be equated to the number of U. S. Flag and, perhaps, U. S. owned merchant ships. With this vast fleet theoretically at our disposal at some future date, definite plans for its utilization are now being made. The Naval Oceanographic Office, in collaboration with other interested Offices of the Navy Department, is considering the development of an oceanographic system consisting of a transportable oceanographic laboratory, manned by one person, capable of obtaining oceanographic and meteorological measurements in ships-of-opportunity at speeds up to 23 knots. The laboratory van would contain essential instruments and equipment, including expendable sensors, to accomplish this mission. It would be self-sustaining with respect to electrical power and essential services. It would be of light, rugged construction, fully weatherproof, transportable to and from port areas by truck, rail, or air and designed for simplified loading and offloading from ships of various sizes and configurations.

An engineer or graduate student would operate the laboratory, including attached appurtenances (boom, winch), recorders, and expendable sensors. The data would be obtained with modern electronic instrumentation and recorded in analog or digital format, as appropriate, with provision for the entry of complementary navigational data. The format in which the data would be collected must be compatible with data processing, storage, and retrieval methods employed by the National Oceanographic Data Center and the Naval Oceanographic Office, which would be the recipients of the data collected.

The essential components of the ships-of-opportunity oceanographic system would be as follows:

(a) An expendable sensor capable of measuring temperatures and sound velocity to a depth of 2,000 feet. This instrument might consist of two parts, namely, a buoy at the surface to telemeter data to the laboratory van and a free-fall element containing the sensors.

Above—Special winch for handling bathythermograph.

Right—S. S. AFRICAN RAINBOW, first of a new class of Ships-of-Opportunity.

Photos—courtesy Farrell Lines

(b) An underway water sampler with the capability of collecting water samples from preselected depths to 2,000 feet, the quantity of which will be sufficient for quantitative and qualitative analyses of alkalinity, disolved gases, nutrients, and trace elements, namely, oxygen, nitrogen, reactive phosphate, total phosphate, reactive silicate, nitrate, and magnesium sulphate, within state-of-the-art precision.

(c) A high-speed plankton sampler with the capability of collecting plankton samples at preselected depths to 2,000 feet, and indicate the total volume of water sampled.

(d) A towed echo sounder with an accurate depth recorder of high resolution.

(e) Other sensors to record wind direction, wind speed, barometric pressure, air temperature, and solar radiation.

The immense unit cost of the transportable oceanographic system may, due to the ever present budgetary consideration, limit the number of units available for the synoptic network. The following is a rough estimate of what the van concept may cost:

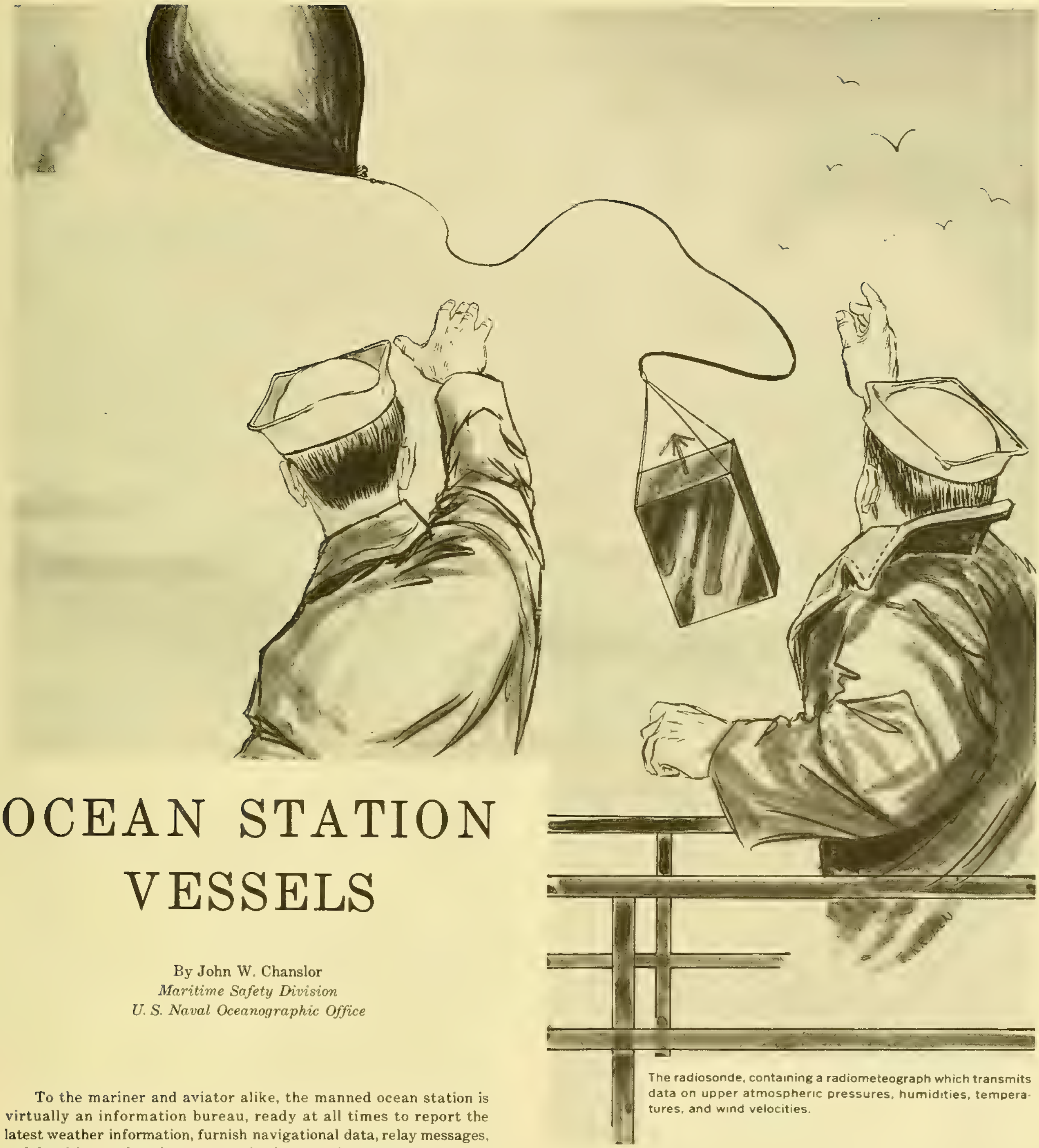
Van	$10,000	
Equipment	$150,000	
Personnel	$10,000	(year)
Ship Services	$8,000	(10 crossings/year)

Such a high cost of establishing a single data base may tend to defeat the original purpose of the ships-of-opportunity program, for low operating costs is cited as being one of its more attractive features. If it hinders a maximum expansion of the synoptic network, so necessary to military and commercial operations, it will have fallen short of its main objective.

Accordingly, project officials are not abandoning the concept of using inexpensive, foolproof instruments aboard ships-of-opportunity, utilizing ship's personnel to obtain and transmit the data. For the very near future, available instrumentation will restrict observations primarily to temperature versus depth observations. As simple equipment to acquire data concerning other parameters is developed, the program could be modified to include it.

CONCLUSION

The forementioned projects, all experiments in the physical utilization of ships-of-opportunity, have proven that an undeterminate potential for marine data acquisition exists in that mode. Participants in each of the projects undertaken to date are generally agreed that we have only begun to explore that potential. Certainly, a number of problems have yet to be solved before total utilization becomes a reality. Most of the problems are apparently technical ones which undoubtedly will be resolved as the need arises. The important thing is that project officials are convinced that a useful system will evolve. If it does, the ships-of-opportunity concept will bring together, in a unique fashion, military, academic, and commercial organizations seeking a common objective—the advancement of our Nation's welfare through the improvement of our knowledge of the oceans.



The radiosonde, containing a radiometeograph which transmits data on upper atmospheric pressures, humidities, temperatures, and wind velocities.

OCEAN STATION VESSELS

By John W. Chanslor
Maritime Safety Division
U. S. Naval Oceanographic Office

To the mariner and aviator alike, the manned ocean station is virtually an information bureau, ready at all times to report the latest weather information, furnish navigational data, relay messages, and furnish search and rescue service in case of emergency.

An ocean station is an arbitrarily selected section of ocean 210 miles square, strategically located hundreds of miles from the nearest land. Ocean station vessels are, strictly speaking, "on station" when they are within this square.

The actual establishment of ocean station vessels had its beginning with World War II. With the cessation of weather reports from merchant ships, weather data became of paramount importance in the safety of transocean flights. For this reason ocean station vessels were first established in the Atlantic in 1940 and later in the Pacific in 1943. Additional stations were added as needed, with the numbers of ocean station vessels fluctuating greatly during the war and postwar years. There are at present 9 ocean station vessels in the Atlantic and 3 in the Pacific, Figure 2.

Ocean station vessels, frequently referred to as "weather ships", have been under the cognizance of the International Civil Aviation Organization (I.C.A.O.) since 1947. United States participation in this international weather program falls within the jurisdiction of the U. S. Coast Guard. The following article is intended to describe some of the various functions of these vessels.

METEOROLOGICAL SERVICE

Despite progress in ship design, weather at sea is still the greatest single cause of marine casualties and delays. Head winds increase the length of a sea voyage and are of vital concern to an aircraft on a transocean flight. Accurate information on the velocity and direction of winds at several levels along established routes is essential to proper loading and fueling prior to an overseas flight.

The daily weather observational program of each ocean station vessel consists of:

(1) All foreign ocean station vessels and two of the six United States ocean station vessels, BRAVO and NOVEMBER, make and report hourly surface observations. The remaining ocean station vessels report surface observations every 3 hours. These surface observations include wind, weather, visibility, pressure, air temperature and humidity, sea temperature, direction, period and height of waves, and details regarding cloud formation.

(2) Upper wind observations, by radar, to an average height of about 54,600 feet, every 6 hours.

(3) Radiosonde observations (pressure, temperature and humidity), to an average height of about 80,400 feet, every 12 hours. These upper air observations involve launching of a gas-filled balloon equipped with a radar reflector and/or a miniature radio transmitter.

Reports from United States North Atlantic Ocean Station Vessels are forwarded by radio to the U. S. Weather Bureau collection center at Washington, D. C., and those from the North Pacific waters are sent to the Coast Guard radio station in San Francisco, California. Distribution of the data is made to domestic meteorological offices over teletypewriter circuits and to foreign services by radiotelegraph and radioteletypewriter broadcasts. Observations originated by weather ships maintained by other countries are relayed to the U. S. Weather Bureau along with other weather data in international radio exchanges. All weather observations are prepared for transmission in international weather codes.

Reports furnished by weather ships, along with other reports received from merchant vessels and continental and island stations, complete the synoptic and upper air meteorological coverage over the Northern Hemisphere. These data are first plotted on charts for the surface and for several levels in the upper atmosphere. Upper air charts show temperature, wind distribution and moisture values for the 850 millibar (averaging 4,800 feet above sea level), 700 mb. (about 10,000 feet), 500 mb. (about 18,000 feet), 300 mb. (about 30,000 feet), 200 mb. (about 40,000 feet) and 100 mb. (about 54,000 feet), constant pressure surfaces. From these charts, the meteorologist prepares weather forecasts and advisories for scheduled ocean flights. Frequently, because of the distance between ocean stations, he must forecast conditions over a large area of the route on the basis of successive upper air reports from a single ocean station vessel. Hence, the accuracy of data is of paramount importance.

Flight plans are made on the basis of conditions shown on the weather charts. Aircraft, of course, are primarily interested in making accurate determinations of fuel requirements and maximum payloads that can be carried with safety. The route and flying altitude is selected by the pilots to take maximum advantage of favorable weather and winds so the flight can be completed in the shortest possible time. Ocean flights sometimes follow one of the contour lines shown on a constant pressure chart for as much of the route as possible in order to take advantage of the favorable winds. This technique is familiarly known as "pressure pattern flying."

There have been many occasions when upper air reports from weather ships provided the only data on which the meteorologist was able to forecast the development of storms over the oceans. Apart from the large number of lives saved by the ocean station vessels and the reliable forecasts made possible by their observations, the mere presence of these stations takes a considerable strain off the minds of pilots.

In addition, an aircraft can obtain reports of observations from an ocean station vessel in plain language or "Q" code, or in the appropriate international meteorological code, according to the method requested by the aircraft. As English speaking operators are carried on commercial transocean flights, "Q" codes are seldom used, and an intended change in ICAO procedures will abolish "Q" codes for ship to aircraft transmissions.

OCEANOGRAPHIC DATA COLLECTION

United States ocean station vessels have traditionally collected the maximum amount of oceanographic data possible. These include bathythermograph observations, plankton tows, and echo soundings. Lack of adequate instrumentation, however, has precluded any full-scale observations.

Prior to 1961, oceanographic work by the Coast Guard was limited to the support of the International Ice Patrol, and what could be accomplished on a cost free and not-to-interfere basis. However, Public Law 397-87 was intended to bring the facilities and capabilities of the Coast Guard into the National Oceanographic effort. Along with this legislation, the Coast Guard, representing the Treasury Department, became a member of the Interagency Committee on Oceanography.

To implement oceanographic observations from ocean station vessels, one ship was outfitted in 1962 as a prototype and, to date, has conducted a complete oceanographic program on two ocean station cruises. These observations were made under the supervision of a team of U. S. Naval Oceanographic Office and Coast Guard oceanographers.

Based on the experience gained with the prototype ship, a continuing program is now underway for outfitting all major cutters assigned to ocean station duties, so that a basic oceanographic capability will be provided in all ships. In cooperation with the U. S. Naval Oceanographic Office, and in addition to other oceanographic instrumentation, these ships are being equipped with wave recorders and electronic bathythermographs. Installation has commenced and will proceed at the rate of about one ship per month over the next two and one-half years.

POSITION—INDICATING GRID SYSTEM
OCEAN STATION VESSELS

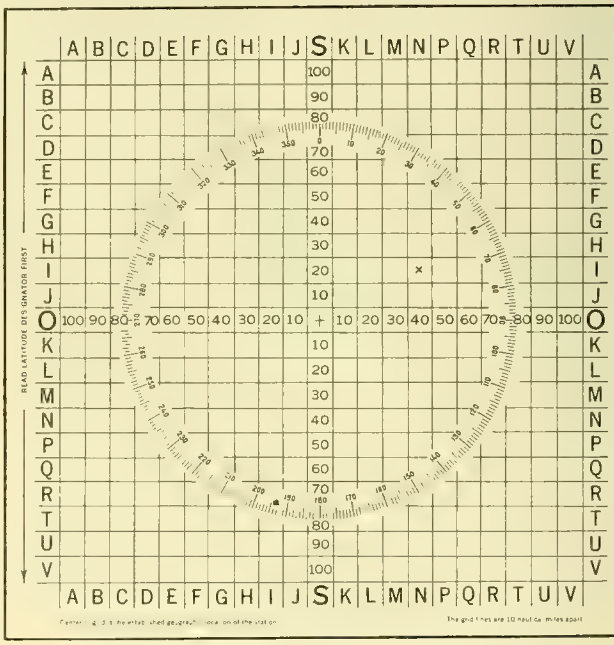


Figure 1. Position indicating grid.

NAVIGATIONAL AIDS

Originally, an ocean "station" included the area within a 100-mile radius of an assigned control point. World War II proved this impractical, and, consequently, this limit was discarded. After the war, to assist weather ships in carrying out their mission as aids to surface and air navigation, the "station" was changed to a grid 210 miles square, Figure 1. This grid is divided into 10-mile squares. The purpose of the grid is to provide a device for the ocean station vessel to indicate its position on her medium frequency radiobeacon. The signal transmitted by the radiobeacon is a continuous carrier wave with identifying letters superimposed on it. This signal consists of four letters; the first 2 letters comprise the characteristic signal of the station and the last 2 indicate its position within the grid. If a ship is on station, i.e., within the 10-mile square at the center, the last two letters of the signal are "OS", the latitude and longitude designators, respectively. If the ship is outside the center

Maintaining position, during winter in the North Atlantic at ocean station BRAVO.

Official U. S. Coast Guard Photographs

10-mile square but still on the grid, the latitude and longitude designators of whatever square the ship is in are transmitted as the last 2 letters of the signal. The latitude designator is always given first. The center of each grid square should be considered the location of the station vessel for all computations, thus giving a maximum error of 7.1 miles and an average probable error of 2.5 miles.

EXAMPLE: Assuming we are considering station "ALFA" with the actual position of the station vessel at the point marked "X" on the grid in Figure 1, her signal would be "YAIN". It is also evident that the station vessel bears 63° true 45 miles from its assigned position.

The emission of the radiobeacon has a high degree of vertical polarization which may enable a surface vessel to obtain a good bearing at distances in excess of 200 miles. If the regular beacon equipment breaks down, the same service as described above will be given, except that the ship's communication transmitter will give an interrupted tone-modulated signal in place of the continuous carrier wave. In this case, the identifying signal will be followed by a 20-second dash in order to provide service for automatic direction finders. If a station vessel is off the grid completely, as when on a distress mission, no beacon service will be furnished, except when specifically requested for homing purposes. In this event, the international radio call of the station will be used as the identifying signal.

CAUTION TO ALL SHIPMASTERS — AVOIDANCE OF COLLISION WITH OCEAN STATION VESSELS—Instances have been reported of ships "homing" on beacon transmissions of these vessels on station. This practice creates a grave danger of collision. Vessels occupying ocean stations may be drifting with engines on standby. Standby, in this instance, means that the vessel is not able to maneuver as propulsion power is not immediately available to the bridge. While ocean station vessels are drifting on station they use the lights and shapes prescribed by Rule 4(a), International Rules, and the fog signals prescribed by Rule 15(c)(v), International

Station	Nationality	Assigned position		International call	Radiobeacon	
		Latitude	Longitude		Identification	Frequency (kc/s.)
ALFA	British; Netherlands; French; Norwegian; Swedish.	62°00'N.	33°00'W.	4YA	[3]YA	347
BRAVO	United States	56°30'N.	51°00'W.	4YB	[3]YB	391
CHARLIE	United States	52°45'N.	35°30'W.	4YC	[3]YC	385
DELTA	United States	44°00'N.	41°00'W.	4YD	[4]YD	350
ECHO	United States	35°00'N.	48°00'W.	4YE	[4]YE	362
INDIA	British; Netherlands; French.	59°00'N.	19°00'W.	4YI	[4]YI	388
JULIETT	British; Netherlands; French.	52°30'N.	20°00'W.	4YJ	[4]YJ	370
KILO	British; Netherlands; French.	45°00'N.	16°00'W.	4YK	[4]YK	357.5
MIKE	Norwegian-Swedish; Netherlands.	66°00'N.	2°00'E.	4YM	[5]YM	340
NOVEMBER	United States	30°00'N.	140°00'W.	4YN	[3]YM	335
PAPA	Canada	50°00'N.	145°00'W.	4YP	[3]YP	388
VICTOR	United States	34°00'N.	164°00'E.	4YV	[3]YV	391

[1]The collective sign for any or all United States ocean station vessels in the Atlantic is NMMZ.
[2]The collective call sign for any or all United States ocean station vessels in the Pacific is NDLZ.
[3]Operates for 5-minute periods beginning at 5, 20, 35, and 50 minutes past each hour and on request.
[4]Operates for 5-minute periods beginning at 5, 20, 35, and 50 minutes past each hour but may be interrupted 1100—1200 and 2300—2400 GMT due to radiosonde observations.
[5]On request.

Figure 2. Pertinent data regarding ocean station vessels.

Rules. Therefore, all precautions to avoid collision must be observed. The beacon transmission may be used by surface ships to determine positions and should be used to avoid collision with the transmitting vessel.

The assigned geographical position of each ocean station vessel is indicated on the appropriate Pilot Chart. Additional information regarding radio aids is shown in Figure 2.

As it is rare for modern aircraft to be fitted for transmission on "medium frequency", the ocean station vessel's medium frequency direction finder is now used only for her own navigational purposes and getting bearings on surface vessels or other survival craft in emergency.

The air search radar in ocean station vessels is primarily used for tracking the radar target used on balloons, when measuring upper winds. This radar is also used when providing navigational fixes to aircraft. Currently, all U. S. and many European ocean station vessels are being equipped with balloon tracking radar in addition to their air search radar.

When in contact with ocean station vessels, nearly all aircraft request a radar fix in addition to the latest information regarding upper winds and surface weather. The frequency with which these requests are made varies from station to station. However, a good example is station "J", with an average of 78 weather and navigational requests each day from aircraft. A summary of the services provided by station "J" during 1962 follows:

Weather reports to aircraft	5,223
Radar fixes	13,874
Radiobeacons by special request	9,424
Total	28,521

SEARCH AND RESCUE

In addition to supplying meteorological information and acting as limited navigational aids, ocean station vessels are required by ICAO agreement to participate in search-and-rescue, and to maintain a high degree of readiness. These ships guard 500 kcs. continuously for distress, urgency, and safety communications. Also, United States ocean station vessels continuously guard the international distress voice frequency 2182 kcs., the international aeronautical emergency frequency 121.5 mcs. (voice), air-search VHF working frequency 126.7 mcs. (voice), air-surface UHF working frequency 272.7 mcs. (voice), and the U. S. Military common emergency frequency 243 mcs. (voice). The international survival craft frequency 8364 kcs. is guarded only during the distress or alert phase of SAR incidents.

The frequency of 500 kcs. is the one that should normally be used by merchant ships when calling the ocean station vessels. After contact has been made on 500 kcs., a working frequency will be established. Ocean station vessels, BRAVO and CHARLIE in the Atlantic and VICTOR in the Pacific have medical officers aboard and are prepared to give medical assistance.

Search and rescue is under the cognizance of the U. S. Coast Guard and is greatly supplemented by the AMVER (Atlantic Merchant Vessel Report) system. This maritime mutual assistance program is explained in H. O. Pub. No. 117A, *Radio Navigational Aids—Atlantic and Mediterranean Area.* Search and rescue of aircraft in the Pacific Ocean is affected by SAR Plan ALFA. This plan, plus additional SAR information, is explained in H. O. Pub. No. 117B, *Radio Navigational Aids—Pacific and Indian Oceans Area.*

A governing rule for search and rescue states: "If an ocean station vessel is able to lend assistance to an aircraft or vessel in distress, or survivors from same, it shall immediately grant priority of service to search and rescue."

Frequently, the Commanding Officer of an ocean station vessel is called upon by a rescue coordination center to control search and rescue at the scene of the incident. During such events he ensures complete coverage of the area by assigning search areas to all available ships and craft. In addition, he maintains a communication center, keeps a search plot, and prevents a hazardous concentration of searching units.

The final decision to leave an ocean station for a search and rescue mission rests with the Commanding Officer of the ocean station vessel. This decision is weighed on the probability of rescue against the hazards to air traffic created by the ships absence. The *ICAO Ocean Station Vessel Manual* states that the vessel shall go on a search and rescue mission only when, in the opinion of the Commanding Officer, there is a reasonable chance of succeeding.

A recent example of the effort an ocean station vessel will make on a search and rescue mission was the successful recovery by the U. S. Coast Guard Cutter *Absecon* of a German seaman after he had spent 17 hours swimming in the Atlantic. This ordeal, as reported by the U. S. Coast Guard, began on the evening of 12 September 1963 when Franz Strycharczyk, third engineer of the German cargo ship *Freiberg*, was leaning over the guardrail for a breath of air, prior to retiring. Unexpectedly, the *Freiberg* took a heavy roll and threw him into the sea.

The spot where Franz fell overboard was in the middle of the Atlantic, approximately halfway between Bermuda and the Azores. A lonelier place could scarcely be imagined. On all sides of Franz stretched an immensity of heaving water. In that vast watery expanse, it didn't seem possible for anything so insignificant as a human being to survive. Fortunately for Franz the water was a warm 80 degrees, and the air was mild.

Nevertheless, the odds against his being spotted were astronomical. Mathematically, they could be calculated at the figure one followed by nine zeroes. It is just as well that he wasn't a mathematician, because it wouldn't have done his morale much good.

Racing through Franz's mind was the disturbing thought that it would be several hours before his absence would be discovered, as he wasn't due to relieve the watch until midnight. And, even if a search were undertaken by the *Freiberg*, what chance was there that they could find him?

Stubbornly, he held on, hoping for a miracle. And sure enough, a few hours later, the *Freiberg*, having discovered Franz's absence returned to the approximate spot where he had fallen overboard. After a search of several hours, she had broadcast a "man overboard" message to all ships in the area. That was at 0122. Ironically, the *Freiberg* had come so close to Franz that she nearly passed over him. Once again he was left to the loneliness and darkness of the mid-Atlantic. It was heartbreaking, after being so close to rescue. He fell back on his last resource—prayer. His worst enemies now, in addition to the black water, were fear and despair. His situation wasn't made any easier by an 8-foot sea, a heavy sky, and constant drizzle.

The big thing now was not to panic. To conserve his strength, Franz swam as little as possible, floating most of the time.

About 130 miles from the area where Franz was putting up his heroic fight for survival, the Coast Guard cutter *Absecon* was patrolling on Ocean Station ECHO. It was after midnight and, except for the duty watch, her crew, including the skipper, had turned in. The *Absecon* was now in the 19th day of her patrol and was due to be relieved in two days to return to her home port of Norfolk, Va. The radioman was at his post, but so far it had been a routine mission. Then, at 0122, the *Freiberg's* anxious message came through. Excitedly the radioman gave the news to the supervisor of the watch,who followed routine procedure and immediately relayed the message to the Coast Guard's Eastern Area Command. There it was fed into the Coast Guard's Atlantic Merchant Vessel Reporting (AMVER) office in New York City. At this nerve center of rescue operations, the Coast Guard maintains contact with merchant vessels in the Atlantic. By using an electronic computer, it is able to determine within seconds which vessels are closest to the emergency and to forward this information to the distressed ship.

After sending off the message to New York, the supervisor of the watch on the *Absecon* went forward to awaken the Commanding Officer and give him the news. The *Freiberg's* call had put into motion the Coast Guard's entire search and rescue complex along the Atlantic coast. Once again an ocean station vessel was demonstrating its readiness to mobilize all its resources to save a single human life.

Even before he had finished dressing, the Commanding Officer phoned the bridge and ordered full speed ahead to the area of search. He estimated there was an outside chance that Franz was still alive.

By 0140 the *Absecon* was under way. Enroute, the Commanding Officer held a council with his executive officer and navigator. They decided upon a "Papa Sierra" or Parallel Track Single Unit search pattern as offering the best chance of success.

A typical U. S. Coast Guard ocean station vessel.

At 0759 the *Absecon* reached the search area. But, its operations were hindered by heavy skies and steady rain. Things didn't look too promising until a little after one o'clock, when the weather cleared a bit. That gave the Captain the opportunity to take a "murky haze" fix with a sextant. After calculating drift and other factors, he decided that the most promising possibility lay about eight miles to the north. Accordingly, he changed the search sector.

Every man that could possibly be spared was now on the deck of the *Absecon* searching the horizon. One of the ship's officers, standing on the bridge, saw what appeared to be a speck moving in the water. As the ship changed course and came closer, he could make out a man vigorously shaking an article of clothing. Incredibly, it was the German seaman. He was waving his undershorts to attract attention. That was about 1402. Two minutes later, the *Absecon* came alongside Franz, lowering its cargo net for him.

Despite his exhausting 17 hours in the water, Franz climbed the net and reached the deck where willing hands pulled him on board. It was then that he collapsed. But, he had won an incredible battle with the sea. His stamina and indomitable will to survive had pulled him through. That, plus the good professional judgment and skill of the Commanding Officer of *Absecon* had brought about a sea rescue that would be long remembered.

After a couple of hours of rest, Franz was examined by a Chief Medical Corpsman, who was amazed at his excellent physical condition. The expertise of the Coast Guard had paid off well indeed.

After Franz regained his strength, the *Absecon* arranged a rendezvous with his ship, the *Freiberg*, and on September 14 he was restored to his shipmates.

So if you think Friday the thirteenth is unlucky, don't mention it to Franz Strycharczyk. As far as he's concerned, it'll always be the biggest day on his calendar.

Since 1953 no less than 253 lives have been saved by ocean station vessels. Most of these rescues were related to marine accidents. It has been more than 7 years since a large number of air travelers have been rescued by an ocean station vessel. On 16 October 1956 the U. S. Coast Guard Cutter *Ponchartrain*, while serving on ocean station NOVEMBER, vectored and controlled the ditching of a distressed transpacific airliner. All of the 31 passengers and crew were saved. Since then, only military aircraft have ditched and required assistance.

Apart from providing necessary navigational information to pilots who have decided to ditch their aircraft, the ICAO Manual recommends several means of assisting pilots. During periods of reduced visibility, the ocean station vessel may lay out a flare path of lighted floats along the ditching track indicated by the pilot. And, in addition, a searchlight beam may be trained horizontally in the ditching direction. During the hours of daylight, smoke floats may be utilized to indicate wind direction to the aircraft. Of course, radio and radar bearings will guide the aircraft to the chosen path of ditching. By turning circles with a diameter of more than one mile or by laying an oil slick, it is possible for vessels, under certain conditions, to smooth the seas.

OPERATIONS

United States ocean station vessels are cutters especially equipped for taking meteorological and oceanographic observations. In addition to the regular crew, four highly trained U. S. Weather Bureau technicians are assigned to each vessel to conduct the meteorological program.

These ships remain at sea from 25 days to 6 weeks. United States ships spend 21 days "on station" steaming within the 10-mile square center of the station grid. The depth at each station is well over 1,000 fathoms. However, the U. S. Coast Guard has marker buoys moored at ocean stations CHARLIE, NOVEMBER and PAPA, and in the near future plans to have all U. S. stations so marked.

For all practical purposes, the Commanding Officer of a station vessel does not need to know his exact position. However, it is obvious that the greater navigational accuracy he can achieve, the greater will be the accuracy of fixes to aircraft, meteorological data obtained, as well as being in a better position to commence a search and rescue mission. Under average conditions the accuracy of a radar fix given to aircraft at a slant range of 50 miles is about 7 miles. At a slant range of 100 miles the accuracy is about 10 miles.

The United States nominally operates 18 vessels in this program, 3 for each of the assigned stations. However, the U. S. Coast Guard actually employs a total of 32 vessels in the program. This additional number is to maintain a uniform schedule throughout the Coast Guard Fleet. Thus, these ships are available for other duties as well as ocean station patrols.

When the wind exceeds force 10, Commanding Officers of ocean station vessels have found that they are usually required to steam at slow speed. However, the decision to run with the wind, or place it on one bow, depends on circumstances. Usually it is preferable to place the wind on one bow, so that it will not interfere with the upper air balloon launching schedule. During the 23 years that weather ships have been in operation, there have been few occasions when very prolonged storm conditions forced a ship outside the limits of the station grid.

ATLANTIC—HISTORY

The prelude of an international weather service began with The International Conference on Safety of Life at Sea, *"Convention and Final Act"*, which was signed in London, 31 May 1929. During this conference it was agreed that ships encountering tropical storms would make weather observations and further transmit their findings. Such reports were to include: (a) position and movement of the storms, (b) barometric pressure, (c) barometric change during the previous two to four hours prior to the storm, (d) wind direction, (e) wind force, (f) state of sea, and (g) sea swell. Amplifying reports were to be transmitted every three hours thereafter, as long as the ship remained under the influence of the storm. In addition, certain selected ships were to take meteorological observations at specified hours for the benefit of other ships and various official meteorological services.

At the onset of World War II in 1939 surface weather reports which had normally been transmitted by transatlantic shipping were discontinued. For their own protection, belligerent nations required their ships to maintain radio silence. The passage of the Neutrality Act then halted U. S. shipping in the European trade. This resulted in the almost complete absence of weather reports from the North Atlantic Ocean area. Further complicating the situation was the increase in transoceanic flying activity, which required complete and accurate weather information. Thus, there was a self-evident need for an Atlantic weather observational service from ships strategically placed to best provide the required meteorological data.

In January 1940 the President withdrew the U. S. Coast Guard cutters performing neutrality patrol off the Grand Banks and directed the Coast Guard to establish ocean weather stations with the vessels. Two stations were established 10 February 1940 namely, Atlantic "1" and "2" at 35.6°North, 53.3°West and 37.7°North, 41.2°West, respectively between Bermuda and the Azores. These stations were occupied by cutters with the Weather Bureau providing the meteorological personnel and equipment.

In 1940 Great Britain was suffering great shipping losses and a decision was made to fly American-built bombers directly from Newfoundland to Britain. This resulted in the establishment of a third ocean station about 500 miles northeast of Newfoundland. By July 1942 the first fighter planes were being flown across the Atlantic via a chain of U. S. Army airfields bridging the ocean from Labrador to Greenland to Iceland. As a result of this new operation, two more plane guard stations were established; one at 58°North, 52°West, between Labrador and Greenland, and the other at 63°North, 31.5°West, between Greenland and Iceland. These plane guard stations were primarily established for air-sea rescue and navigational assistance rather than to obtain meteorological data. As the stations were not a part of the ocean weather program, few meteorological records were obtained.

The number and locations of ocean weather stations manned by U. S. ships were originally determined by the U. S. Weather Bureau in consultation with commercial airlines. With the advent of the war, stations were determined by the cognizant committees under the Joint Chiefs of Staff, primarily the Meteorological Committee, of which the Weather Bureau was a member. Later, with the establishment of the Air Coordinating Committee, that body recommended and approved the number and location of stations. The locations of previously mentioned Atlantic "1" and "2" were changed several times during the war as the increase of air transportation dictated different flight routes. Even these positions could not be maintained consistently, due to enemy submarines and rescue duty. Consequently, these two stations were moving much of the time.

The operational control of the entire weather patrol in the Atlantic Ocean was assumed by the Navy for reasons of military security and exercise of command in March 1944. The United States stations in the North Atlantic were then operated by Task Force 24 and station numbers as well as locations varied in accordance with requirements.

After VE Day in May 1945 the biggest movement of aircraft in history began across the North and South Atlantic to the Pacific theater. To safeguard the tremendous increase in air traffic, plans were laid for increasing the number of weather stations in the Atlantic resulting in a total of 21 by June 1945. Of these 21 stations, 6 were maintained by the United Kingdom, 2 by Brazil, 2 jointly by Brazil and the United States, and the remaining 11 by the United States.

At a conference with the Chief of Naval Operations on 1 March 1946 it was agreed, because of personnel limitations, to reduce the Atlantic stations to 6 by 15 March and on that date to return operational control back to the Coast Guard. The British were suffering from similar personnel limitations and progressively withdrew their vessels, until on 1 May 1946 the United States was the only government maintaining any ocean station vessels.

The need for the services supplied by the patrol vessels had not decreased since the war, because, as military flying decreased, commercial flying operations increased. The first steps to establish the weather patrol on a permanent peacetime basis were taken at the North Atlantic Route Conference of the Provisional International Civil Aviation Organization (PICAO) in March 1946 at Dublin, Ireland. To maintain a North Atlantic weather service that would also provide adequate air navigation facilities, the conference recommended that a minimum of 13 stations be established. These stations were to be maintained continuously by vessels thoroughly equipped with modern meteorological instruments, electronic navigational gear, and trained technical personnel. The United States, operating approximately sixty-five percent of the transatlantic aircraft, was to provide seven stations, plus an eighth station in cooperation with Canada.

The Council of PICAO (now ICAO) approved these recommendations in the latter part of May 1946. To further implement this action, the United States of America was requested to meet with Belgium, Canada, Denmark, France, Iceland, Ireland, The Netherlands, Norway, Portugal, Spain, Sweden, and the United Kingdom to investigate the situation thoroughly. This conference was held in London, England, in September 1946 and resulted in a signed International Agreement that 13 permanent Atlantic ocean weather stations were to be established not later than 1 July 1947. All terms of the agreement were to come into force 25 August 1947 and remain until 30 June 1950. Further, a conference was to convene not later than 1 April 1949 to consider revision and renewal of this agreement.

On 1 July 1946 the Coast Guard was assigned directional control of the entire program for stations maintained by the United States.

Since 1954 there have been 9 ocean station vessels in the North Atlantic and these will apparently remain for many years.

PACIFIC—HISTORY

The history of the Pacific ocean station vessels began in 1943 when the Commander in Chief of the U. S. Fleet ordered the establishment of two weather reporting stations in the Pacific. One was established between the Hawaiian Islands and the California coast, the other in the Gulf of Alaska.

During the war all stations were manned by the U. S. Navy. Since the war, however the stations have been manned by the U. S. Navy or by the U. S. Coast Guard with U. S. Weather Bureau observational personnel.

The Pacific network was progressively expanded until 1 January 1946 when a total of 24 weather and plane guard stations were in operation. Except for one Canadian-manned station, the U. S. Navy exercised full directional and operational control over the Pacific station vessels.

Late in February 1946 the Pacific network began to feel the impact of the same obstacles which were forcing a reduction in the Atlantic operation and several stations were discontinued.

On 15 April 1946 the U. S. Coast Guard took over operational control and on 1 July 1946 assumed directional control.

Currently a total of 3 ocean station vessels exist in the Pacific. Two of these stations are manned by the United States and one by Canada.

Removing a 300-ton shroud of ice, to maintain stability.

SUPPORT

At the present, a total of 22 nations share in the cost of operating Atlantic Ocean Station Vessels. The contribution of each nation is based upon the number of Atlantic crossings by civil aircraft belonging to it, plus a share of the "non-aeronautical benefit" factor. In addition to the support furnished by the operating nations, eleven nations assist with cash contributions.

During the years that ocean station vessels have been in existence, their regular meteorological observations have proved very valuable not only for aviation but also for general meteorological purposes. Member nations have held conferences regularly, the latest one being the Fifth North Atlantic Ocean Station Conference held at The Hague, Netherlands, in March 1960. At the suggestion of the Government of the Netherlands during this meeting, adjustments were made in the scale of cash contributions to take into consideration the prevalent tendency for cost increase.

It is difficult to assess the actual cost of operating all of the ocean station vessels, as some are also used for other purposes. However, the 1961 figures show that for ships used entirely for this purpose, the annual cost varies from $270,000 for Norwegian ships to $943,000 for U. S. ships. For each of nearly one and a half million passengers who flew across the Atlantic, this means that only a few dollars were spent on the essential services of ocean station vessels. Or stated in a different way, the cost of operation of all weather ships cost just slightly more than the purchase price of one jetliner, with required spares.

The number of years ocean station vessels will be required to fulfill all of their current duties remains to be seen. Even with rapid progress in constant level balloons and satellites, the International Civil Aviation Organization will have a need for these ships for decades yet to come.

THE DISTRIBUTION OF DISCOLORED WATER

By Marine Sciences Department
U. S. Naval Oceanographic Office

INTRODUCTION

Discolored water is recognized as patches, streaks or very large areas of more or less opaque brown, yellow, red and other tints on the water, or under the surface. These areas frequently resemble shoals. The purpose of this article and accompanying chart is to demonstrate the geographical factors in the distribution of these areas. We hope that this will be a significant contribution to the mariners' problem of the clarification and correction of erroneous notations of shoal water on charts.

Since about 1880 the Hydrographic Office has been receiving discoloration records from many sources, chief among which is the Merchant Marine. Reports in American and foreign scientific publications and nautical journals have likewise been used. The HYDROGRAPHIC BULLETIN, Hydrographic Office PILOT CHARTS, and the MARINE OBSERVER of the British Meteorological Office, have been most helpful. This collection of observations forms the basis for the accompanying chart and probably comprises the most complete record of the distribution of discolored water.

HISTORY

The phenomenon of the discolored water has undoubtedly been observed by voyagers and inhabitants of coastal areas since before the beginning of the written record. One of the earliest reports is found in the Bible, (seventh chapter of Exodus, the twentieth and the twenty-first verses:)

> "And all of the waters that were in the river (The Nile) were turned to blood and the fish that was in the river died; and the river stank, and the Egyptians could not drink of the water of the river."

Such reports may be found, also in the Iliad and the works of Tacitus and in the logs of a number of navigators of the 16th century and on.

A few early records may be found with detailed description of the discoloration and of the organisms which cause it. For example, in 1594, Sir Richard Hawkins, entering a cove in the Straits of Magellan, observed a bright red discoloration of the water. He stated, "they sounded a cove some sixteen leagues from the mouth of the straits, which after we called Crabby Cove. It brooked its name well for two causes; the one for that all the water was full of a small kind of red crabbes; the other, for the crabbed mountains which overtopped it; a third, we might add, for the crabbed entertainment it gave us." Again, specifically mentioning discolored water, Simon D'Cordex in 1598, reported "having passed the Rio de la Plata, the sea appeared as red as blood, the water was full of little red worms which when taken out jumped from the hand like fleas. Some were of the opinion that with seasons of the year the whales shook these worms from their bodies but of this they have no certainty." The available records prior to 1800 attribute the discoloration in the sea to various factors such as sea dust, submarine earthquakes, submarine sulphur springs, spawn of fish, etc. In 1729, during the voyage of the ship *St. George*, Capt. William Dampier described an encounter with discolored water off the coast of Peru as follows:

> "The 19th instance, our men all being at dinner and our ship about ten leagues off shore, going with a fine fresh gale of wind at East, we were suddenly surprised with the change of the colour of the water, which looked as red as blood to as great a distance as we could see, which might be about seven or eight leagues. At first we were mighty surprised; but recollecting ourselves, we sounded, but had no ground at one hundred and seventy fathoms. We then drew some water up in buckets, and poured some in a glass. It still continued to look very red, till about a quarter of an hour after it had been in the glass; when all of the red substance floated on the top, and the water underneath was a clear as usual. The red stuff which floated on top was of a slimy substance, with little knobs, and we all concluded it could be nothing but the spawn of fish."

During the 19th century with the increase in shipping and the publication of the results of scientific expeditions and private investigations, considerable interest was aroused in the distribution of and the explanation for discolored water. Sailing directions requested that areas of discolored water be carefully surveyed and sounded to eliminate the possibility of their being recorded on the charts as shoal areas, and statements were published in nautical journals to the effect that some of the areas then reported as shoals were thought to be discolored water.

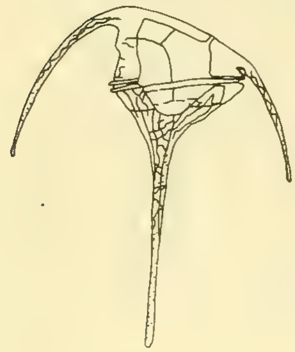
In recent years outbreaks of discolored water appearing off the Florida and California coasts have been watched and studied with increasing interest. Comparison of data from the many known affected localities provides clues for the study of these areas which may, in turn, contribute to the discovery of the direct cause or the possibility of prediction of the phenomenon.

NOTE: In the Interest of this problem, the U. S. Navy Hydrographic Office has issued a request to mariners to take soundings in discolored water to insure correct diagnoses before reporting. It has also requested reports on observations of discolored water as a check on present shoal notations.

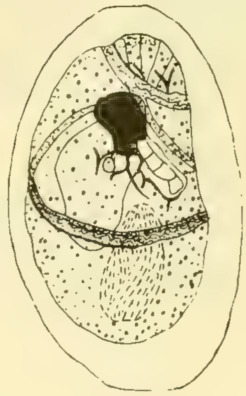
CAUSES

The causes of the normal color of the sea are physical. The characteristic indigo of the open ocean can be explained by the scattering of the light as it reflects from the water. Coastal waters are generally greener, often with shades of brown or yellow. These colors can be traced to the pigments in the tiny plants and animals that inhabit the coastal waters, to the color of the bottom sands and muds where the water is shallow, and to the erosion products washed from the land by rivers and rainfall. Different water masses, when they meet, as when bay

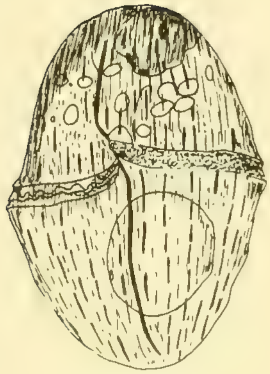
COMMON TYPES OF PLANKTON AFFECTING COLOR CHANGES IN SEA WATER



CERATIUM

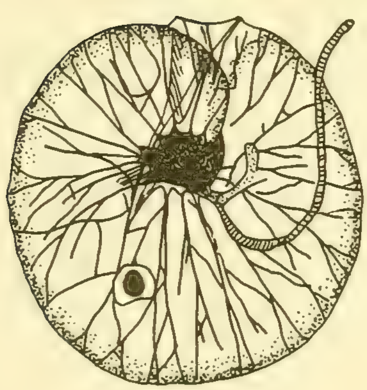


POUCHETIA



GYMNODINIUM

PERIDINIUM



NOCTILUCA

water enters the ocean, can often be recognized by the differences in their color.

The discolorations discussed in this article however, are largely caused by living organisms. These plants and animals, floating at and near the surface of the water, depending almost entirely on water currents for their transportation, are known collectively as *Plankton*. The organisms range in size from microscopic bacteria to forms as large as jellyfish and carry colored granules, (most frequently red), in their bodies. These colored organisms are distributed throughout the world from the polar waters to the tropics. Although they occur in almost all waters in large numbers, their color does not become noticeable until they exceed their normal abundance. Millions of organisms in a small volume of water are required for definite discoloration.

When the necessary combination of factors is just right, the *Plankton* reproduces at a great rate and the tremendously increased population is called a "bloom". If these organisms contain pigments, the bloom is visible as discoloration. Some of these causative factors are increased food material, more favorable temperature or salinity, etc.

The bloom, however, is usually short lived. This tremendous population begins to compete with itself for food which is fast being consumed. Also the waste products which may have been caused by killing off enemy forms now begins to pollute the water to the point where it kills off the bloom itself. The original situation which made conditions right may now have changed, the temperature may have dropped or risen to an unfavorable point, oxygen may have become scarce, etc. A change in wind or tide may often be sufficient to dispel the bloom.

As is the case in all living forms, the basic foods are nutrient chemicals, (nitrates, phosphates, dissolved organic matter etc.) and the energy from the sun. The plant *Plankton* makes use of these and the animal *Plankton* lives on the plants.

Coastal waters provide these nutrients in greater abundance than do the open seas because decomposing matter which supplies these chemicals, settles to the bottom, but in the shallow coastal water, remains within reach of the *Plankton* near the surface. Also, the population of these waters is greater than that of the open sea, accounting for the large supplies of decomposing material. Organic material washed from the land is another important source of food for the life of the coastal waters. Where the shore is steep-to and the water deep, upwelling may occur, bringing bottom materials to the surface. Such regions are often rich in *Plankton*.

Polar waters are also rich, but mainly during the spring season when the products of decomposition, accumulating during the long dark winter, are released by the turbulence of the warming water for the use of the *Plankton* which is coming out of a sort of hibernation under the influence of the sun.

Thus while coastal waters are characterized by a variability of conditions frequently favorable for *Plankton* blooms, the open ocean is stable and rarely changing even from place to place. *Plankton* and food are generally scarce. Nevertheless, unusual effects of wind or weather or unusual current movements may occasionally lead to discoloration.

DISTRIBUTION

The phenomenon of discolored water is almost cosmopolitan in distribution, although individual species causing discoloration may have a relatively localized range. There are reports of it from the antarctic seas, the temperate seas, the tropical seas and the arctic.

Although records included on the accompanying chart are mainly those submitted by the merchant marine, and are therefore restricted to commercial ship lanes, other data obtained by scientific expeditions and coastwise vessels corroborate the theory that discolored water is primarily a coastal phenomenon.

The areas best known for discoloration are areas of upwelling. Here, at seasons when the current regime is proper for the phenomenon, the cold deep waters are brought up to the surface, carrying with them nitrogen and phosphates from decomposition products. This suddenly abundant supply of nutrients is often a "trigger mechanism" for the *Plankton* bloom. Upwelling is common off the coasts of Peru and Chile, the coast of Latin America, Mexico and California, the Florida Keys, the Malabar and South Kanara coasts in southwest India at certain seasons, the Madras coast in southeast India, Walvis Bay and elsewhere in southwest Africa, the Arabian coast between Aden and Perim, the east Japan coast and the East Australian coast. In many of these areas, the discoloration is an annual occurrence and may be seasonal.

As in upwelling, a general change of water mass may also occur by a change in current direction. This may also be seasonal, as it is in cases of *El Nino* and *Aquaje,* off the Peruvian coast.

Before discussing these currents, it would be well to decribe briefly the normal currents and temperature distribution off the west coast of Peru from Pisco north to the Gulf of Guayaquil.

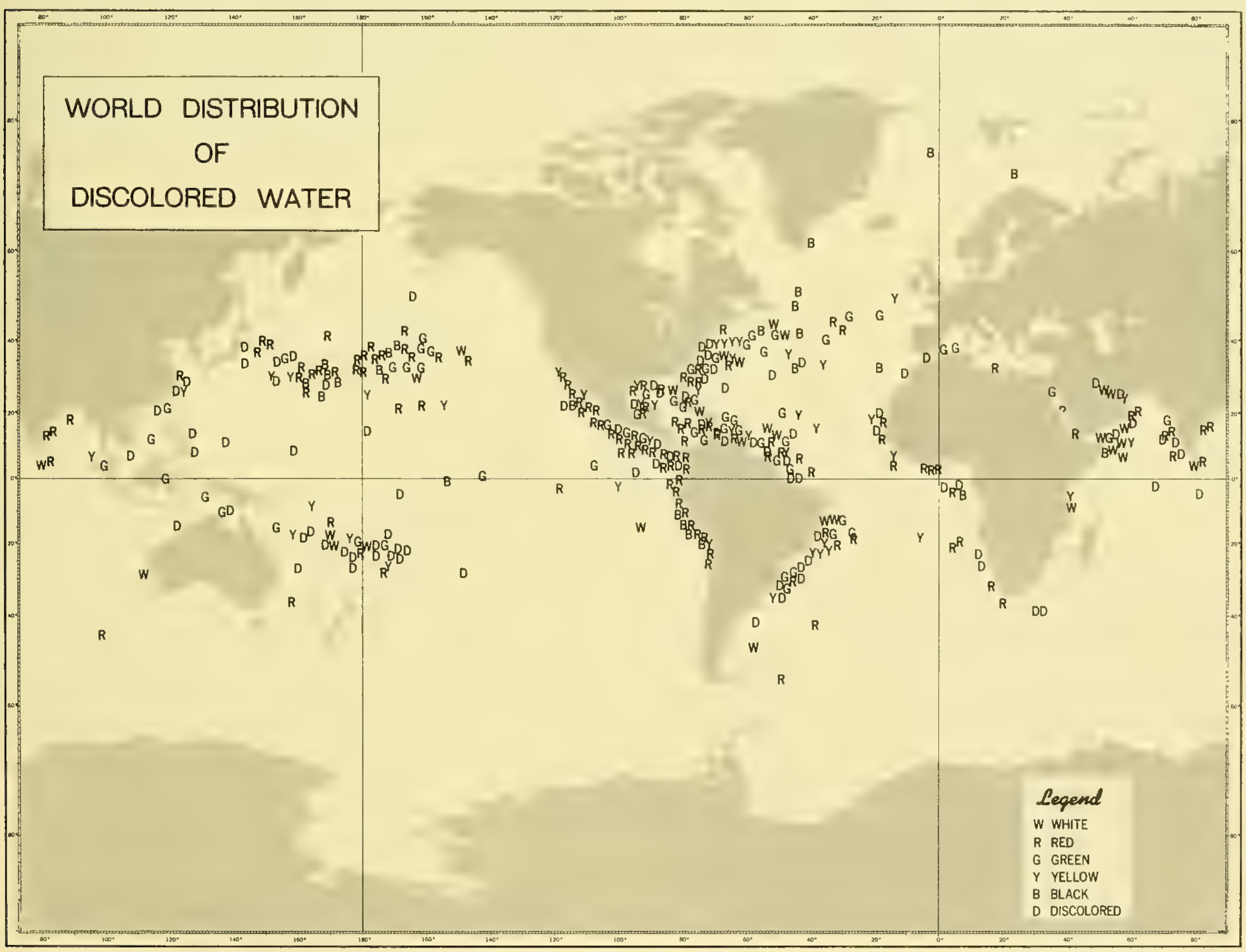
The Peru current, also known as the Humboldt current, which moves from south to north, is a northerly branch of the Pacific Antarctic Drift and is particularly noted for its sustained low temperatures (mean annual temperature close to the shore line of central Peru is 10 to 11° C. lower than the theoretical value for that latitude). This low temperature extends from a point somewhere south of 45° S. to Punta Arina, 4°40' S., and is caused by the upwelling of the deeper waters. Along the northern coast of Peru, the current normally swings to the west and converges with the Equatorial Counter Current running East. The line of convergence marked by a "tide rip," runs along irregularly from Punta Aguja to the Galapagos Islands. The Counter Equatorial Current, which normally turns northward along the coasts of Ecuador, Colombia and Central America, seasonally swings to the south during January-March, bringing a counter current of warm water down the coast of Peru, displacing the ordinarily cold water of the Peru Coastal Current. This influx of warm water may reach as far south as Salaverry, 8°13' S., and even occasionally Pisco. The drastic temperature reversal causes widespread mortality of littoral invertebrates, fish and even guano birds. The disturbance to the *planktonic* life commonly results in extensive discoloration.

A similar current change ocurring farther south during the months of April through June is called *Aquaje.* High temperatures appear off the coast of Peru between the latitudes 9° and 12°S., caused by the movement inshore of the outlying oceanic waters of high temperature and relatively high salinity. As is true of *El Nino,* the surface waters are usually colored blood red.

Destruction of fish by the "Red Tide" off the Gulf Coast.

Polar waters are often discolored in spring because of the abundance of winter-accumulated nutrients.

These are regular occurrences whose causes are clearly marked. Discoloration however, can occur locally and unexpectedly even in mid-ocean. Here the causes are obscure. Some meteorological quirk or unusual temperature change may bring it about. In coastal waters, even the addition of trace elements brought down with river runoffs has been considered a possible cause. Thus it would seem that regularity of environmental cycles brings about a regularity in occurrences of



discolored water, and where there is a variable ecological regime, discoloration occurs only sporadically.

IMPORTANCE

The interest in discolored water is not limited to the mariner. Inhabitants of shore communities where discolored water recurs, find the phenomenon very disturbing. In many of the outbreaks, notably the ones in Florida in recent years, the great numbers of organisms dying and decomposing in the water produced an ugly, evil-smelling scum, and with the rapidly depleted oxygen supply killing fishes by the millions and driving them ashore, the stench becomes unbearable. The decay and anaerobic conditions frequently also contribute to the production of hydrogen sulfide gas, the substance with the "rotten egg smell" which has blackened the paint on houses near the beach and the brightwork on ships passing through it. Because this aspect is so conspicuous, the Peruvian outbreaks are called "El Pintor", "The Callao Painter."

Besides these odors, an irritating vapor was noted in these outbreaks which affected the mucus membrane of the nose and throat, causing extreme discomfort even to people living several miles from the beach.

Certain of the discoloring organisms have been found to be definitely poisonous, and it is believed the mortality among the invertebrates and fish is caused by the toxins as well as by the oxygen depletion. Although the exact nature of the poison is not yet known, it is known to be sufficiently potent to be fatal even to humans who may eat oysters, clams, mussels, etc., which have the organisms in their stomachs.

These conditions and the red water may last only a few hours, washing away with the tide, or may persist for days and weeks until dispersed by the wind, which mixes the water and causes the products of the decomposition to sink to the bottom, or to be diluted until they are no longer critical.

The losses to the shell fisheries industries are tremendous for, although some fish caught by the tide can swim out of the area, the sessile animals can protect themselves only by closing their shells. If the outbreak lasts more than a few hours they are annihilated. Even among the birds which are dependent on marine forms for food, the mortality is extensive. The Guano industry in Peru is imperiled regularly by *El Nino* and the *Aquaje.*

Not all discoloring organisms are poisonous, of course, and discolored water is not always destructive. Some outbreaks in fact, would pass unnoticed if they did not occur in a locality under the attention of hydrologists.

OCEAN CABLES AND DEEP-SEA TRAWLERS

A cable vessel loaded with an expensive stock of repair cable ready to proceed on a repair mission

By Joseph W. Lermond, *Maritime Safety Division, U. S. Naval Oceanographic Office*

From the very beginning of recorded history, and probably before, the lives of mankind have been influenced by the oceans. From the writings of Homer, which make reference to the sea, to our vastly expanded knowledge of the oceans today, man has ventured upon, lived, worked, studied, fought on and used the sea for his economic gain. Among the vastly expanded oceanic activities is found the problem confronting two important industries using the sea today; the deep sea fishing industry and that of undersea communications. Each is important and provides basic needs or economic wants. Both are carried on in a "No Man's" wilderness of ocean depths.

The economic success of both of these industries is subject to frequent mishaps in the ocean depths. Communication cables are broken and service is interrupted frequently by deep sea trawls. New and improved cables are laid out, and broken cables are repaired on a continuing basis by the cable companies. Fishing trawls are fouled and lost daily in the depths. Service to the public and economic gain are the motives of both industries. That these two may better serve humanity with a clearer understanding of their mutual interests is the objective of this article.

During recent years the fishing industry and the submarine cable companies have been plagued with rising operating costs because of the fouling of submarine cables by deep sea trawling gear. This serious development poses a problem that is the concern of all maritime nations. Solution of the problem with its manifold complexities, is indeed, a most formidable task. The annual cost for cable repairs to one company alone has been as much as one half million dollars. The inconvenience to the public caused by disrupted cable service cannot be figured. The number of breaks and the loss of cable service increase each year. The cost of labor and materials have also risen steadily. The mounting costs incurred by the breakages are significant financial losses paid for indirectly by the general public. Widespread knowledge of the problem is desirable, as cooperation between the two industries is the only immediate way known to reduce the tremendous losses in time, labor and material.

In the early days of the ocean cable industry, fishermen seldom damaged cables because most commercial fishing was carried on largely with hand lines from dories. With the advent of the steam trawler with otter boards, damage to the cables became appreciable. The otter trawl at present is still the most efficient method of bottom fishing, its general and widespread use has both generated and aggravated the problem with respect to ocean cable communications. Increased demand for fish, along with the development of refrigerated transportation, have influenced the growth of the fishing fleet. These fleets now fish in greater depths and constantly extend their area of operations.

The science of communication by cables under the sea has also progressed. A telegraph cable previously utilized to carry 55 words a minute now carries 300. A transatlantic telephone cable may carry as many as 36 two-way conversations simultaneously on each pair. Messages now transmitted include high-priority-government, military and diplomatic traffic in addition to the many business and personal messages. The prediction 40 years ago that radio would in time replace cables as the medium of overseas communication has proven to be only partly true. The cables are the "work horse" of transoceanic communications and perform a very vital role in the world's business.

Outbreaks of cable interruptions are often sporadic and may occur in an area which has been free of damage for years. In 1946, cables landing in Trinity Bay and Conception Bay, Newfoundland, were broken a number of times, after being trouble free for 75 years. Within 10 weeks three separate breaks on one cable were reported. By 1950, the breaks in this area had increased to as many as 15 failures in a year, with as much as 130 days of cable time lost. This is a serious interruption in service, in addition to being a heavy financial loss. Costs for repair of one break run from $2,000 to $20,000 for cable alone depending upon the length and type of cable. To include the repair ship costs would bring the expense to as much as $50,000 or more. Service losses on one transatlantic cable off Newfoundland may run into thousands of dollars per hour. Costs to the individual trawler that fouls a cable are difficult to compute. The fishing gear will be replaced by the cable companies if the fisherman will make a claim reporting the time, location and depth of the fouling. However, a trawler working a long way from its home port would have a considerable financial loss, above the price of gear alone, if he lost his trawl and had to return to port without a catch of fish.

Investigation of many breaks has revealed miles of trawler-damaged cable with numerous crushed places, broken armor wires, and electrical faults. The increasing number of cases of cable cut with an axe, burned with a cutting torch, or parted under strain require that the problem be given prompt attention. An examination of the background of both the fishing and undersea communication industries may lead to a better understanding of the present situation.

Historically, fishing has played an important role in the economies of many nations, and it is the leading industry of at least one nation, Norway. Actually fishing is probably the oldest industry pursued by man and may even have preceded his efforts at hunting. Man's first venture from shore in a dugout canoe may have been to "go fishing". In medieval times, fish was a most important winter food and it still is the "Lenten Fare" of Europe. Fishing fleets were also the backbone of many early navies.

At present, commercial fishing is generally conducted within the limits of the 200-fathom curve, although the trend is toward greater depths. Fish in any great abundance are not easy to locate or catch outside these depths. The fish populations are constantly on the move and normally productive fishing grounds are often temporarily deserted. Commercial fishermen are alert to these migrations and concentrate eagerly wherever fish are found.

The Grand Banks of Newfoundland, one of the world's important fishing grounds, is located on the North American continental shelf. The fishermen of many nations appear on these banks regularly. Their fleets of powerful ships are equipped with the latest and most modern navigational instruments including loran, Decca, gyro compass, fathometer, and specialized devices. Factory ships and even hospital ships accompany the fleets. Their fishing gear includes otter trawls and nets for taking ground fish such as cod, haddock, pollock and redfish.

The otter trawl is a device for taking bottom fish. It is so constructed that when fully assembled and rigged it will take the shape of a huge funnel while traveling along the bottom. Correctly rigged, the trawl doors or "otter boards" keep the mouth of the net open by operating at an outward angle from the direction of the towed trawl. The fish are swept into the belly of the net by the wings and are trapped in the "cod end" until the catch is hoisted on deck. The net is usually towed at 2 to 3 knots, using two flexible steel wire cables about 11/16 of an inch in diameter. The rig weighs about 2 tons and a good haul can average about 1 ton of fish. A spare set of gear may be rigged for use on the port side of some trawlers but the starboard gear is used almost exclusively. Parts from the port side gear are used as replacements, when needed. Most trawlers would not be able to continue fishing after fouling and losing the working net. A replacement will cost $2,500 or more and would usually have to be purchased in the home port.

Since the trawl is operated at depths which preclude a visual examination of its workings, it is extremely vulnerable to snags, wrecks, rocks, cables, or any other obstruction with which it may become entangled during its sweep along the bottom. However, it is usually profitable to fish in the vicinity of known wrecks. Trawlermen will

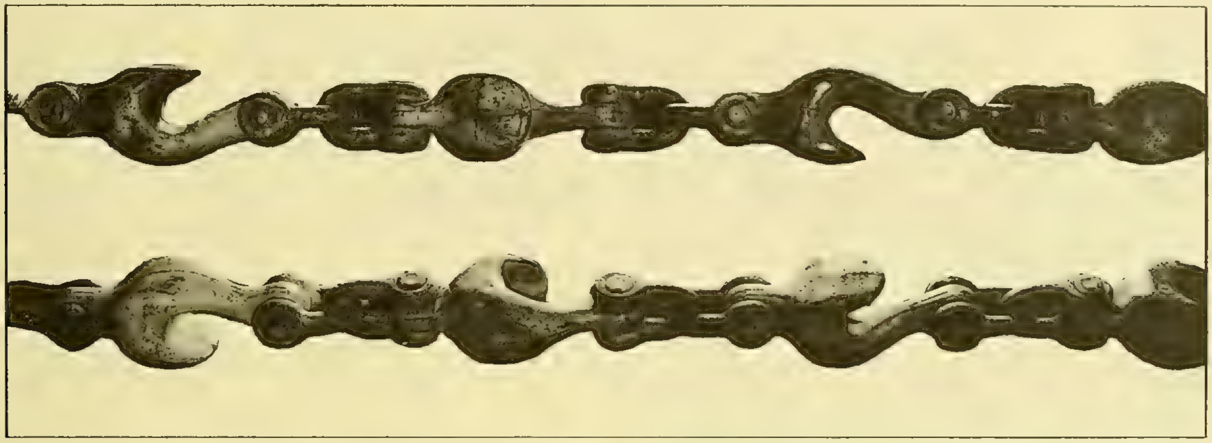
A trawler head-rope and floats being cleared from a communications cable during repair operations aboard a cable vessel.

do this carefully and only with a knowledge of the wreck position checked by fathometer and loran or Decca. In fishing near cable areas where the exact positions of the cables are not clearly defined, an element of risk is introduced. Most trawler skippers are experienced navigators and as good seamen, they are extremely careful in the vicinity of known obstructions.

The captain and crew of the average trawler do not recieve salaries, but share in a division of the profits after all expenses are deducted. An average fishing trip may bring in $10,000 worth of fish. The margin of profit is so slender that a broken voyage, caused by loss of gear, may spell the difference between a profit and a loss for the entire year.

In 1850, after many years of experimentation and planning, the first communication cable was laid between Dover and Calais. The cable was soon broken and not successfully reestablished for over a year. Seven years later an attempt was made to lay a transatlantic cable. This failed when the cable parted in a depth of 2,000 fathoms and could not be recovered. In August, 1858, the first successful transatlantic cable was laid between Valentia, Ireland and Hearts Content, Newfoundland. Service was interrupted by a break in deep water after only a few months operation. Transatlantic communication by cable was finally achieved in 1866. By 1929 there were 21 cables across the Atlantic alone and many more elsewhere in the world.

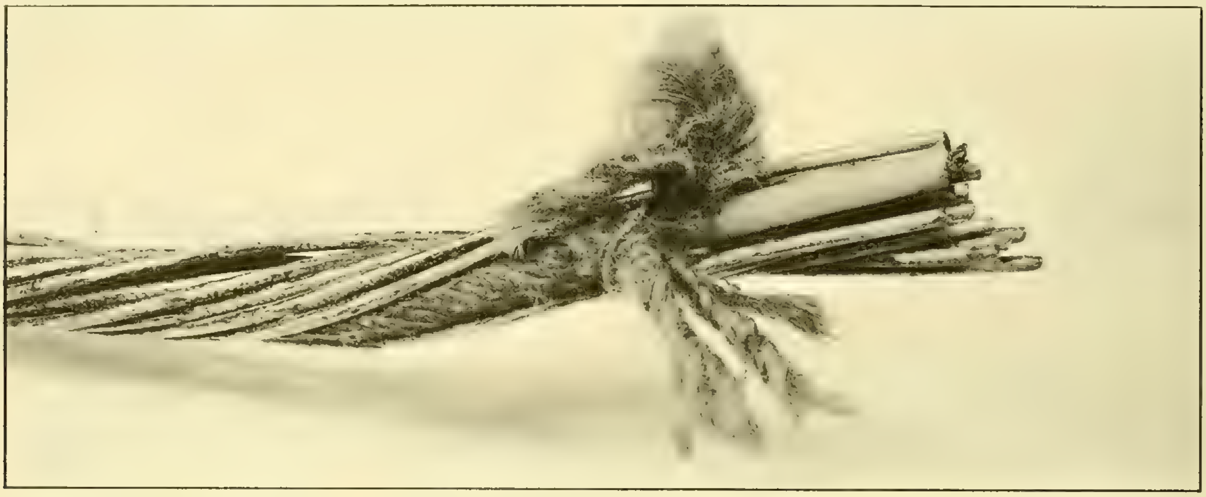
Laying the cable was but one of the many problems to overcome before submarine communication could be called a commercial success. Sensitive instruments and complex methods of operation gradually increased the capacity of each cable. Cable construction details



The Gifford Grapnel, one of the types used in submarine cable work.

Landing a cable buoy on deck after repairing a difficult break in deep water were perfected for varying usage, depending on location. The ordinary deep sea type cable is only one inch in diameter and weighs about 2 tons per mile. Such cables, brought up after more than 40 years in deep water, have shown but insignificant signs of deterioration. A cable laid near the shore or on shoals has added protection against damage by ships anchors and trawling gear. The shore end of a cable may thus be up to three inches in diameter and weigh 30 tons per mile and have a breaking strength of 12 tons or more. By far, the most common source of damage is fishing trawls. Damage caused by underwater slides and volcanic action can be extensive but fortunately it is relatively rare.

The theory of how fouling occurs is based largely on conjecture since there are no witnesses and few reports are made. Experiments have been made proving that a well constructed and maintained otter board can cross a cable laying on the bottom hundreds of times without fouling. Snagging frequently occurs as the trawler ends the tow and swings around to heave in the catch. This maneuver allows the trawl boards to flatten on the bottom and when the trawl is raised



Undersea cable damaged by being cut with an axe

Ocean cable damaged by a break under heavy strain.

A trawl ridden submarine cable showing a kink the leading edge of the otter board may pass under a cable. Where the cable lies flat on an even bottom, fouling will not generally occur, but where tension remains in the cable over a slight bottom depression, fouling is likely. At times excessive slack is the cause of fouling and unfortunately slack in some form is bound to exist wherever a repair has been made, and it is this slackness resulting from a repair which makes the cable more vulnerable than before.

That broken cables have long been an international problem is indicated by the Articles of the International Convention held in 1884. The Articles which follow were approved by the member nations and are still in force, but they have done little during the years to alleviate the situation.

International Convention of March 14. 1884 for the protection of submarine cables

His Excellency the President of the United States of America,. . . [the heads of state of Germany, Argentine Confederation, Austria-Hungary, Belgium, Brazil, Costa-Rica, Denmark, Dominican Republic, Spain, United States of Colombia, France, Great Britain, Guatemala, Greece, Italy, Turkey, Netherlands, Persia, Portugal, Roumania, Russia, Salvador, Servia, Sweden and Norway, and Uruguay], desiring to secure the maintenance of telegraphic communication by means of submarine cables, have resolved to conclude a convention to that end, and have appointed as their Plenipotentiaries, to wit:

. . . [naming the representatives from the various countries]

Who, after having exchanged their full powers, which were found to be in good and due form, have agreed upon the following articles:

ARTICLE I.

The present Convention shall be applicable, outside of the territorial waters, to all legally established submarine cables landed in the territories, colonies or possessions of one or more of the High Contracting Parties.

ARTICLE II.

The breaking or injury of a submarine cable, done willfully or through culpable negligence, and resulting in the total or partial interruption or embarrassment of telegraphic communication, shall be a punishable offense, but the punishment inflicted shall be no bar to a civil action for damages.

This provision shall not apply to ruptures or injuries when the parties guilty thereof have become so simply with the legitimate object of saving their lives or their vessels, after having taken all necessary precautions to avoid such ruptures or injuries.

ARTICLE III.

The High Contracting Parties agree to insist, as far as possible, when they shall authorize the landing of a submarine cable, upon suitable conditions of safety, both as regards the track of the cable and its dimensions.

ARTICLE IV.

The owner of a cable who, by the laying or repairing of that cable, shall cause the breaking or injury of another cable, shall be required to pay the cost of the repairs which such breaking or injury shall have rendered necessary, but such payment shall not bar the enforcement, if there be ground therefore, of article II. of this Convention.

ARTICLE V.

Vessels engaged in laying or repairing submarine cables must observe the rules concerning signals that have been or shall be adopted, by common consent, by the High Contracting Parties, with a view to preventing collisions at sea.

When a vessel engaged in repairing a cable carries the said signals, other vessels that see or are able to see those signals shall withdraw or keep at a distance of at least one nautical mile from such vessel, in order not to interfere with its operations.

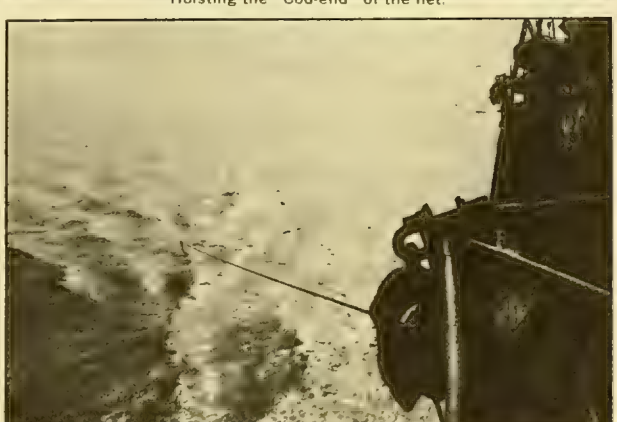
Fishing gear and nets shall be kept at the same distance.

Nevertheless, a period of twenty-four hours at most shall be allowed to fishing vessels that perceive or are able to perceive a telegraph ship carrying the said signals, in order


Fore door or otter board ready for release at the gallows.


Ocean perch or rose fish on deck


Hoisting the "Cod-end" of the net.


Hauling in on wires at the end of a run

that they may be enabled to obey the notice thus given, and no obstacle shall be placed in the way of their operations during such period.

The operations of telegraph ships shall be finished as speedily as possible.

ARTICLE VI.

Vessels that see or are able to see buoys designed to show the position of cables when the latter are being laid, are out of order, or are broken, shall keep at a distance of one quarter of a nautical mile at least from such buoys.

Fishing nets and gear shall be kept at the same distance.

ARTICLE VII.

Owners of ships or vessels who can prove that they have sacrificed an anchor, a net, or any other implement used in fishing, in order to avoid injuring a submarine cable, shall be indemnified by the owner of the cable.

In order to be entitled to such indemnity, one must prepare, whenever possible, immediately after the accident, in proof thereof, a statement supported by the testimony of the men belonging to the crew; and the captain of the vessel must, within twenty-four hours after arriving at the first port of temporary entry, make his declaration to the competent authorities. The latter shall give notice thereof to the consular authorities of the nation to which the owner of the cable belongs.

ARTICLE VIII.

The courts competent to take cognizance of infractions of this convention shall be those of the country to which the vessel on board of which the infraction has been committed belongs.

It is, moreover, understood that in cases in which the provisions contained in the foregoing paragraph cannot be carried out, the repression of violations of this Convention shall take place, in each of the contracting States, in the case of its subjects or citizens, in accordance with the general rules of Penal competents established by the special laws of those States, or by international treaties.

ARTICLE IX.

Prosecutions on account of the infractions contemplated in Articles II., V. and VI. of this Convention shall be instituted by the State or in its name.

ARTICLE X.

Evidence of violations of this Convention may be obtained by all methods of securing proof that are allowed by the laws of the country of the court before which a case has been brought.

When the officers commanding the vessels of war or the vessels specially commissioned for that purpose, of one of the High Contracting Parties, shall have reason to believe that an infraction of the measures provided for by this Convention has been committed by a vessel other than a vessel of war, they may require the captain or master to exhibit the official documents furnishing evidence of the nationality of the said vessel. Summary mention of such exhibition shall at once be made on the documents exhibited.

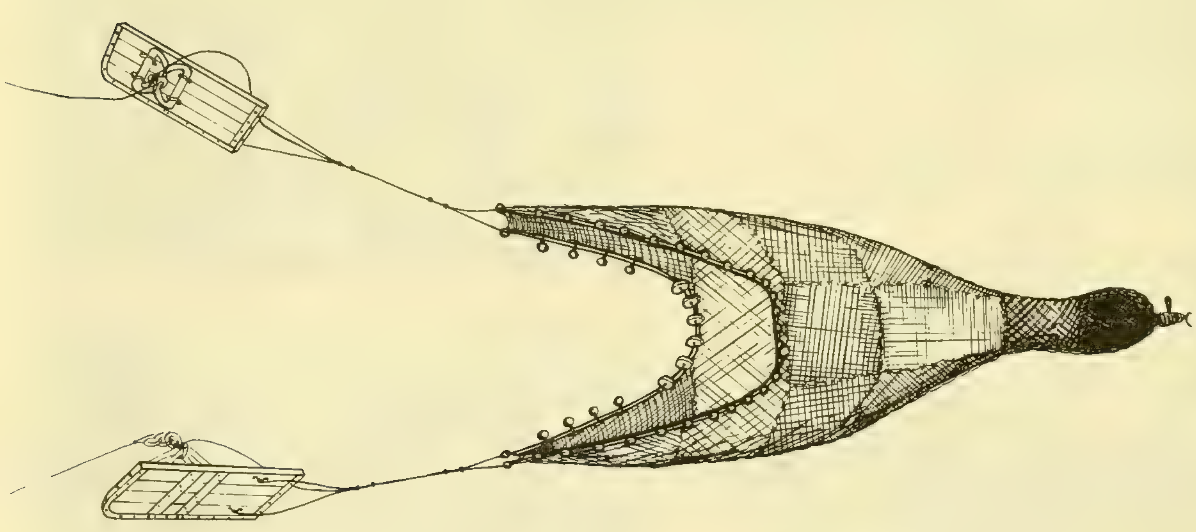
Reports may, moreover, be prepared by the said officers, whatever may be the nationality of the inculpated vessel. These reports shall be drawn up in the form and in the language in use in the country to which the officer drawing them up belongs; they may be used as evidence in the country in which they shall be invoked, and according to the laws of such country. The accused parties and the witnesses shall have the right to add or cause to be added thereto, in their own language, any explanations that they may deem proper; these declarations shall be duly signed.

ARTICLE XI.

Proceedings and trial in cases of infractions of the provisions of this Convention shall always take place as summarily as the laws and regulations in force will permit.

ARTICLE XII.

The High Contracting Parties engaged to take or to propose to their respective legislative bodies the measures necessary in order to secure the execution of this Conven-



The otter trawl.

tion, and especially in order to cause the punishment, either by fine or imprisonment, or both, of such persons as may violate the provisions of Articles II., V. and VI.

ARTICLE XIII.

The High Contracting Parties shall communicate to each other such laws as may already have been or as may hereafter be enacted in their respective countries, relative to the subject of this Convention.

ARTICLE XIV.

States that have not taken part in this Convention shall be allowed to adhere thereto, on their requesting to do so. Notice of such adhesion shall be given diplomatically, to the Government of the French Republic and by the latter to the other signatory Governments.

ARTICLE XV.

It is understood that the stipulations of this Convention shall in no wise affect the liberty of action of belligerents.

ARTICLE XVI.

This Convention shall take effect on such day as shall be agreed upon by the High Contracting Parties.

It shall remain in force for five years from that day, and, in case none of the High Contracting Parties shall have given notice twelve months previously to the expiration of the said period of five years, of its intention to cause its effects to cease, which shall continue in force for one year, and so on from year to year.

In case of one of the Signatory Powers shall give notice of its desire for the cessation of the effects of this Convention, such notice shall be effective as regards that Power only.

ARTICLE XVII.

This Convention shall be ratified; its ratifications shall be exchanged at Paris as speedily as possible, and in one year at the latest.

In testimony whereof, the respective Plenipotentiaries have signed it, and have thereunto affixed their seals.

Done in twenty-six copies, at Paris, this 14th day of March, 1884.

[Signatures of the representatives follow.]

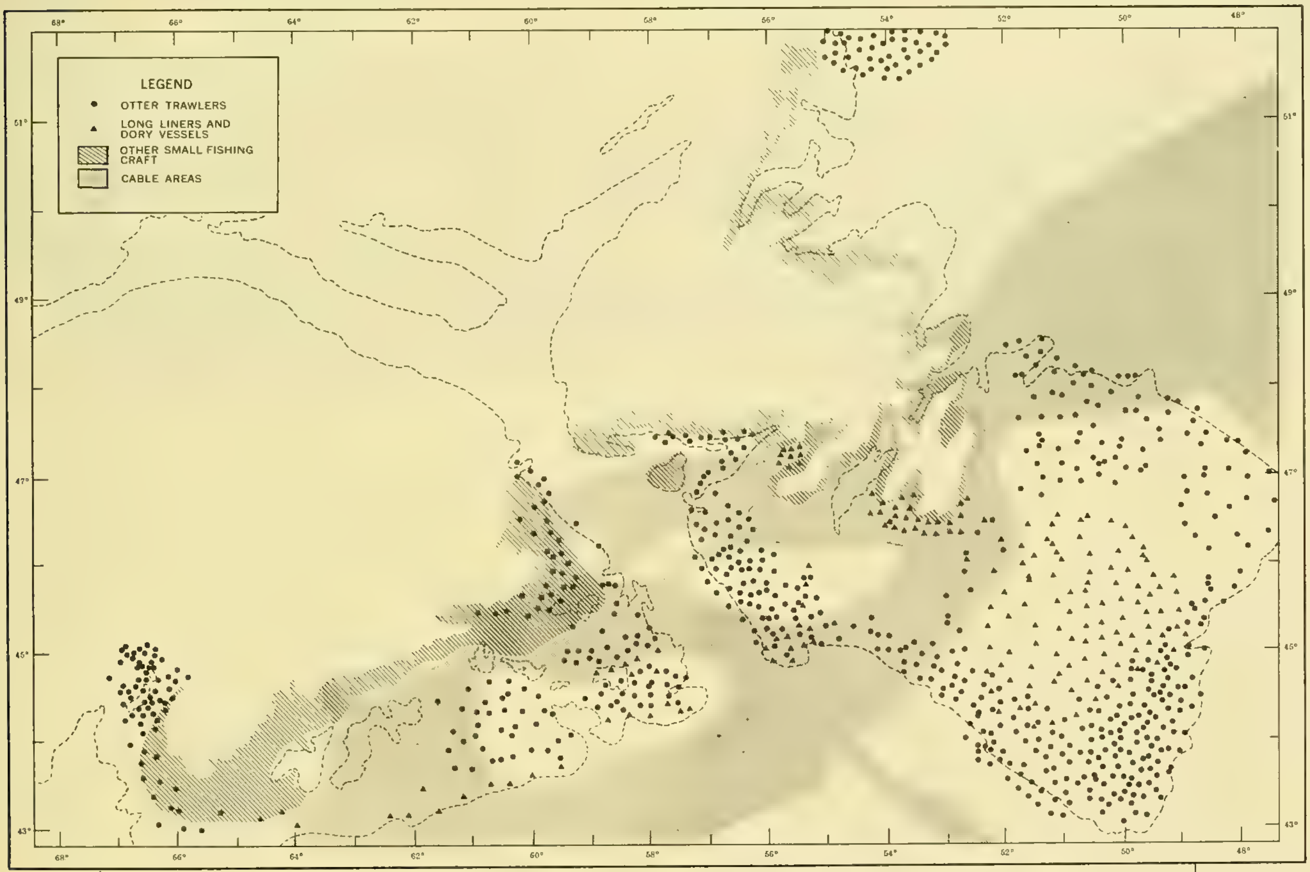
Measures taken to minimize damage to ocean cables have not proven effective. None have reduced the damage appreciably. The 1884 International Convention, and later action by participating countries making it a misdemeanor to willfully damage or break a submarine cable, has had no visible effect. An attempt around 1920 to persuade trawler fishermen to use otter boards of an improved design, recommended as better able to avoid fouling, met with no enthusiasm. The standing offer by cable companies to reimburse fishermen for gear abandoned to save cables has probably been most impressive as a gesture of mutual cooperation.

Some of the measures listed below may serve to alleviate the situation:

(a) Chart cable positions on the best scale navigation charts. This is now being done and these charts may be obtained free of charge by writing to any of the following:

Cable Damage Committee
Mercury House, Theobald's Road
London W.C. 1, England

The Western Union Telegraph Company
International Communications
General Plant Engineer



Grand Banks of Newfoundland showing the cable areas and a typical concentration of fishing vessels.

60 Hudson Street
New York 13, N.Y., U.S.A.

The American Telephone & Telegraph Co.
Long Lines Department
32 Avenue of the Americas
New York 13, N.Y., U.S.A.

Commercial Cable Company
Marine Superintendent
67 Broad Street
New York 5, N.Y., U.S.A.

(b) If a cable is hooked the fisherman should cut his gear and forward a claim to any of the above who will see that the claim is forwarded to the company whose cable is involved.

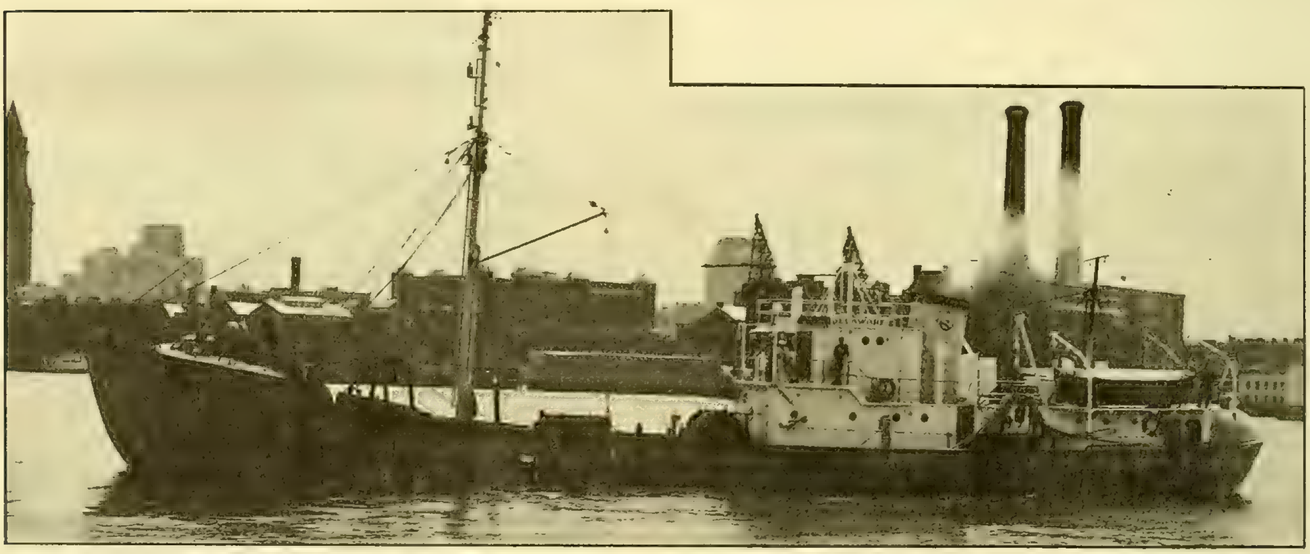
(c) Trench the cable in areas where damage is likely to occur. This has already proven effective in relaying four transatlantic cables across the active trawler area southwestward of Ireland. Unfortunately, the rocky bottom and strong current off Newfoundland make the problem of burying the cables in that area extremely difficult and the means to accomplish this are not now available.

(d) Remove abandoned cables. Cable companies have replaced the original cables with more heavily armored types in fishing areas, but numerous abandoned cables remain on the bottom and are a hazard to the fishermen.

Some cables carry voltages in excess of 2,000 and any attempt to cut these on deck would be extremely hazardous.

A pressing need for closer cooperation between the fishing and communication industries is evident. Fishermen lose far too much time and gear because of cables laid in fishing areas. Cable breaks and service interruptions are far too frequent to be condoned. The development of an improved trawl gear, invulnerable to cable fouling, would be a step in the right direction. Diversion of the cables to waters clear of fishing areas, or into unified routes which could be charted across larger fishing areas, might appear to lead to a satisfactory solution. However, this has already been attempted by one cable company which spent considerable time and money for major re-routings of the cables northward on the advice of qualified fisheries experts only to find that the fish also moved northward.

New factors which might revolutionize both industries may materialize in the future. The number of cables laid across fishing areas may decrease with the use of modern coaxial design cable using submerged repeaters. Improvement in fish detection technique may change fishing methods. Another development which appears promising is the use of mid-water trawling or otter boards that swim. This would not only avoid damage to the cables but would also greatly reduce the power expended by towing present day otter boards along the bottom. This waste of power amounts to as much as 30 percent of the trawler's main propulsion. But, while waiting for these developments, a practical policy of eliminating the present hazards and inconveniences should be undertaken. The problem of compatibility must be solved in an effort to serve the best interests of both the fishing and ocean cable industries.



A diesel powered trawler proceeding seaward from a New England port

COLLISIONS—1969

By Frederick W. Fricker
Maritime Safety Division
U. S. Naval Oceanographic Office
Washington, D. C. 20390

INTRODUCTION

In a previous Pilot Chart Article, titled *More About Collisions*, the results of an examination of ship casualties for the years 1957 through 1961 indicated that, on an average, approximately 20 percent were COLLISIONS. In the effort to establish a trend since that period and, hopefully, report an improvement in the COLLISION rate, a similar study was conducted for the decade 1958 through 1967. The statistics used in both studies were from the annual reports issued by the Liverpool Underwriters' Association, which lists all casualties reported for vessels of 500 gross tons and over. Unfortunately, no improvement was indicated by the recent study which again disclosed that an average of approximately 20 percent of all casualties occurring during the 10-year period were COLLISIONS. The term *all casualties* includes ship damage or loss due to weather, groundings, fires and explosions, etc., as well as collisions. Since the study showed that, on an average, more than one third of all ships considered suffered a casualty of some sort during the period, it can be said that approximately seven percent of the world's fleet was involved in a collision during each of the years specified.

Judging by the apparent consistency with which collisions occur each year, the annual average thus provided could conceivably be used as a forecast for future years. Carrying the hypothesis further, we could say that almost seven percent of the world's fleet, roughly between 1,700 and 1,800 ships, will suffer a collision during the coming year. It would mean that approximately one ship in every 15 would be the victim of a collision in any given year. This is indeed a matter of serious concern.

Fortunately, mariners have at their disposal the time and the means to control, for the most part, the destiny of their own vessels and consequently to improve the casualty records of the future. They should start by accepting the fact that the majority of collisions occur as the result of a few human shortcomings. A study of recent collision cases is considered to be a good method to identify these frailties of the mariner. As the philosopher *Publilius* once said, "He who gains wisdom from the mistakes of others is truly wise."

The following cases are, therefore, presented to focus attention on some of the shortcomings that have contributed to collisions. They were particularly selected because each of the incidents occurred in what might be described as the classic situation, the head-to-head meeting during limited visibility, and because all of the ships implicated were equipped with operational radar. Although all are based on authentic incidents, none of the cases is to be construed as being a complete report, for facts considered immaterial to the purpose of this article were intentionally omitted.

The opinions and conclusions expressed in the analyses are those of the author and are intended to place maximum emphasis on the lessons to be learned. Serious consideration of these lessons by all mariners involved in the navigation of ships could lead to a significant reduction in the number of collisions in the future.

CASE 1

The principals in this case were two American dry-cargo vessels that collided in the Yellow Sea off the west coast of Korea during a period of restricted visibility. The weather at the time consisted of a southwesterly wind, force 3-4, with light rain, mist, and patchy fog. The range of visibility was estimated to be less than a mile. A slight to moderate sea was running with very little swell. Both vessels were equipped with radar which was reported to have been in good operation at the time of the casualty.

NARRATIVE

SHIP A

Ship A was enroute from Inchon, Korea, to Pusan, Korea, with general cargo. After departure the master maintained the conn until the ship was clear of the island group just south of Inchon. Shortly after midnight the ship entered the relatively open waters of the Yellow Sea, whereupon the master relinquished the conn to the mate of the watch and went below.

The vessel proceeded southward at 16 knots on a course of 186°T. Due to the limited visibility and the unexpected presence of local fishing craft, the watch officer frequently scanned the radar screen which was set on the 8-mile scale. At 0324 he thus observed a large target, *Ship B*, which he estimated to be dead ahead (186°T) at a distance of approximately 8 miles. This fix as well as the subsequent radar fixes of *Ship B* by *Ship A* proved to be erroneous by 11°E to 15°E in bearing and consistently 1¼ miles in excess of that which can be substantiated by reconstruction.

One minute later, obviously unaware of his radar's error, the watch officer observed that the target bore 184°T, range 7.5 miles. Believing this contact to be a large, fast ship because of its pip size and high closing speed, the watch officer changed course to 209°T. At 0328 he calculated that the target bore 183°T, 5.5 miles distant. Around 0330, again noting the speed at which the target was closing and that the bearing had not changed appreciably, the watch officer changed course to 229°T. At this time the two ships were

about four miles apart.

At 0333, *Ship B* was sighted visually close aboard off the port bow and on a collision course. Shortly after the sighting the watch officer ordered **Right 20° Rudder** followed by **Hard Right.** He then sounded the general alarm. Collision occurred within a minute as *Ship B* knifed into the port side of *Ship A*. At the time *Ship A* was still making turns for 16 knots.

SHIP B

Ship B was enroute from Kobe, Japan, to Inchon, Korea. About 0040 the master set a course of 008°T and instructed the watch officer to give all ships a wide berth. He then went below for the night. During the next three hours the watch officer made numerous course changes to avoid fishing craft. From several radar fixes it was estimated that *Ship B* was making good 20 knots over the ground. About 0300 the radar was switched from the 8-mile scale normally in use to the 20-mile scale to get a fix on land features. No targets that might have been ships were detected outside of the 8-mile range. At 0315 the radar was again switched to the 20-mile scale, but no target that might have been *Ship A* was noted.

Sometime between 0315 and 0320 radar contacts believed to be more fishing vessels were picked up off the port bow, and the watch officer ordered a substantial course change to starboard. After estimating that the ship was clear he returned to the base course of 008°T.

At approximately 0328 the watch officer thought he detected a radar target bearing 018°T on the 4-mile range ring. He changed course to 000°T in case the target was another fishing vessel, and estimated that it would pass about 1 mile off the starboard side. At 0330 the watch officer again switched to the 20-mile scale to get a fix. Upon switching back to the 8-mile scale, he noticed that the target now presented a much larger pip. Suspicious of the contact the watch officer ordered **the helmsman to come left** to course 350°T and stepped out into the starboard bridge wing. He then saw several white lights bearing two points on the starboard bow and knew immediately that he was looking at a large ship. Quickly estimating that it was about 2 miles distant he ordered **Hard Left Rudder.** Next, he placed the telegraph on **full astern** and called the master on the voice tube. Without waiting for a reply he returned to the bridge wing. Seconds later the bridge of *Ship A* loomed forth, broad on the starboard bow. Collision followed

No case cited in this area.

minutes later as the bow of *Ship B* penetrated deeply into the port side of *Ship A*.

ANALYSIS

The primary causes of this collision were the excessive speed at which both ships were navigated during conditions of limited visibility and the failure by the watch officer of each vessel involved to reduce speed or stop upon detecting another vessel ahead whose course and intention were unknown. In each instance the responsible officer was guilty of violating Rule 16. A contributing factor which certainly should be cited was *Ship A's* overreliance on faulty radar information.

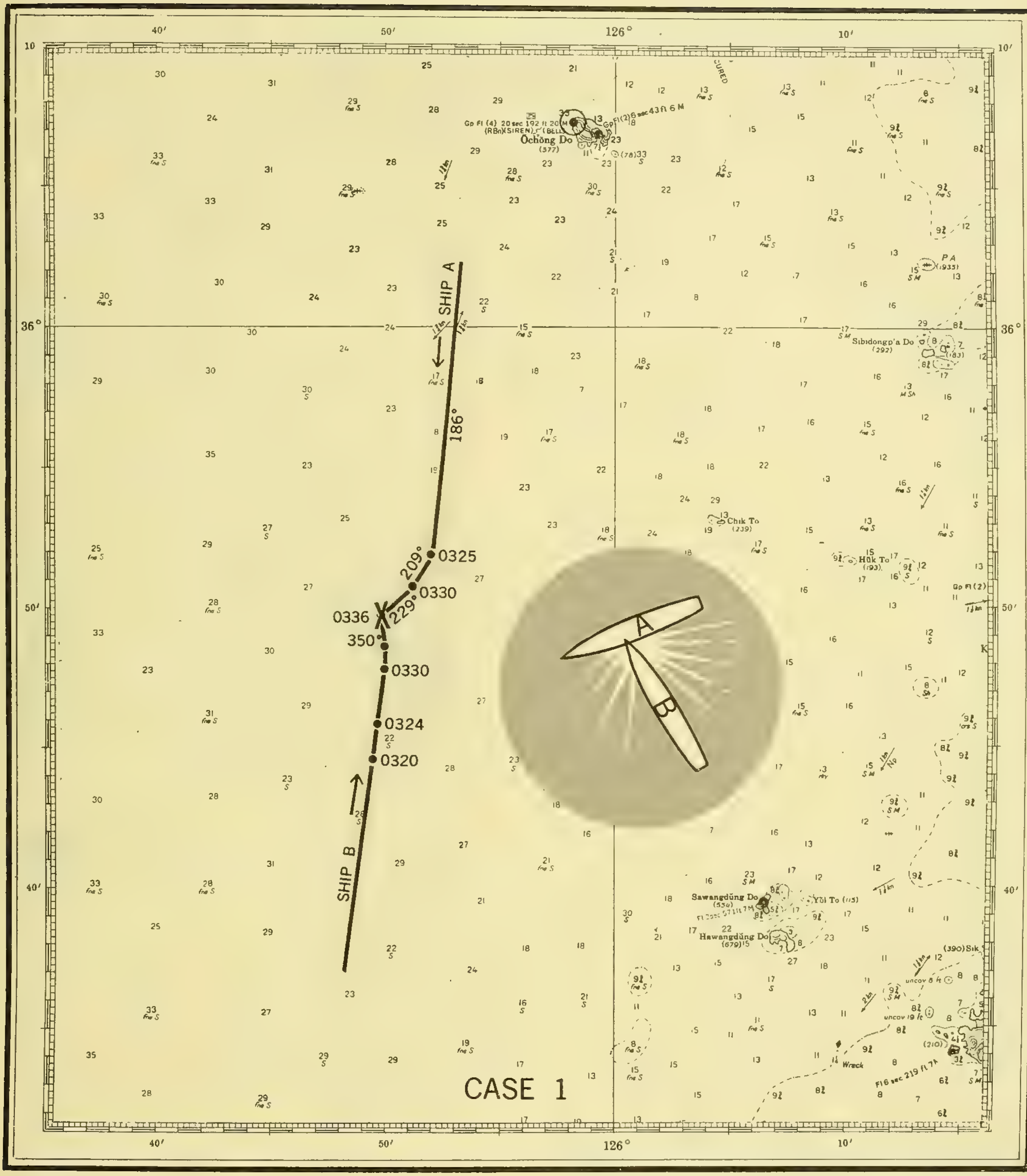
As early as 12 minutes before the casualty, *Ship A's* conning officer had detected *Ship B* and recognized it as a large ship. One minute later he further established that it was closing at high speed and made the first of two substantial course changes to the right in the effort to avoid a close quarter situation. Had *Ship B* actually been in the relative position reported, that is, dead ahead when first detected, the evasive course changes made by *Ship A* would probably have had the desired effect. Unfortunately, such was not the case. A reconstruction of the courses steered by the two ships during the final hour indicates that *Ship B's* track was westward of *Ship A's*. At 0324, therefore, *Ship B* would have been about one point on *Ship A's* starboard bow. Subsequent events tend to support this contention. The obvious misinterpretation of radar information by *Ship A*, due probably to the large pip size on the 8-mile scale and the now apparent miscalibration of the radar set, led to the watch officer's decision to turn to the right directly into the path of *Ship B*. Here is a perfect example of the fallacy of placing too much reliance on radar data.

Even five minutes before the casualty, *Ship A's* watch officer had a further warning of the impending danger when he noted that *Ship B's* bearing had not changed appreciably. He failed to heed this last warning and permitted the ship to continue at top speed toward the approaching vessel.

Ship B's watch officer was, of course, blissfully unaware of *Ship A's* existence until less than five minutes before the tragedy. Here was a large ship, being navigated almost solely by radar, proceeding through open water at high speed during conditions of limited visibility, and the watch officer was employed, for the most part, in avoiding local fishing craft. So occupied was he in doing so, that rarely was his radar scope set to anything but the 8-mile range, contrary to the tenets of Rule 29, keeping a proper lookout. His turns to the left, upon discovery of *Ship A*, were probably correct tactics under the circumstances, but the ship's high speed, unchanged until moments before impact, placed it *in extremis* before a truly effective plan could be formulated.

CASE 2

The principals in this case were two dry-cargo vessels which collided in heavy fog in the Pacific Ocean approximately 10 miles westward of Cape San Martin, California. The visibility at the time of impact was variously reported as ranging from zero to one-half mile. The wind was northwesterly, force 4 to 5, sea conditions moderate with negli-



gible coastal current. Both vessels were equipped with radar, reportedly in good operating condition prior to, and at the time of, the casualty. A radar plot was not maintained by either ship.

NARRATIVE

SHIP A

Ship A was enroute from Oakland, California, to Los Angeles, California, with general cargo. Departure was taken at the San Francisco Lightship at 2300, and the vessel proceeded southward at 21 knots on a course of 148°T, following the usual coastwise steamer track. Before going below for the night the master left orders to alter course as necessary to stay within a mile of the designated track line.

The midwatch was uneventful, but at 0400 the relieving watch officer obtained a radar fix which indicated that the ship was about one mile seaward of the track. He, therefore, changed course to 147°T to bring the ship gradually back to the desired track line. Shortly thereafter heavy fog set in, reducing visibility to less than one mile. The master and the engineer on watch were notified, and the engine was placed on standby. The automatic fog signal was activated, but no change in speed was made. A few minutes later the master arrived on the bridge to check for radar contacts, but none was observed. After spending about five minutes on the bridge he went below again where he remained until the collision. At 0443, after another radar fix placed the vessel seaward of the track line, the watch officer changed course to 144°T.

Ship B was first observed at 0447 as a radar contact bearing 003° relative at a distance of approximately 8 miles. At 0449 another radar fix was obtained which plotted seaward of the desired track, and the course was again changed to the left to 139°T. At 0450 *Ship B* appeared on radar to be about 012° relative at a distance of 6 miles. The watch officer alerted his bow lookout that a ship was off the starboard bow and cautioned him to keep a sharp lookout. He failed, however, to notify the master or to reduce speed. At 0457 the watch officer again observed *Ship B* on the radar screen and noted that the target appeared to be bearing 020° relative at 2 miles before being lost in the sea return. He then went out on the starboard bridge wing to listen for fog signals and heard the bow lookout sound the bell signal indicating a vessel to starboard. At about 0458 the watch officer heard one prolonged blast close aboard. Moments later *Ship B's* port side light, masthead light, and range lights suddenly appeared out of the fog about 003° relative to *Ship A* at less than 1,000 yards. The watch officer ordered **Hard Right** and put the engineroom telegraph on **full astern.** One short blast was sounded, followed by several more. Collision occurred seconds later with *Ship A* just beginning to answer her right rudder. *Ship B* penetrated *Ship A* to a distance of 40 feet on the starboard side of No. 2 hold.

SHIP B

Ship B was enroute from La Libertad, El Salvador, to San Francisco, California. On the morning of the collision the ship was proceeding northward along the coastal route on a course of 334°T at a speed of 16 knots. At 0345, when the ship drew abeam of Pt. Piedras Blancas Light, a heavy fog set in. The master was informed of the situation, and he reduced speed to 12 knots. The telegraph was placed on standby, the engineroom notified, fog signals started, and a lookout posted on the forecastle. The course at this time was 334°T.

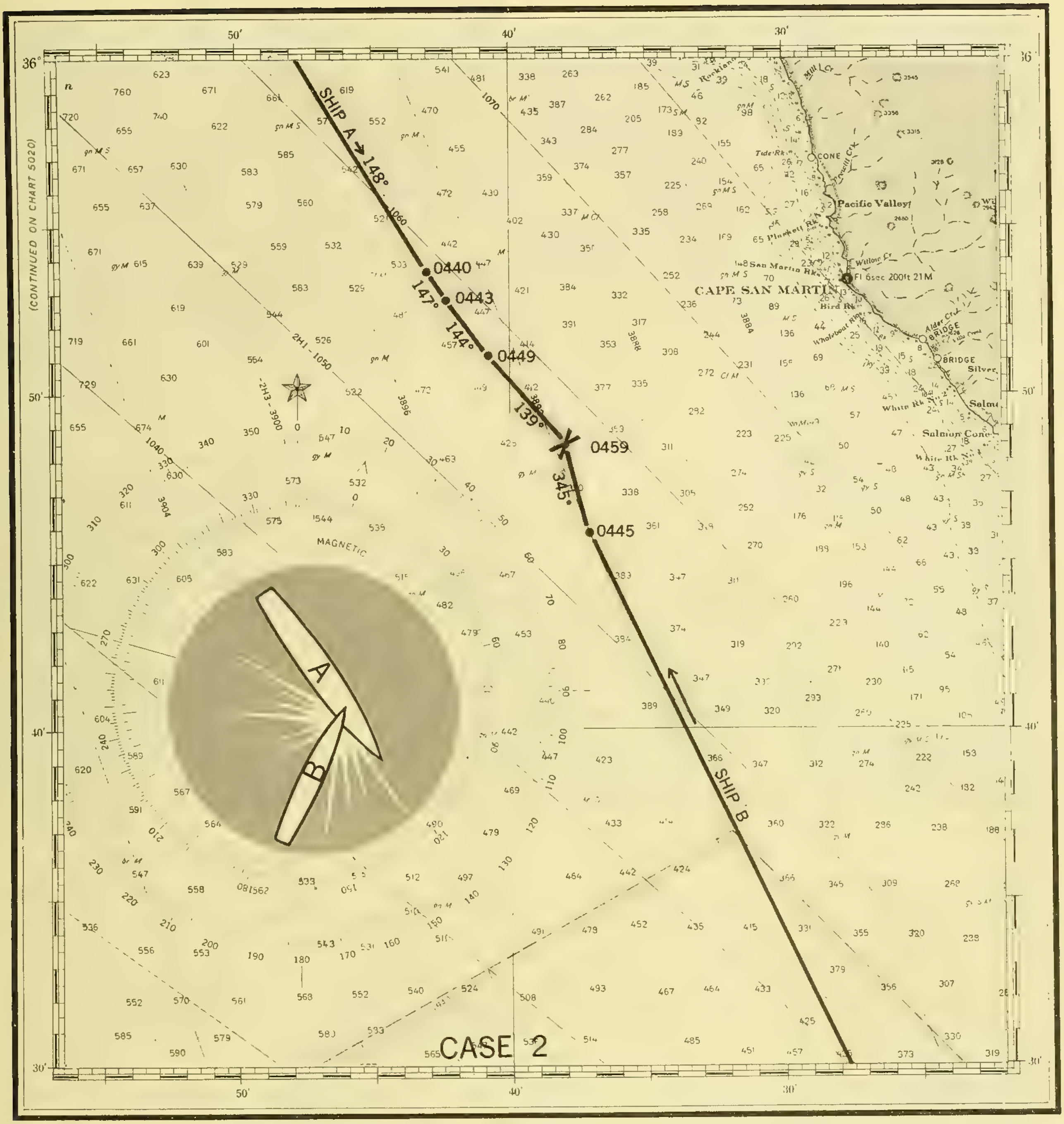
At 0445 a target was picked up on radar bearing 357° relative, range about 7 miles. The contact was reported to the master who changed course to 345°T. The limit of visibility at this time was approximately one mile. A few minutes later the target was observed at a range of 4.5 miles, but no bearing was obtained. At approximately 0455 the watch officer scanned the radar screen and determined that the range was 2 miles and that the bearing appeared to be opening. Shortly thereafter the master assumed the conn.

At 0458 the bow lookout sounded the bell signal indicating a ship off the port bow, and the master ordered **Right 20° Rudder.** Less than a minute later *Ship A* appeared out of the fog, her port and starboard side lights, masthead light, and range lights all visible. The master immediately ordered **Hard Right** and **sounded one short blast.** Collision occurred seconds later as the bow of *Ship B* tore into the starboard side of *Ship A*. At the time of impact *Ship B* was still making turns for 12 knots.

ANALYSIS

The primary cause of this collision was the excessive speed at which both ships were navigated during conditions of extremely restricted visibility. Equally responsible was the failure of the watch officer on each vessel to stop their engines and navigate with caution after hearing, apparently forward of the beam, the fog signal of a vessel the position of which is not ascertained. Both citations are, of course, in violation of Rule 16. Contributing greatly to the casualty was the amazingly casual manner in which personnel of both ships utilized available radar information.

Ship A, proceeding at an unusually high rate of speed, encountered heavy fog shortly after 0400. Neither the master nor the watch officer felt it necessary to reduce speed, presumably secure in the knowledge that radar data was available. Then, after detecting *Ship B* in such a position as to indicate a meeting situation was probably developing, the watch officer altered course to the **left** for no better reason than to return to the track line. However, the close-quarter situation could still have been avoided if the radar had been properly used, for what the watch officer saw on



the screen somehow deluded him into believing that the bearing of *Ship B* was opening to the right. A reconstruction of both tracks tends to indicate that the bearing could not have changed significantly during the 12 minutes prior to the collision.

Ship B's personnel wisely reduced speed soon after the fog set in, but in view of the state of visibility even 12 knots could not be considered a moderate speed. If the master was depending on radar to alert him of dangers ahead it was not evident in his subsequent actions. *Ship A* was first detected at a range of 7 miles, a relatively short distance if it develops, as it did, that the target is on a reciprocal course. Some five minutes transpired before the next radar observation was made, and it revealed that the target was only 4.5 miles away. This alone was a clear indication that the closing speed was great, yet no bearing was taken at the time. The casualty could still have been avoided, however, if the last radar observation, taken four minutes before impact, had correctly imparted the fact that the two ships were on a collision course.

CASE 3

The principals in this case were a dry-cargo vessel and a bulk carrier which collided during a period of restricted visibility in the Atlantic Ocean approximately one mile south of Chesapeake Bay Entrance Lighted Whistle Buoy *2CB*. The casualty occurred in international waters, and both ships were credited with having been displaying proper navigation lights and sounding appropriate fog signals. The weather at the time was foggy with visibility from 500 yards to one mile. The wind was from the ESE, force 5.

Both vessels were equipped with radar, and both reported that it was in use and functioning properly at the time of the collision.

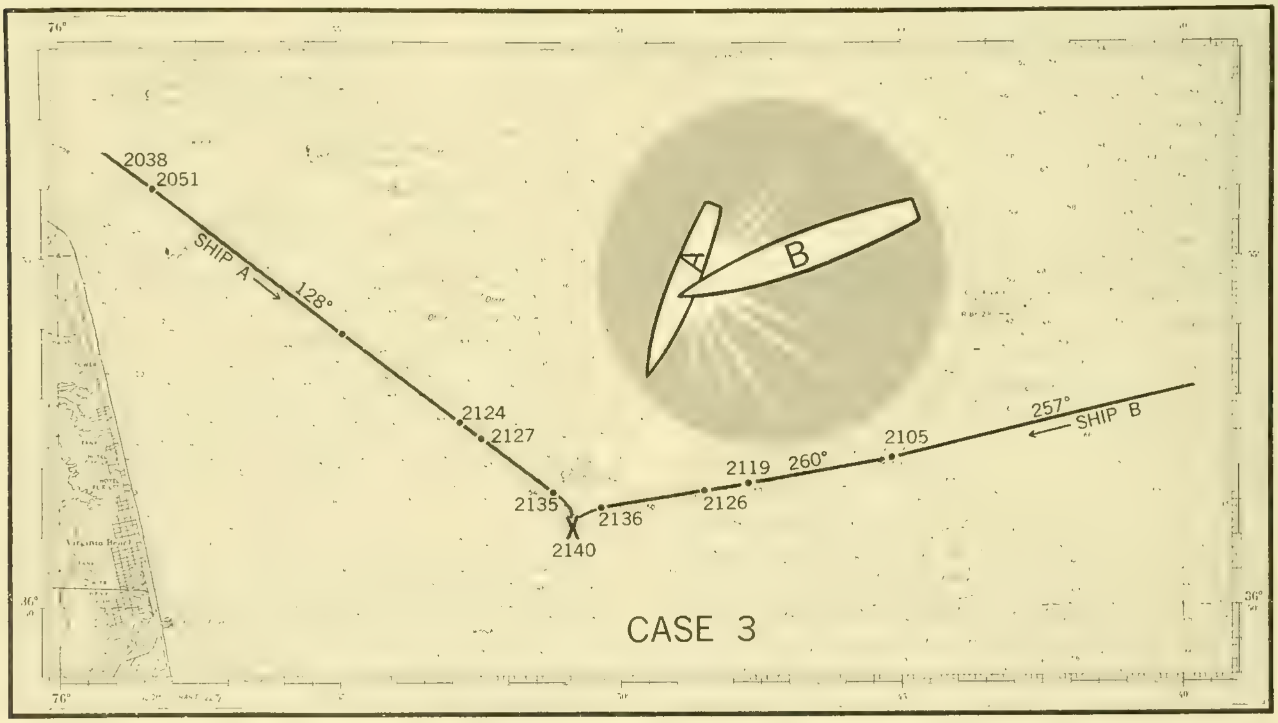
NARRATIVE

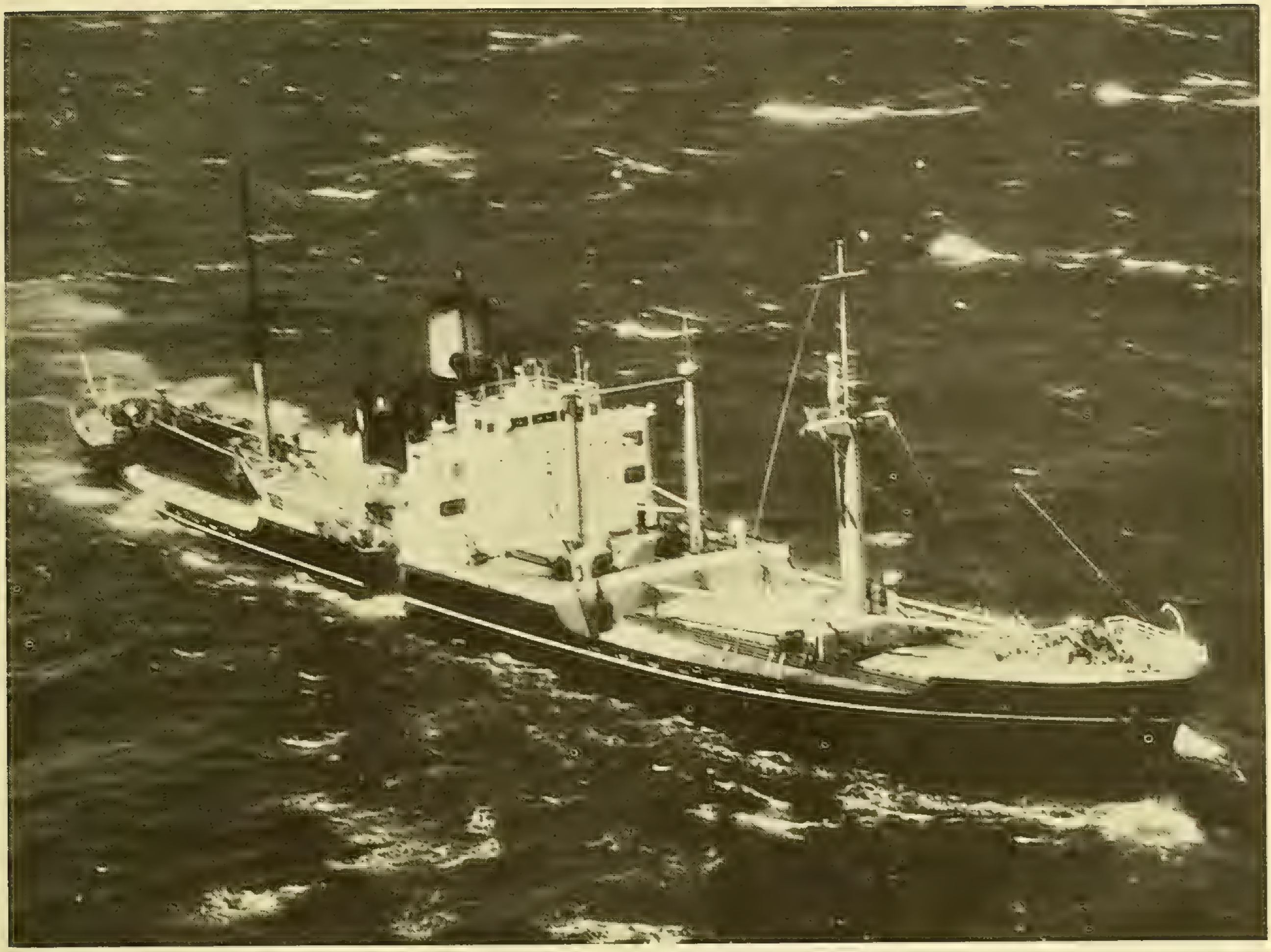
SHIP A

Ship A departed Baltimore, Maryland, with general cargo enroute to Jacksonville, Florida. After completing an uneventful transit down the Chesapeake Bay, the pilot disembarked at the Maryland Pilot Boat anchored about 1.8 miles east-northeastward of Cape Henry Light. The weather consisted of patchy fog with visibility ranging between 500 and 4,000 yards. Following the pilot's departure at 2051, the master set a course of 128°T to pass south of Chesapeake Bay Entrance Buoy *2CB*, some 9 miles distant. A lookout was stationed on the bow, and the prescribed fog signals were being sounded. The engines were placed on standby. On the bridge with the master, who was conning, were the watch officer and a helmsman. The master frequently observed the radar screen which was set on the relative motion display. During the passage from the pilot boat to Buoy *2CB*, several course and speed changes were made due to conditions of visibility and the avoidance of inbound traffic.

According to the master's account, *Ship B* was observed at 2124 as a radar contact bearing 001° relative at a distance of 4 miles. The master incorrectly estimated the contact to be about 1 mile east of Buoy *2CB*. Shortly after this initial contact, *Ship B* was observed to have moved from *Ship A's* starboard bow to close on her port bow. From this apparent relative movement it was assumed that *Ship B* was inbound and would pass safely to port with a CPA of about 1 mile. No attempt was made to plot the radar contact to determine its true course and speed.

At 2127, *Ship A* increased speed to approximately 12 knots (maneuvering speed). Shortly thereafter, the master, watch officer, and bow lookout all heard fog signals off the port bow. The master assumed that the signals were being made by the radar contact he'd been observing, thus confirming his previous deduction that a safe port-to-port passing would take place. At 2130, a glare of lights was seen broad on the port bow in which the master and watch officer saw what appeared to be the range lights of *Ship B*. From the position of the lights, they determined that





A freighter limps back to port after receiving collision damage on the starboard side, amidships.

they were looking at the port bow. Although neither officer saw a red side light, both felt that a port-to-port passing situation still existed. At 2135, *Ship A* passed Buoy *2CB* abeam to port. A half minute later, the watch officer shouted that he saw *Ship B's* green side light. Convinced that *Ship B* had come left while he had been observing the radar screen, the master immediately responded by ordering **Right Full Rudder** and **Full Speed Astern.** Whistle signals for each of these maneuvers were sounded. At 2139, *Ship A* was presumed dead in the water and **All Stop** was ordered. During the ensuing minute the distance between the two ships closed rapidly. At 2140, *Ship A's* master realized that a collision was imminent and decided to turn his vessel more to starboard to possibly limit the expected contact to a glancing blow. With the rudder still hard right, **Half Speed Ahead** was ordered. Collision occurred seconds later.

SHIP B

Ship B was approaching Chesapeake Bay Entrance on the last leg of a voyage from Hamburg, Germany, to Norfolk, Virginia. At 2105, with the ship about 3 miles southwest of Chesapeake Light, the course was changed to 260°T. The master intended to take the ship to a point about ½ mile south of Chesapeake Bay Entrance Buoy *2CB* before shaping a course for the pilot station. Bridge personnel consisted of the master, watch officer, and helmsman, and a lookout was posted on the bow. At 2119 speed was reduced to slow ahead due to low visibility. The engineroom was on standby. Visibility was between zero and 75 yards in patchy fog. About 2126 speed was increased to half-ahead (approximately 8 knots) because steering had become sluggish. Both the master and watch officer intermittently checked the radar screen which was showing a relative presentation on a 12-mile scale.

As *Ship B* approached Buoy *2CB*, several radar contacts were observed bearing 045° relative at a distance of about 7 miles. These contacts

The unmistakable imprint of another ship's bow torn into the forecastle of this freighter, is mute evidence of the force of impact.

were presumed to be outbound vessels from the Virginia Capes. No plot was started for any of the contacts to determine their true course and speed. Several minutes before the collision occurred, the watch officer observed that one contact, *Ship A*, had closed to a range of 2 to 3 miles and was still bearing 045° relative. He failed, however, to inform the master of this fact or to take any action of his own. At 2136 an object was sighted on the starboard bow which appeared to be a large, light-colored mass or cloud. Neither officer was able to distinguish any navigational lights, nor were any fog signals heard coming from its direction. The master ordered **Left Full Rudder** and **sounded two short blasts.** At 2138 the engines were stopped; then backed full. Three short blasts were sounded. No one on *Ship B* heard any signals from the contact except one group of 3 short blasts shortly before the collision. At 2140 the starboard bow of *Ship B* made contact with the port side of *Ship A*, amidships. At the time of impact *Ship B* formed an angle with *Ship A* of about 45 degrees tending aft.

ANALYSIS

The primary cause of this casualty was the violation of Rule 16(c) by the masters of both vessels. Each of these officers detected the other ship in ample time to comply with Rule 16, but neither took early and substantial action to avoid a close quarter situation, nor did they stop their engines and then navigate with caution until the danger of collision was over.

A factor which contributed greatly to the casualty was the failure of personnel of both ships to evaluate properly or to analyze the radar information available. Neither vessel attempted to maintain a graphic plot of radar data and, therefore, were never fully aware of the other's course and speed prior to the collision. During the passage from the pilot station to Buoy *2CB*, *Ship A* had maneuvered to the right several times, by the master's own admission. After each such maneuver, he attempted to return to the track line by steering to the left of base course. It is evident that *Ship A's* heading was well to the left of base course when the master first observed *Ship B* on the starboard bow. It is also evident that subsequent changes in *Ship B's* relative bearing must have been the result of heading changes in *Ship A*. Parenthetically, this situation exemplifies the risk involved in using a relative motion display without a clear understanding of what it actually indicates.

Ship B's radar watch left much to be desired. After the initial contact, the master apparently left the job up to the watch officer. The latter's failure to alert the master or take action himself after he observed the proximity and unchanging bearing of *Ship A* minutes before the collision is, of course, inexcusable.

In retrospect, it appears likely that the collision might have been averted had *Ship B* elected to turn right instead of making the always risky turn to the left. Here again, the maintenance of a plot would have provided the master with some knowledge of *Ship A's* relative movement and aided him in taking proper avoiding actions.

There was some evidence that *Ship B* was exhibiting lights which could have been, and probably were, mistaken for prescribed navigation lights.

CASE 4

The principals in this case were two American ships that collided in the vicinity of West Penobscot Bay, Maine, during a period of dense fog. A light breeze was blowing from the south and there was a slight southerly sea running at the time of the casualty. The tide was flooding with high water at Monhegan Island scheduled at 2038.

NARRATIVE

SHIP A

Ship A, enroute to Linden, New Jersey, departed Buckport, Maine, at 1420. The vessel proceeded down the Penobscot River and entered West Penobscot Bay using various courses and speeds under the direction of a pilot. At approximately 1724 the engineroom was placed on standby and the ship's engine speed reduced to half-ahead due to fog closing in. The vessel commenced sounding fog signals, and a lookout was stationed in the bow.

With the master on the bridge, the vessel continued at half-ahead (about 9 knots) on a course of 180°T down West Penobscot Bay, stemming the flood tidal current. At 1748 a radar bearing indicated that Two Bush Island Lighted Whistle Buoy *TBI* was abeam approximately ½ mile to port. The course was altered to 240°T in order to enter Two Bush Channel. A short time after steadying on this course a large target was noted on the radar screen about seven or eight miles ahead. The master and pilot together estimated that the target was on a generally northeast course heading toward Two Bush Channel and that it was a few degrees on the starboard bow of *Ship A*.

At approximately 1753 the pilot changed course to 235°T intending to make a starboard-to-starboard passing with the approaching vessel and to leave Two Bush Ledge Lighted Gong Buoy to starboard. Sometime later the course was altered to 230°T in order to leave still more room for the intended starboard-to-starboard passing. At 1812 a fog signal was heard from the approaching vessel, and the pilot stopped the engine. The

Too much speed during periods of too little visibility is often the cause of collision.

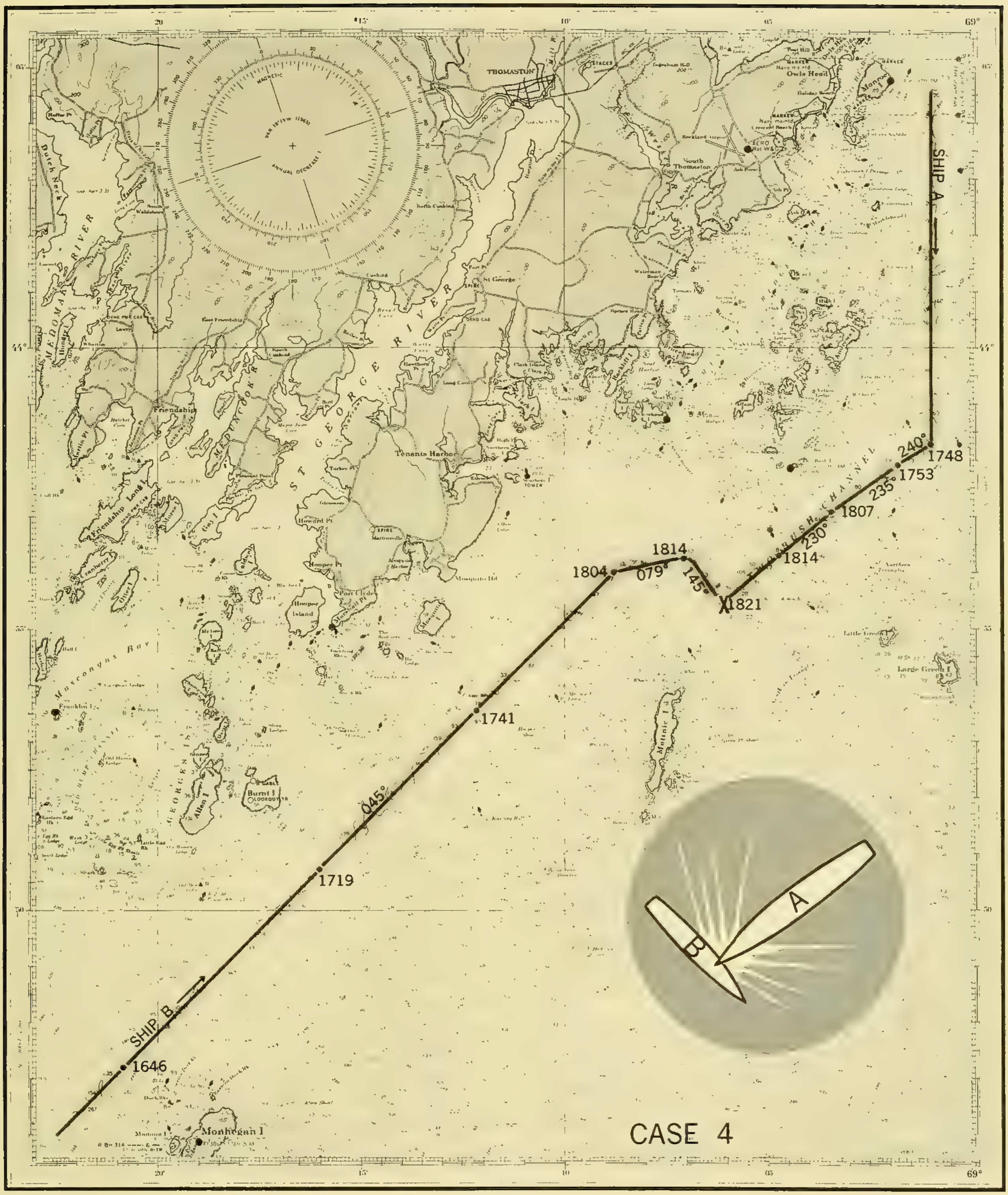
radar indicated that the approaching vessel was still off the starboard bow and heading toward Two Bush Ledge Lighted Gong Buoy at approximately eight or nine knots. At 1814, observing that the bearing continued to increase, *Ship A* again went ahead at half speed still sounding fog signals.

At 1816 the radar indicated that the relative bearing ceased to open, and, again, the engine was stopped. Visibility at this time was restricted to such an extent that personnel in the wheelhouse could not see beyond the ship's bow. Fog signals were alternately exchanged between the two vessels as they steadily approached their rendezvous with fate.

The master ordered **emergency full astern** and sounded the appropriate signal when, at 1819, three short blasts were heard at close range from the ship ahead. The following moments were filled with anxiety as all eyes strained to pierce the mist ahead. At 1821 a slight jar was felt, and it was determined that *Ship A* had collided with *Ship B* almost perpendicular to its port side.

Closeup of impact area

SHIP B



Ship B was proceeding through the Gulf of Maine on the last leg of a voyage from Newport News, Virginia, to Searsport, Maine. With the master at the conn, the vessel made a normal approach to Penobscot Bay, westward of Monhegan Island, and continued toward Two Bush Channel on a course of 045°T at a maneuvering speed of approximately 9 knots. At 1646 hours the vessel was abeam of Monhegan Island and approximately 2 miles westward. At this point the vessel began to encounter patches of fog, and the master commenced sounding fog signals.

The passage continued toward Two Bush Channel, the navigation now being accomplished entirely by radar and by use of the fathometer. All fixes obtained were the result of radar ranges and bearings. At 1719 the vessel was fixed abeam of Burnt Island Lookout Tower at a distance off of approximately 3,500 yards. The vessel continued ahead at maneuvering speed.

After passing the Burnt Island landmark the fog became more dense over larger areas. At 1741 the vessel was abeam of Marshall Point Lighted Whistle Buoy *1* at a distance off of approximately 800 yards. At 1804, when almost abeam of Tenants Harbor Lighted Bell Buoy *1*, the master altered the ship's course to 079°T so as to enter Two Bush Channel.

At 1811 the radar revealed a target ahead which the master initially evaluated as being a large ship at anchor in the lower reaches of West Penobscot Bay. He thereupon reduced the engine speed to half-ahead and a minute later further reduced engine speed to slow-ahead. At 1814 the master heard the fog signal of an approaching vessel. Finally realizing that the ship observed on radar was in fact underway, he stopped the engines. At this time the two vessels were about 1½ miles apart.

Closely watching the other ship's movements on the radar screen *Ship B's* master automatically decided on a port-to-port passing and attempted to shape his course accordingly. Observing that the downbound ship bore steadily to the right, he made rapid, successive course changes to the right finally steadying on 145°T. At 1818, aware of the proximity of the approaching vessel and that his ship was headed toward shoal water, the master ordered **full astern** and **sounded three short blasts** on the ship's whistle. Shortly thereafter three short blasts were heard from the approaching vessel at close range.

At 1820 the bow of *Ship A* was visually observed as it loomed out of the mist about 100 yards to port. Convinced that a collision was now imminent, the master ordered **full ahead** and **full left rudder** in an attempt to lessen the impact. At 1821 the bow of *Ship A* struck *Ship B*, cutting deeply into the port side of number 2 hold.

ANALYSIS

The primary cause of this casualty was simply that both ships were operated without due caution and at immoderate speeds in restricted waters during a period of extremely low visibility. Each ship was in Inland Waters and was, therefore, bound by Article 16 of the Inland Rules. Neither ship, however, could be said to have been fulfilling the intent and purpose of that article.

Ship A detected *Ship B* by radar approximately 30 minutes before the unfortunate encounter, but no change in speed was effected as a result. Upon hearing the fog signals of *Ship B* nine minutes before the casualty, *Ship A* stopped her engine in accordance with accepted practice and Article 16. Two minutes later, *Ship A* went half-speed on her engine. This action was taken just seven minutes and approximately 1 mile from the scene of the collision, at a time when some drastic collision avoidance action was obviously necessary. True, it had been determined by radar that *Ship B's* bearing was opening progressively to the right. However, Recommendation 3 in the Annex to the International Rules, *Recommendations on the Use of Radar Information as an aid to avoiding Collisions at Sea*, which, it would seem, are applicable to the use of radar in any circumstance, states, *When navigating in restricted visibility, the radar range and bearing alone do not constitute ascertainment of the position of the other vessel under Rule 16(b) sufficiently to relieve a vessel of the duty to stop her engines and navigate with caution when a fog signal is heard forward of the beam.*

Even after *Ship B's* bearing ceased to open, five minutes and less than a mile before the fateful meeting, the only action taken by *Ship A* was to stop her engine. *Ship A's* emergency full astern order 2 minutes before the collision was given too late to counter the way of a large ship.

Ship B encountered dense fog shortly after entering inland waters yet continued toward the narrow waters of Two Bush Channel with no reduction in speed. Ten minutes before reaching the collision site, *Ship B's* engine speed was reduced and a few minutes later stopped when it was realized that *Ship A* was underway. No radar plot was maintained on *Ship B*, a device which might have revealed *Ship A's* intentions in time to prevent *Ship B's* radical course changes to the right. As in the case of *Ship A*, *Ship B* did not attempt to negate the way until too late.

Ship A's decision to attempt the unconventional starboard-to-starboard passing during a period of poor visibility and without a passing agreement was an exercise in poor judgement.

Finally, both ships violated Article 18, Rule IX, in sounding the *three blast whistle signals to indicate full astern*, for neither vessel was in sight of the other at the time.

CONCLUSION

The majority of mariners will undoubtedly agree that the risk of collision increases with speed and reduction of range; that close-quarter situations are dangerous and at high speed, an invitation to disaster; and that all of these risks are compounded by factors which tend to limit visibility and the sources of information. Well acquainted as they are with these truisms, mariners continue to be plagued by a high incidence of collision that, annually, accounts for serious loss of life and costly property damage.

Other than the Rules of the Road, there is no panacea for the prevention of collisions. Even the Rules, although meticulously forged to cover every possible situation, will not prove effective if they are carelessly applied or wilfully ignored. Fortunately, all Rule violations don't necessarily result in collision, but very few instances have been recorded in which a collision was not the result of some Rule violation. Obviously, successful collision avoidance depends, in no small way, upon a strict adherence to the Rules of the Road by all parties concerned.

In the foregoing cases the prevalent cause of each collision was the violation of Rule 16 (Article 16 of the Inland Rules in Case 4). This rule is, to an extent, an interpretive one in that it permits the shiphandler a certain latitude in determining speed and/or disengaging maneuvers. To prevent possible misinterpretations, however, the International Rules of the Road include an *Annex to the Rules* which helps to explain the somewhat vague phrasing of Rule 16 for radar-equipped vessels.

Under Rule 16(a), for example, a ship in restricted visibility shall *go at a moderate speed* and have *careful regard to the existing circumstances and conditions.* The precise value of what constitutes moderate speed is not given for the simple reason that it will vary with the situation. Paragraph 2 of the forementioned Annex to the Rules states that Rule 16(a) applies to radar-equipped vessels and further indicates that the vessels so equipped use their radar information in determining moderate speed. It is only reasonable to expect, therefore, that personnel of radar-equipped ships would interpret the meaning of the word moderate in a somewhat different sense than those in a ship without radar. In the final analysis, the same responsibilities exist, and it must be borne in mind that any speed which contributes to a collision will be deemed immoderate by the courts.

According to the Annex, radar-equipped ships are not exempt from the requirements of Rule 16(b) simply because they hold radar contact with the vessel under advisement. All ships must stop their engines and *navigate with caution until danger of collision is over.* Radar or not, this is sound advice, for in most cases when a fast moving ship hears the fog signal of another, she is probably already too close for safety.

Rule 16(c) permits and encourages ships to take *early and substantial action* to avoid a close-quarters situation when they detect the presence of another vessel forward of the beam. Detection, in this rule, obviously means radar detection, and radar navigators should pay particular attention to the alternatives offered. The determination of when is early and what is substantial rests with the mariner and depends upon the circumstances of the case. Certainly, any action taken by either of two ships with a relative closing speed of 36 knots (as in **Case 1**) should occur before they are only seven or eight miles apart. On the other hand, a small change of course, even at considerable range, is not to be considered as substantial action.

The point in Rule 16(c) that seems to have been missed by all of the ships is that if a close-quarters situation cannot be avoided by early action the vessel shall *stop her engines in proper time to avoid collision and then navigate with caution until danger of collision is over.*

There is nothing in either the Rules or its Annex, of course, which can regulate the efficiency with which radar is used. This is a matter of individual proficiency, the same as being a good or poor helmsman. There is little excuse for a mariner obtaining an incorrect value of bearing and distance by radar observation, whether it be a true-motion or relative-motion observation. Such inept usage of radar can *lead him down the primrose path* and place him in a position where good fortune, rather than skill, becomes the prime factor in whether or not a collision will occur. Skillful interpretation of the radar picture and a full appreciation of the developing situation are essential if behavior is to be based on the use of radar.

It is well known that the maintenance of a graphic plot is essential to intelligent radar usage. Without assistance, however, a watch officer of a merchant ship may be unable to plot contacts continually due to the pressure of other duties. In this case a simple timed record of ranges, bearings, and course changes should be kept. But if the risk of collision truly exists, a watch officer needs the data provided by a plot, and he should not hesitate to call for qualified assistance on the bridge.

International Rule 27 (and its companion Article 27 under Inland Rules) when judiciously applied is indeed a *General Prudential Rule* when the situation becomes *tight.*

U. S. GOVERNMENT PRINTING OFFICE : 1969 O - 356-697