POLAR SHIPS AND NAVIGATION IN THE ANTARCTIC

By J. P. MORLEY

ABSTRACT. A brief survey is presented of the history of the development of icebreakers and ice-strengthened ships. The characteristic features of modern polar ships are described and exemplified by the icebreaker *Moskva* and the ice-strengthened ship *Nella Dan*. Ships used by the British Antarctic Survey are also described.

Navigation and ice pilotage in the Antarctic are described and an account is given of the procedures followed under various conditions.

The usefulness of icebreakers in support of Antarctic expeditions is emphasized. The bibliography includes selected publications on polar ships and navigation.

THE success and efficiency of a modern polar expedition, particularly one continuing over a number of years, depends largely on the ease with which it can be placed in the field, annually maintained and assisted throughout the summer season in spite of the occurrence of sea ice.

The use of aircraft in the Antarctic, notably by the United States, has increased greatly in recent years, but ships specially constructed for work in ice and operated by experienced personnel remain vital.

Before World War II, Antarctic expeditions were usually ventures of short duration in which the role of the supporting ship was mainly confined to the location and establishment of winter quarters and to such reconnaissance of the coastline as could be accomplished in the prevailing ice conditions. Shore bases were established, as far as possible, at places where sea ice would not prevent the return of the ship the following year. Reinforced wood and steel ships with little engine power, such as the Norwegian *Fram* and the British *Terra Nova* used at the beginning of this century, were remarkably successful in performing these tasks. Heavy concentrations of pack ice were avoided, for, when beset, there was little alternative but to await a shift of wind to bring release. The German *Deutschland* drifted for nine months in the Weddell Sea before being safely released; the Swedish *Antarctic* and the British *Endurance* were both crushed by ice and had to be abandoned.

A new era of Antarctic exploration by sea commenced with the establishment of permanent scientific stations during and after World War II. These stations require annual supply and maintenance, and ever-increasing amounts of cargo must be delivered safely, even in adverse ice conditions, to meet the requirements of the scientific parties ashore. The greater the suitability of the ships employed, and the greater the experience and skill of their crews in ice navigation, the more efficiently will these routine tasks be carried out.

POLAR SHIPS

The first ships modified for working in ice were tugs and harbour vessels with reinforced hulls and extra power. They were used to clear ice and assist the passage of cargo ships in and near harbours. The earliest record of this type is probably the United States *City Ice Boat No. 1*, a paddle-wheel steamer built in Philadelphia in 1837 for use on the Delaware River. In Europe, the Swedish *Polhem* was built in 1858 to maintain a winter mail service between the mainland and the island of Gotland, and a Russian tug *Paylot* was employed in 1864 to assist ships through the ice at the port of Kronshtadt. A more powerful type of ship, *Eisbrecher 1*, was built in Hamburg in 1871 for service on the river Elbe, and by the end of the nineteenth century, icebreakers and ice-strengthened ships were in winter use both in Europe and in North America.

A. *Icebreakers*

Experience with these early ships formed a basis for the construction of the first polar icebreaker, the Russian *Yermak** which was built at Newcastle, England, in 1899 and used in the Arctic until 1961. With the advance of shipbuilding technology, the design, power and

* See Table I for the specifications of some polar ships.

size of icebreakers developed steadily. By the outbreak of World War II, they were in common use in the Baltic, the Gulf of St. Lawrence and, though less frequently, in the Russian and Canadian Arctic. Military demands during the war stimulated the building of the Russian *Stalin* class and the United States *Wind* class ships. Post-war activity has included the building of increasingly large and powerful icebreakers such as the Argentinian *General San Martín*, the United States *Glacier* and also the Russian *Moskva*, which is now the most powerful conventionally propelled icebreaker. The Russian icebreaker *Lenin*, with a hitherto unprecedented nominal horsepower of 44,000, is the world's first nuclear-powered surface ship (Fig. 1).

Fig. 1. The Russian nuclear-powered icebreaker *Lenin*.
(By courtesy of the Novosti Press Agency (A.P.N.), Moscow.)

Heavily reinforced hulls, a sloping forefoot and a ratio of horsepower to displacement of more than unity are characteristics common to both icebreakers and ice-strengthened ships. However, the icebreaker may usually be distinguished by more powerful engines, higher ratio of beam to length, smaller cargo capacity and by such distinctive features as heeling tanks. Forward propellers are only fitted to those icebreakers intended for service in regions other than the Arctic or Antarctic, e.g. the Baltic or the Gulf of St. Lawrence; they are too easily damaged when breaking heavy polar ice to be of practical use.

Modern icebreakers are vessels of great strength and power, designed and constructed to break fast ice and to manœuvre freely in heavy pack ice. Because of their fine hull lines and the large volume of space taken up by their powerful engines, they are unable to carry more than a nominal amount of cargo. Their usefulness lies in their ability to assist ice-strengthened transport ships and to carry out geographical reconnaissance in regions where heavy ice is found; many carry helicopters to assist navigation.

On account of their great cost and limited cargo capacity, icebreakers have not yet been widely used in the Antarctic. The first to be employed were *Burton Island* and *Northwind* which took part in the United States Operation "Highjump", 1946–47. Since then, several others belonging to the United States and one belonging to Argentina (*General San Martín*) have also been used. Other nations have relied exclusively upon ice-strengthened vessels.

1. *Characteristics of icebreakers*

Hull. Icebreakers work by ramming ice, rising up on to it, and crushing and breaking it under their weight. The form of the hull, and in particular the forebody, is therefore important.

TABLE I. SPECIFICATIONS OF SOME POLAR SHIPS

Name and Region of Operation	Date;* Country;* Type	Over-all Length; Beam, max.; Draft (ft.)	Tonnage	Engine; h.p.; Screws	Strengthening	Notes
Fram Polar	1893 Norway Wood	128 36 8	402 g. 370 n.	Steam 220 1	Reinforced hull	Built for Nansen's drift across Arctic Ocean. Designed to withstand crushing under ice pressure. Used by Amundsen in Antarctic. Auxiliary engine.
Yermak Arctic	1899 England Steel	320 71·5 24	7,875 D.	Steam 9,000 3 (+1)	Full icebreaker	First polar icebreaker, built by Russia for use in Arctic. One forward propeller removed after first voyage.
Wind Class Polar	1944 U.S.A. Steel	269 63·7 25·7	5,300 D.	Di./elec. 10,000 2	Full icebreaker	*Northwind*, *Burton Island* and sister ships belong to this class. Most successful wartime design. Two helicopters.
General San Martin Antarctic	1954 Germany Steel	277·8 62·3 21·3	4,830 D.	Di./elec. 6,500 2	Full icebreaker	Built for Argentinian Antarctic operations. Two helicopters.
Glacier Polar	1955 U.S.A. Steel	309·6 74 25·7	7,750 D.	Di./elec. 21,000 2	Full icebreaker	Modified and larger type of *Wind* Class vessel. Two helicopters.
John A. Macdonald Arctic	1960 Canada Steel	315 70 28	6,186 g.	Di./elec. 15,000 3	Full icebreaker	Built as re-supply icebreaker for Canadian Arctic. Two helicopters. No heeling tanks.
Lenin Arctic	1959 Russia Steel	440 90·5 30·2	16,000 D.	Nuclear 44,000 3	Full icebreaker	First nuclear-powered surface ship built for use in Russian Arctic. Three helicopters.
Magga Dan Polar	1956 Denmark Steel	246·5 45 20	2,100 g. 1,650 Dw.	Diesel 2,000 1	Lloyds Class 1 for ice	Cargo/passenger expedition ship built as a result of experience with first ship of type, *Kista Dan*.
Piloto Pardo Antarctic	1959 Holland Steel	265·5 38·7 15	1,200 Dw.	Di./elec. 2,300 1	Lloyds Class 1 for ice	General purpose Antarctic vessel for Chile. One helicopter.

* Of building.

All icebreakers have a sloping forefoot and flare at the waterline. In the bow profile the stem makes an angle of about 30° with the waterline to allow the bow to ride up on to the ice. A nearly vertical step in the lower part of the stem prevents the ship from riding up too far and becoming lodged, and gives a secondary blow to the ice.

Two types of hull form have developed independently in recent years. One is that adopted by the United States *Wind* class ships, which includes *Glacier* and the Canadian *Labrador*; the other is that developed in Scandinavia and used in *Voima*, *Sampo* and *Moskva*.

Apart from minor divergences, such as the degree of stepping of the forefoot, there is little difference between the two hull types. As the Scandinavian type has been influenced less by military considerations and more by economy of constructional cost, it is perhaps more practical to regard this as a prototype for future icebreakers, particularly those designed for expedition use in the Antarctic.

Length affects the volume of space available below decks, and also the size of superstructures and the helicopter deck. A short ship may provide insufficient space for machinery and other requirements, but a long ship may be less manœuvrable in narrow channels.

The beam of the icebreaker must exceed that of the broadest ship to be convoyed. The usual practice in ocean-going icebreakers is to adopt a length-to-breadth ration of 4·0–4·5 : 1 or, in the case of recent larger vessels, approaching 5 : 1. Excessive beam may force more ice to pass under the ship and into the propellers.

The amount of freeboard influences performance both in ice and in the open sea. A high freeboard, which is usually associated with considerable sheer and flare, serves to keep solid water off the decks in stormy weather and to prevent the stern immersing when the bow rides up on the ice. It is, however, essential to allow the navigator an unobstructed view of the ice immediately ahead of the ship.

As a result of their large beam and heavy scantlings, icebreakers have large metacentric heights and, although superstructure icing may be encountered, stability is normally very good. This large metacentric height and the round hull form easily lead to violent rolling in heavy seas which causes strains on the hull structure and on the machinery foundations, besides general discomfort to all on board. Bilge keels cannot be fitted satisfactorily to ships working in ice, but the installation of stabilizing fins merits consideration. *Labrador* is the only icebreaker which has been fitted with stabilizers. Fears that the stabilizers would easily become damaged in the ice have proved unfounded.

At slow speeds in heavy ice, friction between the shell plating and the ice may overcome the propulsive thrust of the engines, bringing the icebreaker to a halt. This friction may be reduced and the vessel released by the use of heeling tanks producing a heeling angle of 5–10°. The greater the volume of ballast that can be transferred from one side to the other, and the quicker that this can be done, the more effective will be the heeling system.

Quick response to the rudder is essential when working pack ice, and for holding the icebreaker to her course following an oblique impact with fast ice. This control is determined by hull form, mass distribution within the ship and the combined effect of the propellers and rudder.

Power. The kinetic energy of the icebreaker will largely determine the effectiveness of her thrust when charging ice. However, what continuous speed of advance is possible through ice depends not so much on free running ability as upon the combination of thrust and displacement at such a speed.

Few types of machinery offer the degree of flexibility and reliability which is required by an icebreaker. Nuclear power is undoubtedly the ideal means of propulsion but its high cost precludes its common use. Diesel-electric power has replaced steam in most icebreakers, having the advantage of comparatively low machinery weight, high manœuvrability, flexibility and economy of fuel consumption.

Recently built icebreakers, including *John A. Macdonald*, *Moskva* and *Lenin*, have been fitted with three propellers aft, a feature first incorporated in *Yermak*. Triple propellers minimize the effect of damage to any one of them, and with 50 per cent of the total power on the centre propeller and the remaining 50 per cent varied between the wing propellers, optimum manœuvrability is achieved. The propellers are of large diameter, deeply immersed to reduce the risk of damage in ice, and deep draft is therefore necessary.

2. *The polar icebreaker* Moskva

In Finland the Wärtsilä-koncernen A/B, Helsinki, has specialized in building icebreakers since 1945. One of these, *Moskva* (Figs. 2 and 3), exemplifies the latest designs and, although

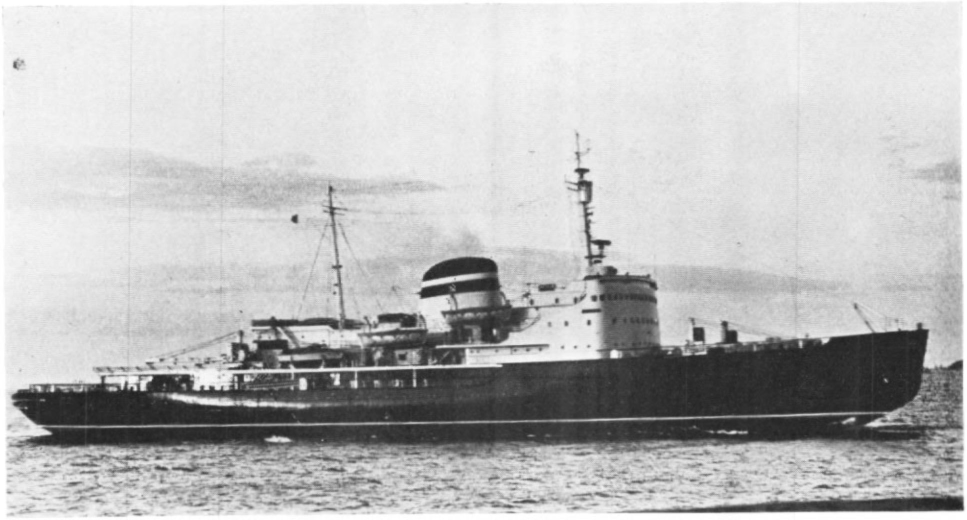


Fig. 2. The polar icebreaker *Moskva*.
(By courtesy of Wärtsilä-koncernen A/B, Helsinki.)

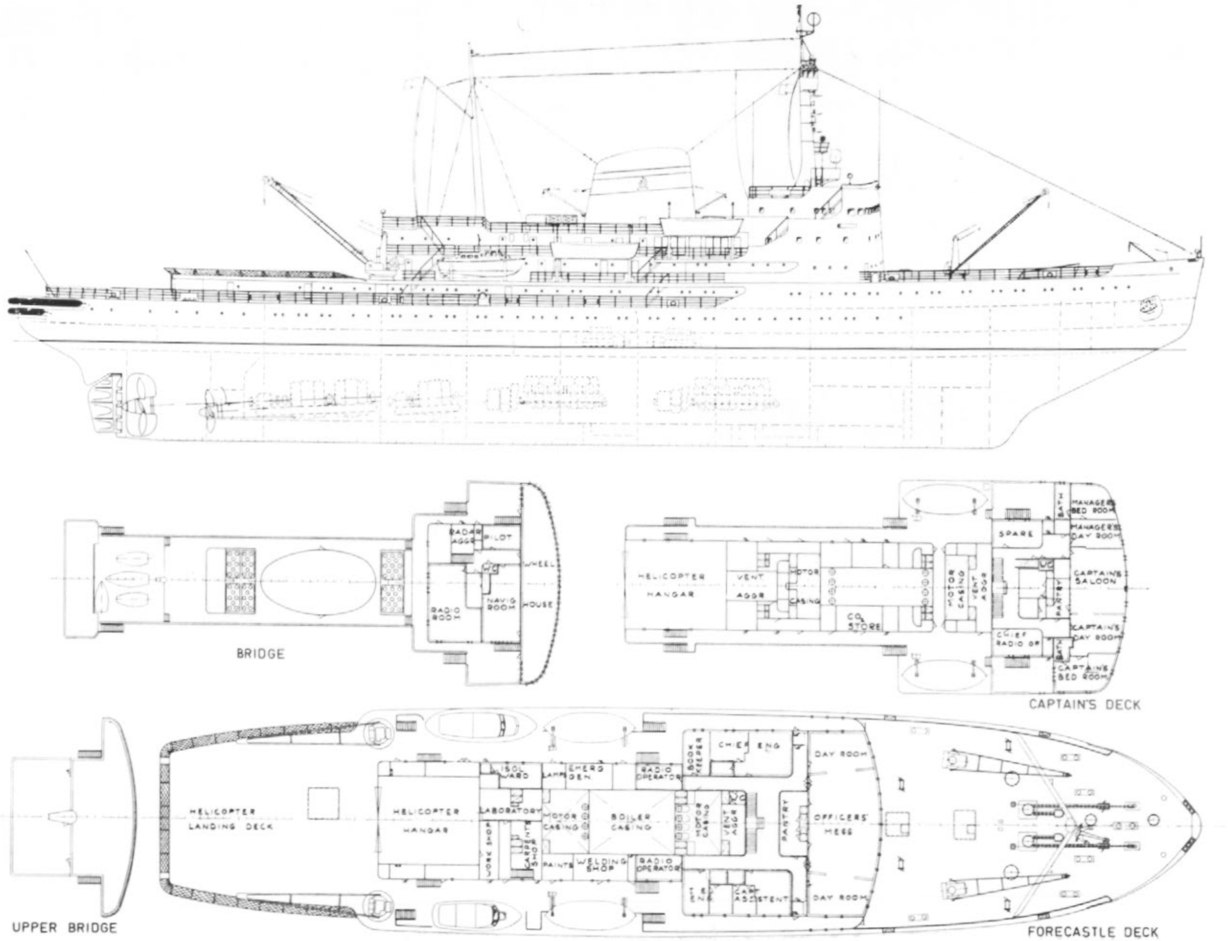
she has so far been used only in the Arctic, may be regarded as an attractive prototype for future Antarctic icebreakers.

Specifications

Length, over-all	122·1 m. (400 ft. 7 in.)
Length, between perpendiculars	112·4 m. (368 ft. 9 in.)
Breadth, moulded maximum	24·5 m. (80 ft. 4 in.)
Breadth, moulded at C.W.L.	23·5 m. (77 ft. 1 in.)
Draught, normal	9·5 m. (31 ft. 2 in.)
Draught, maximum	10·5 m. (34 ft. 5 in.)
Displacement, normal	13,290 tons (metric)
Displacement, maximum	15,360 tons (metric)
Machinery output	22,000 s.h.p.
Number of propellers	3
Speed in open water	18 kt.

The *Moskva* was launched on 10 January 1959 at the Helsinki shipyard and delivered to her Russian owners on 11 June 1960. A sister ship, *Leningrad*, was delivered in November 1961 and a further sister ship is contemplated. These vessels are intended for service in the Arctic regions north of Siberia. *Moskva* has already spent three successful seasons on the Northern Sea Route.

Hull construction. The hull has an extended forecastle reaching well abaft the front bulkhead, and a heavy superstructure ending aft with a helicopter hangar and landing deck. Three continuous decks extend from stem to stern and the hull is divided into nine watertight compartments. As the hull is fitted with wing tanks, it is double up to the 'tween deck, well above the waterline. The capacity of the double bottom, wing, peak and deep tanks is sufficient to store 3,200 tons of diesel oil, 290 tons of boiler fuel, 130 tons of lubricating oil, 350 tons of fresh water and 20 tons of aviation spirit. There are also spare tanks allowing a maximum bunker capacity of 5,300 tons.


BRIDGE
RADAR AGGR
PILOT
WHEEL HOUSE
NAVIG ROOM
RADIO ROOM
CAPTAIN'S DECK
HELICOPTER HANGAR
VENT AGGR
MOTOR CASING
CO2 STORE
SPARE
CAPTAIN'S SALOON
PANTRY
CHIEF RADIO OP
CAPTAIN'S DAY ROOM
CAPTAIN'S BED ROOM
MANAGER'S BED ROOM
MANAGER'S DAY ROOM
BATH
UPPER BRIDGE
FORECASTLE DECK
HELICOPTER LANDING DECK
HELICOPTER HANGAR
LABORATORY
WORK SHOP
CARPENTER'S SHOP
PAINTS
WELDING SHOP
MOTOR CASING
BOILER CASING
RADIO OPERATOR
BOOK KEEPER
CHIEF ENG
VENT AGGR
PANTRY
OFFICERS' MESS
DAY ROOM
CAPT ASSISTENT

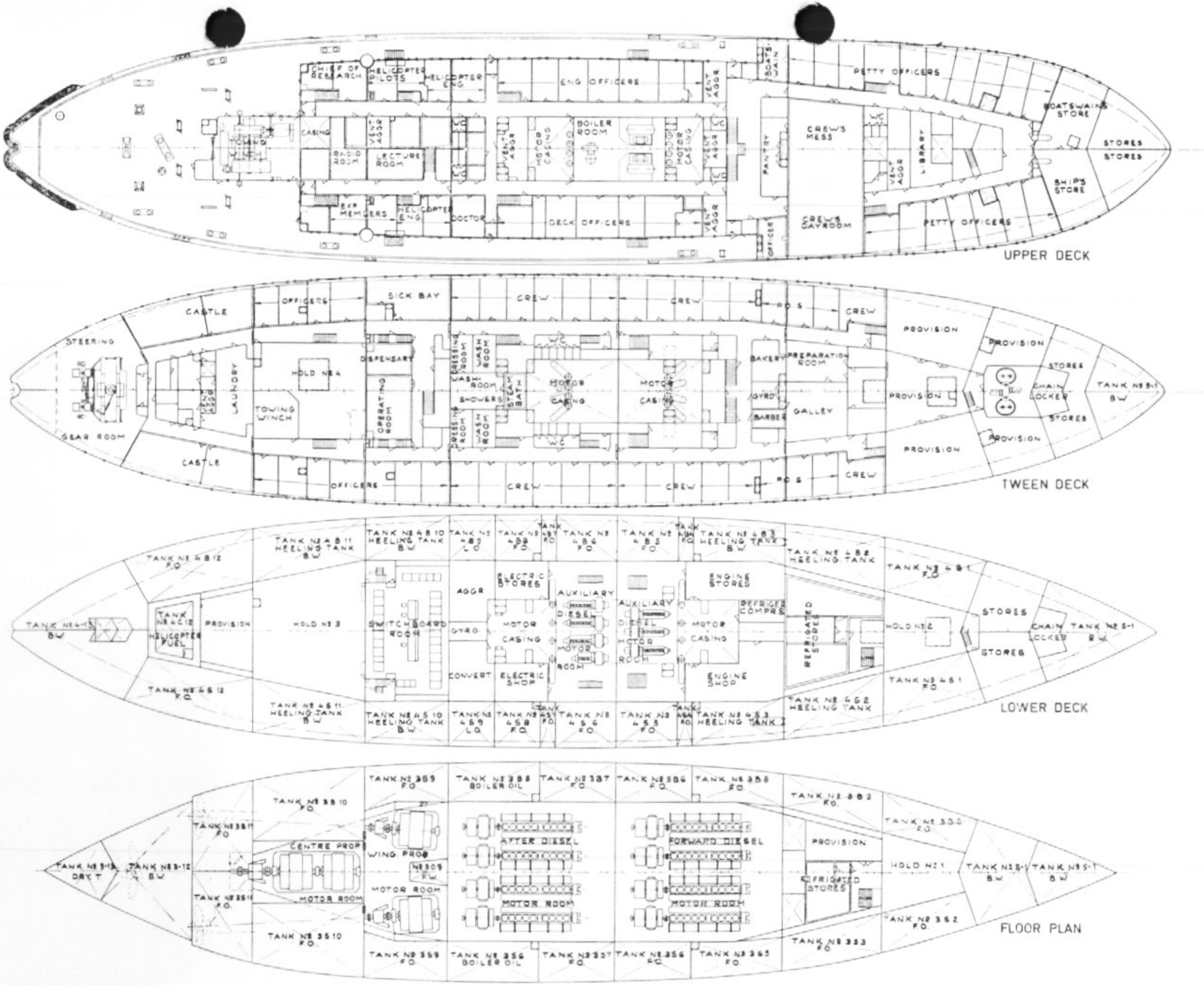


Fig. 3. *Moskva*, general arrangement plan.
(By courtesy of Wärtsilä-koncernen A/B, Helsinki, and reproduced by permission of the Editor, *Polar Record.*)

The hull strength is in excess of both Lloyd's Register of Shipping Class 100 A1, strengthened for navigation in ice Class 1, and the Finnish Ice Class 1A. The hull is completely welded and the shell plating is constructed from special steel with high impact strength at low temperatures. Frame spacing is at 400 mm. (15·75 in.) intervals and there are 1·5 m. (4 ft. 11 in.) deep webs at every fourth to sixth frame, as well as heavy longitudinal stringers. The double bottom height is 1·8 m. (5 ft. 11 in.) and all floors are of the solid type and fitted with welded stiffeners. All bulkheads, frames and deck beams are placed transverse to the shell plating, which in the ice strake has a maximum thickness of 54 mm. (2·125 in.). The waterline plating can withstand a pressure of 1,000 tons/m.^{2} forward, 600 tons/m.^{2} amidships, and 800 tons/m.^{2} aft (a corresponding figure for an unstrengthened vessel would be between 15 and 30 tons/m.^{2}). Steel castings include the stern frame of 72 tons and the centre propeller of 36 tons.

Four heeling pumps are capable of transferring 480 tons of water from one side to the other in 2 min., resulting in a heeling angle of about 14°. The pumps can be operated automatically, resulting in a continuous rolling of the vessel.

Machinery. The main diesel generators are placed in two diesel motor rooms. The propelling motors are placed aft in two compartments, the centre motor in one and the two wing motors in the other. Above the forward propelling motor room is the electrical control room with all switchboards for main and auxiliary power.

Eight 9-cylinder non-reversible single-acting two-stroke diesel generators feed d.c. to four propelling motors. Each diesel develops 3,250 b.h.p. at 330 r.p.m. and can be overloaded by 10 per cent for one hour. The diesels are directly connected to the generators.

The centre propelling motor is fed by four generators and each wing motor is fed by two generators. The motor circuits are laid out on the Leonard principle and it is possible to connect two generators of the centre motor system to the circuits of the wing motors and *vice versa*. The centre propelling motor consists of two motors in tandem, each developing 5,500 h.p. at 1,200 V and 3,600 A. Each wing motor develops 5,500 h.p. giving a total s.h.p. of 22,000. The nominal r.p.m. is 115, but full power can be obtained at all revolutions between 110 and 150. Excitation current is supplied by five converters fed from the auxiliary net; two of these are spares. The main diesels run at three constant speeds, which can be selected in the switchboard room, depending on the power required for navigating different ice conditions.

Two direct engine control positions are fitted on the upper bridge, three in the wheelhouse and one on the after bridge above the helicopter deck. The steering gear is electro-hydraulic with two pumps. With both pumps in operation, the rudder can be moved from hard over port to hard over starboard at full speed in 20 sec.

Auxiliary power is supplied by seven diesel generators in two compartments above the main motors. Steam for domestic heating and for keeping the cooling-water intakes free from ice is supplied by two water-tube boilers. An evaporator in the boiler room has a capacity of 30 tons/day.

Motor-room temperatures are controlled by varying the ratio of outside air with engine room scavenging air, and by separate ventilation fans. The ship is heavily insulated for operating at temperatures down to −35° C (−31° F). A ventilation system supplies pre-heated and filtered air to all parts of the ship, and is calculated to maintain an inside temperature of 20° C (68° F) in the living quarters down to an outside temperature of −10° C (14° F). At lower outside temperatures supplementary heat is provided in the living quarters by warm-water radiators.

Equipment and accommodation. The vessel is built to conform to Method III of the International Convention for passenger vessels employing A- and B-class fire-resistant or fire-retarding bulkheads. A fire-detection system is connected to an alarm panel in the wheelhouse. There is a central carbon dioxide store from which pipes are led to all fuel tanks, motor rooms, switchboards and boiler rooms. Other fire-extinguishing systems utilizing foam and water are provided.

Aluminium lifeboats are fitted in accordance with international rules, and extra motor and survey launches are carried.

Besides normal deck machinery, an electric towing winch with automatic tension and reclaiming control is placed in a deck-house aft. This has two barrels for 60 and 30 tons pull.

A steering console in the wheelhouse incorporates an engine telegraph, a gyroscope

repeater and a rudder indicator. Besides a spacious chartroom, the vessel is equipped with two radars, two gyroscopic compasses with nine repeaters, course-recorder, two logs, two echo-sounders and a radio direction-finder. A command broadcast system forms part of the equipment in the radio room. Four searchlights are provided, the biggest of which is an 18 kW arc-lamp unit, for working in ice during darkness. Two helicopters are carried.

The crew of 117 and a research group of nine are accommodated in one- or two-berth cabins. Group accommodation is provided for a further 36 men. There is also an operating theatre complete with dental facilities, a dispensary, a sick bay with four beds, and an isolation ward with two beds.

B. *Ice-strengthened ships*

1. *The characteristics of ice-strengthened ships*

Before the middle of the nineteenth century, winter ice frequently brought commercial shipping to a halt in the Baltic and North America. Ordinary steel cargo ships proved unsuitable for independent navigation in ice, as their thin hull plating was easily pierced. With the increase in trade it became necessary for ships to deliver their cargoes throughout the year. Ships engaged in regular trade in regions where seasonal ice was encountered were therefore made stronger and more powerful, and eventually the principal marine classification societies, such as Lloyd's Register of Shipping, introduced rules for the ice-strengthening of steel cargo ships.

Before World War II, Scandinavian sealing vessels were frequently chartered by Antarctic expeditions. These stout wooden vessels were built for work in ice, but they are usually too small and under-powered for modern expeditions. Larger ice-strengthened steel ships, with more space for both cargo and expedition personnel, are now commonly used. Vessels of this type, built specifically for Antarctic work, include the British *John Biscoe* and the Chilean *Piloto Pardo*, whilst others, such as the Japanese *Soya Maru*, are conversions of ordinary ships.

The modern ice-strengthened ship is normally a cargo and passenger transport with a reinforced hull and increased engine power, designed to withstand pack ice if carefully navigated. Because of the space required for cargo, however, strengthened ships cannot be given the extra hull strength and engine power which would enable them to navigate through the heaviest pack ice and to break fast ice. Consequently, in seasons when heavy ice remains in the summer shipping season, they may be unable to reach some shore stations.

Since 1952, many expeditions have chartered the Danish ice-strengthened ships belonging to Lauritzen Lines of Copenhagen. Some of these ships, e.g. *Kista Dan*, *Magga Dan* (used by the Commonwealth Trans-Antarctic Expedition) and *Thala Dan*, have been built especially for polar expeditions. Others, such as *Thora Dan* and *Erika Dan*, are larger ships intended for service in Greenland in the northern summer and Baltic trade in the winter.

The latest addition to this Danish polar fleet is *Nella Dan* (Figs. 4 and 5), an ice-strengthened cargo and passenger transport built primarily for Antarctic service. She made her maiden voyage during the 1961–62 season on charter to the Australian National Antarctic Research Expeditions. A distinctive feature of the vessel is her helicopter platform and she represents a most up-to-date example of this type of ship. The description which follows, when compared with that of *Moskva*, illustrates the principal differences between the ice-strengthened ship and the icebreaker.

2. *The ice-strengthened ship* Nella Dan

Specifications

Length, over-all	75·2 m. (246 ft. 8 in.)
Length, between perpendiculars	65·5 m. (215 ft.)
Breadth, moulded	14·3 m. (46 ft. 11 in.)
Draught, normal	6·26 m. (20 ft. 6 in.)
Draught, maximum	6·52 m. (21 ft. 6 in.)
Gross tonnage	2,206 tons
Nett tonnage	1,060 tons

Displacement, normal	3,675 tons
Deadweight, normal	1,970 tons
Cubic capacity, grain	83,700 cu. ft.
Cubic capacity, bale	75,870 cu. ft.
Cubic capacity, refrigerated	3,390 cu. ft.
Machinery output	2,240 b.h.p.
Number of propellers	1
Speed in open water	13 kt.

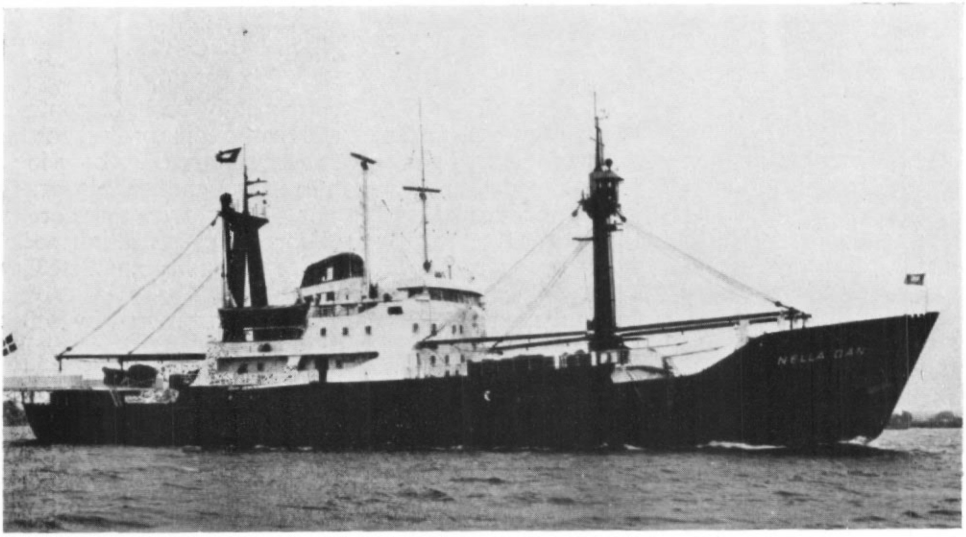


Fig. 4. The ice-strengthened ship *Nella Dan*.
(By courtesy of J. Lauritzen Lines, Copenhagen.)

Nella Dan was launched on 13 June 1961 at the shipyard of Aalborg Vaerft A/S, Denmark, and delivered to her owners on 5 October 1961.

Hull construction. The vessel is a full-scantling, single-propeller cargo and passenger ship. Accommodation and engines are amidships and aft of the superstructure is a helicopter deck. The vessel has two cargo holds forward, one of which may be used as a deep tank for oil fuel, and one hold aft. The hull strength is in excess of both Lloyd's Register of Shipping Class 100 A1, strengthened for navigation in ice Class 1, and the Finnish Ice Class 1A. The hull is completely welded and the frame spacing is at 305 mm. (12 in.) intervals throughout. Shell plating has a maximum thickness of 25 mm. (1 in.). In the bow profile, the stem makes an angle of 30° with the waterline, which allows the bow to ride up on the ice. At the stern in front of the propeller on both sides of the hull are three broad horizontal fins. These help to keep the propeller clear of ice and protect it from damage. At the stern, an ice-knife protects the rudder from damage when going astern in ice.

Machinery. The vessel is propelled by an 8-cylinder, two-stroke, single-acting, direct reversible diesel engine. This develops 2,240 b.h.p. at 300 r.p.m. and is coupled to a single left-handed four-bladed variable-pitch propeller which can be directly controlled both from the navigation bridge and the crow's nest. The ship has an oil fuel capacity of 736 tons, which gives a steaming range of 28,000 miles (45,000 km.) at cruising speed. Auxiliary machinery includes three diesel generators, a fresh-water evaporator, refrigeration plant and an air-conditioning unit.

Equipment and accommodation. Fire-fighting equipment and lifeboats are fitted in accordance with international regulations. Cargo handling gear consists of two 10-ton derricks at each hatch, one 25-ton derrick at No. 2 hatch and one 35-ton derrick at No. 3 hatch. Twin radar

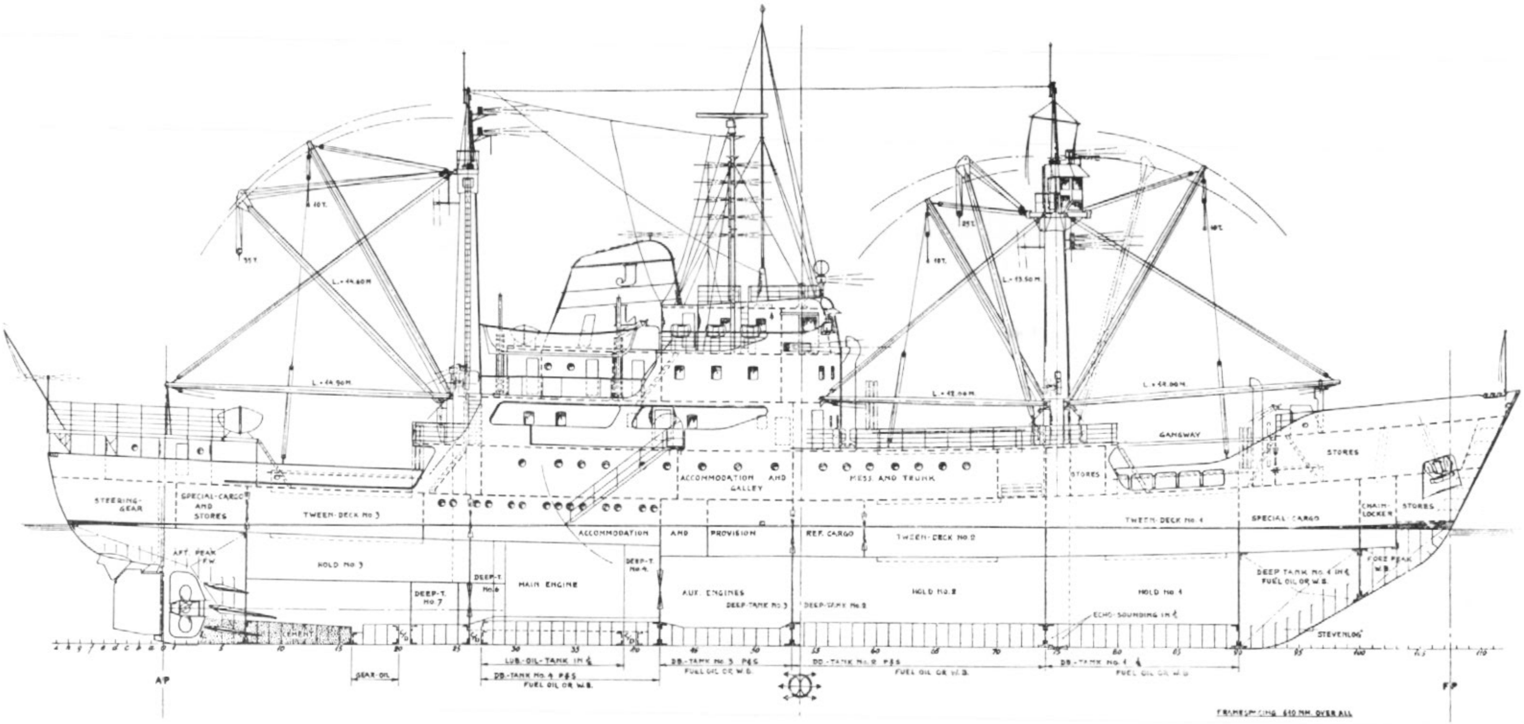


Fig. 5. *Nella Dan*, profile arrangement.
(By courtesy of J. Lauritzen Lines, Copenhagen.)

sets, direction-finding apparatus, echo-sounders, electric log and both gyroscopic and magnetic compasses form part of the navigational equipment. An automatic gyro-pilot is also fitted. The vessel may be manœuvred from the crow's nest, which affords a better view of ice immediately ahead of the ship than the navigating bridge.

The crew of 35 are berthed in single and double cabins. Accommodation for 42 expedition members consists of one two-berth and ten four-berth cabins.

C. *Ships used by the Falkland Islands Dependencies Survey*

Since 1943 the Falkland Islands Dependencies Survey (now known as the British Antarctic Survey) has been served by a succession of vessels of varying capabilities (Figs. 6a–h; Table II). Until 1947 vessels were chartered each season. *William Scoresby*, a steel ship similar to a whale catcher, and *Fitzroy*, an unstrengthened steel cargo ship, together established the first permanent British stations at the beginning of 1944. Between 1944 and 1947 the wooden Newfoundland ships *Eagle* and *Trepassey* were also used. All these ships were deficient in strength and engine power, but were the best available at the time.

The first purchase was made in 1947. This was *John Biscoe*, a wooden naval ship of 900 gross tons, 56·3 m. (184 ft. 6 in.) length over-all and 750 n.h.p., which was built in the United States in 1944. She was sheathed with greenheart and proved capable in ice. In 1954 she successfully broke a channel through 7 miles (11·3 km.) of fast sea ice, 1·5–2·7 m. (5–9 ft.) thick, in Penola Strait. Although under-powered, she accomplished this task in less than 10 days and was undamaged. By 1956 she was too small for the increasing cargo requirements of the Survey and was sold to New Zealand. Re-named *Endeavour*, she continued to serve in the Antarctic until 1961.

A second ship was purchased in 1955 and re-named *Shackleton*. This was a steel ship of 1,102 gross tons, 61 m. (200 ft.) length over-all and 785 n.h.p., built in Sweden in 1954 to Lloyd's Register of Shipping Class 100 A1, and strengthened for navigation in ice. She is propelled by a diesel engine and a single variable-pitch propeller. After a minor collision with an ice floe in her second year of service, additional hull strengthening was incorporated. During recent years she has worked mainly in the northern part of Graham Land and has carried out seaborne scientific work.

In 1956 the wooden *John Biscoe* was replaced by a steel ship of the same name, which had been built for the Survey in Scotland. Her principal dimensions are 1,584 gross tons, 67·1 m. (220 ft.) length over-all and 1,350 n.h.p. She has a single propeller and diesel-electric engines. Her draught is 5 m. (16 ft. 6 in.) and she is also built to the requirements of Lloyd's Register of Shipping Class 100 A1, strengthened for navigation in ice. From time to time she has been extensively damaged by ice, mainly on account of her full forward hull shape. She has twice been additionally strengthened.

Shackleton and *John Biscoe*, assisted by the naval guardship *Protector* and latterly by the chartered *Kista Dan*, have been responsible for the Survey's marine activities since 1956. With the exception of years in which extensive and heavy ice has remained during the summer navigation season in the southern parts of Graham Land, particularly in the Marguerite Bay area, these ice-strengthened ships have been able to carry out routine relief operations satisfactorily. However, their navigational limitations in heavy ice have on some occasions resulted in the failure to relieve the southernmost stations. In the past when this has occurred, generous assistance from United States icebreakers has made possible the timely re-supply or evacuation of stations inaccessible to the Survey's own ships.

Navigation and Ice Pilotage

There are many factors, not found in lower latitudes, which complicate the navigation of ships in Antarctic waters—notably, the presence of floating ice and the difficulty of determining the ship's precise position. The magnitude of these difficulties has been considerably reduced in recent years by shipboard navigational aids, particularly the echo-sounder and radar, but practical experience of ice navigation and knowledge of local hydrographic conditions remain vital.

TABLE II. SPECIFICATIONS OF SHIPS USED BY THE FALKLAND ISLANDS DEPENDENCIES SURVEY

Name and Seasons Used	*Date;* Country;* Type*	*Over-all Length; Beam, max.; Draft†* (ft.)	*Tonnage*	*Engine; h.p.; Screws*	*Strengthening*	*Notes*
William Scoresby 1943–46	1926 England Steel	134 26 13·8	326 g. 109 n.	Steam 1,050 1	Some	Built as oceanographical vessel for Discovery Committee. Used to establish first permanent British bases.
Fitzroy 1943–48	1931 Scotland Steel	165·7 32·6 13	853 g. 392 n.	Steam 700 1	None	Used on charter to establish first permanent British bases.
Eagle 1944–45	1902 Norway Wood	176 29·9 12	677 g. 458 n.	Steam 450 1	Some sheathing	Hit small berg off Hope Bay in 1945 and suffered some damage. Scuttled off Newfoundland in 1950.
Trepassey 1945–47	1945 Canada Wood	124·4 28 12·4	325 g. 191 n.	Diesel 400 1	Some sheathing	Slightly damaged by fire in Marguerite Bay in 1947.
John Biscoe 1947–56	1944 U.S.A. Wood	184·5 37 16	899 g. 411 n.	Di./elec. 750 1	Some sheathing	Built as Admiralty net-layer. Sheathed with greenheart. Capable vessel in ice.
Shackleton 1955–	1954 Sweden Steel	200 36 14·2	1,102 g. 274 n.	Diesel 785 1	Lloyds Class 2–3 for ice	Variable pitch Kamewa propeller. Hit small berg off South Orkney Islands in 1957 and suffered some damage. Subsequently additionally strengthened.
John Biscoe 1956–	1956 Scotland Steel	220 40 16·5	1,584 g. 615 n.	Di./elec. 1,350 1	Lloyds Class 3 for ice	Built specially for the Survey. Repeatedly damaged in heavy ice in Marguerite Bay and southern Graham Land. Twice additionally strengthened.
Protector 1955–	1936 England Steel	338 53 15	3,690 D.	Turbine 9,000 1	Some slight	Admiralty converted net-layer which accompanies British ships. Unsuitable for entering any ice. Carries two helicopters.
Kista Dan 1959–	1952 Denmark Steel	212·8 36·7 18	1,239 g. 577 n.	Diesel 1,560 1	Lloyds Class 1 for ice	Prototype of modern ice-strengthened cargo ships. Used on charter for voyage into Weddell Sea to relieve the station at Halley Bay. Variable-pitch propeller and forward navigation position in mast.

* Of building. † Normal.

Additional notes

1. *Bransfield* (ex *Veslekari*), which was commissioned for the first season, developed a leak and did not sail.

2. The following ships have also been used by British parties:

   a. 1949–50 *Gold Ranger* Transported fuel to Deception Island for F.I.D.S.
   1954–55 *Norsel* Established bases on Anvers Island and Horseshoe Island for F.I.D.S.
   1955–57 *Oluf Sven* Supported Hunting Aerosurveys in their work for F.I.D.S.
   1955–59 *Tottan* Relieved Halley Bay station for the Royal Society and F.I.D.S.

   b. 1955–56 *Theron* Supported Commonwealth Trans-Antarctic Expedition.
   1956–57 *Magga Dan* Supported Commonwealth Trans-Antarctic Expedition.

   c. In addition, between 1948 and 1955, various naval ships performed tours of duty and assisted F.I.D.S.

1. *General navigational problems*

Many problems arise from the lack of comprehensive and reliable hydrographic surveys, and all Antarctic charts are consequently used with caution. Some charts are based on surveys with little ground control; others may be accurate only over certain areas. Appreciable errors may exist between the charted positions of islands and their true positions from the shore, especially when they lie some distance from the mainland. The accuracy of soundings may only be relied upon in areas close to the land from which their positions were fixed. Current and tidal stream data and topographical descriptions of the coast, which are normally found in sailing directions, are invariably incomplete. Navigational aids ashore, such as lights and radio beacons, are rare and channel buoys are impracticable because of the ice.

Long periods of overcast skies make solar observations difficult to obtain, and nearly continuous daylight during the summer season usually precludes stellar observations. Abnormal refraction may introduce unknown errors into sights and, if ice is present, a satisfactory horizon may not exist. Strong and variable ocean currents may also set the ship off her course and the mariner making a landfall after a long sea passage may be unsure of his position. Long periods of inclement weather with poor visibility and the prevalence of fog may add further complications.

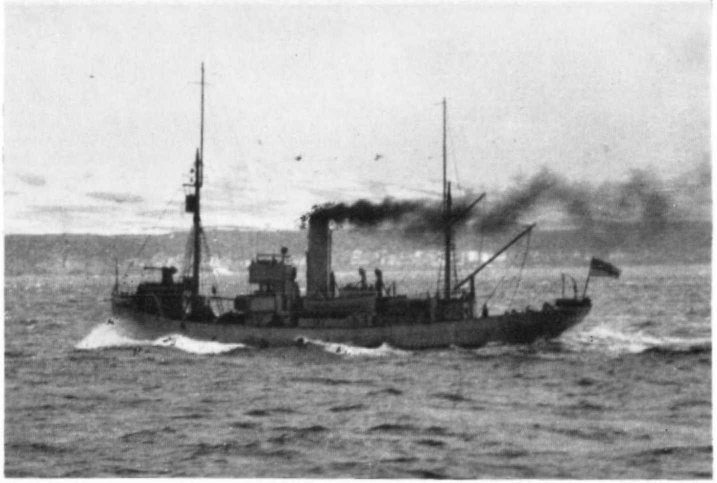
Radar, especially if capable of long-range land detection, is a valuable aid in making a landfall in poor visibility and when, for this and other reasons, astronomical observations are not possible. During fog, or at night, it is frequently the only means available for determining the ship's position. When sailing off the coast, however, positions determined from astronomical observations or visual compass bearings may not agree with radar ranges from the coast; this may be because the geographical position of the land itself has been charted inaccurately, but for the purposes of practical coastal navigation these discrepancies do not matter greatly. Radar ranges from several points of land which are incorrectly charted in relation to each other will also give an inaccurate fix. It is therefore preferable to combine a single radar range with the two gyroscopic compass bearings of one close landmark which has been identified on the chart. This fix will be correct with reference to the nearest land. A series of these radar fixes will give an estimate of the ship's course and speed made good, and, if radar contact is lost, this track can be continued as the basis for a dead-reckoning plot. When in ice and out of radar range of land, only a rough approximation of the ship's position is possible. The normal log line streamed astern cannot be used, and the rapid alterations of course and slow speeds necessary for working ice preclude the keeping of an accurate dead-reckoning plot.

In some areas of the Antarctic, the magnetic compass is of little value for navigation because of the proximity of the south magnetic pole. Graham Land, however, is sufficiently far from the pole for the compass to function satisfactorily, although local magnetic anomalies may be experienced. The gyroscopic compass, which now forms part of the equipment of every polar ship, is reliable in high latitudes provided that it is correctly compensated.

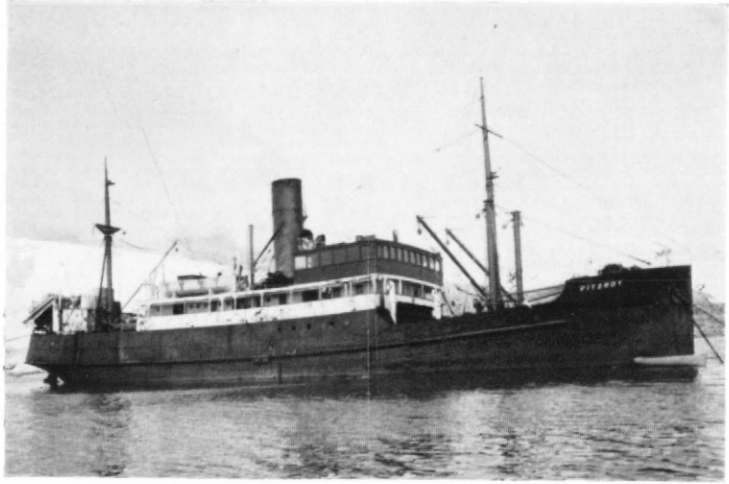
Underwater rocks and shoals are also general Antarctic hazards, particularly when sailing close inshore or in uncharted waters, and the echo-sounder must be used continuously. Some rocks and shoals rise so steeply from deep water that only limited warning of their approach is possible, and the ship must therefore reduce speed when depths are variable. Coastal features may give some indication of the nature of the sea bottom; if the coast is precipitous, deep water may extend close inshore, but near low headlands, shelving beaches and small islands there is a greater probability of shoals. A small boat equipped with a portable echo-sounder scouting ahead of the ship is used when the nature of the bottom is uncertain, or when approaching an unfamiliar or uncharted coast for the first time. In ice, however, the echo-sounder may not give distinct readings.

2. *Navigation in ice*

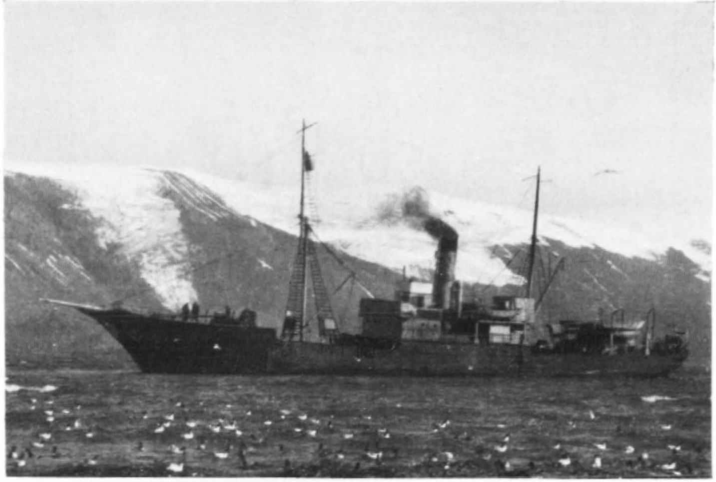
Ice encountered at sea is of two main types: icebergs originating from glaciers and ice shelves, and sea ice formed on the surface of the sea by freezing. Both are dangerous obstacles to navigation. Icebergs are a hazard to all ships however strong; sea ice may be traversed by suitably strengthened ships in capable hands.



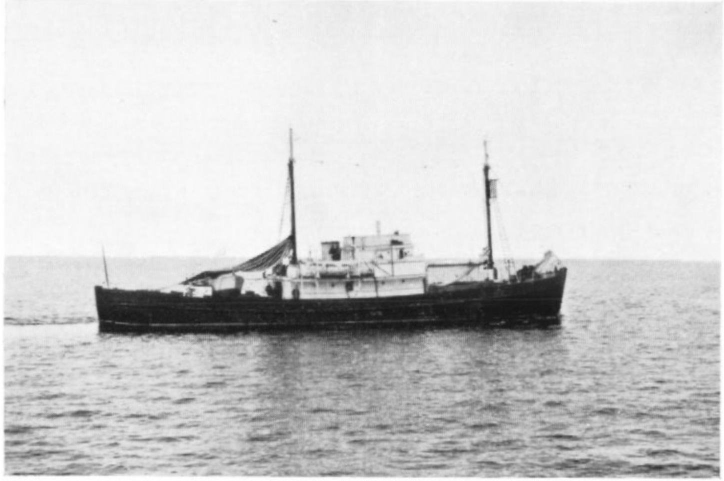
a. *William Scoresby.*



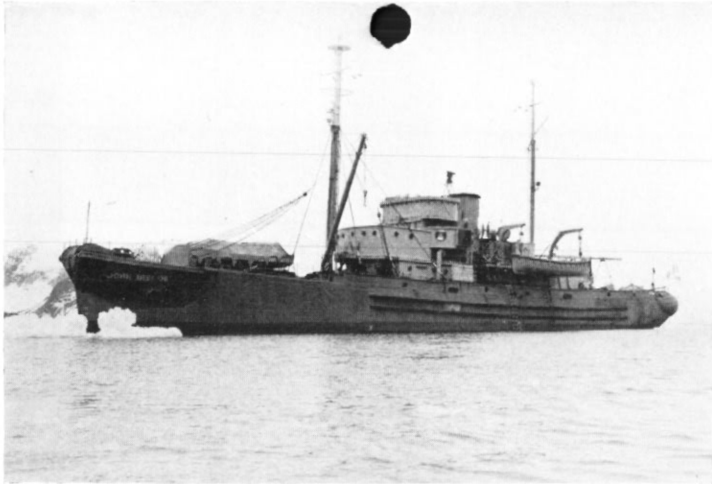
b. *Fitzroy.*



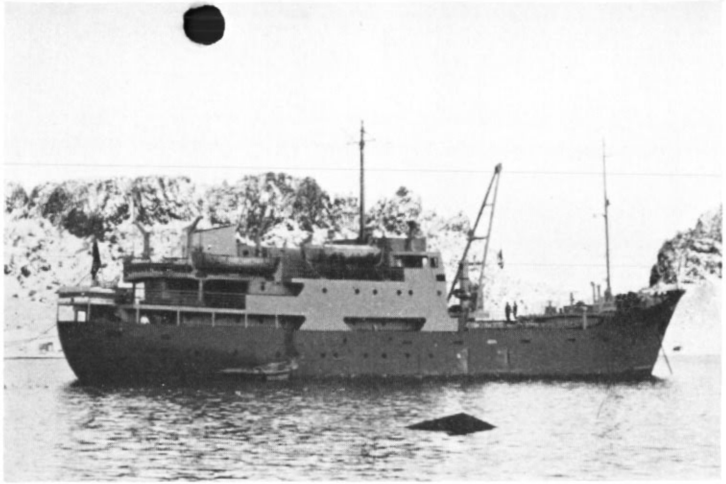
c. *Eagle.*



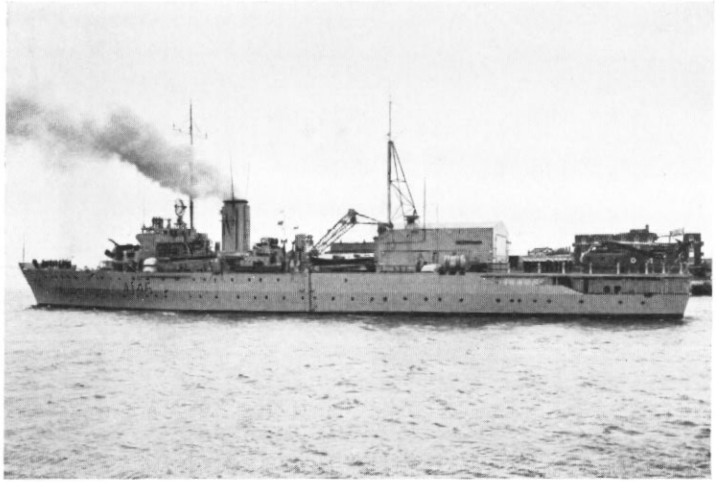
d. *Trepassey.*



e. *John Biscoe* (1947–56).



f. *Shackleton*.



g. *Protector*. (Official photograph: Admiralty.)

h. *Kista Dan*.

Fig. 6. Ships used by the Falkland Islands Dependencies Survey.

The largest icebergs are many square miles in area and often more than 50 m. (164 ft.) in height. A typical tabular iceberg may have over five-sixths of its total mass submerged and consequently drifts chiefly under the influence of ocean currents. Many have underwater spurs projecting some distance into the sea and even the smallest icebergs, together with bergy bits and growlers,* are of sufficient size to do considerable damage to the strongest ships if hit at speed. In daylight icebergs are easily seen, but in fog or during darkness there are no reliable signs which will indicate their proximity and there is no alternative but to proceed slowly and with the utmost caution. Even in daylight when heavy seas are running, bergy bits and growlers lying in the troughs of waves are difficult to identify.

The first sign that pack ice is in the vicinity may be the reflection of the ice in a clear or clouded sky known as "ice blink". It usually appears as a whitish band above the horizon and may even be visible at night. When in or near pack ice, darker patches in the sky, known as "water sky", indicate the presence of open water. A further sign of pack ice is a smoothing of the sea surface and a reduction in the amount of swell, especially when the ship lies to leeward of the ice. Although the movement of sea ice is affected by surface currents, its drift is mainly controlled by wind, and every advantage is taken of those winds which open up leads and pools in pack ice. When offshore winds prevail, leads are often found close inshore, but a shift of wind can bring the ice back rapidly to the coast and trap the ship. In tidal waters, especially in narrow straits, pack ice tends to open up on the ebb tide.

Although radar is a valuable aid to navigation in polar waters, it is not an infallible detector of ice and a constant watch is therefore necessary. Most icebergs are detected at measurable ranges, depending on their size, but small bergy bits and growlers can only be detected when the sea surface is calm, and then only within about 1 mile (1·6 km.) of the ship. When the sea surface is rough, echoes even from large icebergs may be masked by echoes from wave crests, and under these conditions radar will give no warning of the ice. Echoes from rain and snow also obscure returns from ice. Pack ice may be detected by radar when the sea surface is smooth, but little indication of its concentration will be given.

Information concerning the distribution of sea ice is of the greatest value in planning a ship's route as both time and fuel can be saved by avoiding the heaviest ice. Codes have been devised for reporting ice conditions by radio. Ice reports from shore stations give approaching ships a picture of local ice conditions, and aircraft flying over shipping routes may extend this information over a wider area. Helicopters, carried by all icebreakers and some ice-strengthened ships can, if necessary, fly ahead to locate leads and pools of open water in the pack ice and direct the ship towards them.

Ice conditions in the Antarctic vary considerably not only from place to place and year to year but also from day to day during the shipping season. Off the west coast of Graham Land, ice north of the Argentine Islands is unlikely to present more than temporary delays to an icebreaker or ice-strengthened ship. Farther south, towards Marguerite Bay and in the Weddell Sea, however, both heavy pack ice and fast ice are frequently encountered (Figs. 7 and 8), and in some years it may be too severe even for an icebreaker to combat.

Before reaching polar waters precautions are taken to prepare the vessel for cold weather operations. Anti-icing compounds may be applied to decks, superstructure and rigging to reduce the formation of icing and facilitate its removal if it does form. Large accumulations of ice can occur if heavy spray is encountered in low temperatures; this can hamper the working of deck machinery and, in extreme cases, impair the ship's stability. Ice anchors and deadmen for mooring ship are made ready, and if a motor launch is to be used in ice, it is provided with survival equipment in case it becomes isolated from the ship. Extra look-outs are posted if visibility is poor when approaching waters where ice may be present. The log is handed and if the engines are not directly controlled from the navigating bridge, the engine room is warned that instant manœuvres may be necessary; watertight doors are tested. Trim by the stern is preferable when entering ice, both for good manœuvrability and for deep immersion of the propeller blades beneath the ice.

When sea ice is encountered, a decision is made either to traverse it or to proceed round it in the hope of finding further open water; if the limits of the ice field are visible, it is normally

* For definitions of these terms see Armstrong, T. E. *and* B. B. Roberts. 1956. Illustrated Ice Glossary. *Polar Rec.*, **8**, No. 52, 4–12.

skirted. Ice is very rarely entered when visibility is low and if the visibility deteriorates when the ship is already in the ice, it is normal to stop and wait for an improvement before proceeding. When large fields of pack ice of more than six-tenths density are met, every effort is made to find a way round them, but if the ice is below four- or five-tenths density it may be quicker to traverse them.

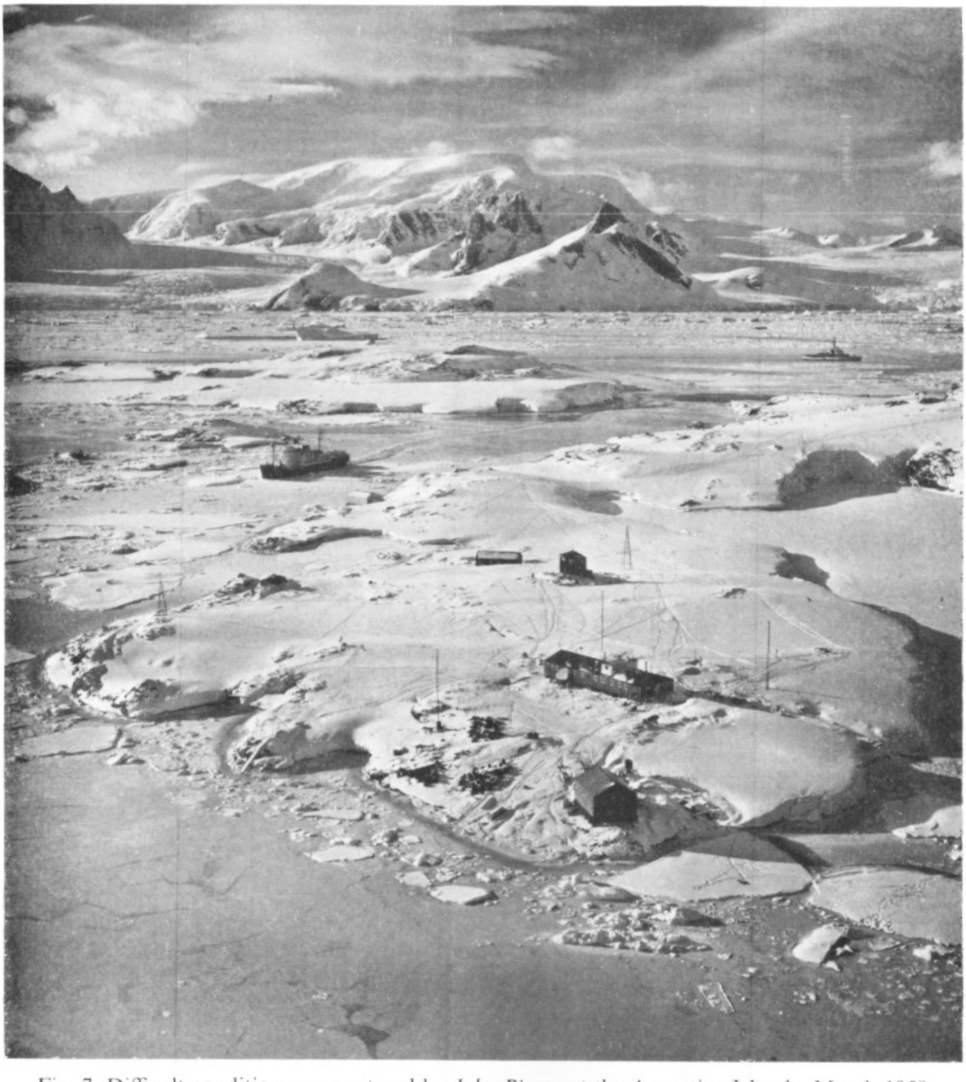


Fig. 7. Difficult conditions encountered by *John Biscoe* at the Argentine Islands, March 1959. (Official photograph: U.S. Navy.)

The ice edge is approached at right angles and at a slow speed so that most of the way is off the ship as the bows enter the ice. The point of entry into the ice field is selected with care, taking into consideration the concentration of the ice and the ship's capability. If possible the ice is entered up wind where the swell is least and the edge is more compact. A bay formed in the ice edge by wind action provides a natural place of entry. Areas of pressure in close pack ice where rafting and tenting is observed are avoided.

In many ice-strengthened ships rudder and engine controls are duplicated in the crow's nest and from this position the navigator can see ice immediately in front of the ship which is concealed from the wheelhouse by the bows. Advantage is taken of any leads and pools of open water even if they do not always run in the desired direction.

Once in the ice, power is increased to maintain a steady speed through the floes while yet avoiding excessively heavy impacts. Short bursts of full power are necessary to force ice aside, but some engine power is reserved for coming astern in emergencies and only the minimum amount of rudder is used. A floe blocking a lead is hit squarely with the stem and levered aside. An experienced helmsman can take advantage of any swing imparted to the ship by glancing off a passing ice floe, and is therefore given latitude in guiding the ship through pack ice. Care is necessary to prevent the stern from swinging into ice floes which pass down the ship's side. When ice collects round the stern, the propellers are kept revolving

Fig. 8. The icebreaker *Northwind* assisting *John Biscoe* off Adelaide Island, March 1959.

to reduce the likelihood of breaking the blades. If the ship is stopped by heavy ice, it may be necessary to come astern, but ice is first cleared away aft by the wash from the forward turning propellers.

Progress through pack ice depends on the concentration and size of the floes, the power of the ship and the magnitude of the impacts she can safely withstand. Concentrations of three- or four-tenths may be navigated at speeds up to 6 or 7 kt., but between five- and six-tenths more manœuvring between floes is necessary and speed must be reduced in order to avoid collisions. Above eight-tenths concentration progress depends mainly on the size of the floes and whether they are in contact with each other.

Ice-strengthened ships make only slow progress in concentrations above eight-tenths, because they lack power to push the floes into the remaining open water, so these ships avoid close pack ice as far as possible. Once in very close pack ice, a certain amount of careful backing and charging may occasionally have to be undertaken to reach lighter ice, but this is a difficult manœuvre requiring skill. Icebreakers, in contrast, have sufficient strength and power to force their way through the closest pack ice and any backing and charging which may be necessary can be undertaken with comparative safety. These ships may find it quicker to traverse pack ice rather than make long detours (Figs. 7 and 8).

Deep snow cover on the surface of sea ice makes progress extremely difficult and it is avoided where possible. On close pack ice the snow binds the floes together; friction between the hull and the snow-covered floes may be sufficient to bring the vessel to a halt. Ice-strengthened ships are powerless under such conditions. On fast ice, the snow cover has a cushioning effect on the charges of an icebreaker attempting to break a channel through it. Heeling tanks must be used continuously to prevent frequent jamming and, if the snow cover is more than about 50 cm. (20 in.) thick, only slow progress will be possible.

The channel broken by an icebreaker through fast ice or large floes in pack ice is normally considerably wider than the ship itself in order to allow the small floes and brash to be displaced astern. The icebreaker charges the ice from a distance of about 100 m. (330 ft.) at full power, and hits the ice at a speed which may be as great as 10–15 kt. She rides up on to the ice, breaking and crushing it under her weight. The engines are put astern before forward motion ceases, to prevent jamming at the end of each charge. The ship then moves astern in preparation for a further charge. If the ice is 3–4 m. (10–13 ft.) thick, progress may be no more than about 15 m. (50 ft.) at each charge.

Anchoring in heavy ice is inadvisable as the tremendous force of moving ice may cause the anchor to drag on the bottom and may easily part the cable. A ship may be safely stopped in close pack ice during darkness or bad visibility provided that she is clear of ordinary navigational hazards, and that the ice is not under considerable pressure. Mooring with ice anchors may prevent a quick shift of position if icebergs approach too close. Wooden deadmen may be used for holding the ship in position at the edge of fast ice.

A vessel beset by ice may be subject to pressure and, if caught near the coast, may be pushed into shoal waters; she will then have to attempt to break free and take up a more favourable position. If there is sufficient room to manœuvre, it may be possible to open up cracks along lines of weakness in the ice, but care must be taken to avoid wedging the ship between two floes under pressure. In this case, the engines are put alternately from full ahead to full astern to induce the ship to move. Altering the trim, listing the ship or, in icebreakers, using the heeling tanks will also help to free the ship. In an emergency it may be possible to ease the vessel's position and release the pressure by using explosives, but blasting is only effective over a very small area. Extreme pressure may also sometimes be relieved by breaking up the ice round the ship's sides with pick-axes and crowbars. A vessel beset in a bay sheltered from pressure may be able to survive the winter without serious damage but, if beset in an exposed position, she is liable to be crushed. Serious damage is not always a sudden occurrence and may be brought about gradually by increasing pressure.

When extricating a ship beset, the icebreaker loosens up the ice by making a series of runs past and around the ship before taking up her position ahead, with the rescued ship following close behind. This latter manœuvre is difficult because the icebreaker may easily be brought to a sudden stop by a heavy floe across her path and may then be rammed by the ship astern; the icebreaker's propeller wash is, however, normally sufficiently strong to push the other ship's bow clear of her stern. In close pack ice or heavy brash, when the channel left by the icebreaker closes up quickly, it may be necessary to tow the other ship. It is sometimes necessary to convoy one or more ice-strengthened ships through heavy ice. The ships convoyed follow in the channel made by the icebreaker at intervals which are determined by the concentration of the ice, the least powerful being placed first in line astern. Both convoying and towing require a high degree of co-operation and a system of manœuvring signals between the ships involved (Figs. 9 and 10).

Despite all precautions, ships working in Antarctic ice invariably sustain some damage and should be provided with materials for emergency repairs. When going astern, the rudder and steering gear may be strained and propeller blades broken. Excessive speed is the most frequent cause of hull damage as impacts from floes may buckle the shell plating.

The Use of Icebreakers in the Antarctic

Only two of the nations which now maintain permanent scientific stations in the Antarctic have yet made use of icebreakers; these are the United States and Argentina. The others have relied solely on ice-strengthened cargo ships and the degree of success of their annual relief

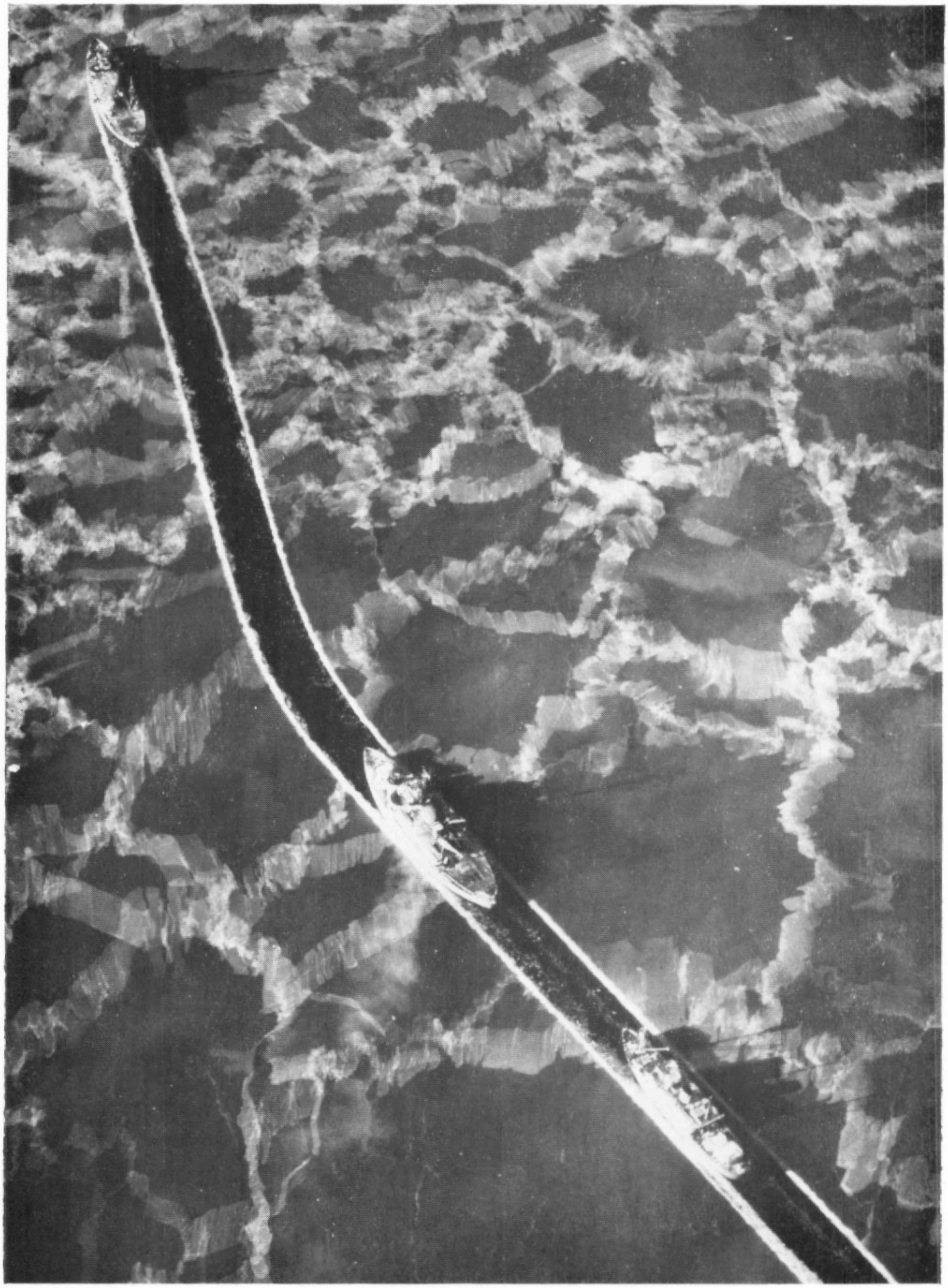


Fig. 9. The icebreakers *Edisto* and *Northwind* preceding *John Biscoe* in Penola Strait, March 1959. The ships have taken up convoy formation in young ice prior to entering pack ice. (Official photograph: U.S. Navy.)

Fig. 10. The same convoy working through open pack ice with helicopter assistance.
(Official photograph: U.S. Navy.)

has consequently depended very largely on ice conditions. In severe conditions ice-strengthened ships are only of limited value to large-scale expeditions unless they are assisted by icebreakers. On the other hand, icebreakers cannot generally be used on their own because of their small cargo capacity.

The vital importance of adequate shipping has long been acknowledged but the high initial cost of icebreakers has so far restricted their use. There is no doubt that icebreakers offer the most economical long-term solution to the recurring logistic problems which confront all expeditions, but ice-strengthened ships will still be required for transporting cargo.

Greater use will undoubtedly be made of fixed-wing aircraft and helicopters, and, looking further ahead, hovercraft, nuclear-powered icebreakers and submarines unrestricted by conventional fuel problems. These may all help to open up areas where the ice has hitherto been considered impenetrable, but it is unlikely that any of these will prove more efficient and economical than icebreakers at least for some years. In the meantime, further icebreakers, similar to but perhaps smaller than *Moskva*, would be invaluable in providing the maximum reliable support for parties carrying out scientific and geographical exploration in the Antarctic.

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