The Design and Building of Icebreakers

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This paper deals with experiences of the Canadian Department of Transport in operating a fleet of icebreakers over a period of twenty-five years. The paper is mostly concerned with the application in practice to icebreaker design of information obtained from the operation of icebreakers under Canadian conditions.

The Canadian Arctic consists mainly of islands and inlets which stretch over an area of 2,000 miles north and south and a little more east and west. A large part of the area is eternally ice bound and cannot be reached by ships at all, but by far the largest part of the Arctic is accessible to icebreakers in season.

The advent of flying has made it possible for Canada to establish development and control centres on a much larger scale in the Arctic, but the flying must be complemented by the use of icebreakers as the large quantities of materials required cannot be taken in by aeroplanes.

There is only one established port (Churchill) and in all other places in the north there are few ports of refuge from ice or weather. There are no wharves at which cargo can be landed and there are no permanent cargo handling facilities.

The geographical set-up shows tremendous ice pressure concentrations due to the shape of the land and the effect of wind and ice in the large areas of open water in the ocean. The ice itself presents greater difficulty than the ice farther south because new ice very often simply forms a matrix for heavy old Arctic ice which is heavy enough and which is liable to do serious damage to underwater plating of ships, particularly bilge plating, if approached at speed.

It is therefore essential that the icebreaker be self reliant, that it should carry lifting equipment which is heavy enough to land all the material which has to be put ashore, and that it should also carry a sufficient quota of landing craft to get materials from the ship to the shore.

In order to carry out operations in this area successfully, the ships also require to be fitted with helicopters.

The paper, therefore, is intended to describe in some measure the evolution which has taken place with regard to improvements in design as found necessary by actual operation.

HISTORICAL

The history of icebreaking and winter navigation in Canada goes back a long way and one reads of Champlain, making his year 1611 trip to Montreal, leaving France in March and finding that the ice made the passage to Tadoussac very difficult. The first recorded attempt to maintain winter navigation in Canada was made by the steamer *Albert* which ran between the mainland and Prince Edward Island. This craft was small and quite unfit for the task and was followed by a ship called the *Northern Light,* built at Quebec in 1876. This ship could develop all of 120 h.p., less than a quarter of the power used today in the workboats which take cargo ashore. This vessel proved unfit to maintain winter contact with the Island. The service later passed under railway control and is today carried out by the *Abegweit* assisted by the *Prince Edward Island.* The *Abegweit's* 12,000 h.p. is a far cry from the 120 h.p. of the *Northern Light.*

The first recognized icebreaker designed for the purpose appears to be that built by Russia in 1870 to maintain winter navigation at the Port of Cronstadt.

Successful icebreaking on a large scale to open icebound ports was subsequently practised by Sweden. The experience gained in such quarters brought about a demand for icebreaking assistance to facilitate longer use of the ports of Montreal and Quebec. In 1904/05 two icebreakers were built by Messrs. Fleming and Ferguson of Paisley, the *Montcalm* and *Champlain.*

The *Montcalm* was a successful icebreaker and Percival St. George, a Montreal engineer of repute, then reported to the Minister of Fisheries: "The ice was very thick, ranging I should judge between fifteen and twenty feet thick. The work being done by the steamer is marvellous considering the immense thickness of the ice and the enormous power to contend with. If I may suggest anything, I would recommend that another steamer be used in conjunction with the *Montcalm* so that two steamers could work jointly together, one either side of the channel".

This practice was adopted and it remains so today. The sight of the icebreakers working together as they move up the river provides a thrill to thousands of people who flock from nearby towns and cities to watch the show. The performance is shortened now, however, as the *d'Iberville* alone can reach Montreal at any time during the winter.

The *Montcalm* and *Champlain* were followed by the

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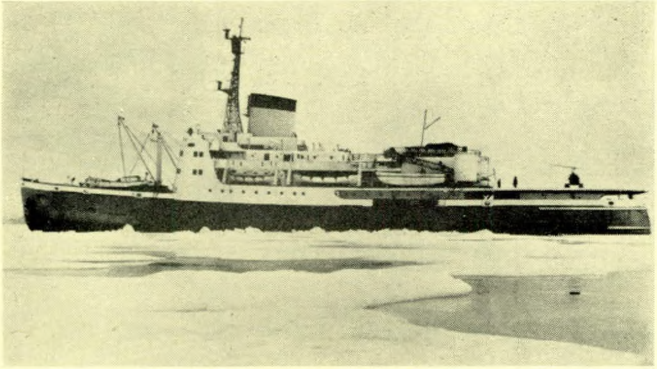

FIG. 1—*Icebreaker* d'Iberville

Lady Grey, Mikula, Saurel, N. B. McLean, Ernest Lapointe, d'Iberville, a new *Montcalm,* the *Labrador,* and the icebreaking ferry *William Carson,* all except the first built in Canada. (Figs. 1 to 6). The *Mikula* was a powerful icebreaker but her usefulness was limited by the coal fired boilers and lack of steam pressure.

The Canadian coastline extends some 100,000 miles between latitude 41°–41′ and latitude 83°–09′ and a great range of ice conditions are encountered. The great bodies of fresh water represented by the River St. Lawrence and the Great Lakes all freeze in winter, augmenting difficulties of ice navigation operations in Canadian waters. The coastline mentioned above includes that of the many islands, large and small, contained within the bounds of Canadian Territory, including the Canadian Arctic.

All forms of ice conditions* are found in Canadian waters, ranging from heavy, embedded, hard "old" Arctic ice (having a very high strength of a possible 1,000lb. per sq. in. in compression and a tensile strength of 250lb. per sq. in.) to nearly zero for slush ice. Free icebergs are also common.

In typical Arctic navigation it is necessary to search for leads to use as passages through Arctic ice fields and large floes as it would be quite impossible for any existing vessel to navigate successfully through the heavy eternal ice of the polar seas. On the other hand, ice navigation and icebreaking work farther south, in the Arctic, Labrador, Newfoundland and Maritime waters, is more practical by penetration of drifting fields of pack ice, sheet ice, frazil ice, etc. Pack ice

FIG. 2—*Icebreaker* Montcalm.

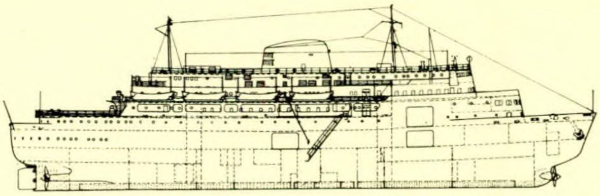

FIG. 3—*Profile of the* William Carson

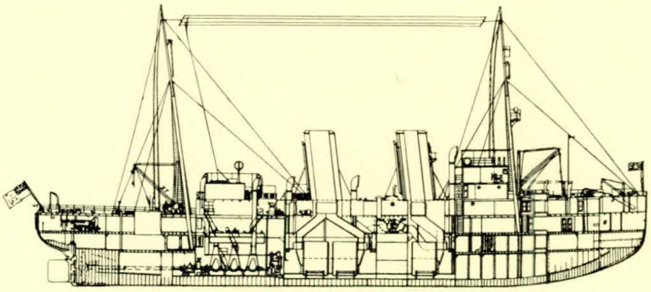

FIG. 4—*Profile of the* N.B. McLean

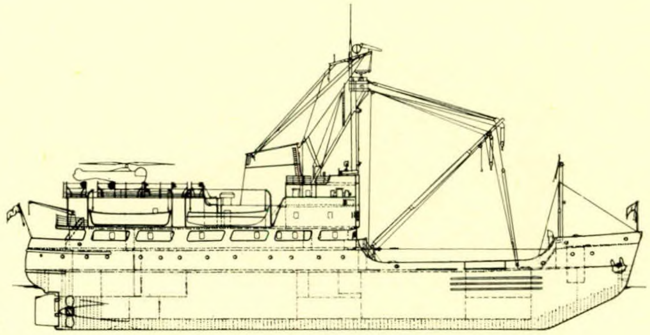

FIG. 5—*Profile of the* Montcalm

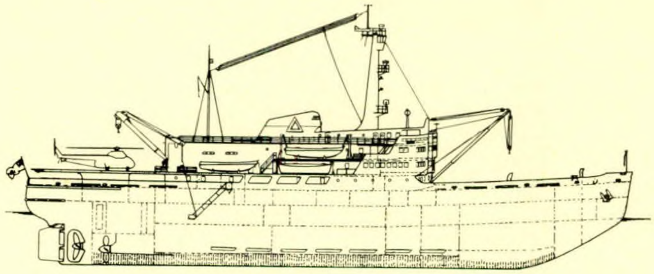

FIG. 6—*Profile of a triple screw icebreaker*

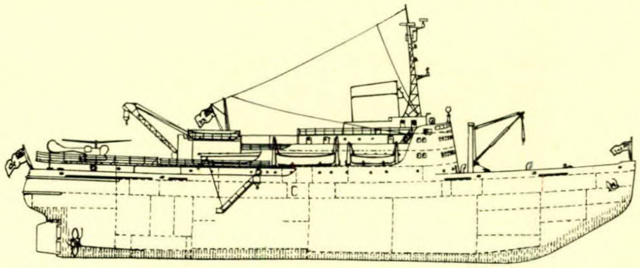

FIG. 7—*Profile of the* d'Iberville

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* For ice nomenclature see "Illustrated Ice Glossary", describing and giving names for sea ice of all forms, written by Terence Armstrong and Brian Roberts, and published by the Scott Polar Research Institute, Cambridge.

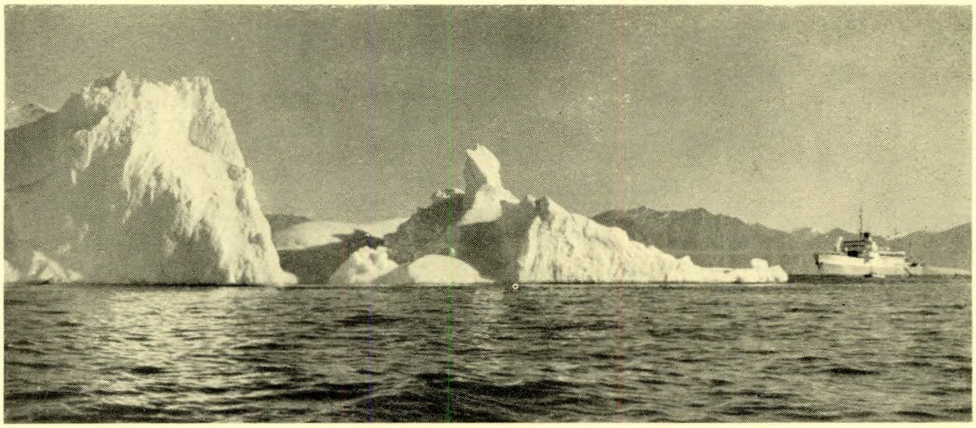


FIG. 8—C. D. Howe *and icebergs at Pond Inlet*

in ocean areas, although rafted to a height of 30ft., can be penetrated by heavy icebreakers. This is often necessary in carrying out rescue operations in the freeing of icebound vessels. River and lake ice is often composed of shelf ice with frazil ice underneath, which is composed of fine spicules or plates of ice in suspension in the water. It is actually the first stage of freezing, giving an oily opaque appearance to the surface of the water. This ice can be very sticky and difficult to move through when covered by sheet ice of even medium thickness and a snow cap. Although it has no strength, when trapped between the sheet ice and bottom it does impose an additional compressive load on the icebreaker's hull (Figs. 9 and 10).

Confined areas, such as estuaries, straits, bays, etc., usually present difficult icebreaking problems due to congestion of the drifting icefields under landlocked conditions by action of tide and wind.

Sheet thickness of blue ice on the St. Lawrence and Richelieu Rivers runs to a maximum of about 38in. On the Great Lakes the ice is generally lighter but under the action of wind and current often forms into pressure ridges, plugging channels and canals, often grounding and causing distant ice fields to raft over, greatly increasing the difficulty of icebreaking.

The West coast of Canada has no icebreaking problem. The Western Arctic, however, presents difficult ice problems, in some ways more difficult than the Eastern Arctic.

FIG. 9—*Close up of ice being broken by* d'Iberville *in Norwegian Bay*

Icebreaker operations in Canada are complemented by the use of survey planes. The Department of Transport carries out four regular surveys: i.e. Quebec to the Gulf, The Gulf of St. Lawrence, The Belle Isle Strait and Hudson Bay and Strait. Helicopters are also used on all the icebreakers. Written reports are wired from the ice observation officer and transmitted to all shipping companies and other parties interested, approximately eighty-one in all. Facsimile graphs are sent direct to ships having receiving equipment and are reproduced by Canada House, London. Aerial surveys were started fifteen years ago and have proved most beneficial for navigation in ice infested waters. The main purpose of these reports is to forecast ice conditions and find the best possible ice free track for commercial ship traffic. A representative ice survey chart is shown in Fig. 11. These charts are prepared at frequent intervals, the intention being to furnish information of conditions just ahead of the incoming vessels. The master of an incoming commercial vessel cannot, without danger or assurance of benefit, depart from his course to seek open water, unless he receives information which permits him to do so.

All Canadian icebreakers are composite duty ships. As icebreakers they function to open up frozen rivers, channels, harbours, ocean tracks, etc. The relieving of ice jams in rivers prevents flooding of a serious nature and without this assistance important industries on the St. Lawrence River, and the lower parts of cities such as Montreal, and towns along the river bank, would in some winters suffer loss of production and property damage. The majority of seasonal ports have by use of icebreakers been given a longer operating season and many ports which were seasonal have become year-round ports on a somewhat interrupted schedule basis. For the first time in history a ship operated into Quebec throughout the winter of 1957-58. Places in the Canadian Arctic, such as Eureka, which at one time could not be reached at all even by expeditions, are now reached annually by heavy icebreakers.

CONTINUOUS SERVICE DUTIES AND EFFECT ON DESIGN

In order that full use may be made of icebreakers throughout all seasons it is essential that in designing these ships the general purpose duties which the ship will be required to perform be kept in mind. The icebreaker is not a revenue producing ship but overall operating efficiency can be gained if the ship can be used for off-icebreaking season duties, even if it cannot perform all of these duties as efficiently as a vessel designed for each purpose. Icebreaking and convoy duties require to be carried out in the lower latitudes from the end of November until, in some years, the middle of May. In the North icebreaking and supply duties require to be carried out from the middle of June until, in some years, late November. Icebreaking, medical convoy, supply, and scientific operations are frequently all carried on during the same voyage. Briefly,

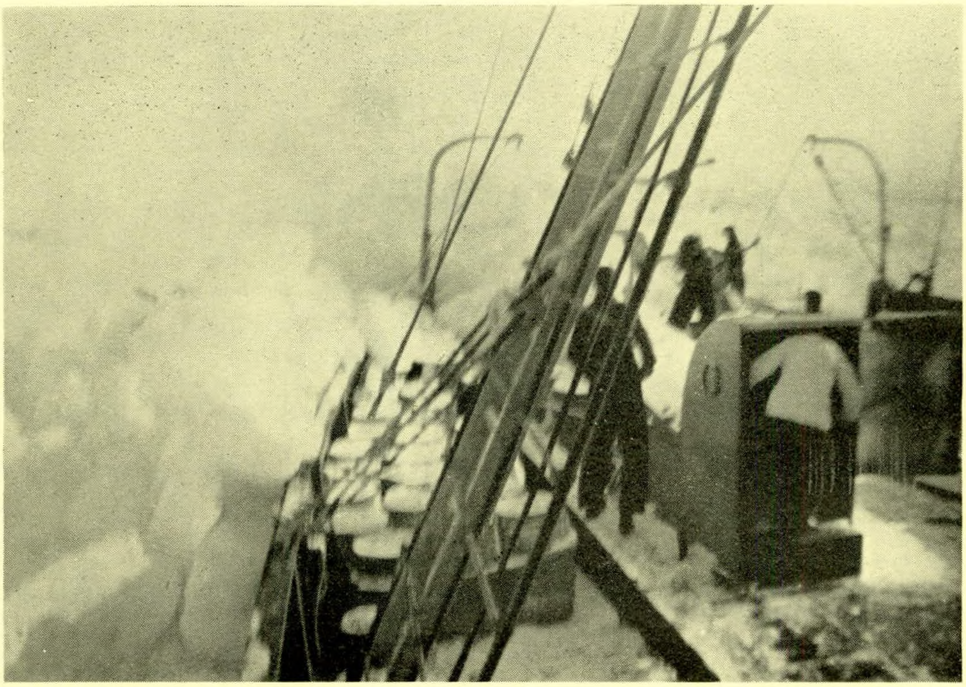


FIG. 10—*Saurel in heavy rafted ice forward*

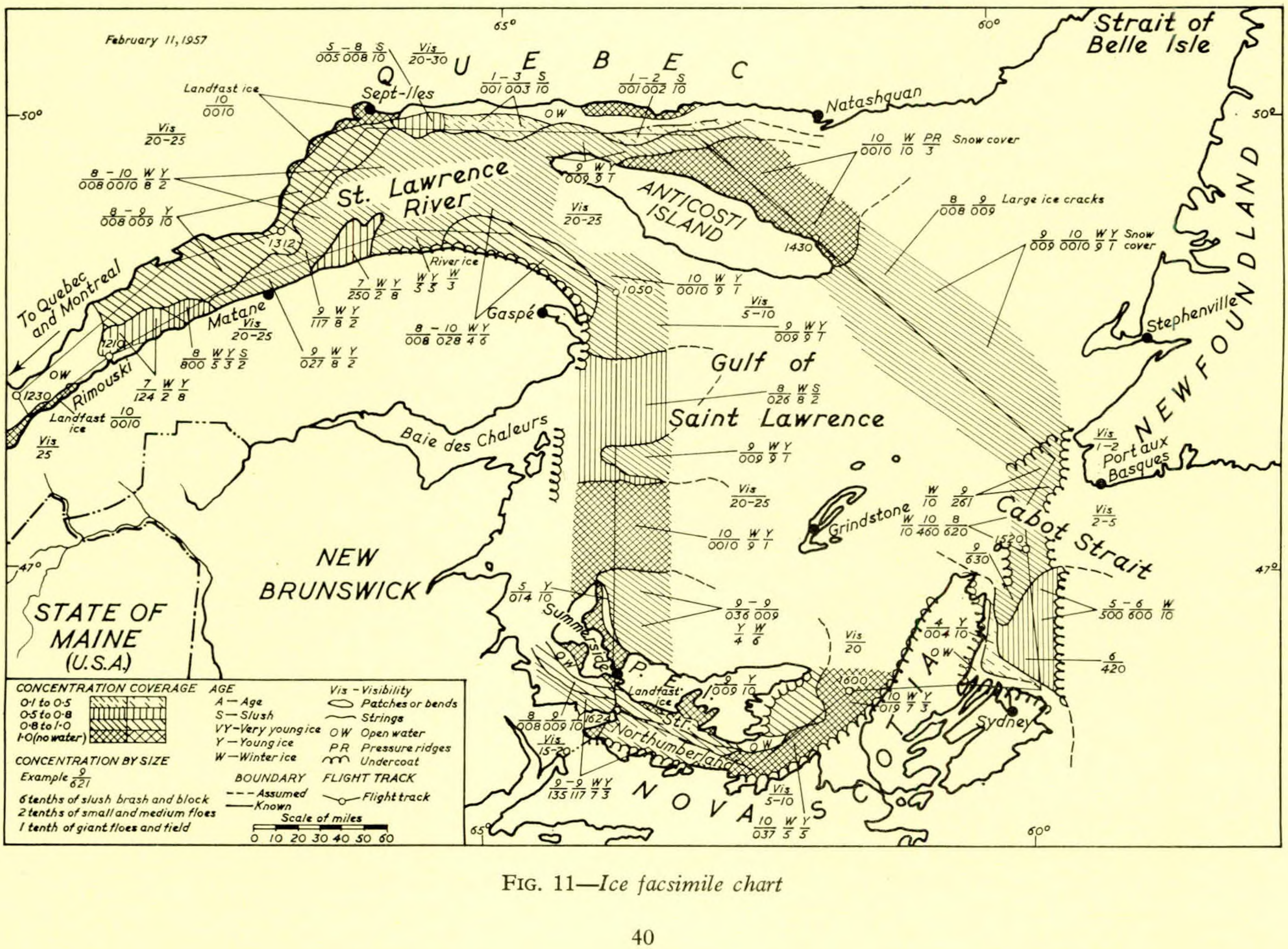


FIG. 11—*Ice facsimile chart*

therefore, the icebreaker must be capable of carrying out in some measure complemental services such as:—

1. The laying down in charted positions and the lifting, making good and replacing of floating buoys and other aids to navigation.
2. Transporting supplies and personnel.
3. Providing medical and scientific assistance.
4. Carrying out search and rescue, towing, and other salvage work.

The characteristics required to provide an efficient ship for the aforementioned services conflict. Tabulating the requirements we find that for icebreaking service the following qualities are desirable:—

1. A bow having a strong stem bar.
2. A bow having the best angle of fore foot for the desirable compromise of power distribution; i.e. of power used for breaking ice by tension loading as against power used for breaking by direct compression.
3. A bow having sufficient curvature and shape normally to prevent sticking.
4. In relatively clear water with sheet ice of medium thickness, a bow propeller or propellers (mostly used for icebreaking ferries or on lakes).
5. A relatively fine lined body if the vessel is to be used alone for transportation of cargo to distant northern stations where very heavy rafted ice conditions with embedded Arctic ice are to be encountered.
6. A fuller bow and body where operation involves convoy of commercial vessels through ice fields, so as to leave a clearer wake for ships being convoyed. A limited draught so as to enter harbours.
7. A hull structure strong enough to maintain form when charging heavy ice ahead, or drilling ice astern; or simply beset in a river or similar condition where the vessel may be well supported by ice along one side and have a large area batture forced on to the ship at one point of contact by river current; or beset in heavy ice either in the Maritimes or Arctic under conditions where heavy drift surrounds the ship and great pressure is exerted by summation of pressure movements built up by action of wind and tide on large areas of floating ice to windward, and setting against the shore line.
8. A system of intakes requiring perforated bays, high and low suctions. Extra large intake strainers heated by return of hot water to intake chambers or steam heating, etc.
9. Underwater gear capable of standing up to working astern in heavy ice. This involves a stern frame rudder and rudder stock which will not fail or change position when the vessel moves astern into ice; a steering gear powerful enough and with locking equipment to hold the rudder in position, and shafts and propellers designed for astern icebreaking.

FIG. 12—*Icebreaker* Ernest Lapointe *showing wall sided construction for buoy work*

For icebreaking service the large beam, excessive power, and heavy scantlings required generally result in a stiff vessel which has boisterous movement and is most unseakindly in operation. Large power and fuel requirements leave little space for cargo.

For buoy work a vessel having an easy roll and limited pitch and surge characteristics with a long low buoy well deck is desirable. This makes it difficult to have adequate accommodation for passengers or suitable space for stowage of commodities which have to be delivered at the various points of discharge on a routine basis. It is also difficult to provide adequate space for refrigeration capacity and equipment. Absence of high bow flare is essential for easy approach to buoys (Fig. 12). It is also difficult to provide adequate space to stow lifeboats and landing craft which the supply vessel must carry as there are no wharves or landings. Cargo must go ashore by boat and be delivered on the strand or rocky coast, as the case may be.

Icebreaking itself presents many problems. The general concept of course, is, a strong, powerful ship having a bow which, when advancing, will contact the sheet ice at an angle which will result in a vertical force component which will produce tension stress on the ice shelf. Ice is relatively weak in tension but is very strong in compression. The bow being in effect the tool which determines how much ice will be broken by tension loading and how much will be broken by compression loading is, in the author's opinion, the most important part of the icebreaker. If too much ice is broken by tension loading, large slabs are forced down and along the body and if the vessel is fine lined they appear at the propeller (where they are liable to impose undesirable shock) or appear in the wake where they interfere with successful convoy work. If the bow angle is steep and the buttock lines too full the resistance set up by the broken ice as it passes down and out becomes so great that the advancing bow is breaking ice by compression loading only and the large expenditure of power quickly brings the ship to a stop. In the latter stages of this operation the ice becomes broken so small that it actually rises and, in appearance, looks like the bow wave of open navigation. This, and too much heavy ice in the wake, constitute the two extremes for compromise by shape of bow and underwater body. The bow should also be designed with a view to preventing the bow becoming fast when breaking heavy ice by ramming. The stability of the ship under conditions where the ice is very heavy must also be considered, as a vessel which is partly supported on the ice has, in effect, raised its centre of gravity.

The freeing of the icebreaker when fast in ice at the bow can be facilitated if the centre of flotation is kept as far forward as possible, for (by use of the propellers) what has been described by one of the icebreaking masters as a better jackknifing effect.

All Department of Transport icebreakers are fitted with underwater gear which will stand up to the impact of breaking ice astern and propellers which will in effect drill drift ice piled as high as 20 to 30ft. The propellers will also handle sheet ice up to approximately 3ft. thick plus the snow cap. This is a most important faculty when breaking ice in a river as, although the river freezes over on top, the water continues to flow to the sea under the ice. Frazil concentrations, however, have the effect of blocking the deep water passages, forcing the water to find passage in the usually still shoal areas. The effect of this is to raise the water level in these areas, which action frees the anchored shelf ice. This ice is often of large area and it commences to move with the wind from its shore anchorage into the stream. It then causes further jams at restricted passages. The river then has to build up sufficient pressure to break the jam by raising the level. This can cause flooding. With the icebreaker upstream, little progress can be made by breaking in the normal manner down stream as the broken ice merely forms a cushion for each succeeding charge. Progress is made, however, by using the propellers as drills and proceeding astern. This action is slow but positive and takes place sometimes under conditions where the ice jam is so high that part of it falls on to the aft deck as the ship proceeds astern. Under heavily rafted light field ice, heavy slush and frazil ice, the action of a forward propeller, or two forward propellers, greatly simplifies the icebreaking procedure.

Under heavy ice conditions in convoy work where no suitable leads can be found, it is essential for the icebreaker to proceed ahead of the commercial vessel. This operation requires an icebreaker having physical characteristics which will provide a relatively ice free wake. The master of the icebreaker must have skill in this operation also, since it is desirable for the commercial ship to avoid the closing of the wake passage by keeping close to the icebreaker. Danger arises from the fact that the icebreaker, in proceeding through the ice closely followed by the commercial ship, may meet added resistance due to heavier ice concentrations. This slows the icebreaker but is not felt by the ship coming on astern and serious damage can be done by the oncoming commercial ship. This operation is always difficult but where possible the icebreaker operates on reduced power and increases power where required to maintain safe distance. Design should, as far as possible, cover the power increment angle even if only by temporary overloading. Good telephonic communication is necessary for this operation, especially under fog conditions.

Having briefly described the general conditions in which Canadian icebreakers are expected to work, design for application in practice is now considered.

Table I has been prepared to give a comparison of the principal particulars of various Canadian icebreakers.

The shapes of stern and bows of Canadian icebreakers have not been deduced mathematically or by calculation but are rather the product of results in practice. It is not possible to simulate ice conditions as they are found in nature, or the reactions between ship and ice by models, as in open water navigation, and, although the *d'Iberville's* bow has given excellent results, it may well be that the best all-purpose bow has not yet arrived. Although the form of the bow presents the greatest amount of the unknown and uncertain in regard to the angles, curvatures, etc., for best results a great deal of planning and model work requires to be done on the body of the ship itself in order to secure the best compromise there. Most Canadian icebreakers are required at one time or another to carry out convoy work and in order to have a wake which is reasonably free from ice or infested with ice which has been broken into relatively small particles, it is essential, therefore, to have the ship fairly full bodied. If this is accompanied by excessive flare angle at the waterline, the curvature to maintain that flare below the waterline cannot be maintained and the form below the waterline, therefore, has a tendency to flatten out in order to ensure satisfactory bilge displacement and rise of floor. The result of this flattening makes it difficult to blend the bow and buttock curvature into the midship section of the vessel and by providing extensive rather than point contact has a tendency to sticking by large surface contact. It will be seen from Fig. 13 that most modern Canadian icebreakers are designed with a stem cut-up angle of less than 30 degrees, usually more nearly 25 degrees and in certain cases as low as 23 degrees. Running approximately parallel to and outboard of the stem, the buttock lines are sloped to a similar degree, and a glance at the body plan will indicate how the ice is subjected to severe downward bending pressure, resulting in the breaking up of the ice. The

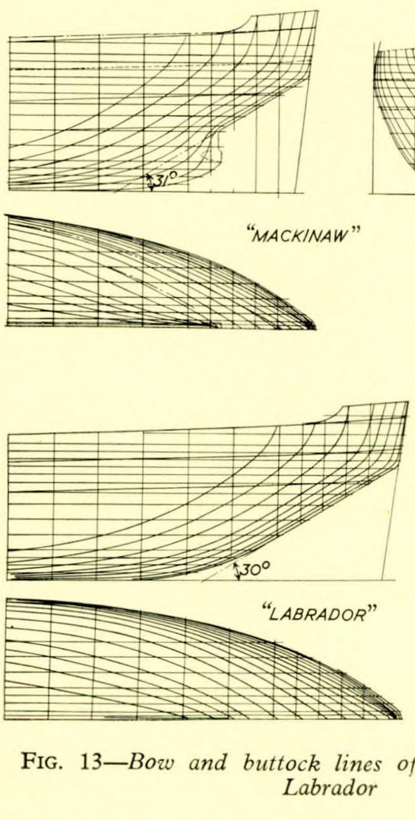


FIG. 13—*Bow and buttock lines of the* Mackinaw *and* Labrador

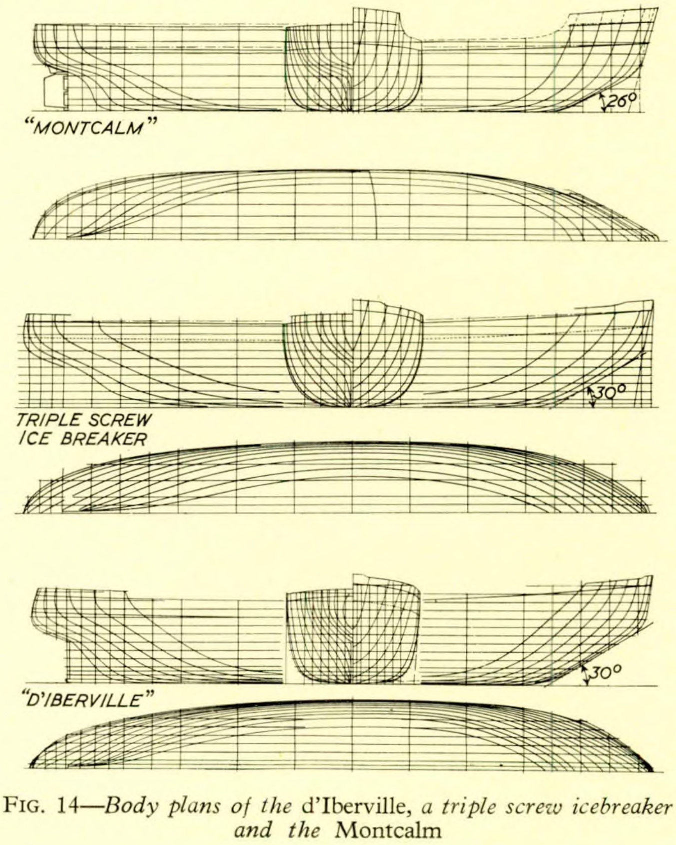


FIG. 14—*Body plans of the* d'Iberville, *a triple screw icebreaker and the* Montcalm

broken ice then follows down the buttock lines. Moving aft and outboard, much of it comes to the surface abaft the maximum section of the vessel. If it rises to the surface too far aft, large slabs of ice may come into the propellers which, of course, is a condition to be avoided if at all possible. Notwithstanding the fact that the propellers are designed to withstand shock, they require when being used to drill or pump ice to be fed into the ice gently as a drill into metal. Reference to Fig. 14 will show the lines of a very recent Department of Transport icebreaker, supply and buoy vessel, C.G.S. *Montcalm,* and it will be apparent that these lines are very full and round forward. This was the result of several compromises on overall conflicting design requirements and also their knowledge that such round forward lines function well in river and lakes icebreaking. The little ship has proved to be an excellent icebreaker. Full lines forward also provide a higher bow wave. After a channel has been broken through sheet ice, the field adjacent to the broken track can be widely broken by using the icebreaker to pass through the track at full speed. The resultant bow wave develops large cracks through the ice at the sides and thus greatly widens the passage without ice contact at all.

From an inspection of Table I it will be seen that the block coefficients for Department of Transport icebreakers range from 0·52 to 0·58 approximately, a suitable form for rapid acceleration beyond this range being difficult to derive. Twelve different bow models were made up in designing latest icebreakers. Acceleration is important when breaking heavy ice by repeated charging.

The line drawings in Fig. 14 illustrate that the trend of recent Canadian Government icebreakers has in effect eliminated tumble home and excessive flare at the waterline. Icebreakers built outside Canada all appear to be designed with substantial midship flare and tumble home. The reasoning behind this appears to be to enable crushing pressures of ice to lift the vessel rather than crush her. Flare angles at midships producing flat sections below the waterline have been used on the *Mackinaw* and *Labrador*. A much rounder midship section form can be achieved by reducing the angle of flare to 5 degrees to 10 degrees (depending upon the fullness of the vessel) resulting in more convex lines throughout. This is an important aspect of an icebreaker's line. As one of the senior icebreaker captains expressed it—"The bow should be shaped like the fine end of an egg". This idea is embodied as far as possible in the lines of *d'Iberville* and the 18,000-b.h.p. triple-screw icebreaker now being built.

The amount of flare which is required for entrance and run in order to satisfy icebreaking requirements in practice appears ample to effect the upward movement of the vessel under the action of a steadily applied crushing force along the waterline and still enable the midships flare angle to be kept to within 5 degrees to 10 degrees to the vertical. In addition, ice pressure when applied with reasonable uniformity along each side, does not appear to be sufficient to either crush or lift modern icebreakers.

The stern form should, like the bow, have an ice entrance angle somewhat similar to bow form. This, of course, is only a target and the degree of similarity depends upon necessary propeller diameters and arrangement, shafting, bossings, clearance of propeller, deck area required aft; and, in addition, the position of longitudinal centre of buoyancy which they try to arrange a little forward of amidships. Propeller position and adequate tip clearance from hull is important. They should be kept as low as possible and clearance between blade tip and for twin screws should not be less than diameter over seven (Fig. 15).

The *pros* and *cons* of bow propellers have been discussed in other technical papers and articles but Department of Transport practice has borne out that under sheet ice of minimum thickness bow propellers are advantageous. The aperture for the shafting and propeller, however, does interfere with the usefulness of the bow in forward breaking without forward propellers. U.S. icebreaker *Mackinaw* on the Great Lakes uses a bow propeller with good results and ferries working on a regular run, such as the *Abegweit,* find them useful for manœuvring and icebreaking in limited ice conditions. The American Wind Class vessels, which first proceeded into the Arctic fitted with bow propellers, encountered much difficulty with the bow shafting and propeller and later designs have an icebreaking bow fair and without propeller. The Department of Transport has never used a bow propeller in the Arctic service and considers that the interruption of the bow lines to fit a propeller imposes too great a loss in icebreaking ability. On the icebreaking ferry *William Carson* a bow propeller was fitted but it interfered with the speed and proved unsatisfactory for use in the heavy ice conditions encountered in the Maritimes.

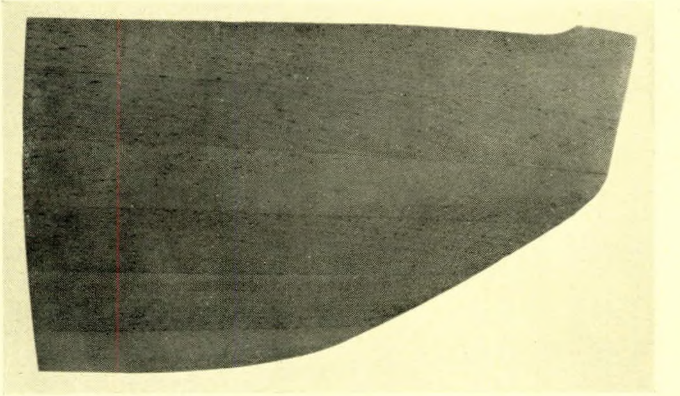


FIG. 15—*Model triple screw bow profile*

Government icebreakers of the Department of Transport are called upon to deal with heavy ice concentrations in the St. Lawrence River and Gulf and, in some cases, Lakes ice, in winter and spring. They are, therefore, not fitted with bow propellers but, as mentioned, operate astern where conditions demand.

WELDING

The application of welding technique to ship construction has made a significant difference to the construction and maintenance of icebreakers. Riveted hulls after each winter's operation required a minimum of 1,000 and a maximum of about 30,000 rivets, either renewed or welded. Internals and frame connexions were shaken loose, holes enlarged, and, in short, it was not possible to build a riveted hull which would stand up without continuous repair and replacement of parts. The long, cold winter in Canada for construction of a riveted ship required large covered-in building berths, whereas large sections are now welded inside the steel fabricating shops, outside assembly being timed for favourable weather or using an air space heater tenting the heater and the area of work.

The hulls of Department of Transport icebreakers are fully welded except for one riveted stringer bar at the strength deck. In view of the heavy shock imposed on the hull by icebreaking, there was considerable apprehension as to possible shell plate fracture, but in practice, although there has been some superstructure failure, the shell plating below the strength deck has shown no sign of weakness or failure. Great care, however, is exercised both as to material and labour qualification and rigid marking and testing is insisted on. In short, welding practice for icebreaker hulls constitutes pressure vessel practice except that they have no furnace large enough to anneal the completed shell.

The Department of Transport does not use alloy steel for hulls. The alloy steel requires special heat treatment and is more difficult to form and repair. There is little information available as to how rapidly it fatigues under icebreaking conditions. The specification for hull steel reads: —

> ". . . steel and plate for work of primary importance to have a chemical composition, by ladle analysis, in

accordance with the following requirements, to owner's special approval:

Thickness less than 1/2in.

Carbon percentage to be not more than 0·30

Thickness from 1/2in. to 1in.

Carbon,	maximum percentage, 0·23
Manganese,	percentage, 0·60 to 0·90
Phosphorus,	maximum percentage, 0·40
Sulphur,	maximum percentage, 0·05
Silicon,	percentage, 0·15 to 0·30

Note: Plate steels greater than 1-in. thickness are to be made to fine grain practice".

In addition to the foregoing, the specification details the size and material of welding rods and stresses the importance of keeping rods under a bone dry condition day and night and at even temperature. The operator is required to use a welding box for rod storage with a heated and silico-gel packed compartment. Pickling and other processes of plate cleaning are covered, also assembly and welding sequence, in order to provide maximum machine and downhand welding and a minimum of built-in stress. Welding is not permitted at a temperature of under 40 deg. F. nor under conditions of rain, sleet, strong wind, etc.

Particulars of the welding processes and preparation of plate edges, etc., have been described in the appendix.

If heat by fission becomes cheap and simplified, its application to the heating of river water could in some measure offset natural cooling but the cost and large quantities of heat required make it not yet available for such a proposal. The bubbler system is limited in application to relatively short distances and reasonable depth of water without excessive tide or current conditions. Icebreakers, therefore, seem to be the only practical answer for navigation in ice infested waters.

Although many proposals have been made to save underwater gear (such as shearing pins and slip couplings) by unloading, they are useless in practice as ice cannot be broken by gentle means. Great strength, therefore, is needed for icebreaking vessels. Reference to Table I will give the reader information regarding ice belt plate thickness, frame spacing, etc., used on some existing vessels.

One of the first steps in developing the design of a new icebreaker after fixing dimensions is to decide how strong the hull must be. Someone has said that determination of scantlings for steel ships is an arbitrary business based on successful practice, rather than derivation from first principles, and this can truly be said of icebreaker hulls and machinery. Operating experience of existing, and earlier, icebreakers is used and the displacement power and speed of the proposed new vessel compared with the existing vessels. The type of icebreaking service is also considered; small icebreakers for shoal water, a large breaker for Northern service, a lighter scantling vessel for the Great Lakes. From this and from consideration as to the strength of ice compression, a deflexion and strength check calculation is made by using an ice loading diagram on the hull, treating the longitudinals as a combined beam with a fixed end at each bulkhead and the deep webs and frames fixed at the strength deck and tank margin, the whole loaded at the centre and combined stress and deflexion calculated. From this the sizes of frames, webs and side strings are deduced and are finalized after comparison with existing vessels. The strength requirements are far in excess of Lloyd's Register of Shipping's classification requirements, even Class as revised in 1958. Lloyd's Register's new rules do, however, represent sound icebreaking progress and form a most useful contribution to the ever growing business of building icebreakers and ice reinforced ships.

For icebreakers proper they generally put in the closest possible frame spacing in order to reduce the span of unsupported plating to an absolute minimum. The plating itself is very thick, and the decisions as regards plate thickness and frame spacing are largely arrived at by judgement from previous experience. The frames, webs, stringers and internal bracing for a section are treated, as noted above, using assumed ice loadings and tempered by a "factor of experience". If the highest figures given for hard blue ice were always applied, the excessive strengthening could result in serious internal space problems.

Once the primary hull structure has been determined, it is necessary to give special consideration to the bow framing and to the stern framing. In general, the frame spacing is closed at the ends but sometimes it is not closed any further in large icebreakers due to the fact that the frame opening is already as close as practicable for the full strength of the vessel. However, extra strength is built into the hull at these parts by means of: (a) increased plate thickness which stiffens existing unsupported framed span; (b) closely spaced horizontal side stringers. At the extreme ends of the vessel, where these become extended breasthooks which form large flat shelves of solid material, the horizontal spacing is made as close as practicable and in some of their recent icebreakers this spacing is reduced to as little as 14in. (Fig. 16). The frames are also laid normal to shell curvature. The use of welding facilitates such eggbox construction. Experience shows that ordinary side keelson spacing in the bottom is insufficient to prevent the floors near the ends of the vessel from tripping due to the heavy impact forces imposed by icebreaking and it has become the custom to tie together the tops of floors (where there is no actual tank top) with tie girders placed across the floor tops. All this results in very rugged construction. Some typical stem details are shown in Fig. 17. Detailed construction varies but it is now the Department of Transport standard practice to use a round bar stem rather than a cast stem as this has proved to have utmost reliability, even cutting into a solid cement pier without deformation. The rabbeted connexion also provides a very solid continuous connexion for the shell plates and a sound welding set-up (Fig. 18). A rudder stock coupling guard is fitted but a full ice knife construction is not used as it is considered that a vessel going astern into the ice will have the ice weakened for hull contact by the action of the propellers in reduction of supporting pressure and later completely broken by contact with the propellers.

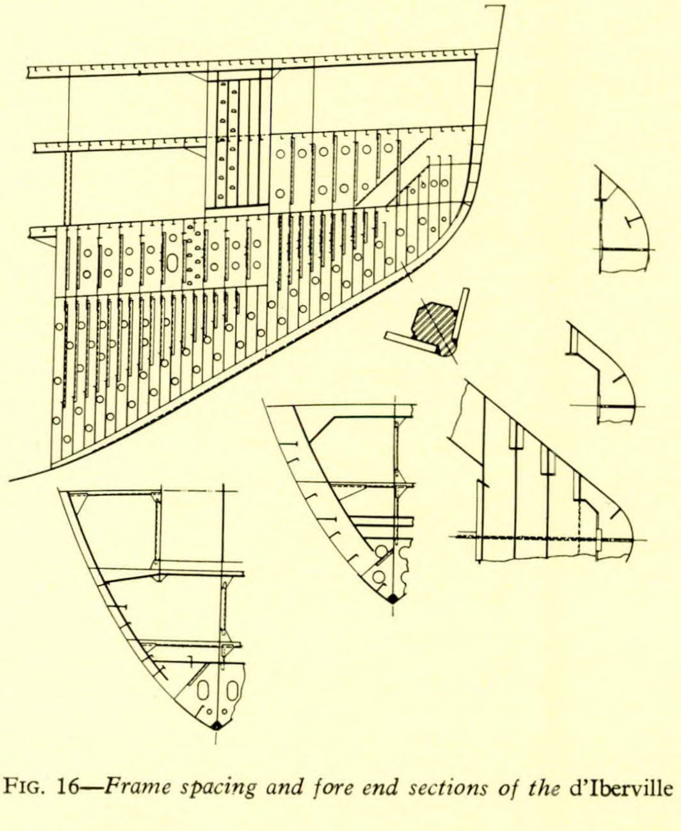


FIG. 16—*Frame spacing and fore end sections of the* d'Iberville

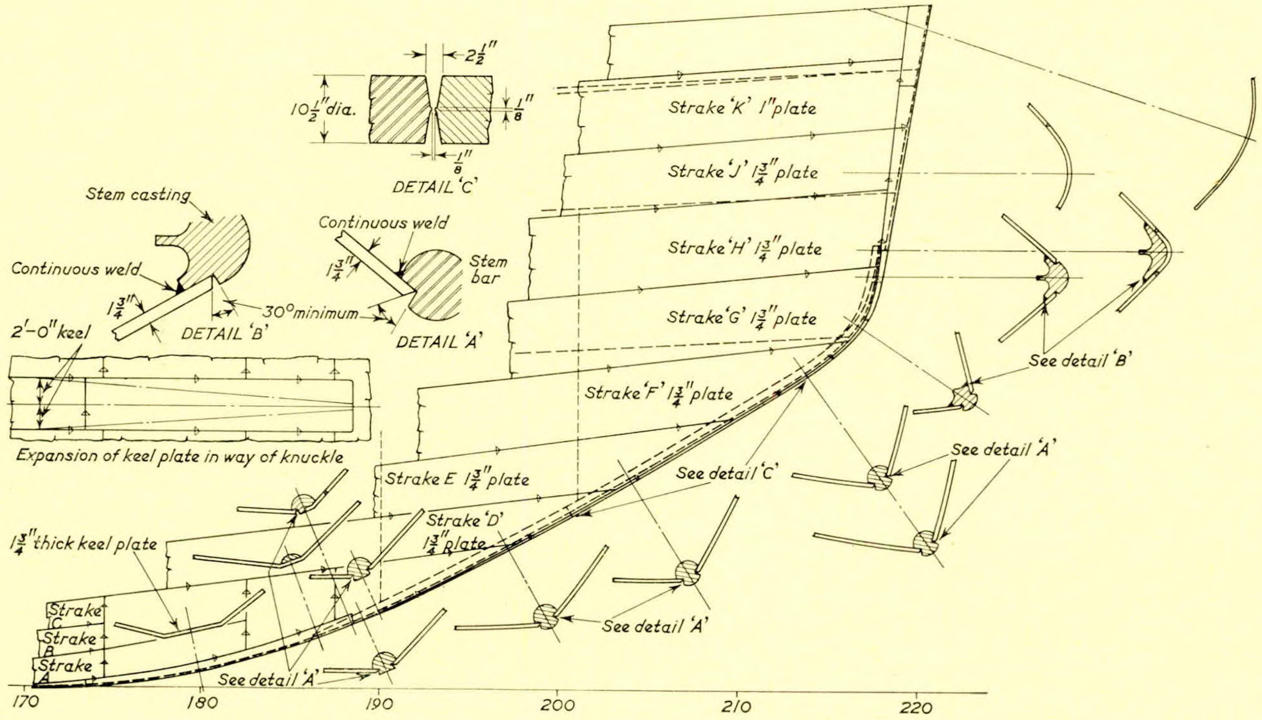


FIG. 17—*Stem bar and bow profile of the* d'Iberville

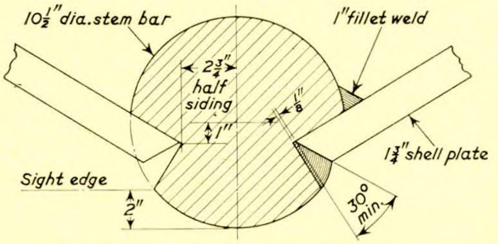


FIG. 18—*Section showing stem bar and plate connexion*

MACHINERY

The propulsive machinery for an icebreaker should have the following qualities and characteristics:—

(1) Power in relation to displacement should be, if possible, double.
(2) Twin or more screws; freedom from dangerous torsional criticals or barred ranges.
(3) Utmost reliability, including ability to absorb external resistance and shock.
(4) Ability to stand still under full throttle and to provide power by increments of revolutions and under control from zero to the maximum speed of revolutions; ability to carry large overload.
(5) Economical by weight measurement in fuel consumption.
(6) Rapid manœuvrability and maximum shaft horse power over a wide range of propeller speed.
(7) Ability to pack the maximum amount of power into a limited space.
(8) A control system which is simple and which can be used through all the speed ranges with a minimum of labour.

On steam propelled icebreakers the Department of Transport uses triple expansion, Christiansen-Meyer and Skinner engines with steam provided by watertube boilers of the B and W type, watertube boilers of the Foster Wheeler type with economizer and the reliable but heavy "Scotch" boilers with uptake superheaters and uptake air preheaters.

On large Diesel electric vessels the propulsion motors are fed power by banks of three generators in parallel. If it were possible to use generators comparable in power to the motor the relations between the generator supply and the motor use would be simpler. Power supply for the propulsion motor cannot be drawn from a large power bank and therefore the supply generators in a sense stand in the shadow of the propulsion motor. Motors in the smaller icebreakers are fed by single or banks of two generators in series. Diesel electric is actually the only type of power which has all the desirable machinery characteristics in some measure. Steam machinery in practice has a greater measure of the characteristics given in items 3, 4, 6, and 8; but the important qualities outlined in numbers 5 and 7 are essential in far ranging Arctic icebreakers dealing with heavy Arctic ice and cannot be attained at all by using steam machinery.

It is for this reason that all major icebreaking vessels are propelled by direct current electrical generators and motors. Variable voltage is used to control the speed of the propulsion motor from zero to maximum full field speed in either direction. This is accomplished very simply by exciting all of the generators which supply power to one motor from a common exciter, and varying the exciter voltage in magnitude and polarity by a small potentiometer rheostat in its field circuit. Control for manœuvring is carried out by reduction of engine speed to an idling condition and below that by excitation of generator field alone. Excitation and pneumatic control of the Diesel engine governor are simultaneous.

Because of the fact that if the forward motion of a vessel is retarded or brought to a stop by contact with heavy ice, the power required to drive the propeller at a given speed increases over that required when the vessel is running in open water, and the propulsion motor must have a wide constant horse power speed range in order to utilize fully the available prime mover horse power both in ice and open water. In an icebreaking vessel it is desirable to obtain maximum available output from the power plant with any number of prime movers in operation, from stalled to free-running condition.

To do this, all the prime movers must be kept running constantly at rated speed; therefore, to provide the necessary flexibility, the motor field must be capable of adjustment according to load conditions. It would be very difficult for an operator to follow rapid changes in a ship's operating conditions; therefore an automatic constant horse power regulator is used to adjust propeller speed.

The series loop circuit for connecting propulsion motors and generators has many desirable features. One of the most important is that it is possible to utilize the full rated horse power of all available engines regardless of the number of engines in operation. Another is that load division between the various engines is satisfactory, regardless of minor differences in engine speeds or generator voltages. With generators connected in series, a reduction in the number of engines in use brings with it a proportional reduction in voltage applied to the motor terminals and this results in a proportional reduction in motor speed. Since the power required to drive a propeller varies as the cube of the speed, it is desirable to weaken the motor field to such an extent that the motor will return to a speed which will utilize the full available engine horse power.

In contrast to the series case, for generators connected in parallel a reduction in the number of engines in use does not reduce the voltage applied to the motor terminals and the motor will attempt to maintain full speed. This will result, of course, in the overloading of the connected generators and engines. It is necessary therefore, to increase the motor field flux sufficiently to slow down the motor and thus match required propeller horse power with available engine horse power. Built-in propulsion generator droop of approximately 7 to 9 per cent combined with hydraulic governors is essential for satisfactory automatic paralleling.

An examination of the requirements of a multiple engine, d.c. Diesel electric ship drive will, in most cases, result in the selection of the series loop circuit. However, there are special cases where parallel connected generators will offer a sufficient number of advantages to dictate that this circuit be used.

Even with Diesel generators the consumption of fuel by weight for the steam powered ships is almost for all purposes twice that of the Diesel electric jobs. The Christenson Meyer steam machinery is most economical. This machinery can only be supplied in small powers due to the limitations imposed by the combined piston and valve of the l.p. engine. The large piston required and the steam passages and ports at the centre of the l.p. cylinder involve large complicated castings even for moderate powers.

Skinner engines having positive poppet valve cut-off make each cylinder in effect a separate engine. These engines are smooth running and provide excellent smooth power and low cost machinery maintenance. The diagram factor of this machinery as it is shut in improves as the cut-off under that condition is advanced and considerable expansion of the high pressure steam takes place in the long stroke of the one cylinder. This is contrary to the conventional steam reciprocating engine, and, while this feature provides reasonable economy as shut-in power, the fuel consumption under full out or overload conditions is extravagant. This engine will give 25 per cent overload without labour or distress of any description. The bunker capacity of the *d'Iberville* is close to 3,000 tons and the cargo capacity about 400 tons, so that even a 30 per cent saving in fuel weight will allow transport of considerable additional cargo. This is important as only the icebreakers can transport cargo (mostly fuel and aviation gas) to distant Arctic stations (Fig. 19). Such cargo can only be flown with difficulty, as the pay load on planes to distant points is relatively small in view of the large fuel margin which the plane requires to carry to ensure its safe return to alternate distant landing fields in the event of unfavourable weather and no landing at site. The Department of Transport is still building small icebreakers with B and W boilers and Skinner engines for use under conditions where extensive steaming radius is not important.

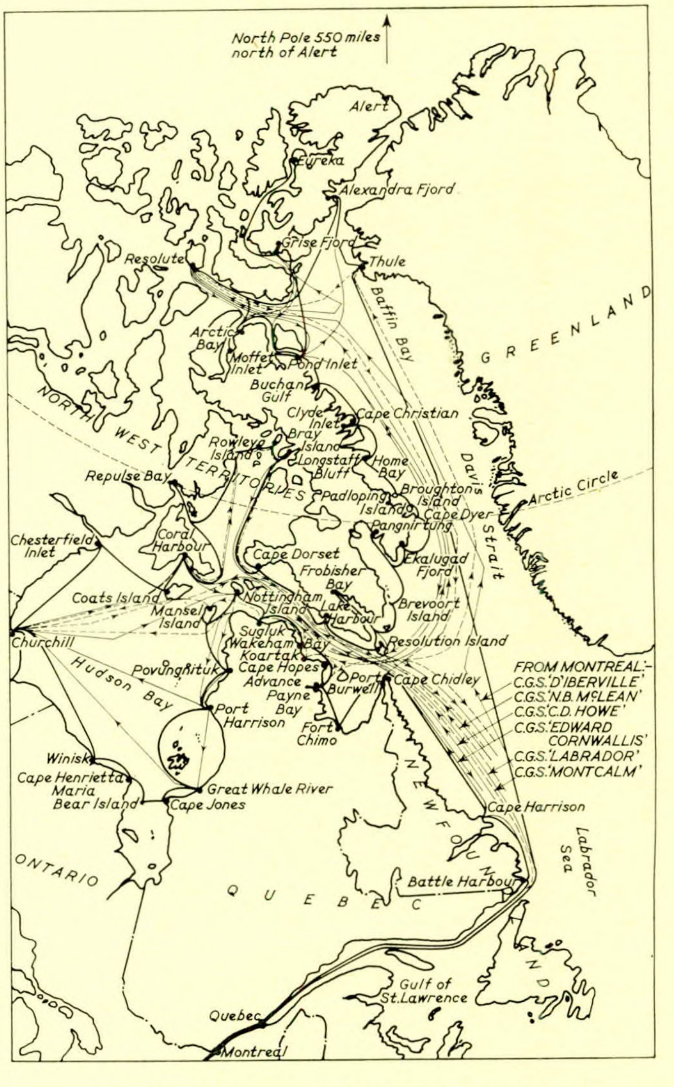
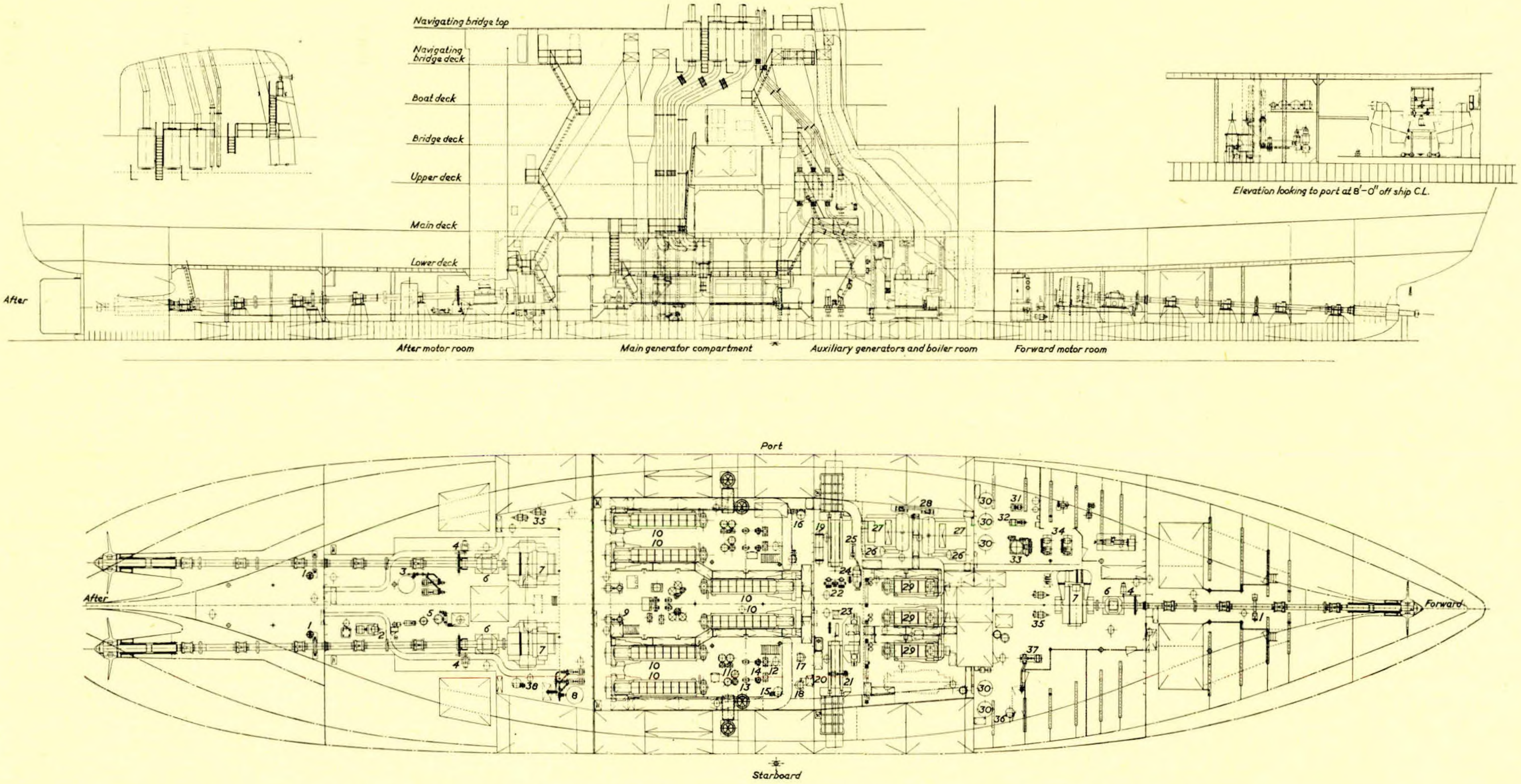


FIG. 19—*Ports of call in the Eastern Arctic*

The wished-for icebreaker condition of a steam engine without a boiler may, in effect, come with nuclear power. The Department of Transport has done some work on the design of such a unit.

To improve the resistance to shock condition (item 3) the Department of Transport endeavours to make shafts of propulsion motors as long as possible (Figs. 20, 21 and 22). External resistance imposed on the propeller absorbs through the shaft the energy of rotation of the motor armature and shafting and owing to the great inertia of the revolving masses the stress and consequent angle of shaft deflexion may exceed elastic limits. On the steam units the specification requires that the whole propulsion assembly with full throttle should fall from full revolution to standstill in one evolution. The steam reciprocating engine is in itself something of a spring due to the braking effect of the energy of translation in the reciprocating parts.

As regards item 6, in theory Diesel electric gives quicker manœuvring but, as the power in the final analysis comes from the reciprocating Diesel engine driving the generator, care must be exercised to ensure that the load applied to the accelerating engine (being fed fuel on a full governor) by excitation of the generator is at a rate which keeps the excitation curve lower than the engine accelerating curve or the engine will falter and die. Various methods of control time relays are used for this purpose so that the excitation does



FIGS. 20 and 21—*Engine room arrangement of Diesel electric icebreaking ferry* William Carson

1. Brake
2. Capstan motor generator set
3. Fresh water unit
4. Turning gear
5. Sewage ejector system
6. Thrust block
7. Propulsion motor
8. Sanitary water unit
9. F.O. transfer pump
10. Main engine and generator
11. L.O. strainers
12. L.O. priming pumps
13. L.O. coolers
14. F.W. coolers
15. Fire and bilge pump
16. Ballast pump
17. Standby F.W. circulating pump
18. Standby S.W. circulating pump
19. Preheater
20. Stabilizer
21. Sludge pump
22. Boiler feed pump
23. Stabilizer main power unit
24. Pressure fed filter
25. D.O. cold-start pump
26. F.D. fan
27. Main heating boiler
28. Main boilers pumping, heating and straining unit
29. Auxiliary Diesel generator
30. Main air reservoir
31. Air compressor
32. Watertight door machinery pump and motor
33. Evaporator unit
34. Main air compressors
35. Motor cooling and lubrication pumps
36. Fire pump
37. Sprinkler pump
38. Fire and general service pump

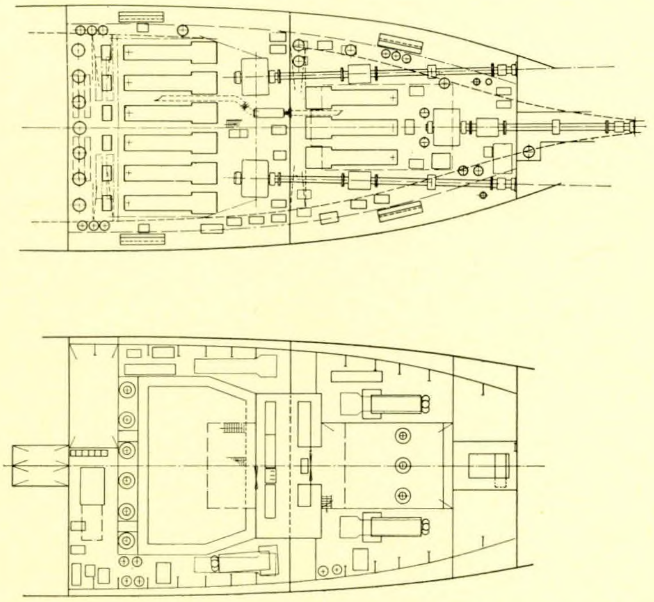


FIG. 22—*Diagrammatic engine room arrangement of triple screw icebreaker*

not follow the control stick if it moves over quickly. The steam jobs with pneumatic throttle control reverse in a flash (Fig. 23). One cannot even see the coupling bolt heads, the change in rotation takes place so quickly.

The Department has completed a direct drive through a Vulcan Sinclair coupling Diesel powered icebreaker, but operating results are not to hand.

It might be of interest to mention here the numerous sawing, chopping, melting and other proposals for icebreakers invented by persons who, generally speaking, have had little knowledge of ice conditions or the perplexing conditions under which icebreaking work has to be carried out. A German vessel with vertical plungers appears to have merit but none of the other proposals seem to have ever come to life.

For large powers triple screws aft are considered desirable although this has not so far been tried out in practice. The new Department of Transport icebreaker has three screws. It is considered that the centre propeller will in the main be under the Arctic ice and free from wake ice with a better propeller area application effect from three smaller propellers than two large ones. The unknown is the effect of ice thrown from one propeller to another (Fig. 24).

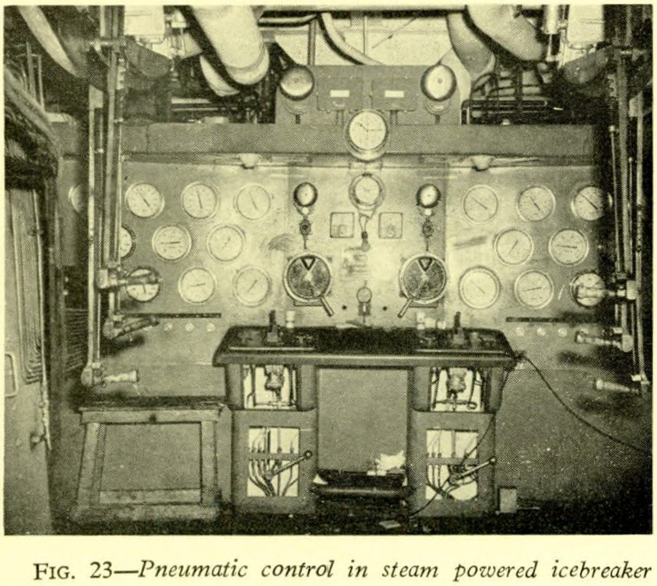


FIG. 23—*Pneumatic control in steam powered icebreaker*

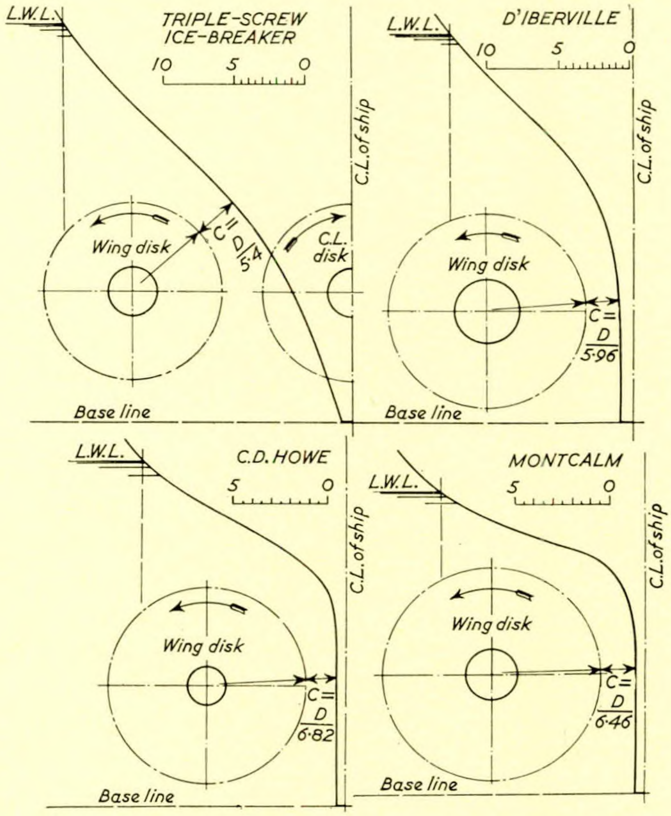


FIG. 24—*Propeller clearance diagram of a triple screw icebreaker, C.D. Howe, d'Iberville* and *Montcalm*

INSULATION

Icebreaker shells should be insulated inside in way of the machinery spaces, as otherwise there is a great loss of heat here.

Diesel generator engine spaces should be sound proofed. There is a great contrast in noise and vibration between the steam and Diesel powered icebreakers. On the *d'Iberville* the operation is so silent that one has to look over the side to see if the vessel is under way.

Economy of operation has not been touched in this paper. Icebreakers, although they pay dividends in improving the economy of the country, are not revenue producing vessels and achievement becomes more important than economy. If the much greater cost of Diesel fuel is allowed for, the steam icebreakers, however, are less costly. On the other hand, to avoid excessive smoke contamination of boiler uptakes, heating, pumping problems, etc., the Arctic icebreakers do not usually burn Bunker C as fuel, but a more expensive, compounded, and lighter, naval fuel.

A large item in the cost of operating any vessel is wages. The wages cost for icebreakers, due to the increased power rating, is much larger than on ships of the same size. Diesel electric ships require larger engine room crews than either the steam or the direct drive Diesel and the average rate is higher. Considerable progress has been made in this respect by eliminating cross-over requirements. The earlier icebreakers were generally constructed so that any generator could be put on to any shaft. The generators and shaft in line on the new designs are quite separate and this eliminates a great deal of cable, bus bar, and control equipment. It has been proved in practice that the cross-over arrangement is not justified. Electrical equipment manufacturers consider this to be a great forward step.

PROPELLER, SHAFTING GLANDS, ETC.

The assembly consists (Fig. 25) of: —

1) Tailshaft coupling bolts.
2) Tailshaft inboard bearing.
3) Gland consisting of flanged bronze follower with holding studs, ring, packing. Inboard bearing adjacent to lantern ring.
4) The stern tube.
5) The stern bearing, consisting of sleeve bearing material, neck ring and fasteners.
6) The tailshaft with liner, nut and stopper.
7) The propeller hub.
8) The propeller studs, nuts and stoppers.
9) The propeller blades.
10) The Fairing and tailshaft protecting cone.
11) The lubrication gun and connexions.
12) The connexion and piping for filling the tube with oil when laying up cold.

The foregoing twelve items constitute the tailshaft propeller and bearing assembly and as this part of the ship has proved to be the Achilles' heel of the icebreaker, Department of Transport design includes material and strength proved necessary by the acid test of performance. Any serious failure of the foregoing items may result in a ship powerless and beset under conditions where help cannot be provided. These units are therefore of the utmost importance. In a normal ship, failure generally at worst constitutes a towing job, but in the icebreaker it may well mean the loss of the ship by drifting with the ice on to shoals, or ashore, or being abandoned in the Arctic.

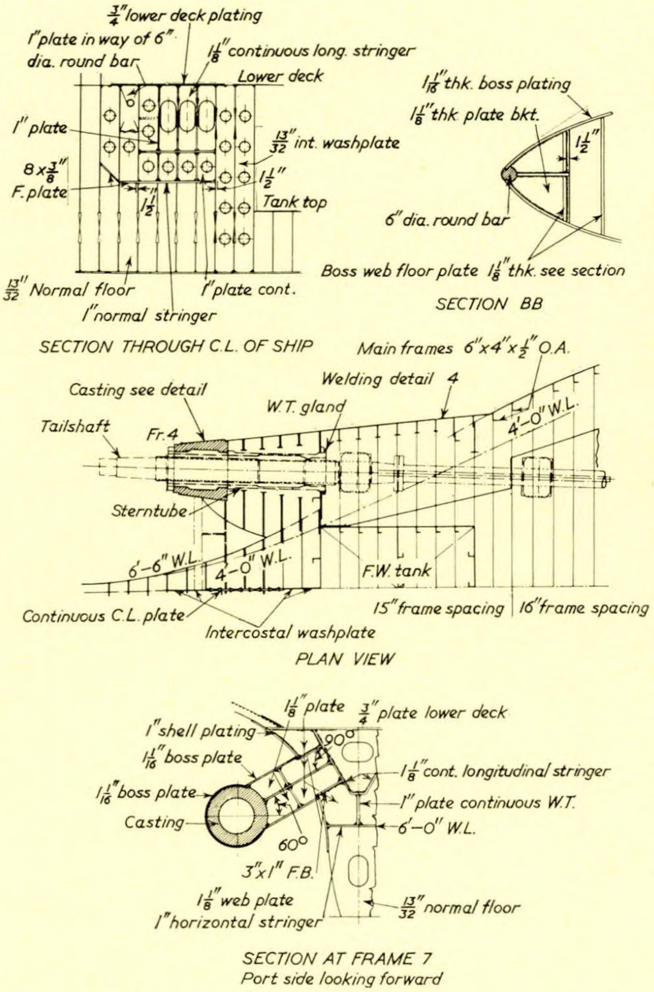


FIG. 25—*Tailshaft, stern tube, etc., and hull assembly in way*

1) *Tailshaft Coupling Bolts*

Bolts are of Lloyd's Register carbon steel. They are in proportion to the tailshaft. They should be fine threaded and parallel. Taper type bolts will not stay in position when icebreaking as the small end of the bolt seems to work clear and with this type it does not appear to be possible to work up sufficient friction between the flange faces when tightening up.

2) *Tailshaft Inboard Bearing*

This bearing is fitted to the tailshaft between the gland and the end coupling. It requires to be a full bearing, mounted on a solid bracket rooted to the frames and adjacent shell. This bearing is essential for successful icebreaking astern by propellers.

3) *Gland*

The box should be almost twice the depth of that used for ordinary propulsion and the packing should be at least 50 per cent heavier. The gland should be fitted with ring tightening gear of substantial design.

It should be in one piece and should have six heavy studs, two of them long for fitting extra packing afloat. This bearing should not be less than 1¾ times the shaft diameter. The idea is to have an assembly which constitutes a soft but solid bearing and packing that cannot be chewed or shaken out.

4) *Stern Tube*

The stern tube can either be a casting or a welded, rolled, heavy steel, fabricated tube with supporting rings. If a casting is used, the entire inside should be machined as this properly cleans out foundry sand or other foreign materials which tend to ruin the bearings. The casting should be a nickel steel alloy having enough nickel to give it some anti-corrosive value but not enough to make it too hard to machine. If the tube is fabricated it can be welded on to floor sections outside the whole, being centred for line shafting and welded into the ship structure (Fig. 26). This construction has worked out well in practice.

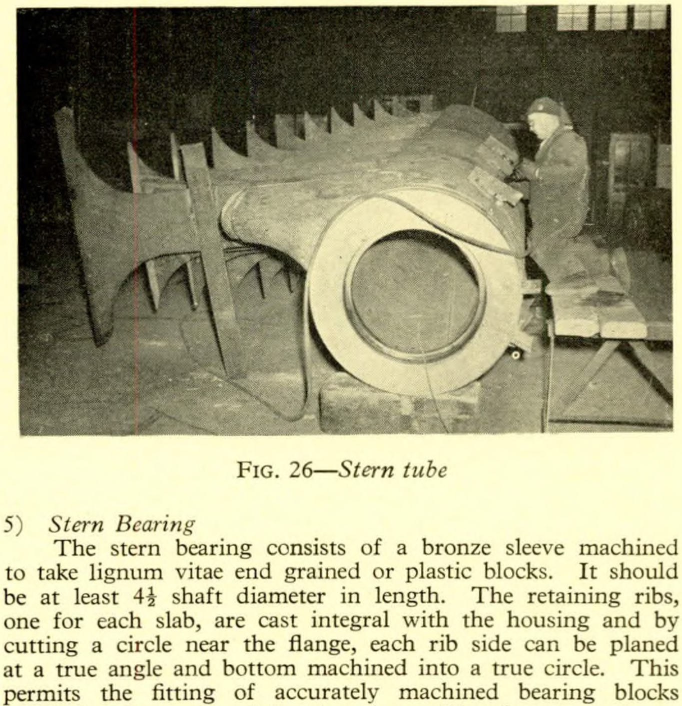


FIG. 26—*Stern tube*

5) *Stern Bearing*

The stern bearing consists of a bronze sleeve machined to take lignum vitae end grained or plastic blocks. It should be at least 4½ shaft diameter in length. The retaining ribs, one for each slab, are cast integral with the housing and by cutting a circle near the flange, each rib side can be planed at a true angle and bottom machined into a true circle. This permits the fitting of accurately machined bearing blocks positively fastened solidly in place. The housing of the bearing must be heavier than normal and must be well fastened with heavy tap bolts for both flange and neck ring with substantially wired stoppers.

TABLE II—COMPARATIVE PARTICULARS OF SHAFT SIZES FOR CANADIAN ICEBREAKERS

Name	Type of drive	Rating for shaft sizes		Tailshaft		Lineshaft		Maximum continuous torque stress (as fitted size)		Strength as fitted size as percentage of Lloyd's Register normal	
		H.P.	R.P.M.	Lloyd's Register normal, in.	As fitted, in.	Lloyd's Register normal, in.	As fitted, in.	Tailshaft lb./in.²	Lineshaft lb./in.²	Tailshaft, per cent	Lineshaft, per cent
d'Iberville	Uniflow steam	7,120	162	16¼	21	14 5/16	19	1,530	2,060	216	233
Montcalm	Uniform steam	2,500	156	12⅝	16½	11⅝	12⅞	1,145	2,400	223	136
Hull 169	Direct drive Diesel through fluid coupling	1,775	250	8 7/16	13	7½	10¼	1,040	2,115	365	255
Hull 614	Diesel electric	2,125	105	11 13/16	17	10 5/16	14	1,315	2,355	298	249
Hull 620	Diesel electric	5,000	136	14¼	22½	12⅝	19	930	1,545	393	343
Hull 257	Diesel electric	1,450	200	8⅜	12	7 5/16	10	1,340	2,320	295	252
William Carson (car ferry)	Diesel electric	5,000	136	14¼	18	12⅝	16½	1,820	2,360	202	223
Abegweit (car ferry)	Diesel electric	5,000	128	14⅝	17⅛	12⅞	16	2,500	3,060	162	192

TABLE III—PARTICULARS OF PROPELLER STUDS, ETC., FOR CANADIAN ICEBREAKERS

Vessel	Propeller diameter, ft.	in.	Propeller pitch, ft.	in.	Developed area, sq. ft.	Studs for normal service		Studs for icebreaking service		Increase, per cent	
						Number	Diameter, in.	Number	Diameter, in.	Diameter	Area
N. B. McLean	14	6	18	0	76·0	9	2	9	3½	75	244
d'Iberville	14	0	13	6	77·0	10	2⅝	10	4¾	81	253
Montcalm	11	6	11	3	53·0	8	2⅛	8	3½	65	200
Saurel	11	6	11	9	42·3	7	1⅝	7	3	85	268
Hull 614	11	6	12 11	9 to 8	54·0	8	1⅞	8	3½	87	270
Ernest Lapointe	10	0	10	9	35·0	7	1½	7	2½	67	210
William Carson	14	0	9 8	11 to 3	74·0	9	2⅝	9	4	53	164
Abegweit	13	0	13	6	70·0	8	2¼	8	4	78	286

Note: Percentage increase in area is taken at bottom of thread

6) *Tail Shaft*

The tail shaft is made of Lloyd's Register steel with solid connecting flange. The Department of Transport has not used alloy steel shafts for astern icebreaking as adequate strength can be obtained with carbon steel and they are not sure as to how fast alloy steels fatigue when stressed under low temperature conditions. The tailshaft liner should be 1/8in. thicker than required by Lloyd's Register's rules and, if too long for fitting in one piece, to avoid welding should be fitted in two pieces with a short section of shaft in the centre rubberized. The tailshaft nut has a slotted stopper and a positive pin stopper through the shaft end as well, to prevent the loss of the propeller in the event of a loose nut. (Table II).

7) *Propeller Hub*

All large Department of Transport icebreakers have built propellers. Icebreaker propellers sometimes encounter materials harder than ice, such as buoys or large stones which have been lifted. Even if the propeller will stand up to ice the angle of yield can be too small for harder substances and it is a simple matter to replace a broken blade. The hub is carbon cast steel.

8) *Propeller Studs and Nuts*

The holding studs are of nickel alloy steel, ASE 3120 or equal. They are without collars, fine threaded, tightly screwed into the hub all the way and bottomed to avoid wedging at the thread root. For the large twin screw icebreakers each blade is held in place by fourteen studs 4½in. in diameter, and others are in proportion (Table III).

The nuts are of alloy steel—carbon 0·118 per cent, steel 0·92 per cent, chrome 20·92 per cent, nickel 8·75 per cent, molybdenum 2·97 per cent. Each nut is cupped, collared and machined all over. Each nut is matched and marked for its own stud.

9) *The Propeller Blades*

It will be seen that the propeller blades are very heavy. This size has been found necessary to stand up under heavy icebreaking. Propellers are four-bladed. Three blades have been tried but the four-bladed unit has a better chopping effect as the ice wedges between the blades are smaller and impose less load on the blade itself. The blades are drilled for easy hanging and tallow holes for plugging the hollow flange and boss. Round one pitch holes only are drilled in the blade flanges. The propeller blades are designed for an icebreaking speed of about 140 to 150 revolutions as this appears to be the best compromise speed for the conflicting requirements of acceleration when charging and ice pump work when breaking astern (Table IV and Fig. 27).

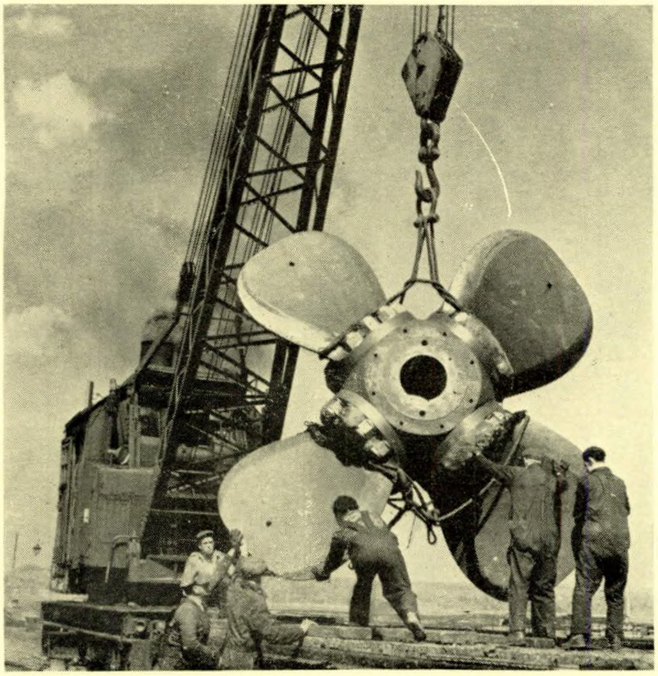


FIG. 27—*Icebreaker propeller blades*

In practice it has been found that the propeller shaft near the hub and the studs and blades are the weakest link. By working on the blade itself, then the studs, then the shaft and back again to stud stoppers, it is believed that a unit has been achieved which will stand up to a stopping of the power unit under any icebreaking condition without breakage and, if greater stress is applied, the intermediate shafting should distort. The important units to preserve are the engine crankshaft or propulsion motor shaft, the tailshaft, the propeller and its stud and nut assembly.

Specification for Propeller Blade Material

"Blades to be good quality 'alloy cast steel'.
Nickel content to be not under 1·5 per cent
Approximate carbon content 0·18 per cent
Vanadium 0·10 per cent to 0·12 per cent

"Tensile and bend tests to be witnessed and made by the Director of Ship Construction or his representative. Tensile tests will require to prove an ultimate tensile of not under 75,000lb. per sq. in. associated with an elongation on two inches of not under 25 per cent. The standard test bar to prove 160 degrees without fracture. Record of tests to be stamped on the machined face.

"Raw castings to be *double annealed;* to be machined as per drawings and templates. Blades to be X-rayed at the discretion of D.O.T. representative, and will be rejected if found porous or otherwise defective. For identification purposes a hole ¾-in. diameter is to be drilled in the trailing edge near the tip approximately one inch from the edge". This alloy has been used for fifteen years and during that period no blade has been broken.

In order to maintain ductility, blades should be annealed at five-year service intervals.

10) *Fairing Cone* (cone going astern)

The fairing cone is cast or steel fabricated and heavy enough to stand going astern into ice. The flange particularly must be heavy, together with the fastening studs, which must be of steel. Retention of the cone is important when breaking ice astern.

11) *Hub Gun*

A large grease gun is fitted to each stern bearing for lignum vitae bearings, as these bearings will run without water on grease alone. Plastic seems to wear better than wood but it requires a great deal of water. The seals of sealed bearings have failed in heavy icebreaking.

12) Connexions for pumping oil into the tube for lay-up in cold weather consist of extra heavy bronze piping with flanged shut-off valves at bulkhead and tube.

GENERAL

Part of the foregoing complies with good commercial shipbuilding practice, but perhaps the following explanatory remarks based on experience will be useful.

1) Parallel coupling bolts, if they are not driven too tight, are easily fitted and provide the ultimate in flange face friction. It is not essential to have bolts driven fit full length if they are well hardened.

2) This bearing is essential if the shaft gland and packing is to remain intact in heavy icebreaking.

3) With smaller glands packing has been completely chewed up and spewed through the gland after a few months' icebreaking.

TABLE IV—PARTICULARS, S.H.P., ETC., AND COMPARISON OF PROPELLER DIMENSIONS

Vessel	Type of propulsion	Maximum h.p. per shaft	R.P.M.	Propeller diameter ft. in.	Thickness of blade at root for normal service, in.	Increase in root thickness for icebreaking, in.	Increase, per cent
N. B. McLean	Triple expansion	3,550	150	14 6	6¼	8½	36
d'Iberville	Skinner unaflow	7,120	156	14 0	5½	8¾	68
Montcalm	Skinner unaflow	2,500	156	11 6	5¼	7⅛	35·9
Saurel	Triple expansion	1,775	150	11 6	5¼	6½	23·8
Hull 614	Electric	2,125	145	11 6	5¼	7¼	38
Ernest Lapointe	Steam	1,230	144	10 0	4¼	5¾	35·2
William Carson	Electric	5,000	136	14 0	5½	7⅜	34
Abegweit	Electric	5,000	128	13 0	6	8	33·3

TABLE V—RUDDER STOCK SIZES

Name	Type	Lloyd's Register normal, in.	Lloyd's Register Class I Ice, in.	As fitted, in.	Strength as fitted as percentage of	
					Lloyd's Register normal	Lloyd's Register Class I Ice
d'Iberville	Icebreaker	13·89	17·36	21·00	348	178
Hull 620	Icebreaker	14·125	17·66	21·00	330	170
Montcalm	Icebreaker	9·23	11·54	12·00	220	112
Hull 614	Icebreaker	9·325	11·65	11·875	206	106
Hull 165	Icebreaker	9·45	11·81	12·00	205	105
Abegweit	Car ferry	14·00	17·50	17·25	187	96
William Carson	Car ferry	11·94	14·92	18·00	342	176
Edward Cornwallis	Buoy and supply	10·00	12·50	10·75	124	64
Walter E. Foster	Buoy and supply	9·00	11·25	11·00	182	94
Hull 22	Buoy and supply	10·25	12·81	13·25	216	111

4 and 5) The bearing surface requires to be longer than required by Lloyd's Register's rule. In heavy icebreaking the bearing takes heavy punishment and excessive bearing clearances are worn in a short period of service unless surfaces are ample.

6) The Department has not broken a tailshaft with the dimensions now used. Earlier broken shafts were expected in bad ice years. Shafts are still being broken by other than Department of Transport icebreakers doing heavy work.

7) Steel flanged nuts are used in spot faced, round holes. It was found that bronze nuts with ordinary stoppers were not satisfactory. The icebreaking effort caused biting and consequent clearance between the bronze nut and area of landing around the slotted hole. This permitted the stud and nut assembly to become loose and the constant hammering unscrewed the stud assembly. Ships have been docked to find the propeller hanging on by one loose stud, the others having unscrewed and departed. After hardening, a perforated ½-in. plate is meshed to fit over the nuts and tack welded thereto. This stopper system has proved reliable.

REFRIGERATION

Considerable quantities of refrigerated cargo requires to be carried on icebreakers for far northern stations requiring cooler chambers for fruits, vegetables, etc., as well as frozen meat. These chambers are arranged with automatic controls and separately arranged air cooled compressors. Ships have also domestic compartments with smaller, daily use units for either a.c. or d.c. Large, portable boxes, which can be stowed in 'tween decks or on deck and cut in to take ship's power, are used for additional capacity.

PASSENGER ACCOMMODATION

Accommodation for both Eskimos and other passengers must be provided as well as accommodation for doctors, dentists, Post Office, Royal Canadian Mounted Police, Northern Affairs and other branches of the Canadian Government. A large public room is also required for movies and general entertainment.

STABILIZERS

Large icebreakers, generally speaking, roll heavily, due mainly to large metacentric height, weight and shape of underwater body. The smaller ships can be made quite seakindly by arranging the bunker fuel capacity in deep storage tanks which can be used as needed to raise centre of gravity and improve radius of gyration. Some of the larger vessels have been fitted with stabilizers but these cannot be operated in ice infested waters although they are effective in open water. Stubby bilge keels have reduced the roll by from 15 per cent to 20 per cent.

MEDICAL AND SCIENTIFIC EQUIPMENT

Large icebreakers for the Arctic require a hospital fitted up with complete medical and dental equipment, including X-rays for carrying out medical services to the Eskimos and other residents of the north in places away from established centres. Stowage for a full stock of drugs and medicine is also provided for.

Scientific equipment for various purposes as required by the various Departments of the Canadian Government, including Oceanographic, Meteorological, Hydrographic, Ionospheric, Wild Life and Flora and Fauna studies, Photography, etc., requires to have adequate space provided for installation.

CRANES AND GENERAL LIFTING EQUIPMENT

An important functional item of icebreaker design is to provide adequate lifting gear in properly located positions. All ships use lifting gear but in an icebreaker it must be designed for shock, etc. The obvious uses for such gear are:—

1) The handling of heavy lifts consisting of building contractors' machinery which cannot be broken down below, in some cases, 20 tons.

FIG. 28—*Typical flexible type landing unit operation*

2) The handling of landing craft fully equipped for ship to shore transport. (Note: there are no wharves at the fifty odd points which require to be served in the Eastern Arctic except for one wharf at Churchill). (Fig. 28).

3) Providing rapid and accurate handling from ship to water of helicopters, cargo in the form of small tugs, oil fuel tanks for installation ashore and for rescue and salvage work, etc.

Items 1 and 2 require lifting gear of the derrick type having a five-drum winch which gives control for lifting, topping, slewing and a quick lift. This unit requires a capacity of not less than 35 tons and is slow in operation. It is generally fitted at the aft end of the forward well, the well being designed free from obstruction in order to handle heavy cargo. The topping lift is fastened to an extended A-frame built into the forward end of the superstructure. This arrangement is simple, stands shock well, has great flexibility and has proved very satisfactory in service.

Item 3 has been satisfactorily taken care of by fitting two revolving cranes of 15-ton capacity at the aft end of the vessel. These cranes are most useful under conditions where it may be necessary to lower gangways on to the ice or lift equipment from the ice.

CROW'S NEST

An important item in design is the crow's nest. It should be high, commodious and warm. The Department of Transport does not plan to use the crow's nest for control of propulsion machinery purposes; although this has been done in icebreakers they do not consider it to be desirable.

TOWING

Towing notches are not now fitted on Department of Transport icebreakers, as in practice, due mainly to the difference in height between the icebreakers aft deck and the bow of the commercial ship, the connecting hawser or hawsers is high for satisfactory binding, and this, associated with difficult ice conditions, throws the tow's stem out of the notch. They have also abandoned the practice of using regular towing winches. These are suitable for long distance tows in open water but they find that a more rigid contact, through fairleads and extra large towing bits with line handling capstans, give a more flexible and positive arrangement for short distance

FIG. 29—*Landing bulk fuel at Eureka*

towing under difficult conditions. Some of the smaller icebreakers are fitted with a towing eye through the stem. This gives a more level towing connexion and is very useful for steering a towed ship under difficult ice and other conditions. Nylon tow lines are generally used now.

BULK FUEL

Built-in tanks should be fitted in the icebreaker for:—

1) Taking fresh water from shore either by direct connexion or by boat.
2) For transporting fuel oil for heating.
3) For transporting a supply of fresh water for ship, or, in some cases, shore stations.
4) For transporting aviation gas in bulk (Fig. 29).

Items 1, 2 and 3 are, outside of arranging suitable easily portable pump capacity hoses and boats, not difficult. Item 4 requires a tank where the bulk gas is completely surrounded by water and water displaces the gasolene under pressure. This is a satisfactory arrangement but the large amount of deadweight involved in the water robs the vessel of cargo carrying capacity.

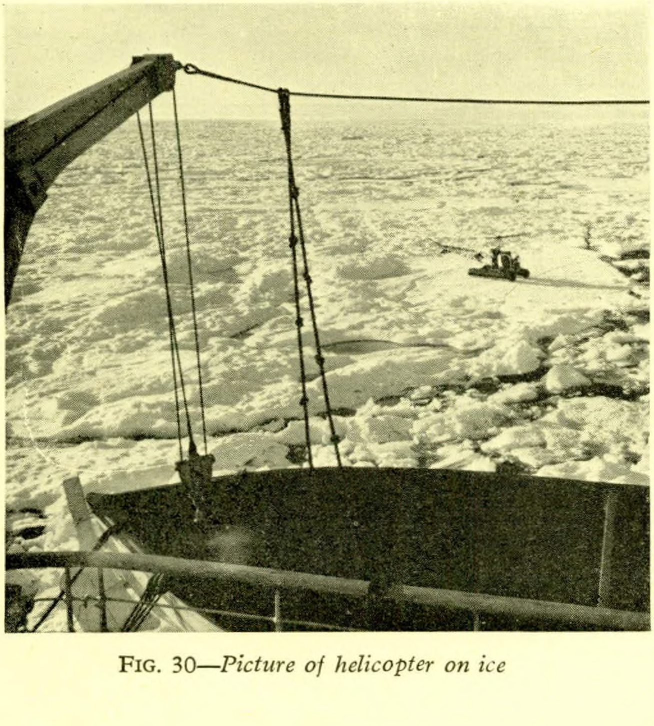


FIG. 30—*Picture of helicopter on ice*

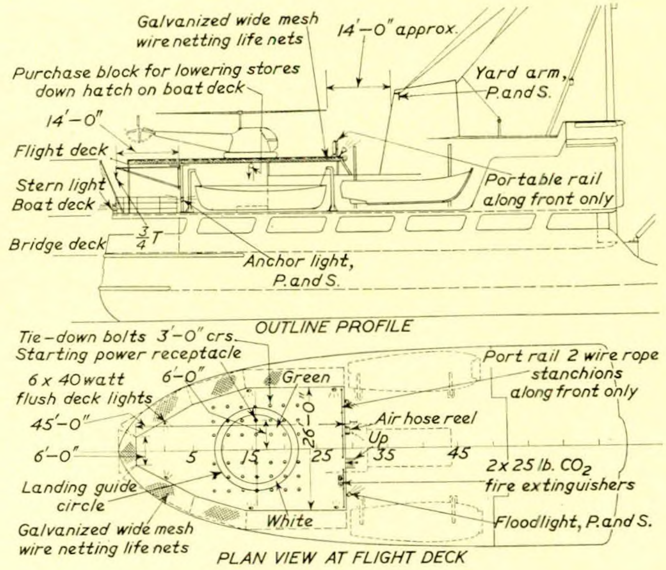


FIG. 31—*Plan and profile of the helicopter platforms*

HELICOPTERS

Helicopters have proved most useful for reconnaissance in seaching for leads and open water and also for carrying out limited cargo and personnel ship to shore assignments. The larger icebreakers carry two helicopters which should be completely housed in a permanent hangar on the deck aft. Protection for the fabric on the propeller is necessary, particularly with steam powered ships, to prevent damage from funnel gases. When hangars are not provided, temporary aluminium shelters are rigged and provision must be made for adequate fastenings and lashings for use in stormy weather. A repair section where minor repairs can be made and an adequate spare parts store room are necessary. Plastic pumping equipment is used to fuel the helicopters on a closed circuit basis from drums stowed on deck. Guard net around the quarter flush attachment clips, portable air compressor, moving dolly, special fire fighting equipment, battery charging, etc., all require to be provided for, both in supply and stowage space on board. Sometimes a trunked hatch must go through the platform, which complicates matters further. The largest helicopters used carry three men and have a hook for rescue work. To accommodate these and to provide a platform having adequate rotor clearance, it is sometimes essential to transfer the work boats to the forward well deck where they in turn reduce deck space available for heavy cargo, etc. Much compromise is required to make the best use of available space (Table VI and Fig. 30).

HEELING TANKS

The Department of Transport uses fore and aft trimming tanks and has observed the operation of heeling tanks. It is not considered that the space and equipment required for heeling is justified and the Department has never provided for such equipment.

FERRIES

Ferries in many instances have to operate in ice and under such conditions they have built in many of the characteristics of icebreakers. Their size, generally speaking, precludes a reasonable icebreaker displacement to power factor and full icebreaker blades are too inefficient for satisfactory out-of-ice season ferry operation. Full icebreaker support should be available for an ice strengthened ferry under very heavy ice conditions. This will permit a ferry design with propeller blades having reasonable efficiency. Full icebreaking blades are very inefficient, having in some cases a 25 per cent

TABLE VI—PARTICULARS OF HELICOPTER PLATFORMS

Vessel	Type	Dimensions			Area of operation	Number of helicopters	Size of platform			Hangar space
		Length B.P.	Breadth	Depth			Length	Width at bullseye, ft.	Area, sq. ft.	sq. ft.
		ft. in.	ft. in.	ft. in.			ft. in.			
C. D. Howe	Supply vessel	276 0	50 0	26 0	Eastern Arctic, including Hudson Bay and Strait, Baffin Island, Lancaster Sound, Resolute Island and Labrador Coast, also Gulf and Straits of Belle Isle	One Bell 47J	34 0	33	918	Portable platform, 363
d'Iberville	Icebreaker	302 0	66 6	40 0	Eastern Arctic, including Hudson Bay and Strait, Baffin Island, Lancaster Sound, Resolute Island, Norwegian Bay, Eureka, Labrador Coast, also Gulf and Straits of Belle Isle	Two Bell 47J	76 0	36	3,268	Hangar, 672
Montcalm	Icebreaker	208 2	48 1	18 1	Hudson Bay and Strait, Labrador Coast, Foxe Basin, Belle Isle Straits, Gulf of St. Lawrence and St. Lawrence River	One Bell 47J	51 6	25	1,287	None
Labrador	Icebreaker	250 0	63 6	37 9½	Eastern Arctic, Hudson Bay and Strait, Baffin Island, Lancaster Sound, Resolute Island, Norwegian Bay, Eureka, Labrador Coast, Smith Sound, Kane Basin, Kennedy Channel, Northern Ellsmere Island, Gulf of St. Lawrence, St. Lawrence River, Gulf and Straits of Belle Isle	(Formerly three)	72 0	42	3,025	Hangar, 448
Triple-screw icebreaker	Icebreaker	290 0	70 0	41 0	Eastern Arctic, including Hudson Bay and Strait, Baffin Island, Lancaster Sound, Resolute Island, Norwegian Bay, Eureka, Labrador Coast, Smith Sound, Kane Basin, Kennedy Channel, Northern Ellsmere Island, Gulf of St. Lawrence and St. Lawrence River, Gulf and Straits of Belle Isle	Three Bell 47Js or one 47J and one Sikorsky	64 0	39	2,340	Hangar, 1,478
Icebreaker for Maritimes and northern waters	Icebreaker	223 6	48 0	21 0	Hudson Bay and Strait, Labrador Coast, Foxe Basin and Gulf of St. Lawrence	One 47J	56 0	30	1,680	None
Icebreaker for Western Arctic	Icebreaker	204 4	48 0	21 0	From Cape Caution, north end of Vancouver Island to the head of the Portland Canal, including Queen Charlotte Islands, along the coast of Alaska, through the Bering Straits, through the Beaufort Sea, along the shores of Alaska, Yukon and North West Territories as far east as Spence Bay	One Bell 47J	56 0	30	1,680	None
Icebreaker buoy and service breaker for Maritimes		249 4	45 0	21 6	The coast of Nova Scotia from Yarmouth to Cape North and the southern and eastern coast of Newfoundland	One Bell 47J	57 0	35	1,995	None
Alexander Henry	Icebreaker and buoy vessel	190 0	43 6	21 0	The ports on Georgian Bay, Canadian ports on Lake Huron and Lake Superior	One Bell 47J	45 0	26	919	None
Hull 272	Icebreaker	208 2	48 1	18 1	The coast of Newfoundland, Cabot Straits, Cape Breton	One Bell 47J	58 0	41	2,320	None
Icebreaker search and rescue, west coast	Icebreaker	184 3	42 0	18 0	From Victoria through the inland passage north to Cape Caution and the west side of Vancouver Island	One Bell 47J	49 0	32	1,470	None
Icebreaker search and rescue, east coast	Icebreaker	184 3	42 0	18 0	Northumberland Straits and ports, Pictou, St. George's Bay, Canso, Magdalen Islands, western shore of Cape Breton, Port aux Basques	One Bell 47J	49 0	32	1,470	None
Reinforced buoy vessel	Buoy vessel	164 9	42 0	18 0	Saint John, Bay of Fundy south to American Border and Canadian Mainland and South to Yarmouth	One Bell 47J	48 0	32	1,536	None

loss when compared with efficient blades for open water propulsion.

ACKNOWLEDGEMENTS

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Messrs. Milne, Gilmore and German, Naval Architects, Montreal, P.Q., Davie Shipbuilding, Limited, Lauzon, Levis, P.Q., Marine Industries, Limited, Sorel, P.Q., Mr. James Wasmund, Western Electric Company, East Pittsburgh, Pa.

APPENDIX

ICEBREAKER WELDING

General

All welding is carried out to the classification rules and the Canadian Welding Bureau regulations. The welding procedure and the operators are qualified for manual metallic arc and submerged arc welding. All welders working on shell must be certified.

Scope

In the construction of a ship, welding is employed from the time the first two plates or shapes are joined together to the time when the ship sails away for the service for which it has been designed and built. It is evident therefore that welding in such a construction is employed for the joining of a large number of different shapes and forms. These shapes and forms may consist of the vessel shell, the structural sections such as frames welded to the shell, the decks, the superstructure, the innumerable angles, beams, ties, etc., which go into the finished ship. The welding of structurals to shell plating, decks and other flat surfaces, consists mainly of fillet welding, which unless properly controlled will show lack of penetration, undercutting, slag and other defects, but it is through long practice and rigid control an easier type of weld to make soundly than butt welding. As butt welding has a greater amount of metal deposited in the joint than in fillet welding, it is more susceptible to defects and requires good control along with the use of the proper electrodes, and procedures of equal importance, for butt welding is the geometry of section where the weld metal is deposited and the sequence in which it is deposited. As the difficulty of butt welding increases with an increase in thickness of the plates being welded, there is no better example of this type of welding than the shell of an icebreaker, where of necessity the shell plates are thicker than is normally found on other types of ships. It is for this type of vessel that the description of welding procedure is intended.

Edge Preparation

Before any two plates are welded together, the welding edges must be prepared. Preparation of the plate edge consists in cutting the edge to give a square edge, an edge with a single bevel or an edge with a double bevel.

The cutting operation to form the plates to size and to prepare the plate edge either square, single or double bevel is done by hand controlled, mechanically controlled or electronic equipment.

The hand equipment consists of small portable machines which are either operated free or on a track for straight line cuts. The freely operated machine cuts square edges, the track mounted machine is fitted with more than one torch and can cut bevel edges. Both types are driven by variable speed motors.

Mechanically controlled burning is used for the edge preparation of parallel edge plates. The equipment consists of parallel tracks which may vary in spread. An electrically driven bridge travels on these tracks, the bridge carrying burning machines which can be adjusted to suit the width of plate as required. These burning machines can carry several torches and cut square, single, or double bevel edges and also trim the ends of the plate square.

The electronically controlled machine is of the pantograph type and has a head with an electronic eye which follows a heavy black line on a white template giving the form of cut required. The pantograph arm can carry one to four burning heads and this can cut out one or more pieces from the steel plate on the table. The pantograph machine cuts only square edges.

For the largest size of plates, the edge preparation is done on the burning tables. A gantry supporting a large number of torches runs the length of the table and two directly opposite edges of the same plate can be prepared.

Joint Selection

The method used for welding and the conditions under which the welding will be carried out is of prime importance in selecting the type of joint to be used. In the first stages of construction large prefabricated sections as heavy as 50 tons are welded in the shops, where full advantage can be taken of automatic welding machines. With large capacity lifting facilities available in the shops, advantage is taken of the fast rate of deposit and high current characteristics of automatic welding machines by first welding on the topside of the plate sections and then turning the whole plate assembly over and carrying out a similar operation on the bottom side. For this reason both edges of a joint generally have a double-V preparation, as with the machines all welding is done in the flat position. For manual welding at the ship when the prefabricated sections are being welded together, the edge preparation is made to suit downhand welding and sometimes consists of a double bevel plate welded to a square edged plate but generally consists of two double bevel or V plates, for longitudinal seams, and two double bevelled plates for transverse butts. The type of joint between two plates is referred to as "Joint Geometry".

Joint Geometry

a) For machine welds in the shop the shape of the joint is

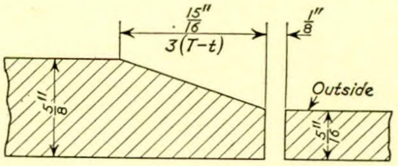

FIG. 32—*Plates less than ⅝in.*

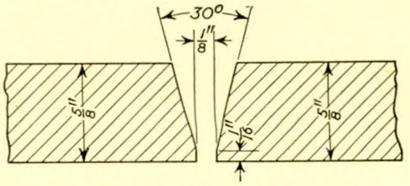

FIG. 33—*Plates ⅝in.*

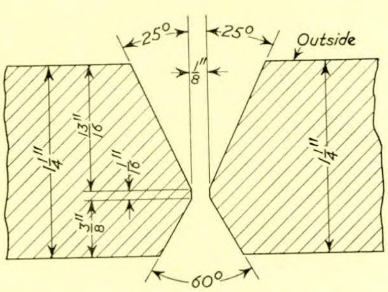

FIG. 34—*Typical plate of ¾in. and over*

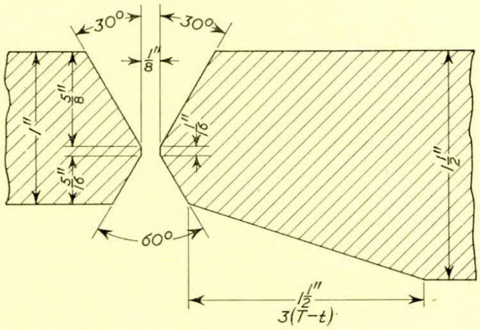

FIG. 35—*Typical for different plate thickness*

as shown in Figs. 32 to 35 for typical plate thicknesses. The plate thicknesses shown cover the average encountered and do not provide a comprehensive coverage of all thicknesses.

It will be noted from Figs. 32 to 35 inclusive that for plates less than 5/8-in. thick the joint geometry is square; for 5/8-in. thick plates a single bevel on each plate is used; for plates greater than 5/8-in. thick double-V groove is used on each plate. Generally, the gap between two plates is 1/8in. while the land zone on single and double-V joints is 1/16in.

The ratio of groove depth between the outside and inside grooves is approximately 3 : 1, sometimes varying to 4 : 1, for double-V grooves. Where two joining plates have a difference of plate thickness greater than 1/8in. the thicker plate is tapered back from the edge a distance equal to three times the difference in the two thicknesses. This applies regardless of the type of joint. The included angle on the outside varies 50 degrees and 60 degrees. The included angle on the inside varies between 60 degrees and 70 degrees.

Plates less than 5/8-in. thick have a square joint preparation, as deep penetration is readily obtained for these thicknesses with the high current capacities of the automatic welding machines. This is not true for joints prepared for hand welding.

b) For hand welding, square edge joints are not used in any thickness. For plates up to 5/8-in. thick a single bevel joint as shown in Fig. 33 is used. Joints for all other plate thickness are double bevelled, as shown in Figs. 34 and 35. As hand welding is used mostly for seams and butts when assembling the prefabricated sections at the ship, the outside in one instance may be the inside in another so that for double bevelled joints the outside joint groove is not necessarily deeper. The exact opposite may be true but the general proportions of depth remain the same. As downhand welding is used as much as possible, the side with the deeper groove is preferably the side which is more accessible and lends itself easily to downhand welding. It is preferable to use out of position welding on the side which requires the least number of passes.

Welding Operation

a) *Automatic Welding*

All automatic welding is carried out in the shops, in the flat position. For plates less than 5/8-in. thick, with square edge preparation, two plates or more are laid down on the floor and 1/8-in. spacers are placed between the edges to give the "root" gap. The spacers are removed and a high current pass is made, with the automatic machines using No. 36 wire and No. 20 flux. The plate assembly is then turned over and impurities, if any, are chipped out, and a pass with the same procedure as previously applied is laid in the groove.

For plates 5/8-in. thick with a single-V, as in Fig. 33, one plate edge is laid over a backing strip and light tack welds are applied at the juncture of the shoulder and the backing strip. The excess amount of tack weld is chipped out, leaving a right angle as shown in Figs. 36 and 37.

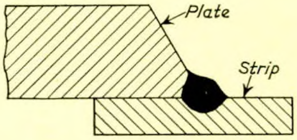

FIG. 36—*Tacking strip to plate*

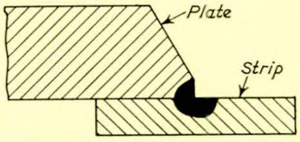

FIG. 37—*After chipping tack square*

The second plate is then laid on the strip and 1/8-in. spacers are used to get a uniform gap. The spacers are removed and automatic welding with wire No. 36 and Flux No. 2 is carried out to fill the groove. The plates are turned over, the backing strip is removed and the root pass is chipped out. Automatic welding is again applied to close the gap. For plates thicker than 5/8-in., a different procedure applies. The plates are laid out on the floor with the outside up and spaced at the joints with 1/8-in. spacers. The spacers are removed and two to three hand passes of E-6020 or E-6027 electrodes are laid in. Either of these electrodes gives a good wash up. E-6020 gives good penetration and little porosity. E-6027 is an iron powder electrode, gives a flat to slightly concave profile, has a fast rate of deposit and like E-6020 has good radiographic qualities. When either of these electrodes are used, little porosity, blowholes, etc., are encountered on any automatic welding laid over them. After the hand passes, automatic welding is laid into the groove to fill the gap. The plates are turned over and the root pass is chipped out. Automatic welding is again applied to fill in the gap. In some instances, especially for the thicker plates where the gap is wide, a dual wire welding machine is used. This differs from the usual type in that two wires are fed simultaneously. The wires may be placed in parallel, in which instance a wide deposit is laid or in tandem for narrower gaps, in which instance the deposit is very fast but still possesses some spreading quality due to the magnetic fields. Welding current is very high and the rate of deposit is very fast.

b) *Manual Welding*

Manual welding is used for joining the prefabricated sections at the ship. The joints are as shown in Figs. 34 and 35, which are double-V. The first pass laid into the root is with an E-6010 electrode, which has a deep penetration. This type of electrode is used on d.c. with reversed polarity only and because of this and its coating constituents causes considerable liberation of heat in the base metal. Porosity is negligible and ductility of the weld is high. Because the slag is fast freezing it is ideal for vertical and overhead welding. Subsequent passes are made with E-6027 electrodes. The last two passes are made using E-6024 electrodes, which have low spatter and give an extremely fine finish. The root pass is chipped out from the underside of the joint and the groove is then filled in, using E-6010 electrodes, usually 3/16in. in size. The top side of the joint is welded, usually in the downhand position, while the underside is very often done in the overhead position.

For such longitudinal seams as bilge seams and after end plates, where the positions are other than flat, E-6010 electrodes are used.

It will be noted that in all instances of single- or double-V welding, the root pass is always chipped out. This is because the root pass, being the first pass, is more subject to impurities on the back side of the weld and chipping being carried to sound metal removes any impurities present.

Inspection

All tee joints are radiographed on the ship and spot shots are taken at random as requested by the surveyors. Periodic checks are made on the welders through unscheduled tests. In addition, all welders undergo operators' qualification tests once a year.

Distortion

To control distortion when welding prefabricated sections, welding is started about amidship of midsection and progresses evenly outboard to the sides and towards the bow and stern.

Discussion

MR. A. C. HARDY, B.Sc. (Associate Member of Council) said the Institute was very privileged to have Mr. Watson's paper before it, because there was so little documentation on the question of icebreakers. Indeed, he did not know of any British institution which had had a major paper on the subject for many years. The Institute had dealt with icebreakers some years ago in a very famous paper which was given to it in the early days of the development of the Nobel Diesel engine but as far as he could discover no one else had covered it since.

It would seem that the icebreaker was particularly *à propos* at the present moment, because it was a strategic ship. With submarines working under ice caps and with the Russians opening up the North West Passage with atomic icebreakers, and with the general concept that the Arctic and, indeed, the Antarctic held out a promise of treasures which had not yet been exploited, one could not know too much about this type of ship.

The Canadian approach seemed to be different from that of other countries. The icebreaker intended to keep traffic moving in ice-blocked lanes was different from the highly specialized units which Mr. Watson had described. He knew of no other country which had icebreaking supply ships, concerned with communications between home bases and otherwise isolated communities rather than with the actual opening up of sea lanes. It would be interesting to hear from Mr. Watson later what he thought of the possibilities of developing a special icebreaker which might help to keep open the Seaway and hence carve a path to the Lakes in the ice blocked season of the year. Maybe some new devices would be produced which would enable an icebreaker to take ordinary merchant ships through the Seaway. If this were so, the type would indeed have justified itself.

The United States were building landing ships which were icebreakers. They were also building special oil carriers and tankers for service in the far north. What Mr. Watson had presented, therefore, was part of the general picture of an important ship type.

He himself would have liked Mr. Watson to go into more detail regarding the powering of icebreakers but no doubt there was security round atomic icebreakers. He understood some Russian friends were present. Possibly they would be kind enough to say what they thought about their new atomic icebreakers. It would seem that atomic powering could give two years' operation without refuelling and this was an important point.

He would also have liked to hear a little more about the controllable pitch propeller. Was it better than Diesel electric drive for this type of ship?

Again, was there any possibility, for example for the future, of the free piston gasifier and turbine with a controllable pitch propeller?

At one time many icebreakers were built in this country. In fact, they were built for the world in two great shipyards; the old Armstrong-Whitworth works on the Tyne, and Swan, Hunter and Wigham Richardson. The latter built icebreakers towards the end of the first world war, the former also at the turn of the century. He believed one of the big icebreakers with the two tallest funnels put into any ship was still somewhere in service.

Mr. Watson had told his story very modestly, and perhaps he could have gone into more detail. The problems concerning icebreaker design, propulsion and operation in Canada were very special. It was nice that their friend Mr. Baker, formerly head of naval construction for the Canadian Navy, was present. He knew a lot about the Canadian icebreaking service, and he would help to discuss the matter in his usual inimitable manner.

MR. J. BURTON DAVIES said that his interest in this very specialized type of vessel did not arise from experience of Canadian service. But he had had a little experience of Baltic icebreakers, and his main interest in the paper was perhaps in the way Canadian practice appeared to differ from Scandinavian.

One of the biggest differences would appear to be in the shape of the midship section of the vessel and in the provision of trimming tanks.

Icebreakers built outside Canada were designed with a substantial tumble home, and they were usually provided with trimming tanks which the Canadian Department of Transport did not consider worth the space or the equipment. He was not an expert on icebreaking, but he had taken some interest in it, and he thought these two features possibly went together.

He understood that in the Baltic trimming tanks were used mainly on two occasions. The first was if the icebreaker was frozen in at night with the temperature possibly down to 40 degrees of frost. In the morning they had to get the icebreaker out and the trimming tanks were used to set up a good roll and help free the vessel. The second was if the icebreaker was stuck in a high ice wall and he believed that then also they tried to roll her free. He did not know whether the same problems occurred in Canada.

There might be a difference in that the Baltic ice was fresh water, whereas Canadian ice would be salt water for the most part, he presumed. He believed salt water ice was considerably softer and trimming tanks might not be so useful under open sea conditions.

Another main difference was the adoption of forward propellers, which were very popular in Baltic icebreakers. Some of the latest Finnish and Swedish icebreakers of 15,000 s.h.p. had two propellers forward and two propellers aft, and Diesel-electric machinery. This would appear to give good flexibility in operation. He believed that vessels with bow propellers were considered suitable for three to five feet of ice, and he had been told they were useful if there was a lot of snow on the ice. He did not understand why, and he did not know whether Mr. Watson could help him, but that was what he had been told.

The author said that the Canadians no longer arranged a towing recess aft. Most of the Baltic icebreakers still had this, and he believed they still used it. He did not know why there was this difference. He would have imagined it was one of the things that if it worked in one place would have worked in another; but there must be some reason why the Canadians, unlike the Swedes and the Finns, had discontinued it.

On page 42 the author said progress might be made by proceeding astern. From what he had seen of icebreaking, he wondered how one got in position to proceed astern, for the channel was generally little broader than the beam of the icebreaker. Perhaps the author was considering a more open water condition than the Baltic icebreakers normally enjoyed.

Finally, with regard to Mr. Hardy's remarks regarding previous papers on icebreakers, he believed he was right in saying there was one* read before the Society of Naval Architects and Marine Engineers in New York a few years ago.

MR. H. TWITCHEN said that, like the previous speaker, he had been wondering why the controllable pitch propeller had not been mentioned. Whilst not knowing very much about icebreaking, he would have thought that the essential characteristics laid down by Mr. Watson on page 45 were a very good specification for the controllable pitch propeller, particularly items 2, 3, 4, 5, 6 and 8.

In the case of item 2 the torsional criticals could of course be very conveniently avoided by the controllable pitch propeller.

In the case of item 3 it should be possible to design the controllable pitch propeller to give the reliability required, particularly if the designer were free to use boss to diameter ratios similar to those illustrated in Fig. 27, which would appear to have a ratio of something like 0·375.

As regards item 4, the ability to stand still under full throttle could of course be achieved with the controllable pitch propeller and the thrust increased from zero as required, power being provided and absorbed continuously.

Referring to item 5, it should be possible with the controllable pitch propeller to improve fuel consumption, as the fixed pitch propeller could only be efficient at a particular condition. This would appear to be a major consideration in view of the wide range of operation of these icebreakers.

As for items 6 and 7, the manœuvrability of the controllable pitch propeller could be as good as, and better than, that of the Diesel electric, fixed pitch propeller combination.

The controllable pitch propeller with automatic control, i.e. single lever from the bridge, would, he believed, enable optimum conditions of engine and propeller to be selected automatically under all conditions. This could be achieved by selecting engine speed and fuel, the governor automatically changing the pitch of the propeller to maintain maximum possible b.m.e.p. of the engine.

Alternatively, engine speed and fuel could be selected, and the speed of the governor could be made to change the pitch to maintain the selected r.p.m.

With either of these systems the maximum available horse power could be utilized at any ship speed. It would be interesting to know why the controllable pitch propeller, which in theory would appear to be rather attractive, was not utilized.

MR. W. MCCLIMONT, B.Sc. (Member) said he had found the paper fascinating and he was sure it would be a valuable addition to the TRANSACTIONS. Before reading Mr. Watson's admirable survey, he knew nothing at all about this business of icebreaking, and probably many members were in the same position. He did not know whether he would ever need to concern himself professionally with the problems of icebreaking but it was a good thing to look at someone else's problems for a little while and try to learn something from them.

His principal interest was in the sections dealing with propellers and shafting. The concept of using propellers as drills to go astern through sheet ice up to three feet thick took a little getting used to. It was little wonder that the author described the tailshaft, propeller and bearing assembly as the Achilles' heel of the icebreaker.

He could not share the enthusiasm of previous speakers for the use of the controllable pitch propeller in this sort of application.

The observations regarding the preference for parallel tailshaft coupling bolts rather than taper-type bolts for a job of this sort were certainly not surprising. When recommending that they should not be driven too tight, however, too much emphasis could not be laid on the need for them to be well hardened. The author had mentioned this, but it should be very strongly emphasized. It was recommended that these bolts should be fine threaded; could some indication be given of the pitch and thread form envisaged?

The tailshaft inboard bearing on which so much stress was laid would probably be necessary with a heavy propeller, even without the additional loads imposed by using the propellers for astern icebreaking. Had any difficulty been experienced in aligning this bearing with the stern bearing? In view of its proximity it did not look as though it would make alignment any easier.

It was surprising to learn that longer stern bearings were an advantage; perhaps it depended on what was regarded as excessive bearing clearance and—probably more than anything—on where the clearance was measured. Did this experience apply to plastic blocks as well as lignum vitae? He took it that end-grained lignum vitae was used all round the bearing and not just for the lower segments.

The reluctance to use alloy steels for tailshafts under low temperature conditions was to be commended. It would be interesting to know exactly where the earlier shafts which gave so much trouble actually broke, and also some indication of the life would be useful. No doubt, under the operating conditions outlined by the author, a large number of cycles of stress reversal at a high level was soon built up; it might be helpful for guidance in other applications to know at what point failure was experienced. Bending stresses must be unusually high, and the effect of bending stress on tailshaft fatigue was very much in everyone's mind at the moment. Had hardening of the tailshaft by rolling been tried? That might be useful in this application.

On the question of adding ⅛in. to the thickness of the tailshaft liners, it would be interesting to know why that extra ⅛in. was valuable. Also, because of the peculiar temperature conditions, it would be interesting to know what interference fit was considered appropriate to liners working at these very low temperatures. Certainly, if the values normally adopted in this country were used, there should be no risk of liners rotating on their shafts. The avoidance of welding long liners was interesting. One wondered whether welding had given trouble when this approach was considered necessary. Could the author indicate what was the maximum length of liner he would be prepared to see fitted in one piece? None of his liners looked as though they would be anything like

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* Johnson, H. F. 1946. "Development of Ice-Breaking Vessels for the U.S. Coast Guard". Trans. S.N.A.M.E., Vol. 54, p. 112.

the maximum length that one would think of for fitting in one piece. He personally would look with the greatest suspicion on the rubberized centre section of the shaft. Had there been any trouble with that?

Would the author indicate the conditions in which it was found desirable to run the lignum vitae bearings on grease alone without water and whether this was applicable to plastic bearings also? Presumably there was a reason why the use of a water service connexion to the stern bearing was not a practicable arrangement.

The propeller holding studs were interesting. They appeared to have given trouble in the past, but the nature of the trouble was not indicated. If it were fatigue failure, the avoidance of wedging at the thread root was a sound arrangement, but the use of a bottoming stud seemed the least desirable way to achieve this. For this purpose, a stud with a collar was indicated, yet the holding studs were without collars. The present arrangement looked more as though it was devised to prevent the holding studs working loose; to overcome loosening a bottoming stud was good and a stud with a collar was poor. The author might care to comment on this.

He had one or two observations to make on insulation. The author said that icebreaker shells should be insulated inside in way of the machinery spaces. Just what effect did this really have with his very close frame spacing and very deep frames? The question arose whether the insulation was carried right round the frame, and, if not, to what extent it was bypassed by the frames. Under the conditions operated here, he wondered if the insulation stayed put, or if there was any trouble with breaking off.

Soundproofing of the Diesel generator engine spaces was mentioned. Was there any particular reason for this recommendation or had it been made because the background was steam reciprocating machinery and going over to medium-speed Diesels was a bit of a change in noise level?

Finally, he must apologize to the author for asking questions rather than offering constructive criticism; it was an indication, however, of the interest he had found in the paper, on which the author was to be congratulated.

Mr. G. M. Boyd said he must first apologize because he had had only a short time to study the paper. He was not a member of the Institute and had received it only recently. This was a great pity, because he had found it extraordinarily interesting and even in that short time he had added up enough points to keep going for the rest of the evening. He must therefore select his points carefully and if he confined his remarks to a few of them he hoped Mr. Watson would not take it that the other parts of the paper were uninteresting—far from it!

He proposed to confine his remarks to welding, which was dealt with in the section beginning on page 43. He had had a great deal to do with the study of the type of fracture referred to in merchant ship welded construction. It had always appeared very strange to him that icebreakers seemed to be so free from trouble. He had looked through a lot of records to find out whether there was any trouble in icebreakers, but he had found little, and this was confirmed by what Mr. Watson had said—that the shell plating below the strength deck had shown no sign of weakness or fracture. In studies on merchant ships, he had found that the lower the temperature the more risk there was of fracture. Although there were fewer failures at low temperatures than there were at about zero centigrade, that was because there were fewer ships and so one consoled oneself with the feeling that the risk in an average ship of reaching a low temperature was quite small.

But an icebreaker started off in life with 100 per cent risk of meeting these conditions, and therefore it was amazing that there was so little trouble.

He was also interested in the steel specification, and he noticed particularly that in thickness less than ½in. the only specification was that the carbon percentage should not exceed 0·30. He knew that a lot of American specifications had carbon in that region, but in this country and in Europe and most other countries carbon over, say, about 0·25 for welded construction was frowned upon and was generally considered unweldable. Had some special technique been developed for a steel containing that amount of carbon? Or was this merely a specification figure that was not reached in practice? American and Canadian steelmakers liked a considerable margin over what they would actually put into steel.

For materials from ½ to 1in. thick the specification looked like a fully killed steel, but no mention was made of heat treatment. For example, one would have thought that with a thickness over about 1 or 1¼in. it would be wise to normalize steel of that type. The thickness actually used in the ship ran up to 1¾in. and it might be even higher.

No mention was made of impact tests. He wondered why. It had become apparent in all studies of fractures in ships that the notched bar properties were of great importance. They could be achieved by various methods which were not always easy to specify in metallurgical terms. The tendency on this side of the Atlantic was therefore to rely on the physical properties rather than the metallurgical specification, and that meant using some form of test.

On the other hand, a mere impact test could be misleading and rather unnecessarily worrying unless it was properly interpreted.

He did not want to suggest that possibly it would be found if an impact test were applied to some of these steels in icebreaking that they would not turn out to be very wonderful. But it was all the more surprising that they had so little trouble. It might mean in the end that the energy in the impact test was not everything.

He would like to know what air and water temperatures were experienced. Presumably the water itself was not likely to be much below about −5 deg. C., but the air temperatures experienced by the ship might probably be quite low. He had seen a figure of −40 deg. F. mentioned from time to time, but he wondered if such low temperatures were actually experienced in service.

Coming to the welding itself, he saw that welding was not permitted at temperatures below 40 deg. F., which was above freezing point. This was a question which had often intrigued him. He knew that welding was done in many parts of the world at very much lower temperatures. In fact, quite recently Professor Rykelin was over here from the Soviet Union and he had said that as far as he knew there was no lower limit under which welding would not be permitted in the Soviet Union. The only requirement was to make sure the welder was welding in comfortable conditions.

There was one little detail in Fig. 18 showing the welding of the 10½-in. diameter stem bar to the shell plate 1¾-in. thick. A 30-deg. angle was shown for the welded joint, with ⅛-in. root gap. To what extent was it important that the root of the weld should be so small and what was achieved by such a narrow angle on this small root gap? One would have thought that J-type preparation would allow better root penetration, but he was sure any difficulties had been overcome and that the method had been developed satisfactorily. However, it did look rather difficult to obtain a good root there.

It was a little out of his sphere, but he was intrigued about the enormously heavy propeller, and he wondered whether any facilities were provided in these ships for repairing the propeller or replacing blades. One imagined that if it were put out of action the situation would be rather serious.

There was one point about the relative immunity of these ships—stresses. The general nominal stress in these ships must be very low, but they were probably subject to impact and there must be high local stresses. Had anything been done with strain gauges to measure the actual stresses while ploughing through the ice?

Mr. R. Baker, O.B.E., R.C.N.C., said that Mr. Watson had told him he could come to the meeting if he did not ask any questions, so he would answer a few of the questions put to Mr. Watson instead.

The first related to the variable pitch propeller. The icebreaker itself was pretty complicated. It went a long way from home for a long time with a crowd of operators who were not, on the whole, the most intelligent. Why consider another complication? Suppose a man was trying to sell one a variable pitch propeller. There was a big boss already, and the answer was, why have a bigger one?

Next there was the temperature question. If he had understood the previous speaker rightly, he had said that the Russians were quite content to do welding at −40 deg. but he did not say whether that was −40 deg. F. or −40 deg. C.

MR. BOYD said it was the same thing.

MR. BAKER, continuing, said this was absolutely dead right. But the next thing the Russian said was that the welder had to be comfortable. He had not been in the far north himself, but he had been in Canada when the temperature was down to −30 deg. F. or −35 deg. F. in Ottawa. It was most uncomfortable, so it would seem to him that welding in −30 or −40 degrees could not arise. No comfort, no welding. He did not know whether the Russians told the truth or not. Maybe they were trying to deceive Mr. Boyd. But it was absolutely certain that to get a welder to work it was necessary to warm him up and get above −40 degrees. He was sure Mr. Watson would agree with these remarks.

Then there was another point on which he could throw some light—notch toughness and stress. It must be borne in mind that the icebreaker operated in the summer with very rare exceptions, certainly not under the most severe conditions of weather. It did not get the very low temperatures, therefore, that one could dream oneself into. Also Mr. Boyd had made a small mistake about the water temperature. As far as he knew, the coldest that water could get, and remain water, was about 28 deg. F. It was certainly not possible to get 10 or 11 deg. F. and still have water.

MR. BOYD said he was taking Centigrade −5 deg.

MR. BAKER said that this was lower than 28 deg. F. He did not think one would get −5 deg. C. and still have water.

All he was doing was helping Mr. Watson, who could not be expected to answer all the questions that were asked by the gentleman who specialized in propellers and tailshafts. However, he might be able to throw a little light on some of them.

Perhaps he ought to explain, for the benefit of those who did not know, how he had come to be interested in this problem at all. Ten years ago he had gone to Canada and the day that he arrived he found he was supposed to design an icebreaker. (*Laughter.*) There was no need to laugh. He had designed things before and, of course, the thing one really had to learn in designing anything was that one had to have a starting-off point. If one was clever one would start by copying something someone else had done. This was most important and it was where most of the questions that had been raised could be answered.

He did not suppose he would get this straight, but if anyone copied what he had done precisely, he wondered whether he should be flattered to think that someone had recognized how clever he was or annoyed to think that someone had pinched his idea! That was really the background to the present evening. Mr. Watson won on all counts. He had copied what he (Mr. Baker) did, not so much in the matter of icebreakers, where Mr. Watson was first in the field, but in the matter of landing craft, which were now also used up in the north. He had designed them ten years before and had forgotten all about them. Mr. Watson had discovered a type and had thought them a good idea. He had taken one that had been cast ashore on all the beaches of the world. He (Mr. Baker) had told him not to use it because it would let him down. He went and used it and it worked! He thought he was absolutely clear with Mr. Watson, therefore, and they were the closest of friends; as between them it was collaboration, not plagiarism.

It was not particularly easy to design an icebreaker and he had been directed by the Canadian Government to copy an American ship. That was the start and a good start, but having got so far one had to examine the pattern and use a modicum of intelligence; and if there was something about the pattern one did not understand, one had either to find out about it or to discard it.

It was here that one came to the bow propeller. In the room there were, perhaps, many people who had never seen ice at all. The idea of the bow propeller might seem all right to them. People explained that it turned away in the ice and the ship got along. But one did not expect the bow propeller to churn its way through the ice like cutting pieces off with a drill. It made a tunnel under the ice so that the ice would be temporarily unsupported by the water underneath and would collapse of its own weight. This worked in so far that, if a hole were made underneath, the ice was more likely to fall in than if there was no hole underneath. Many skating accidents arose from this cause.

The icebreaker he had to design (the *Labrador* in Mr. Watson's paper) was supposed to go up into the Arctic where the ice was thick and any hole might be a long way down, so he had got hold of Mr. Watson in the first place and tried to discover what were the factors. The pattern had an enormous great bow propeller. The shape of the bow passed comprehension. The water line came along and the bow came down, and there was a knob and an enormous propeller (Fig. 37); this was what actually went up into the Arctic before his time. When it came to a large lump of ice, it was easy. The propeller knocked off large pieces of ice and in a little while the ice knocked large pieces off the propeller. In the end, he had decided to keep off that, and this led him to the shape of bow described in the paper. It was really the result of collaboration between Mr. Watson and the naval architects in Montreal and himself. This he had got away with: it was a change from the American design, made through using a modicum of intelligence.

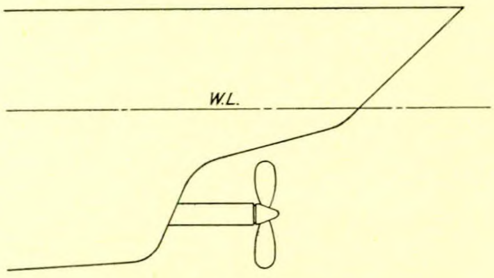

FIG. 37

But he had not been satisfied. It did not seem to him that anyone in Ottawa knew very much at first hand about conditions in the Arctic, so he talked to one of Mr. Watson's captains; he had had much experience and a lot of questions were put to him. What did he do? As far as he could recollect all he would say was that "the ice was thick". That was the contribution obtained from the user! This was not a joke, either, because this was one of the most serious aspects. It was very hard to get the user to explain precisely what he did and why he did it and this was a common factor affecting all designers always.

Various people had brought up points and had asked "Why do you do this?" He believed it was impossible for Mr. Watson to answer some of these questions. The reason was that one had to start from something; one had to start from what someone had done before. One could not go through the whole thing and work bit by bit, asking questions about every item. Some things had to be taken on trust. In an icebreaker, or any other ship, or in any machine there might be things that were not precisely right, and one was bound to copy some good things and some bad things, and there would be things one could not explain.

This brought him to the notch described as a towing notch. This was fitted into the *Labrador* because the Americans had fitted it. Mr. Watson said it was not much good, and he himself agreed. If one had time to think rationally, it was hard to believe it could ever be any good. But when on a previous occasion he had suggested that it was a towing notch and was a survival, Mr. Burgess had written to say it was not a towing notch. It was a notch for pushing. He believed Mr. Burgess was right. That was long, long ago. When one had 180 h.p. it was a good idea if the icebreaker got stuck to have another ship behind to give it a push.

But things had moved away from that. The power had increased a hundred fold and a more efficient ship had been obtained. There was still the towing notch, which was very hard to explain because it had started as a pushing notch. He believed, though, that his copying of Mr. Watson's ships was not bad. The bow was better; a number of other things were the same.

Then there was the question of the tumble home and the roundness of the bilge. This was taken on because it was what the Americans did. He did not believe it was absolutely essential. It was obvious that the bow went into the ice first and therefore it was natural to concentrate attention on the bow first. But he believed there was a field for development in considering the aft end.

What happened now in most cases was that the water line was pretty pointed at the aft end. There might be two propellers and the ice went past and knocked off the blades. He thought that could be improved by making the water line wider. It would be possible to go further up and carry the round bilge from midships back aft in the form of a chine or even a skeg (Fig. 38). The ice when it broke would sink as it was pushed down and then be thrown up again. One tried to take the ice away aft, clear of the propellers, and for that purpose it had to be taken outwards. It was picked up and allowed to go along the side of the ship, up and out.

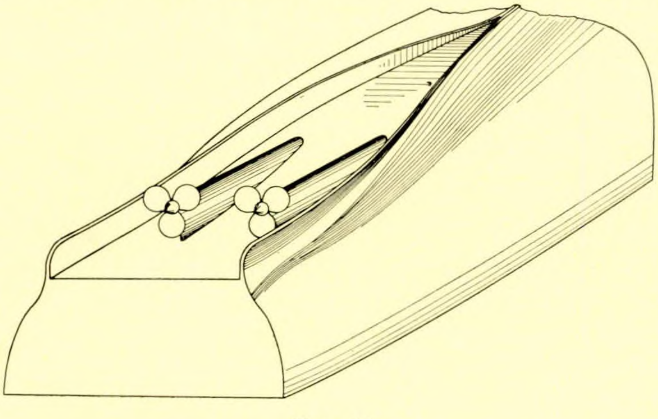

FIG. 38

He was not asking Mr. Watson to say whether he agreed with this or not. He was not asking questions, but wanted to make the point that there was a field for development. The present vessels were much improved and a lot of attention had been given to the bow so that it would ride upon the ice and break it. Further effort could now be put into the stern, so that the whole ship would ride clear of the broken ice.

MR. R. J. HOOK (Associate Member) said that no doubt, as the previous speaker had stated, one of the reasons free piston gas turbine machinery was not used in icebreakers was that these ships were complicated enough already, so why make them more complicated? That was, of course, true and perhaps its application was in the future—maybe a long way in the future.

There was little as yet in the way of service results in ordinary ships and perhaps when this became available the use of free piston machinery might be extended to icebreakers.

From a study of Figs. 20 and 21 and of the triple screw vessel shown in Fig. 22, it would appear that the machinery occupied a disproportionately large part of the ship's length. It would seem that with free piston gas turbine machinery a convenient layout could be obtained by locating the gasifiers on an upper flat, with the turbine gearbox and shafting located below, with which electric drive could easily be incorporated if desired. Such an arrangement would make hold space available in the wide body of the ship for the carriage of supplies and cargo mentioned in the paper as one of the main functions of vessels of this type.

With regard also to Fig. 22, Mr. Watson had mentioned that in the proposed new design two generators were linked to one propeller motor and they were not interchangeable. This would not appear desirable, although no doubt there were very good reasons for it since it had been designed by experts. But he would have thought a greater degree of flexibility than was offered by this arrangement would have been desirable and greater flexibility could be obtained by the use of free piston gas turbine machinery. He understood that some of their Russian friends were present and he seemed to remember reading in the technical press that free piston gas turbine machinery was under construction in Russia. He would be very interested to learn of the actual or proposed applications of such plant and he hoped that in the written contributions to the discussion their Russian friends would be able to give some information in this connexion.

Finally, he would like to ask the advocates of the controllable pitch propeller what service experience could be offered in applications of the type under consideration.

MR. J. STEVENSON (Member) asked what was the effect, if any, of electrolytic action on the hull of icebreakers when Diesel electric propulsion was used.

Correspondence

DR. JAN-ERIK JANSSON considered that the author had given an extremely valuable paper on a ship type which was very complex, and especially in Canada where the icebreakers had several different duties to perform.

Icebreakers were of interest to the Finns, because their coasts were icebound for three to five months of the year and merchant ships entering or leaving Finnish ports therefore needed icebreaker assistance. The ice conditions were never so difficult as in Canadian arctic waters, however, and they could be compared to the situation in the Great Lakes and Northumberland Straits between Prince Edward Island and Nova Scotia. It had therefore been possible to take advantage of bow propellers. All their earlier icebreakers were equipped with one bow propeller. This however, resulted in a lack of symmetry, steering difficulties, etc., and from 1953 on all their icebreakers, starting with the *Voima*, had been built with two propellers in the bow and two propellers aft.

The main advantage with the bow propellers (which were inward turning), in their ice conditions, where much pack ice was encountered, was that they washed the bows of the icebreaker and therefore decreased the coefficient of friction between the ice and the shell plating. They had very good experience with the Diesel electric system, and all their propellers were of the solid type (not with bolted blades) and four-bladed.

One Finnish shipyard, the Wärtsilä-koncernen A/B Sandvikens Shipyard in Helsinki, had during recent years specialized in icebreaker construction. The 12,000-b.h.p. (maximum power) *Voima* was followed by four sister ships, three for the Soviet Union and one, the *Oden,* for the Royal Swedish Navy. This series was followed by two 8,800-b.h.p. icebreakers for the Finnish government, the *Karhu* class, and would probably be followed by a third sister ship. At the present time the yard was building two Arctic icebreakers ordered by the Soviet Union, the first of which would be called *Moscow.* These ships were of 26,000 b.h.p. (maximum) and were surpassed in size only by the atomic icebreaker *Lenin,* now under outfit in Leningrad.

The two last ships mentioned, which had no bow propeller, had three screws aft (of the built and bolted type), the centre of which absorbed 50 per cent of the total power and the wing propellers 25 per cent each. This power distribution was also used in the *Lenin,* and had already been tried by the Russians in the *Kirov* class icebreakers (three ships) built in 1938/40. Incidentally, three propellers aft with even power distribution were installed by the Russians in the *Jermak,* built in 1899 by Vickers-Armstrongs in England (it had a fourth screw in the bow, but this was removed as a result of its unsatisfactory performance in Arctic ice) and in the four steam driven icebreakers of the *Stalin* class, built in 1937/39.

Technical data on all the icebreakers mentioned were given in the paper*, "Ice-Breakers and Their Design", presented in 1956 before the Scandinavian Conference of Naval Architects in Oslo. Mr. Watson mentioned on page 44 the new ice classes of Lloyd's Register for merchant ships. They were actually partly based on the new Finnish ice class rules, which would be published officially in 1959.

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*Jansson, J.-E. 1956. "Isbrytare och deras konstruktion". Teknisk Ukeblad, Nr. 37, 38 und 39. "Ice-Breakers and Their Design". Slightly shortened edition in English published by "European Shipbuilding", Nos. 5 and 6, Vol. 5, 1956.

Author's Reply

The author noted Mr. Hardy's remarks about the Nobel Diesel engine and the icebreaking paper which appeared in the TRANSACTIONS OF THE INSTITUTE OF MARINE ENGINEERS for the year 1923, with a picture of the *Ermack* in heavy ice near Murmansk, and the difficulties associated with propeller troubles they had there. He found this article very interesting and it was indeed his first contact with icebreaking.

It would be impossible to carry out what were now considered normal shipping operations in Canada without the use of icebreakers. Business had been increased greatly by icebreaking assistance under conditions where the ice was not too heavy for the commercial ships to follow the icebreaker. Their approach was, he supposed, somewhat different from other countries because Canada, as mentioned on page 38 of the paper, extended from latitude 41 deg. 41 min. to latitude 83 deg. 09 min. and therefore they had both a summer and a winter icebreaking operation.

None the less it was not possible to employ any of the icebreakers throughout the full year for icebreaking work alone so they designed them to carry out other work such as supply work to areas beyond the reach of commercial ships, re-supply by water transport to isolated ports, and for the establishment of aids to navigation. For the full icebreakers, this did not interfere with their characteristics or ability to perform full icebreaking work, but it did, of course, give them ships which carried out the ancilliary duties in a less efficient measure than ships designed wholly for that purpose.

He did not think it would ever be possible to develop an icebreaker which could carve a path to the Lakes or even to Montreal and keep the Seaway channel open on a year-round basis in a manner which was necessary for safe transport of standard commercial ships. The icebreaker might be able to break the ice but it could not dispose of it, and when it reached a condition where the ice making under very cold weather conditions was faster than the process of dispensing with it through the River and out to the warm waters of the ocean, then the broken ice became even more difficult to deal with than the shelf ice which was broken in the first instance by the icebreaker. In addition to this, of course, in order to dispense with large masses of ice in a satisfactory manner, warm water was required somewhere. The Gulf of St. Lawrence, for instance, would harbour ice which came to it from Montreal all winter; the temperature was such that the ice would not disappear, whereas in the spring the ice passed into the ocean and disappeared. If temperatures were low, broken ice could knit and present a condition which was too difficult for commercial ships even after only one night's exposure.

The St. Lawrence or Seaway could possibly be kept clear by a mammoth reactor or reactors stationed at strategic points heating the water sufficiently well to keep it ice free on its way to the ocean. This might do the trick but in practice that could not yet be accomplished.

With the information available at the present time, the combination of free piston gasifier and turbine with a controllable pitch propeller did not appear to give more power or longer steaming radius than the machinery which was now used. Economy by weight was more important on an icebreaker than the fuel cost and the utmost reliability for a given power, including ability to absorb shock, was an important factor. He had considered the controllable pitch propeller for icebreaking but had not yet received any evidence that a controllable pitch propeller had been used for large icebreakers, nor had it been proved to have strength equal to the propellers used in Canada today. Controllable pitch propellers had been used on commercial ships which went to the Arctic, but a low powered, single-screw ship could not be treated as an icebreaker, although such a ship could be quite safe in ice but would be beset under conditions which a powerful icebreaker could handle. The ability to alter pitch could be advantageous in certain ice conditions.

He saw no relation between Diesel electric and the controllable pitch propeller. If the controllable pitch propeller were good, it would be good for either steam reciprocating or Diesel electric, which were the two types of power presently in use.

A great deal of icebreaker know-how had come from the

United Kingdom and, regarding the reference to Armstrong Whitworth and Swan Hunter, he believed the first really successful icebreakers were constructed in the United Kingdom.

There was no relation between tumble home and trimming tanks. Their earlier icebreakers were built with tumble home. This added to the cost of construction and robbed the ship of a considerable amount of valuable deck area. It seemed to be something which had come down from sailing ship days, the idea apparently being to give the ship above the waterline more clearance to prevent damage to bulwarks, mast, ratlines, etc.

Two sets of tanks were used in some icebreakers. One set of tanks was for trimming and the other was for heeling motion. The Department of Transport did not use the heeling tanks at all. This operation had been observed on numerous occasions by their captains and they felt that the amount of equipment which must be carried and the amount of space which required to be sacrificed in order to accommodate it was not justified by the results obtained. Trimming tanks were essential on all icebreakers, as under difficult conditions trimming tanks could be used advantageously to free the ship and also, of course, they could be used effectively to put the ship into the best icebreaking trim for any particular assignment.

Their icebreakers did not freeze in at night. Even with insulation a sufficient amount of heat escaped from the ship to keep a film of water between the ice and the shell plating. An icebreaker could possibly make faster progress through heavily rafted ice with heeling tanks but they deemed that the space used for the large heeling pumps and the tanks could be put to better overall advantage by increasing the power and steaming radius.

He could not add much to the paragraph on page 43 regarding bow propellers. The aperture for the bow propeller interfered with the usefulness of the bow wedges for imposing horizontal and vertical components in the conventional manner. In the Arctic, where leads had to be followed, the bow propellers could not be fed into very heavy ice and used as a drill; the contact where the leads turn at a sharp angle was too sudden and the exposed bow propeller, as they knew it today, would not stand up. They had thought of fitting an icebreaker with a stubby screw type bow propeller which could be useful to drill any kind of ice, but the uselessness of such a propeller for propulsion and the interference with the bow lines had made them doubtful as to results. Bow propellers had proved useful under shelf ice condition of limited thickness with open water underneath. The concept of two bow propellers forward and one bow propeller was quite different. They used two bow propellers very successfully on ferries which operated in ice infested waters without 100 per cent cover and limited concentration. The description of ice as being so many feet thick could be very misleading. Ice packed 20 feet thick could sometimes be much easier to penetrate than blue shelf ice about two feet thick with a heavy snow cap and frazil underneath. In tidal or open waters exposed to the wind and tide, shelf ice generally became broken and piled by the effect of the wind. The Baltic being completely south of the Arctic circle, he doubted very much if the undisturbed blue shelf ice in this area ever exceeded 30 inches thick.

It was generally considered that there was a difference between salt water ice and fresh water ice although after ice had formed it was all fresh water. Generally speaking it appeared that fresh water ice was harder but salt water ice was more sticky, due to the more lengthy freezing process and the larger bodies of warm water. This gave the salt water ice stickiness which fresh water ice did not have except within very, very limited temperatures.

The towing recess had never been used for pushing the icebreaker and great difficulty had been found in endeavouring to tow ships with the stem bar in the recess due to the very large angle of the connecting tow lines from the commercial ships high forehead to the low deck of the icebreaker.

The ship could proceed astern when beset because movement could be effected by using the propellers as ice pumps for this purpose or in the breaking of ice downstream under conditions where a jam had formed. Conditions, particularly on the St. Lawrence and Saguenay Rivers, were very congested; the icebreaker had to keep within the 200-ft. channel and better control and direction could be exercised by proceeding astern. The action of the propellers pointing the ship into the jam, although slow, was very positive.

Replying to Mr. Twitchen—realizing the difficulties and the processes of elimination which had been used in developing their present icebreaking propellers as against ordinary propellers for open navigation, they did not plan to replace with controllable pitch propellers. He did not think any one would claim that a controllable pitch propeller could be designed to be stronger than an ordinary propeller and their propellers were, if he might use the word, both as to material and scantling, superordinary. Not only had the scantlings been increased but the material and workmanship was to very strict standards which had been found necessary in practice. The locking of the propeller together with the propeller fastenings, and the protection of the tailshaft nut, were practices which had come about as a result of acid tests by performance. A controllable pitch propeller also involved a special tailshaft and a lot of operating mechanism, and while they did not fear ice, under certain conditions rocks and such like obstacles were encountered and it was a simple matter to renew hubs, blades or shafts.

An important difference between the controllable pitch propeller and the icebreaking propeller would be found in items 8 and 9 on page 51. They had not yet been offered a controllable pitch propeller which was comparable in strength and which was provided with the studs, nuts and scantlings established as being necessary for the icebreaking propellers which they used.

The implications regarding standing still under full throttle applied to a condition where the propeller had been brought to a standstill while still carrying full throttle. It was not standstill for the ship but rather standstill for the power unit while still in the process of delivering its power and this came about by the increase in external loading on the propellers.

The essential requirement in an icebreaking propeller was that it must stand up. All other considerations, which were important factors in their ferries and such like, which did not have to deal with any large amount of ice, must give way to the strength requirement, and it had not been proved that controllable pitch propellers would stand up to the conditions imposed by propellers used by large icebreakers under the ice conditions they had to deal with in Canada.

With Diesel electric machinery, the torque increased automatically by automatic change in the motor field and with steam reciprocating machinery this process also took place by increase in the m.e.p. of the engines as the external resistance was imposed. It would not be possible for anyone to bring about a reduction of pitch quickly enough to take care of the varying ice densities, and, in addition, the effectiveness of the propeller as an ice pump under conditions where the pitch was limited to allow the engines to maintain speed under increased external load conditions would bring about a condition in which the propeller would not function as an ice pump or maintain maximum horse power.

In reply to Mr. McClimont, the bolts used on the *d'Iberville*, for example, were 3¾-in. diameter and 6 threads per inch. They had not had any difficulty aligning the stern bearing with the rest of the shafting because this did not make any difference to the procedure which was used by starting with the tailshaft and working forward. Stern bearings on icebreakers had to be kept reasonably free from wear as too much wear caused hammering of the shaft in the bearing which would quickly damage the bearing. The longer stern bearing was simply a matter of minimizing the wear while using extra surface. The bearing clearance, of course, was measured by movement of the tailshaft itself. A gauge was fitted over the rope guard or in cases where there was no gauge a jacking of the shaft in dry dock was used. A clearance of not less than

1/16-in. on new bearings on large shafts, was used both on plastic and lignum vitae blocks. End grained lignum vitae was generally used all round. Actually they had had shafts in service over ten years without any sign of stress or failure of any description. Generally speaking they had to replace shafts due to liner difficulties and sometimes on account of corrosion. Fracture of a shaft was generally associated with the propeller coming in contact with rock or other immovable surface. They had never tried hardening of the tailshafts by rolling. Heavy combined stress on the tailshaft was undoubtedly imposed when working astern in ice, and for that reason special strength margins were required. The ⅛-in., generally speaking, was added to the liner simply for dressing purposes. Perhaps it was due to the heavy pounding and some torsional deflexion of the shaft due to sudden external loading, but whatever the reason they had had difficulty with tailshaft liners at the joint.

The rubberized joints had not seen lengthy service but they felt that this would be an improvement since it would only tie the liner to the shaft in shorter lengths. The longest liner used at the present time was 21ft. overall.

Lignum vitae bearings could be run on grease alone although even with grease a certain amount of water would still pass through the bearing channels from the sea. Plastic bearings would not operate in this manner as it was difficult to make sure sufficient water would pass to cool the plastic blocks and they had had difficulty with these blocks heating up and spreading. They considered, therefore, that grease should not be applied to plastic blocks.

With regard to the propeller studs and the difficulties attached thereto, this matter was covered by item 7 on page 53 of the paper. They did at one time use studs with collars but abandoned this practice many years ago because, in the first place, the collar interfered with the renewal of a broken stud without taking off the propeller blade; then they reasoned that the process of screwing the stud tight all the way to the bottom worked out well in practice and the top fastening was designed to positively prevent both the stud or the nut from coming loose under conditions where, due to the heavy pounding, there might be a certain amount of clearance caused by biting.

The reason for insulating icebreaker shells was simply to save heat. Sprayed insulation or fibreglass was used and the frames were covered as well as the shell plating.

The sound proofing of the Diesel engine spaces was simply a matter of comfort. They sound proofed the control room in the engine room and the engine room casing was sound proofed to limit the noise throughout the ship, and particularly in cabins adjacent to the engine room. The Department had used Diesel engines for over fifteen years but the high speed machinery which was used on Diesel electric icebreakers today, even for the auxiliaries, had a very high pitched intense noise which should be mitigated if at all possible for the habitable accommodation.

With regard to Mr. Boyd's comments, he thought one of the reasons why icebreakers had so far been free from trouble was first of all due to the insistence of an absolutely high standard practice both in workmanship and material, and also due to the fact that the icebreakers were, after all, stubby vessels which did not carry very much in the way of a load and, therefore, did not by deflexion change form to any material extent. It was quite true that these ships operated under very difficult temperature conditions but as a large part of the ship received a certain amount of internal heat, the shell itself did not exactly follow the temperature outside. He might say that they were very pleased that there had been so little trouble with welding on the hulls and even on their old riveted icebreakers they were introducing welded sections as part replacement.

He agreed with Mr. Boyd that the 0·30 represented a figure which had been reached in practice. They would be quite willing to take 0·23 for all the plating. On the other hand, of course, there did not appear to be any point in running up expense to secure plating with low carbon property under ½-in. where such plating was, generally speaking, not used for the strength part of the vessel. Heat treating was desirable but, in practice, facilities were not always available at the steel plant. The specifications required that all welding be covered by spot X-ray photography and sections of welding were trepanned as might be necessary. Full advantage by prefabricating was taken of automatic welding. Impact tests, as Mr. Boyd pointed out, could be misleading unless properly interpreted, and they believed that the soundest method of all consisted of well qualified welders, good welding materials, and checks for porosity, etc., and, of course, a sound welding sequence diagram and insistence that it be adhered to. They felt that if application in practice were carried out in this manner, the test bars which were taken would all show good physical properties, including impact.

With regard to limiting welding to 40-deg. temperatures, the welder himself was a very important factor in the results and he would be more comfortable and likely to give better application to his work if he were working under good temperature conditions. He could hardly imagine a condition where the welder was comfortable and his work was kept at an entirely different temperature. In any case they had no information as to successful welding of icebreaker hulls under low temperature condition and they did not plan to experiment on this matter as it was quite easy to tent the operator and the plate at the building berth.

The air temperature quite frequently went between 20 degrees below zero and above freezing. Even a fraction of a degree would cause water to freeze and even in fractions of a degree the water in motion would be carrying ice needles although it did not solidify.

The idea of the small root gap in connexion with the shell plating to the stem bar was simply to maintain as far as possible the face of the stem bar itself. There appeared to be no difficulty in making a good fill on the 30-deg. angle. The rabbet in this bar required to be machined and the bar bent afterwards. The V section was considered most satisfactory after carrying out various welding tests on short pieces. Good penetration was achieved with joint preheating and low hydrogen rods with increased amperage.

Generally speaking, blades could not be replaced without dry docking; on some of the small icebreakers it was possible to carry out the replacement of a blade under tidal conditions but this had not been done for many years for the simple reason that they had not had any propeller difficulties for a long time. If the ship were to be out of action as a result of damage to the propeller, it would indeed be serious, and that was why they aimed to have propellers and underwater gear which would not be put out of action by contact with ice.

He agreed fully with what Mr. Baker said about welding and also with his remarks about water temperature. Mr. Baker had brought a great deal of knowledge with him to Canada and in their operation in the north they successfully used his landing craft although they did have to reinforce them for working in ice.

The matter of the towing notch had been covered earlier and also the tumble home and he agreed with Mr. Baker's conception of endeavouring to keep the ice in the wake as small as possible. It did not follow, however, that the waterline at the aft end could be made wider. This interference with the ability of the vessel to free herself by jack-knifing and the whole matter of hull and ice infestation of the wake must, in the first instance, be considered from the standpoint of whether one was looking for an icebreaker which would carry out convoy work or a ship which would itself pass through the maximum amount of ice. There were, of course, many compromises between the two and each case had to be given special consideration and the end, of course, was always some form of compromise.

It was quite possible that free piston or other equipment which was being used at the present time would some day be used for icebreakers but at the present time changes would, he felt, only be made to secure more power, more steaming radius and greater reliability. The machinery always occupied a large part of the length of the ship in icebreakers because the ship itself was small in relation to the power. The free piston arrangement proposed could probably be worked out but the whole business of icebreaking had been built up from little ships to bigger ships and from experience all the way along. If someone wished to experiment they could do almost anything but one could not justify experiment where the end result must be professional performance. An icebreaker alone in the Arctic should be absolutely self reliant and able to return alone.

The matter of hull space was not by itself a measurement of the ability of the ship to carry cargo. On icebreakers a large part of the transportation was carried out on deck because the equipment often lent itself to deck storage. In addition to this, of course, the ship had to float at a certain draught, and a larger hold, while it would give additional cubic space, would not by itself assure additional deadweight. With direct connected machinery it was not possible to transfer from one shaft to another and after considering the implications both with regard to equipment and labour they had decided that the ability to transfer power from one shaft to another was not worth the price. In fighting ships the picture was different, but for civilian icebreakers they felt it was not necessary.

The author wished to thank all the contributors for their questions and comments. He was sorry that it had not been possible to give specific answers to many of the questions, but if there was any further information required on any particular points he would willingly provide it.

INSTITUTE ACTIVITIES

Minutes of Proceedings of the Ordinary Meeting Held at The Memorial Building on Tuesday, 11th November 1958

An Ordinary Meeting was held by the Institute on Tuesday, 11th November 1958 at 5.30 p.m., when a paper entitled "The Design and Building of Icebreakers" by A. Watson, M.B.E., P.Eng., was presented and discussed. Mr. James Calderwood, M.Sc. (Vice-President and Honorary Treasurer) was in the Chair and seventy-two members and visitors were present. There were eight contributions to the discussion.

A vote of thanks to the author, proposed by the Chairman, was accorded by acclamation. The meeting ended at 7.45 p.m.

Section Meetings

Scottish

General Meeting

A general meeting was held at the Institution of Engineers and Shipbuilders in Scotland, Glasgow, on 14th January 1959 at 7.30 p.m., which was presided over by Mr. John Robson, M.B.E., B.Sc. (Chairman of the Section), who referred to the wintry conditions prevailing which kept the attendance down to thirty-seven.

The Chairman introduced Mr. C. E. Phillips, Wh.Sc., A.C.G.I., and Mr. A. C. Low, B.A., and their paper "Research and Failures of Metals in Service" was read by Mr. Low. In the interesting discussion which followed, both authors dealt in a very able manner with the questions raised.

The meeting terminated at 9.15 p.m., after Mr. D. D. McGuffie (Member) had aptly proposed a vote of thanks to the authors for their excellent paper.

Joint Meeting

A joint meeting with the Aberdeen Mechanical Society was held at Robert Gordon's Technical College, Aberdeen, at 7.45 p.m. on Friday, 16th January 1959.

The President of the Aberdeen Mechanical Society, Mr. C. W. Hall, welcomed the Scottish Section representatives, and then asked Mr. John Robson, M.B.E., B.Sc., to preside.

The Chairman called on Mr. Low to present the paper entitled "Research and Failures of Metals in Service" by C. E. Phillips, Wh.Sc., A.C.G.I., and A. C. Low, B.A., which was a repeat of that given in Glasgow on 14th January 1959.

An interesting discussion followed, and the meeting terminated at 9.15 p.m. with a vote of thanks by Mr. C. W. Hall to Mr. Low for his excellent paper and to the Scottish Section representatives for coming to Aberdeen.

West Midlands

At a meeting held at the Birmingham Exchange and Engineering Centre on Wednesday, 7th January 1959, Mr. W. R. Wootton presented an illustrated lecture entitled "Nuclear Steam Propulsion for Merchant Ships". Mr. R. S. Robinson (Member of Committee) was in the Chair and the meeting was attended by forty-five members and guests, a remarkable attendance considering that a heavy snow fall during the day had made road travel extremely difficult.

Mr. Wootton opened by saying that in order to apply nuclear propulsion to a ship of 50,000 to 60,000 tons it had been necessary to scale down the type of reactor at Calder Hall to give a heat output of about 50,000 horse power, compactness being achieved by raising the gas pressure and utilizing enriched fuel.

By means of numerous lantern slides, Mr. Wootton described the construction of the reactor vessel, charge machine, heat exchangers and ancillary equipment required. As a comparison with this gas cooled reactor, Mr. Wootton showed further slides detailing the water cooled type fitted in the American merchant ship *Savannah*.

Mr. Wootton concluded by discussing some of the economic considerations involved, pointing out that costs would be reduced as experience increased.

Fourteen members took part in the lively discussion which followed. The Chairman expressed the members' appreciation of an extremely interesting lecture, and the meeting closed at 9.0 p.m.

Student Meetings

Film Show

A meeting of the Student Section was held at The Memorial Building, 76 Mark Lane, London, E.C.3, on Monday, 19th January 1959 at 6.15 p.m., when the following films were shown: "Men of the Ships", "Horizons Unbounded", "Animal Vegetable Mineral", "A Hydrocarbon Story", "Blue Riband of the Atlantic", and "Gale Warning".

Questions on the first two films were ably and amusingly answered by Mr. W. Girvan (Member).

Mr. P. J. Humphreys (Member) was in the Chair and 110 members and visitors attended. A vote of thanks to Mr. Girvan, proposed by the Chairman, was carried by acclamation. The meeting ended at 8.30 p.m.

"Watchkeeping, Maintenance, Repair and Survey of Ships"

A meeting of the Student Section was held at The Memorial Building, 76 Mark Lane, London, E.C.3, on Monday, 2nd February 1959 at 6.30 p.m., when a Panel consisting of a superintendent engineer, a chief engineer, and representatives of a classification society, underwriters, and a ship repairing firm, discussed "Watchkeeping, Maintenance, Repair and Survey of Ships".

Mr. F. A. Everard (Member) was in the Chair and forty-six members and visitors were present.

A vote of thanks to the members of the Panel, proposed by the Chairman, was carried by acclamation. The meeting ended at 8.30 p.m.

Election of Members

Elected on 9th February 1959.

MEMBERS

Thomas Golder Cleghorn
David John Coppin
William Bernard Craggs
Donald Leitch Findlay
David Kenneth Fraser
Mohabbat Khan
Donald McLeod
John Ingram Marfell
Arthur Leslie Martin
Dennis Herbert Neave
John Thomas Bosher Oxford, B.A.(Oxon.)
James Smith
James Templeton

ASSOCIATE MEMBERS

Norman Harry Bayliss
Arthur David Burrell Brown
Hugh William Campbell
John Leishman Connell
George Depastas
Reginald Lionel Dinshawe
Edward Fairless Dixon
George Merion Dixon
Denis George Dominy
Robert Walter East
Nari Pahilajrai Hiranandani
Walter Campbell Chapman McKenzie
Norman Ian McQueen
Raymond Louis Marsh
Gerald Edward Marston
Gordon Frank Mason
Geoffrey Michael Painter
Lorraine Frederick Ridout
Herriot Anthony Rodricks
Jyotish Chandra Shome
J. Chandrashekar Simon
Harold Spencer, B.Sc.(Eng.) London
Harry Stretton
Gordon Swingler
Peter David Thomas
David Towell

ASSOCIATES

P. A. D. Anbu
Phelim Devitt
William Harry Drew
Arthur William Ernest Hellingman
Iver Lunn
David Alan Saward
William Pritchard Sommerville

GRADUATES

Ramesh Chand Bansal
George Edward Caine
Ronald Leslie Gray
Colin Robertshaw Greenhough
Robert Maurice Scott Haig
Colin Wyatt Hall
Graham Hawes
Afsar Ahmad Khan
Marnoch Shearer Thomson
John Tucker

PROBATIONER STUDENT

William S. Ballingall

TRANSFER FROM ASSOCIATE MEMBER TO MEMBER

Donald Dyer
Ronald Aubrey Wood

TRANSFER FROM ASSOCIATE TO MEMBER

William Evershed Carter

TRANSFER FROM ASSOCIATE TO ASSOCIATE MEMBER

Gershom Henry Bassey
George Kenneth Hancock
Anthony John Monk
Michael Murfin
Madhavan Ramachandran Nair
Hunter Kerr Owen
Andrew Thomas Russo
Ronald Bertram Tyler
Brian Thomas Whittle

TRANSFER FROM GRADUATE TO MEMBER

Hugh Gordon Rankine

TRANSFER FROM GRADUATE TO ASSOCIATE MEMBER

James Peter Carter
Michael J. Fonseca
Richard John Clive Galliver
Derek George Reeves Hall
Alfred Humble
Brian Anthony Lynch
Kunduvalappil Vijayan Menon
Naughton James Morgan
Om Prakash
Joseph James Sewell
Kenneth Ronald Shaw
Clifford Granville Solloway
Peter Wilkinson
John Alexander Wright

TRANSFER FROM STUDENT TO GRADUATE

Kenneth Nichol Bexon
Geoffrey Joseph Dixon
Donald Adrian Mieras
Rex Young

TRANSFER FROM PROBATIONER STUDENT TO GRADUATE

Brian John Down
Robert Jackson Fullerton
Phillip Thomas Zoller

TRANSFER FROM PROBATIONER STUDENT TO STUDENT

Michael Bach
David Edward Gue
John Brian Hawkins
David Harold Martin
John Richard Pawsey

OBITUARY

GEORGE AGAR (Member 11265) was born in 1893. He served an apprenticeship with Vickers Ltd. at Barrow-in-Furness from 1918/23 and continued his association with the company and its Canadian associates until his retirement in September 1957 through an illness which led to his death on 22nd June 1958.

After completing his apprenticeship Mr. Agar was a draughtsman at Barrow until 1918, when he went to Canadian Vickers, Ltd., in Montreal as assistant chief draughtsman. In 1927 he was promoted chief draughtsman and estimator and in 1935 became assistant manager in the engineering department, being appointed manager two years later. He was made executive engineer in 1946 and his final appointment, in 1955, was as assistant to the president of the company.

Mr. Agar was a Member of the North East Coast Institution of Engineers and Shipbuilders, of the Engineering Institute of Canada, and of the Corporation of Professional Engineers of Quebec. He was elected to Membership of the Institute of Marine Engineers in 1947.

LUKE JOSEPH AHEARNE (Member 11917) was employed by John I. Thornycroft, Ltd., of Southampton from 1916/23, first as an apprentice and then as draughtsman. For the next five years he was an engine fitter chargehand with Harland and Wolff, Ltd., in Southampton and then went to Middlesbrough as foreman at Smith's Dock Co., Ltd., where he was engaged on trawler engine building and installing. In 1934 he was appointed machine shop foreman by Russell and Co., Ltd., Liverpool, and stayed with this company until the outbreak of war, when he spent five years, from 1939/44, as overseer for the Admiralty in Liverpool of destroyer and submarine engine repairs. He was a ship and engine surveyor in the Sea Transport Division of the Ministry of Transport until 1946, when he joined the staff of the Shell Petroleum Co., Ltd., in whose service he continued until his death on 20th December 1958.

Mr. Ahearne was a Member of the Institute from 1948.

JOSEPH GAVIN LANDELLS BLACK (Member 9153) was killed on 13th January 1959 at the age of thirty-eight when the 20,762-ton Panamanian tanker *Mirador* exploded and sank at Iskenderun, Turkey, where he was acting as special officer for the Salvage Association. The explosion covered the harbour with burning oil and nearby ships were towed to safety.

Mr. Black was educated at the Royal Grammar School, Newcastle on Tyne, and served an apprenticeship to marine engineering at the Wallsend Slipway and Engineering Co., Ltd., Wallsend on Tyne, spending an additional year in the drawing office. He served four years with the Elder Dempster Lines, Ltd., as fifth to chief engineer, and then sailed as chief engineer with the British Oil Shipping Co., Ltd. He joined Swan, Macfarlane and Co., Ltd., in 1947, of which company his grandfather was chairman, and in May 1948 he was appointed a director.

Mr. Black was a Member of the North East Coast Institution of Engineers and Shipbuilders and a Fellow of the Society of Consulting Marine Engineers and Ship Surveyors. He was first elected to membership of the Institute of Marine Engineers as a Probationer Student in 1939, transferring to Studentship in the following year and to Associateship in 1944; he became a full Member in 1950. In 1954 he was elected to membership of the Committee of the North East Coast Section of the Institute, on which, except for one year, he served until his death. In 1956 he gave a paper entitled "Some Cases of Marine Insurance and Salvage" at a meeting of the Section.

EDWARD LESLIE CHOUNDING (Member 6318) served an apprenticeship with Mort's Dock and Engineering Co., Ltd., Sydney, from 1900/05, and then went to sea until 1916, obtaining a First Class New South Wales Certificate. He then joined the Bellambi Coal Co., Ltd., of Sydney as superintendent engineer, the appointment he held for the rest of his professional career. In his youth Mr. Chounding was a keen swimmer and in 1902 won a gold medal in a 100-yards championship held by the West Sydney Swimming Club, of which he was a member. He died, aged seventy-four, on 16th September 1958.

Mr. Chounding has been a Member of the Institute since 1929.