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Juniper Class Operational Guide for Icebreaking

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INTRODUCTION

The 225-ft WLB Juniper Class was designed as an ice-strengthened vessel and is currently expected to perform domestic icebreaking support missions as a part of its operation. These new cutters have replaced the 180-ft WLB buoy tenders that have served well for many years. The new 225-ft WLB Class have been designed with more horsepower and more ice-strengthening so they are capable of breaking more ice. But this class of cutters has limitations because they were designed primarily as buoy-tenders so they cannot be operated in the same manner or as effectively as dedicated icebreakers. Hence, knowledge of their icebreaking capability in terms of hull form limitations, hull structure limitations and machinery limitations will be described so proper and effective icebreaking operations can be performed. In addition, in severe ice years, some cutters from year-round ice-free ports will be deployed to assist in ice-infested waters, and the crews of these cutters will need guidance for icebreaking in order to employ their cutter effectively. The purpose of this report, therefore, is to provide an Operator Guidance Manual for Icebreaking for the 225-ft WLB Juniper Class tenders.

Knowledge of this class's icebreaking performance, performance limitations and systems configuration necessities will allow this class to perform domestic icebreaking missions effectively and safely. This operator guidance manual for icebreaking is intended to assist new, inexperienced and out of practice operators in understanding the performance capabilities of the cutter. Finally, mission planners will be able to match mission requirements due to existing ice conditions to available fleet resources with greater effectiveness.

LAKE AND SEA ICE IN THE ATLANTIC OPERATING AREA

The Atlantic operating area encompasses the coastal waters, harbors and rivers of the East Coast and the Great Lakes. The ice that grows in these different regions can have different mechanical properties that influence how easily the ice breaks and therefore the icebreaking performance and ice loads that press against the hull. The mechanical properties of ice such as the crushing strength and bending strength are influenced by the salinity of the water and the temperature of the ice.

The sea ice is formed from salt water in the coastal waters of the East Coast. Bays and rivers that are tidal can have lower salinity in the water and therefore lower salinity in the ice when it forms. Great Lakes ice is formed from fresh water. Northern parts of the Great Lakes can be extremely cold making the ice hard and brittle. Areas like Buzzards Bay have ice that retains a fraction of the water's salinity, the frozen salts retained in the ice make it less hard and more ductile. Snow cover can insulate the ice from colder air and make the ice softer as well. However, snow on the ice also increases the friction between the icebreaking ship and the ice, making it harder for the ship to proceed.

Ice forms starting with frazil ice, a collection of ice crystals forming a slurry-like film on the surface that eventually coalesce into a thin layer of flexible ice called nylas. Initially the ice has a granular crystal structure that is randomly oriented, but as it gets thicker in calm areas, the crystals orient themselves and form long needlelike structures in the direction of the ice growth (down from the surface). The ice cover can break apart into pieces called floes due to the action of wind, current or waves. Ice is called landfast if it is frozen into a channel or bay that prevents it from drifting. When ice breaks into floes, it is termed pack ice and its areal concentration on the water surface determines whether it is open pack or close pack ice. Close pack ice is the term used to describe concentrations of ice that cover more than 60 percent of the water surface.

In pack ice, wind and current can create pressure in the ice field that causes the floes to bunch together and collide. These collisions between floes cause the ice at the edges to break and the pieces to pile up both above and below the waterline of the touching ice floes. This pile of broken ice between two colliding floes is known as a pressure ridge or, on the Great Lakes, a windrow. The part of a ridge that is below the water (keel) is typically about three times deeper than the height of the part above water (sail). An idealized cross-section of a 10-ft sail height pressure ridge is shown in Figure 1. The proportions of this idealized pressure ridge are based on the averaged measurements of many ridges in the Bering Sea normalized by their sail heights. Based on this figure, pressure ridges of other sail heights would have proportionally smaller or larger dimensions on average.

When pressure ridges are newly formed (Figure 2), they are easier to break through. Older ridges (Figure 3) have a chance to refreeze and consolidate (form a single mass of ice) in the central part of the ridge if temperatures are cold. These older ridges can be much more difficult to break and should probably be avoided if their sail heights are more than several feet high.

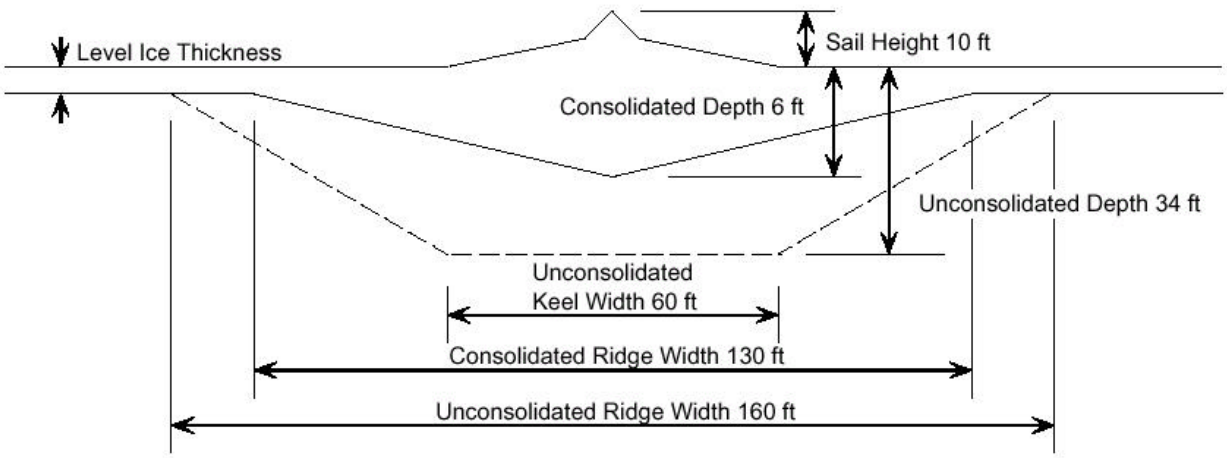


Figure 1. Representative proportions for a 10-ft sail height pressure ridge.

Figure 2. Newly formed pressure ridge in the center of the picture on the edge of a small floe.

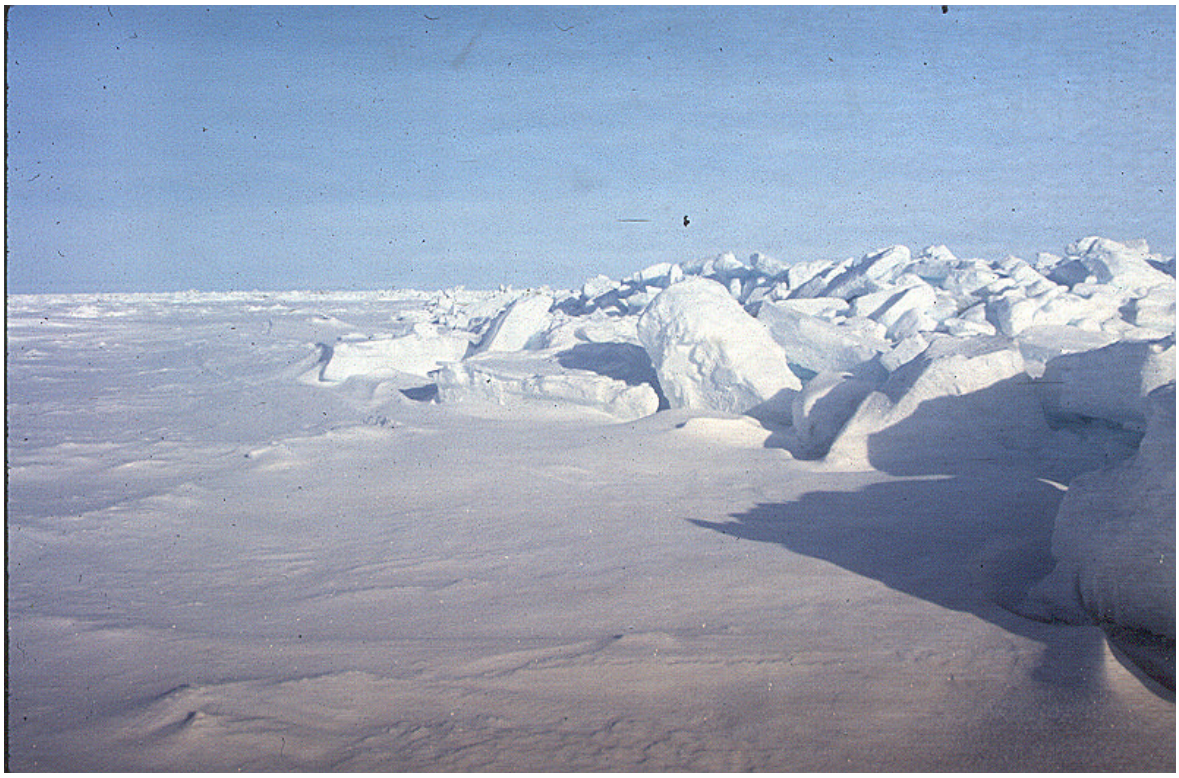


Figure 3. Older ridge of annual ice that may be refrozen. Note the snow cover.

In heavy ice conditions on some of the navigable rivers, ice jams can form. These jams are essentially pressure ridges or rubble fields that ground on the bottom or some obstruction. As ice continues to drift downriver, more and more ice builds up causing the jam to grow and restrict or stop traffic. Breaking up ice jams is both difficult and dangerous. When the ice jam is released it can carry the ship downstream with the current if it does not have sufficient power to resist the forces exerted by the ice.

HULLFORM AND APPENDAGES

The Juniper Class WLB has an icebreaking bow (See Figure 4) characterized by a low stem angle and parallel buttock lines that generate flair in the forebody. As the ship moves forward in the ice, it rides up slightly (causing the cutter to pitch) on the ice cover and generates a downward bending force on the ice that causes the ice to break. The amount of pitch is almost imperceptible in level ice but increases with ice thickness. If the ship were to ram a ridge, then the pitch becomes more noticeable and, in fact, the ram may not break the ice feature. The waterline and bow have a pointed wedge shape that provides a balance between maneuverability in level ice and the ability to "grab" into the ice edge when turning out of an existing track in ice. This bow shape also facilitates backing out of a ridge that fails to break.

Figure 4. Sloped stem and flared bow shape of the 225-ft WLB for icebreaking.

The requirements for high speed in a relatively short ship length meant that the waterline for the WLB was maximized. Consequently, backing in ice was compromised to meet the primary, AtoN mission of the ship. The rudder was placed at the transom along with an ice knife that goes through the

waterline (see Figure 5). With this arrangement, the ice knife impacts the ice cover first when backing and serves to protect the rudder. On typical icebreaking ships, the rudder is lower and further forward so that the hull breaks the ice prior to the ice reaching the ice knife and rudder during backing. Note that the rudder must be kept amidship when backing for the ice knife to be effective in protecting it. If the rudder is not behind the ice knife, it is in danger of being pushed to the limits of its travel and potentially damaged. The 225-ft WLB Class cutters are not able to back in ice when the thickness is much greater than 8 to 10 inches because the ice knife does not break solid ice cover easily, and the resistance is sufficient to stop the ship.

The 225-ft WLB Class cutters have controllable-pitch propellers. These types of propellers are efficient and responsive for the buoy tending mission. However, they have a drawback that must be considered during ice operations. The backing thrust of a controllable-pitch propeller is about 50 percent of its ahead thrust when both are in the bollard or zero-speed condition. For icebreaking, this means there may be plenty of thrust to go ahead into a tough ice area but only half the thrust to back out if the ship is stopped. For operators accustomed to direct-drive diesel-electric configurations, the lack of stopping power is critical to understand. When breaking out a ship that is stuck, a fair amount of power is required to get close enough to have any effect. But slowing the 225 ft WLB to stop it at the right relative position to the ship that is stuck requires earlier action than would be normal on some other classes of cutters.

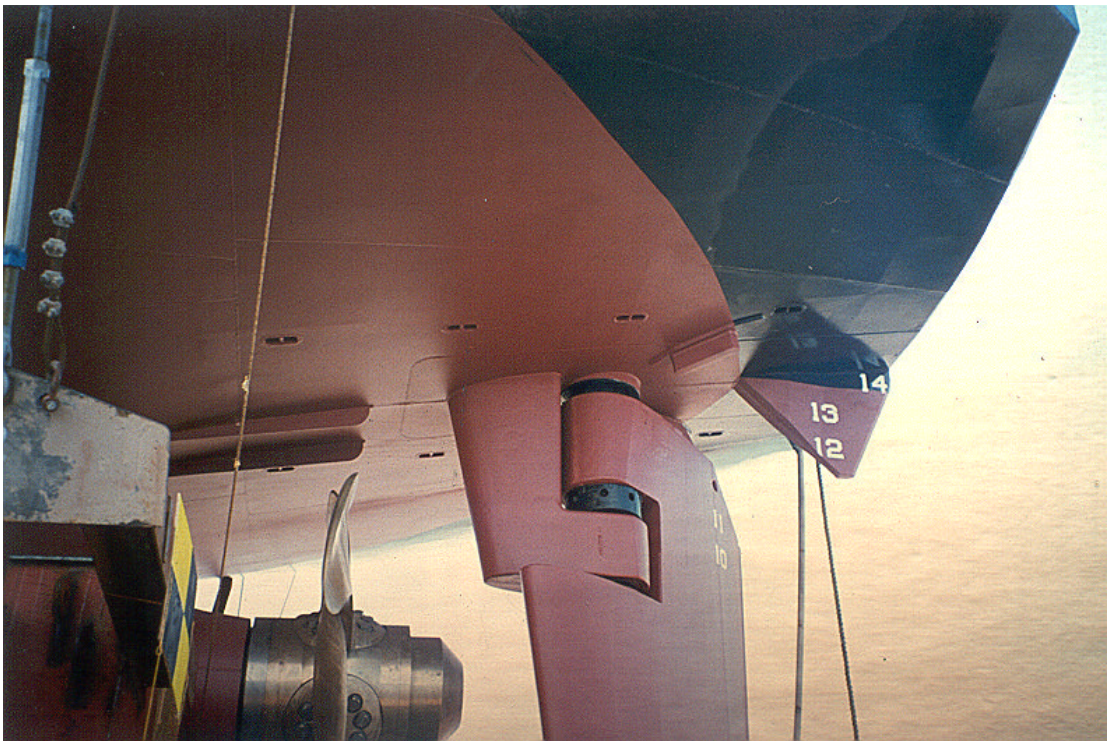


Figure 5. WLB rudder and propeller showing the ice knife behind the rudder to protect it from ice impacts when backing and the fairing above the propeller on the A Class.

The tip clearance for the A-Class of 225-ft buoy tender and the 5 in deep flow-accelerating fins are shown in Figure 5. In the B-Class, a fairing over the propeller, shown in Figure 6, was installed to provide a better way to accelerate the flow into the propeller and reduce propeller cavitation and therefore noise. The fairing prevents the pulses from impacting the hull. An added benefit of the fairing on the B-Class is that the prop wash is highly concentrated and can be effective in bow flushing during escort operations when applying full power from a standstill in a broken channel. The fairing reduces the clearance over the top part of the propeller to about 15 inches from the 24 in clearance below the hull of the A Class. It is assumed that this restriction may cause increased frequency of milling ice and some increase in resistance in all ice conditions when operating in ice. Further investigation of the performance of the fairing in ice must be done to quantify its effect on icebreaking operations.

Figure 6. WLB B-Class rudder, propeller and hull showing the fairing over the propeller to accelerate the flow into the propeller and reduce propeller cavitation.

ICE STRENGTHENING AND THE ICEBELT

The “icebelt” is the portion of the shell structure around the waterline where the ice loads impact the hull. The icebelt and its supporting structure are designed for the ice loads that can occur in the Great

Lakes during operations in up to 24 in of hard level ice. The coverage of the icebelt for the 225-ft WLB is as shown in Figure 7.

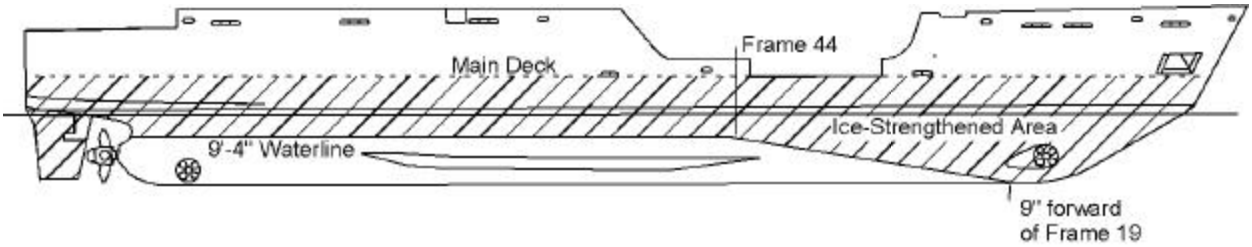


Figure 7. Extent of the icebelt for ice strengthening on the WLB.

Ice loads exert a high pressure over a small area when the ship impacts an ice floe. As such, the loads are local but intense, and they can occur anywhere within the icebelt region. To resist these local ice loads, the WLB has been designed with a system of closely spaced (21 to 23 inches) transverse frames and thicker icebelt shell plating. Midspan girders (stringers) transfer some of the load from one frame to the adjacent ones and help prevent the frames from tripping (collapsing by lying over) under the high local loads. Such a system gives the ship tremendous reserve capacity to take loads well above the design load without rupture or catastrophic failure. Higher grades of steel have been used to prevent brittle fracture (forming of cracks under load) in the cold air temperatures.

A hierarchy of strength has been used in the design. The “weakest link” is designed to be least critical or most easily replaced element. The best example of this approach might be the propulsion system where the propeller blade fails before the hub and key components like the reduction gear.

THE MACHINERY PLANT OPERATION IN ICE

Machinery Control System

The 225-ft WLB cutters are equipped with two modes of operation for the propulsion control. Transit mode varies both the pitch and rpm of the controllable-pitch propeller in combination as the throttle lever is moved. This mode ensures the most efficient conditions for the propeller throughout the range of ship speeds in open water. In ice, however, the maneuvering mode must be used. In this mode, shaft speed is held constant at 203 rpm at the shaft (720 rpm at the main diesel engines) and pitch is varied with changing throttle position. To remain in maneuvering mode, the shaft speed must be between 196 and 204 rpm. Most propellers on icebreakers are broken when the propellers are stopped or barely rotating. By keeping the shaft spinning and only varying pitch, the propeller is better protected and thrust response ahead or astern is rapid.

For operation in heavy ice with a controllable pitch propeller system like the Juniper Class has, high propeller rpm should be maintained to prevent damage. Propeller blade damage is most likely to happen when you are doing maneuvers like backing and ramming and the ship backs into solid ice with the propeller turning at lower shaft speed. During maneuvers like this, the propeller operates in unusual directions to the inflow of water such as reversing pitch while the ship is still moving ahead. The propeller is more vulnerable to a load on the back or face where it's bending strength is weaker than hitting on the blade edge. In flow direction to the propeller is a function of the speed of the ship and the propeller. If the shaft speed is increased, the in flow angle is closer to the plane of the propeller disk and therefore ice pieces are more likely to strike the edge of the blade where it is stronger. This is one significant reason maneuvering mode should be used. The control system also protects the shaft line from over-torque in this mode as well.

For maneuvering mode, there is a non-linear relationship between pitch at the propeller and throttle level position. The pitch/throttle level relationship currently in use on USCGC HOLLYHOCK is shown graphically in Figure 8. Two curves are shown for one or two engine operation. These curves are used to relate throttle position to icebreaking performance in the following sections. Two curves reflecting the default setting are present in Appendix D.

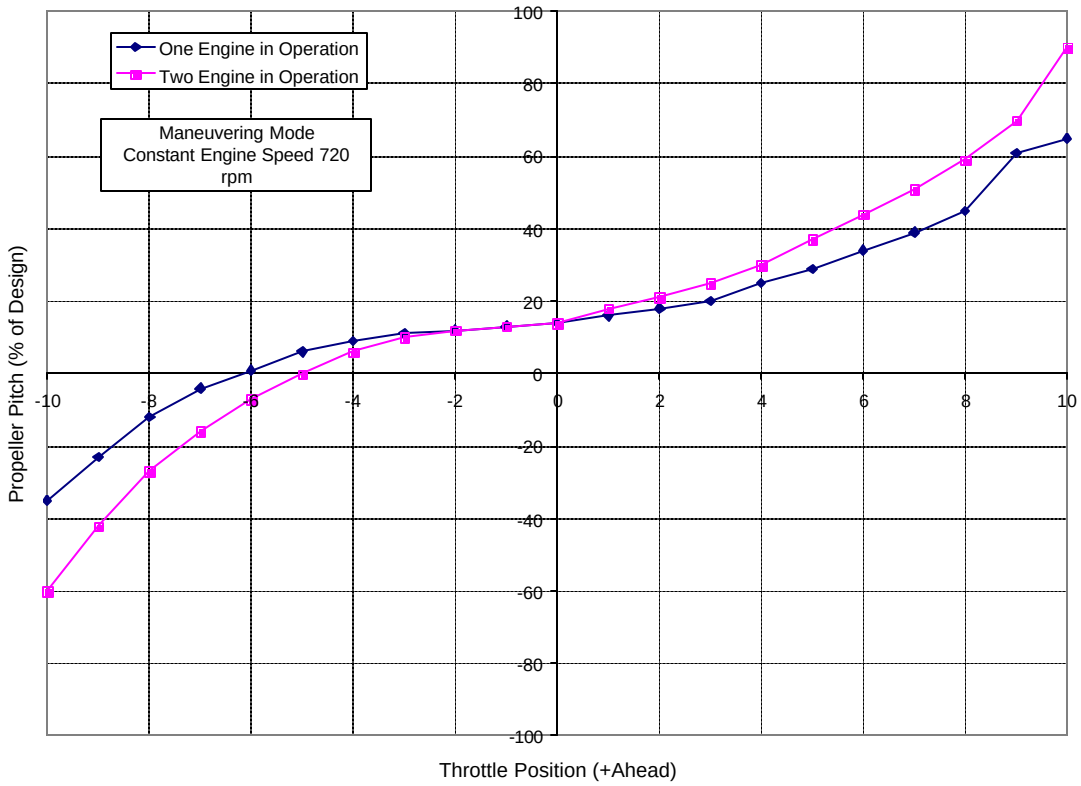


Figure 8. Relationship between throttle position and pitch for maneuvering mode based on Hollyhock experience.

Reduction Gear

During the JUNIPER trials in 24.5 in level ice, ice milling events were recorded where the ice induced torque was at or slightly above design load for the shafting system. Some higher torque events are expected with prolonged operation in these conditions. During the reevaluation of the ship for operation in thicker ice, the reduction gears were strengthened for the 225-ft WLB B Class. Therefore, extended operation in heavy ice conditions is not recommended for A Class ships but B Class ships should be fine.

Steering Gear

The 225-ft WLB class cutters must align the steering gear to zero degrees (positioned amidships) when going astern in ice. Use of the steering gear to maneuver the vessel while going astern risks potential loss of steering control and potential damage to the system. The overhauling loads created by ice impact while going astern, particularly on a rudder which is not aligned to zero, can generate excessive hydraulic pressure in the steering gear system as the rudder is physically forced against the external rudder stops.

The typical relief valves installed in a steering gear system are intended only to relieve the full flow of one of the hydraulic pumps. If a rudder is jammed, and there is a signal for the pump to move the rudder, the relief valve will allow the pump to go to full stroke without damage. However, when the ship backs into ice with the rudder not behind the horn, the rudder is forced over and excessive pressure and near instantaneous volumetric flow of hydraulic fluid are generated. This condition can overwhelm the relief valve by an order of magnitude, creating forces which must be relieved or absorbed somewhere. Several years ago, a POLAR Class icebreaker was locked between two moving ice flows, and the rudder was overhauled against the external rudder stops by the shifting ice, creating excessive forces which destructively twisted the steering gear off of its foundation before the rudder stopped.

Current design policy for icebreaking vessels is that the overhauling forces and fluid flows from those forces must be addressed. The use of burst disks as a bypass between the supply and return is the least costly alternative for protecting the hydraulic system and equipment on an occasional basis. Standard relief valves (in a larger size to permit high flow rates) do not react as quickly as “Fast Acting” type relief valves, and are not acceptable. “Fast Acting” type relief valves are pilot operated and must be maintained in order to assure operational value.

The 225-ft B-class cutter steering gear systems were fitted with burst disks in addition to the normal relief valve system as part of the equipment installation. See drawing 225B-WLB-561-001. The burst disks are not documented in the technical publication. These disks take effect at a setting of approximately 125 percent of the normal service relief valves. When the disks rupture, they instantaneously provide for full-flow of fluid between supply and return, minimizing the physical damage to the system, and retaining the oil within the system. The rupture event can not always be recognized immediately. The steering system alarm will be triggered more than likely in a few minutes if any large rudder movements have been required. One of the indications that can be used as the practical way of identifying the problem is to verify the elapsed time of rudder standard maneuver from 30-degree starboard to 30-degree port. This time should nearly double with either of the disks ruptured.

Although replacement of the disks must be done manually, the disks were installed with cut-out-valves, permitting very quick recovery of the system by closing these valves. Under normal operating conditions, the normal operational forces in the steering system do not approach the relief valve pressure level, and the rupture disk will have no operational impact.

With regards to the steering gear, the 225-ft A- and B-class cutters can be safely operated under ice conditions. The steering system design was based on the rudder and rudder stock design strengths, which incorporated factors for ice operation conditions. The cutters must align the steering gear to zero degrees when going astern in ice, however. Use of the steering gear to maneuver the vessel while going astern risks potential loss of steering control and potential damage to the system. If cutters encounter conditions under which ice impact causes the relief valves and/or burst disk to actuate, the potential for damage to those cutters with burst-disks will be minimized.

Thrusters

The 225-ft WLB Class is equipped with both a bow and stern thruster for improved maneuverability at slow speed and station-keeping intended for use in open water. The thrusters have been shown to be effective in light ice situations. The ship can be turned in light broken ice by using the thrusters. Thrusters do not provide enough thrust nor does the ship have sufficient flare in the stern area to break solid ice and turn. Further, in heavier ice conditions where ice pieces are forced down the hull, the use of thrusters will not be effective and is not recommended. The tunnel thrusters have grates at their openings but ice pieces will be trapped on the grates, blocking flow and starving the propellers of water. The thrusters can be damaged if they are starved for water or mill significant amounts of ice. It is recommended that the thrusters be secured when not in use. Securing will prevent them from jamming and slowly heating up the motor windings due to inability of the propeller to spin freely.

Icebreaking Guidelines for Seawater System

The system consists of a port and starboard sea chest supplying a sea bay at the centerline. It is recommended that either the port or the starboard sea chest be on line but not both simultaneously. If the cutter is operated with both sea chests on line, then there is the possibility of both becoming clogged simultaneously. If the cutter is operated with only one sea chest on line and the valves on the other sea chest shut, then the other sea chest can be in standby with its strainer clean.

Both sea bay vent valves and both 2 inch sea bay recirculation valves should be kept open to maximize the recirculation of water back to the sea bay and to allow entrained air to escape through sea bay vents.

The 6-in. sea chest recirculation valve serving the stand by should be cracked open and the 6-in. sea chest recirculation valve serving the sea chest on line fully open.

The PMC controller serving the Leslie 3-way temperature control valve should be in manual mode and set the valve to recirculate 100% of the water.

The overboard discharge valve downstream of the Leslie 3-way valve should be closed.

Sea bay temperature should then be manually regulated to approx. 80 degrees F. This can be done by manually adjusting the standby sea chest recirculation valve. Opening this standby sea chest recirculation valve will divert more of the warm water away from the online sea chest and lower the temperature of the sea bay. Closing this standby sea chest recirculation valve will direct more of the warm recirculation water to the online sea chest and raise the temperature of the sea bay. Note that the sea bay temperature sensor is sluggish in responding to changes in valve position and that it might take a few minutes to see the resulting change on the temperature display after adjusting the standby sea chest recirculation valve. Also the starting and shutting down of various seawater services such as fire pumps and changes in vessel speed can upset the sea bay temperatures and require some adjusting of the standby sea chest recirculation valve to maintain the desired temperature. Using this standby sea chest recirculation valve to regulate sea bay temperature will also cause some back flushing of the standby sea chest to ensure it is ice free and ready for use if it is ever needed.

It is recommended to switch the PMC and the Leslie 3-way valve back to automatic mode when operating in ice free waters. Note that the seawater system design was intended for automatic sea bay temperature control in both ice and open water. However, it is suspected that the Leslie valve fails to perform in a stable manner due to the sluggish response time of the temperature sensor. Therefore it is recommended to switch to manual mode when operating in ice.

Operational experience indicates that in cold waters instead of adjusting the Leslie valve in the automatic mode and trying to find the proper set point for temperature, one could switch to manual mode and completely close the overboard discharge to recirculate all water back to the sea bay with only a small amount diverted to the standby (offline) sea chest to prevent its clogging. The sea bay and sea chest vent pipes could be fitted with collapsible rubber hoses to prevent ingestion of air in the event that the strainers or sea chests become clogged. By doing this, sea bay temperatures could be kept high without losing

cooling water even when running the fire pump. Cooling water flow could be lost with the Leslie valve in auto mode or when recirculation waste water to the sea chests and sea bay. Stern tube cooling water could be lost first, perhaps because the MDE raw water pumps overpower the single o/l ASW pump for the limited water available in the sea bay. Higher sea bay temperatures have been observed when recirculating to one or both sea chests in addition to the sea bay. Even when the sea bay high temperature alarm on MPCMS triggered, all MDE temps remained in the normal range.

It should be noted that cleaning an ice-clogged sea strainer on the WLB Class can be a difficult operation which should not be attempted during icebreaking operations.

ICEBREAKING PERFORMANCE

LEVEL ICEBREAKING PERFORMANCE

Level icebreaking performance is estimated based on the USCGC Juniper (WLB-201) Ice Trials. Figure 9 shows the effect of ice temperature on level ice performance at full throttle in maneuvering mode. The ice flexural strength varies with temperature and this is the parameter that affects performance. Within this plot, ice strengths of 75 psi for normal winter ice, 110 psi for cold winter ice, and 50 psi for decaying spring ice are used. Figure 10 presents the performance for the full range of propeller pitch and throttle positions in level ice of normal winter strength.

The Atlantic operating area includes regions where extremely cold temperatures occur, resulting in areas where fresh water ice and sea ice can develop. Sea ice and fresh water ice have different ranges of ice strength. Generally, if the water is more saline, the ice is weaker. But temperature plays a role as well. If the temperature is colder then the ice is stronger. The normal winter ice of Figure 10 is probably representative of most areas in the lower Great Lakes and eastern rivers. Buzzards Bay ice is probably slightly weaker, closer in strength to decaying spring ice in Figure 9 on average. Duluth ice is more like the cold winter ice in Figure 9 on average. Ship performance will vary depending on ice strength typical in Great Lakes, Hudson River, and Buzzard's Bay, for instance. Figure 11 shows differences in WLB performance in winter ice of Buzzard's Bay and the Great Lakes.

There are other factors that can affect icebreaking performance as well. Hull-ice friction is a significant one. The 225-ft WLB Class has a low friction hull coating but surface conditions on the ice such as snow can affect performance. Within the Atlantic area, there are areas of high snowfall and also areas where high winds sweep the ice clean. A reasonable overall estimate of the effect of snow is to reduce speed by 1 kt for every 12 inches of snow cover on the ice. In some cases where the snow is very sticky, this same 1 kt reduction can be caused by only 8 inches of snow cover on the ice.

Trim is important for good icebreaking performance and safe operation. Trim by the stern reduces the bow's effectiveness in icebreaking, but the influence is small for such a small change in angle. Icebreaking astern is adversely affected if the transom is in the water because the transom is vertical and does not break the ice. The flat transom hitting solid ice generates large ice loads, and there is some possibility of damage to the transom in this condition. However, propellers are more protected from ice impacts the deeper they are submerged. Given all these considerations, even keel is recommended.

In situations when the ship is severely stuck, especially in windrows, moving liquids from the forward tanks to the aft tanks is effective in freeing the ship. In level icebreaking, filling ballast tanks in the ends of the ship increases the pitch stiffness and steadies the icebreaking process, improving efficiency. Ballast tanks forward can be filled, but they have to be counter-balanced with weight aft to keep an even trim.

Vibration should be considered as well when ballasting the ship for icebreaking. Specifically, filling tank 4-21-0 W with ballast and keeping fuel tank #17 full as long as possible may reduce the vibration of the front part of the ship. Conversely, keeping peak tanks 4-0-0 W and 4-0-6-W full but fuel tank #21 empty may increase vibration.

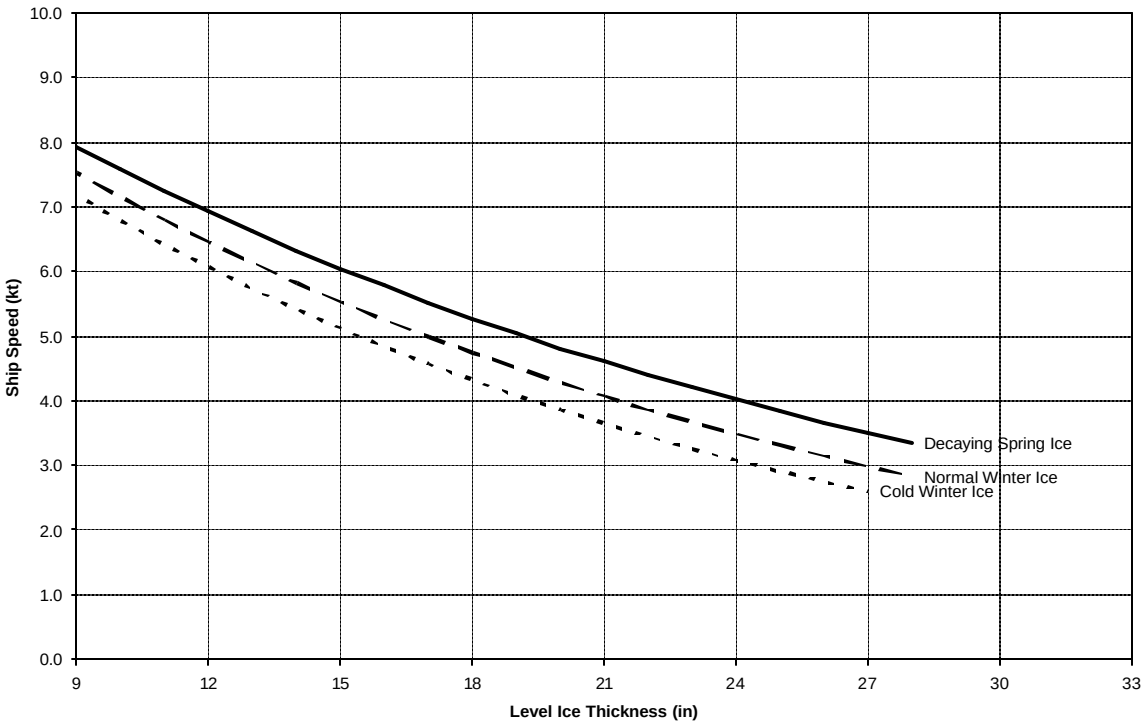


Figure 9. WLB performance in Great Lakes level ice at different temperatures (maneuvering mode).

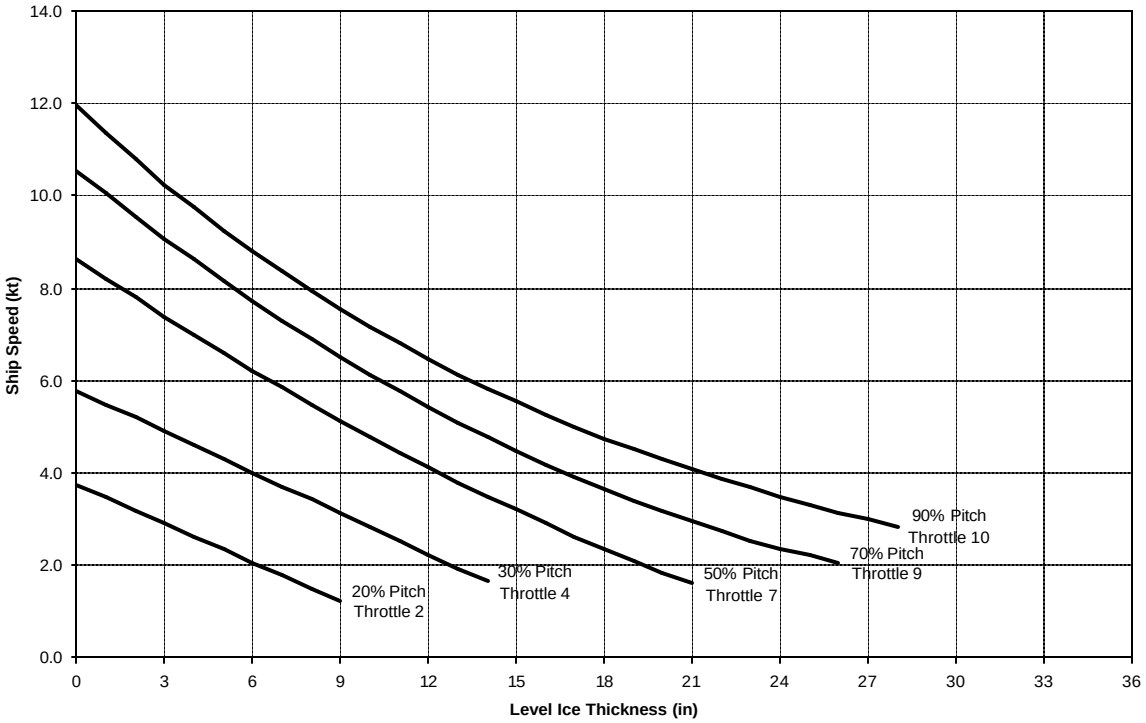


Figure 10. WLB performance in normal Great Lakes winter landfast level ice (maneuvering mode).

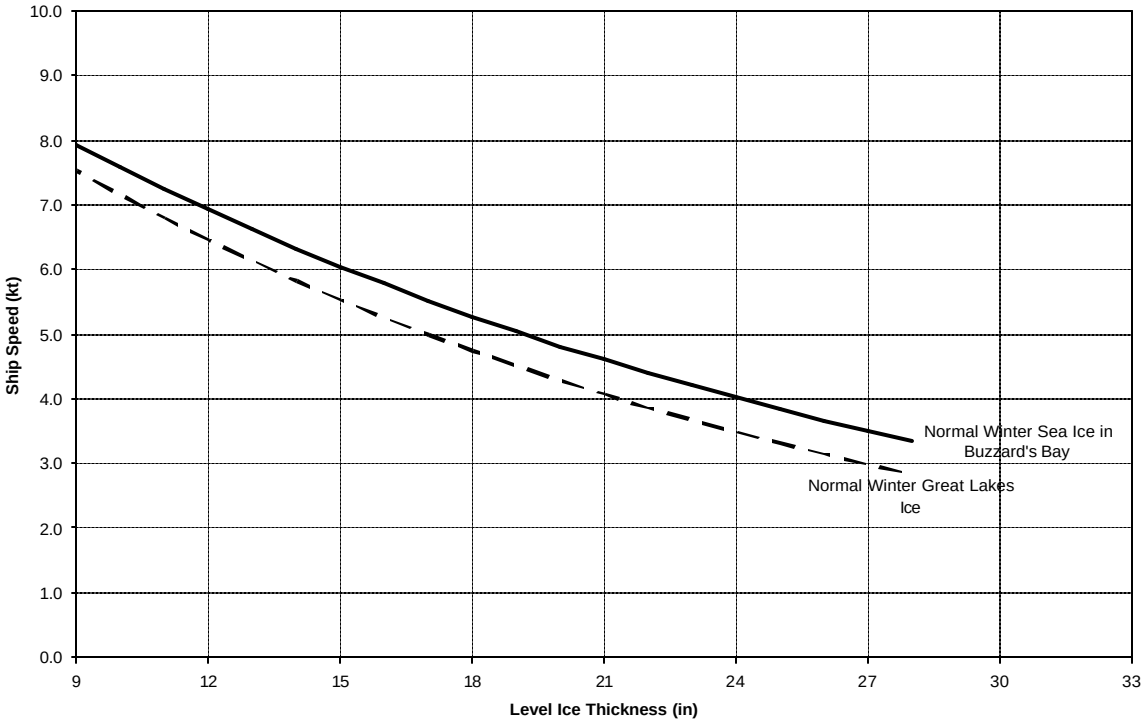


Figure 11. WLB performance in ice of sea water (Buzzard's Bay) versus fresh water (Great Lakes) (maneuvering mode).

PERFORMANCE IN A TRACK (BROKEN ICE AND BRASH ICE PERFORMANCE)

Shown in Figure 12 is the WLB performance in a freshly broken track for different throttle positions, while presented in Figure 13 is the performance in an old channel (after many transits through the channel) for different throttle positions. The brash ice thicknesses in Figure 13 are large. They can be expected in the older channels formed in places such as the St. Mary's River. Performance in broken ice was estimated based on measurements taken during the USCGC Juniper (WLB-201) Ice Trials. Brash ice performance was determined analytically based on a model that was correlated to model tests for the Great Lakes Icebreaker Replacement (GLIB) program.

It should be noted that snow and dense brash in the channel might create conditions for ice "sticking" to the hull. This condition, some times called an ice "moustache", will significantly increase ice resistance, slow progress, and make maneuvering more difficult. At least one reported incident of this condition has been reported by a 225 ft WLB. This phenomenon is known to occur more frequently at very low speed and is also affected by the hull conditions (friction). The best way to minimize the probability of this phenomenon is to sustain reasonably high speed whenever it is possible. It is important to maintain the hull surface in good condition painted with an ice-resistant coating.

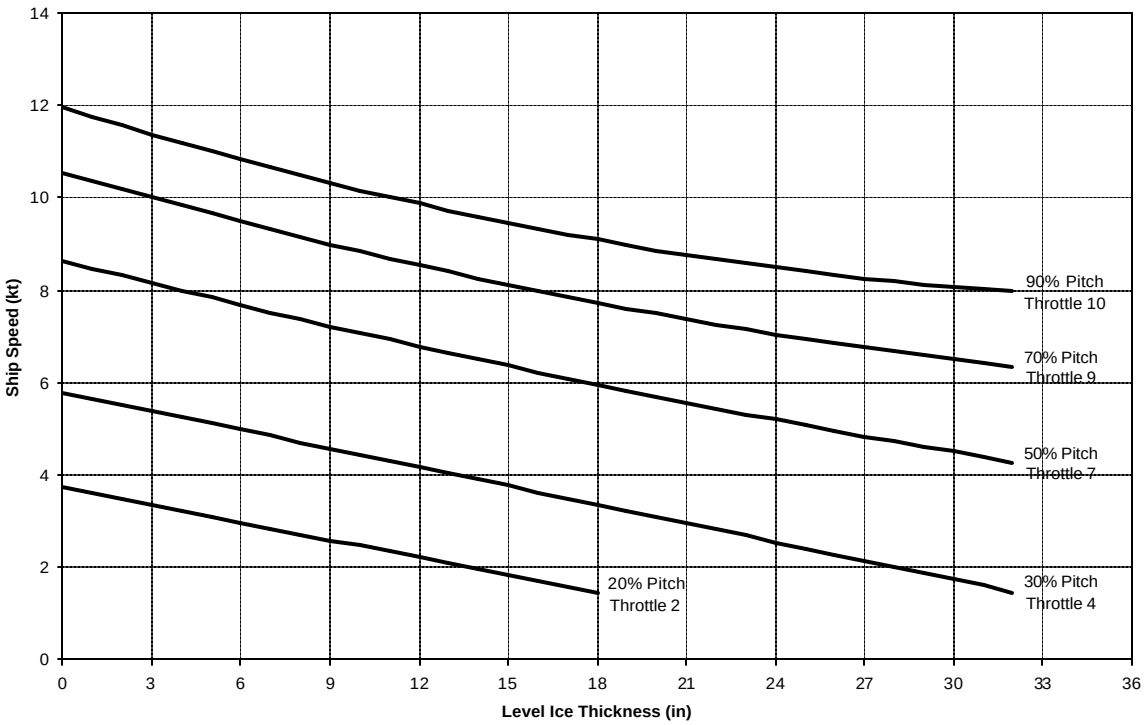


Figure 12. WLB performance in a freshly broken track (maneuvering mode).

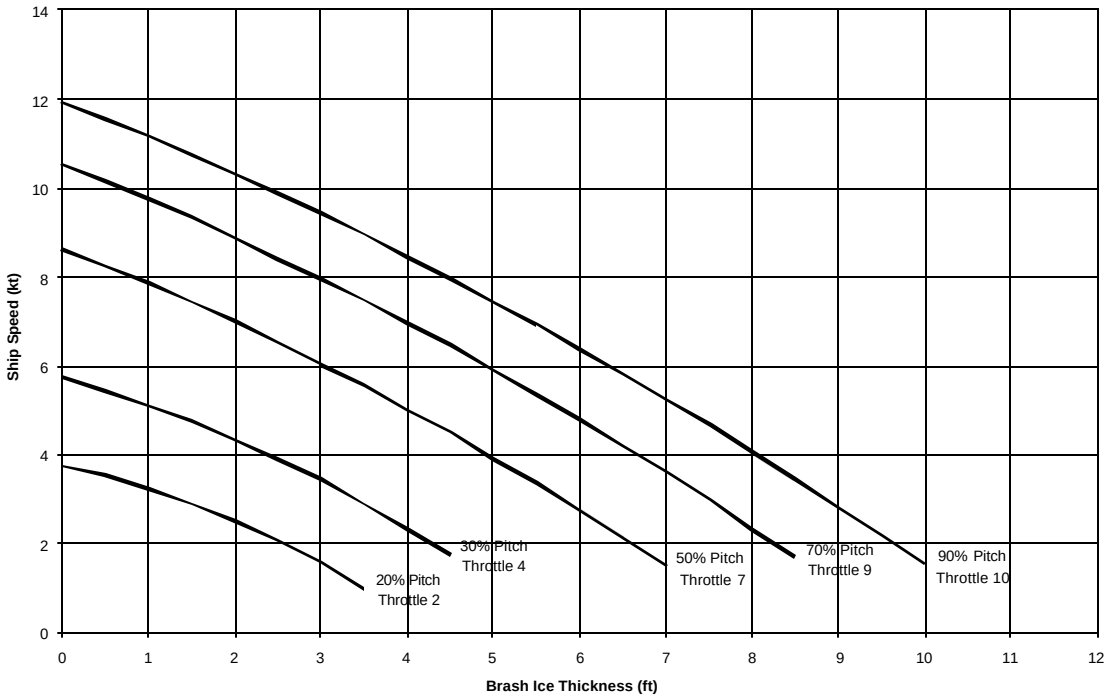


Figure 13. WLB performance in an old channel (maneuvering mode).

ESCORT PERFORMANCE

Presented in Figure 14 and Figure 15 is the performance of a Great Lakes ore carrier (laker) proceeding alone or escorted by various combinations of icebreaking ships in level ice. Two typical sizes of laker are presented, the 1000-ft Class (newer ship with 105 ft beam) or the more traditional AAA Class (75 ft beam). The combination of a 225-ft WLB Class cutter working together with a 140-ft WTGB cutter is particularly effective. These figures are only intended to show the relative performance of icebreaking ships and escort vessel in level ice. They represent the results of escort simulations that include both continuous escort and direct assists based on Great Lakes escort statistics used for the GLIB concept design. In real operation every escort is different, and the 140-ft WTGB cutter may well outperform the 225-ft WLB Class cutter if the situation requires a much greater number of direct assists than average. The escort efficiency may also be different if a WLB is escorting vessels through an established track and starts out behind the assisted vessel to be in position for an easy relief track pass if or when the vessel becomes stuck. (See also “Operations with other icebreaking ships”, page 31).

Safety during escorting is of great importance. Proper separation between lead and escorted vessels must be maintained to avoid collisions in the event that an icebreaker suddenly stops or slows significantly. In a two-ship track-breaking operation, it is possible to cut a much wider track that could allow increased separation between the lead ships and the escorted ship(s). The escorted ships have a better opportunity to proceed without getting stuck in a wider channel. Much depends on the capability of the ship being escorted.

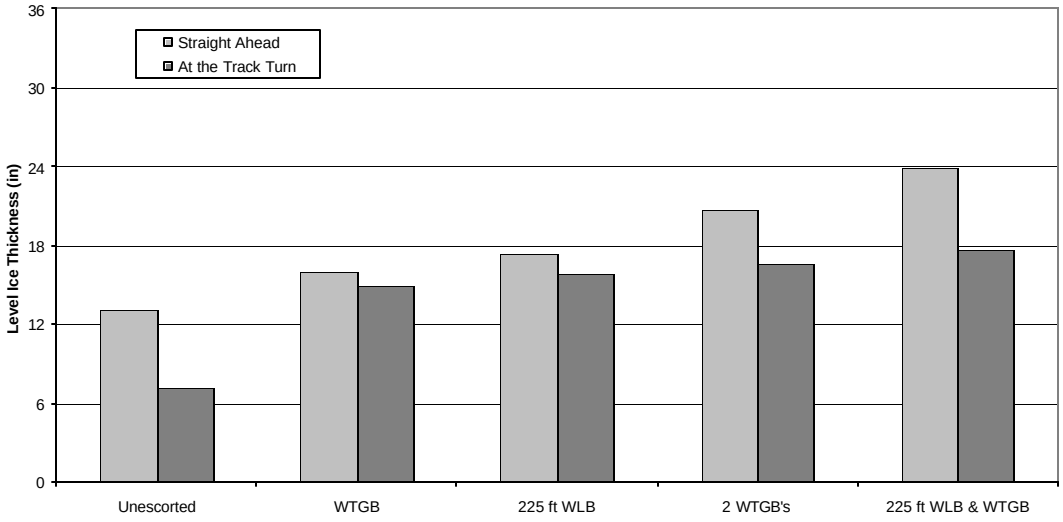


Figure 14. The effect of various escort options on the performance of a 1000-ft laker in ice (3 kt convoy speed).

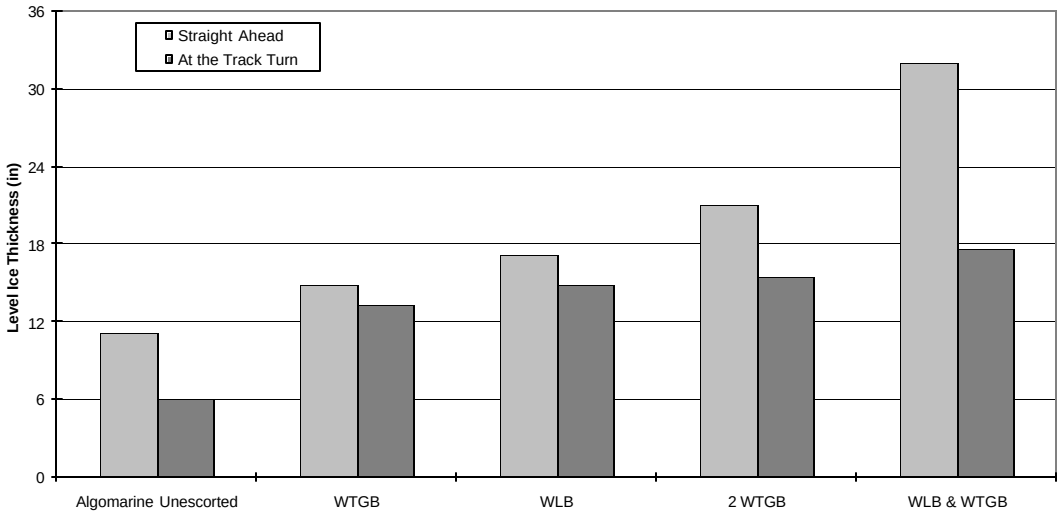


Figure 15. The effect of various escort options on the performance of a typical 75-ft beam laker in ice (3 kt convoy speed).

PERFORMANCE IN PRESSURE RIDGES OR WIND ROWS

Performance in pressure ridges was determined analytically based on a model that was developed for the GLIB Concept Design Study and specification development. The model simulates the ridge ramming cycle that can be described as follows:

1) the ship is stopped at the start of the ram within a charge distance from the ridge,
2) acceleration up to impact speed,
3) impact and penetration until stopped,
4) reverse motion,
5) backing to a charge distance for the next cycle, and
6) reverse motion until stopped.

Simulation results are shown in Table 1 presenting the impact velocity and approach distance required to transit a ridge of a given height in a single ram. The 225-ft WLB is capable of transiting in a single ram only the small ridges (up to 4 ft) formed in the relatively thin ice. In order to transit more significant ridges, it is necessary to conduct multiple backing and ramming cycles. Some representative times and number of rams to transit the ridge are presented in Table 2.

Table 1. Transiting a Small Ridge in a Single Ram

Sail height (ft)	2		3		4	
Surrounding level ice thickness (ft)	1	2	1	2	1	2
Charge Distance (ft)	240	710	392	N/A	604	N/A
(Ship length)	1.2	3.7	1.9	N/A	3	N/A
Impact velocity (kt)	8.2	11.6	10.2	N/A	12.4	N/A

Table 2. Representative Time to Transit a Ridge

Sail height (ft)	3		5		8		10	
Surrounding level ice thickness (ft)	1	2	1	2	1	2	1	2
Charge Distance (ft)	392	350	267	325	620	395	485	399
(Ship length)	1.9	1.7	1.3	1.6	3	1.9	2.4	2
Impact velocity (kt)	10.2	9.2	8.6	8.9	12.3	9.6	11.1	9.7
Number of rams	1	2	2	3	2	4	3	5
Time to transit (min)	3.3	12.2	10.8	25.8	16.8	51.6	43.2	64.6

PERFORMANCE IN OTHER TYPES OF ICE CONDITIONS

This section discusses general performance in some typical ice conditions that are not covered above. These include pack ice, pressure ice and backing in high ice concentrations.

Performance in Open and Close Pack Ice

The 225-ft WLB performance in Open Pack Ice (ice concentration from 4/10 to 6/10) and especially Very Open Pack Ice (ice concentration from 1/10 to 3/10) is not significantly affected by the presence of the ice. The ship speed in this case is limited more by the water resistance than ice resistance because typically there is a lot of room to transit through the leads and navigate around the big ice floes. However, it is not always possible to avoid collisions with heavy ice formations that may generate some dangerous ice loads on the hull structure and/or the propeller and rudder. The following precautions are recommended when entering the Open Pack Ice:

- Switch main machinery to constant RPM mode (maneuvering mode)
- Slow down to 12 to 13 knots if ice thickness does not exceed 1 ft.
- Slow down to 10 to 11 knots if ice thickness exceeds 1 ft.

The 225-ft WLB performance in Close Pack Ice (ice concentration from 7/10 to 8/10) will vary between Open Pack Ice performance and Level Ice performance depending on ice thickness. Open Pack Ice precautions are applicable for Close Pack Ice. Performance in Very Close Pack Ice (ice concentration from 9/10 to 10/10) is usually equal to or slightly better than performance in level continuous ice.

Performance in Pressured Ice

Two categories of ice pressure can be specified. These are:

Regional ice pressure. Ice is compacting and actively building up pressure over a large area.
Local ice pressure. Ice pressure only exists in the area of contact between two or several large floes but regional ice pressure is not present.

Regional ice pressure can be detected by the ice cover and ship behavior. Ice pressure is typically graded somewhat subjectively as “mild”, “moderate”, and “severe”.

- Mild: Ice is compacting and there are very few open water areas visible. Brash ice between the floes is compacting and getting dryer (changes color towards white). The track behind the vessel is slightly narrowing down. The ship slows down.
- Moderate: Ice concentration is approaching 10/10 and some cracks and fractures oriented perpendicular to the axis of pressure can be observed. Brash ice between the floes is squeezed up onto the ice floe edges. The track behind the vessel narrows quickly behind. Ice deformation of thin ice (up to 10-12 in) is actively occurring. The ship slows down sharply or comes to a stop.

- Severe: Ice concentration is 10/10 and no cracks and fractures can be observed. The track behind the vessel is completely closed. Ice deformation is actively occurring at the edges of floes and alongside the vessel. The ship typically is unable to move and remains beset.

Moderate and severe ice pressure conditions should be avoided whenever possible. In case transiting an ice field under pressure is unavoidable, a course that is perpendicular to the pressure direction is recommended as much as possible. In case of besetment, especially under severe ice pressure, it is recommended that the shaft be kept spinning and periodically change propeller pitch direction in order to flush more ice from the stern and the rudder.

Local ice pressure is harder to detect but it should always be anticipated in an area where big ice formations come in contact or in a narrow lead or fracture between two ice floes touching each other at several points. It is recommended that places as presented in Figure 16 and Figure 17 not be used for transit.

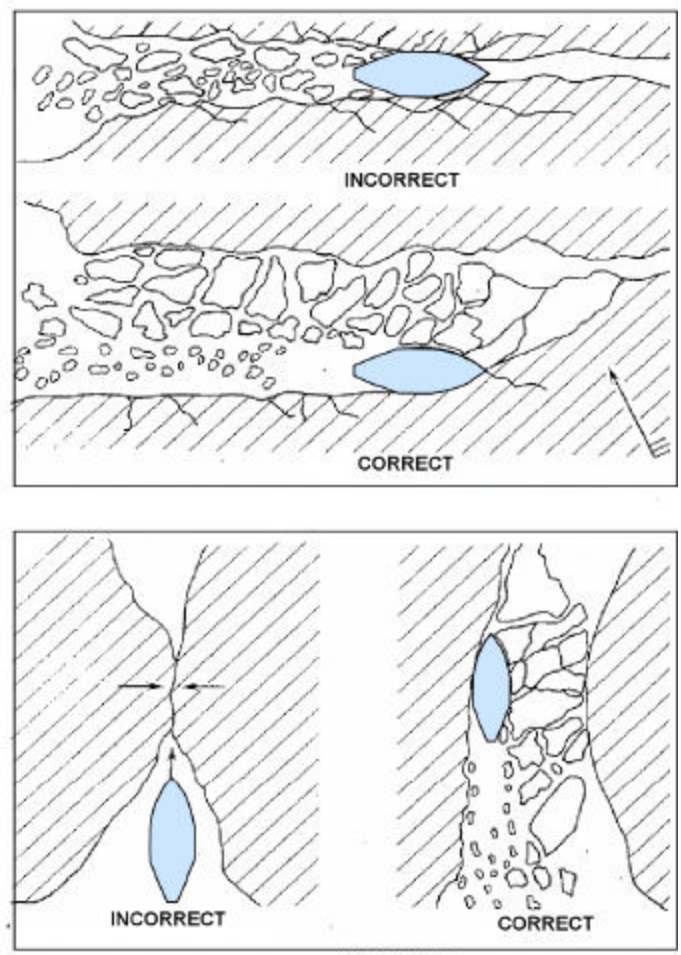


Figure 16. Examples of transiting ice under pressure.

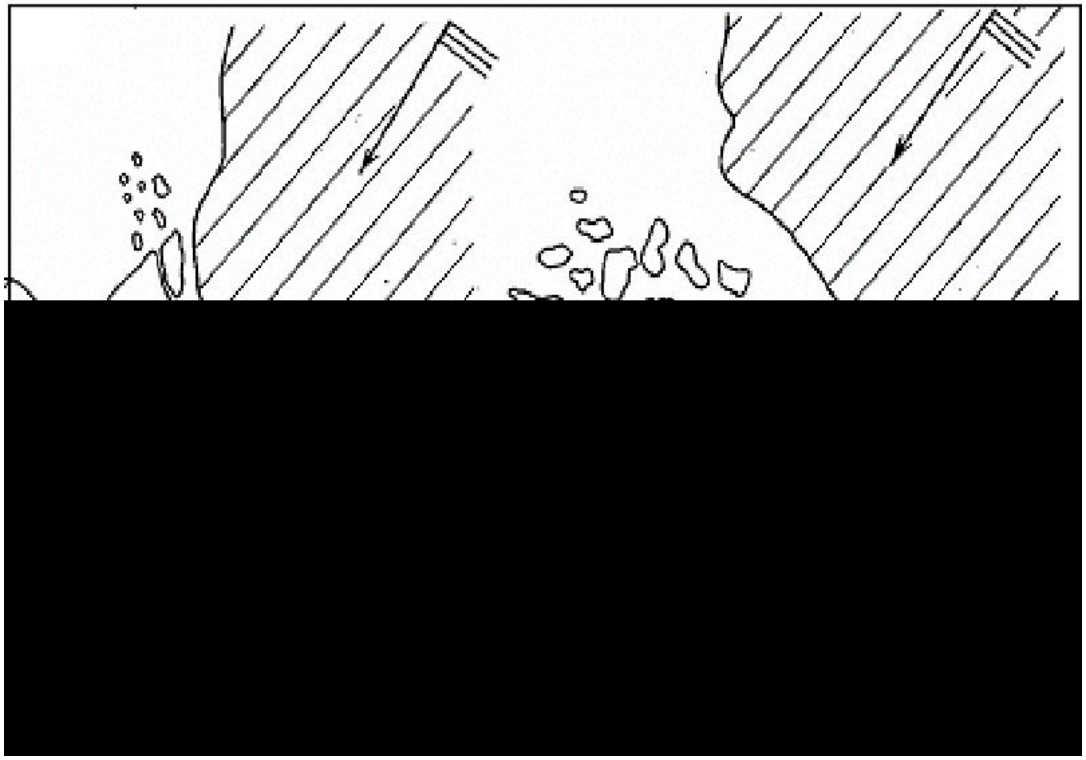


Figure 17. Transiting the ridge (windrow) under pressure.

Backing in Level Ice and Broken Channel.

The 225-ft WLB is unable to move steadily astern in level ice greater than 8 to 10 in. Backing in broken ice is possible and safe provided that the rudder is brought to zero degrees angle. It is recommended that the speed be limited to 4 or 5 knots while moving astern to reduce the risk of rudder damage. In light ice conditions it is possible to maintain the directional control when backing by using the thrusters. In this case, limiting backing speed even more to about 2 knots will improve directional stability and reduce ice-induced vibration.

MANEUVERING IN ICE

STEADY TURNS IN LEVEL ICE

Turning circles in level ice were performed during the Ice Trials of the USCGC Juniper (WLB-201). Data from the trials were averaged for different ice conditions and are presented in Table 3. These are considered to be representative turning circles in level ice for the 225-ft WLB Class though there is variability in the duration and diameter due to the applied rudder angle, the initial ship speed, and the actual ice conditions.

Table 3. Turning Circle in Level Ice

Ice Thickness (in)	Rudder Angle (deg)	Ship Speed (kt)	Duration (min)	Diameter (ft)	Diameter (Ship Lengths)
12	30	8	2.8	610	3.0
20 to 24	30	4	4.7	720	3.6

Due to several factors, the 225-ft WLB may not turn as well in ice as the WTGB. The 225-ft WLB's high length-to-beam ratio, relatively full waterline area, greater length relative to that of the WTGB, single screw, and fixed shaft propulsion do not allow the vessel to be highly maneuverable in ice. In order to turn or break out of the track the vessel should be able to break ice by the side, especially in the stern quarter. The WLB has midbody with vertical sides. This results in extensive ice crushing instead of causing ice failure through bending. Crushing is regarded as the most ineffective way to break ice.

BREAK-OUT OF AN EXISTING TRACK

The break-out maneuver starts in a broken track and is a maneuver to leave the track. The maneuver is useful in turning around in a track in limited space. The data for the break-out maneuver, as with the turning circles, were also taken from the Juniper Ice Trials. Presented in Table 4 is the time to turn out of the track from the time the helm is put over until the ship has reached a heading 90 deg from the original heading in the track. The time to complete the maneuver is a function of the applied rudder angle and initial speed. The test rudder angle and initial speed are given in the table.

Table 4. Time to Turn 90 Degrees Out of an Existing Track into Level Ice

Ice Thickness (in)	Rudder Angle (deg)	Ship Speed (kt)	Duration (min)
12	30	12	0.4
20 to 24	30	12	1.4

STAR MANEUVERS IN LEVEL ICE

The star maneuver is an effective means for turning around in ice for many icebreakers. A number of such maneuvers were attempted during the Ice Trials of the USCGC Juniper (WLB-201). The trackline from the star maneuver test in 12 in. of ice is presented in Figure 18 and illustrates the problem with this maneuver for the Juniper Class. The ship is unable to back into an unbroken ice cover or turn while going backwards. However, turning while going ahead is quite good. The trackline shows a series of back and forth movements in the broken channel after the initial turn while going ahead ceased to be effective. It was only the hard turns to port while going ahead that later completed the course reversal. In thicker ice, turning while going ahead was more difficult, and a star maneuver was not possible. The thrusters were found to be effective in turning the ship in thin ice when an area big enough to turn the ship could be broken first.

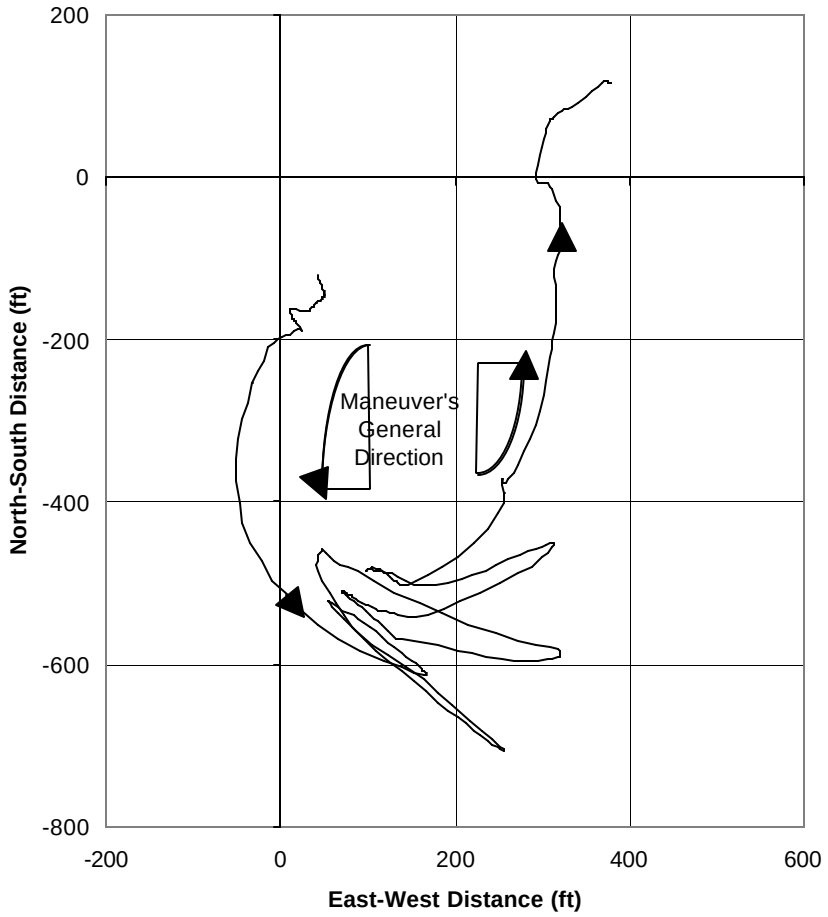


Figure 18. Trackline of the star maneuver in 12-in thick level ice from the Ice Trials.

A method for turning around in an existing track has been developed during 225-ft WLB operations on the Hudson River. A pictorial view of this maneuver is shown in Figure 19. The cutter repetitively turns out of the track to the left and to the right, each time backing down its track into the original one. Eventually, all the ice is broken in a large area forward of the cutter forming a turning basin that is big enough to maneuver the ship around. Thrusters may be used to accomplish the turn in the turning basin. It is also prudent to use the turning basin created by other ships operating in the area that would most likely be available in established tracks of the St. Mary's River.

The 225-ft WLB propeller rotation direction provides slightly better turning ability to port. It may be preferable to cast to port vice starboard and also to perform relief passes on beset vessels on the port side whenever possible.

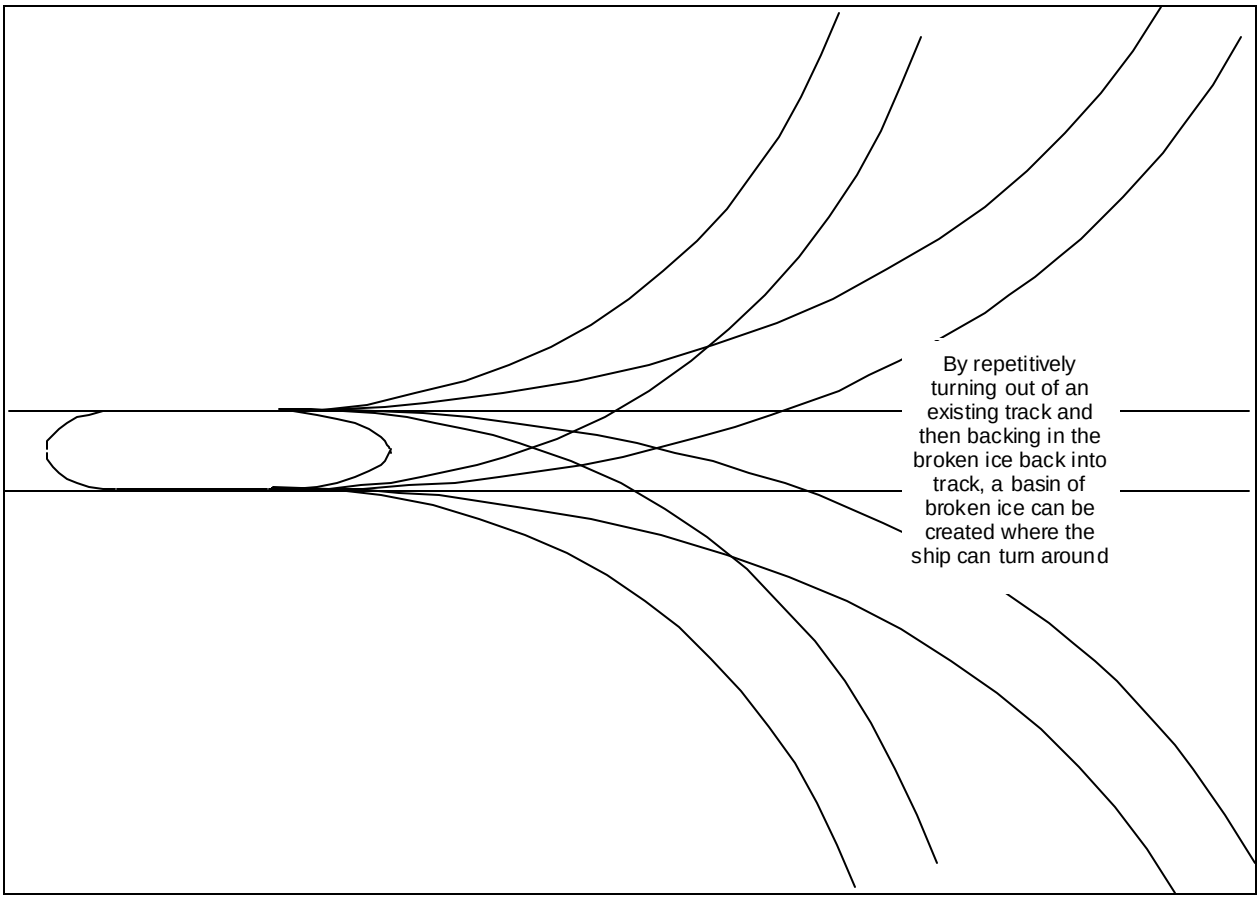


Figure 19. Maneuver developed on the Hudson River for creating a turning basin in the ice from an existing track.

OPERATIONAL ISSUES IN ICE

OPERATIONAL LIMITS

The operation limits given here are based on limiting ice properties corresponding to cold winter ice on the Great Lakes. Limits are as follows:

Solid level ice thickness of 24 inches.

Speeds of 11 kt ahead and 3 kt astern in ice floes up to 24 inches in thickness.

Speeds of 8-9 kt ahead and 2 kt astern in the ice floes greater than 24 inches.

Speeds of 8-9 kt ahead and 3 kt astern in the track, established in ice greater than 24 inches.

Speeds of 8-9 kt while ramming the windrows surrounded by ice greater than 24 inches.

BREAKING ICE WITH THE WAKE

When an icebreaking ship moves fast in an existing track or in thinner level ice, the wake of the ship can be effective in breaking a channel much wider than the ship's beam. Wake breaking is often used in breaking new track in generally open areas where relatively thin level ice exists. It provides a means to break a wide channel for a vessel that may be considerably wider than the icebreaker's beam without making two passes or requiring two icebreakers. In restricted areas in rivers, such as the St. Mary's River, it is much more advantageous to maintain a stable ice cover on either side of the track. For this type of ice condition, wake breaking is bad so speeds must be kept low to avoid breaking the ice on the sides of the channel. These areas can have high traffic and cold air temperatures. Each time the ice is broken, water is exposed to the cold temperature and new ice is formed. Brash ice grows many feet deep in the old and repetitively broken channels. Stable ice cover minimizes growth outside the channel and prevents ice floes broken from the level ice from jamming in the channel.

OPERATIONS TO AVOID

Avoid using too much power while icebreaking ahead as the possibility exists of getting stopped ahead such that astern thrust is insufficient to get unstuck. Astern thrust is about 50 percent of ahead thrust. The ice knife limits backing in level ice and inhibits turning by backing out of a track. Do not get "beached" on a ridge when ramming ridges.

Note that operations in ice occur in slow motion relative to operations in open water. The uninitiated operator must resist the temptation to apply too much power to make events happen faster than

is prudent. A certain amount of reserve power should be saved in case the ship becomes stuck, and it is needed to break free.

A summary of the operations that should be avoided, if possible, by the 225-ft WLB Class are listed below:

High speed operation in open pack
Hitting windrows too fast. More rams at slower speed is better.
When operating in areas of unknown ice thickness, transiting an established track for the first time, or where ridging is known to exist, keep speed to less than 11 kt.

ICE CONDITIONS TO AVOID

A summary of the ice conditions that have been discussed and should be avoided, if possible, by the 225-ft WLB Class are listed below:

Pressured ice
Ice floes in rapidly moving currents
Ice jams
High vibration when ice milling occurs

OPERATIONS WITH OTHER ICEBREAKING SHIPS

Considering that the 225-ft WLB Class does not demonstrate good backing performance, it is recommended that they be employed in joint operations with other icebreaking ships mostly for breaking track or leading an escort, and not for helping a stuck vessel. Helping a stuck vessel requires good maneuverability to circumnavigate the beset vessel or cutting it free by backing alongside. The use of a 225-ft WLB with a 140-ft WTGB (Bay Class) may significantly increase the escort efficiency for the following reasons.

- The WLB has better performance ahead in level ice than the WTGB. In the case that the WTGB is working behind the WLB, icebreaking for her is easier. This scenario allows the Bay Class cutter to break the ice slightly greater than its single operation icebreaking capability.
- The WLB is bigger and longer, which provides more directional control and a straighter track.
- Two ships are capable of breaking a track 120 ft wide or greater.
- The WTGB is more capable than WLB in direct assist operations.

The most typical scenario for these two ships types to work together icebreaking is presented in Figure 20. A comparison plot of WLB and WTGB performance in Great Lakes normal winter level ice is presented in Figure 21. The difference in open water speed between the two ships in Figure 21 is the fact that the WLB is operating with reduced pitch and rpm in maneuvering mode for level icebreaking. There are other scenarios to consider for two-icebreaker operation. It may be more efficient for WTGB to follow the escorted vessel while WLB leads the laker in the established track.

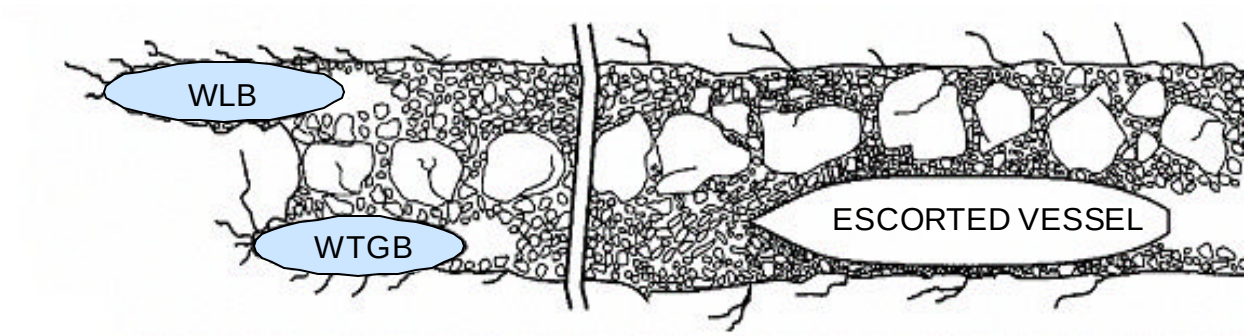


Figure 20. Escorting a vessel jointly with a WTGB.

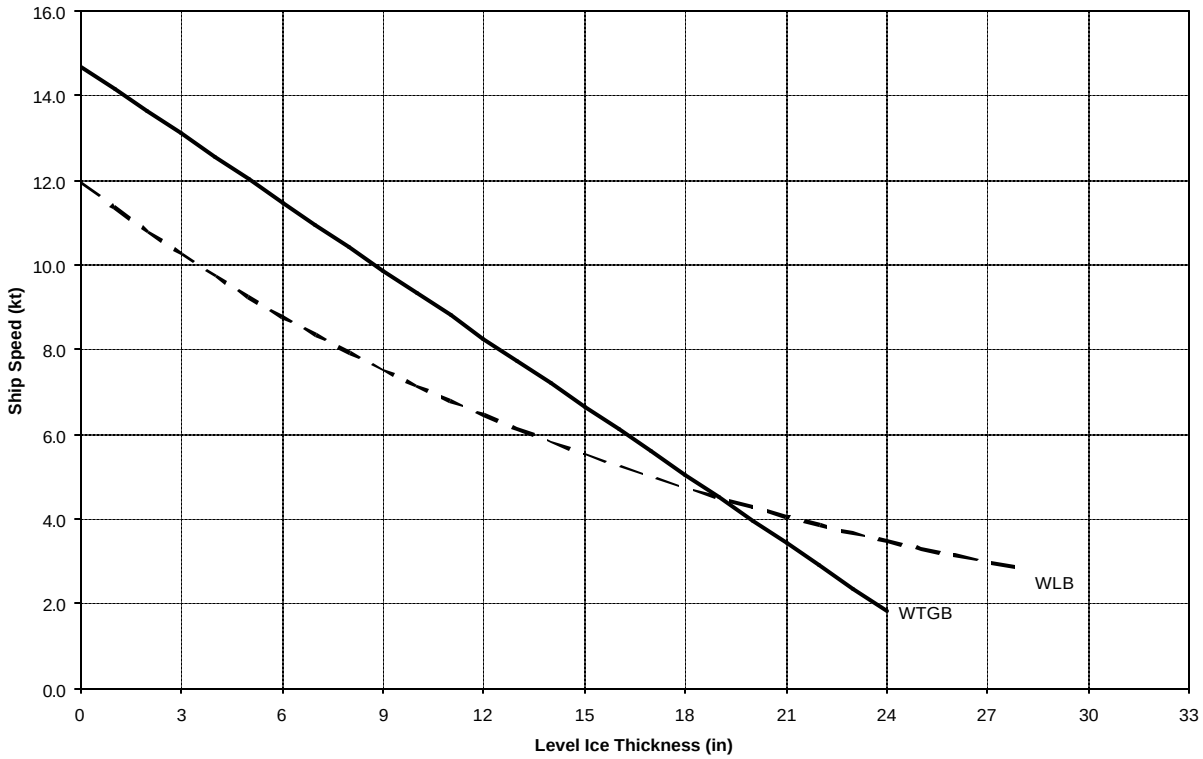


Figure 21. 225' WLB vs. 140'WTGB Performance in Great Lakes normal winter level ice (WLB maneuvering mode).

APPENDIX A

ICE AND ICEBREAKING TERMINOLOGY

GREAT LAKES OR SHIP SPECIFIC ICEBREAKING TERMS

The Atlantic operating area encompasses the coastal waters, harbors and rivers of the East Coast and the Great Lakes. The ice that grows in these different regions can have different mechanical properties that influence how easily the ice breaks and therefore the icebreaking performance and ice loads that press against the hull. The mechanical properties such as the crushing strength and bending strength are influence by the salinity of the water and the temperature of the ice.

Icebelt – The "belt" of strengthened framing and plating around the ship above and below the waterline that resists the ice loads during operations in ice.

Ice Knife – The heavy appendage placed on the centerline of the rudder and directly behind it to protect against ice sliding into and loading the back of the rudder.

Windrow – a Great Lakes term for a pressure ridge.

Ice Jam – a Great Lakes term for a grounded pressure ridge or rubble field in river with current that blocks the flow of ice and water and often causes local flooding.

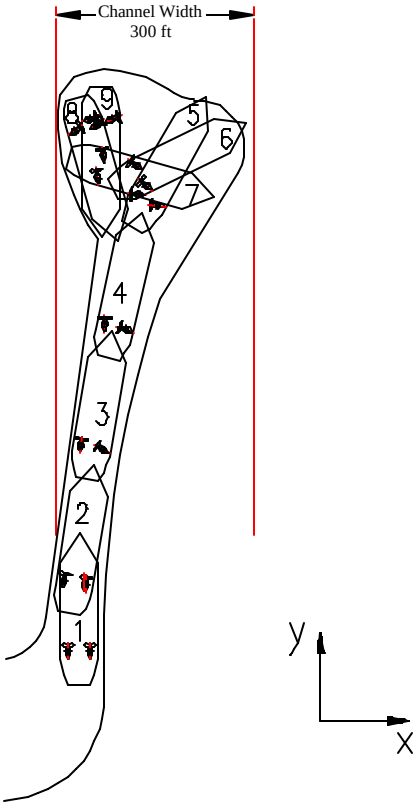
Plate Ice – level ice.

Ice-strengthened vessel – A vessel whose hull, rudder, propellers and machinery are strengthened specifically to withstand a certain level of ice loads, both dynamic generated by the collision with the ice feature and static generated by the ice pressure. This term does not reflect the vessel's ability to break the ice cover or transit any type of ice nor does it not imply that the vessel has a hull form designed for icebreaking.

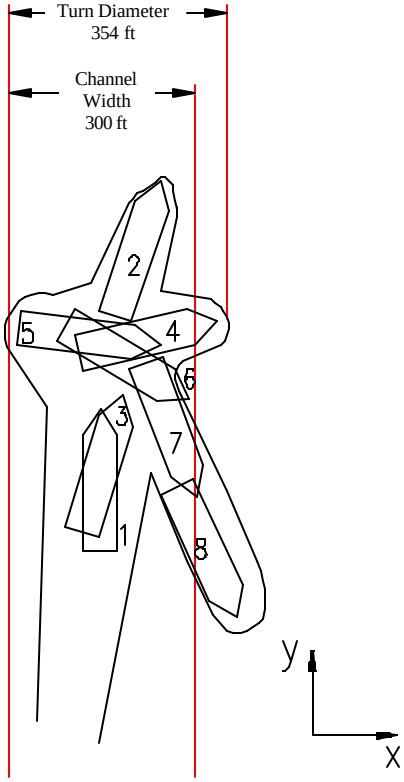
Icebreaking vessel – Any ship whose operational profile may include active icebreaking in order to transit ice-covered waters independently or with the assistance of other vessels. The term implies that the ship has sufficient ice strengthening and its hull form and propulsion plant provide sufficient icebreaking capability for the mission.

Icebreaker – Any icebreaking ship whose operational profile may include escort or ice management functions and whose hull form and propulsion plant allow it to undertake aggressive independent operations in ice-covered waters.

Star maneuver – The commonly used piloting technique to turn the ship around in the ice when use of a turning circle is not possible or not feasible. This type of maneuver is usually performed when the ice thickness exceeds the capability of the ship to move continuously while turning or when sufficient space for such a turning circle maneuver is not available. The maneuver typically starts from the vessel breaking out of the channel and turning until the ship is stopped by the ice, fairway limit, or other limitations. After that backing into unbroken ice is conducted as far as possible or desirable. It takes several "backing and ramming" cycles, each of which provides a relatively small angle turn. The maneuver is complete when the vessel has changed heading 180 deg and entered its own track. The imprint of such a maneuver very often looks like a star. However, there are a number of different terms applied to the same or very similar technique. Some of the most common terms include cast about, modified captain's maneuver, herring bone, and Christmas tree. Examples of the star maneuver for podded and conventionally-shafted tank models are shown below.



Podded Drive



Conventional CPP/Geared Diesel Drive

EXCERPT FROM *MANUAL OF STANDARD PROCEDURES FOR OBSERVING AND REPORTING ICE CONDITIONS*

MANICE

Manual of Standard Procedures for Observing and Reporting Ice Conditions

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Assistant Deputy Minister
Meteorological Service of Canada

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Meteorological Service of Canada

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[redacted]

Type of ice / Type de glace
Thickest / Plus épais
Second thick / Deuxième
Third thick / Troisième
Additional / Groupes

LAKE ICE SYMBOLS/SYMBOLES DE LA GLACE D'EAU DOUCE

Open Water / Eau libre
Fast Ice / Banquise côtière
Ice Free / Libre de glace

Stage of Development/Stade de développement ($S_0S_4S_5S_7S_8S_9S_{10}$)

Description/Élément	Thickness/Épaisseur	Code
New ice/Nouvelle glace	<5 cm	1
Thin lake ice/Glace de lac mince	5-15 cm	4
Medium lake ice/Glace de lac moyenne	15-30 cm	5
Thick lake ice/Glace de lac épaisse	30-70 cm	7
Very thick lake ice/Glace de lac très épaisse	>70 cm	1+
Undetermined, unknown or no form/ Indéterminée, inconnue ou sans forme		X

Floe Size/Grandeur des floes ($F_aF_bF_c$)

Description/Élément	Width/Extension	Code
Pancake ice/Glace en crêpes		0
Small ice cake, brash ice/Petit glaçons, sarrasins	<2 m	1
Ice cake/Glaçons	2-20 m	2
Small floe/Petits floes	20-100 m	3
Medium floe/Floes moyens	100-500 m	4
Big floe/Grands floes	500-2000 m	5
Vast floe/Floes immenses	2-10 km	6
Giant floe/Floes géants	>10 km	7
Fast ice/Banquise côtière		8
Undetermined, unknown or no form/ Indéterminée, inconnue ou sans forme		X
Strips (concentration = C)/ Glace en cordons (concentration = C)		CC

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LAKE ICE SYMBOLS
SYMBOLES DE LA GLACE D'EAU DOUCE

WMO Concentration Colour Code - Lake Ice
Code de couleurs de l'OMM Concentration - Glace d'eau douce

- Ice Free / Libre de glace
- < 1/10
- 1-3/10
- 4-6/10
- 7-8/10
- 9-10/10
- Fast Ice / Banquise côtière
- Undefined / Glace non définie

Colour is based on total ice concentration.
La couleur utilisée est établie en fonction de la concentration totale de la glace.

Concentration of Ice
Concentrations de glace

<1/10	Open water / Eau libre
1a/10	Very open drift / Banquise très lâche
4a/10	Open drift / Banquise lâche
7a/10	Close pack/Drift / Banquise serrée
9/10	Very close pack / Banquise très serrée
9 /10	Very close pack / Banquise très serrée
10/10	Compact/Consolidated ice / Banquise compact/consolidée

WMO Stage of Development Colour Code - Lake Ice
Code de couleurs de l'OMM Stade de développement - Glace d'eau douce

- Ice Free/Libre de glace
- Open Water/Eau libre
- New Ice/Nouvelle glace *<5 cm*
- Thin Ice/Glace mince *5-15 cm*
- Medium Ice/Glace moyenne *15-30 cm*
- Thick Ice/Glace épaisse *30-70 cm*
- Very Thick Ice/Glace très épaisse *> 70 cm*
- Fast Ice/Banquise côtière
- Undefined Ice/Glace non-définie

Colour is based on stage of development of predominant ice.
La couleur utilisée est établie en fonction du stade de développement de la glace prédominante.

Canadian Ice Service/Service canadien des glaces (CIS/SCG)

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WMO STANDARD SEA ICE NOMENCLATURE

PART I

ICE TERMS ARRANGED BY SUBJECT

1. **FLOATING ICE:** Any form of ice found floating in water. The principal kinds of floating ice are lake ice, river ice, and sea ice which form by the freezing of water at the surface, and glacier ice (ice of land origin) formed on land or in an ice sheet. The concept includes ice that is stranded or grounded.

1.1 **Sea ice:** Any form of ice found at sea which has originated from the freezing of sea water.

1.2 **Ice of land origin:** Ice formed on land or in an ice sheet, found floating in water. The concept includes ice that is stranded or grounded.

1.3 **Lake ice:** Ice formed on a lake, regardless of observed location.

1.4 **River ice:** Ice formed on a river, regardless of observed location.

2. DEVELOPMENT

2.1 **New ice:** A general term for recently formed ice which includes frazil ice, grease ice, slush and shuga. These types of ice are composed of ice crystals which are only weakly frozen together (if at all) and have a definite form only while they are afloat.

2.1.1 FRAZIL ICE: Fine spicules or plates of ice, suspended in water.

2.1.2 GREASE ICE: A later stage of freezing than frazil ice when the crystals have coagulated to form a soupy layer on the surface. Grease ice reflects little light, giving the sea a matt appearance.

2.1.3 SLUSH: Snow which is saturated and mixed with water on land or ice surfaces, or as a viscous floating mass in water after a heavy snowfall.

2.1.4 SHUGA: An accumulation of spongy white ice lumps, a few centimeters across; they are formed from grease ice or slush and sometimes from anchor ice rising to the surface.

2.2 **Nilas:** A thin elastic crust of ice, easily bending on waves and swell and under pressure, thrusting in a pattern of interlocking "fingers" (finger rafting). Has a matt surface and is up to 10 cm in thickness. May be subdivided into dark nilas and light nilas.

2.2.1 DARK NILAS: Nilas which is under 5 cm in thick- ness and is very dark in color.

2.2.2 LIGHT NILAS: Nilas which is more than 5 cm in thickness and rather lighter in color than dark nilas.

2.2.3 ICE RIND: A brittle shiny crust of ice formed on a quiet surface by direct freezing or from grease ice, usually in water of low salinity. Thickness to about 5 cm. Easily broken by wind or swell, commonly breaking in rectangular pieces.

2.3 **Pancake ice:** cf. 4.3.1.

2.4 **Young ice:** Ice in the transition stage between nilas and first-year ice, 10-30 cm in thickness. May be subdivided into grey ice and grey-white ice.

2.4.1 GREY ICE: Young ice 10-15 cm thick. Less elastic than nilas and breaks on swell. Usually rafts under pressure.

2.4.2 GREY-WHITE ICE: Young ice 15-30 cm thick. Under pressure more likely to ridge than to raft.

2.5 First-year ice: Sea ice of not more than one winter's growth, developing from young ice; thickness 30 cm - 2 m. May be subdivided into first-year ice I white ice, medium first-year ice and thick first-year ice.

2.5.1 THIN FIRST-YEAR ICE/WHITE ICE: First-year ice 30-70 cm thick.

2.5.2 MEDIUM FIRST-YEAR ICE: First- ice 70-120 cm year thick.

2.5.3 THICK FIRST-YEAR ICE: First-year ice over 120 cm thick.

2.6 **Old Ice:** Sea ice which has survived at least one summer's melt. Most topographic features are smoother than on first-year ice. May be subdivided into second-year ice and multi-year ice.

2.6.1 SECOND-YEAR ICE: Old ice which has survived only one summer's melt. Because it is thicker and less dense than first-year ice it stands higher out of the water. In contrast to multi-year ice, summer melting produces a

regular pattern of numerous small puddles. Bare patches and puddles are usually greenish-blue.

2.6.2 MULTI-YEAR ICE: Old ice up to 3 m or more thick which has survived at least two summers' melt. Hummocks even smoother than in second-year ice and the ice is almost salt-free. Color, where bare, is usually blue. Melt pattern consists of large interconnecting irregular puddles and a well-developed drainage system.

3 FORMS OF FAST ICE

3.1 **Fast ice:** Sea ice which forms and remains fast along the coast, where it is attached to the shore, to an ice Hall, to an ice front, between shoals or grounded icebergs. Vertical fluctuations may be observed during changes of sea-level. Fast ice may be formed in situ from sea water or by freezing of pack ice of any age to the shore, and it may extend a few meters or several hundred kilometers from the coast. Fast ice may be more than one year old and may then be prefixed with the appropriate age category (old, second-year, or multiyear). If it is thicker than about 2 m above sea-level it is called an ice shelf.

3.1.1 YOUNG COASTAL ICE: The initial stage of fast ice formation consisting of nilas or young ice, its width varying from a few meters up to 100-200 m from the shoreline.

3.2 **Icefoot:** A narrow fringe of ice attached to the coast, unmoved by tides and remaining after the fast ice has moved away.

3.3 **Anchor ice:** Submerged ice attached or anchored to the bottom, irrespective of the nature of its formation.

3.4 **Grounded ice:** Floating ice which is a-round in shoal water (cf. stranded ice).

3.4.1 STRANDED ICE: Ice which has been floating and has been deposited on the shore by retreating high water.

3.4.2 GROUNDED HUMMOCK: Hummocked grounded ice formation. There are single grounded hummocks and lines (or chains) of grounded hummocks.

4. **PACK ICE:** Term used in a wide sense to include any area of sea ice, other than fast ice, no matter what form it takes or how it is disposed.

4.1 **Ice cover:** The ratio of an area of ice of any concentration to the total area of sea surface within some large geographic local; this local may be global, hemispheric, or prescribed by a specific oceanographic entity such as Baffin Bay or the Barents Sea.

4.2 **Concentration:** The ratio expressed in tenths or oktas describing the mean areal density of ice in a given area.

4.2.1 CO.MPACT PACK ICE: Pack ice in which the concentration is 10/10 (8/8) and no water is visible.

4.2.1.1 *Consolidated pack ice:* Pack ice in which the concentration is 10/10 (8/8) and the floes are frozen together.

4.2.2 VERY CLOSE PACK ICE: Pack ice in which the concentration is 9/10 to less than 10/10 (7/8 to less than 8/8).

4.2.3 CLOSE PACK ICE: Pack ice in which the concentration is 7/10 to 8/10 (6/8 to less than 7/8). composed of floes mostly in contact.

4.2.4 OPEN PACK ICE: Pack ice in which the ice concentration is 4/10 to 6/10 (3/8 to less than 6/8), with many leads and polynyas, and the floes are generally not in contact with one another.

4.2.5 VERY OPEN PACK ICE: Pack ice in which the concentration is 1/10 to 3/10 (1/8 to less than 3/8) and water preponderates over ice.

4.2.6 OPEN WATER: A large area of freely navigable water in which sea ice is present in concentrations less than 1/10 (1/8). There may be ice of land origin present, although the total concentration of all ice shall not exceed 1/10 (1/8).

4.2.7 BERGY WATER: An area of freely navigable water with no sea ice present but in which ice of land origin is present.

4.2.8 ICE-FREE: No ice present. If ice of any kind is present this term should not be used.

4.3 **Forms of floating ice**

4.3.1 PANCAKE ICE: Predominantly circular pieces of ice from 30 cm - 3 m in diameter, and up to about 10 cm in thickness, with raised rims due to the pieces striking against one another. It may be formed on a slight swell from grease ice, shuga or slush or as a result of the breaking of ice rind, nilas or, under severe conditions of swell or waves, of grey ice. It also sometimes forms at some depth, at an interface between water bodies of different physical characteristics, from where it floats to the surface; its appearance may rapidly cover wide areas of water.

4.3.2 FLOE: Any relatively flat piece of sea ice 20 m or more across. Floes are subdivided according to horizontal extent as follows:

4.3.2.1 Giant: Over 10 km across.

4.3.2.2 Vast: 2-10 km across.

4.3.2.3 Big: 500-2,000 m across.

4.3.2.4 Medium: 100-500 m across.

4.3.2.5 Small. 20-100 m across.

4.3.3 ICE CAKE: Any relatively flat piece of sea ice less than 20 m across.

4.3.3.1 Small ice cake: An ice cake less than 2 m across.

4.3.4 FLOEBERG: A massive piece of sea ice composed of a hummock, or a group of hummocks, frozen together and separated from any ice surroundings. It may float up to 5 m above sea-level.

4.3.5 ICE BRECCIA: Ice Pieces of different age frozen together.

4.3.6 BRASH ICE: Accumulations of young ice made up of fragments not more than 2 m across, the wreckage of other forms of ice.

4.3.7 ICEBCRG: cf. 10.4.2.

4.3.8 GLACIER BERG: cf. 10. 4. 9. 1

4.3.9 TABULAR BERG: cf. 10.4.2.2

4.3.10 ICE ISLAND: cf. 10.4.3.

4.3.11 BERGY BIT: cf. 10.4.4.

4.3.12 GROWLER: cf. 10.4.5. 4.4 Arrangement

4.4.1 ICE FIELD: Area of pack ice consisting of any size of floe, which is greater than 10 km across (cf. patch).

4.4.1.1 Large ice field: An ice field over 20 km across.

4.4.1.2 Medium ice field: An ice field 15-20 km across.

4.4.1.3 Small ice field: An ice field 10-15 km across.

4.4.1.4 Ice patch: An area of pack ice less than 10 km across.

4.4.2 ICE massif: A concentration of sea ice covering hundreds of square kilometers, which is found in the same region every summer.

4.4.3 BELT: A large feature of pack ice arrangement; longer than it is wide; from I km to more than 100 km in width.

4.4.4 TONGUF: A projection of the ice edge up to several kilometers in length, caused by wind or current.

4.4.5 STRIP: Long narrow area of pack ice, about I km or less in width, usually composed of small fragments detached from the main mass of ice, and run together under the influence of wind, swell or current.

4.4.6 BIGHT: An extensive crescent-shaped indentation in the ice edge, formed by either wind or current.

4.4.7 ICE JAM: An accumulation of broken river ice or sea ice caught in a narrow channel.

4.4.8 ICE EDGE: The demarcation at any given time between the open sea and sea ice of any kind, whether fast or drifting. It may be termed compacted or diffuse (cf. ice boundary).

4.4.8.1 Compacted ice edge: Close, clear-cut ice edge compacted by wind or current; usually on the windward side of an area of pack ice.

4.4.8.2 Diffuse ice edge: Poorly defined ice edge limiting an area of dispersed ice; usually on the leeward side of an area of pack ice.

4.4.8.3 lee limit: Climatological term referring to the extreme minimum or extreme maximum extent of the ice edge in any a given month or period based on observations over a number of years. Term should be preceded by minimum or maximum (cf. mean ice edge).

4.4.8.4 Mean ice edge: Average position of the ice edge in any given month or period based on observations over a number of years. Other terms which may be used are mean maximum ice edge and mean minimum ice edge (cf. ice limit).

4.4.8.5 Fast-ice edge: The demarcation at any given time between fast ice and open water.

4.4.9 ICE BOUNDARY: The demarcation at any given time between fast ice and pack- ice or between areas of pack ice of different concentrations (cf. ice edge).

4.4.9.1 Fast-ice boundary: The ice boundary, at any given time between fast ice and pack-ice.

4.4.9.2 Concentration boundary: A line approximating the transition between two areas of pack ice with distinctly different concentrations.

4.4.10 ICEBERG TONGUE: cf. 10.4.2.3.

5. PACK-ICE MOTION PROCESSES

5.1 **Diverging:** Ice fields or floes in an area are subjected to diverging or dispersive motion, thus

reducing ice concentration and/or relieving stresses in the ice.

5.2 **Compacting:** Pieces of floating ice are said to be compacting when they are subjected to a converging motion, which increases ice concentration and/or produces stresses which may result in ice deformation.

5.3 **Shearing:** An area of pack ice is subject to shear when the ice motion varies significantly in the direction normal to the motion, subjecting the ice to rotational forces. These forces may result in phenomena similar to a flaw (q.v.).

6. DEFORMATION PROCESSES

6.1 **Fracturing:** Pressure process whereby ice is permanently deformed, and rupture occurs. Most commonly used to describe breaking across very close pack ice, compact pack-ice and consolidated pack-ice.

6.2 **Hummocking:** The pressure process by which sea ice is forced into hummocks. When the floes rotate in the process it is termed screwing.

6.3 **Ridging:** The pressure process by which sea ice is forced into ridges.

6.4 **Rafting:** Pressure processes whereby one piece of ice overrides another. Most common in new and young ice (cf. finger rafting).

6.4.1 FINGER RAFTING: Type of rafting whereby interlocking thrusts are formed, each floe thrusting "fingers" alternately over and under the other. Common in nilas and grey ice.

6.5 **Weathering:** Processes of ablation and accumulation which gradually eliminate irregularities in an ice surface.

7 OPENINGS IN THE ICE

7.1 **Fracture:** Any break or rupture through very close pack ice, compact pack ice, consolidated pack ice, fast ice, or a single floe resulting from deformation processes. Fractures may contain brash ice and/or be covered with nilas and/or young ice. Length may vary from a few meters to many kilometers.

7. 1.1 CRACK: Any fracture which has not parted.

7.1.1.1 Tide crack: Crack at the line of junction between an immovable ice foot or ice wall and fast ice, the latter subject to rise and fall of the tide.

7.1.1.2 Flaw: A narrow separation zone between pack- ice and fast ice, where the pieces of ice are in chaotic state; it forms when pack ice shears under the effect of a strong wind or current alone the fast ice boundary (cf. shearing,).

7.1.2 VERY SMALL FRACTURE: 0 to 50 m wide.

7.1.3 SMALL FRACTURE: 50 to 200 m wide.

7.1.4 MEDIUM FRACTURE: 200 to 500 m wide.

7.1.5 LARGE FRACTURE: More than 500 m wide.

7.2 **Fracture zone:** An area which has a great number of fractures.

7.3 **Lead:** Any fracture or passage-way through sea ice which is navigable by surface vessels.

7.3.1 SHORE LEAD: A lead between pack ice and the shore or between pack- ice and an ice front.

7.3.2 FLAW LEAD: A passage-way between pack-ice and fast ice which is navigable by surface vessels.

7.4 **Polynya:** Any non-linear shaped opening enclosed in ice. Polynyas may contain brash ice and/or be covered with new ice, nilas or young ice; submariners refer to these as skylights. Sometimes the polynya is limited on one side by the coast and is called a shore polynya or by fast ice and is called a flaw polynya. If it recurs in the same position every year, it is called a recurring polynya.

7.4.1 SHORE POLYNYA: A polynya between pack ice and the coast or between pack ice and an ice front.

7.4.2 FLAW POLYNYA: A polynya between pack ice and fast ice.

7.4.3 RECURRING POLYNYA: A polynya which recurs in the same position every year.

8. ICE-SURFACE FEATURES

8.1 **Level ice:** Sea ice which is unaffected by deformation.

8.2 **Deformed ice:** A general term for ice which has been squeezed together and in places forced up-wards (and downwards). Subdivisions are rafted ice, ridge or l ice and hummocked ice.

8.2.1 RAFTED ICE: Type of deformed ice formed by one piece of ice overriding another (cf. finger rafting)

8.2.1.1 Finger rafted ice: Type of rafted ice in which floes thrust "fingers" alternately over and under the other.

8.2.2 RIDGE: A line or wall of broken ice forced up by pressure. May be fresh or weathered. The submerged volume of broken ice under a ridge, forced downwards by pressure, is termed an ice keel.

8.2.2.1 New ridge: Ridge newly formed with sharp peaks and slope of sides usually 40º. Fragments are visible from the air at low attitude.

8.2.2.2 Weathered ridge: Ridge with peaks slightly rounded and slope of sides usually 30º to 40º. Individual fragments are not discernible.

8.2.2.3 Very weathered ridge: Ridge with tops very rounded, slope of sides usually 20º-30º.

8.2.2.4 Aged ridge: Ridge which has underdone considerable weathering. These ridges are best described as undulations.

8.2.2.5 Consolidated ridge: A ridge in which the base has frozen to-ether.

8.2.2.6 Ridged ice: Ice piled haphazardly one piece over another in the form of ridges or walls. Usually found in first-year ice (cf. ridging).

8.2.2.6.1 Ridged ice zone: An area in which much ridged ice with similar characteristics has formed.

8 2.3 HUMMOCK: A hillock of broken ice which has been forced upwards by pressure. May be fresh or weathered. The submerged volume of broken ice under the hummock-, forced downwards by pressure, is termed a bummock.

8.2.3.1 Hummocked ice: Sea ice piled haphazardly one piece over another to form an uneven surface. When weathered, has the appearance of smooth hillocks.

8.3 **Standing Floe:** A separate floe standing vertically or inclined and enclosed by rather smooth ice.

8.4 **Ram:** An underwater ice projection from an ice wall, ice front, iceberg or floe. Its formation is usually due to a more intensive melting and erosion of the unsubmerged part.

8.5 **Bare ice:** Ice without snow cover.

8. 6 **Snow-covered ice:** Ice covered with snow.

8.6.1 SASTRUGI: Sharp, irregular ridges formed on a snow surface by wind erosion and deposition. On mobile floating ice the ridges are parallel to the direction of the prevailing wind at the time they were formed.

8.6.2 SNOWDRIFT: An accumulation of wind-blown snow deposited in the Ice of obstructions or heaped by wind eddies. A crescent-shaped snowdrift, with ends pointing down-wind, is known as a snow barchan.

9 STAGES OF MELTING

9.1 **Puddle:** An accumulation on ice of melt-water, mainly due to melting snow, but in the more advanced stages also to the melting of ice. Initial stage consists of patches of melted snow.

9.2 **Thaw holes:** Vertical holes in sea ice formed when surface paddles melt through to the underlying water.

9.3 **Dried ice:** Sea ice from the surface of which melt-water has disappeared after the formation of cracks and thaw holes. During the period of drying, the surface whitens.

9.4 **Rotten ice:** Sea ice which has become honeycombed and which is in an advanced state of disintegration.

9.5 **Flooded ice:** Sea ice which has been flooded by melt-water or river water and is heavily loaded by water and wet snow.

10. ICE OF LAND ORIGIN

10.1 **Firn:** Old snow which has recrystallized into a dense material. Unlike snow, the particles are to some extent joined together; but, unlike ice, the air spaces in it still connect with each other.

10.2 **Glacier ice:** Ice in, or originating from, a glacier, whether on land or floating on the sea as icebergs, bergy bits or growlers.

10.2.1 GLACIER: A mass of snow and ice continuously moving from higher to lower ground or, if afloat, continuously spreading. The principal forms of glacier are: inland ice sheets, ice shelves, ice streams, ice caps, ice piedmonts, cirque glaciers and various types of mountain (valley) glaciers.

10.2.2 ICE WALL: An ice cliff forming the seaward margin of a glacier which is not afloat. An ice wall is aground, the rock basement being at or below sea-level (cf. ice front).

10.2.3 ICE STREAM: Part of an inland ice sheet in which the ice flows more rapidly and not necessarily in the same direction as the surrounding ice. The margins are sometimes clearly marked by a change in direction of the surface slope but may be indistinct.

10.2.4 GLACIER TONGUE: Projecting seaward extension of a glacier, usually afloat. In the Antarctic, glacier tongues may extend over many tens of kilometers.

10.3 **Ice shelf:** A floating ice sheet of considerable thickness showing 2-50 m or more above sea-level, attached to the coast. Usually of great horizontal extent and with a level or gently undulating surface. Nourished by annual snow accumulation and often also by the seaward extension of land glaciers. Limited areas may be aground. The seaward edge is termed an ice front (q.v.).

10.3.1 ICE FRONT: The vertical cliff forming the sea- ward face of an ice shell' or other floating glacier varying- in height from 2-50 m or more above sea-level (cf. ice wall).

10.4 **Calved ice of land origin**

10.4.1 CALVING: The breaking away of a mass of ice from an ice wall, ice front or iceberg.

10.4.2 ICEBERG: A massive piece of ice of greatly varying shape, more than 5 m above sea-level, which has broken away from a glacier, and which may be afloat or aground. Icebergs may be described as tabular, dome-shaped, sloping, pinnacled, weathered or glacier bergs.

10.4.2.1 Glacier berg: An irregularly shaped iceberg.

10.4.2.2 Tabular berg: A flat-topped iceberg. Most tabular bergs form by calving from an ice shelf and show horizontal banding (cf. ice island).

10.4.2.3 Iceberg tongue: A major accumulation of icebergs projecting from the coast held in place by grounding and joined together by fast ice.

10.4.3 ICE ISLAND: A large piece of floating ice about 5 m above sea-level, which has broken away from an Arctic ice shelf, having a thickness of 30-50 m and an area of from a few thousand square hectares to 500 sq. km or more, and usually characterized by a regularly undulating surface which gives it a ribbed appearance from the air.

10.4.4 BERGY BIT: A large piece of floating glacier ice, generally showing less than 5 m above sea-level but more than 1 m and normally about 100-300 sq. m in area.

10.4.5 GROWLER: Smaller piece of ice than a bergy-bit or floeberg, often transparent but appearing green or almost black in color, extending less than I m above the sea surface and normally occupying an area of about 20 sq. m.

11. SKY AND AIR INDICATIONS

11.1 **Water sky:** Dark streaks on the underside of low clouds, indicating the presence of water features in the vicinity of sea ice.

11.2 **Ice blink:** A whitish glare on low clouds above an accumulation of distant ice.

11.3 **Frost smoke:** Fog-like clouds due to contact of cold air with relatively warm water, which can appear over openings in the ice, or leeward of the ice edge, and which may persist while ice is forming.

12. TERMS RELATING TO SURFACE SHIPPING

12.1 **Beset:** Situation of a vessel surrounded by ice and unable to move.

12.2 **Icebound:** A harbor, inlet, etc. is said to be ice-bound when navigation by ships is prevented on account of ice, except possibly with the assistance of an icebreaker.

12.3 **Nip:** Ice is said to nip when it forcibly presses against a ship. A vessel so caught, though undamaged, is said to have been nipped.

12.4 **Ice under pressure:** Ice in which deformation processes are actively occurring and hence a potential impediment or danger to shipping.

12.5 **Difficult area:** A general qualitative expression to indicate, in a relative manner, that the severity of ice conditions prevailing in an area is such that navigation in it is difficult.

12.6 **Easy area:** A general qualitative expression to indicate, in a relative manner, that ice conditions prevailing in an area are such that navigation in it is not difficult.

12.7 **Iceport:** An embayment in an ice front, often of a temporary nature, where ships can moor alongside and unload directly onto the ice shelf.

13. TERMS RELATING TO SUBMARINE NAVIGATION

13.1 **Ice canopy:** Pack ice from the point of view of the submariner.

13.2 **Friendly ice:** From the point of view of the submariner, an ice canopy containing many large skylights or other features which permit a sub- marine to surface. There must be more than ten such features per 30 nautical miles (56 km) along the submarine's track.

13.3 **Hostile ice:** From the point of view of the submariner, an ice canopy containing no large skylights or other features which permit a submarine to surface.

13.4 **Bummock:** From the point of view of the sub- mariner, a downward projection from the under- side of the ice canopy; the counterpart of a hummock-.

13.5 **Ice keel:** From the point of view of the submariner, a downward-projecting ridge on the underside of the ice canopy; the counterpart of a ridge. Ice keels may extend as much as 50 m below sea-level.

13.6 **Skylight:** From the point of view of the sub- mariner, thin places in the ice canopy, usually less than I m thick and appearing from below as relatively light, translucent patches in dark surroundings. The under-surface of a skylight is normally flat. Skylights are called large if bid enough for a submarine to attempt to surface through them (120 m), or small if not.

PART II

ICE TERMS ARRANGED IN ALPHABETICAL ORDER

Aged ridge: Ridge which has undergone considerable weathering. These ridges are best described as undulations (8.2.2.4).

Anchor ice: Submerged ice attached or anchored to the bottom, irrespective of the nature of its formation (3.3).

Bare ice: Ice without snow cover (8.5).

Belt: A large feature of pack ice arrangement; longer than it is wide; from I km to more than 100 km in width (4.4.3).

Bergy bit: A large piece of floating glacier ice, generally showing less than 5 m above sea-level but more than I m and normally about 100-300 sq. m in area (10.4.4).

Beset: Situation of a vessel surrounded by ice and unable to move (12.1).

Bi- floe: (4.3.2.3) (see Floe).

Bight: An extensive crescent-shaped indentation in the ice edge, formed by either wind or current (4.4.6).

Brash ice: Accumulations of floating ice made up of fragments not more than 2 in across, the wreckage of .other forms of ice (4.3.6).

Bummock: From the point of view of the submariner, a downward projection from the underside of the ice canopy; the counterpart of a hummock (13.4).

Calving: The breaking away of a mass of ice from an ice wall, ice front or iceberg (10.4.1)

Close pack ice: Pack ice in which the concentration is 7/10 to 8/10 (6/8 to less than 7/8), composed of J70es mostly in contact (4.2.3).

Compacted ice edge: Close, clear-cut ice edge compacted by wind or current; usually on the windward side of an area of pack ice (4.4.8.1).

Compacting: Pieces of floating ice are said to be compacting when they are subjected to a converging motion, which increases ice concentration and/or produces stresses which may result in ice deformation (5.2).

Compact pack ice- Pack ice in which the concentration is 10/10 (8/8) and no water is visible (4.2.1).

Concentration: The ratio in tenths of the sea surface actually covered by ice to the total area of sea surface, both ice-covered and ice-free, at a specific location or over a defined area (4.2).

Concentration boundary: A line approximating the transition between two areas of pack ice with distinctly different concentrations (4.4.9.2).

Consolidated pack ice: Pack ice in which the concentration is 10/10 (8/8) and the floes are frozen together (4.2.1.1).

Consolidated ridge: A ridge in which the base has frozen together (8.2.2.5).

Crack: Any fracture which has not parted (7.1.1). Dark nilas: Nilas which is under 5 cm in thickness and is very dark in color (2.2.1).

Deformed ice: A general term for ice which has been squeezed together and in places forced upwards (and downwards). Subdivisions are rafted ice, ridged ice and hummocked ice (8.2).

Difficult area: A general qualitative expression to indicate, in a relative manner, that the severity of ice conditions prevailing in an area is such that navigation in it is difficult (12.5).

Diffuse ice edge: Poorly defined ice edge limiting an area of dispersed ice; usually on the leeward side of an area of pack ice (4.4.8.2).

Diverging: Ice fields or floes in an area are subjected to diverging or dispersive motion, thus reducing ice concentration and/or relieving stresses in the ice (5.1).

Dried ice: Sea ice from the surface of which melt-water has disappeared after the formation of cracks and thaw holes. During the period of drying the surface whitens (9.3).

Easy area: A general qualitative expression to indicate, in a relative manner, that ice conditions prevailing in an area are such that navigation in it is not difficult (12.6).

Fast ice: Sea ice which forms and remains fast along the coast, where it is attached to the shore, to an ice wall, to an ice front, between shoals or grounded icebergs. Vertical fluctuations may be observed during changes of sea-level. Fast ice may be formed in situ from sea water or by freezing of pack ice of any age to the shore, and it may extend a few meters or several hundred kilometers from the coast. Fast ice may be more than one year old and may then be prefixed with the appropriate age category (old, second-year, or multi-year). If it is thicker than about 2 m above sea- level it is called an ice shelf (3. 1).

Fast-ice boundary: The ice boundary at any given time between fast ice and pack ice (4.4.9,1).

Fast-ice edge: The demarcation at any given time between fast ice and open water (4.4.8.5).

Finger rafted ice: Type of rafted ice in whichj7oes thrust "fingers" alternately over and under the other

Finger rafting: Type of rafting whereby interlocking thrusts are formed, each floe thrusting "fingers'$ alternately over and under the other. Common in nilas and grey ice (6.4.1).

Firn: Old snow which has recrystallized into a dense material. Unlike snow, the particles are to some extent joined together, but, unlike ice, the air spaces in it still connect with each other (10.1).

First-year ice: Sea ice of not more than one winter's growth, developing from young ice; thickness 30 cm-2 m. May be subdivided into thin first-year ice/white ice, medium first-year ice and thick first-year ice (2.5).

Flaw: A narrow separation zone between pack- ice and fast ice, where the pieces of ice are in chaotic state; it forms when pack ice shears under the effect of a strong wind or current along the fast ice boundary (7.1.1.2) (cf. shearing).

Flaw lead: A passageway between pack-ice and fast ice which is navigable by surface vessels (7.3.2).

Flaw polynya: A polynya between pack ice and fast ice (7.4.2)

Floating ice- Any form of ice found floating in water. The principal kinds of floating ice are lake ice, river ice, and sea ice, which form by the freezing of water at the surface, and glacier ice (ice of land origin) formed on land or in an ice shell. The concept includes ice that is stranded or grounded (1.).

Floe: Any relatively flat piece of sea ice 20 m or more across. Floes are subdivided according to horizontal extent as follows (4.3.2):

GIANT: Over 10 km across (4.3.2. 1).

VAST: 2-10 km across (4.3.2.2).

BIG: 500-2,000 m across (4.3.2.3).

MEDIUM: 100,-500 in across (4.3.2.4).

SMALL: 20-100 m across (4.3.2.5).

Floeberg: A massive piece of sea ice composed of a hummock, or a group of hummocks, frozen together and separated from any ice surroundings. It may float up to 5 m above sea-level (4.3.4).

Flooded ice: Sea ice which has been flooded by melt-water or river water and is heavily loaded by water and wet snow (9.5).

Fracture: Any break or rupture through very close pack ice, compact pack- ice, consolidated pack-ice, fast ice, or a single floe resulting from deformation processes. Fractures may contain brash ice and/or be covered with nilas and/or young lee. Length may vary from a few meters to many kilometers (7. 1).

Fracture zone-. An area which has a great number of fractures (7.2).

Fracturing: Pressure process whereby ice is permanently deformed, and rupture occurs. Most commonly used to describe breaking across very close pack-ice, compact pack- ice and consolidated pack ice (6.1).

Frazil ice: Fine spicules or plates of ice, suspended in water (2.1.1).

Friendly ice: From the point of view of the submariner, an ice canopy containing many large skylights or other features which permit a submarine to surface. There must be more than ten such features per 30 nautical miles (56 km) along the submarine's track (13.2).

Frost smoke: Fog-like clouds due to contact of cold air with relatively warm water, which can appear over openings in the ice, or leeward of the ice edge, and which may persist while ice is forming (11.3).

Giant floe: (4.3.2. 1) (see Floe).

Glacier: A mass of snow and ice continuously moving from higher to lower ground or, if afloat, continuously spreading. The principal forms of glacier are: inland ice sheets, ice shelves, ice streams, ice caps, ice piedmonts, cirque glaciers and various types of mountain (valley) glaciers (10.2.1).

Glacier berg: An irregularly shaped iceberg (10.4.2.1).

Glacier ice: Ice in, or originating from, a glacier, whether on land or floating on the sea as icebergs, bergy bits or growlers (10.2).

Glacier tongue: Projecting seaward extension of a glacier, usually afloat. In the Antarctic glacier tongues may extend over many tens of kilometers (10.2.4).

Grease ice: A later stage of freezing than frazil ice when the crystals have coagulated to form a soupy layer on the surface. Grease ice reflects little light, giving the sea a matt appearance (2.1.2).

Grey ice: Young ice 10-15 cm thick. Less elastic than nilas and breaks on swell. Usually rafts under pressure (2.4.1).

Grey-white ice: Young ice 15-30 cm thick. Under pressure more likely to ridge than to raft (2.4.2).

Grounded hummock: Hummocked grounded ice formation. There are single grounded hummocks and lines (or chains) of grounded hummocks (3.4.2).

Grounded ice: Floating ice which is a-round in shoat water (3.4) (cf. stranded ice).

Growler: Smaller piece of ice than a bergy bit or floeberg, often transparent but appearing green or almost black in color, extending less than I m above the sea surface and normally occupying an area of about 20 sq. m (10.4.5).

Hostile ice: From the point of view of the submariner, 'in ice canopy containing no large skylights or other features which permit a submarine to surface (13.3).

Hummock: A hillock of broken ice which has been forced upwards by pressure. May be fresh or weathered. The submerged volume of broken ice under the hummock, forced downwards by pressure, is termed a bummock (8.2.3).

Hummocked ice: Sea ice piled haphazardly one piece over another to form an uneven surface. When weathered, has the appearance of smooth hillocks (8.2.3.1).

Hummocking: The pressure process by which sea ice is forced into hummocks. When the floes rotate in the process it is termed screwing (6.2).

Iceberg: A massive piece of ice of greatly varying shape, more than 5 m above sea-level, which has broken away from a glacier, and which may be afloat or aground. Icebergs may be described as tabular, dome-shaped, sloping, pinnacled, weathered or glacier bergs (10.4.2).

Iceberg tongue: A major accumulation of icebergs projecting from the coast held in place by grounding and joined together by fast ice (10.4.2.3).

Ice blink: A whitish glare on low clouds above an accumulation of distant ice (I 1. 2).

Ice-bound: A harbor, inlet, etc., is said to be ice-bound when navigation by ships is prevented on account of ice, except possibly with the assistance of an icebreaker (12.2).

Ice boundary: The demarcation at any given time between fast ice and pack ice or between areas of pack ice of different concentrations (4.4.9) (cf. ice edge).

Ice breccia: Ice pieces of different age frozen together (4.3.5).

Ice cake: Any relatively flat piece of sea ice less than 20 m across (4.3.3).

Ice canopy: Pack ice from the point of view of the submariner (13.1).

Ice cover. The ratio of an area of ice of any concentration to the total area of sea surface within some large geographic local; this local may be global, hemispherical, or prescribed by a specific oceanographic entity such as Baffin Bay or the Barents Sea (4. 1).

Ice edge: The demarcation at any given- time between the open sea and sea ice of any kind, whether fast or drifting. It may be termed compacted or diffuse (4.4.8) (cf. ice boundary).

Ice field: Area of pack ice consisting of any size of floes, which is greater than 10 m across (4.4.1) (cf. patch).

Icefoot- A narrow fringe of ice attached to the coast, unmoved by tides and remaining after the fast ice has moved away (3.2).

Ice-free: No sea ice present. There may be some ice of land origin (4.2.7) (cf. open water).

Ice front: The vertical cliff forming the seaward face of an ice shelf or other floating glacier varying in height from 2-50 m or more above sea-level (10.3.1) (cf. ice wall).

Ice island: A large piece of floating ice about 5 m above sea-level, which has broken away from an Arctic ice shelf, having a thickness of 30-50 m and an area of from a few thousand square meters to 500 sq km. or more, and usually characterized by a regularly undulating surface which gives it a ribbed appearance from the air (10.4.3).

Ice jam: An accumulation of broken river ice or sea ice caught in a narrow channel (4.4.7).

Ice keel: From the point of view of the submariner, a downward-projecting ridge on the underside of the ice canopy, the counterpart of a ridge. Ice keels may extend as much as 50 m below sea-level (13.5).

Ice limit: Climatological term referring to the extreme minimum or extreme maximum extent of the ice edge in any given month or period based on observations over a number of years. Term should be preceded by minimum or maximum (4.4.8.3) (cf. mean ice edge).

Ice massif. A concentration of sea ice covering hundreds of square kilometers, which is found in the same region every summer (4.4.2).

Ice of land origin: Ice formed on land or in an ice shelf, found floating in water. The concept includes ice that is stranded or grounded (1.2).

Ice patch: An area of pack ice less than 10 km across (4.4.1.4).

Ice port: An embayment in an ice front, often of a temporary nature, where ships can moor alongside and unload directly onto the ice shelf (12.7).

Ice rind: A brittle shiny crust of ice formed on a quiet surface by direct freezing or from grease ice, usually in water of low salinity. Thickness to about 5 cm easily broken by wind or swell, commonly breaking in rectangular pieces (2.2.3).

Ice shelf:. A floating ice sheet of considerable thickness showing 250 m or more above sea-level, attached to the coast. Usually of great horizontal extent and with a level or gently undulating surface. Nourished by annual snow accumulation and often also by the seaward extension of land glaciers. Limited areas may be aground. The seaward edge is termed an ice front (q.v.) (10.3).

Ice stream: Part of an inland ice sheet in which the ice flows more rapidly and not necessarily in the same direction as the surrounding ice. The margins are sometimes clearly marked by a change in direction of the surface slope but may be indistinct (10.2-3).

Ice under pressure: Ice in which deformation processes are actively occurring and hence a potential impediment or danger to shipping (12.4).

Ice wall: An ice cliff forming the seaward margin of a glacier which is not afloat. An ice wall is aground, the rock basement being at or below sea-level (10.2.2) (cf. ice front).

Lake ice: Ice formed on a lake, regardless of observed location (1.3).

Large fracture: More than 500 m wide (7.1.5).

Large ice field: An ice field over 20 km across (4.4.1.1).

Lead: Any fracture or passage-way through sea ice which is navigable by surface vessels (7.3).

Level ice: Sea ice which is unaffected by deformation (5.1)

Light nilas: Nilas which is more than 5 cm in thickness and rather lighter in color than dark nilas (2.2.2).

Mean ice edge: Average position of the ice edge in any given month or period based on observations over a number of years. Other terms which may be used are mean maximum ice edge and mean minimum ice edge (4.4.8.4) (cf. ice limit).

Medium first-year ice: First-year ice 70-120 cm thick (2.5.2).

Medium floe: (see Floe) (4.3.2.4).

Medium fracture: 200 to 500 m wide (7.1.4).

Medium ice field- An ice field 15-20 km across (4.4.1.2). Multi-year ice: Old ice up to 3 m or more thick which has survived at least two summers' melt. Hummocks even smoother than in second-year ice and the ice is almost salt-free. Color, where bare, is usually blue. Melt pattern consists of large interconnecting irregular puddles and a well-developed drainage system (2.6.2).

New ice: A general term for recently formed ice which includes frazil ice, grease ice, slush and shuga. These types of ice are composed of ice crystals which are only weakly frozen together (if at all) and have a definite form only while they are afloat (2.1).

New ridge: Ridge newly formed with sharp peaks and slope of sides usually 40'. Fragments are visible from the air at low altitude (5.2.2.1).

Nilas: A thin elastic crust of ice, easily bending on waves and swell and under pressure, thrusting in a pattern of interlocking "fingers" (finger rafting). Has a matt surface and is up to 10 cm in thickness. May be subdivided into dark nilas and light nilas (2.2).

Nip. Ice is said to nip when it forcibly presses against a ship. A vessel so caught, though undamaged, is said to have been nipped (12.3).

Old ice: Sea ice which has survived at least one summer's melt. Most topographic features are smoother than on first-year ice. May be subdivided into second- year ice and multiyear ice (2.6).

Open pack ice: Pack- ice in which the ice concentration is 4/10 to 6/10 (3/8 to less than 6/8), with many leads and polynyas, and the floes are generally not in contact with one another (4.2.4).

Open water: A large area of freely navigable water in which sea ice is present in concentrations less than 1/10 (1/8). When there is no sea ice present, the area should be termed ice-free, even though icebergs are present (4.2.6).

Pack ice: Term used in a wide sense to include any area of sea ice, other than fast ice, no matter what - form it takes or how it is disposed (4.).

Pancake ice: Predominantly circular pieces of ice from 30 cm - 3 m in diameter, and up to about 10 cm in thickness, with raised rims due to the pieces striking against one another. It may be formed on a slight swell from grease ice, shuga or slush or as a result of the breaking of ice rind, nilas or, under severe conditions of swell or waves, of grey ice. It also sometimes forms at some depth, at an interface between water bodies of different physical characteristics, from where it floats to the

surface; its appearance may rapidly cover wide areas of water (4.3.1).

Polynya:. Any nonlinear shaped opening enclosed in ice. Polynyas may contain brash ice and/or be covered with new ice, nilas or young ice; submariners refer to these as skylights. Sometimes the polynya is limited on one side by the coast and is called a shore polynya or by fast ice and is called a flaw polynya. If it recurs in the same position every year, it is called a recurring polynya (7.4).

Puddle: An accumulation on ice of melt-water, mainly due to melting snow, but in the more advanced stages also to the melting of ice. Initial stage consists of patches of melted snow (9.1).

Rafted ice: Type of deformed ice formed by one piece of ice overriding another (8.2.1) (cf. finger rafting).

Rafting: Pressure processes whereby one piece of ice overrides another. Most common in new and young ice (6.4) (cf. finger rafting).

Ram: An underwater ice projection from an ice it-all, ice front, iceberg or j7oc. Its formation is usually due to a more intensive melting and erosion of the unsubmerged part (8.4).

Recurring polynya: A polynya which recurs in the same position every year (7.4.3).

Ridge. A line or wall of broken ice forced up by pressure. May be fresh or weathered. The submerged volume of broken ice under a rid-C, forced downwards by pressure, is termed an ice keel (8.2.2).

Ridged ice-. Ice piled haphazardly one piece over another el in the form of ridges or walls. Usually found in first- year ice (8.2.2.6) (cf. ridging).

Ridged-ice zone-. An area in which much ridged ice with similar characteristics has formed (8.2.2.6.1).

Ridging: Ice pressure process by which sea ice is forced into ridges (6.3).

River ice: Ice formed on a river, regardless of observed location (1.4).

Rotten ice-. Sea ice which has become honeycombed and which is in an advanced state of disintegration (9.4).

Sastrugi: Sharp, irregular ridges formed on a snow surface by wind erosion and deposition. On mobile floating ice the ridges are parallel to the direction of the prevailing wind at the time they were formed (8.6.1).

Sea ice: Any form of ice found at sea which has originated from the freezing of sea water (1.1).

Second-year ice: Old ice which has survived only one summer's melt. Because it is thicker and less dense than first-year ice, it stands higher out of the water. In contrast to multiyear ice, summer melting produces a regular pattern of numerous small puddles. Bare patches and puddles are usually greenish-blue (2.6.1).

Shearing: An area of pack- ice is subject to shear when the ice motion varies significantly in the direction normal to the motion, subjecting the ice to rotational forces. These forces may result in phenomena similar to a flaw. (q.v.) (5.3).

Shore lead: A lead between pack ice and the shore or between pack ice and an ice front (7.3.1).

Shore polynya: A polynya between pack ice and the coast or between pack ice and an ice front (7.4.1).

Shuga: An accumulation of spongy white ice lumps, a few centimeters across; they are formed from grease ice or slush and sometimes from anchor ice rising to the surface (2.1.4).

Skylight: From the point of view of the submariner, thin places in the ice canopy, usually less than I m thick and appearing from below as relatively light, translucent patches in dark surroundings. The under- surface of a skylight is normally flat. Skylights arc called large if big enough for a submarine to attempt to surface through them (120 m), or small if not (13.6).

Slush: Snow which is saturated and mixed with water on land or ice surfaces, or as a viscous floating mass in water after a heavy snowfall (2.1.3).

Small floe: (4.3.2.5) (see Floe).

Small fracture: 50 to 200 m wide (7.1.3).

Small ice cake: An ice cake less than 2 m across (4.3.3. 1). Small ice field: An ice field 10-15 km across (4.4.1.3). Snow-covered ice: Ice covered with snow (8.6). Snowdrift: An accumulation of wind-blown snow deposited in the Ice of obstructions or heaped by wind eddies. A crescent-shaped snow drift, with ends pointing down-wind, is known as a snow barchan (3.6.2).

Standing floe: A separate floe standing vertically or inclined and enclosed by rather smooth ice (8.3).

Stranded ice: Ice which has been floating and has been deposited on the shore by retreating high water (3.4. 1).

Strip: Long narrow area of pack ice, about 1 km or less in width, usually composed of small fragments detached from the main mass of ice, and run together under the influence of wind, swell or current (4.4.5).

Tabular berg:. A flat-topped iceberg. Most tabular bergs form by calving from an ice shelf and show horizontal banding (10.4.2.2) (cf. ice island).

Thaw holes: Vertical holes in sea ice formed when surface puddles melt through to the underlying water (9.2).

Thick first-year ice: First-year ice over 120 cm thick (2.5.3).

Thin first-year ice/white ice: First year ice 30-70 cm

thick (2.5.1).

Tide crack: Crack at the line of junction between an immovable ice foot or ice wall and fast ice, the latter subject to rise and fall of the tide (7.1.1.1).

Tongue: A projection of the ice edge up to several kilo- meters in length, caused by wind or current (4.4.4).

Vast floe- (4.3.2.2) (see Floe). Very close pack ice: Pack ice in which the concentration is 9/10 to less than 10/10 (7/8 to less than 8/8) (4.2.2).

Very open pack ice: Pack ice in which the concentration is 1/10 to 3/10 (1/8 to less than 3/8) and water preponderates over ice (4.2.5).

Very small fracture: 0 to 50 m wide (7.1.2).

Very weathered ridge: Ridge with tops very rounded, slope of sides usually 20º-30º (8.2.2.3).

Water sky: Dark streaks on the underside of low clouds, indicating the presence of water features in the vicinity b of sea Ice (11.1).

Weathered ridge: Ridge with peaks slightly rounded and slope of sides usually 30º' to 40º'. Individual fragments are not discernible (8.2.2.2).

Weathering: Processes of ablation and accumulation which gradually eliminate irregularities in an ice surface (6.5).

White ice: See thin first-year ice (2. 5. 1).

Young coastal ice: The initial stage of fast ice formation consisting of nilas or young ice, its width varying from a few meters up to 100-200 m from the shoreline (3.1.1).

Young ice: Ice in the transition stage between nilas and first-year ice, 10-30 cm in thickness. May be subdivided into grey ice and grey-white ice (2.4).

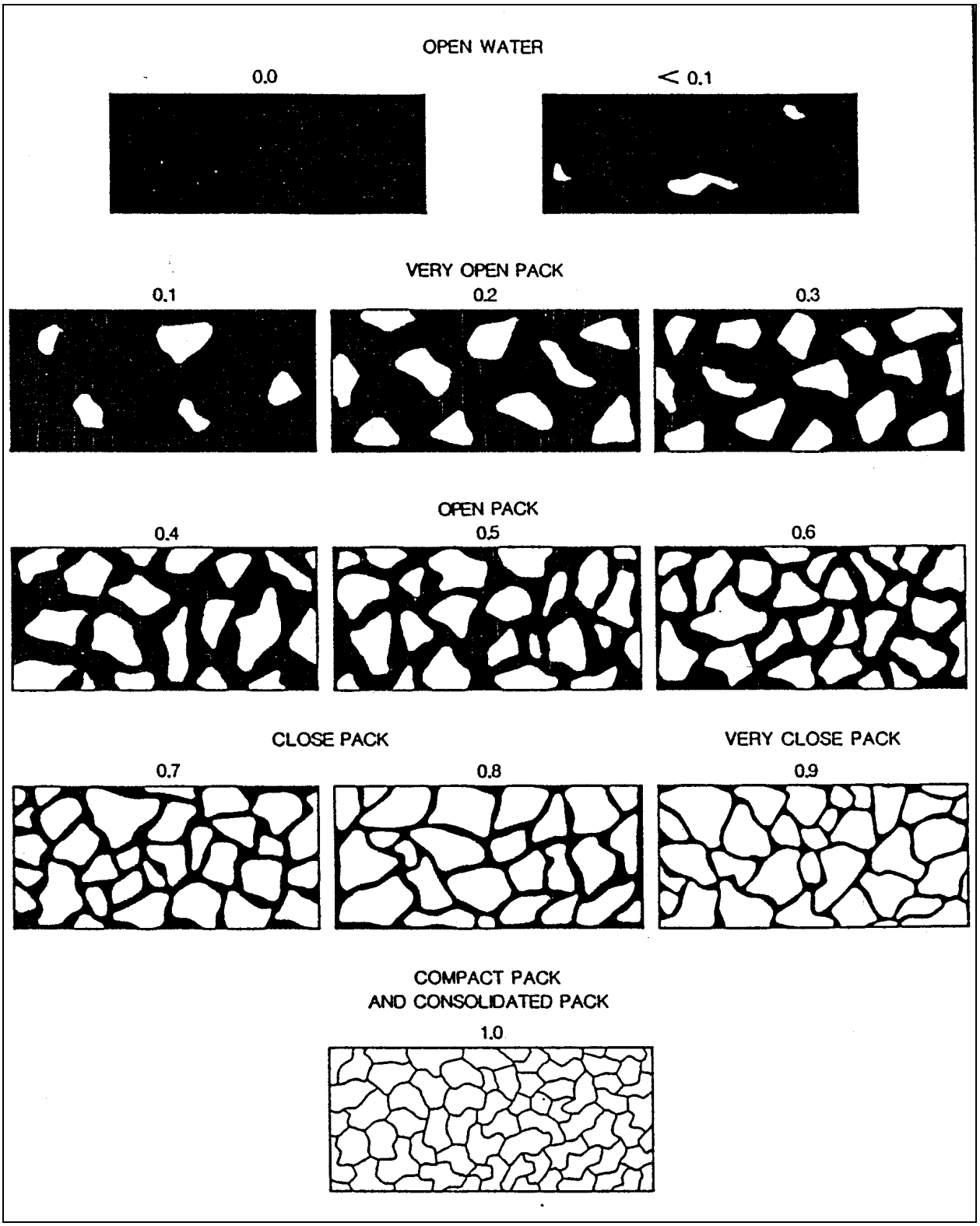


DIAGRAM OF CONCENTRATION IN TENTHS

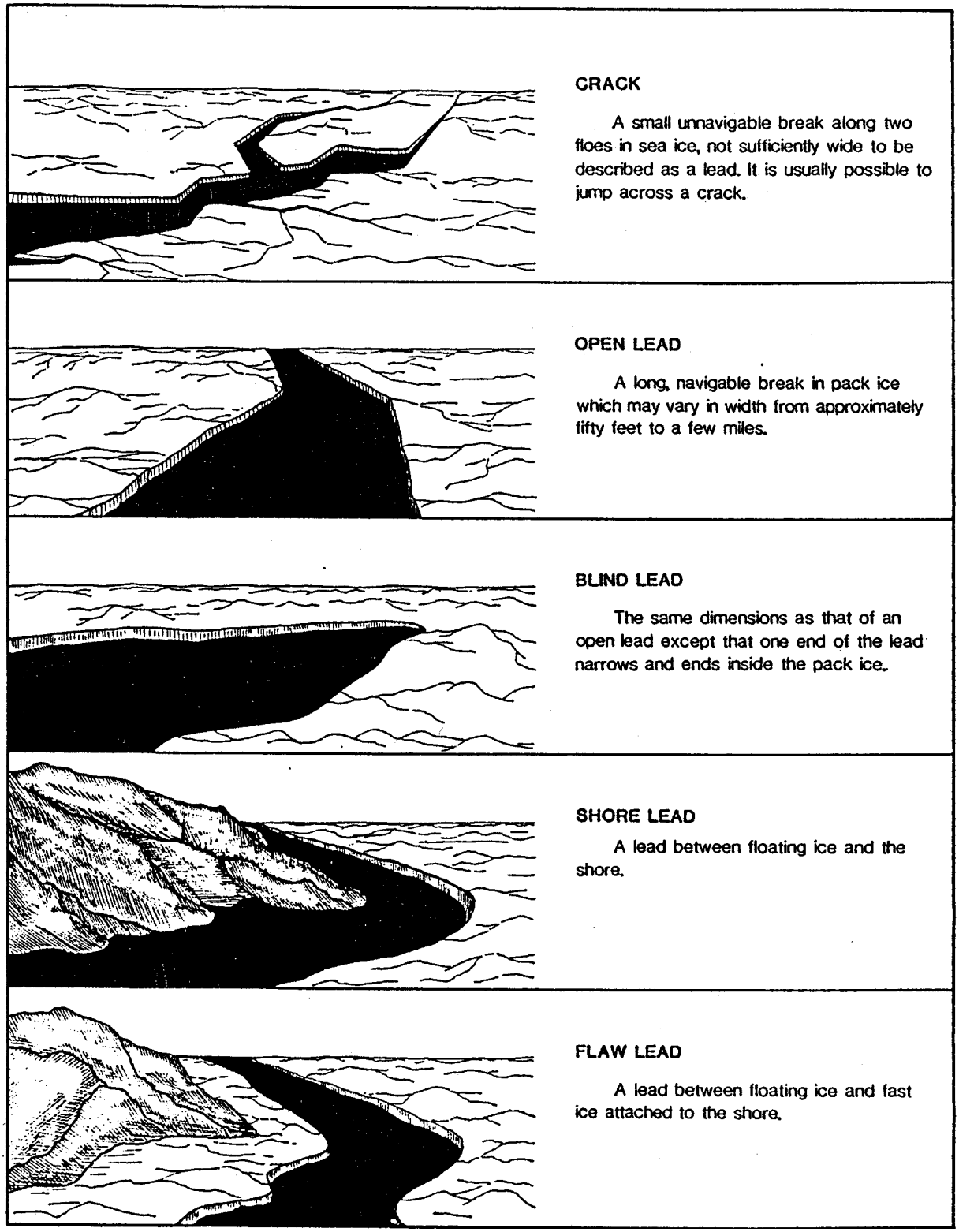


DIAGRAM OF TYPES OF OPENINGS IN THE ICE

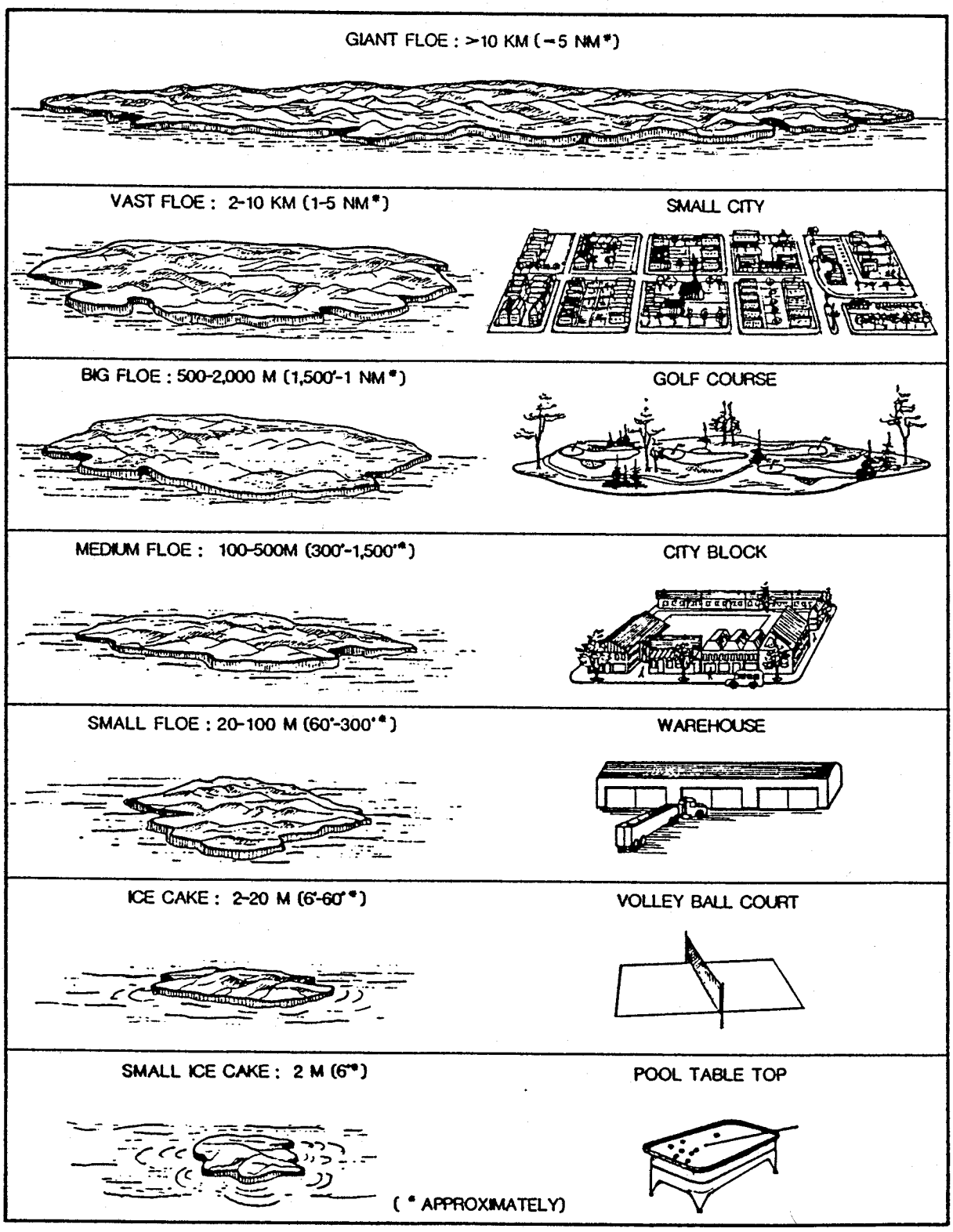
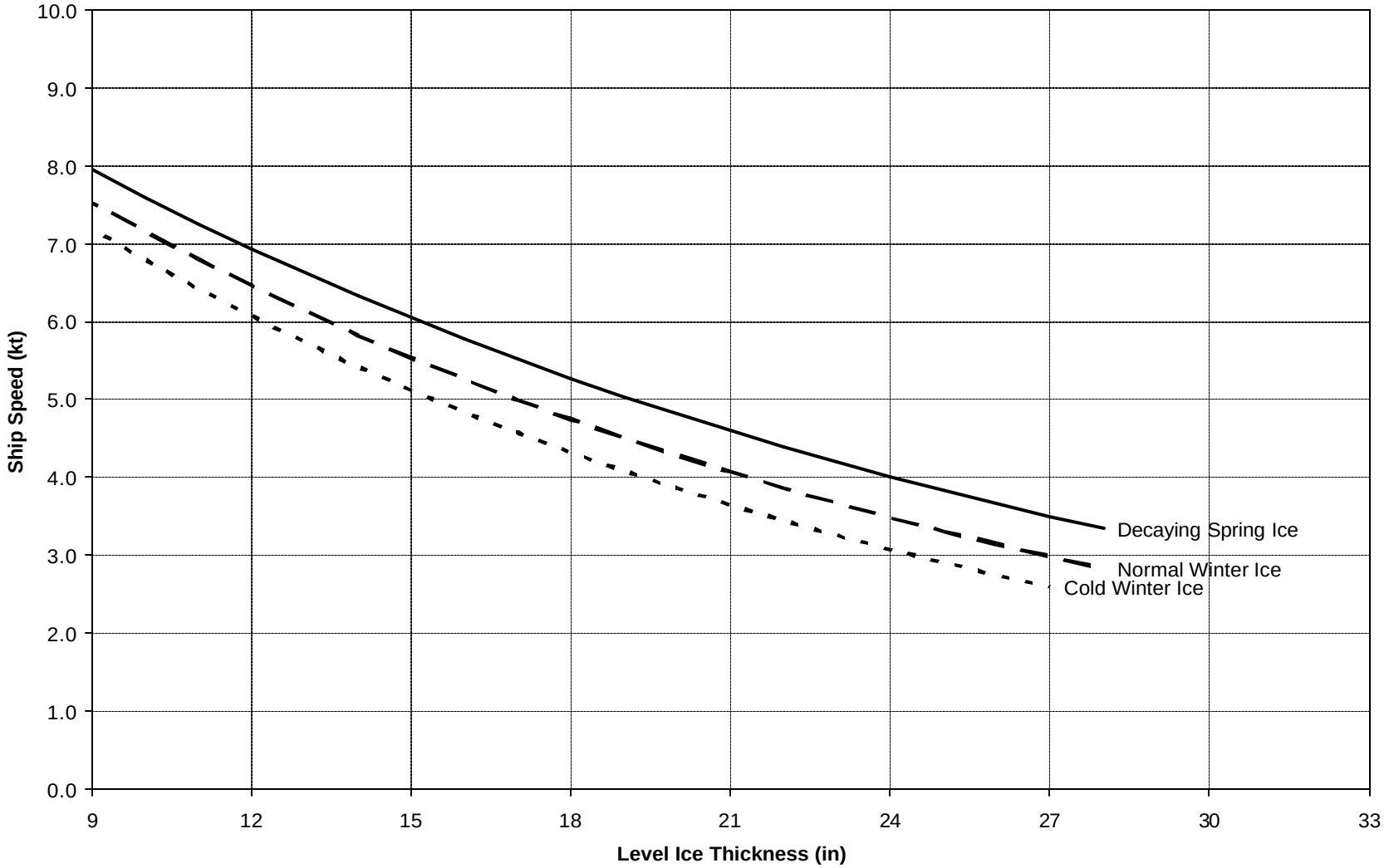


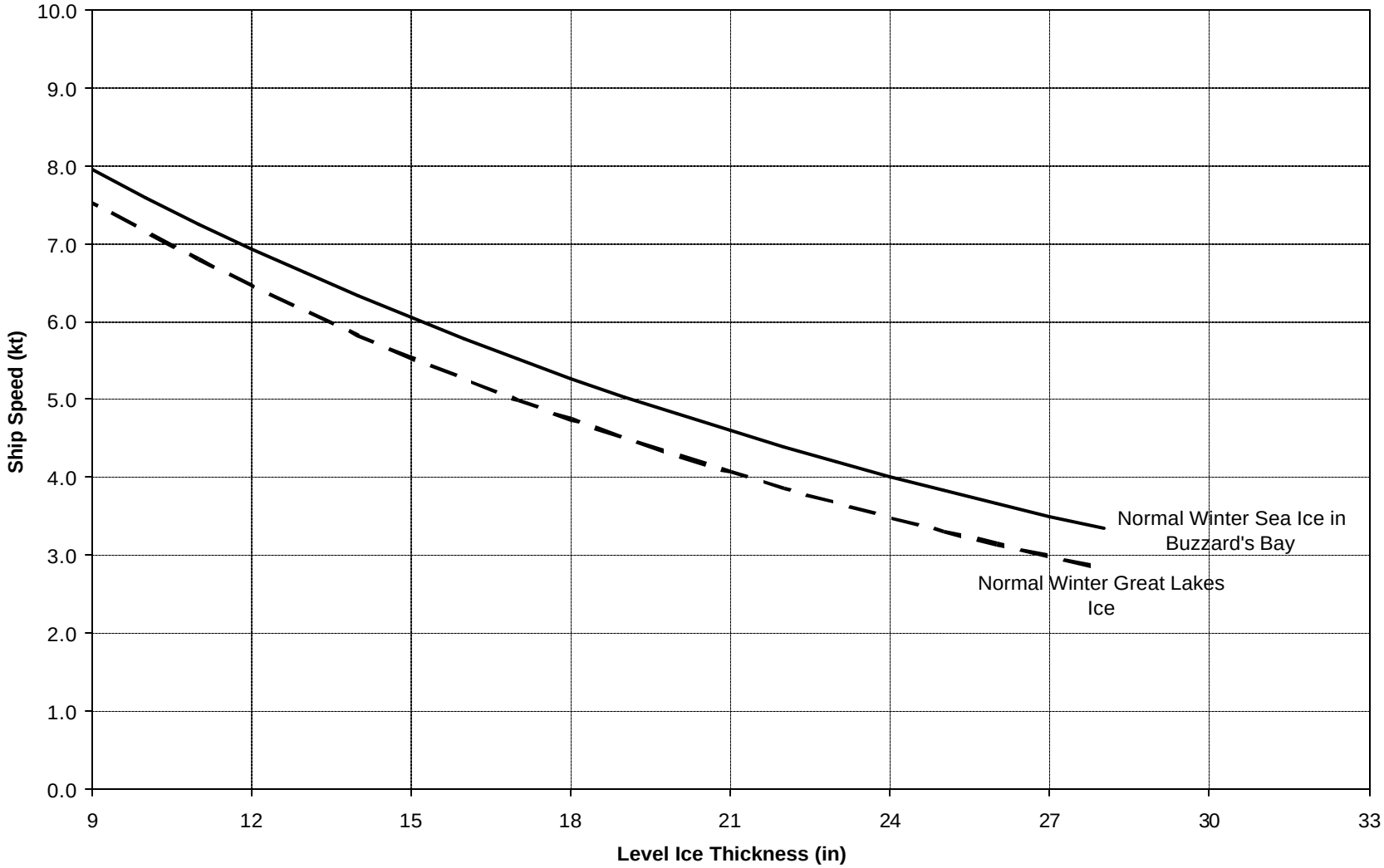
Diagram of Floe Sizes

APPENDIX B

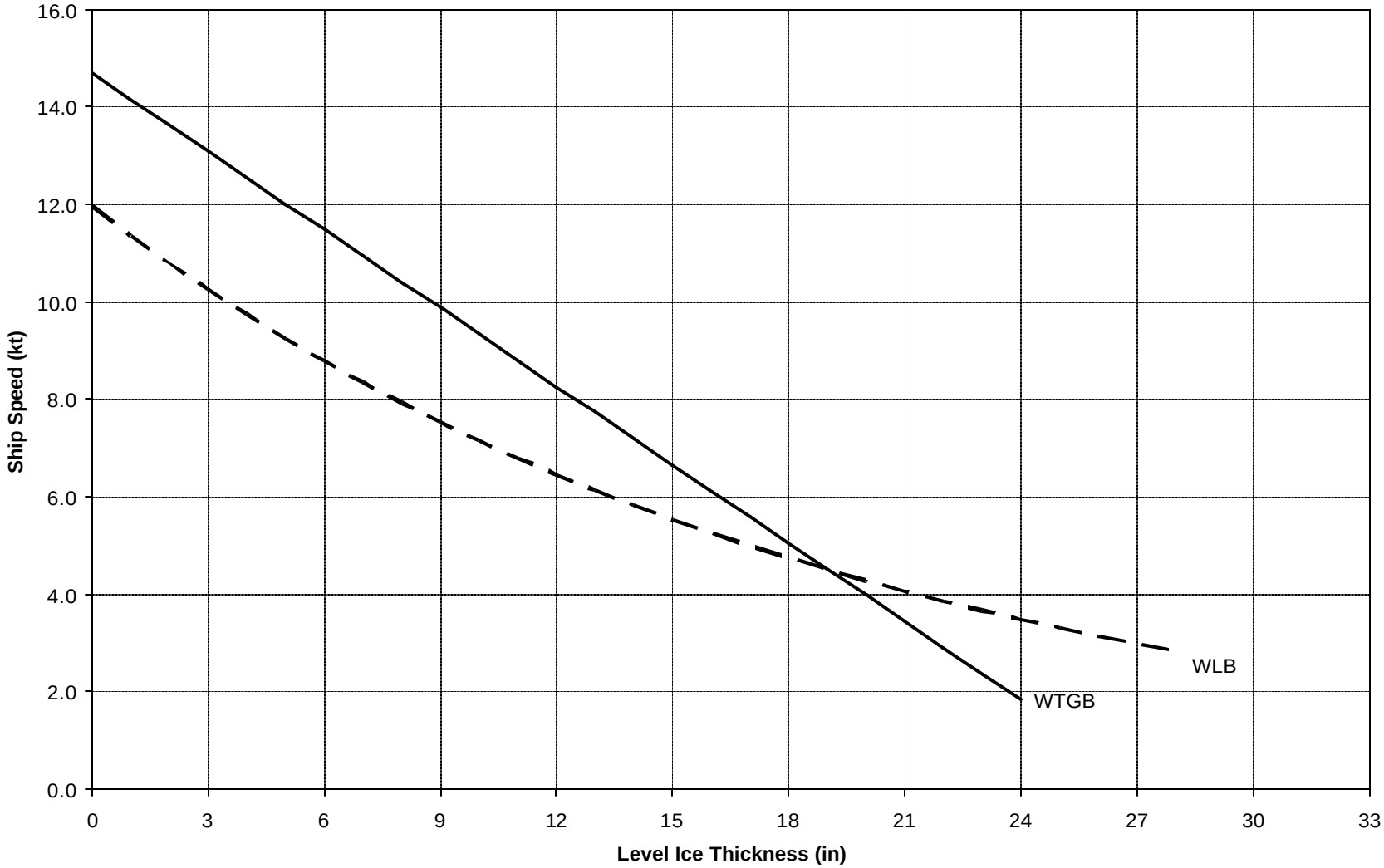
PERFORMANCE PLOTS FOR 225-FT WLB



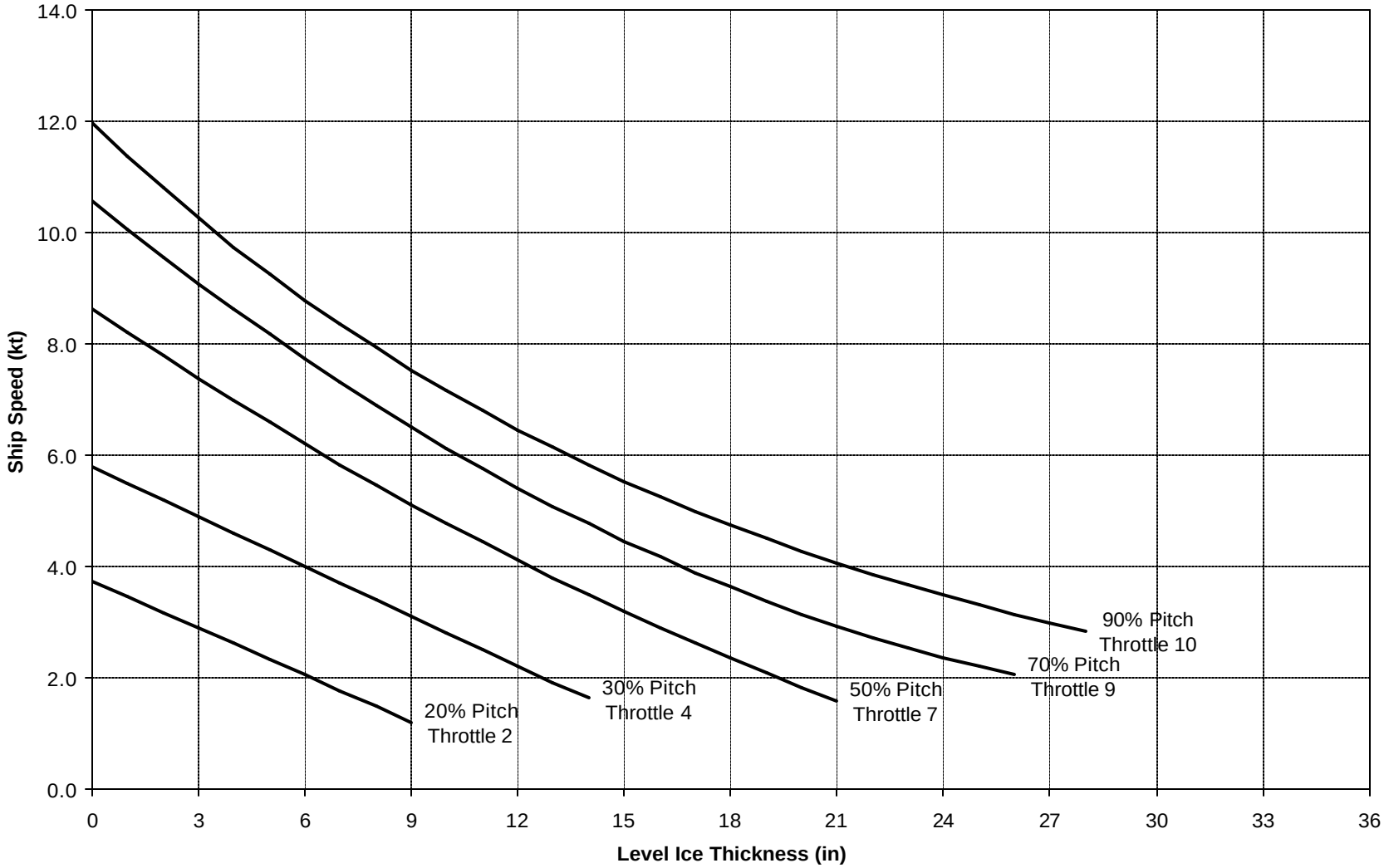
Comparison of WLB Performance in Level Ice of Different Temperatures (Ice Strengths)



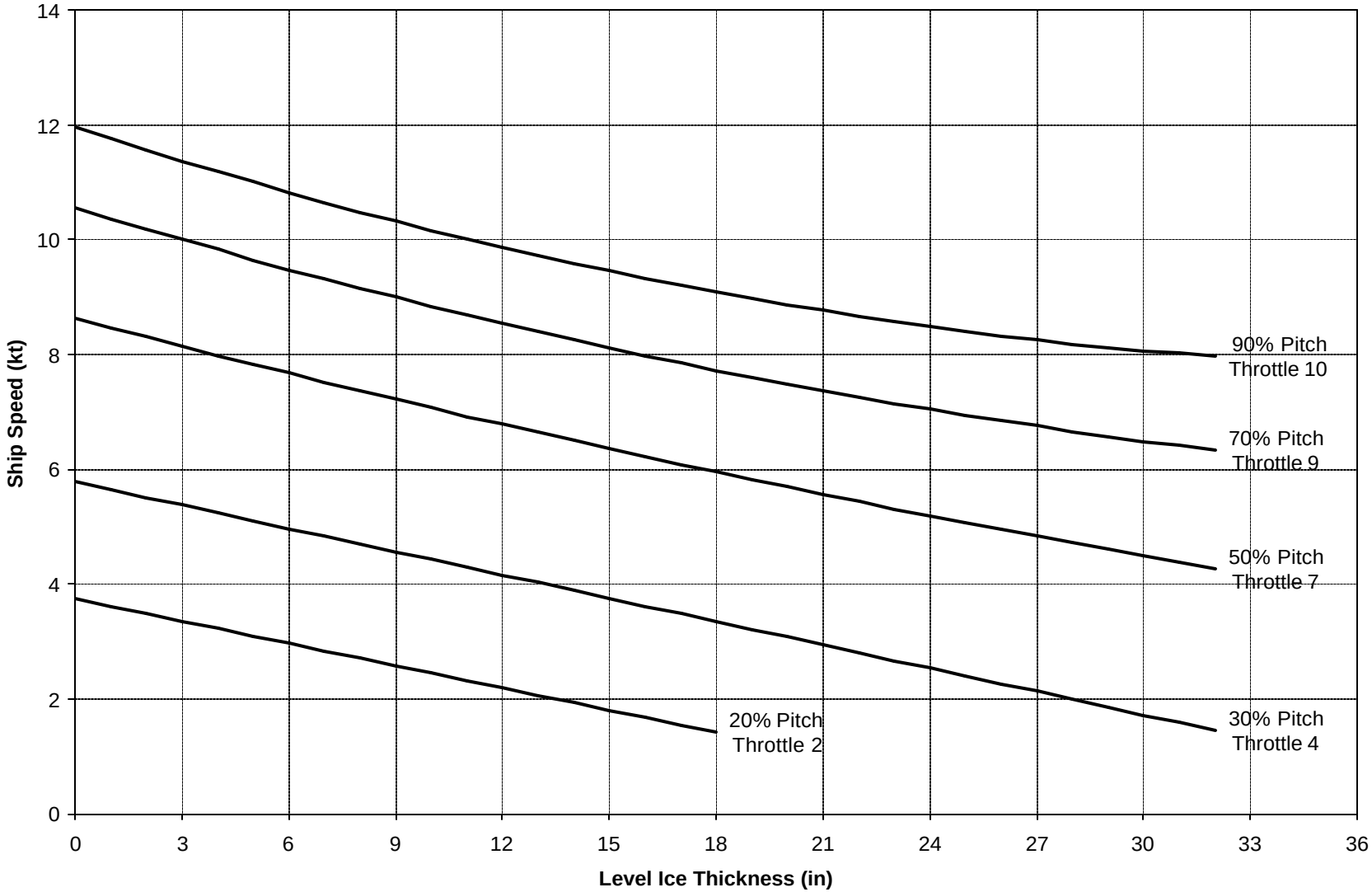
Comparison of WLB Performance in Great Lakes Fresh Water Ice and Buzzard's Bay Sea Ice



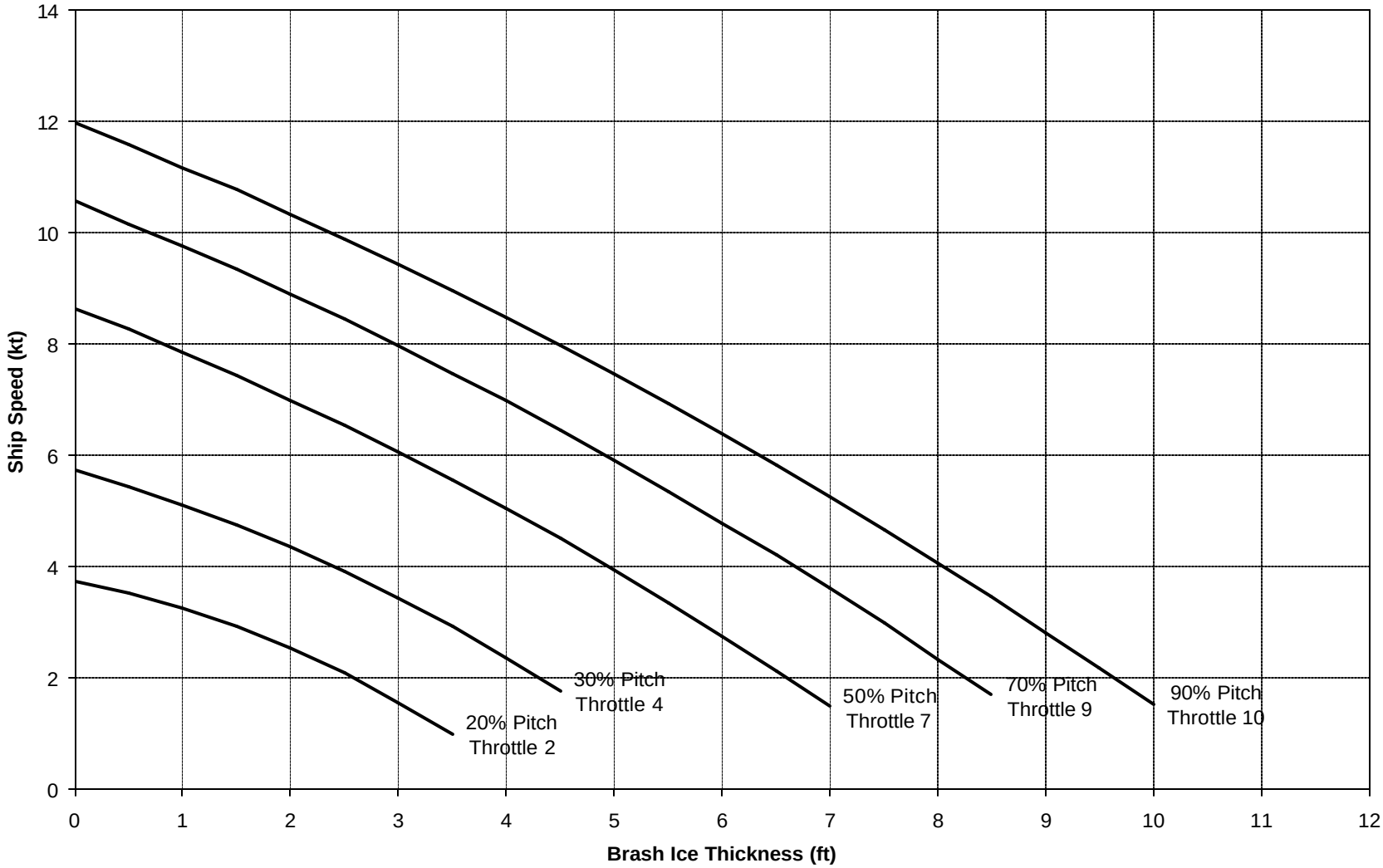
Comparison of the WLB and WTGB Performance in Normal Great Lakes Winter Ice



WLB Performance in Normal Winter Great Lakes Level Ice



WLB Performance in a Freshly Broken Channel (Maneuvering Mode)



WLB Performance in an Old Channel (Brash Ice and Maneuvering Mode)

APPENDIX C

ICEBREAKING RULES ADOPTED FROM POLAR CLASS

ICEBREAKING RULES FOR WLB ADAPTED FROM POLAR CLASS

The following list is meant to be a starting point for discussion to formulate rules specifically for the 225-ft WLB Juniper Class.

- When conning ship in open water or in ice, drive your pivot point. Know how your "tools at hand" work around your pivot point.
- Pivot point tends to shift toward things in contact with the ship such as tugs, piers and ice.
- Protect the propellers and rudder.
- Rudder amidships when backing.
- Back slowly.
- Do not back into heavy ice.
- Best way to transit ice is to AVOID it.
- Know various ice types and leads.
- Know effect that winds and current have on sea ice and bergs.
- Follow leads or open water.
- Go around pack or large floes even if substantial course deviation.
- Never hit large floes if you can avoid it.
- If you must go through larger floes, hit with stem (bow), which is designed to withstand hitting ice. Do not shoulder ice by hitting off beam.
- Frequently check trackline astern for pressure.
- Anticipate changing conditions. Need to have a strategic plan and a tactical plan as Ice Pilots.
- Do not damage the ship or put it in a position to become beset or nipped.
- Be patient. Command needs to balance operational commitments with pace of breaking ice. If we damage ship, we will not meet these commitments.

- Generally, conn from as far aloft as possible when transiting through pack ice when ice concentration is 7/10ths or greater.
- Do not enter ice when pressure is evident. Go around if possible.
- When backing and ramming, use appropriate technique (herring bone, modified herring bone). Repetitively striking along same path without widening your track, greatly increases potential to damage ship or become beset.
- Avoid milling ice, turn slowly if practicable. Slew rudder if necessary.
- When icebreaking near another ship or pier, allow enough time to stop the ship considering the reduced backing thrust of this propulsion system.

APPENDIX D

DEFFAULT PITCH/THROTTLE POSITIONE SETTING FOR 225’ WLB MANEUVERING MODE

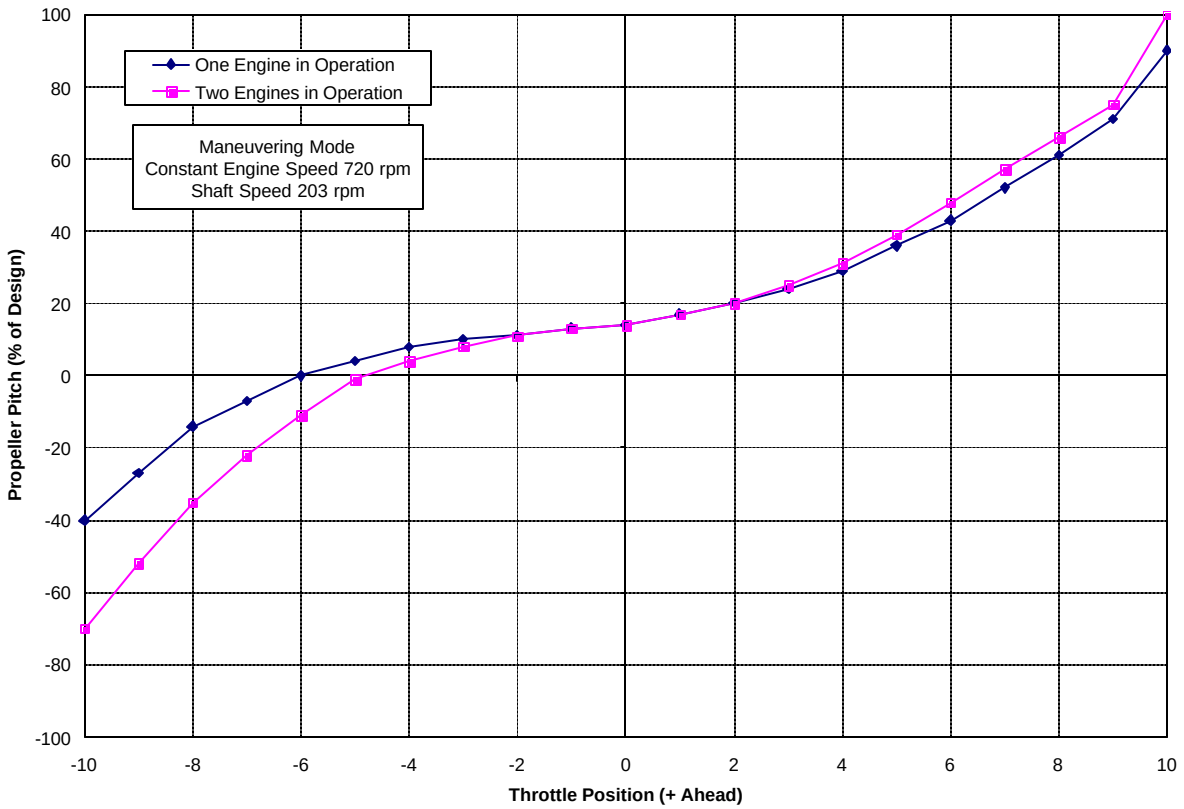


Figure D-1. Default Relationship between throttle position and pitch for maneuvering mode.