ELC-023-08-003

MACKINAW (WLBB 30) Operational Guide for Icebreaking

United States Coast Guard Engineering Logistics Center, Naval Architecture Branch, Baltimore, Maryland
November 2008

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MEMORANDUM

From: Rubin Sheinberg
USCG ELC (023/024)

To: Commanding Officer, USCGC MACKINAW (WLBB 30)

Subj: MACKINAW (WLBB 30) Operational Guide for Icebreaking

1. It is with great pleasure that I introduce this Operational Guide for Icebreaking for your cutter. The purpose of this Guide is to provide the cutter's operators with practical guidance supported by documented technical information to enhance the operation of this ship in the performance of domestic icebreaking missions on the Great Lakes. The Operational Guide for Icebreaking is intended to assist both the experienced icebreaker crewmember and a new, inexperienced or out-of-practice operator in understanding the performance capabilities of the cutter in ice. In addition, mission planners will be able to match mission requirements due to existing ice conditions with available fleet resources with greater effectiveness.

2. This Guide resulted from the efforts of the MACKINAW Ice Trials in the winter of 2005-2006 to determine the actual performance for the icebreaker after delivery to the Coast Guard. The principal objective of the of the ice trials was to evaluate the performance of the cutter in Great Lakes ice conditions in order to provide information on how to operate the cutter effectively and safely. A secondary objective was to ascertain the cutter's performance capabilities in the Great Lakes ice conditions as compared to the design requirements. In order to meet these objectives, the working goal was established for the development of an Operational Guide for Icebreaking.

3. The information needed for this Guide came from two principal sources of operator desires and technical evaluation that were synthesized into a coherent, and it is hoped, effective document for the operators of the icebreaker throughout the MACKINAW's service life. The principal contributors and authors include representatives from Coast Guard District 9, Coast Guard operators of Great Lakes icebreaking vessels (former and present), a former captain of Finnish icebreakers with podded propulsion, and naval architects involved with the ice trials.

4. In developing this Guide it was recognized that this had to be a living document. This is the first time that an icebreaking operator guidance document has been developed while the vessel it is intended for was under construction. In the past, guides of this kind were started by the vessel's initial captains, and then handed down to subsequent captains who in turn added addendums and additional information as it was developed and understood. The authors fully

expect that a similar process will occur with this Guide and strongly encourage its further development.

R. Sheinberg /s/
Chief, Naval Architecture Branch
U.S. Coast Guard Engineering Logistics Center
By direction

Enclosure: (1) "MACKINAW (WLBB 30) Operational Guide for Icebreaking", Report No. ELC-023-08-003, U. S. Coast Guard Engineering Logistics Center, Baltimore, Maryland, July 2008.

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USCGC Bristol Bay (WTGB-102)
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USCGC Mobile Bay (WTGB-103)
USCGC Neah Bay (WTGB-105)
USCGC Alder (WLB-216)
USCGC Hollyhock (WLB-214)

FOREWORD

GREAT LAKES ICEBREAKING HISTORICAL OVERVIEW

At the turn of the Twentieth Century traffic of major bulk commodities was rising astronomically. Iron ore, hard and soft coal and grain were the "big three" in the bulk cargo business, and over 500 ships (steamers) were employed. Shipping business on the Great Lakes was booming!

By the 1920s the "600-footer" lake carrier had become commonplace. The new locks at Sault Ste. Marie were in place. Ship construction techniques had developed to what is considered the standard of the modern era. Self-unloaders were introduced to increase efficiency and reduce cargo-handling time. The shipping season was basically seven and a half months long, from early spring to mid-December. Should a vessel become trapped in the ice, it was a matter of soliciting assistance from another passing vessel or just sitting there to wait for the weather conditions to change. For example, in December of 1926, when 140 steamers were locked in the ice of the St. Mary's River due to a sudden cold wave, it was feared that the ships would be held there until the spring thaw. The weather moderated overnight however, and the imprisoned vessels were freed within a few days.

Prior to the 1930s, domestic icebreaking had not been a primary concern of either the public or the Coast Guard. The annual closing of the Lakes was an accepted fact of life. With a change in home and commercial heating fuel from coal to oil and the sudden increase of automobiles requiring gasoline, the desire to navigate year-round grew. It was a simple fact that sufficient oil and gasoline storage capacity could not be maintained, nor could rail tank cars satisfy the communities demand. Oil barges became the primary means of transporting the large volume of this precious commodity. It became a necessity to keep the waterways open. This, coupled with an ever-increasing demand for iron are delivery to the steel mills in the southern Lakes, focused the need for icebreaking services.

According to the Historical Summary, found in the 1982 version of the "USCG Roles and Missions Study", domestic icebreaking began during the 1930's with memos from President Roosevelt to the Commandant "suggesting" that icebreaking services be provided on the Hudson River and in New England harbors. The icebreaking mission originated with Executive Order No. 7521, dated December 21, 1936, which directed the Coast Guard:

> To assist, as practicable, in keeping channels and harbors open to navigation by means of icebreaking operations in accordance with the reasonable demands of commerce and to use, for that purpose, such vessels subject to its control and jurisdiction as are necessary and are reasonably suited for operations.

The USCGC ESCANABA, first in a new class of cutter with icebreaking capabilities was constructed in 1932. Built at Bay City, Michigan, it was constructed with a steel-strengthened hull and assigned to Grand Haven, Michigan. ESCANABA was followed by construction of the cutter TAHOMA for duty on the Lakes. For these cutters icebreaking was a secondary mission to search and rescue, but their presence brought about a new era of extended season navigation.

Demands for raw materials at the mills and steel plants along the Lake Michigan and Lake Erie shores increased dramatically during World War II. From the beginning of the war, the need for extended navigation was recognized and through the National Defense Appropriation Act, Congress funded the construction of a fleet of 180-ft sea-going buoy tenders (with icebreaking capability) and a 290-ft heavy-duty icebreaker.

In accordance with Public Law 324, 55 Statue 782, dated 26 November 1941, Congress authorized the Coast Guard to construct a cutter for "ice-breaking and assistance work on the Great Lakes". The Act reads in total:

> Be it enacted by the Senate and House of the Representatives of the United States of America in Congress assembled, That in the interest of the uninterrupted flow of interstate and foreign commerce through the Straits of Mackinac in winter seasons, and better to provide assistance to marine commerce industry on the Great Lakes in opening ice-locked channels and ports, the Secretary of the Treasury be, and he is hereby, authorized and directed to construct and equip a Coast Guard cutter of design especially adapted for heavy ice breaking

At the time of launching, MACKINAW was the most powerful, most modern, and most capable icebreaker in the world. The cutters ESCANABA and TAHOMA were transferred to the North Atlantic fleet at the outset of the war. Prior to commissioning the new 180s, the government "acquired" two vessels with icebreaking capabilities and rebuilt them to service aids to navigation. These cutters, renamed and commissioned the ALMOND and ARROWWOOD, were decommissioned directly after the war in September 1945. With the commissioning of the MACKINAW in 1945 and the addition of the 180s to the fleet during the war, the 1950s inventory of icebreaking capable cutters totaled 13 vessels: one WAGB (MACKINAW), seven WAGLs (later re-designated as WLBs) (ACACIA, HOLLYHOCK, MESQUITE, TUPELO, SUNDEW, WOODRUSH and WOODBINE), and five WYTMs (ARUNDEL, KAW, NAUGATUCK, OJIBWA and RARITAN).

After the commissioning of MACKINAW the closed navigation period was reduced from four and a half months to an average of three months. Even with this increase in sailing days there was a growing interest within industry to have the federal government provide year-round navigation on the lakes.

Although the St. Lawrence River had for decades provided a route to the Atlantic for commerce (the Welland Canal was completed in 1888) it was not until the United States and Canada joined to construct the St. Lawrence Seaway in 1959 that the river system would see its full potential. With the construction of seven new locks, which would accommodate large deep-draft ocean-going vessels, a new chapter in Great Lakes navigation emerged.

The demand of the multifaceted missions placed on the Coast Guard was growing. In 1965 the Ninth District floating inventory had grown to eighteen and included MACKINAW, seven 180-ft WLBs, five small buoy tenders and five 110-ft harbor tugs. Icebreakers operated by the government, funded through the general tax structure, had become an integral part of the Great Lakes shipping mosaic.

The 1970 "River and Harbor Act" authorized the Great Lakes-St Lawrence Navigation Demonstration Program, to test the premise of keeping the lakes open for navigation all year long. Conducted over a period of eight years, record amounts of bulk cargo were shipped. A downturn in the economy, coupled with the industry's realization of the additional costs involved in operating year-round (including vessels damaged by ice), a question of who should pay for such services on a continuing basis, and the continuing battles with environmental factions, led to the end of the experiment. One positive result of the experiment, from the carrier's point of view, was the extension of the shipping season which provided for the Corps of Engineers to extend lock operations until 8 January (plus or minus one week) and to re-open the locks as early as 15 March. The previous dates had been 31 December and 1 April. Through the 1970s annual bulk, tonnage averaged 199,700,000 net tons. Several years of new tonnage records were set.

In addition to the previously stated Coast Guard icebreaking resources, a Wind Class polar icebreaker was assigned to the Great Lakes and homeported in Milwaukee. The mode of icebreaking evolved around the two WAGBs (MACKINAW and SOUTHWIND or WESTWIND), with the smaller less capable WLBs and WYTMs assisting wherever they could. Moving traffic through the Straits of Mackinac, Whitefish Bay, and the St. Mary's River was usually accomplished by forming a convoy and escorting the vessels from point to point. The buoy tenders and harbor tugs assisted vessels that needed "direct assistance" and worked in or around harbors.

The decade of the 1970s brought numerous changes for both the Coast Guard and Industry. With the construction of the "new Poe Lock" in 1968, enabling passage of ships just over 1000 feet long and 105 feet wide, a new generation of lake carriers was constructed. In total, thirteen of the thousand foot ships were built and constitute the nucleus of the commercial fleet. These ships had re-enforced bows and additional power to operate in ice. One 1000-footer, with a cargo load of 60,000 to 70,000 gross tons,

was more than the equal of six pre-war lakers with their 10,000 to 11,000 gross ton capacity. During the years 1972-82, 31 ships were delivered, adding 664,500 gross registered tons to the fleet. Also, sixteen older vessels were lengthened and/or converted to self-unloaders. Recognizing the growing demands of industry in domestic icebreaking, and the level of effectiveness of the WLBs and WYTMs, the Coast Guard launched a construction program to design and build a fleet of new icebreaking tugs (replacements for the WYTMs). By the end of the 1970s five WTGBs, 140-ft icebreaking tugs, were built and assigned to the Ninth District. With the commissioning of the last of the five WTGBs for Great Lakes duty in 1982, the last of the WYTMs (ARUNDEL) was decommissioned.

The sinking of the SS EDMUND FITZGERALD in November 1975, in a gale on Lake Superior, brought about a significant change in Coast Guard planning and operations. The Marine Board of Investigation stated that, scheduled maintenance for buoy tenders and icebreakers should be coordinated to provide for "maximize surface search and rescue capability during the severe weather season".

Industry has continued to respond to the challenge of extended navigation. In 1982, TUG MICHIGAN and accompanying barge GREAT LAKES was constructed by AMOCO. Designed to transport oil products year-round, the vessel can operate without assistance in ice in all but the most difficult situations. Likewise, the T/V KIISLA was introduced to the Lakes. A Finnish vessel, designed to operate in ice (with a bubbler system), this vessel has been employed to haul petroleum products, and only rarely needed outside assistance.

Commercial icebreaking assistance through this period has been limited to one vessel voluntarily helping another vessel beset in the ice. During the early 1980s owners of tug companies in Green Bay, Saginaw Bay, Duluth, and a few other isolated areas expressed an interest in providing direct assistance to vessels. The Coast Guard policy has been not to interfere with commercial interest (modeled after USCG SAR policies). For the most part commercial assistance has not developed to substantially impact on the need for federally funded icebreaking services to the mariner.

After a number of attempts to decommission MACKINAW during the 1980s and 1990s, in FY 2001, Congress appropriated funding to design and construct the new MACKINAW (WLBB 30). Awarded to Manitowoc Marine Group/Marinette Marine Corporation the vessel was launched on 2 April 2005 with delivery to the Coast Guard in the fall of 2005.

Captain R. J. Parsons (Ret.)
CO, USCGC MACKINAW 1989-1992

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4. SHIPHANDLING TECHNIQUES USING PROPELLER UNITS

None

CHAPTER ONE

1. USCGC MACKINAW SHIP DESCRIPTION

1.1 INTRODUCTION

The 240-ft Great Lakes Icebreaker, USCGC MACKINAW (WLBB 30), was designed as an icebreaking vessel and is currently expected to perform domestic icebreaking missions as a major part of its operation. This new ship is replacing the 280-ft icebreaker USCGC MACKINAW (WAGB 83) that has served well for many years. The new MACKINAW has been designed with multi-mission capabilities including heavy icebreaking, buoy tending and servicing ATON, search and rescue, law enforcement and has the ability to deploy an oil skimming system for environmental clean-up. With a mixed gender crew of nine officers, five chief petty officers, forty-one crewmembers and civilian training officer, MACKINAW has the capability to operate for extended periods and will depend on contract support for various maintenance requirements (i.e., exterior painting, bilge cleaning, engine overalls, etc.).

Since the new MACKINAW has been designed principally as a dual-mission cutter, icebreaking with buoy-tending capability, the cutter therefore is a smaller and more shallow-draft ship than its predecessor. The new MACKINAW design employs an innovative concept of the azimuthal diesel-electric propulsion system that is unique for the U.S. Coast Guard fleet. This system provides the operator with a number of features both in ice and open water, which were not available on other USCG icebreakers. Those features include exceptional maneuverability and dynamic positioning in open water, full directional control ahead and astern in ice, ability to perform ice maintenance by directing the Azipods toward a ship or the channel edge, and more efficient continuous pressure ridge transit astern as opposed to backing and ramming ahead. Hence, knowledge of the new cutter's icebreaking capability and maneuverability as well as techniques and procedures, its limitations and advanced features will be described to enable proper and effective icebreaking operations to be performed.

The purpose of this report is to provide the cutter's operators with an Operator Guidance Manual for Icebreaking for the 240-ft USCGC MACKINAW (WLBB 30) to help this ship perform domestic icebreaking missions effectively and safely. The Operator Guidance Manual for Icebreaking is intended to assist both the experienced icebreaker crewmember and a new, inexperienced or out-of-practice operator in understanding the performance capabilities of the cutter in ice. Finally, mission planners will be able to match mission requirements due to existing ice conditions with available fleet resources with greater effectiveness.

1.2 WLBB SHIP CHARACTERISTICS AND PERFORMANCE IN OPEN WATER AND ICE

Table 1.1. Principal Characteristics

Length overall	240 ft
Length between perpendiculars	227 ft
Beam at design waterline	57 ft
Beam, maximum	58 ft
Draft at design waterline	16 ft
Displacement in Full Load condition	3537 LT
Deadweight capacity	652 LT
Speed, maximum	15 kts
Speed, cruise	12 kts
Range, maximum	4700 NM
Endurance, maximum	20 days
Main propulsion	AC-AC Diesel – Electric
Main engines	3 x 3,130 kW
Propulsors	2 x 3,360 kW Azipod™, Fixed Pitch
Shaft horsepower	2 x 4,460 HP
Bollard thrust ahead	76 LT
Bollard thrust astern	65 LT
Bow thruster	1 x 480 HP
Auxiliary/Emergency generator	1 x 715 kW
Fuel oil capacity	359 LT
Fresh water capacity	104 LT
Holding tank capacity	10 Days
Crane	20-ton, Hydraulic, 60-foot boom
Buoy Deck Area	4700 ft^2, heated
Deck Load	85 LT

Table 1.2. Maneuvering Tactical Data in Open Water

Turning circle port	
Port pod angle	35 deg
Starboard pod angle	35 deg
Tactical diameter	265 ft-9 kt, 309 ft-12 kt, & 447 ft-15.8 kt
Final Diameter	127 ft-9 kt, 208 ft-12 kt, & 338 ft-15.8 kt
Turning circle starboard	
Port pod angle	35 deg
Starboard pod angle	35 deg
Tactical diameter	261 ft-9 kt, 358 ft-12 kt, & 362 ft-15.8 kt
Final Diameter	135 ft-9 kt, 162 ft-12 kt, & 228 ft-15.8 kt
Stopping distance	
By pods turning around (180 deg)	TBD
By propeller reverse	TBD
By pods turning 90 deg	TBD

Table 1.3. Icebreaking Capability

Level ice ahead at 10 knots	17 in.
Level ice ahead at 3 knots	36 in.
Level ice astern at 2 knots	39 in.
Best trim for icebreaking	Even keel
Refrozen Brash Ice Capability	Up to 11 ft
Ridge Ice Capability	10 ft (penetrate in less than 4 rams)

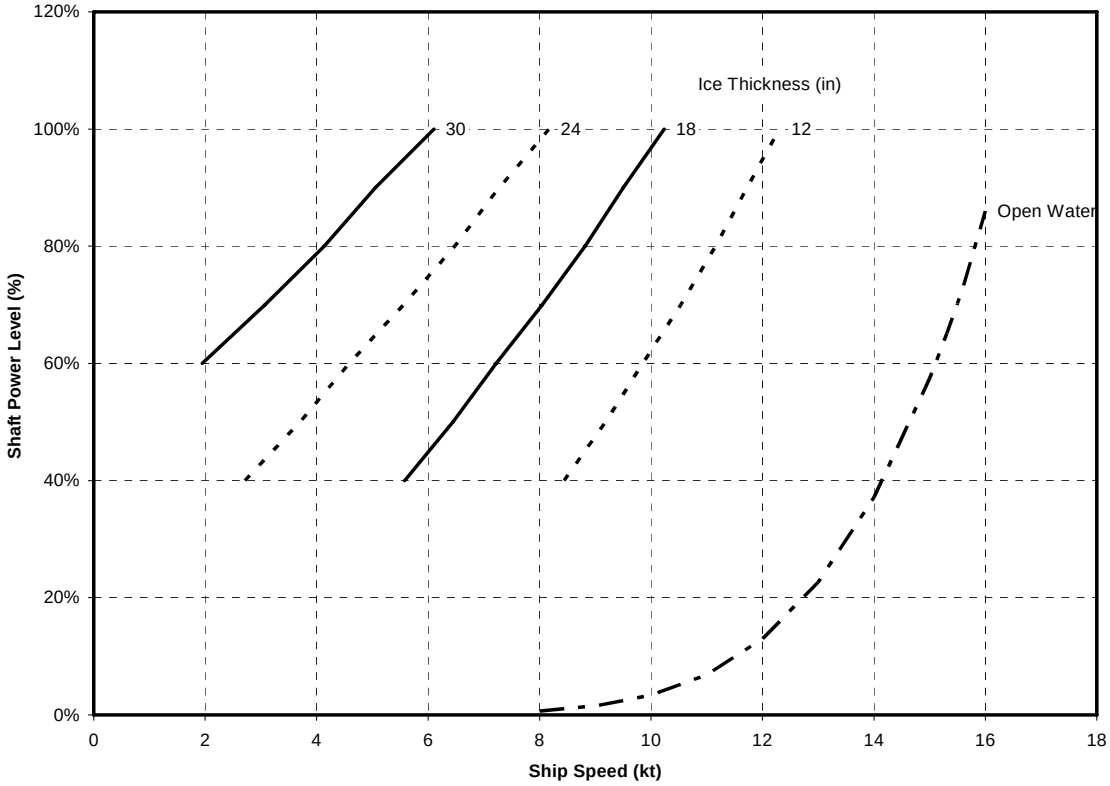

Figure 1.1 Shaft power versus ship speed for plate ice and open water.

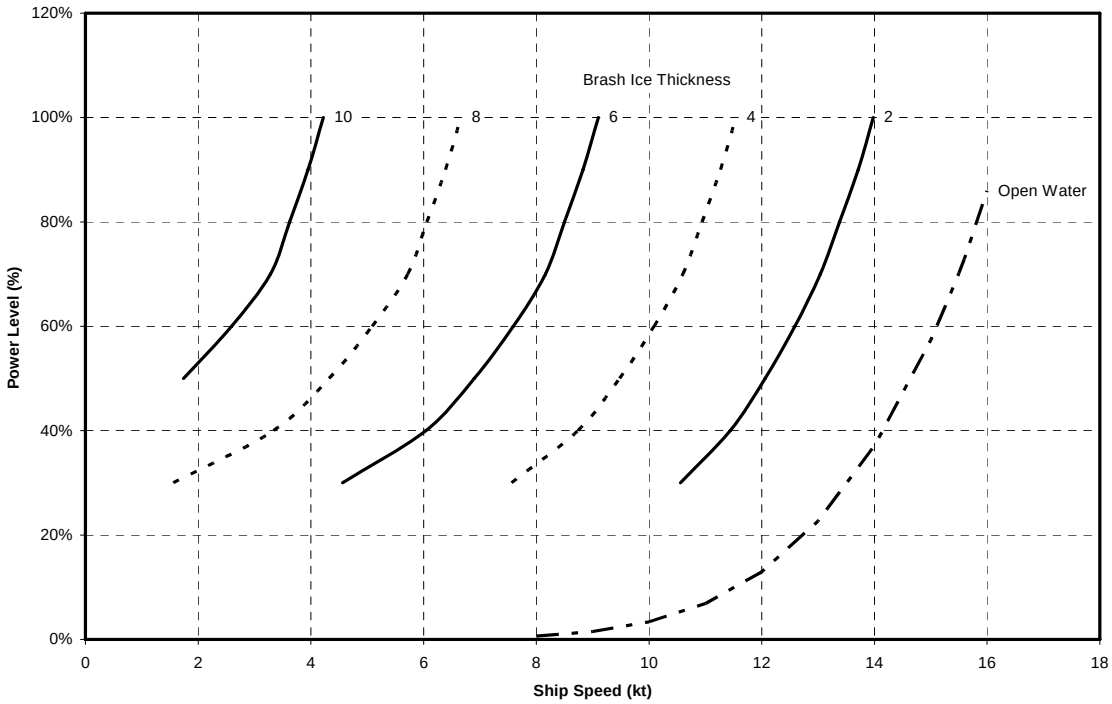

Figure 1.2. Shaft power versus ship speed for brash ice and open water.

Table 1.4. Penetration in a Ridge Different Ice Thicknesses and Sail Heights

Based on an Analytical Model

Ice Thickness	ft	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Sail Height	ft	2.0	2.0	2.0	2.0	3.0	3.0	3.0	3.0
Bollard Pull	%	100%	90%	80%	70%	100%	90%	80%	70%
Impact Speed	kt	5.87	6.37	6.82	7.22	7.45	7.89	8.28	8.65
Charge Distance	SL	0.5	0.6	0.7	0.8	0.9	1.0	1.1	1.2
Penetration/ram	ft	146	146	146	145	162	161	161	161
Ice Thickness	ft	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Sail Height	ft	4.0	4.0	4.0	4.0	5.0	5.0	5.0	5.0
Bollard Pull	%	100%	90%	80%	70%	100%	90%	80%	70%
Impact Speed	kt	9.00	9.39	9.75	10.09	10.55	10.90	11.23	11.55
Charge Distance	SL	1.3	1.5	1.6	1.7	1.9	2.1	2.2	2.4
Penetration/ram	ft	177	178	177	178	193	193	193	193
Ice Thickness	ft	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00
Sail Height	ft	3.0	3.0	3.0	3.0	4.0	4.0	4.0	4.0
Bollard Pull	%	100%	90%	80%	70%	100%	90%	80%	70%
Impact Speed	kt	11.49	11.72	11.94	12.16	12.91	13.13	13.35	13.56
Charge Distance	SL	2.7	2.8	3.0	3.1	3.7	3.8	4.0	4.2
Penetration/ram	ft	162	162	162	162	178	178	178	178
Ice Thickness	ft	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00
Sail Height	ft	5.0	5.0	5.0	5.0	6.0	6.0	6.0	6.0
Bollard Pull	%	100%	90%	80%	70%	100%	90%	80%	70%
Impact Speed	kt	14.36	14.57	14.78	14.98	15.84	16.04	16.24	16.43
Charge Distance	SL	5.0	5.2	5.5	5.7	6.8	7.1	7.5	7.8
Penetration/ram	ft	193	193	193	193	209	209	209	209

Table 1.5. Throttle Position, Shaft Power, and Speed (kt) in Plate Ice and Open Water

Lever Position	Power Level	Open Water	12 inch Ice	18 inch Ice	24 inch Ice	30 inch Ice
0%	0%					
10%	1%	8.5	2.4			
20%	2%	9.3	5.3	1.8		
30%	3%	9.9	7.1	3.9	0.7	
40%	7%	11.1	8.3	5.3	2.4	
50%	12%	12.0	9.2	6.4	3.7	0.4
60%	22%	13.1	10.0	7.4	4.8	1.9
70%	35%	14.0	10.6	8.2	5.8	3.1
80%	50%	14.7	11.2	8.9	6.6	4.2
90%	72%	15.5	11.7	9.5	7.3	5.1
100%	100%	16.2	12.2	10.0	7.9	6.0

The turning radius at various speeds in plate ice is given in Table 2.5 based on the ice trials data.

1.3 WLBB DESIGN FOR ICEBREAKING

The following section describes the aspects of the MACKINAW's design that make her an excellent icebreaker for the Great Lake ice conditions.

1.3.1 Hullform and Appendages

The Great Lakes Icebreaker Class WLBB has an icebreaking bow (see Figure 1.3) characterized by a low stem angle and parallel buttock lines that generate greater flair in the forebody and lesser flair in the midbody. As the ship moves forward in the ice, it rides up slightly on the ice cover and generates a downward bending force 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.

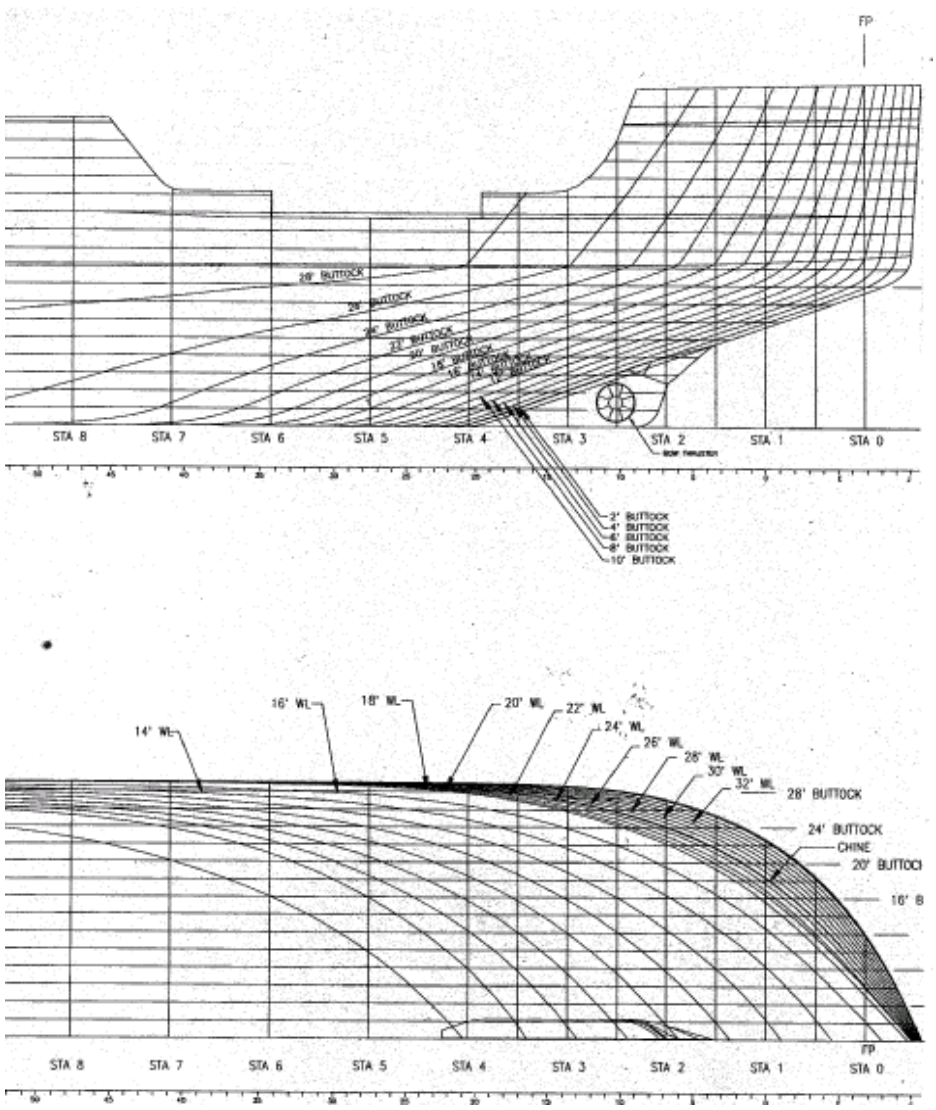

Figure 1.3. Bow shape of the 240-ft WLBB for icebreaking.

The design philosophy for WLBB was to provide the vessel with essentially equal performance ahead and backing in ice. The WLBB stern shape is characterized by low buttock angles forming a flat surface of the stern. The flat surface is transformed into the "arch" in the middle stretched behind Azipods through the waterline. The purpose of the "arch" is to create additional breaking points for the ice cusps moving down the hull before they reach the vertical edges of AZIPOD struts. This is intended to prevent cusps from crushing at the struts, which would generate high resistance forces. The WLBB stern shape and propulsion system provide the ship with excellent backing performance in all types of ice conditions and active directional control by the Azipods. (See Figure 1.4) The stern arrangements are not designed for ramming the ridges, but instead provide the capability to move continuously through the ridge or rubble field at low speed astern and restore the movement without a ram in case the ridge stops

the ship first. The backing thrust of the Azipods is about 86 percent of its ahead thrust when both are in the bollard or zero-speed condition. For icebreaking, this means there is plenty of thrust to go both ahead and to back out if the ship is stopped.

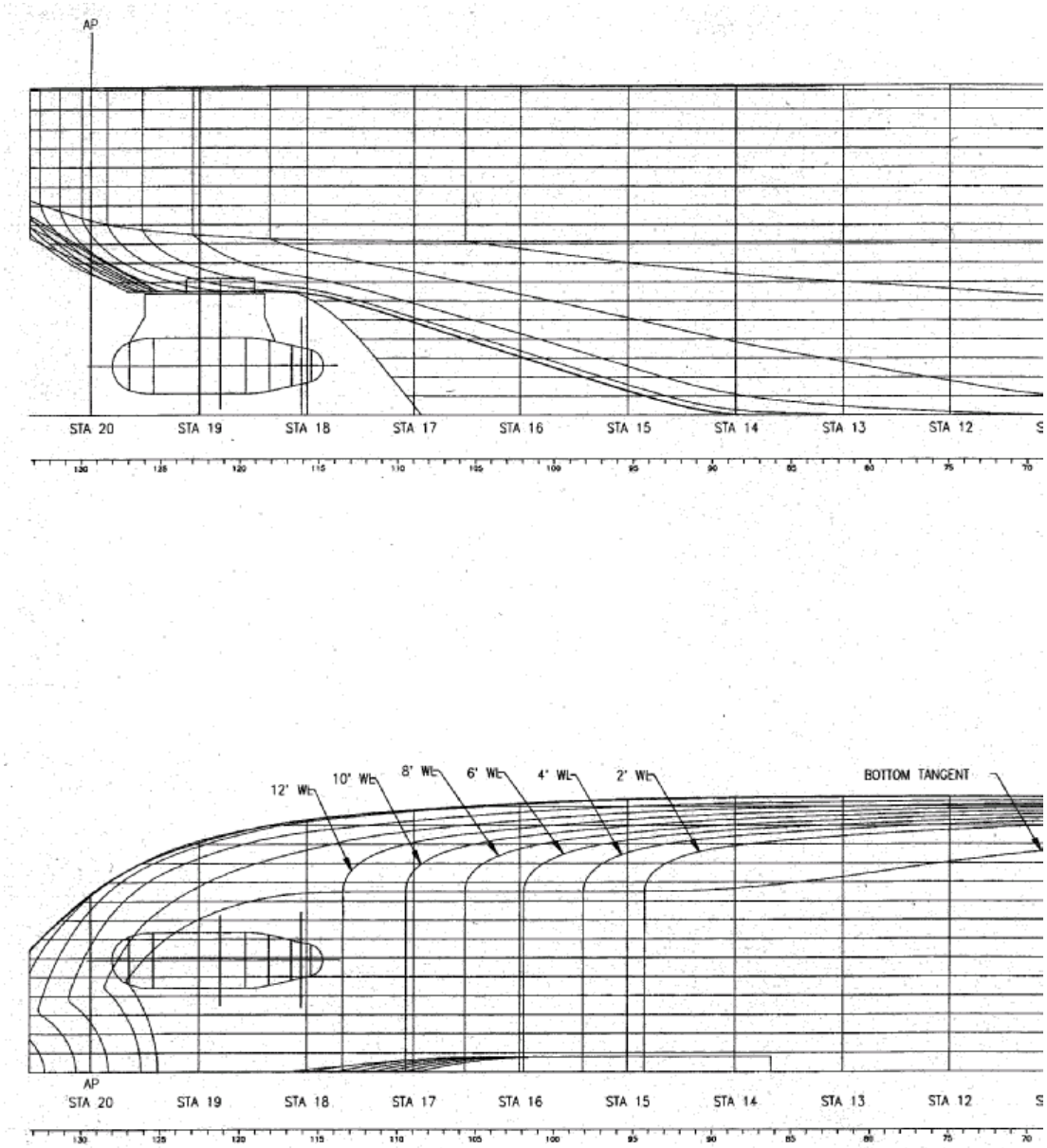

Figure 1.4. WLBB stern and propulsion units.

The combination of azimuthal propulsors and efficient icebreaking stern creates the new capability of performing many standard operations using the astern mode of icebreaking. This is a new unique feature for the USCG fleet of icebreaking ships. The ability to back through ridges and the ability to flush broken ice from a pier or a ship will change the approach for crew experienced in operating

conventional icebreakers. It is assumed that further investigation of the performance of the WLBB in ice must be done to quantify the effect of the new features on icebreaking operations.

1.3.2 Ice-Strengthening and the Icebelt

The "icebelt" is the portion of the shell structure upon which the ice loads may act. The icebelt and its supporting structure are designed for the ice loads that can occur in the Great Lakes during operations in up to 42 in of hard level ice and in greater thicknesses for ramming, including up to 12 ft of brash ice and pressure ridges (windrows) with 12-ft sail heights. The coverage of the icebelt for the MACKINAW is as shown in Figure 1.5. It includes all portions of the hull below the chine and below the main deck in the bow.

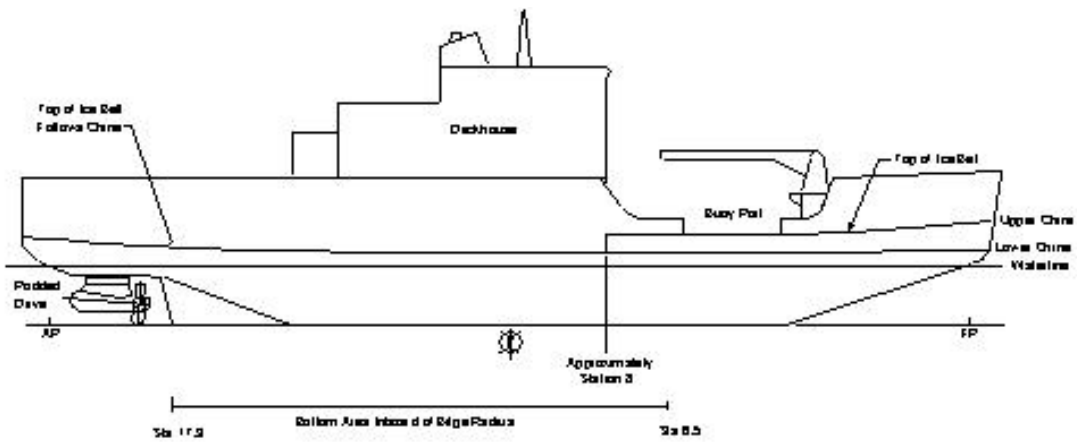

Figure 1.5. Icebelt area.

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 WLBB has been designed with a system of closely spaced (19 to 21 inch spacing) transverse frames and thicker icebelt shell plating. Tripping brackets are installed to 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.

1.3.3 Machinery Plant Operation in Ice

The machinery plant is specifically designed to operate in ice. The plant is an AC-AC common bus electric propulsion system that has excellent torque characteristics and responsiveness for operation in ice. No specific limitations are required for operation in ice.

1.3.4 Consideration of Other Systems for Icebreaking

In the following sections, provision has been made to note any special operating configurations or operational procedures required for ice operations.

1.3.4.a Machinery Control System

The MACKINAW is equipped with two modes of operation for the propulsion control, rpm control and power control. Rpm control tries to maintain constant rpm at a given throttle position. This mode is most suitable for operation in open water. The second mode, power control, tries to maintain constant power for a given throttle position. This mode is recommended for icebreaking. Both modes follow a notional open water propeller curve to relate the throttle to either rpm or power. In ice, torque increases and rpm decreases at the same power level due to the higher resistance so power control is the better option for icebreaking. Since the control system uses the notional open water power curve, increasing throttle increases power slowly at the lower settings and only achieves high power (and thrust) at the high throttle positions as shown in the table in Section 1.3.

For operation in heavy ice, propeller rpm should be maintained to prevent damage. Propeller blade damage is most likely to occur when maneuvers like backing and ramming are being performed and the ship backs into solid ice with the propeller turning slowly or stopped. During maneuvers like this, the propeller operates in unusual directions to the inflow of water such as backing the propeller while the ship is still moving ahead. The propeller is more vulnerable to a load on the back or face where its bending strength is weaker than hitting on the blade edge. Inflow direction to the propeller is a function of the speed of the ship and the propeller rpm. If the shaft speed is increased, the inflow 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. The control system also protects the shaft line from over-torque in this mode as well.

1.3.4.b Azipod Units

The pods are designed to take the ice loads and no excessively high loads were noted in the ice trials (data reduction and analysis is on-going). In general, placing the propellers close to each other or stopping the shaft rotation while the ship is moving significantly in ice is to be avoided as this may cause excessive loads on the units. Generally, the propellers should be turning and pointed toward the ice when advancing into an ice cover or swing the stern into an ice cover to present the best inflow angle to resist ice impacts on the blades.

1.3.4.c Bow Thruster

MACKINAW is equipped with a bow thruster for improved maneuverability at slow speed and station-keeping intended for use in open water. Thrusters have been shown to be effective in light ice situations on the JUNIPER Class WLBs but the MACKINAW does not need the bow thruster to

maneuver in ice because the two Azipods units and the icebreaking hullform provide exceptional maneuverability in ice. In addition, the MACKINAW can operate in heavier ice than the WLBs which would expose the bow thruster to increased potential for damage. Therefore, it is recommended that the bow thruster be secured when in ice.

1.3.4 d Trim and Ballasting for Icebreaking

The ship is designed to have the proper hull angle for icebreaking at even keel and an even keel condition is recommended. Trimming the ship will not affect icebreaking performance significantly but it could influence the ice piece flow around the pods and the frequency they encounter ice pieces. Ballasting toward the ends of the vessel symmetrically fore and aft increases the pitch inertia and improves icebreaking.

CHAPTER TWO

2. WLBB PERFORMANCE IN ICE

2.1 WLBB OPERATIONAL PROPULSION PERFORMANCE

This section covers propulsion performance directly related to icebreaking performance. Greater details and technical information concerning the propulsion performance and characteristics for the cutter can be found in Appendix E.

2.1.1 Bollard Thrust versus Direction

Bollard thrust of the MACKINAW varies with pod orientation. This is shown in Figure 2.1, where the typical ahead operating mode is 0 degrees and astern mode is 180 degrees. Note that bollard thrust is slightly higher ahead than in the astern orientation.

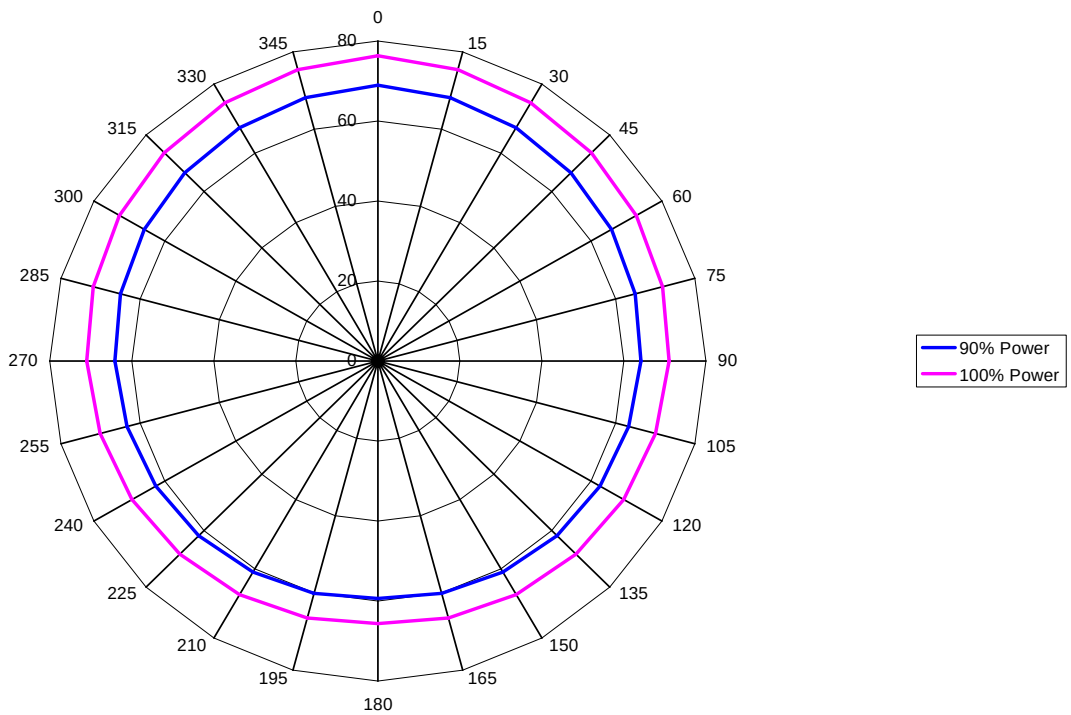

Figure 2.1. Bollard thrust in LT as a function of pod orientation.

2.1.2 Reverse Time

Reversing time, that is the time to go from full speed ahead to full thrust astern, is important for stopping the ship in both open water and ice. The maneuver that records that time is called the crash stop and this maneuver was performed during the Builder's Sea Trials and the Post-Acceptance Trials. Similar tests were not performed during the ice trials because the ship stops very quickly in ice do to the high resistance. In this case reverse power is not generally needed Reducing power to some low level (lever position 1) to keep turns on the propeller is all that is needed. Power can be reduced very quickly. The trials showed that the ramp rate for decreasing power is 121 kW/s or, in other words, the plant can go from full ahead to full astern in 56 sec by shifting the throttle from full ahead to full astern.

Rapid reversals in ice are typically performed during ramming operations where the ice is sufficiently heavy to preclude continuous and steady movement ahead. In this case the ship is going slow near the end of a charge into the ice. Just before the ship is stopped completely the control levers are reversed and the ship stops briefly and accelerates astern. The ramming cycle also includes the opposite maneuver where the ship is moving backward in a track at a steady but slow speed and the control levers are reversed to go ahead. Ramming was not done during the Trials due to the lack of suitable ridges.

With the Azipod propulsion units, there are several ways to reverse thrust. The electric motors in the pods can be reversed thus reversing the propellers. The alternative is to reverse the pod units themselves but keep the motor and the propeller turning in the same direction. In open water at high ship speed, this latter alternative creates a large amount of drag when the pod struts turn perpendicular to the ship motion. Reversing the propellers has none of this effect and is more like stopping a conventional ship. Results taken from the open water trials and Ice Trials are presented in Table 2.1.

Table 2.1. Reversing Results of Open Water and Ice Tests

Conditions	Mode of Reversing	Ship Speed (kt)	Time to stop (m:ss)
Open Water Ahead	Propellers Full Ahead to Full Astern	15	
Open Water Ahead	Pods Rotated Ahead to Astern	15	
24 in Level Ice Ahead	Propellers Full Ahead to Lever Pos 1	8	0:50
22 in Level Ice Astern	Propellers Full Ahead to Lever Pos 1	9.3	0:52
22 in Broken Track Ahead	Propellers Full Ahead to Lever Pos 1	14.6	3:27
22 in Broken Track Astern	Propellers Full Ahead to Lever Pos 1	13.7	~3:45

It is recommended to reverse the pods' direction 180 degrees for a crash stop in open water because this is the most effective way to stop the ship at speed quickly. When ramming ridges and heavy ice, however, reversing the propellers is recommended because this method protects the pods and

propellers more from damaging ice loads. Propellers can be damaged in ice when rotation is slowed or stopped during reversing and the ship is moving, though this is believed to be the safer mode than turning the pods.

2.2 ICEBREAKING PERFORMANCE

This section documents the performance of the MACKINAW for icebreaking. Refer to Chapter 4 for specific approaches for icebreaking operations and recommendations on Azipod angles and level of power for the type of icebreaking encountered.

2.2.1 Level Icebreaking Performance

Level icebreaking performance is estimated based on the USCGC MACKINAW (WLBB-30) Ice Trials. Results have been scaled to specific temperatures representative of typical operation. In all figures of this section, unless described otherwise, the performance in level ice is shown for the zero pod angle (ahead) and 180-pod angle (astern). Figure 2.2 shows the effect of ice temperature on level ice performance at 90% power. The ice flexural strength varies with temperature and this is the parameter that affects performance. Within this plot, ice performance curves are presented for cold winter ice, normal winter ice, and decaying spring ice.

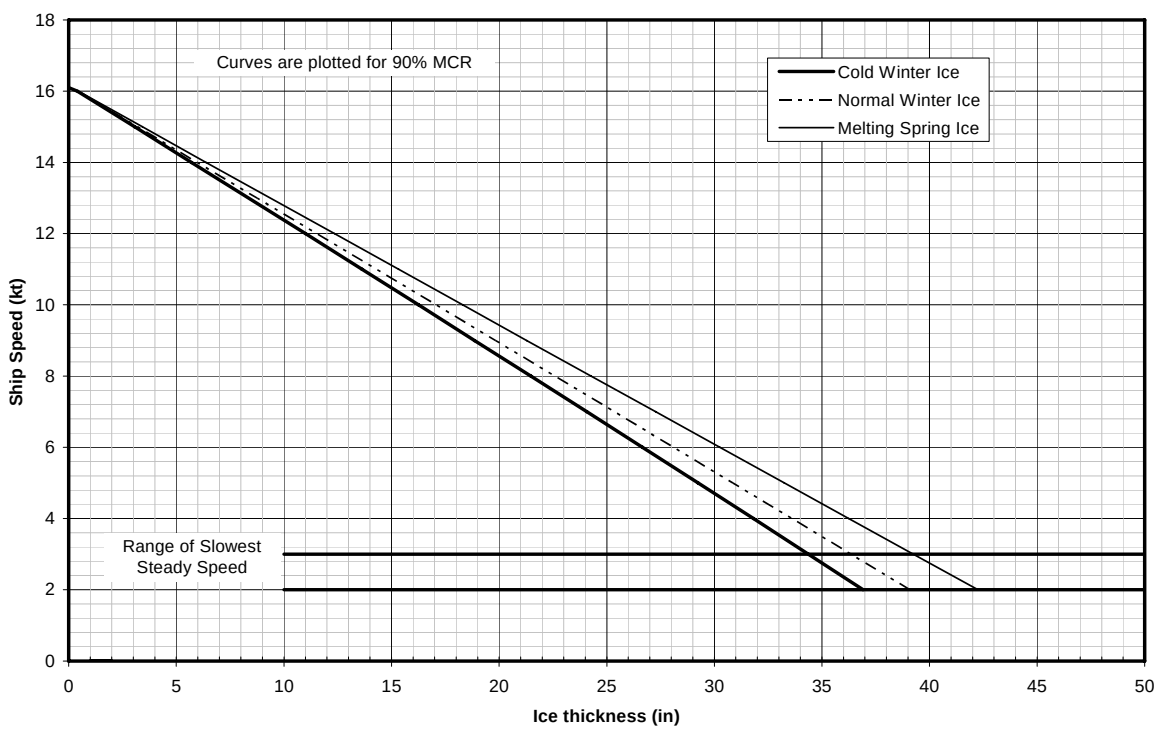

Figure 2.2. Effect of ice temperature on ice flexural strength and level ice performance.

Figure 2.3 presents the performance for the upper range of power levels in level ice of normal winter strength. Lever position were not used in this plot because there is a non-linear relationship between those positions and power plus the fact that actual power can differ from ordered power in changing conditions.

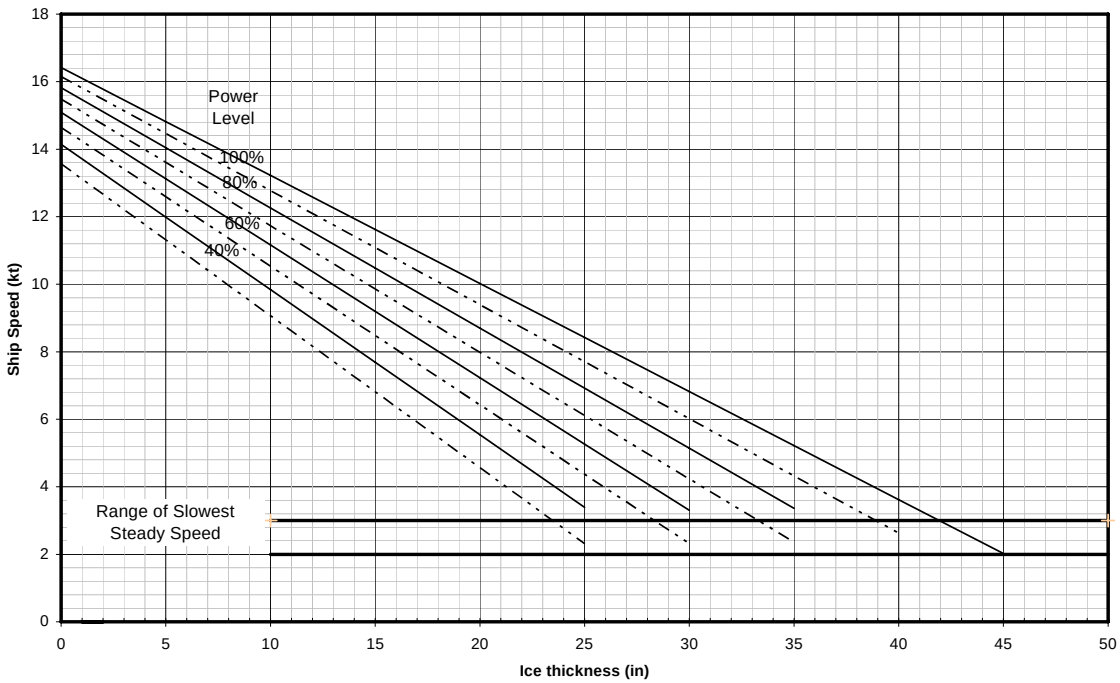

Figure 2.3. Estimate of the performance for the full range of operation in level ice of normal winter strength.

Figure 2.4 shows the reference curve and the lag in actual power during rapid changes in lever during bollard tests. Icebreaking shows big deviation when the lever is changed but still has significant variation during steady transit (vertical clustering of points at one lever position) if ice milling occurs. The power indicator on the bridge is the best indicator of power, not the lever position.

The Great Lakes operating area includes regions where extremely cold temperatures occur, resulting in the development of fresh water ice. Fresh water ice has wide ranges of ice strength. Generally, if the temperature is colder then the ice is stronger. The normal winter ice of Figure 2.3 is probably representative of most areas in the lower Great Lakes, but Duluth ice is more like the cold winter ice line Figure 2.2 on average.

There are other factors that can affect icebreaking performance as well. Hull-ice friction is a significant one. The 240-ft WLBB Class has a low friction hull coating but surface conditions on the ice

such as snow can affect performance. Within the Great Lakes 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 add one inch of ice thickness to the level ice thickness for each 3 inches of snow and use Figure 2.3 to estimate the difference in performance. In some cases where the snow is very sticky, the effect of snow can be as high as adding one inch of ice thickness for each 2 inches of snow.

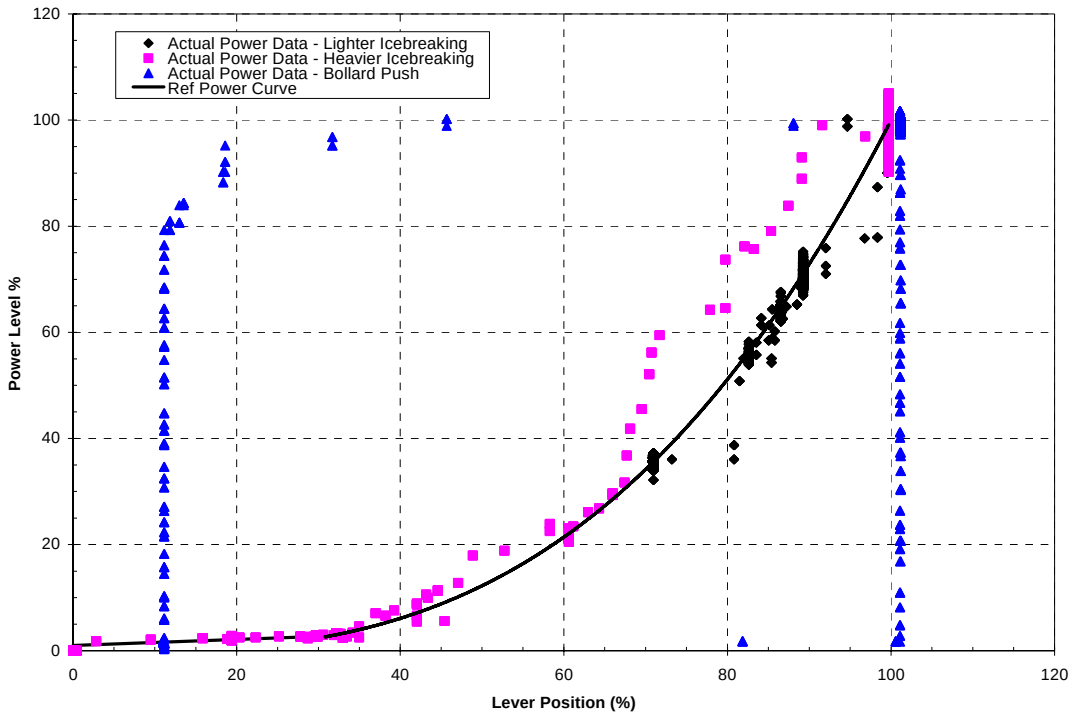

Figure 2.4 Lever position versus reference and actual power level for different operations.

Trim is important for good icebreaking performance and safe operation. The ship is designed to operate in ice on even keel at the 15.5-ft draft. This trim provides the optimum icebreaking capability in both directions. 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 affected by submergence of the propellers and in general it is desirable to keep the aft draft as close as possible to the design waterline. 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 ballast from the forward tanks to the aft tanks is effective in getting unstuck from a forward ram. 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 keel trim.

2.2.2 Performance in a Track (Broken Ice and Brash Ice Performance)

Figure 2.5 and Figure 2.6 present the WLB performance in a freshly broken channel ahead and astern, respectively, for different power levels. Note that performance ahead is better than performance astern. Temperature should have little effect on newly broken channel performance because it affects the ice strength which only affects the breaking portion of icebreaking resistance.

The performance in an old channel (after many transits through the channel) is presented in Figure 2.6 for different throttle positions. The brash ice thickness used in Figure 2.6 is large (11 to 12 ft). This performance can be expected in the older channels under extreme conditions formed in places such as the St. Mary's River and the Straits of Mackinac.

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 (loss of paint along the waterline causing increased 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 such as Inerta 160. No ice "moustache" problems were reported while backing due to the propeller washing effect. For WLBB it is advisable to use the astern mode of transit in the conditions where ice "moustache" formation is highly probable.

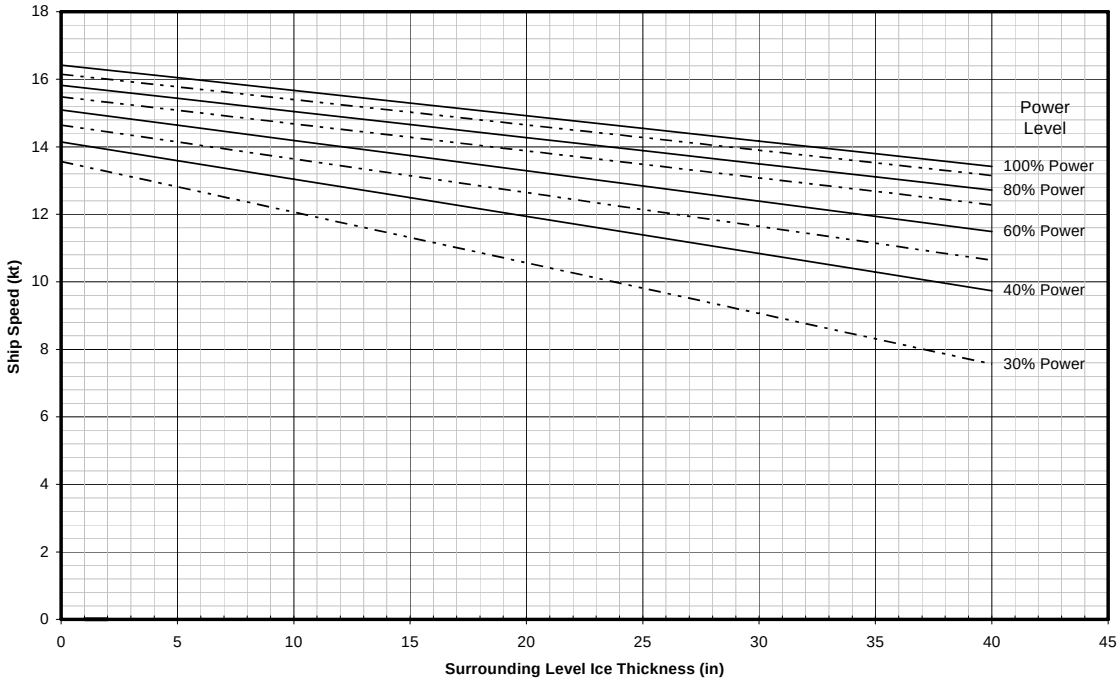

Figure 2.5. WLBB performance in a freshly broken track ahead.

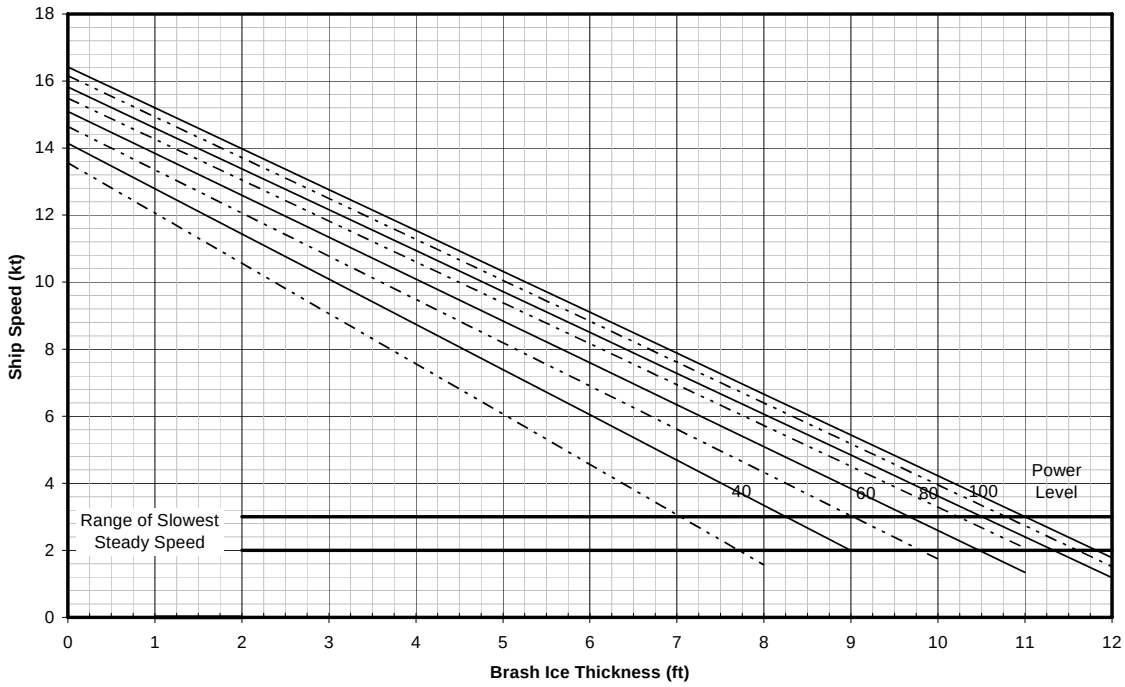

Figure 2.6. WLBB performance in an old channel (brash ice).

2.2.3 Escort Performance

Presented in Figure 2.7 and Figure 2.8 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 240-ft WLBB Class cutter working together with a 225-ft WLB 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 in Great Lakes Icebreaker replacement concept design. In real operation every escort is different. (See also Section 2.2.7, Channel Widening).

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.

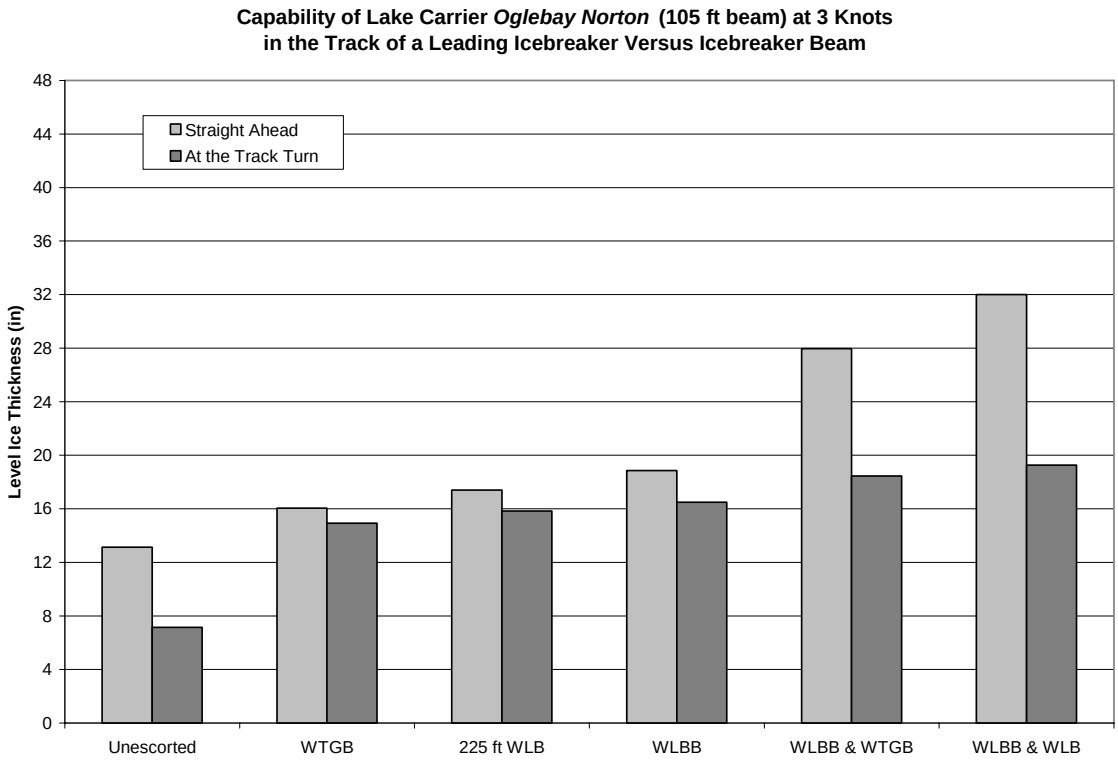

Figure 2.7. The effect of various escort options on the performance of a 1000-ft laker in ice (3 kt convoy speed).

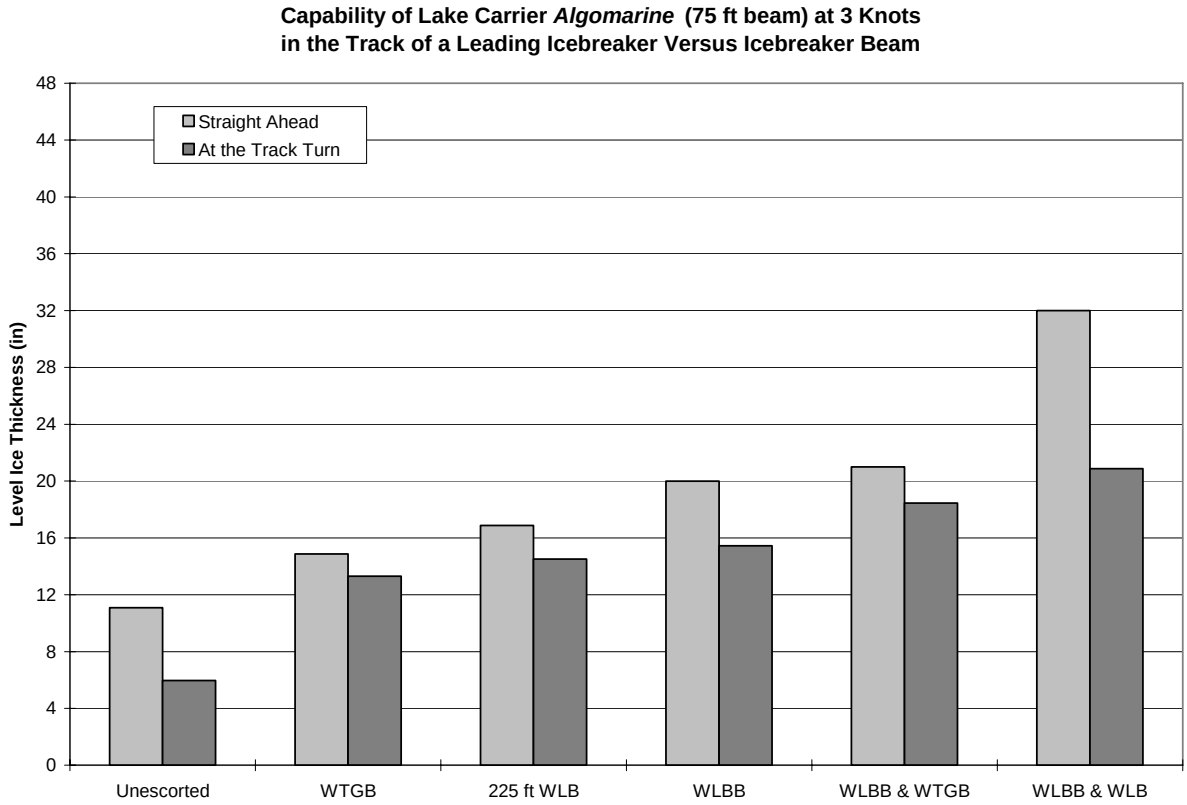

Figure 2.8. The effect of various escort options on the performance of a typical 75-ft beam laker in ice (3 kt convoy speed).

2.2.4 Performance in Pressure Ridges or Windrows

During the Ice Trials, weather conditions were quite warm when ridges were encountered but several large ridges were broken both going ahead and astern. These ridges were able to be transited slowly using the thrust of the propellers. Ramming was not necessary. A summary of the ridge breaking performance is shown in Table 2.2.

Table 2.2. Ridge Performance during Ice Trials

Date	Start Time (hh:mm:ss)	End Time (hh:mm:ss)	Ridge Width (ft)	Transit Time (m:ss)	Operating Mode	Sail Height (ft)	Keel Depth (ft)
13-Mar	18:14:26	18:19:45	122.6	5:19	Astern	5	15
14-Mar	9:22:02	9:24:20	199.9	2:18	Ahead	5	15
14-Mar	11:17:48	11:23:35	286.5	5:47	Astern	5	18

Shown in Figure 2.9 is the performance backing through a ridge. Note the technique employed was to toe-in the pods with the starboard pod fixed at 90 deg and the port pod fluctuating between 40 and 110 deg.

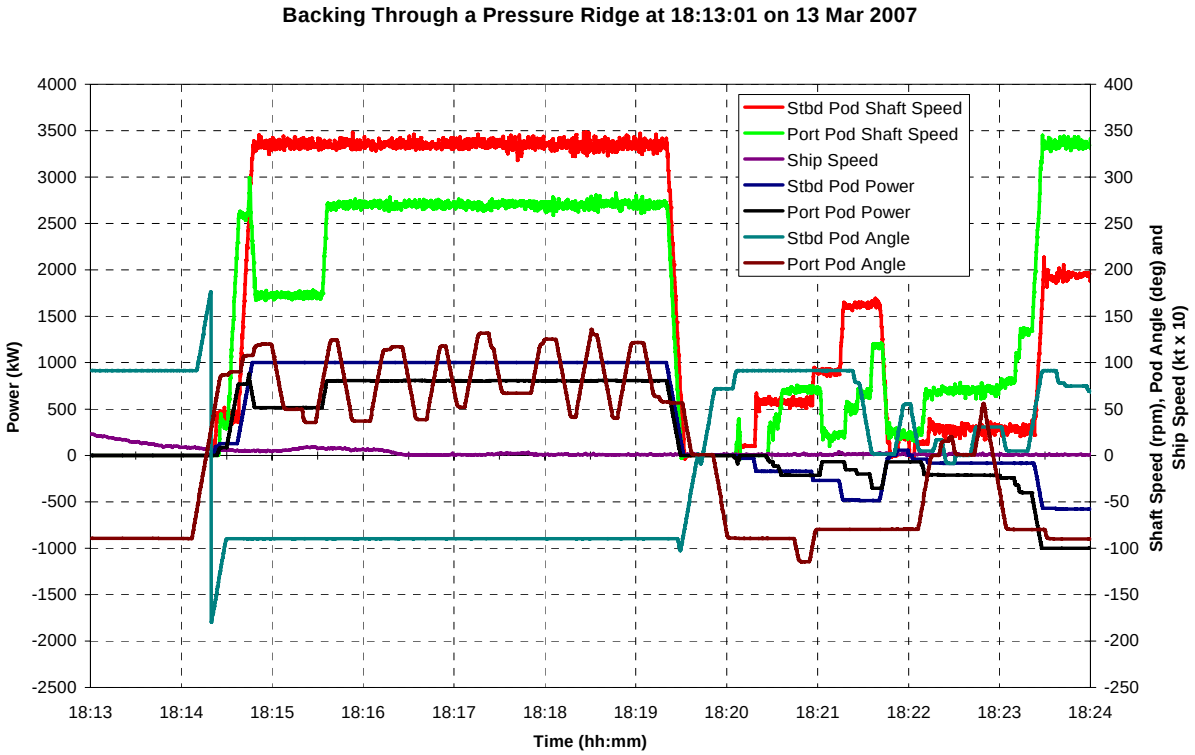

Figure 2.9. Performance backing through a ridge.

Since the ship could not be tested in the conventional ramming mode of operation, an analytical estimate of ramming performance is presented that has been validated using full-scale data from other ships The analytical model that was developed for the GLIB Concept Design Study and specification development. The model predicts performance in other conditions by simulating 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 2.3 presenting the impact velocity and approach distance required to transit a ridge of a given height in a single ram. The 240-ft WLBB is capable of transiting in a

single ram only the small ridges (up to 5 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 2.4.

Table 2.3. 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)	116	435	195	N/A	299	N/A
(Ship length)	0.5	1.9	0.9	N/A	1.3	N/A
Impact velocity (kt)	5.9	10.1	7.5	N/A	9.0	N/A

Table 2.4. Representative Time to Transit a Ridge

Sail height (ft)	3		5		10		12	
Surrounding level ice thickness (ft)	1	2	1	2	1	2.67	1	2.67
Charge Distance (ft)	195	220	433	357	130	482	143	649
(Ship length)	0.9	1.0	1.9	1.6	0.6	2.1	2.4	2.9
Impact velocity (kt)	7.5	7.6	10.6	9.3	6.2	10.1	6.5	11.2
Number of rams	1	2	1	2	5	4	6	4
Time to transit (min)	2.3	4.3	3.3	5.6	8.4	13.3	10.4	16.3
Time to transit in backing (min)								

2.2.5 Performance in Other Types of Ice Conditions

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

2.2.5.a Performance in Open and Close Pack Ice

The 240-ft WLBB 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:

- Slow down to 12 to 13 knots if ice thickness does not exceed 2.0 ft.
- Slow down to 10 to 11 knots if ice thickness exceeds 2.0 ft.

The 240-ft WLBB 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.

2.2.5.b 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 shafts be kept spinning and periodically change pods direction in order to flush more ice from the stern.

Using astern mode of icebreaking in ice pressure may provide some advantage because of the hull flushing effect.

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 2.10 and Figure 2.11 not be used for transit.

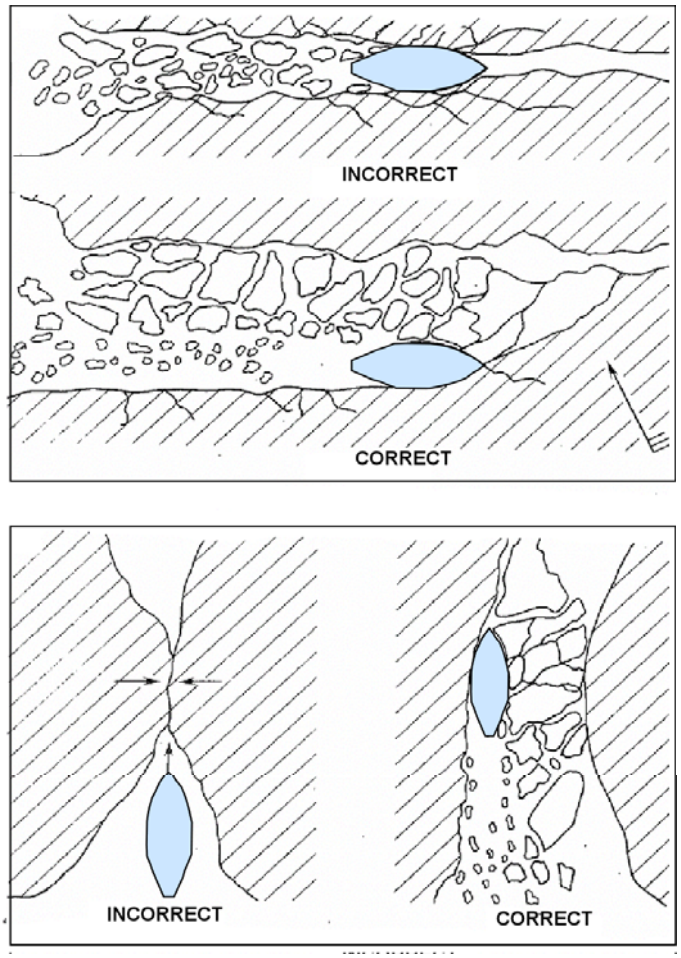

Figure 2.10. Examples of transiting ice under pressure.

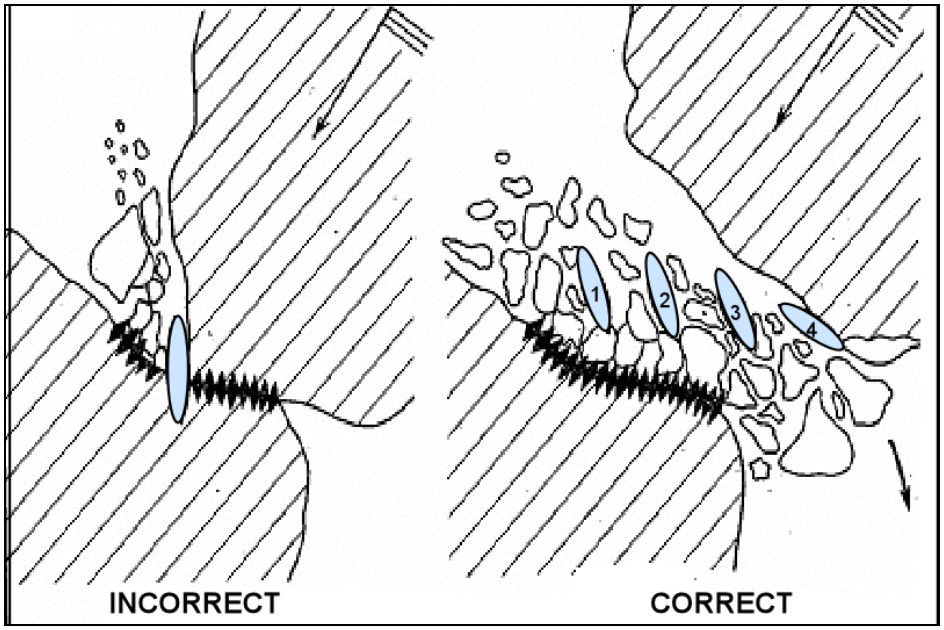

Figure 2.11. Transiting the ridge (windrow) under pressure.

2.2.6 Backing in Level Ice and Broken Channel

The 240-ft WLBB is able to move steadily astern in level ice greater than 32 in. Backing in broken ice is also safe and effective. It is recommended that transit astern is used when going ahead requires switching to a ramming-and-backing mode of operation. Backing performance in level ice versus throttle position is shown in Figure 2.12. Backing performance in broken ice, fresh track, and old track may be somewhat better or equal to the ahead performance. However in the lighter ice conditions the speed will be driven by the open water performance and ship speed will be lower than that of going ahead.

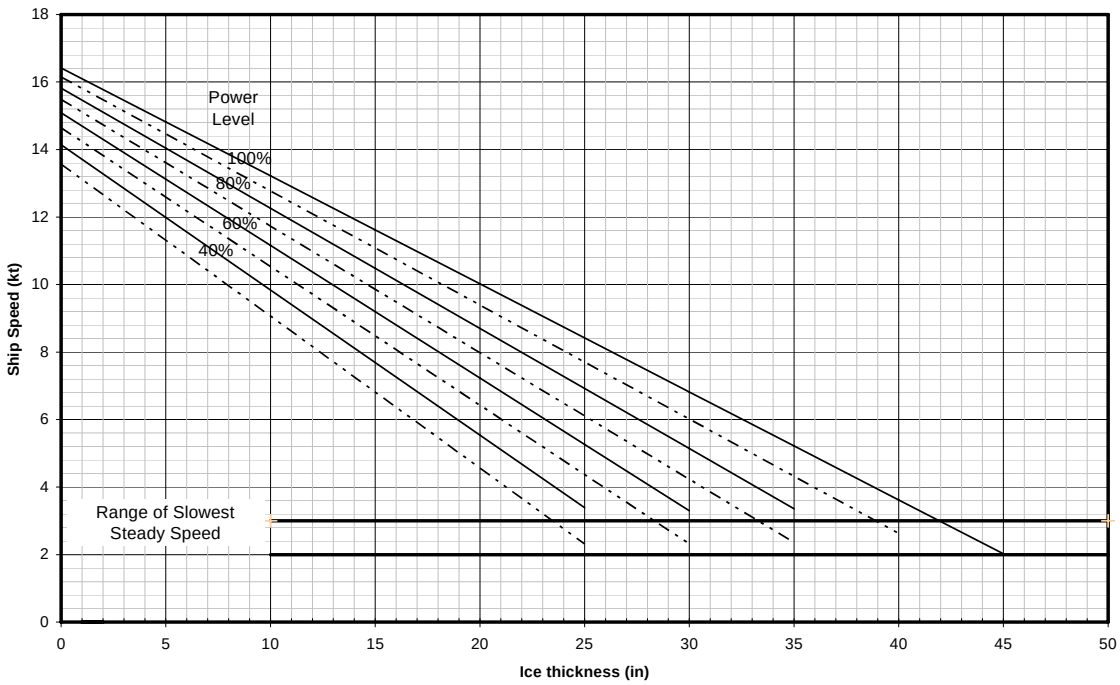

Figure 2.12. Level ice backing performance.

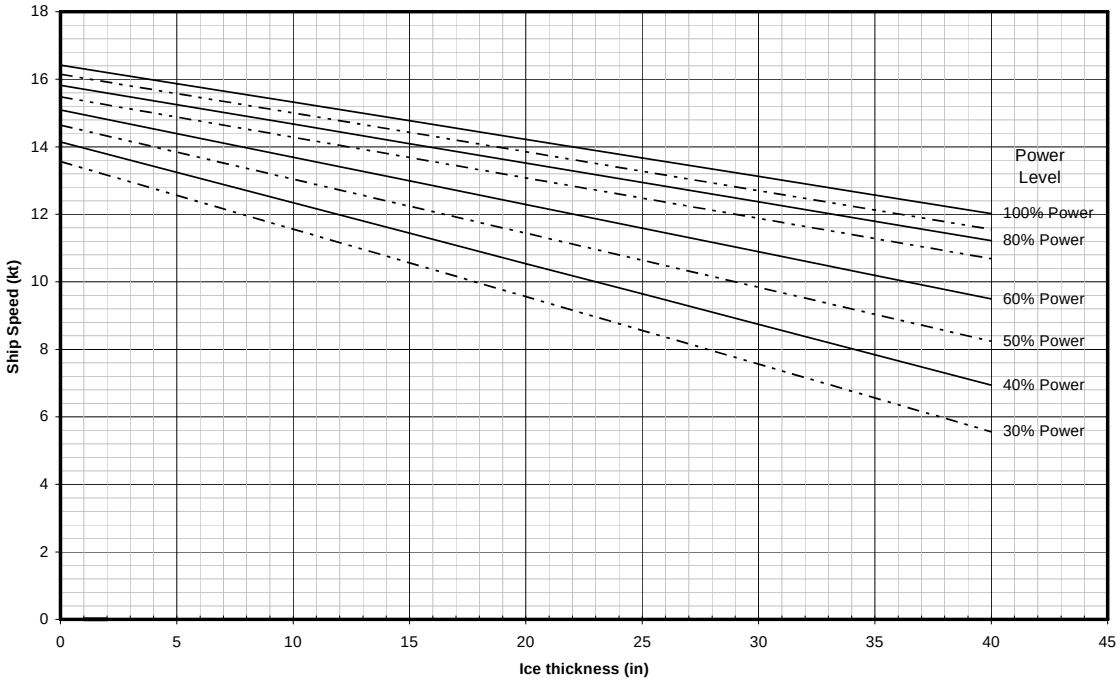

Figure 2.13. WLBB performance in a freshly broken track astern.

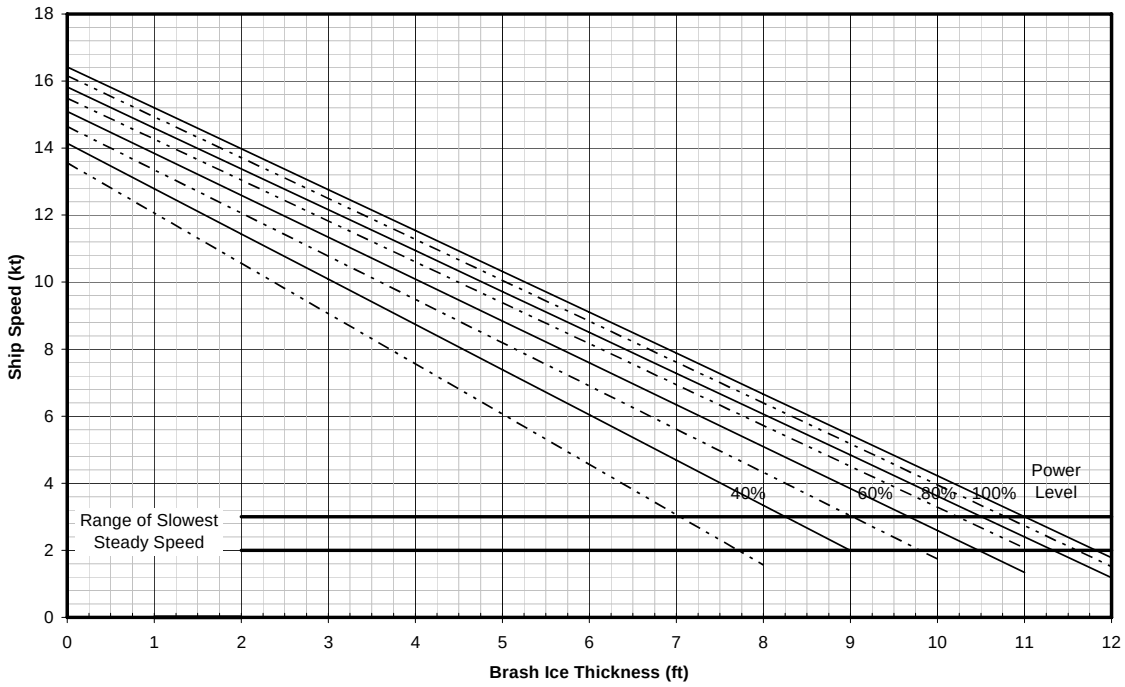

Figure 2.14. WLBB performance in a freshly broken track astern (brash ice).

2.2.7 Channel Widening

Because the new MACKINAW has azimuthal propulsion pods, there is a possibility to direct the pod flow outward at an angle to the ship and consequently break a wider track. As the pods are turned such that the wake is outboard, less thrust is available to move the ship through the ice. The larger the angle of the pods to the direction of motion, the smaller the ice thickness has to be to proceed and the more energy is available to break the ice outboard of the ship. Tests were performed during the Ice Trials to document this effect. Results are summarized in Figure 2.15.

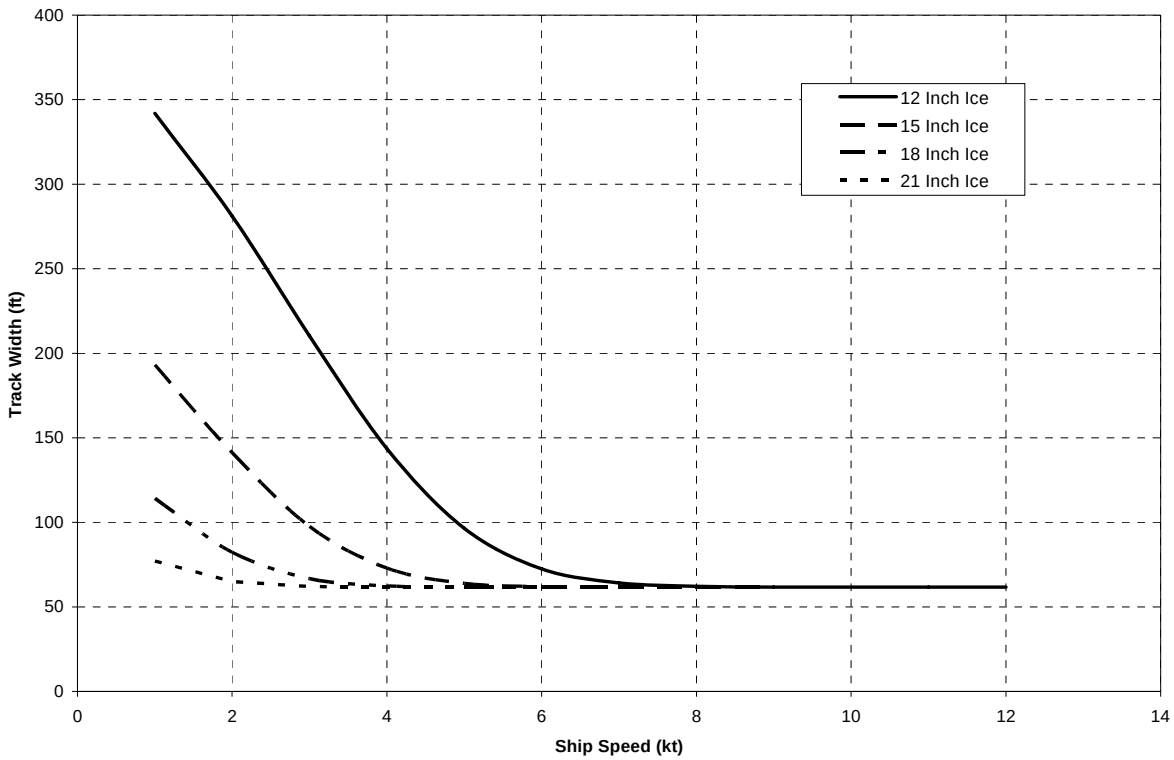

Figure 2.15. Track width versus ship speed results for different level ice thicknesses and 90% MCR.

One can see from Figure 2.15 that the track width is wide at slow speed indicating a high pod angle and less wide at higher speed indicating a lower pod angle. Thicker ice is harder to break with the wake and the pods cannot be directed outboard as much because the resistance to break the ice is higher. In a previously broken new channel, the resistance is lower so the channel widening can be more effective than breaking a new track. If the previously broken track is an old one, however, the resistance in the channel will be much higher than a new one and the channel edges will likely be thickened making track widening much more difficult.

2.3 ICE MANEUVERABILITY

A number of maneuverability tests were performed during the Ice Trials to demonstrate and document performance in this area. The tests included steady turns in level ice (the typical turning circle test), tests to break out of an existing track, and tests of the star or modified captain's maneuver to reverse direction. This section documents the performance of the MACKINAW. Refer to Chapter 4 for specific approaches for executing various maneuvers along with recommendations on Azipod angles and level of power for the type of maneuver considered.

2.3.1 Steady Turns in Level Ice

Turning circles in level ice were performed during the Ice Trials of the USCGC MACKINAW (WLBB-30). Data from the trials were averaged for different ice conditions and are presented in Table 2.5. These are considered to be representative turning circles in level ice for the ship though there is variability in the duration and diameter due to the applied rudder angle, the initial ship speed, and the actual ice conditions. Note that the ship is highly maneuverable in ice. At slow speeds and by maneuvering the pods to high rudder angles, the ship may be turned in its own length up in at least 24 inches of ice. See Chapter 4 for optimum pod angles and a discussion of how to best perform this maneuver.

Table 2.5. Turning Circle in Level Ice

Date	Start Time	End Time	Ice Thickness	Diameter		Entry Speed	Direction
	(hh:mm:ss)	(hh:mm:ss)	(in)	(ft)	(ship lengths)	(kt)	
3/5/2007	13:41:32	13:44:50	19.4	488	2.03	7.11	Port
3/5/2007	13:49:09	13:52:28	19.4	555	2.31	8.19	Starboard
3/5/2007	13:53:35	13:56:00	19.4	411	1.71	8.87	Port
3/6/2008	12:37:17	12:41:11	23.95	364	1.51	5.51	Port
3/7/2008	12:41:12	12:46:14	23.95	391	1.63	5.43	Starboard

2.3.2 Break Out of an Existing Track

The breakout maneuver starts in a broken or old 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 breakout maneuver, as with the turning circles, were also taken from the Ice Trials. Note that an icebreaker with pods performs a breakout maneuver in a completely different manner than a conventional icebreaker. The conventional icebreaker uses some speed in the channel and a sharp turn to "grab" the channel edge. Speed is not necessary for the podded ship. The maneuver can be performed from a stopped position by just turning the pods. Presented in Table 2.6 is the time to turn out of the track from the time the helm is put over until the ship has reached approximately a heading 90 degrees from the original heading in the track. For

these tests, only the inboard pod on the turn was turned outboard to effect the turn and limited forward speed was used.

Table 2.6. Time to Turn 90 Degrees Out of an Existing Track into Level Ice Ahead

Date	Start Time	End Time	Duration to stopped at 90 deg	Ice Thickness	Entry Speed	Distance Along the Track	Distance Off the Track	Direction
	(hh:mm:ss)	(hh:mm:ss)	(mm:ss)	(in)	(kt)	(ship lengths)	(ship lengths)	
3/5/2007	14:35:53	14:38:18	02:25	19.37	7.61	1.49	1.05	Port Astern
3/5/2007	14:52:39	14:54:01	01:22	19.45	8.08	1.60	0.89	Stbd Ahead
3/5/2007	14:57:35	14:58:32	00:57	19.45	8.66	1.24	0.46	Port Ahead
3/6/2007	15:05:14	15:08:12	02:58	24.41	3.37	0.69	1.54	Port Astern
3/6/2007	15:11:44	15:14:41	02:57	24.41	6.16	0.42	1.63	Port Ahead
3/6/2007	15:23:14	15:25:54	02:40	24.41	5.46	1.15	1.35	Stbd Ahead

Schematic drawings of the typical breakout maneuver, both ahead and astern, are shown in Figure 2.16. The maneuver going ahead usually has modest speed but the maneuver astern can be performed from an initial stopped position.

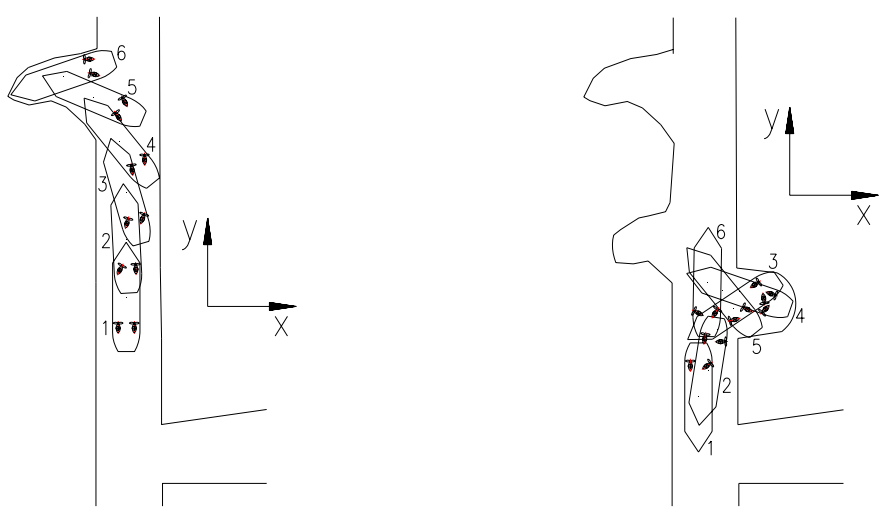

Figure 2.16. Schematic drawings of the break-out maneuvers ahead and astern.

2.3.3 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 MACKINAW (WLBB-30). With the maneuverability inherent in the dual Azipod propulsion arrangement, the classic star maneuver is not necessarily needed in the process of turning around. A typical trackline from the star maneuver test is presented in Figure 2.17. While a trackline for this maneuver for a conventional icebreaker would show a number of back and forth movements to effect the turn, the MACKINAW is able to make a small turn to the right and then back completely around within a 300 ft channel width. The maneuver took 3.5 min in this design ice thickness of 32 in during model testing. In thinner ice, a star type maneuver is not necessary because the ship can turn in place in her own length.

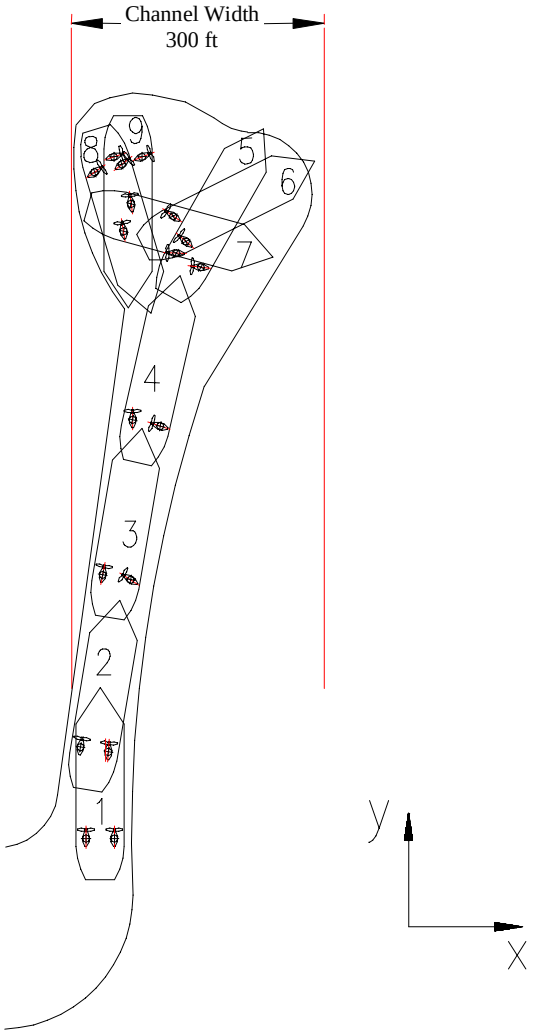

Figure 2.17. Trackline of the star maneuver.

2.3.4 Acceleration and Deceleration in Ice

When operating close to other ship or piers, it is important to know how fast the ship accelerates and decelerates in ice. During the course of the Ice Trials it was possible to measure the response of the ship to changes in throttle position in different ice thicknesses. Results are presented in Table 2.7.

Table 2.7. Acceleration and Deceleration Results

Ice thickness	Time to increase speed	Steady State Ship Speed	Time to Stop
(in)	(min)	(kt)	(min)
19.47	3:15	4.35	
19.46	2:00	8.04	
19.44	1:30	10.56	1:23
25.71	4:42	2.28	
25.09	2:36	5.11	
24.42	1:59	7.93	0:50
17.5	0:50	0.75	
17.4	3:29	6.15	
16.9	2:01	8.86	
16.7	1:39	11.09	1:52

The following two sections (2.4 and 2.5) are examples of the type of data that can be provided when analysis of the loads is complete from the ice trials. Work is still on-going for the data collected. Details will be provided in a revision to this document when the work is completed.

2.4 ICE LOADS ON PROPULSION UNITS

Ice loads were measured on both Azipod units during the Ice Trials. Highest side loads on the pods (perpendicular to the propeller shaft) occurred during aggressive turning in heavy ice when the side of the pod encountered the surrounding ice cover at the edge of a channel. Typical ice conditions were the presence of a ridge keel or an old channel edge where the level ice had thickened due to consolidation and there was a considerable amount of unconsolidated ice below the level ice. Impacts occurred on the outboard pod on a turn where the pod angle and the local drift angle combined to present the side of the pod parallel to the ice edge. Generally higher turning rates produced higher impact speeds and higher loads. The highest longitudinal loads (parallel with the propeller shaft) occurred while backing through ridges astern. Maximum events are as follows:

During turning at ___ time on ___ date at a local impact speed of __kt.
Total side load ___LT or __% of design load
Total lateral bending moment ___ft-LT or __% of design moment
Ice conditions: Old channel with __ ft sail height ridge along the edge, __ in thick level ice.

Going astern through a ridge at ___ time on ___ date. Local impact speed __ kt.
Total load ___LT or __% of design load
Total longitudinal bending moment ___ft-LT or __% of design moment
Ice conditions: __ ft sail height ridge surrounded by __ in thick level ice.

All loads and moments were below the design values with reasonable margin. No particular speed restrictions are required for operation in ice.

2.5 ICE LOADS ON HULL STRUCTURE

Ice loads were measured on frames and bulkheads along the length of the ship for both phases of the Ice Trials. The first phase of the Ice Trials was conduction in light ice conditions with ice thicknesses ranging from __ to __ inches. The second phase of the Ice Trials encountered heavier ice conditions with thicknesses ranging from __ to __ inches. Measured frame loads are compared with allowable frame loads based on the design of the local structure within the icebelt area below the waterline in Figure 2.18 for both phases of the Ice Trials.

The highest loads at the bow occurred during ramming ridges and generally increased with impact speed. The highest loads at the stern occurred near the stern quarter due aggressive turning in heavy ice. All loads measured were within the allowable loads of the ship. No particular speed restrictions are apparent based on the hull ice loads. Maximum events are as follows:

At the bow during ramming at ___ time on ___ date at a speed of __kt.
Total load ___LT
Maximum ice impact pressure __ psi over __ sq in.
Ice conditions: ridge with __ ft sail height surrounded by __ in thick level ice.

At the stern during turning in place at ___ time on ___ date. Local impact speed __ kt.
Total load ___LT
Maximum ice impact pressure __ psi over __ sq in.
Ice conditions: 24 in thick level ice.

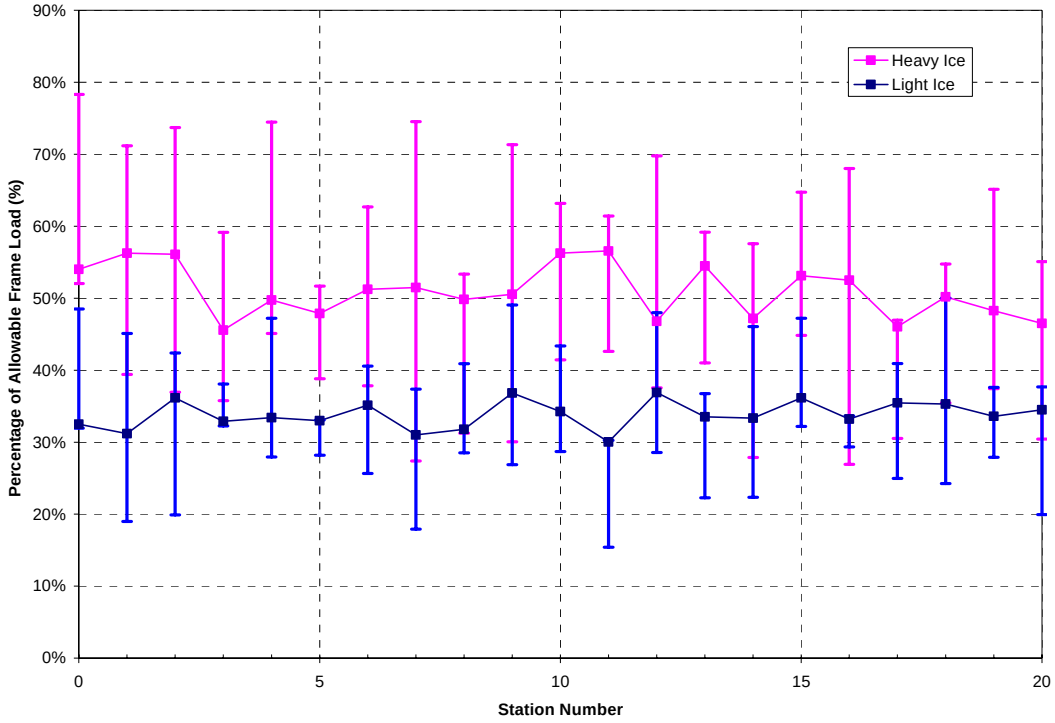

Figure 2.18. Ice loads on frames versus position along the waterline for light and heavy ice conditions.

CHAPTER THREE

3. GREAT LAKES OPERATIONS IN ICE

3.1 GENERAL GREAT LAKES ICE CONDITIONS AND OPERATIONS

3.1.1 Background

From year to year ice conditions on the Great Lakes change quite dramatically. One year will be ice free and the next enough ice to stop the movement of commerce in its tracks. Therefore, a general understanding of ice and ice conditions and ice management theory is a must for icebreaker conning officers. Icebreaking is simply navigation in ice-covered waters with all the basic safe navigational procedures applicable. You must know where you are at all times, the safe navigation depth, vessel's capabilities and acceptable procedures or techniques.

The following are a few basic principles for working in an ice field, which have been passed on from one icebreaker sailor to the next over the years. They apply to Great Lakes icebreaking or Polar operations and form the foundation of understanding icebreaking operations:

1. Work with the ice, not against it.
2. Respect the ice but do not fear it.
3. Do not rush the work, patience is an absolute virtue.
4. Keep moving (potential for damage to the props occurs when stopped).
5. Be aware of ice under pressure (if your track is closing be concerned).
6. Whenever possible avoid ice and go around it.
7. The cutter will always seek the path of least resistance, from heavier ice to weaker ice, into leads, or open water.
8. Enter ice fields head-on vice with the side or shoulders.
9. Be prepared for the unexpected.
10. Expect conditions to change.

When working on the Great Lakes the cutter is almost always in restricted channels and involved in close-in maneuvering situations that require special skills, vigilance, and alertness. This manual does not represent a written set of procedures that will work in every situation. It always comes down to the individual conning officer's skill and knowledge of the cutter's operational capabilities, the present environmental conditions (wind, current, ice properties, ice thickness, etc.). Thus, this guide is intended to provide a "how to" framework from which the individual shiphandler will develop the required skill set. There are very few "right ways" of conducting icebreaking but good decision- making is always

based on a clear understanding of the conditions and capabilities of the cutter relative to the existing situation.

3.1.2 Ice Management Theory

Ice management within the Great Lakes and especially on the various rivers systems, i.e., Upper and Lower St. Mary's, St. Claire, etc. can best be defined as maximizing the efficiency that ice can be controlled while minimizing the effect on vessel movements, damage to vessel machinery and to shore side property. There are three aspects to consider while conducting ice management: Control of ice growth, Control of ice movement and Productive icebreaking techniques.

3.1.2.a Control of Ice Growth

Portions of the Great Lakes will freeze each winter, the time and severity with which it freezes is dependent on a number of factors. These factors include; the water temperature, the ambient air temperature, the flow rate of the river, and the amount of "lake effect" snow that falls in the area. Once ice begins to form (usually in December), the primary mission should be to keep the growth in the navigable rivers to a minimum, because from December to early April, the temperature gets colder. Once freezing degree-days begin accumulating in late November or early December the water temperature will drop. Thus we say in the Fall "the more ice you break, the more you make". The more open water is exposed during this period, the more ice will re-form, if that ice is broken again, it will freeze again, and so on.

Water temperature near 35 degrees primes the river for ice formation. While no significant ice growth will take place with temperatures above 32 degrees, nothing more than a mild snowfall will quickly lower the water temperature enough for ice to form. With water temperature in the low 30s, snow will not melt in the open water, it will appear as a white slurry which will quickly turn into snow ice.

Freezing Degree Days (FDDs) are computed by subtracting the average daily air temperature below freezing (32 degrees F). For example, the average daily temperature was 20, that day 12 FDDs were accumulated. A count of FDDs gives a good indication of potential ice growth. A steady accumulation of consecutive FDDs is more conducive to ice formation than a staggered accumulation of FDDs. Generally, non-restrictive ice will form with 150 FDDs. The river will become difficult for navigation after an accumulation of 250 FDDs.

Ice on the Great Lakes is always subject to current, for example, the St. Mary's River has a steady water flow from the Soo Locks to Detour. The rate that the water flows down-river is dependent on Lake Superior drainage, the number and degree the compensating works are opened above the Soo Rapids, the amount of water Edison Sault Electric, the Soo Locks power plant, and the Canadian power plants are running to keep up with demand. All of these factors combine to form the water flow rate, measured in

cubic feet per second (cfs). When ice forms, it primarily remains on or near the surface of the water. As it melts or is put under pressure, it will sink. However ice forming over a steady current will not tend to freeze as thick as ice in slack water, with shifting of minimal currents. As the ice gets thicker in the river the water flow is restricted to the deeper channels. This restriction will have a dual effect on the river dynamics by both increasing the current flow within the channel and increasing the pressure of the unbroken track edges.

The predominate winds during the winter months are from Northwest to Northeast. Only on occasion do the winds shift out of the south. West and Northwest winds will cause "lake effect" snow to fall in certain areas like the St. Mary's River system, Lake Erie (Buffalo), and several other geographic locations. This is significant due to the fact that heavy snowfalls will "seed" the rivers and shallow areas, rapidly cooling the water to freezing temperatures.

3.1.2.b Control of Ice Movement

The control of ice movement is a vital aspect of this theory. The navigational channel is only 300 feet wide through the most difficult turns in the lower St. Mary's River. With an average water flow rate (approximately 70,000 cfs) and winds out of the West or Northwest, broken ice on or near the surface will move down river with tremendous force. It is the management of this ice movement that this guide is based. Proper management will ease the burden ice places on shipping. When not properly managed, ice will jam into narrow choke points and turns within the river and distort tracks increasing the difficulty of vessel transits. This theory is based on keeping excessive ice from entering the navigational channel and dealing with the ice that is in the channel.

The most effective tool to prevent excessive ice movement is positive control of the ship's wake. This includes the wake of users as well as the wake of the icebreakers. Any ice broken by the wake of passing ships will be drawn into the channel. The higher pressure of the fast ice on the channel edge will force the broken plate toward the lower pressure of the broken ice track. Further damage to the fast ice edge could cause plate to shift into the channel effectively closing any established ice track.

Brash accumulation within the ice track is a reality of winter navigation. However brash can be moved out of the more difficult turns into straight courses where it is more manageable. There are a couple of techniques that may aid in the process of brash movement. The first and most effective is the use of relief tracks. There are two prime areas within the St. Mary's area that greatly benefit using this technique (see relief tracks for Johnson Point and Stribbling). The second method is a little slower, but still yields good results. By maintaining smooth track edges in the turns the river current will slowly move the brash down current. Ship movement compliments this slow brash movement.

3.1.3 Great Lakes Icebreaking Factors

The approach taken to break ice throughout the Great Lakes (rivers, harbors, and straits) will vary depending on many factors: type/thickness of ice, weather, and characteristics of the vessel being assisted.

3.1.3.a Description of Ice Forms

There are various forms of ice. Because ice forms in the winter and melts in the summer there is no ancient ice (that incredibly hard ice that exists at the Polar Regions). The thickness and formation of ice varies widely throughout the Lakes, with the most difficult ice conditions in exposed areas where the ice can raft, building windrows (ridges). Because the rivers are mostly protected from high-sustained winds (unlike Whitefish Bay or the Straits of Mackinac), the ice will be less likely to form difficult windrows. The most prevalent forms of ice are: new plate ice, brash ice, snow ice, and small floe ice. The thickness of ice varies considerably and the thickness of this ice depends upon:

- air temperatures
- water temperatures
- water flow rate
- amount of exposed water during Freezing Degree Days

Plate Ice – Plate ice is the hard, clear ice that forms when water freezes. This ice will snap with the wake of the ship and has a tendency to leave rough uneven edges. Use slow speed and the beam of the ship to get the desired smooth edges while breaking Plate ice in the turns. During hard winters Plate ice has been recorded in excess of 30 inches.

Brash Ice – Every year regardless of the severity there will be certain amounts of brash accumulation. Brash is ice that has been broken, frozen, and broken several times until it takes on the look of crushed rock. Brash is very difficult to maneuver in and causes the screw to loose much of its force. Brash has been recorded in excess of 12 to15 feet in certain parts of the river. These deep accumulations usually confine themselves to turns and choke points, but can by themselves pose a great threat to a vessel's transit.

Snow Ice – Snow ice is the ice that forms from snowfall. It is flat and milky in color. Because it is frozen snow it is aerated making it lighter and not nearly as hard as Plate ice. Snow ice also has flexibility so it does not break as sharp as Plate ice from the ship's wake.

Floe Ice – Floe ice is the small broken plates of ice that travel on the current. These present the biggest problem to navigation. The floes will quickly stack up in choke points often turning on their side due to the current pressure. Even small floes less than one inch in thickness when stacked on their side (like a deck of cards) will pose a serious threat to vessel transits.

Within the international icebreaking community, a system of terminology has been developed to describe ice conditions and is published in the World Meteorological Organization (WMO) table of *Standard Sea Ice Nomenclature*.[1] The following selected material applies to the Great Lakes (Table 3.1):

Table 3.1. Ice Terminology

ICE TERMS	DESCRIPTION
FLOATING ICE	
ICE CONCENTRATION	The ratio expressed in tenths describing the mean areal density of ice in a given area.
Consolidated Pack Ice	10/10 and no water visible.
Very Close Pack Ice	9/10 to less than 10/10
Close Pack Ice	7/10 to 8/10
Open Pack Ice	4/10 to 6/10
Very Open Pack Ice	1/10 to 3/10
Open Water	Less than 1/10
STAGES OF DEVELOPMENT	
New Ice	Includes frazil ice, grease ice, slush , composed of ice crystals.
Nilas	Up to 10 cm (4 in.)
Dark Nilas	Up to 5 cm (2 in.)
Light Nilas	5-10 cm (2 - 4 in.)
Young Ice	10 - 30 cm (4 - 12 in.)
Grey Ice	10 - 15 cm (4 - 6 in.)
Grey-White	15 - 30 cm (6 -12 in.)
First-Year Ice	30 cm - 2 m (12in - 6ft 7 in.)
First Year Thin Ice	30 - 70 cm (1 ft - 2 ft 6 in.)
First Year Medium Ice	70 - 120 cm (2 ft 6 in. - 4 ft)
First Year Thick	120 - 200 cm (4 ft - 6 ft 7 in.)
Old Ice	Includes second year/multi-year ice (not found on Great Lakes)
FORMS OF FLOATING ICE	
Brash Ice	Fragments not more than 2 m (3.5 ft) across; the wreckage of other forms of ice.
Pancake Ice	Predominantly circular pieces of ice 30 cm -3 m (1-10ft) across
Ice Cake	Up to 20 m (66 ft) across
Small Ice Cake	Up to 2 m (6.6 ft) across
Floe	Piece of ice 20 m (66 ft) or more across
Small Floe	20-100 m (66 - 330 ft)
Medium Floe	100 - 500 m (110 - 550 yd)
Big Floe	500 - 2000 m (550 - 2200 yd)
Fast Ice (Plate Ice)	Ice which forms and remains along the shoreline, where it is attached to the shore.

Current and historical information on Great Lakes ice coverage can be obtained on-line from the National Ice Center, Suitland, MD at http://www.natice.noaa.gov/index. Select "Products" and Great Lakes for weekly analysis and other products. NOAA also publishes *An Electronic Atlas of Great Lakes Ice Cover, Winters 1973-2002*, which is available at http://www.glerl.noaa.gov.

[1] WMO Sea Ice Nomenclature, 1970, WMO No. 259 TP 145, Geneva, Switzerland.

3.1.3.b Weather Considerations

Weather is one of the most important factors to consider when undertaking an icebreaking mission. Wind, air temperature, and precipitation (snow or rain) are factors that may negate or benefit your effort.

Wind – Wind is most important during flushing operations. North or Northwestern winds create ideal conditions for moving large quantities of ice out of the rivers. If these conditions do not exist, do not conduct flushing operations. If ice does not move out from the channel the broken plate will simply distort the track and push ATON underwater, out of the mariner's view. A very important part of each turn is the associated ATON marking it, especially the lighted buoy. If, for example the buoy is under the ice or not visible, the tendency of the ship master is to ease off of the throttles (rightly so) thus slowing their turn rate. You can really tell a difference with the aggressiveness of the masters when the associated aids are lit and watching properly. Therefore, be careful not to wake these buoys under the ice when grooming turns. A little extra effort to keep them watching properly will make a big difference.

Air Temperature – Air temperature can create conditions that will severely hamper icebreaking efforts. Extremely cold temperatures (below 5 deg F) will cause the formation of Sea Smoke in any open water area. Sea Smoke is very low lying fog that forms as the open water quickly freezes in the cold air. It is very dense and can create low visibility for low profile vessels. If these conditions exist, then limit icebreaking efforts. Cold temperatures will also affect track conditions, brash ice will quickly refreeze negating track grooming efforts done too far in advance of vessel transits.

Sun – The sun heating the ice will eventually melt the ice, however, even in very cold weather the ice will loosen up a little after the sun has shined on it for a couple of hours, particularly brash ice.

Snow – Snow will greatly diminish ice-breaking efforts. While it does have an insulating effect on ice fields, it creates tremendous drag on the cutter. Heavy snow accumulations will also restrict the effect of the ship's wake. Rain has both positive and negative effects on ice fields. Rain benefits by quickly dissolving any snow accumulation on the surface; it will also begin to melt plate ice. The negative effect is the weakening of stable ice plates. These plates will usually weaken near shore, with the right current or wind vector will move into the channel and have to be dealt with to maintain safe navigation.

3.1.3.c Typical Great Lakes Vessels

Every vessel moving in the Great Lakes system has different characteristics. In general there are three that may be categorized; 1000 footers and smaller Ore carriers, Saltwater bulk carriers (Salty), and Tug-n-tows.

1000 Footers & Ore Carriers – Thousand-foot vessels are the biggest challenge when it comes to breaking proper tracks in the rivers. Their wide beam, plumb bow/beam, large turning radius and deep

draft are the extremely limiting factors in their maneuverability. A structural difference between the 1000-ft vessels and smaller ore carriers is in the construction of their sides, particularly near the stern. The smaller ore carriers' sides are angled allowing their sterns to ride over the ice while turning. Not so for the 1000-ft vessels, their sides are plumb extending straight down through the ice level. This is important to keep in mind when assisting one of the large ships through a turn. The specifics outlined for turn grooming and track maintenance in this guide are designed for their transits. Vessels of smaller dimensions should easily navigate within the same guidelines.

Saltwater Bulk Carriers – Saltys are ocean-going vessels transiting the Great Lakes. They typically have high horsepower propulsion plants. Their sides near the stern also allow for easier turning much like the smaller ore carriers. Usually if there is an established and groomed ice track they have little difficulty making the transit. Saltys have the toughest time when they are transiting in ballast. Typically when in ballast their bulbous bow rides above or near the ice level. The added drag of the bulbous bow can create great difficulty during ice transits.

Tug-n-Tows – Tug-n-tows can present the second greatest challenge during winter transits. The greatest problem comes when the tug is pushing an empty barge. Typically a light barge does not have the displacement to move ice out of its way so the light barge rides up on the brash, and the tug lacks the horsepower to keep it moving. The most ideal tactic is to place the tug-barge behind a large ore carrier for the transit. The lead ship will move brash and floe ice to the sides of the channel ahead of the tug and barge.

3.1.4 Icebreaking Special Circumstances

This section is a catch-all, to include special circumstances of which the conning officer should have basic knowledge.

3.1.4.a Topside Icing

Topside Icing is a relatively common experience and not one to be taken lightly. "When the sea temperature hovers around freezing and the air temperature is even less, spray from waves and the ship's wake can be wind-driven to superstructures and rigging where, on contact forms glaze ice (a particularly dense and sticky sheath of solid water)".[2] Ice coating standing rigging, booms, and superstructure diminish the seakeeping characteristics of the vessel and basic stability. When operating in open water and taking spray the conning officer must be aware of the possibility of icing and take action to minimize the amount of spray coming on board. In certain conditions spray can create ice build up to several inches in an hour. On board WTGBs, which are very wet cutters, 2 to 5 inches of ice build up has been observed

[2] Mariner's Weather, William P. Crawford, W. W. Norton & Co., New York, 1978, page 180.

in an hour's time. It is very hard to monitor ice build-up, even more difficult during hours of darkness, and the conning officer must be most vigilant.

The following general procedures apply when icing has been observed:

1. If icing is possible, rig lifelines early.
2. Secure all weather decks.
3. Change course and/or speed to minimize spray, and run downwind if possible.
4. Quartering to beam seas produce less spray.
5. Take advantage of any lee shore or port of opportunity until conditions improve.
6. Remove ice and snow as soon as conditions permit, using mallets, ball bats and shovels.
7. Warn crewmembers of the danger of falling ice (ice melts and falls from rigging, masts, stays, etc.).

When a severe icing event is expected or has occurred, the onboard Flooding Casualty Control Software stability-monitoring program should be used to evaluate the effect of the icing weight on the cutter's stability.

Details of the cutter's stability characteristics are contained in Part II(a) of the Damage Control Book, which should be referred to for specific instructions concerning intact and damage stability and loading. In general though, intact stability criteria indicate that the vessel will safely withstand a beam wind of 100 knots between the departure Full Load Conditions and arrival after an extended mission with approximately 6 percent fuel oil remaining. It is of course essential that all weather access closures be secured, since large angles of heel may be expected under these severe conditions. In storm seas the largest roll angles occur when the cutter's course places the approaching waves one point abaft the beam. Large angles of roll combined with the quick roll period of this cutter under storm conditions can produce excessive lateral accelerations which should be avoided.

3.1.4.b Night Icebreaking

Night Icebreaking is one of the most difficult seamanship challenges. The loss of depth perception, combined with the inability to see changing ice conditions and features in the ice (windrows, leads, etc.), and the other vessels movements make icebreaking at night one of the highest risk situations. Most Great Lakes operators (Coast Guard and commercial) agree that unless there is a danger to life or property (i.e., a beset vessel drifting into shallow water or structure) the recommendation would be against night operations. If night operations are undertaken the Command must also be alert to crewmembers fatigue, for both the icebreaker and the assisted vessel. The noise of traveling through an ice field is usually enough to keep crewmembers awake, thus human elements and fatigue must always be considered.

3.1.4.c Towing

Towing in ice is a most dangerous operation and is generally undertaken only in emergency situations. Without a wire towing machine the cutter must rely on using synthetic lines, which do not stretch adequately when used in extreme cold temperatures and can part easily with abnormal loading. Additionally, the towing bitt is not specifically designed for towing in ice. If a towing operation has been determined to be necessary, it is recommended that the assisted vessel be towed astern to take full advantage of the ice clearing potential of the Azipods™ to reduce strain on the towing bitt and towline. The propeller wash can be directed outboard to clear ice from the path of the tow.

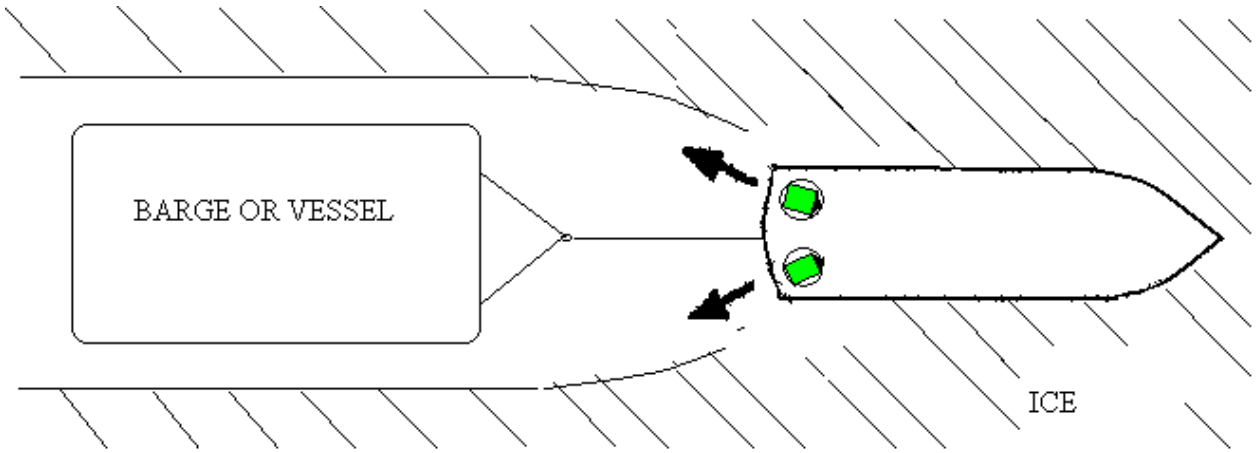

Figure 3.1. Towing in ice with Azipods.

A drawback to using this method of ice clearance is that when the pods are angled outboard (that is the propeller wash is directed outboard), the forward movement of the cutter and tow is reduced. It may be necessary to oscillate the pods from directly ahead to 45° inboard (prop wash outboard) to add forward speed over ground, while flushing ice away from the tow.

Towing astern using WTGBs has been successful in brash and plate ice on the Great Lakes, however, it is recommended that this method should never be attempted in areas of windrows or pressure ridges.

3.1.4.d Convoying

Convoying in today's Great Lakes operational ice management scenario is rarely necessary. The commercial fleet is more powerful and built with strengthened hulls, which, combined with the greatly reduced number of vessels operating on the Lakes, has almost eliminated the call for convoying. Also, D9 ice management policies, including improved methods for track preparation and ice maintenance have contributed to reduce or eliminate the need for convoying.

Should a need for convoying develop, such as a sudden freeze in the Lower St. Mary's River trapping several vessels, there are a few basic principals for convoying. First, organization of the convoy should position the most powerful and widest beamed vessel directly behind the icebreaker, with "weaker" vessels following. Should a half dozen or more vessels be involved, it is recommended that the convoy be arranged with a stronger vessels mixed throughout the convoy, i.e., stronger vessel, weaker, weaker, strong, weak, weak, etc. It is believed that the powerful vessels can assist the weaker vessels by providing momentum and widening the track left by the icebreaker. Should a vessel become beset the entire convoy must stop while the icebreaker backtracks to assist the beset vessel. When two icebreakers are employed with the convoy the second icebreaker is used to cut a relief track and to assist vessels having difficulty. In very heavy ice conditions it may become necessary to stop the convoy and assist each vessel through the difficult area individually, then re-organize the convoy and proceed. Should windrows or ice under pressure be encountered it is advisable to stop the convoy and have the icebreaker scout ahead and prepare the track for the convoy to follow. The icebreaker conning officer must maintain constant communication and complete control over the convoy.

3.1.4.e Flood Relief

Flood Relief is a typical operation in moderate to heavy ice years. Ice Dams (or Ice Jams) can occur naturally (a quick thaw may release more ice than the river can clear, building an ice jam extending from bank to bank and to the bottom of the river) or they may be caused by a beset vessel blocking the flow of ice. Historically, ice jams have occurred on the Lower St. Mary's (near the Rock Cut), on the St. Claire River (in the sharp bends on the lower portion), at various Lake Erie ports (i.e., Monroe, Huron), and the Lower Detroit River in Livingston Channel. Once an ice jam is formed the upstream water rose quickly (up to about a foot an hour on the St. Claire and St. Mary's) calling for a relatively rapid response to prevent low areas and river front properties from flooding. The U.S. Army Corps of Engineers monitors flow rates and lake/river levels and can provide excellent information regarding a flooding situation.

Clearing an ice jam can be accomplished with either of two maneuvers. First, using the power and draft of the icebreaker simply break through the jam head-on. Once the icebreaker is through the ice jam the rush of water will generally break-up the jam, however, it may be necessary to head back upstream and pass through the area several times (passing on each side of the original cut). Should one of the high-powered commercial vessels be nearby and waiting to come downstream they have proven to be very effective in clearing the remains of a jam (especially true in the Rock Cut which a 1000 footer can "blow out the plug" in one pass). Secondly, with a vessel with azimuthing propulsion, the ice jam can be approached from the downstream side, with the cutter backing toward the jam and using the thrust of the

prop wash to blow out and wash away the ice. The same techniques used to clear a windrow (see Figures 4.13 and 4.14).

3.1.4.f Ice Shear Zones

Ice Shear Zones are a phenomenon that usually occurs towards the end of spring each year, as the fast ice deteriorates, the ice field will break free from shore. Driven by the wind and current, the moving ice floe closes the prepared ice channels and impacts on the fast ice extending from the opposite shore. The line of movement between the two ice fields is known as a "shear zone". In addition to the loss of the ice channel, vessels navigating in the area are pushed about, frequently out of the navigable channel (near or into shoal water). This situation often necessitates closing the river system to commercial traffic while the icebreaker breaks the moving floes into small pieces and the river current flushes the broken ice out of the river, into the larger lakes.

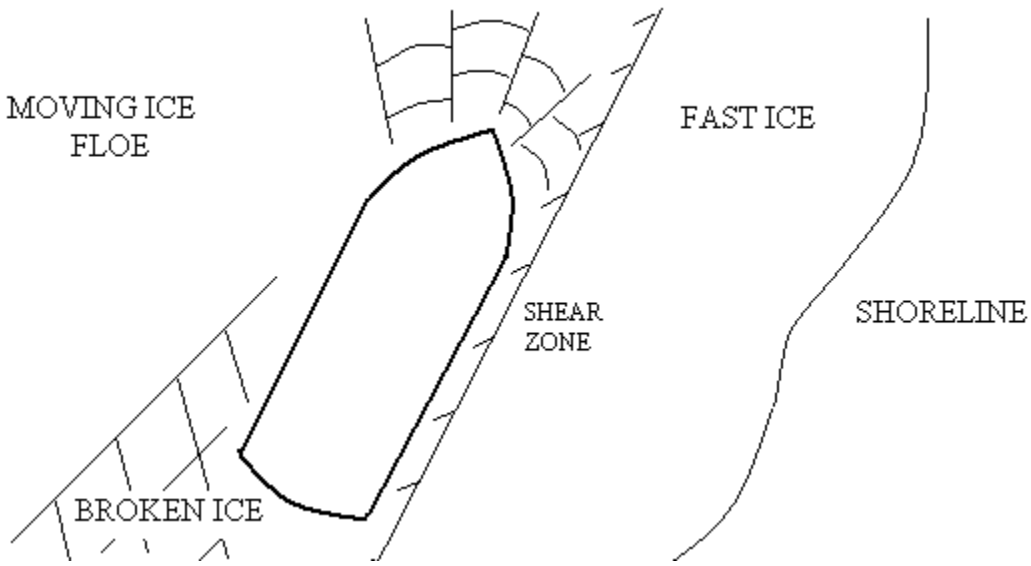

Figure 3.2. Shear zone between fast ice and moving ice floe.

Ice floes that butt together generally created ridges when they come together. The ice thickness may be several times the floe thickness as pressure from the current forces the broken ice up and under the adjacent ice floes. Transiting the area along the shear zone or pressure area should be avoided. If the ridge cannot be circumnavigated, do not attempt to proceed directly up the ridge but rather select a route on either side parallel to the ridge (preferable the leeward side) and proceed.

3.2 ICEBREAKING MISSION AND OBJECTIVES

ACKNOWLEDGEMENT

Portions of this Chapter were written by various individuals who should be acknowledged for their insight, professionalism, and understanding of the needs of mariners operating in ice covered waters on the Great Lakes.

LCDR Charles Alcock, USCG – Past CO, KATMAI BAY (WTGB-101)
CDR Keith Colwell, USCG (Ret) – Past CO, MACKINAW (WAGB-83)
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3.2.1 Background

The first MACKINAW historically had been tasked with operations anywhere needed in the Great Lakes. Year-to-year changes in the ice growth patterns often require heavy icebreaking capability in one or more operating areas. In some years, no operations in a given area would be required. This characteristic of the Great Lakes necessitates the development of an Operational Manual to document the procedures and objectives used when dealing with the varied ice conditions in each potential operating area. The most common areas requiring heavy icebreaking operations are: the Straits of Mackinaw, the lower St. Mary's River, the upper St. Mary's River, and western Lake Superior (Duluth).

This manual is designed simply as a tool to help ensure specific time tested icebreaking approaches and techniques are passed on to icebreaking crews in the follow-on years. The information included here comes from numerous winters of data collection and experience. This by no means makes it gospel, but it is valuable insight gained from many winters each of which seem to be distinctly different. Tactics that were unsuccessful in a light ice year might prove effective in a heavy year and vice versa.

3.2.2 Lower St. Mary's River

The lower St. Mary's River is one of the most critical waterways within Operation Taconite, the largest domestic icebreaking operation in the United States. Under Canadian/United States agreement, Operation Taconite assures icebreaking assistance in Canadian and U.S. waters, where commercial icebreaking resources are either unavailable or incapable of handling the difficult ice conditions. Extreme weather conditions, narrow channels, relatively shallow waters, the locks, and the large number of vessel transits make the St. Mary's River a particularly challenging icebreaking environment.

Icebreaking in the lower St. Mary's River can be divided into four distinct operating phases: Prior to lock closure, during lock closure, reestablishing tracks, and spring breakout/flushing. In addition,

extensive sections have been developed to discuss the preparation, "grooming", of specific areas in the lower St. Mary's River, procedures to deal with the ferry crossings and some insights on ship escorts.

3.2.2.a Prior To Locks Closure

Significant ice can form as early as the beginning of December or as late as mid-January. Typically the first ice formation begins in the Mud Lake area, particularly in the Winter Point area. The slow river current and the relative protection of Neebish Island create ideal conditions for ice formation.

Initial icebreaking in the St. Mary's River should be limited to periodic ice reconnaissance to locate any areas of significant build up. A critical step in establishing tracks at the beginning of the ice season is to let the Lakers show the way. The large ships can easily transit through the first formation of thin ice (less than 1"). These first few transits establish the basic outlines for tracks and turns. It is necessary to see the vital need for "stern relief areas", which must be maintained throughout the rest of the navigation season. Most of the commercial traffic can manage ice up to several inches thick, therefore it is recommended to keep reconnaissance efforts to a minimum and allow the traffic to initially break on its own. Every effort must be made to maintain these very fragile new ice tracks. Breaking ice outside the newly established tracks simply creates opportunity for more ice to form particularly in the late fall and early winter as daily temperatures fall. Periodic ice reconnaissance trips coupled with a close eye on the forecasted weather and an updated ship transit list should provide an adequate sign when daily track maintenance should be conducted. During these early trips it will also be vital to determine that all aids to navigation are on station, noting discrepancies. ATON that is later pulled off station or submerged under the ice will create a significant hazard during icebreaking operations in the spring.

Early, significant ice formation within the river, as was the case in 1995-1996, means almost certain escorts and direct assists. There will most certainly be underpowered tugs, tug/barge combinations, or salt-water seagoing vessels "caught" in the river making their final winter transits. If this occurs, then transiting outside the established tracks will be necessary to free these vessels. Frequent direct assists can cause severe damage to the established tracks and cause freshly broken plate to drift into brash filled tracks, creating brash accumulation and ice jams. An increase in track maintenance ahead of vessel transits along with accurate vessel arrival schedules and slowing vessel traffic approaching the Rock Cut on the Oak Ridge Range may help reduce these damaging measures.

If an early freeze is not the case, then the most important factor to consider is "Ice Management" throughout the entire river system. Ice Management is particularly important around the Nebbish Island area. Minimal icebreaking above Nebbish Island can substantially reduce the broken plates that drift to choke points in Middle (Stribling) and West Nebbish Channels (Rock Cut). Tracks should be broken only to the width to accommodate a 1000-ft ore-carrier with a beam of 105 ft. A good track width is approximately 140 ft. This allows some room for the 1000 footer to push brash from its plumb bow.

3.2.2.b During Locks Closure

Upon lock closure the focus of attention is shifted to the Sugar Island ferry crossing and Oil Tanker escorts. Providing assistance to ferries is explained in the "Ferry Crossings" section of this guide.

With closure of the locks comes the closure of West Neebish Channel. The residents of Neebish Island establish two ice bridges, one above and one directly below the Rock Cut. These ice bridges are extremely important because the ferry will eventually be unable to run and these become the resident's only avenues between the mainland and island. It is extremely important that the ice in these two areas remains undisturbed until as close as possible to the scheduled lock opening of 25 March.

Oil Tanker escorts are vitally important to the residents of Sault Ste Marie (SSM), Ontario. Heating oil is transported by Tank ship to meet the heating demands of the city. The tanker usually maintains weekly runs, but they may increase in frequency if weather is severe. An important aspect of Oil Tanker escort is the fact that they have a narrow beam. A single track approximately 80 ft wide should be all that is required for their transit.

NOTE: Maintaining wider tracks simply exposes more open water to the cold air, which will freeze and add to the ice accumulation within the channel.

Two methods have been successfully employed to provide escort. In thin to moderate ice thickness, set sailing orders in time to meet the tanker for the, up-bound transit at the lower ice edge. Lime Island makes a good overnight mooring location if it becomes necessary. Escort the tanker all the way to SSM and pull into Group Soo for an overnight stay. Set sailing orders for the next morning by coordinating with the tanker's scheduled sailing time. The down-bound escort should, only take the tanker only to the lower ice edge, and then return to homeport. For light to moderate ice it should only require an escort to sufficiently loosen the ice track.

The second method is ideal for moderate to heavy ice. Set sailing orders to transit to SSM the day before the tanker is due. Depart SSM in sufficient time to meet the tanker at the lower ice edge and pick up the escort back to SSM. Schedule the next day's down-bound transit to coincide with the tanker's sailing time. The second method is preferred with heavy ice because it gives two passes (downbound then upbound) to loosen the established ice track for the tanker and an escort during the transit.

3.2.2.c Reestablishing Tracks

The time to begin reestablishing tracks in the lower St. Mary's River depends upon the weather and availability of the other icebreaking assets. Past weather dictates just how much ice is actually in the river. A severe fall/winter usually means thicker ice in the spring. If the weather is less severe during these periods then there will be less ice. This is important because you want to start the Spring Breakout process at the right time. Starting too early means your making ice, too late means the tracks do not get established before the locks open on or about March 25. Quite often upbound traffic will begin arriving

in the river as early as March 23rd to position themselves at the lower lock entrance. If the weather conditions are good (moderate temps, prevailing NW winds), flushing operations can begin in the lower river by the end of the first week in March. The overnight temperatures will most likely be cold enough to still make ice, but nothing that cannot be quickly flushed out by an hour or two of productive flushing the next morning (given the right conditions, as previously discussed). Three inches of newly formed plate ice (from the overnight freeze) is a lot easier to move through than 20 inches of refrozen brash. The more ice that can be moved out of the lower river before starting the reestablishment of tracks the better.

When reestablishing tracks, begin with the dead center of the channel. Most courses are marked with range markers. Follow the deepwater ranges for the initial cut. It is extremely important that a skilled helmsman be utilized to make the initial cut as straight as possible. Some benefit may be gained by operating the Azipods canted inboard (prop wash outboard) during this pass. All further cuts will be based on the initial and the final pass will amplify any small alterations in course. Be careful to disturb the ice outside the track as little as possible. The last two cuts should be half-ship widths to each edge of the track. The final cuts should be executed at slow speed keeping the track edges as smooth as possible. The desire is to establish the required 140-ft track width required for the largest freighters.

3.2.2.d Spring Breakout/Flushing

Spring Breakout should begin in the lower St. Mary's River and at a time when establishing tracks will not create too much extra ice. A careful balance should be established between the reestablishment of tracks and flushing operations. Do not get carried away with flushing too early. Spring overnight freezes may erase any established tracks with refrozen small floes of broken plate.

The flushing process must begin at the mouth of the St. Mary's River so that ice can flow into Upper Lake Huron and hopefully be broken up even more by the wind-driven seas. Ice must be totally broken out past Frying Pan Shoal. If not, broken ice in the river above those areas will jam up onto the Drummond Island Ferry crossing. Thus, it is imperative to begin each lower river flushing operation with a quick look out past Frying Pan to ensure a sufficient open water catch basin exists to receive the ice you will be flushing.

The "wedge" method simply means opening a large area at the bottom of an intended space and breaking ice toward a point at the top of this same area creating a funnel look. This approach combined with the right conditions of wind, current, and moderate weather will force the ice to move down river. It is important to keep the edges along the sides of the wedge as smooth as possible because broken pieces of ice trying to move down river with the current might possibly hang on jagged corners, thus slowing the ice flow.

Once clearing the mouth area is complete, begin breaking a wedge past Watson Reefs Light toward Sweets Point Light in the South Channel. Use whatever methods necessary to break new plate

then "project" a wake as far as possible in towards the shoal water. It is critical to create as much open water as possible behind Watson Reefs Light and Sweets Point Light toward shore. This is the inside of the turns and the prevailing current will push the ice through these areas. Flowing ice will need all the room you can open up to make the bend from above Sweets Point Light.

Resume wedge operations toward Lime Island and this time try and break the ice along the southern shore of Lime Island. A critical jam point is between buoy #14A and the southern end of the dock at Lime Island. The ice along this area (close to the island) should be thinner because it is in the lee of the island and protected from the current (and winds somewhat). This area, like Watson Reefs and Sweets Point is critical because it is the inside of the turn and ice broken up river from here will tend to move into this bend between buoy 14 and the Lime Island Coal Dock. There is ample water outside the buoy line to push the wake toward shore (use caution, as shoal water is present). It may be advantageous to create a fairly large wedge area here just inside the Lime Island Traffic Buoy. This is a fairly sharp turn and is more exposed to the winds, which combined with the tighter space, means that it is more likely the ice will jam here while trying to make the turn.

Continue running the "wedge" upriver towards Point Aux Frenes. Concentrate efforts on the eastern edge from Lime Island to abeam of Round Island. Then shift efforts to the western edge from Round Island to the turn at Point Aux Frenes. Beware of shifting plates that may come from Raber Bay area on a NW or W wind and require the icebreaker to break them into small pieces that can be flushed down river. Again the inside of the turn at Point Aux Frenes is vital for breaching Mud Lake. Use the ship's wake to break ice towards land as far as possible on the "green" side of the channel. As the turn flushes out continue "wedge" operations all the way through Mud Lake.

An area of concern lies at the Mud Lake Junction Buoy. The fast ice between the down-bound and up-bound channels is extremely unstable and may break loose at any time. Be cautious of shifting plates and ensure all the buoys are broken free of ice prior to the plates shifting. If the buoys are encased in ice they will be dragged off station and may become hazards to navigation.

The key to flushing out the Rock Cut starts in Mud Lake. Once the western edge of Mud Lake begins to move, concentrate flushing efforts south of Winter Point near Moon Island turn. Next work the stretch between Moon Island turn and Sawmill turn.

CAUTION: there are many residences on both the mainland and Neebish Island. Wake damage is under close scrutiny in these areas.

To continue flushing operations in the more restricted turns of the river simply use the ship's power to project the wake beyond the channel edges. Perform frequent downriver runs to ensure the broken plate is not stacking up in a turn or choke point.

NOTE: Flushing operations below Moon Island and Johnson's Point are only beneficial with northerly wind directions. Normal river current is not strong enough to move broken plate all the way out of the system. The river current above these two points is strong enough that flushing operations are not dependent on wind direction.

3.2.2.e Turn Grooming

Turns are the most critical part of the waterway because of the difficulty most large, squared stern ore-carriers experience trying to execute a turn. Most of these vessels have sufficient power to move forwards along a straight-line course, and can usually back-up into their own broken track, but turning is difficult. Why emphasize something that seems logical? The important fact to remember is that vessels most likely will do fine on the straightaway within the river, so do not labor on them needlessly. Groom them as mentioned below, but put the majority of effort into the turns. Even if a vessel gets beset in a straightaway, getting them free and underway again in the river is much easier than getting one re-started in a turn.

Anatomy of a turn – Every turn has distinct areas that icebreakers should be aware of. These include, Entry Point, Stern Relief, Bow Riding Area, Bow Relief Area, and Exit Point. Figure 3.3 is a generic right hand turn with these vital areas labeled.

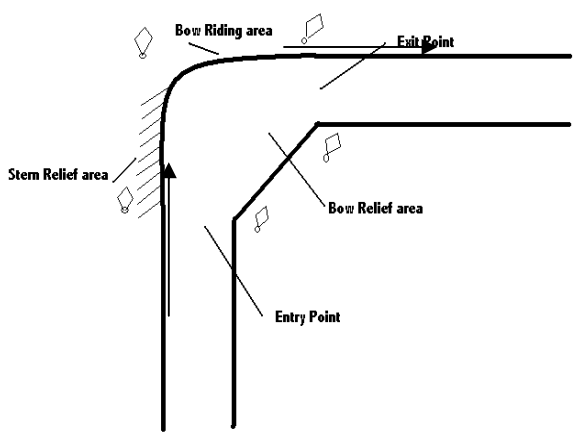


Figure 3.3. Generic right hand turn.

Entry Point – This is the point in the turn where the ship's bow first crests the beginning of the turn. It is at this point that most captains will begin to make their turn. This is also a crucial junction for the ship captain. If their ship's head does not begin to change within the first few feet of the Entry Point

many captains will take off their power diminishing their turning ability. This causes the bow of the ship to reach further into the turn than usual. This reaching of the bow is called "head reaching" and will cause great concern for the commercial vessel operators, as they do not want to over shoot the turn and run into shoal water.

Stern Relief Area – This is where the vessel's stern will swing as the ship's head comes around. It is opposite the direction the ship is turning and subject to great pressure as the ship's square stern moves through the ice. The vital thing about the Stern Relief Area is that it should be loose with plenty of room. At times, to provide enough Stern Relief Area, the ice may have to be broken outside of the buoy line. It is best to use the ship's wake or prop wash while casting for this purpose. The Azipods are ideally suited to washing this area out. Also, a 360° spin right at the entry point may create a hole for the ship's bow to swing into. Commercial vessel masters say this part of the turn is the most critical, if the stern does not move into this area the bow will not turn.

NOTE: When waking the bottom outside edge of the turn and casting within this area be careful not to do too much damage to the inside of the down current point of the turn. If two much ice is broken here, it will settle in the approaches, accumulate, and possibly slow the approaching vessel down at a time when they should be beginning to increase their power.

Bow Riding Area – This is the area of hard ice on the outside edge of the turn. Normally the ship captains do not test this area, unless it has been a very hard freeze and there is a significant amount of ice. Providing there is thick ice (normally greater than 2 ft) the ship captains will use the higher pressure of the Bow Riding Area to assist in getting the bow of a ship to come around.

NOTE: While working turns it is important to leave this area untouched as much as possible. It is GUARANTEED that if the captain feels the Bow Riding Area is not hard enough to deflect his/her bow or slow the progress toward the channel edge, then he/she will not use power, which will inhibit the ship's turn rate.

Bow Relief Area – This area of a turn is the broken ice, encompassing much of the middle ground, on the inside of the turn. The ice in this area should be broken and loose so as not to obstruct the swing of the bow as the ship comes through the turn.

Exit Point – This is the end of the turn. Ships should be steadied up on their exit heading prior to reaching this point in the turn. Even if they are a few degrees shy of their heading, ice pressures on either bow could send them off and prevent them from gaining their track for the next course heading.

The following is a description of how to groom a generic turn. It is just the basics for getting a turn started; ice thickness, snow cover, brash accumulation and air temp will dictate alternate approaches to preparing turns. Thick, refrozen brash or heavy snow may require multiple passes through your own track to generate a wake. Every turn in the St. Mary's River is unique and more precise instructions with

specific tips follow in the "specific turn" sections below. The definitions above serve as reference points for this section. We do not always have a choice from what direction we approach a turn. An important time saving approach is to make every pass through a turn count, so this is written for any approach scenario. A right or left-hand turn designation is based on the direction of the traffic, not the approach of the icebreaker.

Right ***or Left*** -hand turn:

Approach from Entry Point – First pass on left track edge, carry wake through Stern Relief Area (if possible), cut back wake through Bow Riding Area, cast at Exit Point. Second pass through Bow Relief Area, carry wake to track edge (no further than intact plate), cast at Entry Point. Successive passes should work towards the middle of the turn.

Approach from Exit Point – First pass through Bow Relief Area, carry wake to track edge (no further than intact plate), cast at Entry Point. Second pass on left track edge, carry wake through Stern Relief Area (if possible), cut back wake through Bow Riding Area, cast at Exit Point. Successive passes should work towards the middle of the turn.

Left-hand turn:

Approach from Entry Point – First pass through Bow Relief Area, carry wake to track edge (no further than intact plate), cast at Exit Point. Second pass on left track edge, keep wake in check through Bow Riding Area, increase power and carry wake through Stern Relief Area, cast at Entry Point. Successive passes should work towards the middle of the turn.

Approach from Exit Point – First pass on left track edge, keep wake in check through Bow Riding Area, increase power and carry wake through Stern Relief Area, cast at Entry Point. Second pass through Bow Relief Area, carry wake to track edge (no further than intact plate). Successive passes should work towards the middle of the turn.

3.2.2.f Specific Turn Grooming

Frechette Pt Range (6 mile turn) – Both right and left-hand turn. This turn can be characterized by large amounts of broken plate from Sault Harbor that have broken and floated past Little Rapids Cut. The Ice Boom placed above the Sugar Island ferry catches a majority of the floes, but a significant amount of ice will bypass the area. This ice will venture down to the ice edge. If the ice has not formed past 6-mile point it will begin to jam up at this choke point. It is possible to break the fast plate below this area and get the heavier plate to shift down into Lake Nicolet. Extreme caution should be exercised in the use of the ship's power as many ice-fishing shanties are placed near the ice track at this point. **(No picture available at this time)**

Lt "49" Lake Nicolet – Right-hand turn. 21-degree head change, 1300 yards long. This turn takes you out of lower Hay Lake onto Oak Ridge Range. Due to the increased current, ice thickness in this area is usually less than other turns in the river. It is protected from brash accumulation from the fast ice present in Hay Lake as well. During spring breakout this turn will be subjected to shifting plates. The key to this turn is to maintain smooth track edges all the way around. The relative small head change and the longer distance of the turn typically make it an easier turn for the users. **(No picture available at this time)**

Oak Ridge (top of Rock Cut) – Left-hand turn. 38-degree head change, 800 yards long. This is one of the most unique turns in the entire river. This turn will flow clear after grooming. This is due to the heavy current that is funneled into the Rock Cut. At ALL times use lower power to groom this turn; any wake generated will devastate the track edge and quickly block the Rock Cut and may reach the ferry crossing. To groom this turn first ensure the plate is broken in a straight line from Buoy "36" to crib light "32" on the "red side" of the channel. Next establish the outside of the turn. Using slow speed, form a smooth edge along the "green" side. This edge should start opposite of Buoy "36" and proceed all the way down to Buoy "35" as near the channel as practical. This will give plenty of room for large ships to swing their stern and line up for the transit through the Rock Cut. Shown in Figures 3.4 through 3.8 is the progression of grooming this turn.

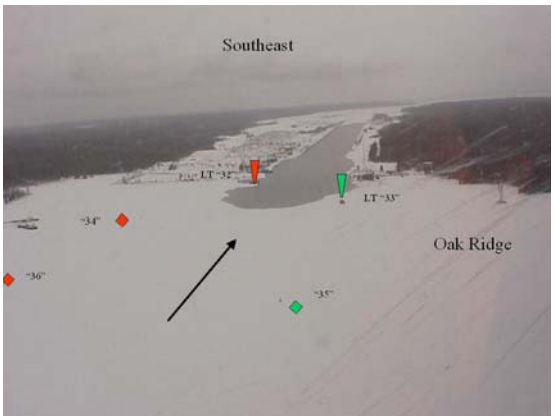


Figure 3.4. Rock Cut before.

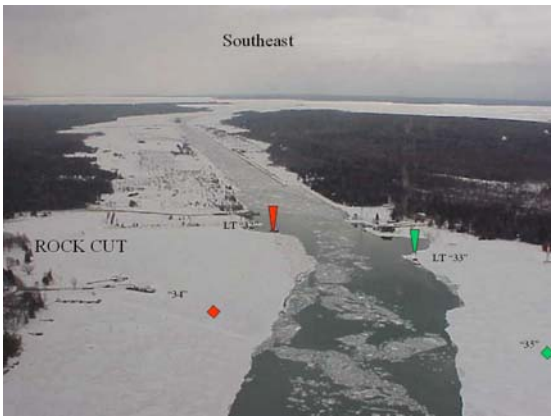


Figure 3.5. Rock Cut first cuts.

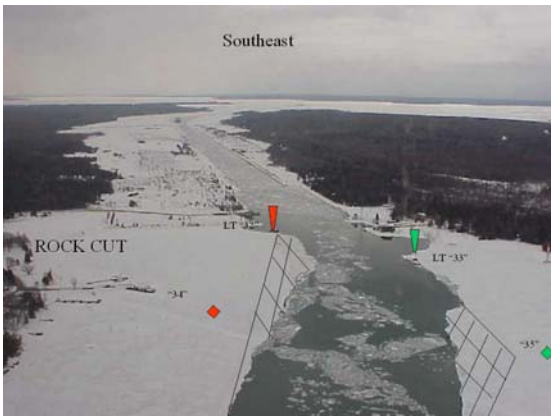


Figure 3.6. Rock Cut second cuts.

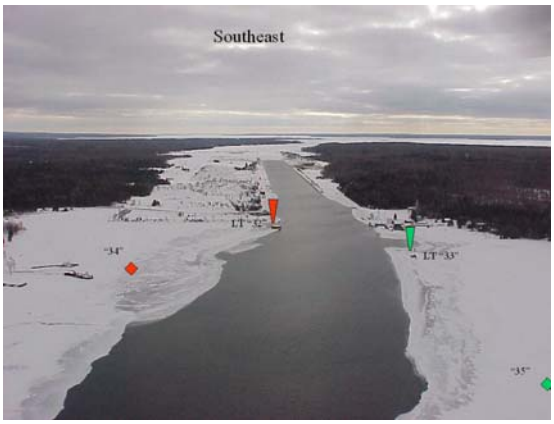


Figure 3.7. Rock Cut second cut complete.

Figure 3.8. Rock Cut wide view.

Sawmill – Right-hand turn. 25-degree head change, 1300 yards long. This is a very long turn extending from the lower end of the Rock Cut down to Sawmill Point. The turn is usually characterized by heavy brash and broken plate from the Rock Cut jammed at the upper end, to lighter brash and refrozen plate at the lower end. The critical area for this turn is the "red" side of the channel just past the lower dam; this is the beginning of the Stern Relief Area. Here heavy brash and refrozen plates jam as the large ships push the ice onto the dam. It is extremely important to break the area just past the dam on the "red" side into the 22-foot area outside the channel (no further than 10 yards outside channel). Large ships need lots of relief for sterns to swing through the turn. All attempts should be made to maintain a smooth edge along the "green" channel edge, which will help with brash flow out of the Rock Cut. **(No picture available at this time)**

Moon Island – Left-hand turn. 40-degree head change, 900 yards long. This is a relatively short turn with a large head change. The turn is characterized with light brash accumulation in the Bow Relief Area. Due to the stability of the surrounding area very rarely is there a problem with shifting plates. The key to this turn is the Stern Relief Area. Begin on the "green" side of the channel approximately 60 yards above the Entry Point. The Stern Relief Area should extend all the way over to the channel limits on the green buoy line, use the wake of the ship to just crack the plate outside the channel if possible. Shown in Figures 3.9 through 3.14 is the progression of grooming the Moon Island turn.

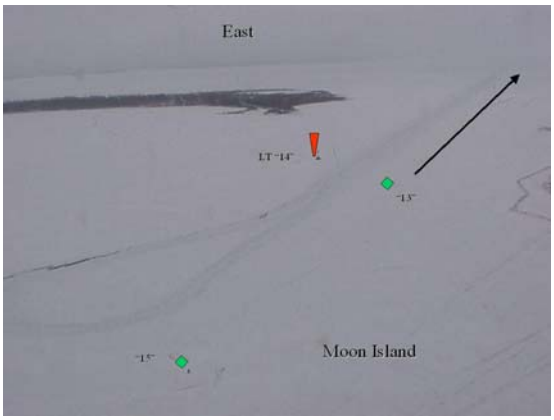


Figure 3.9. Moon Island first cuts.

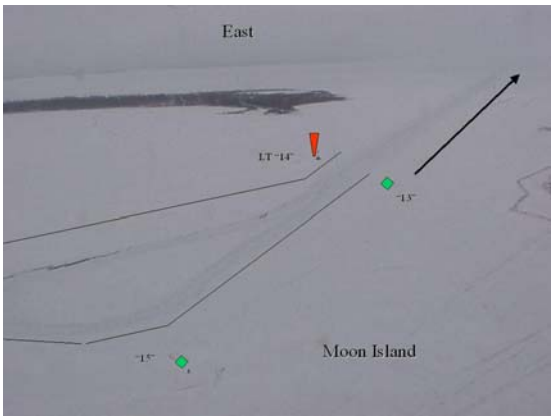


Figure 3.10. Moon Island outer limits.

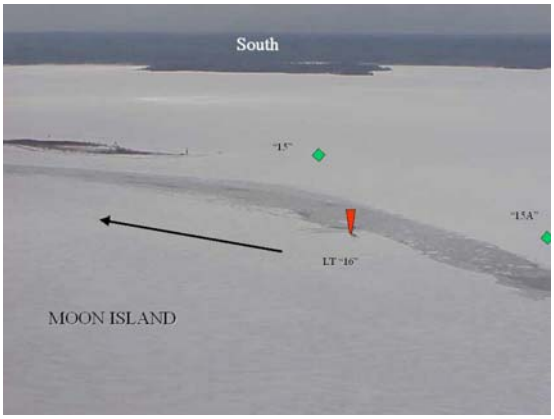


Figure 3.11. Moon Island alternate view.

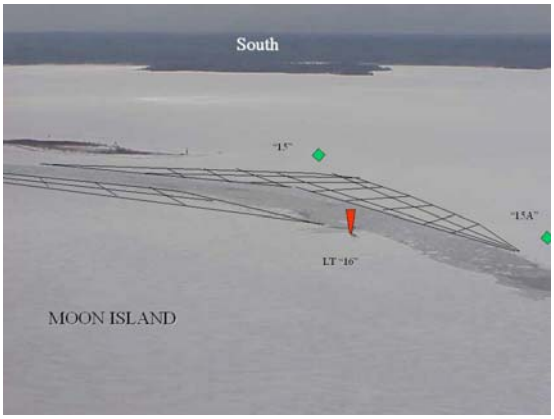


Figure 3.12. Moon Island second cuts.

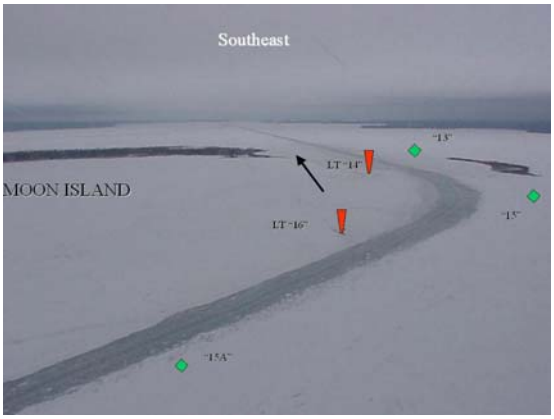


Figure 3.13. Moon Island final view.

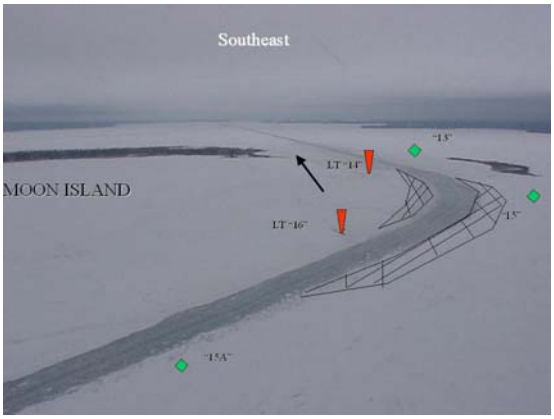


Figure 3.14. Bow & stern relief and bow riding areas.

Winter Point – Right-hand turn. 54-degree head change, 1400 yards long. This is the longest one-way turn on the river. The slow river current and exposure to the weather provides for large ice accumulation in this area. Typically this is the first area in the river to develop ice at the start of the season. The Stern Relief Area should begin abeam buoy "5" and reach well outside the buoy line on the "green" channel edge. The deeper water outside the marked channel provides extra maneuvering room if the Stern Relief Area cannot be broken with the ship's wake. This is one of the turns where a Bow Riding Area is likely to develop. The thicker ice provides a good cushion to help guide the bow of the larger ships. Due to the large size of this turn and the heavy ice, typically this turn will take several passes to prepare. Allow additional time to work this turn during escort operations. This turn is very susceptible to shifting plates from the Northern and Eastern shores during spring breakout. It is very important to ensure the buoys are free of ice plates before these plates start shifting. Shown in Figures 3.15 through 3.18 is the progression of grooming this turn.

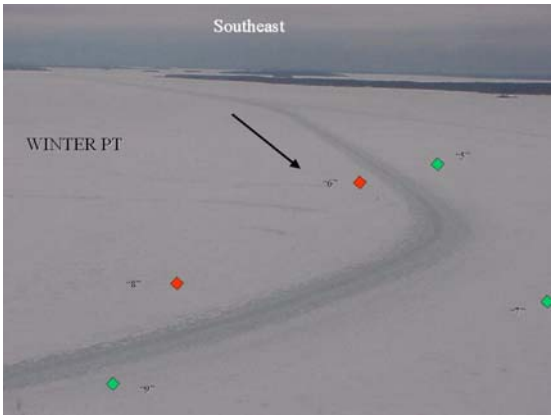


Figure 3.15. Winter Point first cuts.

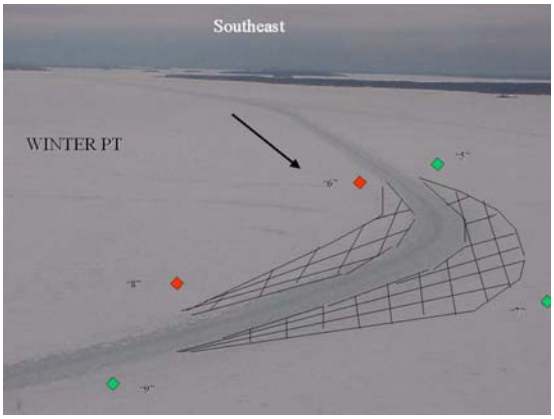


Figure 3.16. Winter Point widening.

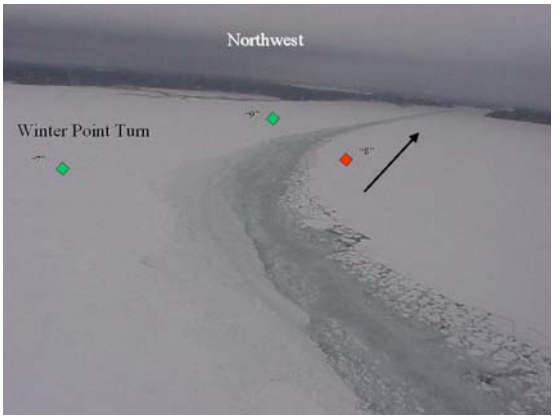


Figure 3.17. Winter Point second cuts.

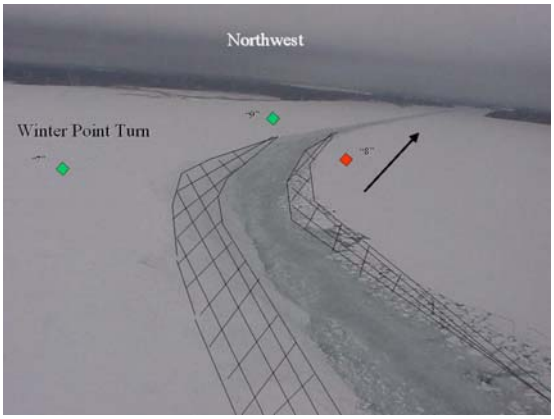


Figure 3.18. Bow & stern relief and bow riding areas.

Johnson Point – Left-hand turn. 61-degree head change, 500 yards long. Absolutely the most difficult turn on the entire river. Not only is there a large head change, but also it must be accomplished in roughly 1.5 ship lengths of a 1000-ft vessel. This requires a very large Stern Relief Area that must begin at approximately buoy #18 and extend east all the way over to the Red buoy line then travel up to the Northern limit of the turn. Tip: Approach this turn from the Exit Point, follow the left edge along the Bow Riding Area then pick up speed as the shallow ranges begin to line up. Make your turn with plenty of time (advance & transfer) to be right on the shallow water range and creating a wake that reaches to the East (toward the red buoy line). Check back your speed and set up for a starboard cast just up current from buoy #18. CAUTION: The starboard cast will take you through the main track below the Entry Point, this ice may be loose and the ship's momentum will be difficult to stop. Shown in Figures 3.19 through 3.22 is the progression of grooming this turn.

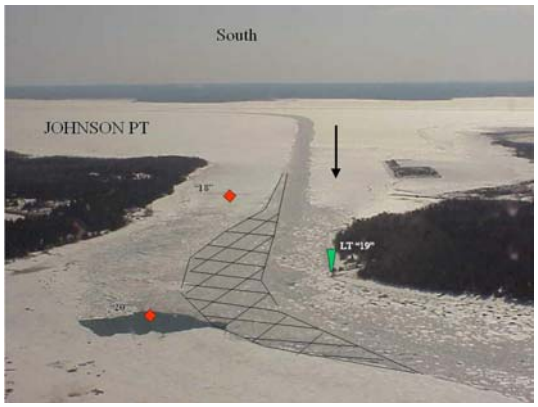


Figure 3.19. Johnson Point stern relief & bow riding areas.

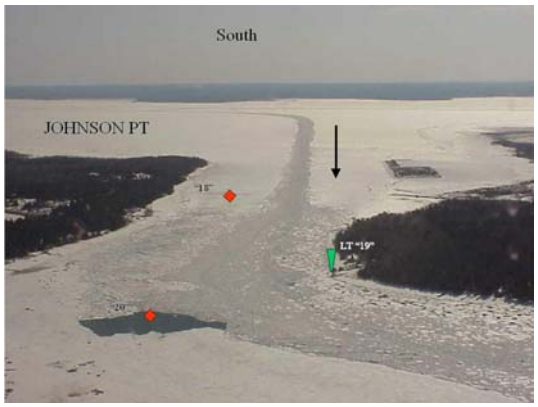


Figure 3.20. Johnson Point final result.

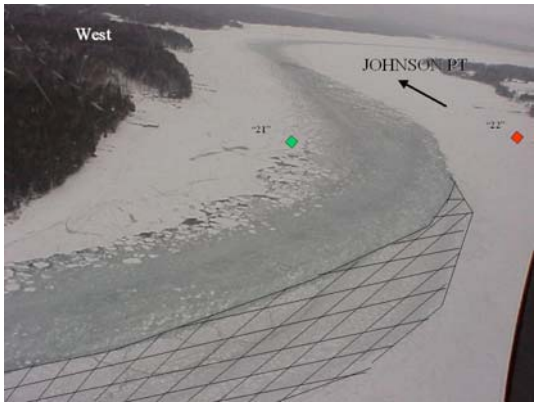


Figure 3.21. Johnson Point up-bound view.

Figure 3.22. Johnson Point final results.

Dark hole – Right-hand turn. 45-degree head change, 800 yards long. The high current in this section of the river creates brash build up at both Entry Point and Stern Relief Areas of this turn. Although this is a short turn it has a long Stern Relief Area. Begin establishing the Stern Relief Area at buoy "23" on the "green" channel edge carry it all the way past buoy "25". This turn usually does not develop a Bow Riding Area, but try to maintain the ice edge between the end of the Stern Relief Area up to buoy "29". The next most important area in this turn is the Bow Relief Area. All the ice between buoys "26" and "28" should be loose to provide relief of the bow as the ship makes the turn. Take precaution not to wake any of the fast plate in this area, shifting plates will quickly push ATON under the ice. Shown in Figures 3.23 through 3.25 is the progression of grooming this turn.

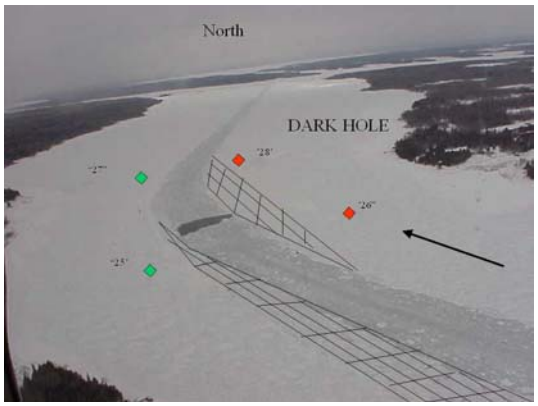


Figure 3.23. Dark Hole stern & bow relief areas.

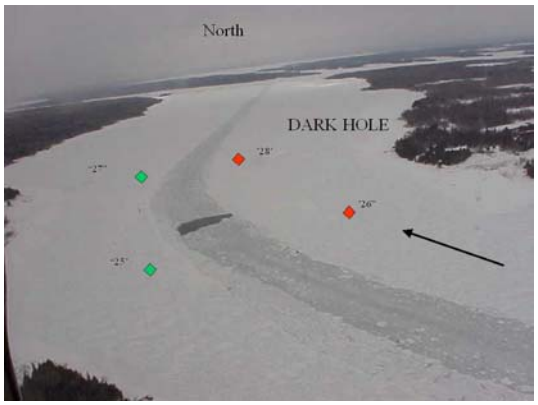


Figure 3.24. Dark Hole final view.

Figure 3.25. Dark Hole approach from Johnson Pt.

Stribling – Left-hand turn. 68-degree head change, 1000 yards long. The large head change and the short distance of this turn make it essential to create a significant Stern Relief Area. Begin on the "red" side of the channel adjacent to the crib light "39". The shallow water ranges on Hardwood Point are excellent reference points for the extreme eastern channel. Carry the Stern Relief Area deep into the turn just until it crosses the Stribling Point Ranges. This turn is subject to fast current. By maintaining smooth edges on both sides of the turn, brash ice will move through fairly easy. Shown in Figures 3.26 through 3.31 is the progression of grooming this turn.

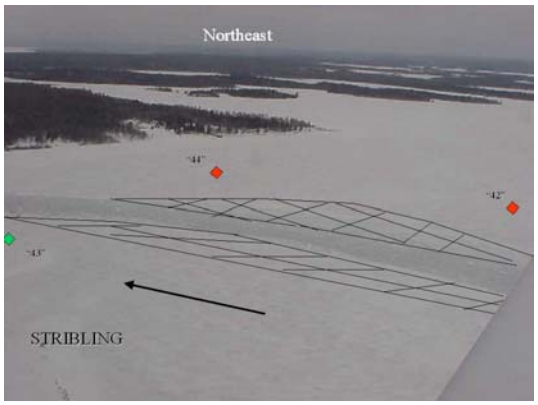


Figure 3.26. Stribling stern & bow relief areas.

Figure 3.27. Stribling final view.

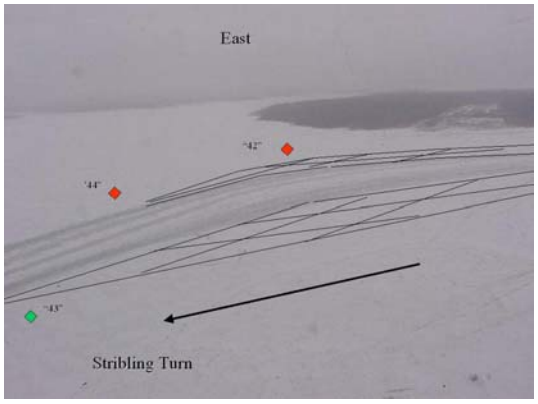


Figure 3.28. Stribling bow relief to exit point.

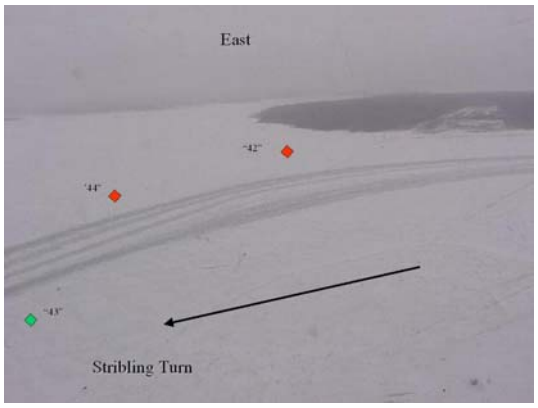


Figure 3.29. Stribling final view.

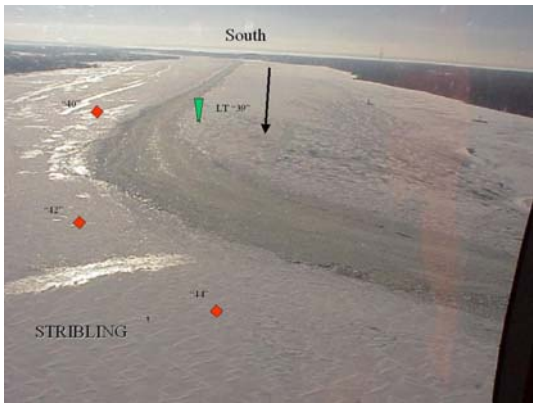


Figure 3.30. Stribling looking at entry point.

Figure 3.31. Stribling looking up-bound.

Lt "62" – Right-hand turn. 39-degree head change, 1400 yards long. Ice formation in this turn is limited due to swift current. In fact it is not uncommon to see open water pools where the current eddies over rocks. This turn can usually be groomed simply by making a single pass through the center and adjusting the ship's power for the wake to reach each track edge. There is a large amount of ice that will flow through this area, mostly broken plate (small floes) moving down current from Hay Lake. Low power techniques should be used while grooming this turn to prevent breaking the ice bridge that forms between Lt "62" and Stribling Dike Lt "58". If this ice bridge is in place it will prevent loose broken plates/brash from entering the Stribling choke point. **(No picture available at this time)**

Point Aux Frenes – Both right and left-hand turn. Like all two-way turns this turn will not have a Bow Riding Area. It is important that the Stern Relief Area extend the entire distance through the turn. This turn is subject to large brash accumulation, and shifting plates. **(No picture available at this time)**

Lime Island – Both right and left-hand turn. There is an option to the way this turn is established and maintained. A traffic buoy marks the up and downbound routes through the turn. Establishing the down bound track to the west and south of the buoy is optional, keep in mind that the users generally prefer to cut to the inside (east) of the traffic buoy. Generally it makes less area to maintain by using only one side of the traffic buoy. The trick to using only one side of the traffic buoy is that you must create a "crossover" ice track so down-bound ships can slide into the down-bound track between Lime Island and Sweets Point. Shown in Figures 3.32 and 3.33 is the progression of grooming this turn.

Figure 3.32. Lime Island single track.

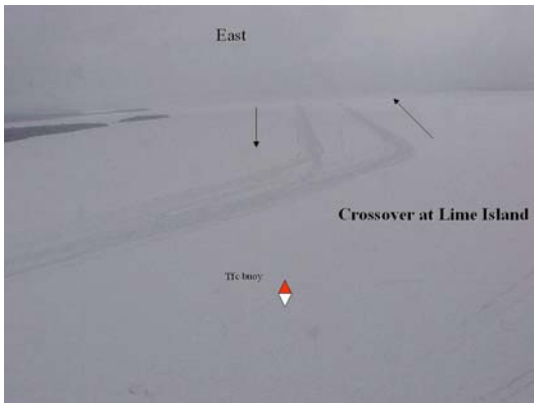


Figure 3.33. Lime Island crossover two-way traffic.

3.2.2.g Straight Track Course Grooming

As a general rule, once the river has frozen and it is apparent that it will remain that way until spring, establish and maintain the tracks only as wide as necessary to move traffic...no wider. To emphasize the point; do not allow the wake of the icebreaker to travel outside the limits of the established

track. That is usually the width of the largest vessel (105-ft) plus approximately 35 ft (105+35=140) to allow room for ice to flow around the column bows of the 1000-ft vessels. This number is only a starting point as the conditions may dictate wider tracks.

Vessel meetings are always something that should be in the back of the mind of the assisting vessel. Keeping close track of vessel call-in points will be your best method of predicting where vessels will have to meet. Ice tracks are cut in two fashions to accommodate meeting situations; two-way tracks and doublewide tracks. Two-way tracks are separate, 140-ft wide tracks, separated by stable plate ice. See Figures 3.34 through 3.37. Doublewide tracks are a massive single track, greater than 300 ft wide, in which two ships could pass (Figure 3.38).

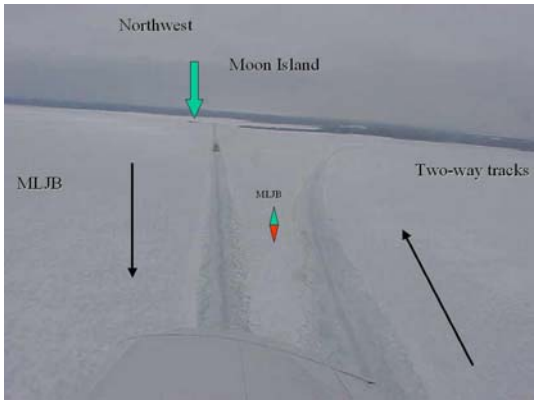


Figure 3.34. Mud Lake Junction Buoy.

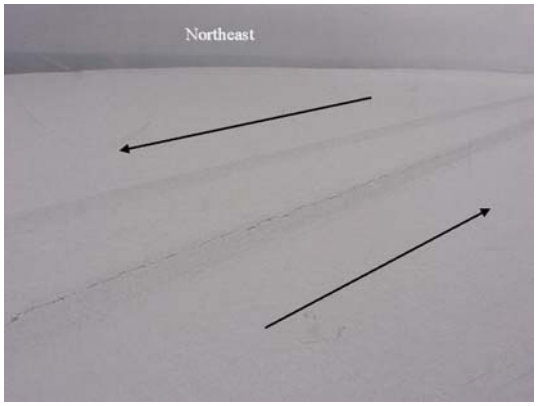


Figure 3.35. Two-way tracks.

Figure 3.36. Two-way tracks.

Figure 3.37. Passing In two-way tracks.

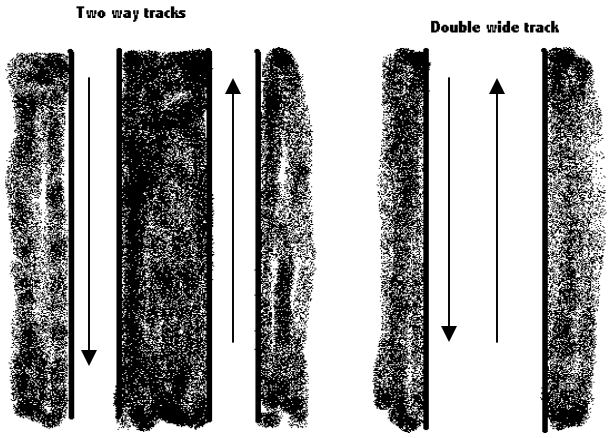


Figure 3.38. Two-way and doublewide traffic tracks.

Upper Nicolet (Hay Lake) – Two-way tracks. Hay Lake is typically the last area to freeze. This lake has both up and down-bound ranges. Establish two-way tracks using ranges as center point for main tracks. Tracks intersect with Frechette Range in vicinity of 6-mile point. **(No picture available at this time)**

West Neebish Channel Upper – Single track. Continuation of down-bound track through Hay Lake. **(No picture available at this time)**

Oak Ridge (d/b course 5) – Single track. Ice very unstable due to current and shallow water outside channel limits. All vessels use minimal power to prevent incidental ice breaking. All free ice broken in this area will move into Rock Cut. **(No picture available at this time)**

Moon Island to MLJB – Single track. Ice fairly Stable, will begin to shift during spring breakout, mostly on westerly wind. **(No picture available at this time)**

Mud Lake Junction Buoy (MLJB) to Point Aux Frenes – Two-way tracks. Establishment of two-way tracks through Mud Lake is essential. This is a primary meeting and staging area. Vessels will also "hove too" in the ice at night in this area. The down-bound track is a continuation of the Moon Island to MLJB course. Use the range as the center point of the down-bound track. Establish the up-bound track roughly 300 feet north of and parallel to the down-bound track. The two tracks converge at Point Aux Frenes turn. (See Figures 3.34 through 3.37 above.)

Point Aux Frenes to Lime Island – Doublewide track. Establishing a single doublewide track between these two points can save a lot of time. The extra wide channel has a very slight course change just about abeam of Round Island. **(No picture available at this time)**

Lime Island to Sweets Point – Two-way tracks. (See Figure 3.33 above.)

MLJB to Winter Point turn – Single track. Center track on range.

Winter Point turn to Johnson Point (LCA course 9) – Single track. Center main track on deep-water range. (See Figure 3.39.) Relief track – There is a great potential for brash to move into this course as it bends around Johnson Point. The best way to create a relief for this track is to make a single pass starting at Winter Point turn all the way up to buoy "18" following the Johnson Point shallow-water range. Make the pass ahead of an up-bound 1000-ft vessel. The displacement of the 1000-ft vessel will move the heavy brash over into the relief area that is created. CAUTION: Be sure the main track on the deep-water range is fully groomed and ready for transit. If it is not the low pressure from the relief track will pull the 1000-ft vessel off the range. Center of main ice track should be cut right on deep-water ranges.

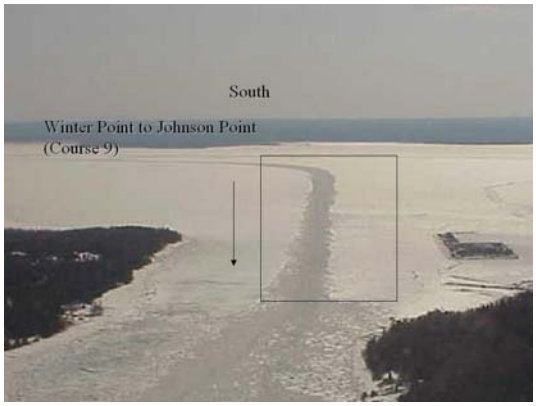


Figure 3.39. Approach to Johnson Pt with relief track.

Hardwood/Dark Hole (LCA course 7) – Single track. Medium brash accumulation in this course. Main ice track cut right on deep-water ranges. Center of main ice track should be cut right on deep-water ranges. (See Figure 3.40.)

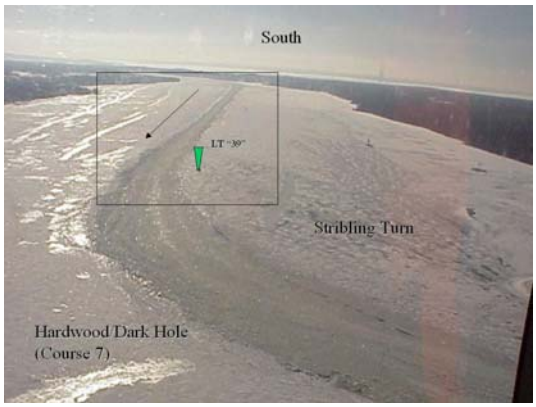


Figure 3.40. Dark Hole to Stribling.

Stribling (LCA course 6) – Single track. Heavy brash accumulation in this area. Free ice from Hay Lake moves into course. An intact "ice dam" between Lt "62" and Lt "58" helps decrease ice flow. Make every effort to maintain this area intact for as long as possible. Center of main ice track cut right on deep-water ranges. (See Figures 3.41 and 3.42.) Relief track – Much like Johnson Point, start at Lt "58" and follow the shallow-water range into Stribling Turn. Do this ahead of an up-bound 1000-ft vessel; the vessel's displacement will move the brash out of the channel. There are a couple of other factors to consider for this area in particular. If there is ice moving into the area from Hay Lake you may be just making a bad situation worse. Also if there will be another up-bound transit following the 1000-ft vessel the next vessel in line will simply disturb the track and pull the brash back into the channel. This move is best timed with one single transit with weather conditions that may freeze the brash out of the channel.

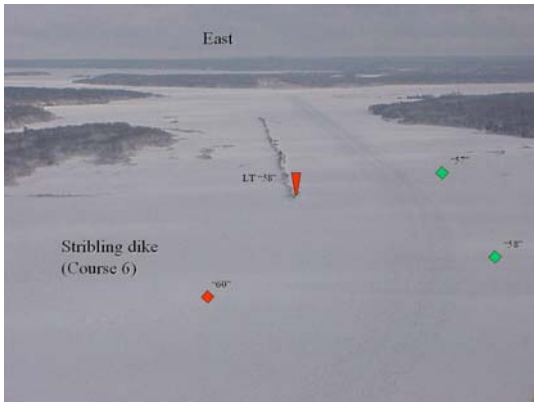


Figure 3.41. Course 6 prior to grooming.

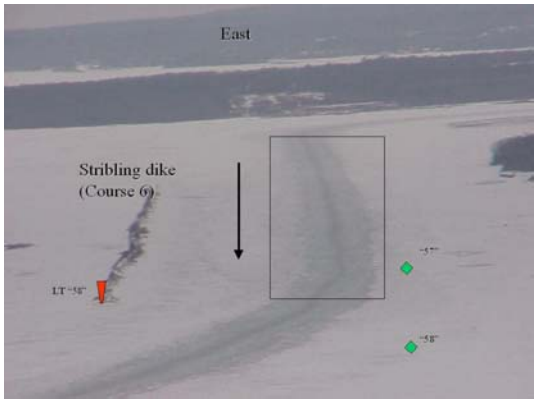


Figure 3.42. Course 6 groomed.

Lt "62" to 9 Mile Point – Single track. Very delicate area, subject to wake, wind and vessel displacement damage. All broken plate in this course will float down into Stribling dike choke point. Center of main ice track should be cut right on deep-water ranges. **(No picture available at this time)**

3.2.2.h Ferry Crossings

Sugar Island Ferry – This ferry services the nearly 300 winter Sugar Island residents, every 15 minutes, seven days a week. The key to this crossing is to ensure the ferry has an adequate crossing lane free from ice. Normally an ice bridge will form naturally just above Mission Point with the right combination of cold air temperatures and light winds, this ice bridge combined with the high current will provide an open pool of water. Also, an Ice Boom is deployed above the crossing to deflect and hold ice. If the Ice Bridge doesn't form or the ice is too much for the Ice Boom, ice flowing over the Soo rapids will quickly stack up below the ferry and backup to obstruct the ferry's crossing. If this occurs, be

prepared to render assistance to the ferry. Assistance may be provided in two stages. First use the ship to perform "race track" maneuvers below the ferry crossing. By using this pattern and ensuring the cutter's wake reaches the shore the broken plate will flow down with the current and away from the crossing. To "drop" the ice below the crossing, running close to each shoreline to past Lights "95/96", then soften the middle plates so that the entire ice field will move down Little Rapids Cut with the current. As little as 200 yards of open water below the ferry will allow for a safe transit. The next stage would be to use the ship (low power) to cut a large intact ice plate from Soo harbor, above the ferry crossing. Locate a sizable intact plate above the ferry crossing in Sault Harbor. Using slow speed carefully carve off a large plate that will float down and wedge across the main channel from the Little Rapids ice-boom to the Western shore of Mission Point. The man-made Ice Bridge should prevent further ice build-up endangering the ferry crossing. If plate thickness is less than 4 inches this may not work due to the weakness of the plate. In the event the plate must be maneuvered through, create a dogleg track pattern with the cutter. This will prevent brash from flowing through a straight-line track and again building up on the Sugar Island Ferry crossing. The best way to manage this ferry is to ensure that an Ice Bridge is formed and take a preventative posture, work the ice below the ferry at every opportunity. You never know when the weather will turn bitter cold and back up the cut.

Neebish Island Ferry – The biggest danger for this ferry is the back up of broken plate that floats through the Rock Cut. The best approach is prevention; keep vessel wakes in check above the crossing. The more plate that is broken on the Oak Ridge Range, the more ice that will float into the Rock Cut. Regardless of the care taken to prevent breakage there will always be certain amounts of ice that will move on the current. The ice will begin to stack up at the lower dams and if not kept moving will quickly reach the ferry crossing. Take every opportunity to break the larger plates within the Rock Cut. The thought here is to make smaller pieces that may move past the lower dam and into Sawmill turn where they are more easily managed. It may be necessary to work the lower area up to and above Lights "28" and "27" need to get the jammed ice moving through the dam area. The ice jam here can often be almost as deep as the channel. Watch for vessel sheering (swerving) to the walls if high-speed passes are used. Beware of wake damage to the sides of the Rock Cut, water thrown into the rock crevasses will freeze and cause significant damage to the structure.

Drummond Island Ferry – The Drummond Island ferries are very "ice worthy" and can move through significant amounts on their own. Biggest concern with the Drummond Island Ferry is the movement of large amounts of ice into their crossing while conducting flushing operations. Strong Westerly winds will move broken plate directly onto their island side landings.

3.2.2.i Escorts (Single and Tandem)

Escorts are the most efficient, time saving, ice wise means of performing the mission. Conducting escorts breaks ice for a purpose. The distance from the escorted vessel is dependent on the severity of the ice conditions and the weather. Generally, when performing escort service try to work about one hour ahead of the escorted vessel. By working ahead the icebreaker is provided ample time to groom a turn and exit toward the next turn prior to the escorted vessel's arrival. This also keeps you within easy turn-a-round distance to render assistance if the vessel gets into trouble. A primary benefit of this method is that it keeps the mariner moving, rather having them stop and wait for you to finish working a turn. The strongest factor that affects the lead-time for escorts is the weather. Cold temperatures may quickly freeze the work just completed creating the need for shorter distance in front of the escorted vessel in order to keep the track fresh. Mild temperatures may provide for a longer lead, even to the point of working a section of the river, and then leaving it before the vessel arrives.

Extremely cold temperatures may dictate close aboard escort. In these conditions the icebreaker may have to perform direct assistance to the freighter while moving through a turn. Close aboard escort is essentially station keeping on the vessel during the turn and using the icebreaker to create low-pressure areas in the ice field. The most critical thing to understand in performing this type of assistance is recognizing the pivot point on the freighter. The idea is to create these low-pressure areas just aft and just forward of the pivot point on opposite sides of the ship. These areas essentially create a moving Stern Relief Area and Bow Relief Area as the vessel makes the turn. Whether relieving pressure build up near the stern, or guiding around the bow, it is important that the icebreaker keep station just forward of the desired low-pressure area. Keep in mind that this assistance is performed employing very slow speeds by the freighter, and good communications with the commercial vessel master is vital to safe operations.

This close in assistance is ideal for two-vessel escorts (illustrated below), but may be performed alone. If performing alone, loosen the Bow Relief Area then take station on the vessel's quarter and ride around the corner with it. Judicial use of the Azipods canted outbound during this maneuver should create a significant weak area for the escorted vessel's stern to slide into. Several key factors here: Try to remain even or forward of the vessel's Plimsol marks for as much of the maneuver as possible. The vessel's stern is swinging, but if you are forward of amidships, it cannot swing into you. Plan your "bail out". Eventually, you have to get out of the vessel's way, either forward past the bow or back past the stern. The ice pressure may get so great that going ahead past the bow is not possible. Remember the vessel's stern will be swinging toward you as you back out so do not be hesitant.

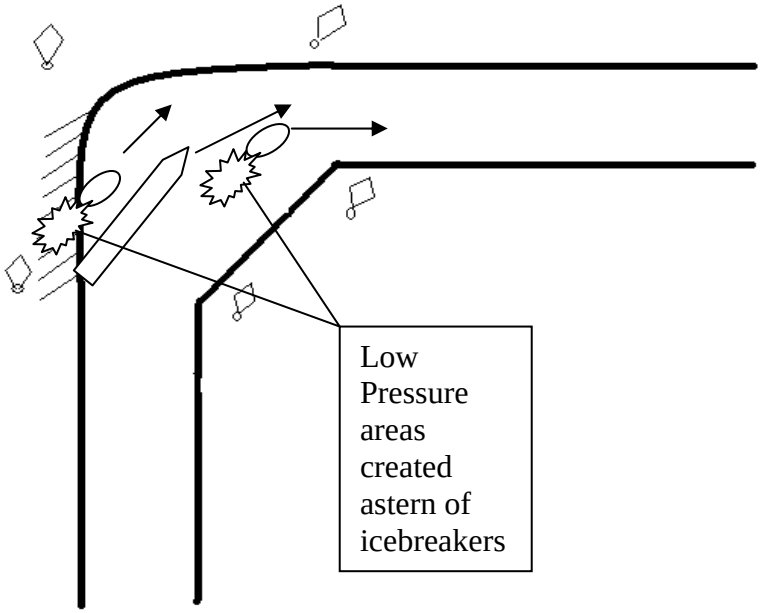


Figure 3.43. Escort in a turn.

3.2.3 Upper St. Mary's River

The upper St. Mary's River, like the lower river, is easily subject to freeze-up during most winters. This segment of the St. Mary's River, for icebreaking considerations also includes all of Whitefish Bay. Because of the stability of the ice fields and the open areas for navigation, generally the upper St. Mary's River presents little problem prior to lock closure. It is a major area of concern though for Spring Breakout. The ice has grown undisturbed for the majority of the winter and has been recorded in excess of 48 inches in some locations with significant windrows. In the winter of 1995-1996 for example, ice thickness was 48 inches from Lt "26" to Whitefish Point and gradually thinning to the ice edge 30 NM further to the NW.

All the techniques and methods discussed in working with the lower St. Mary's River will also apply when working the upper river. Some additional details have been added for dealing with windrows.

The upper river breaks down into two distinct sections; from the Locks to Gros Cap and Gros Cap to the upper ice edge, which can often be beyond Whitefish Point.

3.2.3.a Locks to Gros Cap Light

The upper St. Mary's River from the locks to Gros Cap Light can be categorized as a very wide channel, easily capable of handling two-way traffic, and hemmed in on both sides by shoals and shallows. This is the primary meeting area for both up and down-bound vessels transiting above the locks. Unlike the lower St. Mary's River there are few places for ice to be flushed during Spring Breakout. As a result, ice management above the locks is critical to reducing the amount of ice that builds up at the lock gates on the upper end of the Poe and MacArthur Locks.

At the beginning of Spring Breakout, it is typical to find an unbroken field of ice awaiting the first icebreaker through the locks. Upon exiting the locks, use very slow speed with Azipods canted outboard sufficient to open the ice from the north wall out to about 120 feet. There is a "dip" in the north wall that begins a few hundred feet out from the lock gates and extends west almost to the railroad bridge. The 1000-footers will typically ride their bow along this area, slightly canted away at the stern. As the "dip" ends, the bow will be forced out centering the ship for its entry into the locks. If the track is not wide enough, they will not be able to push ahead into the locks. Too wide, and there will be too much brash ice in the way to get into the locks. Keep the south side of the track as smooth and straight as possible up to the railroad bridge, and then angle slightly away until the end of the north wall. As the season progresses, it will be necessary to break up the ice between the north and south walls. Successive passes rather than wake breaking should be used when the COE decides this is necessary. The COE will try to draw ice into the locks by opening the gates slightly before the lock is full. They are trying to draw in enough ice to fill the lock. This ice will then be "locked down". The lower gates will be opened before levels are equalized and water will be allowed to flow out of the locks from above. This forces the ice out of the locks at the bottom end. You may be requested to break up the brash ice near the lock gates to facilitate flushing operations. The Azipod design should be ideal for this type of operation. With stern toward the locks, sweeping with first the starboard then port pod while opposing with the other pod should allow you to maintain position while flushing ice into the locks. Be careful of the pipe rail fencing around the perimeter of the walls and gates, any overhang can cause you to bend these rails over.

The plate ice attached to shore between the locks and Point Louise is relatively stable in the early part of Spring Breakout. Above Point Louise however, the ice on the Eastern Shore can be very fragile and has a tendency to break away from the shore. This plate will slide south across the Brush Point Course leading to many hours of making big ice into little ice and adding to the amount of brash ice that has to be flushed through the locks. It is prudent to keep wake damage to a minimum in this area until the plate breaks loose. Wake breaking then may be effective at breaking up the north plate.

The most efficient means of maintaining traffic flow in the upper river, is to establish a single doublewide track between the locks and Lt “26”. The track should be centered on the Range Lights. Either “head” of “over the shoulder” ranges mark all but the short Point Louise Channel and turn. Much like the Lime Island turn described earlier, the Lt “26” turn has a traffic buoy marking the separation area. The majority of vessel transits will cut to the inside of this turn staying close on the “red” side of the channel. Cut the south and east sides in a long gradual turn. Open the inside of the turn sufficiently to provide a bow relief area. Between Light “26” and Gros Cap Light, the Birch Point Course, widen the track to 500 ft centered on the Bitch Point Range. This will be used as a staging area for vessels awaiting downbound transit and will be a much safer place to “hove too” than in the channel below Lt “26”. As long as there is room here, vessels will not have to go to the walls at the locks, which will keep the plate ice there intact longer.

3.2.3.b Gros Cap Light to the Upper Ice Edge

Whitefish Bay is a relatively large, open body of water. The exposure to wind and the distant landmasses make this area very unstable and subject to shifting plates. Windrows can form almost anywhere in the Bay, but typically they can be found at Gros Cap Lt, running to the SW from the shore at Ile Parisienne Light and near Whitefish Point.

Just abeam of Gros Cap Light the LCA track lines separate into up and down bound courses. Three methods have been employed to establish ice tracks in this area. Which method to use will depend on the ice thickness. During mild winters, establish and maintain a single track following the separate LCA lines. There are three LCA lines but just use the 138¾° and 328° courses. With stable ice plates and mild temperatures the tracks will be easy for the Lakers to find and follow. During heavy winters an alternate approach must be taken. If ice conditions exceed the ability to maintain separate tracks that follow the LCA’s, two-way tracks can still be established. Two-way tracks may be easier to maintain if they lie in close proximity. Using the down-bound LCA as a base line, establish a second ice track to the west with approximately 400 ft of separation. The second track should run parallel to the down-bound LCA. The added benefit of having the tracks close together is it makes it easy for the ship captains to find them at the upper ice edge. During extreme conditions a singlewide two-way track may be the only alternative. This will allow for meetings along the track and be wide enough so there is room for the transiting vessel to push the excess ice out of its own way. Do not expect these tracks to exist for any length of time. The prevailing NW winds will have little effect on the track but a shift to any other direction will quickly have all the plates in Whitefish Bay moving.

In those areas where significant windrows are encountered, be prepared to spend a longer period of time in preparation work. In order for the large vessels to transit though these areas, you will need to open the track to almost twice the width of the rest of the track angling out 4 or 5 ship lengths before and

after the windrow. This will spread the ice in the windrow out and allow room for it to be shoved aside as the Lakers push through.

3.2.4 Duluth

Duluth/Superior, like all the other harbors in Lake Superior will freeze up during the winter. Ice thickness in the harbor will depend on the severity of the winter. Most years, the ice in the harbor is manageable until lock closure finishes the shipping season. In the winter of 1994-95 it was necessary for heavy icebreaking assistance to work in the harbor to clear the last of the down-bound vessels. This is a very rare occurrence.

The approaches to Duluth/Superior Harbor generally present little difficulty prior to lock closure. During the months of January and February, the area from Duluth to the Apostle Island may freeze over but this ice does not last long. The difficulty comes when a NE wind breaks up and compacts this field of ice into the approaches to Duluth Harbor. Refrozen brash ice may extend out as far as 5 to 7 NM from the harbor entrance and be several feet thick.

3.2.4.a Duluth/Superior Harbor Approaches

For the Duluth Harbor, it may be necessary to establish a track to the harbor entrance. Start at the ice edge and use the 248 ¼° up-bound LCA for this purpose. For the Superior Harbor entrance, establish the track on the 045 ¼° down-bound LCA. The advantage here is that the two tracks converge off Duluth making them easier for the Lakers to find. More often than not the track will not remain for any length of time and direct assistance to transiting vessels may be necessary.

3.2.4.b Duluth/Superior Harbor

At Spring Breakout, heavy icebreaking may be necessary to open the harbor so Lakers can move to their loading facilities. If this occurs, it must be done several days to a week in advance of lock opening. Chapter Four has a section devoted to harbor and facility ice clearance that will work particularly well in this harbor. Enter the harbor through the Duluth entrance breaking out a track leaving the Safe Water Morse “A” buoy to starboard. Continue SE to the East Gate of the North Basin. Widen out from the pier toward the buoy line and open any piers and facilities in this area as required. Continue SE to the Superior Harbor Basin leaving a doublewide track between the two basins. Open any piers and facilities in this area as required. Depart Duluth/Superior Harbor through the Superior Entrance. Widen the track through this entrance sufficiently for vessels to transit unassisted. Then follow the down-bound LCA back to your entry track or the ice edge. Note: There have been several years where the ice jams in the Superior Harbor Entrance have been so severe as to make this area un-passable even to heavy icebreakers. If this happens, widen all the tracks in the harbor so all traffic can use the Duluth Entrance.

3.2.5 Straits of Mackinac

The Straits of Mackinac, for the purposes of icebreaking, is considered to be from the eastern ice edge, generally in Lake Huron, through Round Island Passage then west into Lake Michigan to the western ice edge, near or beyond Lansing Shoals. This is a distance of about 35 NM. This region is characterized as a relatively narrow waterway (about 5 NM at its widest) surrounded by islands and shoals. With prevailing NW winds, any ice that develops in the Straits can easily move in a moderate wind.

Ice formation in this area is typically slow. The region will generally remain open enough for vessel transits until lock closing in mid-January. At about this time, Grey's Reef Passage near White Shoals Light will be closed and all traffic will be from or to the Lansing Shoals area. As the season continues, field ice will develop west and east from the Mackinaw Bridge and become relatively stable from East of Round Island Passage to White Shoals Light. West of White Shoals Light to Lansing Shoals, plates will easily shift and frequent windrows will be encountered. Vessels trapped in a drifting floe anywhere in this area can be easily carried aground. For that reason an icebreaker is kept available during vessel transits. Fortunately, few vessels make this voyage during the period from mid-January until just before lock opening. The tug Michigan with its ice-reinforced barge, Great Lakes, frequently makes this run during the winter months bringing fuel to Cheboygan.

The South Channel between Poe Reef and the Mackinaw Bridge will be closed to vessel transits as soon as ice forms across to Bois Blanc Island. An ice bridge is established to the Island as soon as ice reaches a safe thickness. For this reason, plan additional transit time to go around Bois Blanc Island when heading for the Straits operating area.

3.2.5.a Straits of Mackinaw Track Preparation

Track preparation through the quasi-stable plate ice in the Straits is fairly straightforward. Start on the 090 °T LCA at the eastern ice edge, which is generally North of Bois Blank Island. Follow the charted LCA's westbound track through Round Island Passage and under the center span of the Mackinaw Bridge. Follow the 277 ½ °T upbound LCA track to Lansing Shoals then the 241 °T LCA to the ice edge. Ice fields may be unstable west of White Shoals making any attempt to establish a track through this area a wasted effort. Like the lower St. Mary's River, keep the track widths to just sufficient to allow vessel passage. Keep all turns gradual and open them slightly wider to allow for easy transit.

In areas of windrowing, open the track slightly wider to allow the ice to spread out and be pushed aside as vessel transits. It may be impossible to maintain a nice straight track through windrowed areas. Make all course changes as gradual as possible.

3.2.5.b Vessel Transits

Prior planning for vessel transits is a must. It may have been several days to several weeks since the last icebreaker transited this area. Wind and weather conditions could have closed or obliterated all previous tracks. In anticipation of a scheduled transit, it may be advisable to use an ice reconnaissance flight to assess conditions in the Straits. Set a sailing time that will allow for transit around Bois Blank Island. Explore operating out of St. Ignace or Mackinaw City as a method to shorten transit time. Plan the methods to be employed in preparing tracks and assisting the transiting vessel.

Like the lower St. Mary's River, there are several methods that work effectively with transiting vessels. If a stable ice field exists and the vessel in need of escort is arriving at the western end, typically with fuel deliveries, plan to work the track the day before the vessel's arrival. This will give you plenty of time to establish the track and work out any windrow issues. Meet the vessel at the western ice edge ensuring that they find the start of the track. Then work out one to two hours ahead of the vessel. If the vessel gets in trouble, you will be readily available to lend assistance. Plan your sailing time for the return transit to coincide with the vessel's schedule and work your way back from the eastern to western ice edges one to two hours ahead of the vessel.

If the ice field is not stable, such as commonly occurs west of White Shoals Light, prepare the stable ice tracks as above. Meet the vessel in the vicinity of Lansing Shoals or further west if necessary and escort it through to the start of the stable ice track. In this type of operation, you may be moving from plate ice through windrows and into open water between plates. Be very cautious of the vessels following distance. There is a great tendency for the vessel to close up on you as it crosses open water while you are entering the next ice field. Watch this closely and try to keep a minimum of 1500 yards between the two ships at all times. Once back in the stable ice, work out ahead one to two hours in front of the vessel.

As has happened in the past, you may have to assist a very underpowered vessel through the Straits. With the Azipod design this type of operation could work very smoothly. Always start with a prepared track even if you have to leave the vessel and work out an hour or so in front then return. Through the already broken track proceed ahead of the escorted vessel with Azipods canted outboard to leave as much of a clear track as possible for the vessel to follow. Stay as far ahead as you can as long as the vessel can follow your open track without becoming beset. Be prepared to move quickly ahead if the distance to the escorted vessel starts to close.

3.2.6 Green Bay/Escanaba

Green Bay is a long, relatively narrow body of water that runs from the city of Green Bay on the southern end to the Bays de Noch at the northern end. Depending on the severity of the winter, moderate to thick ice can form, covering the bay from shore to shore. Little windrowing forms in this bay. The ice thickness and lack of windrowing makes the area quite suitable for ice fishing. Large "cities" of ice

fishing shanties can be found throughout the area with the largest concentrations south of Sherwood Pt and in the Escanaba area. Cars, trucks and snowmobiles are the principal method of reaching these fishing shanties. In addition, in heavy ice years it is not uncommon for the bay to be used as a short cut to and from the Door Peninsula.

Limited heavy icebreaking is required in Green Bay and usually none until just before spring breakout. Both Escanaba and Sturgeon Bay are used extensively as lay-up ports during the winter. It is sometimes necessary to clear these ports to get the Lakers started in the spring. Local icebreakers and a WTGB are normally sufficient for this operation. In extreme ice years, it may be necessary for a heavy icebreaker to open tracks into this bay.

3.2.6.a Green Bay Track Preparation

Entry into Green Bay is made along the LCA through Rock Island Passage. The prevailing winds tend to keep most of this passage clear of ice until near Boyer Bluff on Washington Island.

For Sturgeon Bay, lay a track along the LCA from Boyer Bluff southwest past Whaleback Shoal and west of Chambers Island. Continue following the LCA south-southwest toward Green Island. At Green Island the track can be set direct to the entrance buoy at Sturgeon Bay. On the return leg to Boyer Bluff, widen the track. In the areas where windrows are encountered, widen them sufficiently to ease transit through the windrow. This should give the local icebreaking resources a sufficient start to be able to assist the Lakers out of Sturgeon Bay.

For Escanaba, lay the track along the LCA north from Boyer Bluff to Minneapolis Shoal, and then widen the track on the return transit to Boyer Bluff. Avoid going north of Minneapolis Shoal due to concerns with ice fishing and local commercial icebreaking assistance. Also, avoid the temptation to cut the corner at Boyer Bluff to the Rock Island Passage LCA too soon. This will cut loosen a wedge of ice that can easily move with the wind blocking the track. It may be necessary to break up a turn area where these LCA's meet. Continue widening the track to the ice edge on the outbound transit track.

As with all the other tracks established throughout the system, keep all turns gradual. Green Bay has plenty of room for this.

3.2.7 St. Claire River

The St. Clair River is a narrow, fast flowing body of water that connects Lake Huron to Lake St. Clair. The current is such that little ice actually forms in the river itself. A natural ice bridge tends to form early in the year at the south end of Lake Huron and blocks ice from flowing into the St. Clair River. A strong north or northeast wind can however break this bridge and allow large amounts of brash ice to flow in with the river current. When this situation occurs, ice will jam at the lower end of the river starting in the area of the St. Clair Cutoff and St. Clair Flats Channels and filling the river northward to

above Michigan City. Ice tends to flow down the St. Clair North Channel until an ice bridge forms above the Harsens Island Ferry and then the ice flows primarily down the South Channel. Once the ice reaches Seaway Island the natural flow of water is up and around Seaway Island through the South Channel. The St. Clair Cutoff Channel will remain stable. The lower end of the river can become so filled with ice that it will jam the full depth of the river and cause flooding upstream of the jam. Lakers have on occasion been turned beam too the current and pressed against the ice jam further worsening the condition.

An interesting phenomenon occurs in the St. Claire River when ice begins to jam. A stable field of ice will form out from the shore and into the channel while ice further out tends to continue flowing with the river current. This creates a shear line in the ice, which can trap transiting vessels.

3.2.7.a St. Claire River Icebreaking

By far the best way to deal with ice jams in the St. Clair River is to do it without vessel traffic present. Vessels tend to get trapped in the ice and can be swept away when the ice jam gives way. If vessels are present in this part of the river they have to be cleared first. Avoid breaking any ice jams or over using wake breaking as this can destabilize the ice jam. This occurred in the 1995 to ’96 icebreaking season and resulted in a Laker being swept sidewise down the North Channel at Algonac.

Down-bound vessels are the easiest to deal with; they are not fighting the ice and the current at the same time. Clear them first. Usually this can be done by opening a track in the brash ice just ahead of the bow of the vessel. Once they are moving, just staying ahead of them will keep them going. Once the vessel reaches the St. Clair Cut-off Channel, they will be out of danger from the river current.

Up-bound vessels are much harder to deal with. They are fighting both the ice and the current. It will be much harder to get them moving once stopped. One method is to clear brash ice from one side of the vessel with a slow pass then return with a quicker pass down the other side swinging in front of the bow on the second pass and having the vessel come ahead. Keeping just ahead of the vessel will keep the brash from coming back in on its bow. The Azipods may be helpful in pushing brash further out by canting them outboard. Avoid getting an up-bound vessel near a shear zone, its bow will swing right to the shear line and the pressure of ice on the bow will stop the vessel, making it very difficult to get the vessel back out into the main flow of the river.

Once vessels have been cleared from this stretch of the river, it will be much easier to clear the ice jams. Work below the jam to get the ice there moving down into Lake St. Clair. The locations of any ice jams will become readily apparent. Work in and through the jam heading up current. If the jam gives way too quickly, you will have much more control going into the current. Avoid working near the edges of the jam, near the shear zone. It is easily possible to get pinned there between the moving and stationary ice and it is very difficult to get out of the shear. The Azipods may give more control here and increase the ability to force the bow out of the shear zone. Several passes through the jam may be

necessary to get it moving. In heavier ice jams, having a WTBG run up river near the shear zone tends to free up the ice flow and allows movement down river. Have the WTBG start down near Southeast Bend and run the edges of the channel up river to free up the significant portions of ice in the channel. This ice will flow down river around Southeast Bend and above Seaway Island. Avoid waking the jam going down-bound. A sudden release of the jam in the narrow part of the river could take you with it.

Once the jams have been cleared, just transiting from the St. Clair Cutoff Channel to the northern ice edge and back again should keep it moving.

3.2.7.b Freeing Trapped Vessels

Lakers that have been turned beam too the current are a fairly rare occurrence in the St. Clair River. Freeing them from this condition can be difficult. The tendency when one of these situation occurs is for the vessel to get beam too the current and be swept down until they either reach an ice jam or push enough ice along the side of the vessel to create their own ice jam. As with working ice jams above, begin by working up current from below the vessel to get a sense of how badly they are trapped and what the ice conditions alongside are like. If the vessel was heading up-bound, start near the stern. If the vessel is heading down-bound, start at the bow. The idea is to use the jammed ice as a pivot to swing the ship in the direction it needs to go. Work carefully to avoid getting too much ice moving. If a second icebreaker is available they can work at the opposite end of the vessel on the upstream side trying to create relief for either the bow or stern to swing. Once the vessel has been turned into proper alignment with the channel, it can be worked like any other down or up-bound vessel.

Always maintain a sense of where the current is moving. For example, at the northern end of Marine City the current swings out over the shoal and toward the East Side of Fawn Island. This can cause a vessel to slide east out of the channel and toward the shoal if it is not properly aligned and moving down-bound.

3.2.8 Lake St. Clair

Lake St. Clair is fed by the St. Clair River and empties into the Detroit River. The current in the lake normally follows with the channel near the upper or lower reaches of the lake. The average thickness is 8 inches and an average maximum thickness of 14 inches, with some rafting and ridging in the channel do to the number of transits and shifting ice. It is difficult to maintain a substantial track in this area due to shifting plates. The most significant event occurs when a strong westerly or southeasterly wind creates significant pressure on the plates and forces them perpendicular to the channel line. This can cause two issues. First, and more manageable, is the closing of your track behind you. The second issue, and more hazardous, is when the shifting plate causes your track to move across the channel before the vessel you are escorting has a chance to transit through the area. The hazard comes if the vessel gets

slowed down or stuck. The pressure from the wind on the ice can cause the vessel to get pushed aground. To prevent this either delay the escort or keep the vessel close behind. It does not take thick ice to push a Laker sideways.

3.2.9 Detroit River

The Detroit River connects Lake St. Clair with Lake Erie. Like the St. Clair River, it fast moving at the upper end. As the river nears its confluence with Lake Erie, the current slows and ice forms in the shallows. Not as much brash ice flows down this part of the river except when tracks are opened and in use through Lake St. Clair. Ice jams can form in the lower end of the river near the Livingstone and Amherstburg Channels when brash ice is flowing into the system, especially with any component of a southerly wind. Prevailing westerly winds and moderating temperature conditions usually clear this portion of the river by early to mid March. There is little need for heavy icebreaking in this area.

It may be necessary to transit this area between lock closing and opening. The Amherstburg Channel is closed to commercial traffic during the winter. The Livingstone Channel is one-way traffic only but used for both down-bound and up-bound transits. Follow Sarnia Traffic Control winter regulations for check-in information during this time of year. Check-in an hour prior to entering the Livingston Channel up-bound or down-bound in the winter. When transiting the upper Livingston Channel the vessel's wake should be checked to preserve the ice edges and the ice bridge that forms on the upper Amherstburg Channel.

3.2.10 Lake Erie

The shallowest of the lakes, Lake Erie freezes rapidly and the Western Basin freezes fast almost every year. The average thickness is 7 inches and an average maximum thickness of 11 inches, with some rafting and ridging near South Passage and Pelee Island. The channel into Toledo is not usually a problem but it is difficult to keep open during the winter due to shifting plates. The Aids to Navigation in the entire Western Basin tend to shift with the moving plate in this unstable ice environment and can pose hazards to navigation. If possible, place aids back on station but use caution because the mooring chain tends to have significant wear in the area as well.

If a quick thaw occurs, flooding has become a problem in Monroe, Huron, Vermilion and Fairport due to ice jams that build during the spring breakup. The WTGBs have limited effect on most of these ports due to the constraint of their draft in the shallow rivers, however, if the thaw is anticipated preventive ice clearing in these areas has proved effective.

Typically, icebreaking on Lake Erie is handled by the WTGBs and Canadian icebreakers. However, when gale force winds pack ice into the southern Lake Erie ports of Ashtabula, Conneaut, and Fairport Harbor, it may be necessary for heavy icebreaking assistance to move coal between Canadian

ports and these U.S. ports. MACKINAW has been involved during the past. Weather conditions permitting, it should be possible for MACKINAW to clear the entrances to these southern harbor entrances by approaching the entrance stern to and using her Azipods to undermine the ice plug. If significant winds and traveling ice floes exist it may be best to await a change in weather conditions before attempting this maneuver. Another issue of concern is the possibility of shear zones at the mouth of the harbors. The ice will travel along the shear zone if the wind is in a direction which can create a perpendicular force. In gale force easterly or westerly winds, this can create a dangerous situation for any vessel trying to enter or exit the harbor as the ice shear will quickly put the vessel aground on the harbor entrance jetties.

CHAPTER FOUR

4. SHIPHANDLING TECHNIQUES USING AZIMUTHING PROPELLER UNITS

4.1 INTRODUCTION

This chapter is intended to provide basic operating guidance for conning officers using azimuthing propeller units (Azipod). As every shiphandling situation is different, this guide demonstrates Azipod positioning to achieve certain results; i.e., turns, backing, etc. The arrows (➡) shown in the following figures, indicate the direction of the thrust (prop wash) produced by the individual Azipod. It is not the intention to show the specific angle of the thrust or Azipod but rather to provide the operator with general guidance. Environmental conditions, i.e. wind, current, ice thickness or coverage, etc., will dictate the proper Azipod position, direction propeller rotation (forward or reverse) and power setting, and will be learned over time through trial and error.

The best description of how to learn to handle an icebreaker with Azipods is provided by the first Captain of the Finnish Icebreaker FENNICA:

> Maneuvering is easy. First thing a new operator has to realize is that he has to forget many things. I would not say that (shiphandling) experience has turned to "ballast", but very close to it. An easy way to learn is to imagine that you are "driving" a twin outboard motorboat with simple engine levers. A vessel can be turned around the bow or round the stern, and after a few trials it becomes more of a second nature. You cannot put all the important things into writing.[1]

[1] Icebreaker Fitted with Twin Azimuth Thrusters by FENNICA Master J. Kyröhonka.

In this discussion, it is assumed for general maneuvering and icebreaking maneuvers that the conning officer will control the Azipod units through a pair of control levers, known as TC-21 levers.

Figure 4.1 TC-21 Control Lever.

The convention used here is the one where the propellers forward rpm increases as the lever is pushed forward (green side), and the pod is rotated as the control lever is rotated. Thus, with the pods in tractor mode and directed forward along the ship's centerline, pushing the control levers forward will cause the ship to advance straight ahead. The rotating the levers to the port will turn the pods to port driving the stern to port, resulting in the ship turning to starboard. Finally, directing a pod "inboard" means that the pod's propeller is directed inboard, and if rotating with forward rpm, the prop wash will be outboard. MACKINAW's ABB drive system has two modes: "Power" and "Speed". When operating in the ice, the ship should be placed in "Power Mode", thereby allowing the plant to maintain a consistent amount of power when encountering varying degree of ice thickness and consistency. The selection of either "Power Mode" or "Speed Mode" is accomplished by selecting the feature on the ABB Drive Control Screen located in ECC. The Conning Officer can verify that the ship is in "Power Mode" by viewing "Propulsion Drive" selection screen on MPCMS. "Speed mode" is more like cruise control on a car; it tries to keep the propellers spinning at a set RPM, regardless of the power consumption. Just like meeting a hill with cruise control on, speed mode will apply more power to maintain speed when encountering resistance (ice). On the other hand, power mode uses a fixed amount of power, regardless of the resulting RPMs. This is like keeping the gas petal at the same position when going up a hill. Power mode is preferred for icebreaking because it results in more uniform power consumption from the

engineering plant standpoint. Manual operation is the most likely choice for maneuvering close aboard other vessels but not for straight transits. The possibility of and likelihood of deviations in heading will result in an uneven broken track edge.

4.2 OPERATING AHEAD IN LEVEL ICE

Proceeding continuously ahead in level ice is a most common scenario for Great Lakes icebreaking and level icebreaking occurs throughout the winter both prior to and after the Soo Locks closure. The strategy differs in the fall as most track establishment and maintenance is done in level ice, conservatively keeping wakes and broken ice just wide enough to permit the transit of the assisted vessel or within the minimal confines of the channel being worked. This is common practice due to prevailing cold temperatures and "icemaking" conditions. In the spring, as temperatures rise, more judicious use of the cutter's wake is the norm to facilitate flushing and large floe break-up. In the spring the level ice is an average maximum thickness of 22 inches[2]. The actual ice thickness varies due to the severity of the winter, currents, wind, and snow cover.

To facilitate two-way traffic in areas such as Whitefish Bay, in the Upper St. Mary's River (Lake Superior) the level ice is fast (shore to shore), where an open track of about 500 to 600 ft is established between the southwest locks approaches to the upper buoy line at Point Iroquois marked by Gros Cap Reefs Light. From Gros Cap Reefs Light to the ice edge the track should be established to approximately 800 ft wide is made along the navigational track for a distance of approximately 40 to 60 miles (from the Soo Locks to open water on Lake Superior). Level ice is also found in the bay of Green Bay and in Lower St. Mary's River from Detour to the Soo.

MACKINAW has been constructed to operate at a continuous speed of 3 knots in solid level ice up to a thickness of 32 inches.

In level icebreaking, while attempting to break a straight channel, the position of the Azipods remains relatively steady with the thrust leading directly astern. Auto-pilot, with Auto-yaw enabled is a reliable way to lay in straight track in level ice for the initial cut. In uneven ice the operator using the joystick, with Auto-Yaw disengaged, may have greater success in laying straight track. This method also holds true for many level ice scenarios. For more accurate and quantifiable speed/power control, the throttles should be controlled with active levers (TC-21). In most cases, the default gain setting will result in superior performance. However, just as in open water, the various gain aspects can be tuned to enable better performance. Additionally, "synchronous" steering should be selected to provide symmetrical thrust. It should also be noted that following in Auto-track (or remote control from an

[2] U.S. Department of Commerce (NOAA), U.S. Coast Pilot #6, 27th Edition, dtd 9/28/96.

ECDIS) will require additional tuning of the DP Auto-pilot gain to result in satisfactory performance with the added "importance" of the ship's transverse deviation for the track.

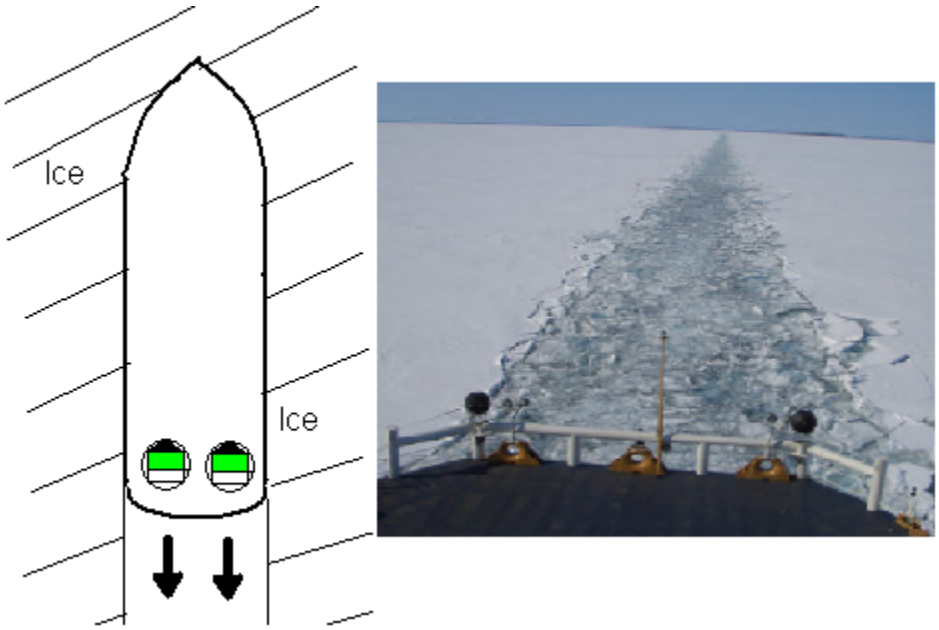


Figure 4.2. Straight track ahead.

A clean straight channel can be developed by positioning the Azipods slightly inboard (thrust outboard) to enhance steering control and provide for a more "ice free" track. This is similar to the "manual fix" thruster allocation in DP (without using a bow thruster to hold a heading). Steering is accomplished by making small incremental changes to the Azipod orientation. Once the conning officer develops a feel for the ice conditions, one Azipod (generally the outboard unit along the ice edge) is left alone and heading changes are made by small adjustments to the other unit.

You will observe during this operation that the thrust of the Azipods push the newly broken ice out of the cut channel under the fast ice along the channel edge. A straight channel is the goal and any areas where the cutter moved out of the channel will need to be straightened by scarfing off the edges of the channel.

It should be noted that selecting the proper level of thrust (instead of power setting) is critical to a smooth operation and the power setting is directly relative to the ice thickness. A desired speed for making the first cut is 3 to 4 knots….a slow steady speed (approximately 80% power) which will provide the conning officer sufficient time to respond to environmental changes, i.e. ice thickness, wind, current, etc. Too much power will result in too much speed and a wider than desired channel with an uneven track edge. Excessive power or speed will, in addition to negatively impacting fuel usage, result in the

cutter's wake breaking additional ice along the channel edge. A straight track edge is important in that it makes it easier for the moving ice in the channel to continue its passage downstream with the current. A scalloped channel edge will tend to collect brash ice and impede the flow of ice downstream.

To establish a track it is highly recommended that the initial cut be made using the methods listed previously and then work off of each edge (and wake) to widen the track. There may be cases in an ice filled channel where the channel edges are cut (outlined) first, before the ice between the two cuts is broken. In most scenarios, the cutter is easier to control and the ice channel edge may be straighter when the ice is broken in this recommended manner. Making both edge cuts defines the channel width and gives the conning office a good visual reference for breaking/clearing the remaining ice within the track.

The propellers on the Azipod units were designed to be operated in the "tractor" mode. The cutter could be operated with the Azipods rotated 180° and operated in the reverse mode, in open water only. This would still provide thrust directed astern, albeit at a loss of power and with less efficiency and exposing the pods to the ice (instead of the propellers). The cutter would also tend to mill more ice and the vibration will be more noticeable.

If operating in <u>heavy ice conditions</u> forward progress can be facilitated by turning the Azipod units a few degrees from one side to the other, and still maintain a reasonably straight track.

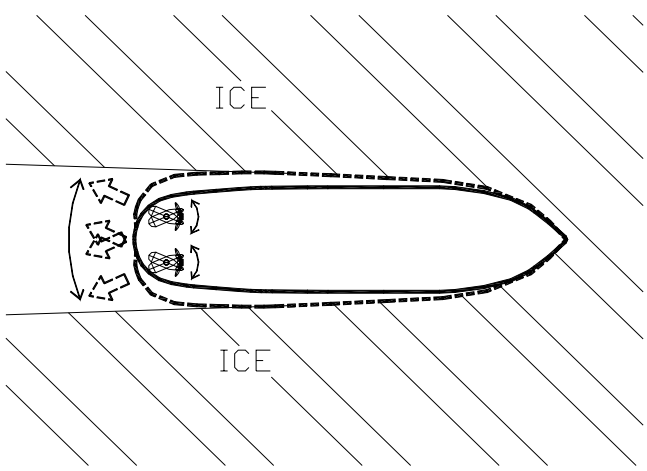


Figure 4.3. Ahead in heavy ice.

Auto-pilot can still be used to facilitate this maneuver, by simply disengaging Auto-yaw, the conning officer takes control of heading control at the joystick and can "sally" the pods. The action produces alternating heeling effect that helps loosen the ice.

4.3 OPERATING ASTERN IN LEVEL ICE

For backing, the preferred method is manual mode, with propellers facing aft. There are a number of situations where it is desirable to back the cutter in level ice, for example, to exit the exiting broken channel or maneuvering around a beset vessel. Consideration should always be given to the fact that backing in ice increases the risk by exposing the azimuthing propulsion units to impact with the ice. In most situations more ice will be milled and heavier hits on the Azipods will be taken, therefore, greater care much be taken when operating astern. Speeds are always slower moving astern though ice to avoid impact damage to the underwater propulsion gear. The propeller revolutions are not stopped in situations where the propulsion units are subject to high ice loads because the blades may experience high bending loads.

There are three basic Azipod set-up options for operating astern in level ice. Each option has a different impact on the efficiency of the operation and one option or another may be more beneficial in a particular environmental condition; i.e. current, wind, ice thickness or pressure.

First option: For the <u>most effective power</u> backing in level ice, rotate the Azipods 180° to the propellers astern position and apply power to the thrust level desired. If the vessel vibrates heavily when going astern, reduce thrust or give some counter streams with the other unit and this might reduce the vibration. Also, rotating the units a few degrees from one side to the other in heavy ice conditions can be efficiently used in heavy brash and windrows.

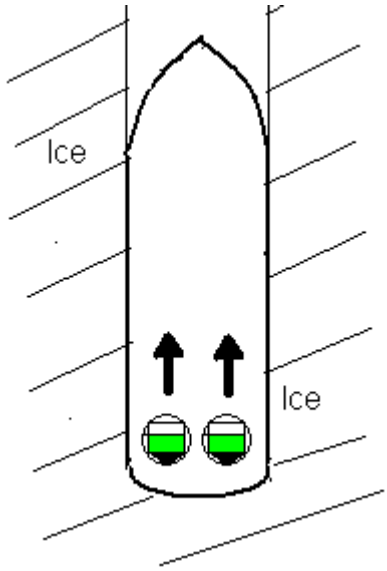


Figure 4.4. Astern in level ice.

Second option: To transition from headway to sternway, simply keep the Azipods in the same position but <u>reverse direction of the propellers</u>, from ahead thrust to astern. (See Figure 4.5.) This will

not give you as much power as rotating the Azipods but will be somewhat quicker and sufficiently effective for backing short distances. Adjust the power settings, equal levels on both units, for the desired speed through the ice. This is not the preferred option because it exposes the pod to the full force of the ice and incurs additional risk of pod damage due to torque on the units.

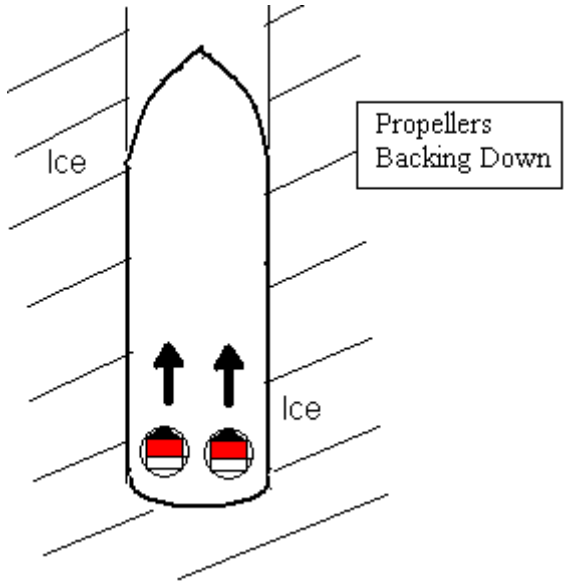


Figure 4.5. Astern by backing down.

Third option: May be necessary in heavier ice conditions, where one Azipod is rotated 180° and the other unit remains in the ahead thrusting position. Power is applied to the rotated unit in sufficient force to move the cutter astern, while the other unit is used to clear the broken ice (pushing the broken ice away). (See Figure 4.6.) In this example, the port unit thrust is 100% and the starboard unit set at approximately 80% thrust. The direction of the cutter is controlled by adjusting the rotated Azipod to port or starboard, which will also move more ice out of the path of the cutter. Power settings will be different for both units, with non- rotating unit operating at less power (not to offset the thrust of the unit providing the astern movement). This method is especially effective when backing into extremely heavy brash ice (in situations where backing with both pods facing astern is not effective.)

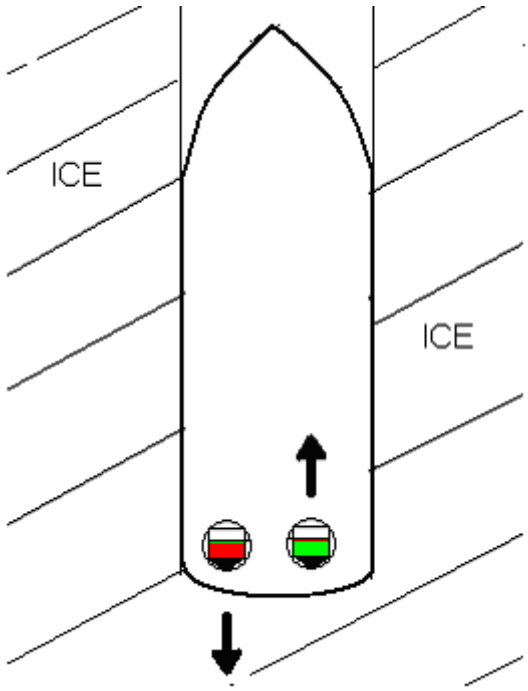


Figure 4.6. Astern in heavy ice with ice clearing.

A big difference compared to a conventional icebreaker is that the icebreaker with azimuthing propulsors can be fully steered when backing, providing the full range of operational maneuvers.

4.4 STOPPING

When operating in ice and navigational conditions permit, simply taking the power off the Azipods will allow the cutter to coast to a stop due to the fiction of the ice on the hull. Of course, this option does not apply to most operational scenarios and a more aggressive method for stopping must be employed.

The most common method of stopping the cutter when moving ahead in ice is reversing the rpm (not changing the pods position) and using the amount of power desired to stop the cutter in the required distance. This method is both safe and effective and probably the most commonly used method. While in Auto-pilot with Auto-yaw, the pods do not work to maintain heading once astern turns are demanded from TC-21 levers. If thrust is maintained at the DP joystick, an astern deflection of the joystick will result in the pods azimuthing oppositely (to port to correct a heading deviation to starboard). However, the pods have so much surface area that they act as rudders down to about 3 knots. Thus, in the example given, the heading would deviate further to starboard. The solution is to disable Auto-yaw, or to go to manual operation.

In an emergency situation, to implement a rapid stopping action, with the Azipod units in normal ahead position, reverse the propeller rotation from ahead to astern, rotate the Azipod units to outboard to the 90° position and apply full thrust. (See Figure 4.7.) This is the quickest method to stop the cutter; however, the risk for damaging the units is significantly increased due to excessive vibration and stress on the mechanical components.

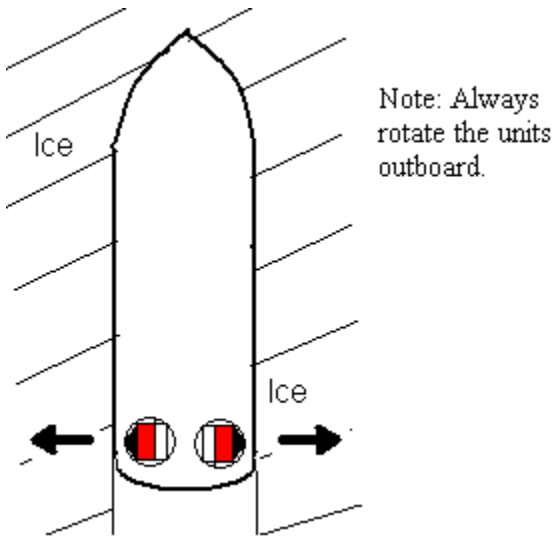


Figure 4.7. Emergency stop.

An alternative method for stopping is a "crash stop", which involves keeping the propellers in the ahead rpm mode and rotating the Azipod units 180 degrees. Always rotate the Azipod units with the propellers outboard…if rotated inboard the Azipod units will be competing for sufficient water supply and lose thrust, while creating unnecessary (possibly damaging) vibration.

The cutter will start slowing as the Azipod units are rotated through the full 180 degrees and the amount of power selected will determine the stopping distance. During this procedure some vibration will occur, dependent on the amount of thrust applied, but it is a safe maneuver. Also, it should be noted that there will be some impact on the ice as the Azipod units rotate, the force of the prop wash will move the ice close to the stern and if you are operating in close proximity to the ice channel edge you may negatively impact the edge (create some scalloping from the wash).

The Azipod manufacturer (ABB) provided the following guidance and recommendations regarding a "Crash Stop", with a suggested training scenario:

> The AZIPOD® units of the USCG Great Lakes Ice Breaker (GLIB) has been designed to withstand loads generated during ice breaking operation and loads that are generated during the open water operation. These loads include also the ones generated

during the Crash-Stop by rotating the units 180 degrees around the turning axis. However due to dynamic nature of the loads generated during the Crash-Stop it is somewhat clear that these loads are not beneficial for the product, even though it is not possible by any means to estimate how these loads affect the lifetime of different components located inside the units. Typically the real need to perform Crash-Stop for a vessel is extremely rare. Due to reasons mentioned above ABB does not recommend performing Crash-Stops frequently.

As USCG have indicated that the vessel shall have new crew fairly frequently and that the standard procedures include training of the Crash-Stop on frequent basis. The purpose of this document is to give a more detailed recommendation in performing the Crash-Stop for training purposes. According to this proposed procedure the Crash-Stop training can be performed as often as wanted, still pointing out that unnecessary dynamic loading is never beneficial for the product.

As during the Crash-Stop loads inside the AZIPOD® units is extremely dynamic by their nature it is not recommended to perform Crash-Stop frequently with full power. For crew training purposes it is considered that the most important is to learn the functionality of control devices and vessel and procedures during the Crash-Stop. These can be achieved by the following procedure (for pod-away Crash-Stop):

1. The power is reduced to 50% of maximum power.
2. The control is taken to position equipped with Azimuth levers.
3. The units are rotated 180 degrees keeping the power setting at same position.
4. Wait until stopping of the vessel.

During the ice conditions it is recommended that Crash-Stop will be performed by reversing the rpm's. For training purposes of this procedure the following is recommended:

1. The power is reduced to 50% of maximum power.
2. Wait until speed has reduced below 10 knots.
3. Reverse rpm's by turning levers to reverse position corresponding 50% of maximum power position.
4. Wait until stopping of the vessel.

4.5 TURNING

Turning the cutter is accomplished by rotating the Azipod units away from the desired direction of the turn (imagine you are driving a boat with an attached outboard motor). While operating in manual and asynchronous mode, it is recommended that the Azipod on the <u>inside</u> of the turn is maintained in the ahead position (to maintain speed), while the unit outside the turn is rotated outboard to provide a thrust away from the cutter (pushing the stern away from the intended direction of the cutter). If both Azipod units are rotated the vessel will turn, however, forward momentum will be sacrificed. (See Figure 4.8.) The orientation of the pod will dictate the arc of the turn; i.e. 90° for a tight turn or 45° for a less steep turn, however, most turns are accomplished using significantly less pod angle, i.e. 10° or 20°. Turning is most easily accomplished by turning both pods, either "grouped" in manual or in Auto-pilot. The maximum of 40° of Azipods used by Auto-pilot is sufficient to complete even the sharpest of turns. Turns should be completed without Auto-yaw, if the Auto-pilot is used. The operator must be aware of the resulting pod azimuth from a given torsional deflection of the joystick, and judge the rate of turn

obtained. Using 30° of pod angle the cutter can turn 360° in 2.35 times the cutter's length (approximately 565 foot turning diameter) in 24 inches of ice.

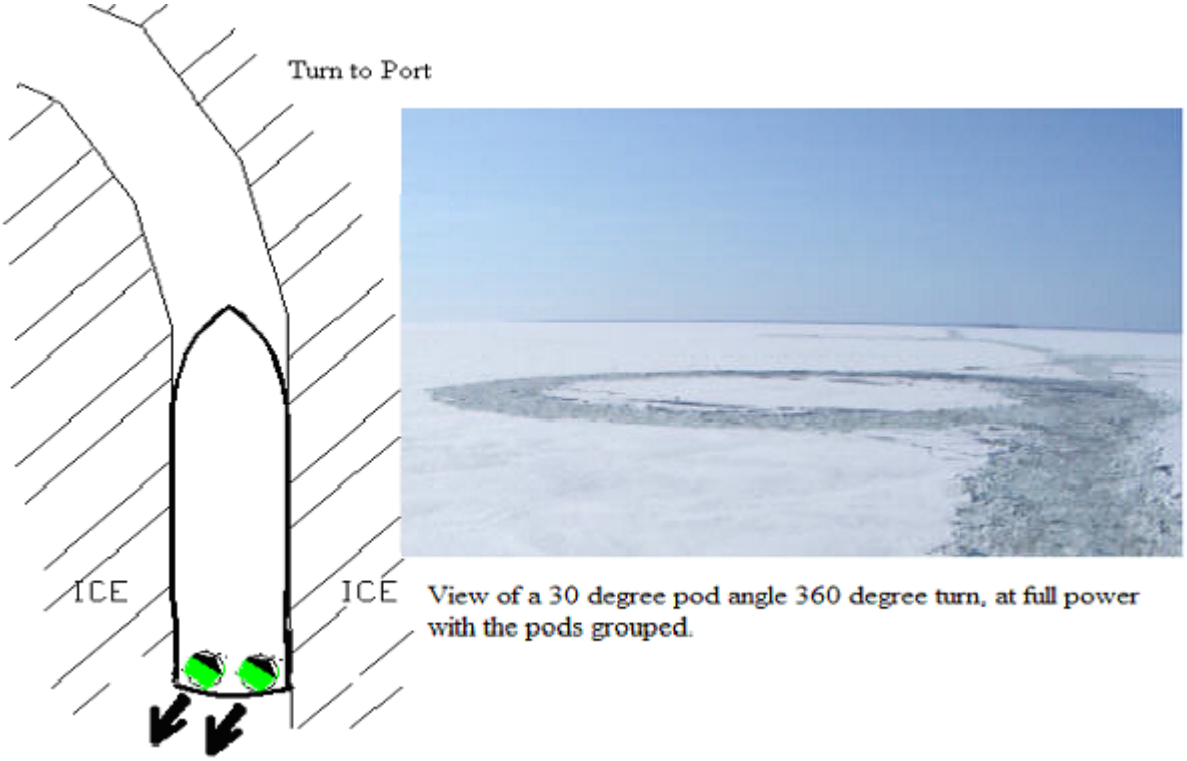


Figure 4.8. Turning.

To execute a steep turn the outboard Azipod can be used to break and flush ice away from the stern (providing open space for the stern). Speed will be reduced but momentum can still be maintained by oscillating the unit through a 70° to 90° arc.

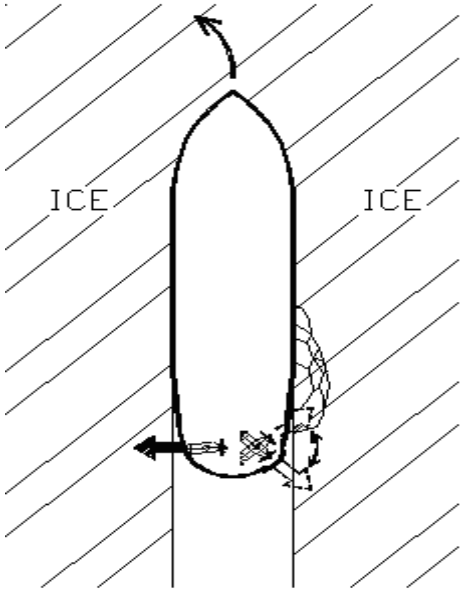


Figure 4.9. Turning 180 degrees.

In a number of icebreaking scenarios it becomes necessary to turn the ship around (head in the opposite direction). For a cutter with Azipods this has become a relatively simple task, whereby the cutter can be pivoted in slightly over its own length. Conventionally driven icebreakers have for years relied on a "star turn maneuver", casting the cutter about in the ice by using the prop wash to recreate a hole in the ice for the stern to back into, before attempting the next cast. This maneuver is not necessary when the vessel is equipped with Azipod units and, in fact, the star maneuver cannot be easily executed. To quickly reverse direction in level ice or brash within the vessels length, with ahead turns on, place one Azipod 90° inboard to the centerline (thrusting outward) and the other unit turned at approximately 70° outboard to rotate the stern into the ice (while washing the broken ice away from the stern).

The following diagrams show two options for a starboard rotational turn to starboard. In the first case (Figure 4.10), the ice is broken by the icebreaker's hull on opposing quarters. In the second case (Figure 4.11), the flow from the port pod is directed into the ice to break it during the turn.

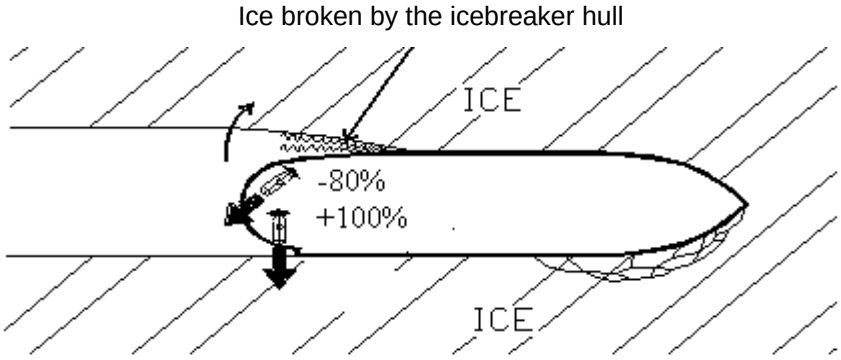
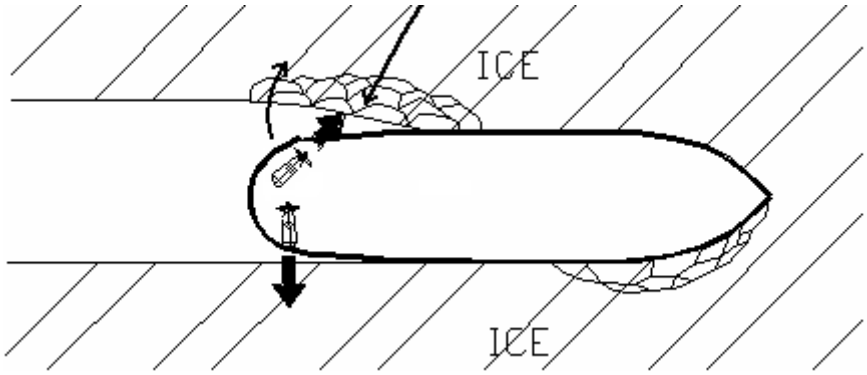


Figure 4.10. Turning in place.

Ice broken by inner thruster



Starboard pod ahead at 100% thrust and the port in reverse at 80%, oscillating 20 to 30 degrees.

Figure 4.11. Turning in place.

During the "Finnish Turn", turning 180° or 360°, as shown in Figure 4.11, the port pod must have a lower percent of reverse thrust at -80% so as not to cancel out turning power of the other pod at +100%. Also, this pod should be moved and redirected constantly to keep prop wash moving over the surface of the ice. A good "Finnish Turn" means lots of water forced onto the ice. If you do not see a lot of water, increase thrust. The starboard pod in the above drawing remains at 270° and 100 percent power.

4.6 ICE CHANNEL MAINTENANCE

4.6.1 Brash Management

The vast majority of the icebreaking conducted on the Great Lakes is involved in keeping the ice channel open for unassisted transit by commercial carriers. Once the level ice is broken and a channel established the river current and wind consolidates this ice in turns and narrows where, during the height of the winter months, the channel refreezes overnight. This scenario is most acute in the Upper and Lower St. Mary's River (where the navigable channel is only 300 to 600 feet wide) and in the Straits of Mackinac (approaching the Mackinac Bridge).

This accumulation of broken ice, often 8 to 10 feet deep, is kept loose and moving with the current. Based on the environmental consideration, the broken channel is transited by an icebreaker daily (sometimes more than once a day). This icebreaker works the ice in the turns and loosens the ice in the main channel to keep the brash ice moving.

There are a number of techniques for maintaining the track. It may be as easy as transiting the designed area, in the center of the channel, using the ship's wake to break up the refrozen brash and the momentum of the cutter to draft the ice downstream. With caution not to disturb the ice channel edges or

in open water areas adjusted speed to not create wake damage to shoreline properties, i.e. break walls, piers, etc. In areas of refrozen brash assisting relatively underpowered vessels an effective assist technique is to transit astern using MACKINAW's pods facing aft. This typically leaves a very open pooled track that is easier for an underpowered vessel to transit.

4.6.2 Channel Widening

Early in the establishment of the track in level ice and later in track maintenance the Azipods can be used effectively to widen the track or loosen brash by positioning the units at an angle of approximately 10 to 15 degrees inboard and directing the prop wash to outboard. In this configuration the cutter can develop an open track about a ship's width wider than the beam. This maneuver forces ice floes to go under the ice and the channel stays open longer.

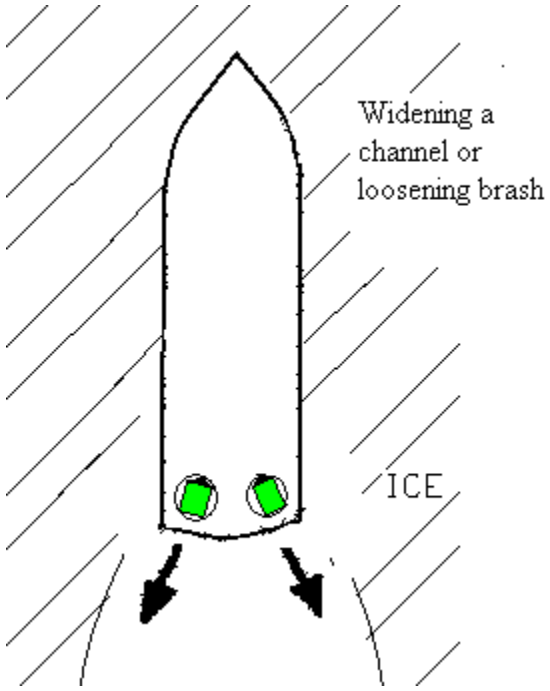


Figure 4.12. Widening a channel.

By directing propeller flow the Azipod units can effectively be used to wash the brash from the channel and open an area previously choked with ice, as shown in Figure 4-13. This is a very slow process and would be used in combination with other ice channel maintenance maneuvers. Though effective in widening the track, the speed over ground is reduced and thus the distance of the track broken is less than if transiting ahead using the wake/break method at a high speed.

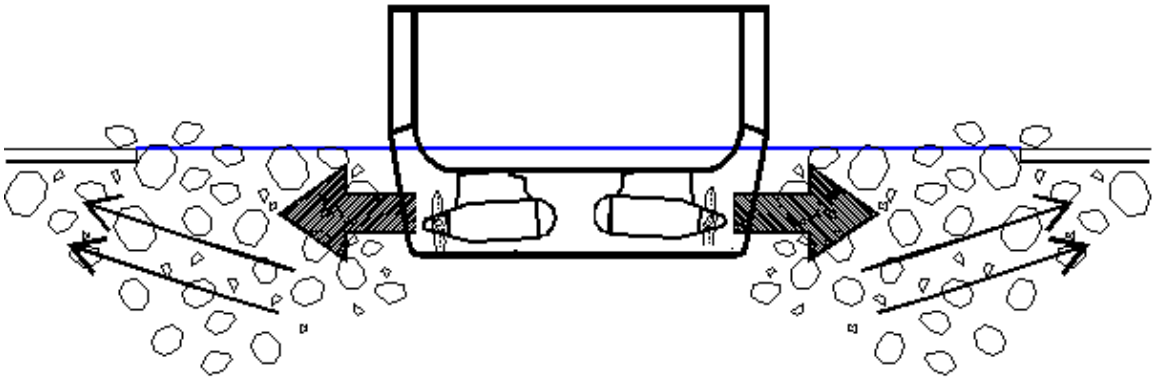


Figure 4.13. Widening a channel with prop wash.

Another way to widen the channel is to “scarf” the existing track edge, putting the bow outside the track and the track edge at the appropriate machine gun mount (for a reference point on the bow), as observed from the centerline. The stern will fall into the track and a turn to port will be necessary to keep the bow “bit into” the track edge. (As shown in Figure 4.14.)

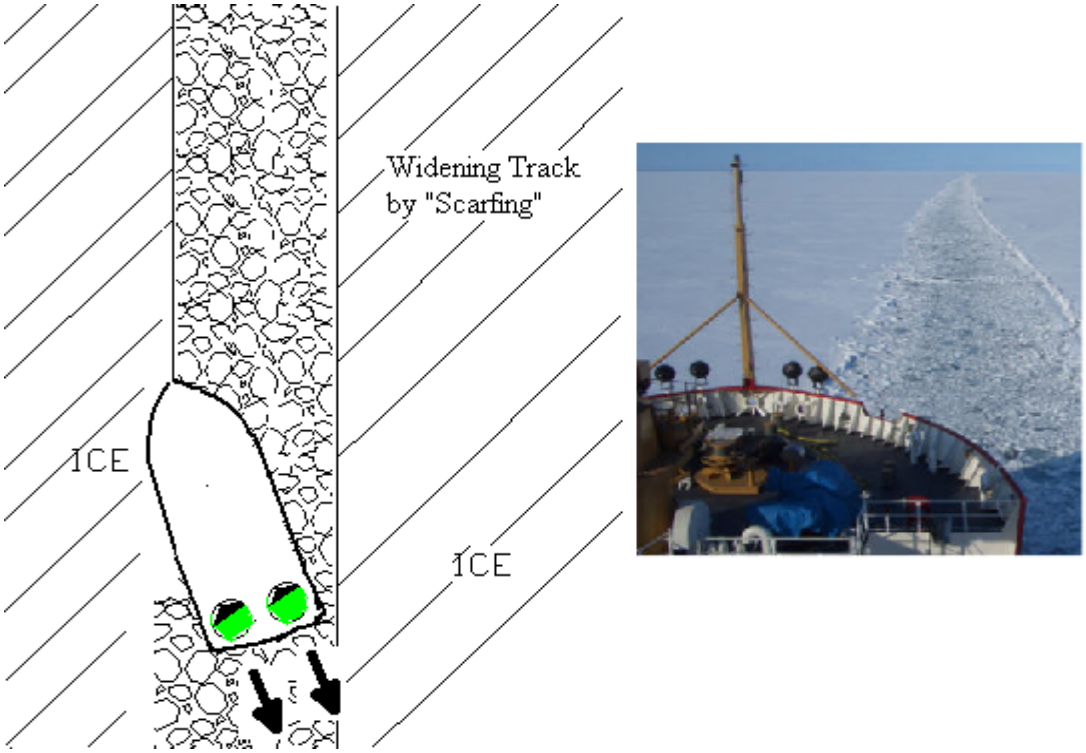


Figure 4.14. Widening channel by scrafing.

Scrafing is especially effective in producing a track 70 to 85 ft in width and can be adjusted by placing the bow off center to either the ice light or the gun mount to widen the scrafed track.

Also, high-speed (greater the 10 kts) runs through an established track or a ship's width outside the broken track will produce sufficient standing wake to break out finite distances from the track edge or loosen refrozen brash.

4.7 WINDROWS (RIDGES)

A windrow is a common phenomenon on the Great Lakes, and is caused by a line or wall of broken ice being forced up by pressure. Windrows are created when two large ice floes (or plates) converge under pressure from the wind or current. The height above the ice level is called the "sail area" and the submerged volume of broken ice is termed an "ice keel". In Whitefish Bay windrows are frequently 4 to 6 feet across, with sail areas from 2 to 4 feet and ice keel measuring down to 10 to12 feet. They have the potential to stop an icebreaker and caution must be used when attempting to break through a windrow as the cutter may become beset.

In passing through a windrow, they are best approached bow-on and, should the cutter's progress be stopped, the situation may require the operator to employ a "backing and ramming" maneuver. The speed used to attempt breaking through a windrow varies, however, backing the cutter approximately 300 yards and approaching the windrow at near full power is a relatively low risk maneuver. Generally, within one or two rams the cutter breaks through and can proceed along the desired trackline. The greatest danger in this maneuver is that the cutter may become beset in a windrow under pressure and will have difficulty extracting itself.

In ice under pressure, it is recommended that the Conning Officer reserve some power when attempting to back and ram a windrow, so that greater power is available for extraction if the cutter becomes beset.

If facing an especially difficult windrow and the cutter has not achieved success in backing and ramming, it is recommended that the cutter be backed through the windrow. Using the Azipod thrust to wash-out the ice, it may be easier to back through the ridge and spin the cutter around and proceed down the trackline. The following are common tactics, which are safe and efficient, currently used in the Baltic areas to work through windrows. Demonstrated in Figure 4.15 and Figure 4.16 are different modes when penetrating windrows stern first.

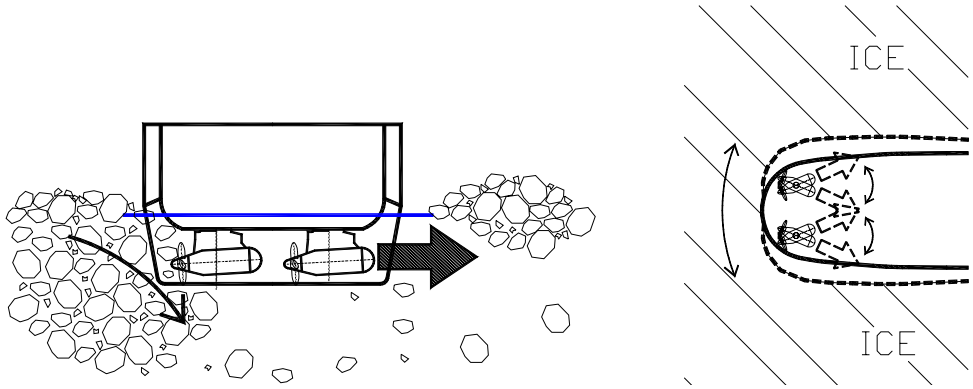


Figure 4.15. Working through windrows stern first while moving the stern from side to side.

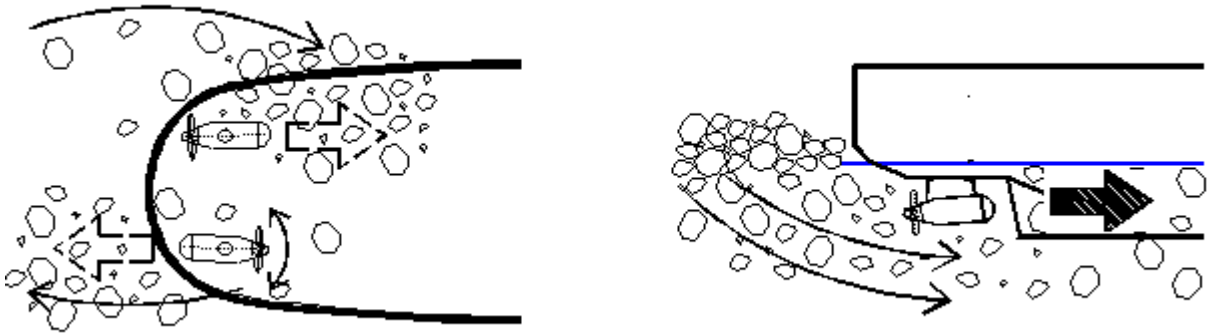


Figure 4.16. Working in windrows and flushing ice by propeller flow.

4.8 HARBOR AND FACILITY ICE CLEARANCE

In conjunction with routine icebreaking operations, the cutter may be called upon to open a harbor or clear the winter's ice from a pier, dock, or marine facility. Often, associated with the spring breakout the U.S. Army Corps of Engineers, at the Soo Locks, require assistance clearing ice from the lock wall approaches. This ice is then flushed through the locks downstream.

In the past, a conventionally configured cutter would approach the facility to be cleared in a head-on manner and angling the cutter about 45° from the face of the pier or dock moving down the face, while scarfing away the ice and flushing it out with the prop wash.

Employing a cutter with Azipod propulsion units for this task is an ideal application of this vessel's capabilities. The increased maneuverability, combined with the use of the dynamic positioning system (DP), dictates a new approach to this task. As shown below, the recommended approach is stern first, with the cutter making two approaches. The first approach is made a ship's width or so off the face, breaking some ice with the prop wash and opening a relief track. The second attempt is down the face of the facility at a 30 to 45° angle to the pier, flushing the ice away with the inboard Azipod while

controlling the direction with the other unit. Going in stern first flushes broken ice out and provides an area of open water ahead and around the cutter. In this open water situation, the bow thruster can be safely employed, which should provide even greater maneuverability in holding the desired angle of the cutter to the pier face.

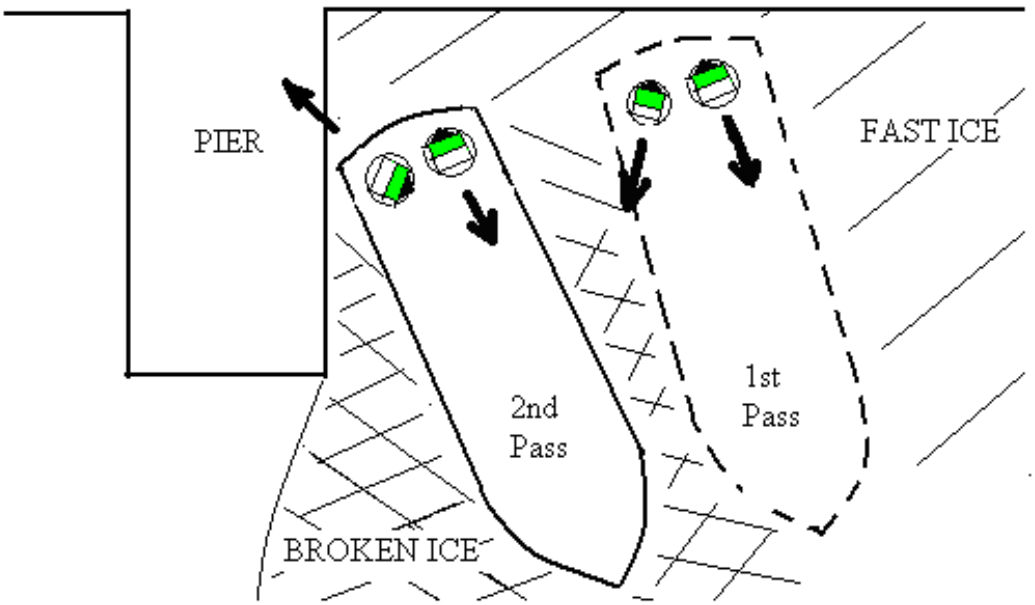


Figure 4.17. Clearing a facility or pier.

For clearing pier faces, a pass parallel and approximately 80 to 100 feet out, using manual mode with opposing pods will throw significant water outboard and the amount of thrust can be tuned for the desired effect. Once an area abeam of the pods has been cleared, ease the cutter forward and stop to let the water do the work. Flushing broken ice away from the facility or pier may be enhanced by heeling the cutter a few degrees (directing the prop wash toward the surface). (See Figures 4.17 and 4-18)

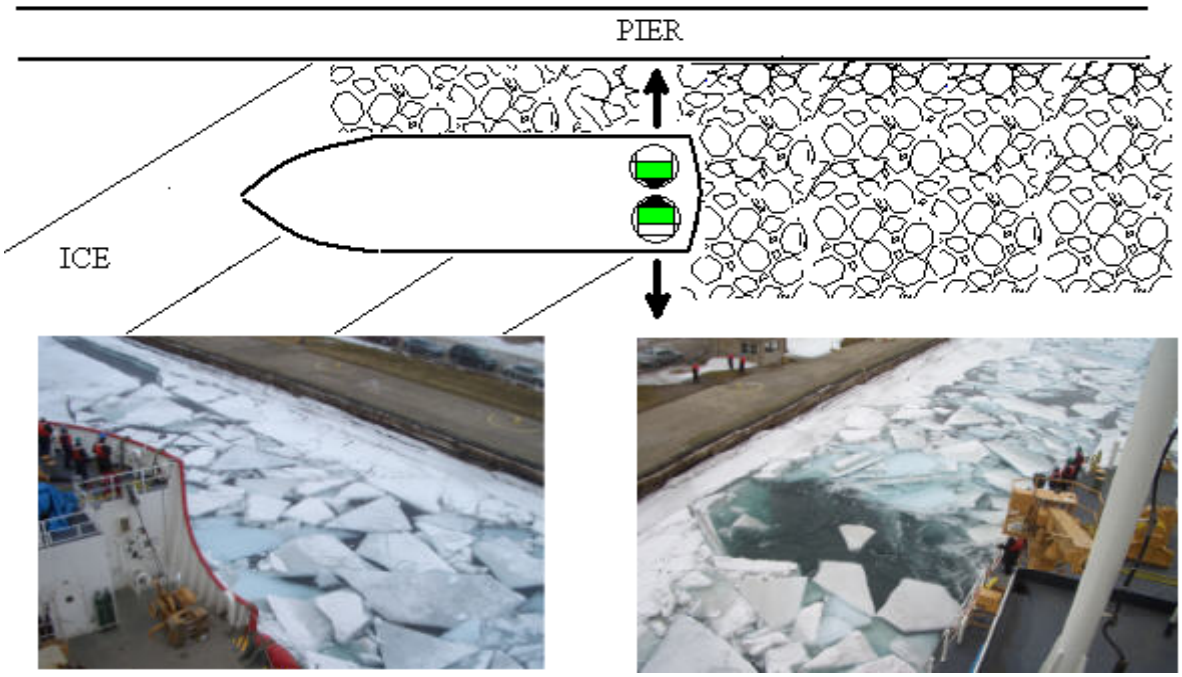


Figure 4.18. Flushing a straight pier face.

4.9 BESET

Although it does not happen often, an icebreaker can become beset in windrows, pressure ridges or heavy brash. The greatest danger in this situation is that the ice may be moving and could possibly drift into shallow water, grounding the cutter. Two of the most frequent situations where an icebreaker becomes beset is when working in an area with multiple windrows (the cutter may have enough power and momentum to pass through the first windrow but is stopped and trapped by the second) or when a cutter is transiting a shear zone (the cutter may have sufficient power and speed to transit the broken ice along the shear but not enough to enter the fast ice). In both these situations, ice under pressure compounds the difficulty of extracting the icebreaker.

Once the icebreaker is beset there are several methods available to the conning officer to extricate the cutter. It should be noted that no one method is guaranteed and the conning officer may have to attempt each method and then repeat them again, seeking to break the fiction of the ice on the hull. Patience is the operative word.

1) Simply backing down full astern may not move the cutter, however, using a combination of full astern alternated with full ahead, while moving the Azipods from port to starboard 30° to 45° may permit the cutter to break free. Often this process must be repeated several times. Also, the use of the prop wash may impact on the ice holding the vessel by directing the thrust to break the windrow apart and wash it away. This maneuver is very similar to that shown in Section 4.7 (Windrows – Figure 4.15).

2) Listing the cutter, using a large buoy sinker hung off the boom and moved outboard to port and starboard, while applying full astern power may break the ice fiction on the hull. This tactic may also be useful in clearing facilities.

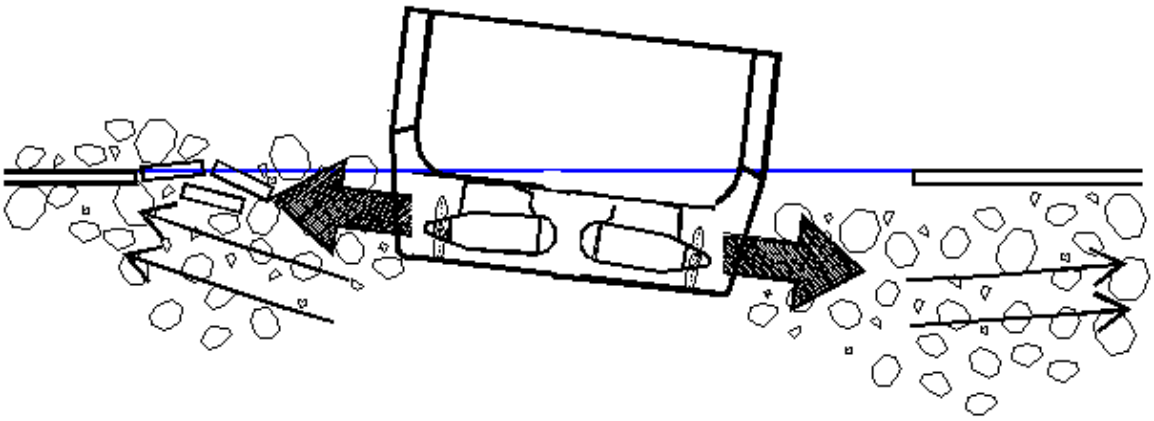


Figure 4.19. Flushing ice while listing the cutter.

The Azipods may also be positioned to thrust towards the beam and moved forward and aft while listing, to direct the prop wash toward the surface. See Figure 4.19. This may have a greater effect on flushing out the windrow and/or weakening the ice.

3) Alternately flooding and emptying the forepeak and aft peak tank may release the cutter from the ice.

4) Attempting to twist the cutter may also loosen the ice. The maneuver is generally used in combination with backing full astern.

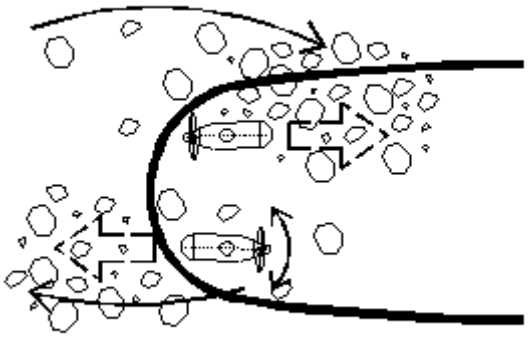


Figure 4.20. Loosening ice.

4.10 BREAKING OUT A VESSEL BESET

On occasion it becomes necessary to assist a vessel that had been "nipped"[3] and cannot proceed. There are several possibilities for the besetment: (1) an ice clogged channel, (2) a vessel underpowered for existing ice conditions, (3) ice under pressure, or (4) an insufficiently wide track for the beam of the vessel.

The method for breaking out the vessel is dependent upon the amount of maneuvering room existing around the beset vessel (distance to shoal water). Provided the icebreaker has sufficient room, the typical breakout scenario is dictated by the initial direction of the approach to the beset vessel. If the icebreaker is ahead of the vessel and must return to conduct the assist, the typical maneuver involves breaking out of the established track several hundred feet in front of the vessel, then proceeding down the length of the vessel (relatively close aboard – the distance is dictated by ice conditions but 50 to 100 ft is a reasonable distance), turning 180 degrees and heading forward along the opposite side of the vessel, turning sharply into the established track ahead of vessel, releasing the pressure around the beset vessel. Generally, this first pass along the vessel will be on the upwind side.

In this situation the Master of the beset vessel is instructed to keep the engines at stop until the icebreaker has re-entered the established track and instructed the vessel to come ahead. Close communications and coordination between the two vessels is an absolute necessity. The Master of the beset vessel will have the tendency to start applying power as soon as the vessel is observed to be free and the icebreaker conning officer must be aware and control the maneuver for the safety of both vessels.

[3] Nipped – the situation of a vessel being pressed by ice on both sides impeding movement.

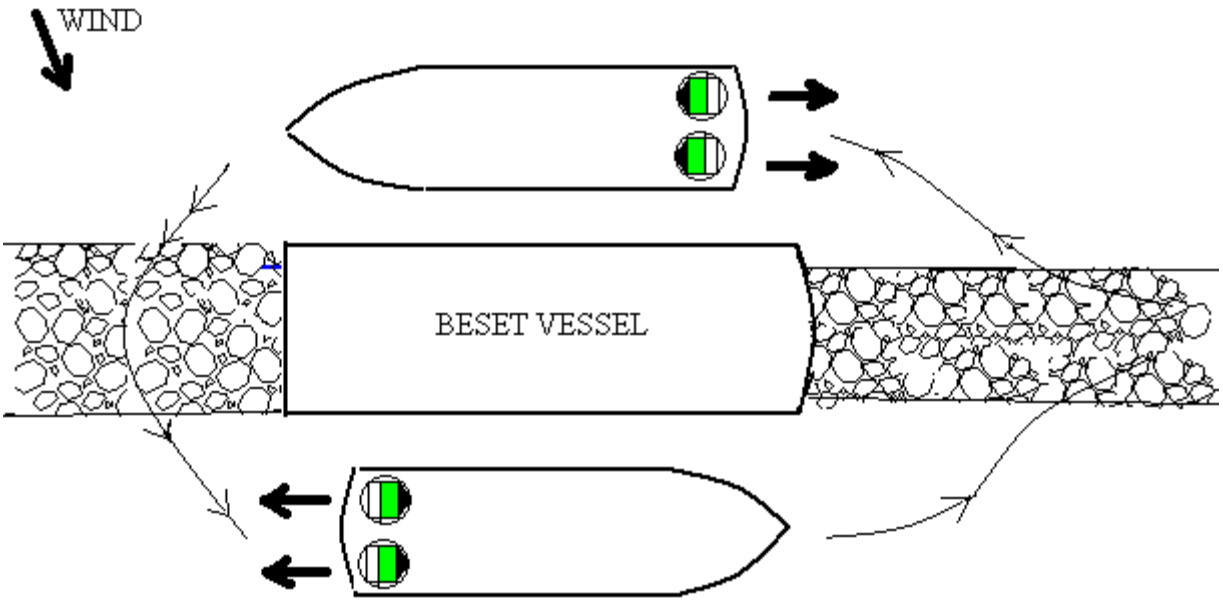


Figure 4.21. Assisting a beset vessel.

If the vessel to be assisted is originally approached from astern, generally only one pass along the length of the vessel is required to free the vessel. Again, this pass should be relatively close aboard (50 to 100ft) and on the leeward side of the beset vessel. The wind (if present) will assist in moving the beset vessel into the newly broken track and the conning officer must be aware of the movement of the other vessel. Communications are equally important in this maneuver and the direction to apply power by the beset vessel must come from the icebreaker.

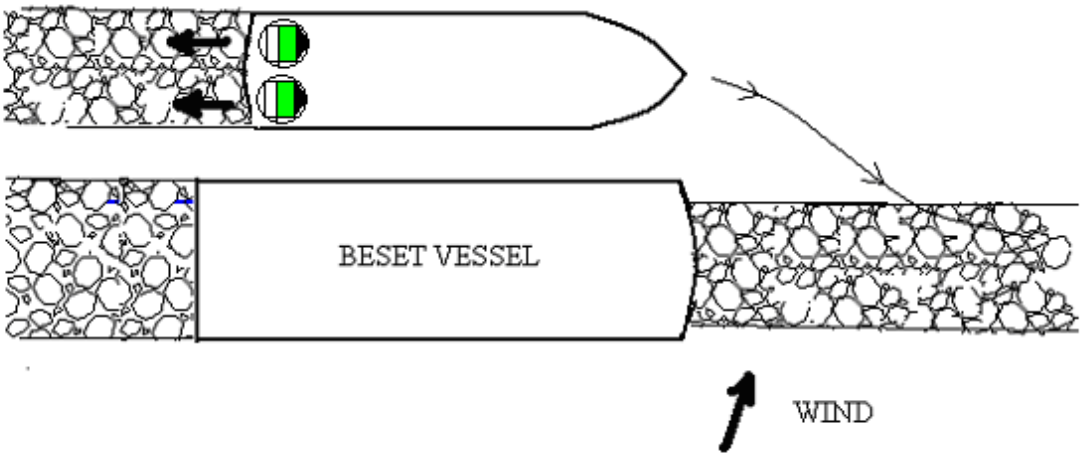


Figure 4.22. Assisting a beset vessel in a single pass.

In some situations, especially in a brash clogged channel, a vessel (i.e., particularly large ore carriers and barges) may tend to pile-up ice ahead of the vessel to the point where the ice stops the vessel. In this case the icebreaker may be required to back down the established channel toward the bow of the beset vessel. To be effective the icebreaker must get very close (20 to 30 ft) to the bow and use the prop wash from the Azipod thrusters in a washing action to dislocate the ice plug. With the icebreakers astern close to the beset vessels bow, the recommended maneuver is to move the Azipods port to starboard though 45° angles, washing the ice away and opening the channel. As the icebreaker moves ahead, with the Azipods at 30° to 45° angles inboard (prop wash is directed outboard) the ice will be flushed aside and the established channel ice loosened for passage of the assisted vessel. It is imperative that the assisted vessel keep its power off (all stop) during the approach and until the icebreaker is moving ahead and directs the vessel to come ahead. However, it is typical in these maneuvers that the assisted vessel will keep a "few turns" on to keep their propeller clear from ice. The icebreaker conning officer must be aware of this situation and be prepared to act immediately if the vessel starts coming ahead during the flushing maneuver. This is a common but high-risk maneuver requiring great attention to detail. Stationing an observer on the fantail to provide accurate distance estimates is most valuable. The fantail watch may also be the first to observe the vessel moving ahead, as he/she has a close-up view of the ice just ahead of the vessel and can see its movement very well (the view from the bridge is obstructed by the icebreaker's fantail).

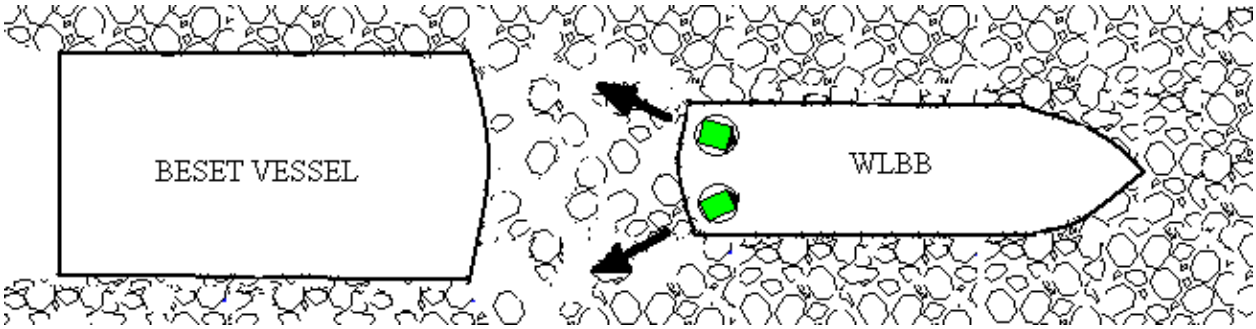


Figure 4.23. Flushing beset vessel's bow.

4.11 COMBINED WLBB/WTGB OPERATIONS

4.11.1 Tandem Vessel Channel Widening

One method to open a wide channel in fast ice involves using a 140-ft WTGB with the WLBB. The combined beams and 30 to 50 ft separation between the vessels provides for a broken channel width of approximately 140 ft. In the spring breakout of Whitefish Bay, where the fast ice can extend 30 to

40 miles out into Lake Superior, this method can be very successful to establish a reasonable channel in only a few days time.

With the WLBB in the lead (given the additional power, beam and maneuverability, to establish the track) the WTGB can operate either on the left or right side at a distance astern of 100 to 200 yards to widen the track. The resulting channel will be nearly ice free, with the broken ice pushed under or on top of the fast ice edge, leaving a relatively open channel. The speed of advance is somewhat dictated by the ice thickness and WTGB's icebreaking ability in that thickness. The WTGB will tend to ride into the open track of the WLBB and the WTGB conning officer will need to counter this tendency with power and rudder selection. The WLBB conning officer will typically set the Azipods to provide thrust directly astern in order to cut the cleanest straight edged track and set power for a steady speed of advance. Coordination between the two vessels is most necessary in setting the speed and distances, in addition to monitoring in case the lead vessel is slowed or stopped by a windrow.

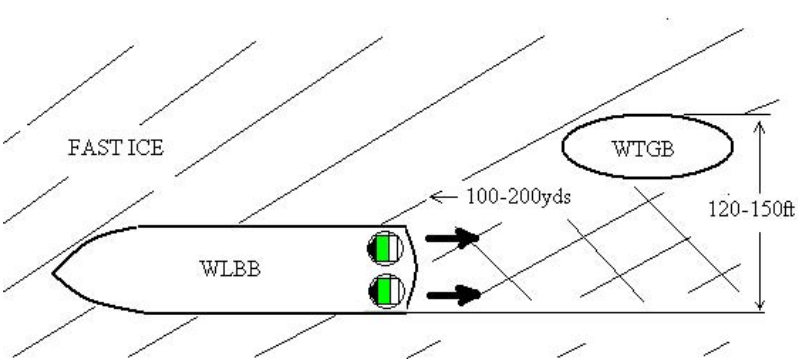


Figure 4.24. WLBB and WTGB tandem operations.

4.11.2 Tandem Vessel Escorting

This method for channel widening with two vessels is also useful in escorting a wide beam ore carrier or barge. In the event the commercial carrier has some difficulty making progress in the broken channel, the WTGB can be dispatched to provide direct assistance, while the WLBB continues slowly ahead breaking the primary channel.

Escorting various tows with barges, low-powered vessels or large ore carriers (wide beam) can be difficult in certain brash ice conditions. As the winter progresses and traffic has run a certain area over and over, i.e., the Straits of Mackinac, and the brash refreezes it becomes very difficult to transit. An attempt to run the area at a high speed, developing a standing wake, may break up the brash. Also, two icebreakers, such as a WLBB and WTGB, working together can open a wider track with the lead vessel cutting a "relief track" for the second icebreaker and escorted vessel, significantly reducing the time and effort required for the escort.

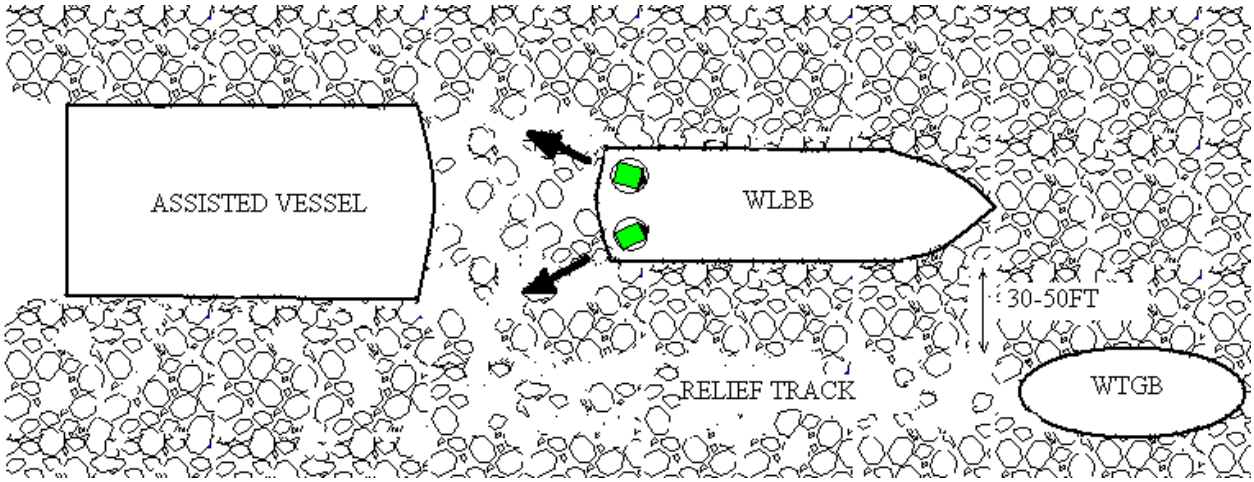


Figure 4.25. Relief track.

4.11.3 Tandem Vessel Break Out of Beset Vessel

Another scenario where tandem icebreaker operations are quite effective is in providing assistance to a beset vessel, i.e., large ore carrier, in the Lower St. Mary's or St. Claire Rivers. With refrozen brash filling certain turns, vessels are slowed and at times stopped. Providing icebreaking assistance in these narrow areas is challenging and requires the icebreakers to work close aboard the beset vessel and in shallow water. Given sufficient maneuvering room, the goal is to clear an open water area near the vessel's quarter for the stern to move into, while clearing an area off the bow on the opposite side for the bow to move into. (See Figure 4.26.) To assist the vessel in moving, a pass along the outboard side (outboard in the turn) to loosen the ice may also be required and is done before attempting to move the vessel. Close coordination between the icebreakers and the beset vessel is required, with the senior icebreaker commander in-charge and issuing direction to the beset vessel. The highly maneuverable WTGB is the preferred vessel to work near the beset vessel's stern, given its smaller draft and power to accelerate out of danger.

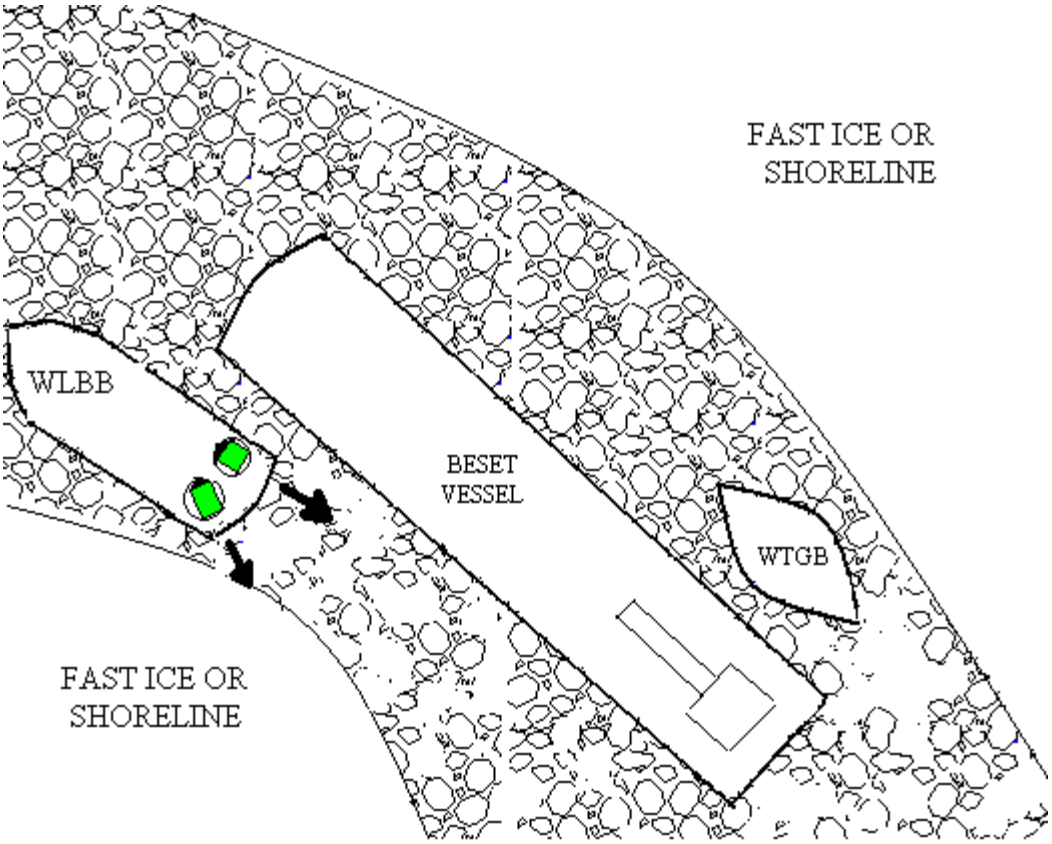


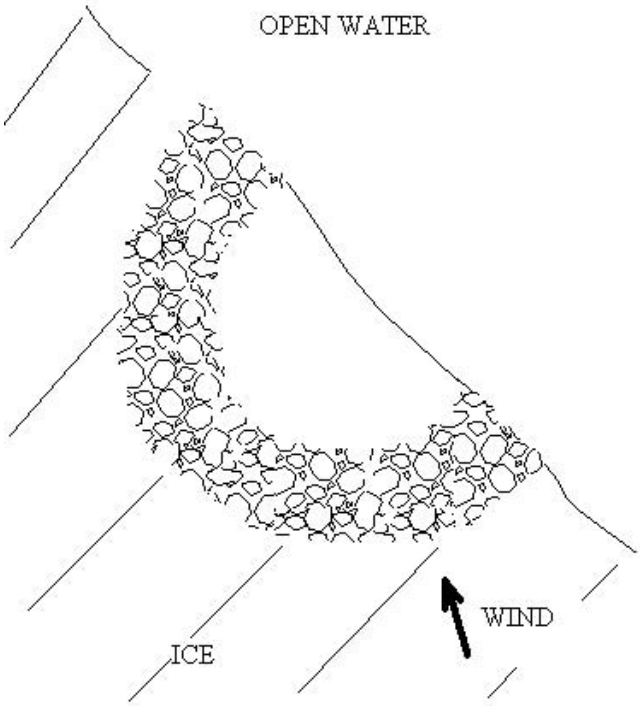
Figure 4.26. Assisting beset vessel in turn.

4.12 CARVING AND WAKING ICE

In certain circumstances it may be advantageous to spend some time and attempt to remove large portions of ice from the area of interest. For example in Whitefish Bay, if the wind is blowing from a southerly direction, removing sections of ice by "carving and waking" will leave fewer miles of ice for track maintenance and for the lake carriers to transit. Carving and waking is accomplished in large areas of fast level ice or areas of consolidated brash, such as Whitefish Bay, the far western portion of Lake Superior, Green Bay, lower Lake Michigan, entrance to Toledo on Lake Erie, to name a few.

Carving and waking is an icebreaking method whereby the cutter, using high speed and the cutter's wake, cuts several hundred feet into the ice, then turns to exit the ice on a near parallel track, carving out a section of the ice to be set free to be blown out by the wind and propelled by the ship's wake. By repeating this maneuver several times, making each new pass deeper into the ice, but not so

deep as to not create cracks in the ice (Figure 4.28), a significant amount of ice can be moved in a relatively short period of time.



High Speed
Use Wake
Use Wind to Move Ice
Scallop out Large Areas

Figure 4.27. Carving and waking.

Icebreaking between passes while carving. Example of Carving & Waking in Whitefish Bay

Figure 4.28. Carving and waking.

APPENDIX A

GLOSSARY OF ICE AND ICEBREAKING TERMINOLOGY

GLOSSARY OF ICE AND ICEBREAKING TERMINOLOGY

A.1 GREAT LAKES OR SHIP SPECIFIC ICEBREAKING TERMS

This glossary is composed of ice terminology that is usually associated with the Great Lakes and coastal waters, rather than the po1ar regions. Some definitions included are part of an international nomenclature adopted by the World Meteorological Organization.[1]

ICE TERMINOLOGY

Age: The stage of development of ice. The term usually refers to the length of time since its formation and to its thickness.

Ball Ice: When small ice elements of any origin become entrapped in a region of extreme water turbulence where the water is at the freezing point throughout its depth. The particles grow by coalescence or accretion to form soft, spongy spheres 1 to 2 inches in diameter. This is a rare form of ice.

Bare Ice: Ice without snow cover.

Brash: Conglomerations of sma1l ice cakes and chunks which have been broken off from other ice formations and then have coalesced and refrozen into irregularly shaped elements, one to six feet in diameter, usually with sharp projections. The wreckage of other forms of ice.

Cakes: Detached segments of ice sheets smaller than 50 feet across.

Concentration: The ratio of the water surface covered by ice to the total area of water surface, both ice-covered and ice-free, at a specific location or over a defined area. Concentration on the Great Lakes is reported in tenths and in the polar regions in oktas (eighths).

Crack: A small un-navigable break in an ice field usually caused by wind and/or wave action.

Drift Ice: Any unattached ice formation. Any area of ice other than fast ice.

Fast Ice: Immobilized ice formations. Ice so firmly frozen into place (along the shore, over shoals or held by islands) that subsequent winds and water currents cannot dislodge the formation.

Fast Sheet Ice: An ice field.

Floes: Detached segments of ice sheets more than 50 feet across.

Frazil: Small cinder-like particles of ice formed in very cold water which is too turbulent to permit a sheet of ice to form.

Frazil Ice: Ice in an accumulation of frazil.

Freezing Degree Day: A negative departure of mean daily air

[1] L.W. Brigham, "A Handbook of Ice Operations for the U.S. Coast Guard's WTBG Class Cutter, June 1982, Appendix B, Glossary, Pages 125-129 (edited)

temperature of one degree from 32 degrees Fahrenheit. A corresponding positive departure is referred as a thawing degree day.

Grease Ice: Where the water surface is completely covered by frazil but the crystals have not yet begun to freeze together. The surface has a greasy, matt appearance and may look like an oil slick.

Ice Edge: The boundary at any given time between the open sea or lake and ice of any kind, whether drifting or fast.

Ice Jam: Formed when drifting masses of floes and cakes are forced into convergent motion by the configuration of shorelines and/or fast ice formations. Local flooding is sometimes caused when an ice jam occurs in a river with current and blocks the flow of ice and water.

Ice Rind: A brittle, shiny crust of ice usually less than 3 inches thick formed on a quiet surface by direct freezing or from grease ice. Ice rind is easily broken by wind or swell and commonly breaks in rectangular pieces.

Ice Skim: Where frazil crystals have frozen together but do not yet exhibit tensile strength. Ripples may move through skim.

Lake Iice: Ice formed on a lake, regardless of observed location. Nearly all ice on lakes can be classified as either "blue" or "white." Blue ice consists of closely packed water crystals with relatively few impurities. White ice incorporates large quantities of air.

Lake Smoke/Sea Smoke: Fog formed when water vapor is added to air which is much colder than the vapor's source. This most commonly occurs when very cold air drifts across relatively warm water.

Lead: A navigable lane of open water between two ice floes or between a floe and the shore.

Level/Plate Ice: Flat ice with approximately uniform thickness and without ridges/windrows.

Pancake Ice: Predominantly circular pieces of ice from 1 to 8 feet across, and with raised rims due to the pieces striking against one another.

Plate Ice: A Great Lakes term for level ice. See Lever Ice.

Polynya: A water area enclosed in ice, generally fast. This water area remains constant in size and usually has an oblong shape.

Pool/Puddle: A small body of water, usually fresh melt water, in a depression or hollow in ice.

Pressure Ridge: A line or wall of broken ice forced upward and downward by pressure. This is usually formed when two floes impinge directly upon each other.

Rafted Ice: A type of deformed ice formed by one floe over- riding another. Some parts of the over thrust will entrap water which may then freeze and cement the two floes together. Other parts will entrap air and take on the characteristic white appearance.

River Ice: Ice formed in or carried by a river, regardless of observed location.

Rotten Ice: Ice that has become honeycombed in the course of melting and is in an advanced state of disintegration. Rotten ice may appear transparent (dark) when saturated with water.

Sea Ice: Any form of ice found at sea which has originated from the freezing of seawater.

Shore Ice: A basic form of fast ice that is compact ice cover attached to the shore or grounded in shallow water.

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.

Whiteout: An atmospheric optical phenomenon in which the observer appears to be engulfed in a uniformly white glow. Neither shadows, horizon, nor clouds are discernible; sense of depth and orientation is lost; only very dark, nearby objects can be seen. On the Great Lakes a uniformly overcast sky, blowing snow and an unbroken ice cover can contribute to a whiteout.

Windrow: Rows of ice piles formed by drifting masses of floes and cakes being pushed against the shore or against fast ice by the wind. Windrows continue to grow as long as the wind persists. This is a Great Lakes term for a pressure ridge

ICEBREAKING TERMINOLOGY

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.

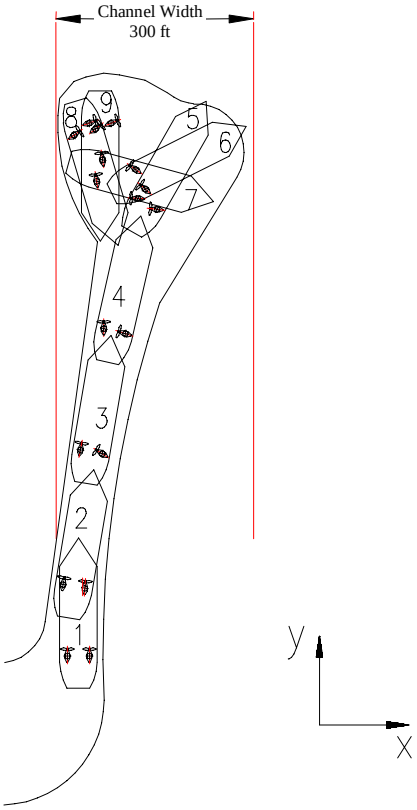
Icebreaker: Any icebreaking ship whose operational profile may include escort or ice management functions and whose hullform and propulsion plant allow it to undertake aggressive independent operations in ice-covered waters.

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 hullform and propulsion plant provide sufficient icebreaking capability for the mission.

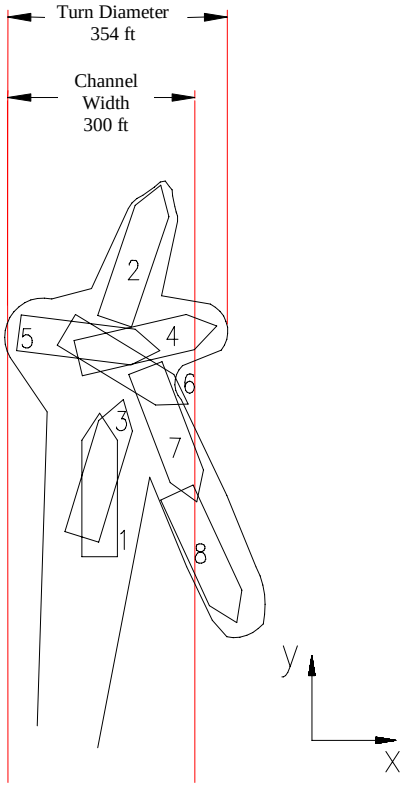
Ice-Strengthened Vessel: A vessel whose hull, rudder, propellers and machinery are strengthened specifically to withstand a certain level of ice loads, both dynamic generated by the collision with the ice feature and static generated by the ice pressure. This term does not reflect the vessel's ability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

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 degrees 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

A.2 EXCERPT FROM *MANUAL OF STANDARD PROCEDURES FOR OBSERVING AND REPORTING ICE CONDITIONS*

MANICE

Manual of Standard Procedures for Observing and Reporting Ice Conditions

Issuing authority:
Assistant Deputy Minister
Meteorological Service of Canada

Originating authority:
Director, Canadian Ice Service
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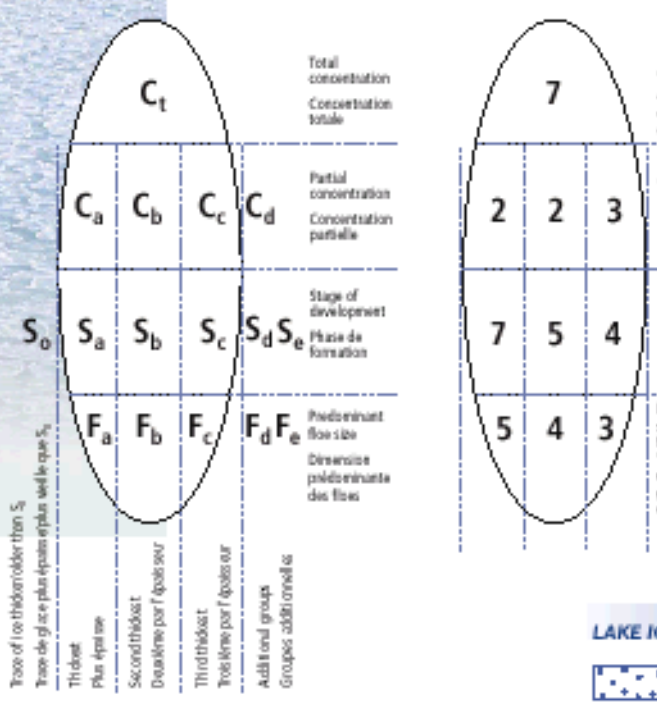
FACT SHEET / FICHE D'INFORMATION

LAKE ICE SYMBOLS
SYMBOLES DE LA GLACE D'EAU DOUCE

2004



Total concentration: the ice coverage of an area determined by its concentration and expressed in tenths (this example, 7/10)
Concentration totale : l'étendue de la couverture de glace, exprimée en dixièmes de la superficie du secteur (cet exemple, 7/10).

Partial concentration: the break-down of the total ice coverage expressed in tenths and graded by thickness. The thickest starting from the left and in this example, 2/10 is the thickest.
Concentration partielle : les concentrations respectives, exprimées en dixièmes, des glaces de différente épaisseur, par ordre décroissant. La plus épaisse commence à la gauche du diagramme, c'est-à-dire, 2/10 est le plus épais.

Stage of development: the type of ice in each of the grades determined by its age, that is, 2/10 is thick lake ice (7), 2/10 is medium lake ice (5) and 3/10 thin lake ice (4).
Stade de développement : le type de glace de chacune des catégories déterminé par son âge, c'est-à-dire, 2/10 est de la glace de lac épaisse (7), 2/10 est de la glace de lac moyenne (5), et 3/10 est de la glace de lac mince (4).

Floe size: the form of the ice determined by the dominant floe size for each section. In this example, big floes (5) for thick lake ice (7); medium floes (4) for medium lake ice (5); and small floes (3) for thin lake ice (4).
Taille des floes : la forme de la glace, déterminée par la taille des floes dominants de chaque section. Dans cette exemple, grands floes (5) pour la glace de lac épaisse (7); floes moyens (4) pour glace de lac moyenne (5) et petits floes (3) pour glace de lac mince (4).

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 ($S_oS_aS_bS_cS_dS_e$)

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

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

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Web site/Site web: http://ice-glaces.ec.gc.ca

Canada

Environment Canada / Environnement Canada

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
	1/10	Very open drift/ Banquise très lâche
	4/10	Open drift/ Banquise lâche
	7/10	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.

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Canada

A.3 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 sub-marine 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 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).

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).

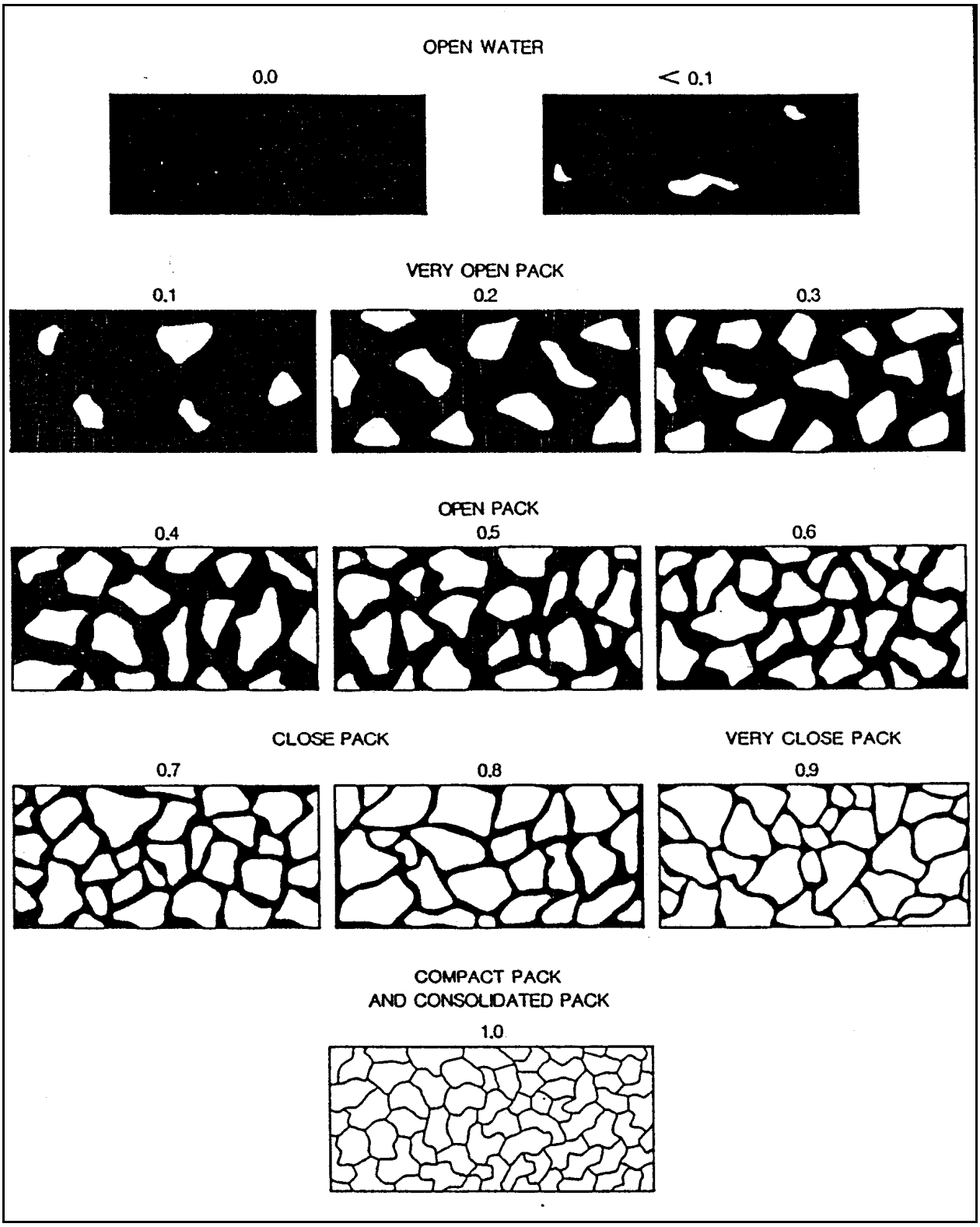

DIAGRAM OF CONCENTRATION IN TENTHS

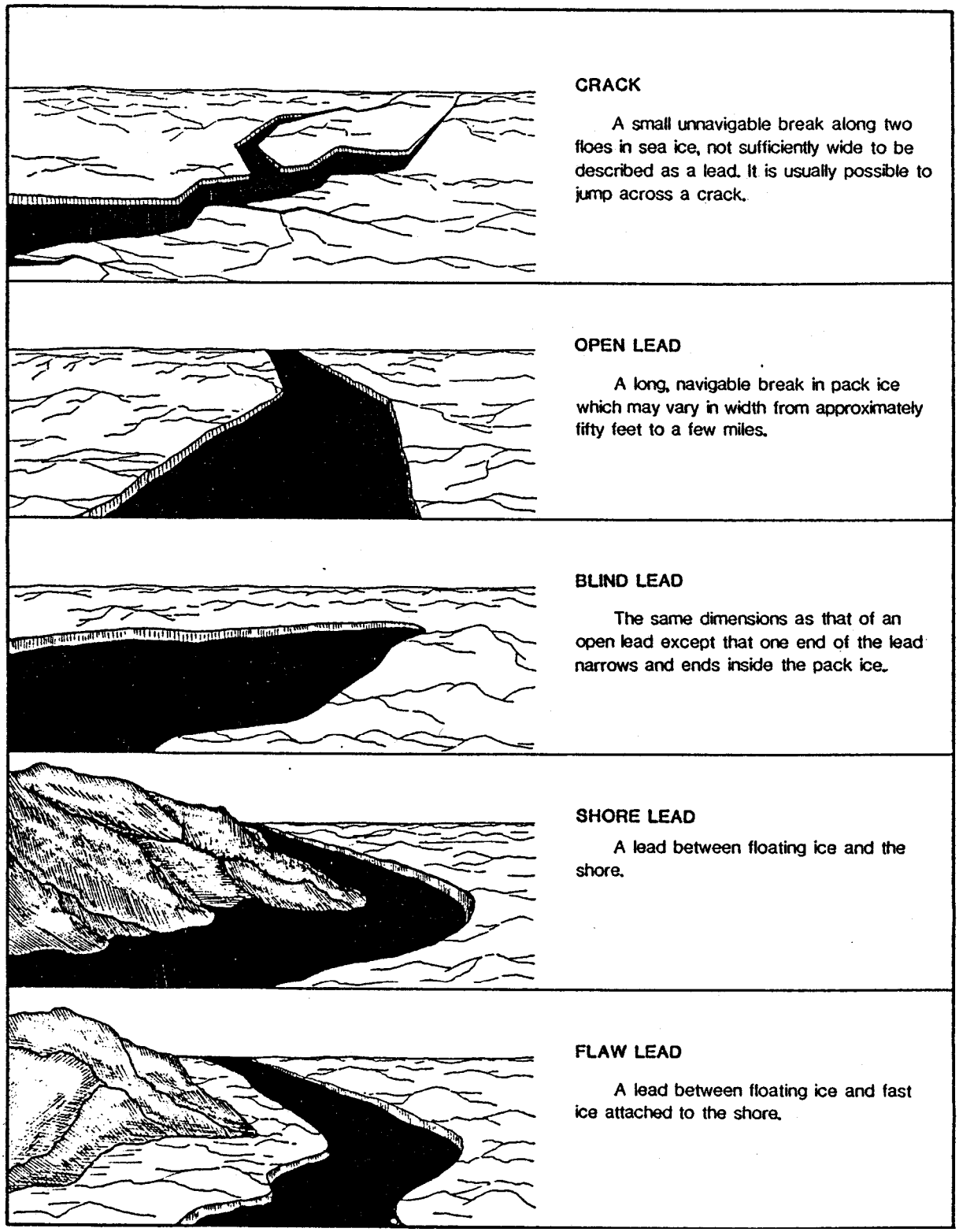

DIAGRAM OF TYPES OF OPENINGS IN THE ICE

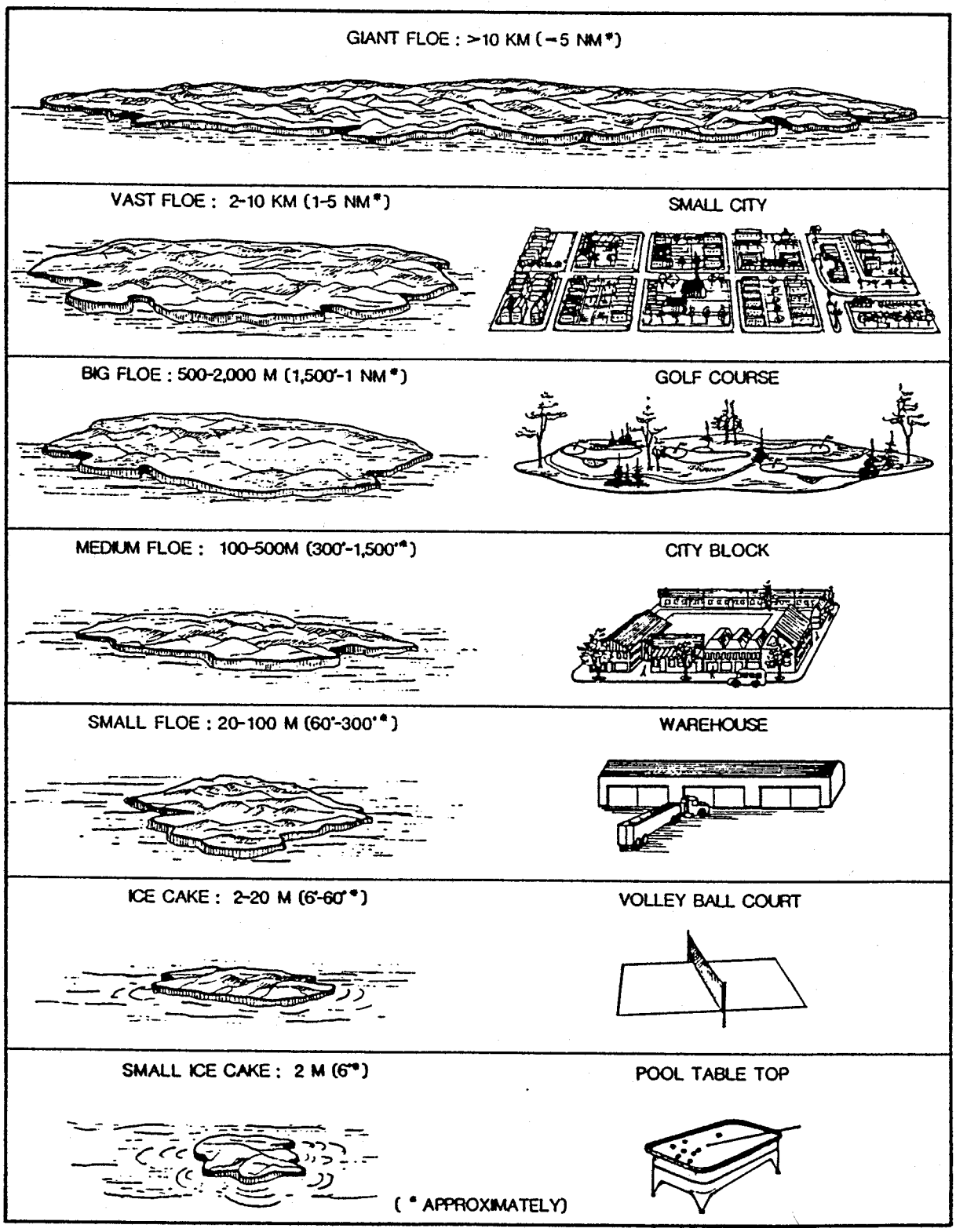

Diagram of Floe Sizes

APPENDIX B

PERFORMANCE PLOTS FOR WLBB

NOTE: This appendix contains full-page plots from Section 2.2 that can be copied for use on the bridge. This appendix is under development.