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ΘΕΜΑ : ICE NAVIGATION & ICE DAMAGE

ΣΠΟΥΔΑΣΤΕΣ : ΣΟΦΙΑΝΟΣ ΠΑΝΑΓΙΩΤΗΣ & ΜΑΝΤΑΛΑΣ ΓΕΩΡΓΙΟΣ

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ABSTRACT

I would like to extend my warm thanks to the supervising professor Miss Panagopoulou for the patience and guidance she provided me during the preparation of this dissertation. The aim of this dissertation is to refer to the Ice Damage and Ice generally. As known the navigation in ice, is a very specialized branch of general navigation and requires specific personnel who are capable and well informed how to act in these adverse conditions. Apparently, for this job there is the suitable equipment and the suitable ships the famous known as icebreakers. Ice navigation is a specialist area of navigation involving the use of maritime skills to determine and monitor the position of ships in cold waters, where ice is a hazard to the safety of navigation. The presence of sea ice requires a ship to exercise caution, for example by avoiding icebergs, slowly sailing through a lead, or by working with an icebreaker to follow a course through the ice to a destination. Additionally ships must also deal with the extreme cold of the climate in regions such as the poles; this involves removal of ice accumulation from the ship, as well as protecting the crew from the elements while working on the deck.Ships and their crews operating in ice will follow established rules of seamanship, as well as complying with national and international regulations such as the Polar Code.

ICE

Ice of land origin Formed on land due to: • coagulation of seawater • the compaction of layers of snow falling one on top of the other from the other and exert pressure on the underlying layer each once, as a result the ice becomes like plastic. Ice cover: If a region is flat (Antarctica) or the external flow is blocked (Greenland) an ion is formed ice cover Glacier: If there is a slope (ravines, mountains) due to gravity ice flows and the glacier is formed. That's him A mass of snow and ice that flows like a river to a lower level flat. The flow velocity can reach 30m per day, but it is generally smaller. Iceberg: If the glacier reaches the sea, the water rises it is cut and the icebergs are formed. They have different shapes: dome, turret, conical, irregular, trapezoid. Those that have an irregular or conical shape come from glaciers that move on an uneven surface, while the trapezoids come from thin surfaces of ice that are pushed directly at sea (Antarctica). In some places the elevation above the sea has a height that reaches about 120 μ., while this below the surface is 500 μ. Especially trapezoidal icebergs can also show Length of kilometers. On average, these are mobile ice islets have a Length from 300 - 400μ. and average height 30 μ. Rarely exceed the Length of 1000 Meters where then represent a weight of millions of tones. They move at a speed of about 0.7 Km / h which can rarely reach 3.6 Km / h. Because most of them are below the surface of the sea the main force that moves them is the sea currents. So sometimes they can move against him existed insecure.

Curious • The largest iceberg found was 335 km long. and width 97 kg. With a total area of 31,000 sq. km., as much as Belgium. • The tallest iceberg found was approximately high 167μ. that is, greater than half the height of its tower Eiffel. • An "arctic iceberg" was once spotted in Verdi, after "traveled" a distance of 4,000 Psiles, while another from Antarctica was located near Rio de Janeiro after traveling 5,500 Farther north. Sea ice It makes up 95% of the ice found in the seas and oceans. It is formed due to the cooling and coagulation of seawater. As the dissolved salt in ocean water results in water to solidifies at a lower temperature (-1.8 ° C for an average value marine salinity). The formation of sea ice is a very slow process which depends on temperature, salinity and depth. Salt water tends to sink and move away from the cold surface before cooling enough to thicken.

To catch up to formed ice, it is estimated that the water column should be cooled at the freezing point μup to 100-150 meters depth. Ice formation may be delayed due to inconveniences, currents and tides. During the crystallization of seawater, its part of dissolved salt accumulates in trapped water droplets in Microscopic gaps (pockets) Between the crystals and constitute the so-called other. The other is gradually eliminated and sinks, and these gaps are filled with air. It is divided into several categories in terms of age, size and Shape of the ice surface. New ice Perennial ice Ice cover Ice cover, i.e. the collection of ice packs in an area, expressed in tenths. Open water: <1/10 Very light ice: 1/10 to 3/10

Open ice: 4/10 to 6/10 Closed ice: 7/10 to 8/10 Very closed ice: 9/10 to <10/10 Compact ice packs: 100%.

Thickness of sea ice Is influenced by: whiteness - the initial thickness of the ice - the air temperature - the velocity of the rough - the opacity - its density sea water - the specific heats of sea ice and its sea water Antarctica: 1 -2 m Arctic: 2 - 3m Vulnerability of sea ice Related to the salt content of water. It is usually expressed in ppt (parts per thousand) i.e. salt in 1000 Hands of water. For every 5 ppt increase in salinity, the freezing point decreases by 0.28 ° C. Density of ice It ranges from 0.72 to 0.94 mg / m3 , with a prevailing average value of 0.91 mg / m3 . Once formed, the ice is thicker because it contains enough salt. It slowly eliminates it and its density increases. When he loses it more salt is less dense than the resulting ice from freezing drinking water as it has more bubbles air. Discount (cut) of ice - discount of the iceberg The cutting of ice from one area is due to: to the homeless - to the currents of the sea

- to the melting - to the evaporation - in the movement of water After cutting, the ice cube or iceberg moves speed equal to 2 to 4% of the wind speed. In the Arctic the indicative value is 5Km / h. Factors affecting his movement: - Comfortable on its smooth surfaces and protrusions. - The sea currents in its submerged streams. - The Coriolis force that drives the icebergs to the right of the course in the B hemisphere and to the left in the N. Detachment of a huge iceberg The detachment of an iceberg the size of Manhattan (Size 7 cubic meters) had the opportunity to watch its creators documentary "Chasing Ice" during filming in the West Greenland. The iceberg detached from the "Jakobshavn Glacier" glacier.

The detachment lasted more than an hour and as stated by its member production crews' ice cubes were thrown from the ocean into height of 180 meters ". The documentary "Chasing Ice" studies glaciers and how they are affected by climate change. (related video) International Ice Patrol Organization dealing with the observation of the presence of icebergs in the North Atlantic and informs about their movements for reasons security. Operated by the US Coast Guard but supported economically from 13 countries, including Greece. It was founded in 1914, after the sinking of the Titanic. The information gathered is: -mainly from aircraft -from merchant ships -from buoys that record sea currents -from GPS tracking devices placed in some icebergs and thus their movements are monitored through satellites Ice detection Locating the ice on the ship is not easy and is achieved In the following Media: - Visual observations - Naval radar - Transmissions from coastal stations and ships - Remote sensing systems

TYPES OF SEA ICE

Sea ice is divided into two main types according to its mobility. One type is drift ice , which is reasonably free to move under the action of wind and current the other is fast ice, which does not move.

1. Floating ice in which the ice concentration is 4/10 - 6/10, with many leads and and where the flows are generally not in contact with one another, is called open ice.
2. Floating ice which the concentration is 7/10 to 8/10, composed of floes mostly in contact, is called lead.

3. Any fracture or passage way through which sea ice is navigable by surface vessels is called lead.
4. Pancake ice comprises of predominantly circular pieces of ice from 30 cm to 3 m in diameter, and up to about 10 cm in thickness, which raised rims due to the pieces striking against one another.
5. Bergy bits are pieces of floating glacier ice generally showing 1-5 m above sea level (a bergy bit is a large piece of ice that breaks off from an iceberg).


CANADA'S ICEBREAKING PROGRAM

The Canadian Coast Guard icebreaking program makes sure that marine traffic moves safely through or around ice-covered waters.

From December to May, icebreakers and hovercrafts operate along Canada's east coast from Newfoundland to Montréal and in the Great Lakes. From June to November, icebreakers provide services in the Arctic.

Canadian Coast Guard ice operations centers task our fleet of icebreakers and guide the movement of marine traffic through ice. With the support of the program, most Canadian ports are open for business year-round.

Services
Our staff and fleet operate out of multiple regions to deliver vital services in different sectors.

Route assistance
The program provides route assistance services, such as:

- freeing vessels beset in ice
- maintaining shipping routes
- escorting ships through ice-covered waters
- organizing convoys (escorts of 2 or more ships) to maximize services in favourable conditions

Ice routing and information services
We provide general routes to shipping and specific routes can be requested.

Harbour breakouts
Our harbour breakout services include:

- clearing ice from:
  - wharf faces of port terminals
  - facilities in commercial and fishing harbours
- breaking out approaches
- end-of-season ice clearance
- assisting shipping within ports and at marine facilities in emergencies

Flood control
The program provides flood control services by:

- helping ice flow during spring break-up
- breaking out river entrances to allow for ice and water flow
- anticipating flood risks by monitoring ice conditions and water levels
- protecting flood-prone areas by preventing ice jams and excessive ice buildup

Northern resupply
We resupply northern settlements and government sites with fuel and dry cargo when commercial carriers aren't available.

Arctic sovereignty
Our icebreakers help to maintain sovereignty in the Canadian Arctic by supporting the Canadian Coast Guard's programs, such as:

- Search and Rescue

- Environmental Response
- Marine Communications and Traffic Services

We also support our mandate by providing the following services:

- weather and ice information
- resupplying northern communities
- breaking out community approaches
- recommending ice routes across the Arctic
- platforms for scientific and hydrographic programs
- escorting ships and organizing convoys through ice
- reinforcing services to and reconciliation with Indigenous peoples

Clients
We hold pre-season meetings with clients to discuss their needs and our traffic expectations. These clients include:

- fishing vessels
- port operators
- Arctic residents
- the general public
- commercial vessels

Environment and Climate Change Canada's Canadian Ice Service forecasts seasonal ice conditions for us and the marine industry. We use this to anticipate any potential areas of concern and plan accordingly.

Our icebreaking program provides high-quality services by following these procedures:

6. developing and improving public standards for services by consulting with clients
7. continually improving the delivery of services to meet standards
8. accounting for performance against our standards
9. monitoring client satisfaction with services
10. providing accessible complaint and correction options when service standards aren't being met

Requesting an icebreaker
Contact your nearest MCTS station to make your official request. You **must** tell us if you need a routine escort or if you're in a distress or emergency situation.

Response time will depend on:

- the weather
- ice conditions
- the priority level of your request

- the amount of traffic needing assistance
- the number of available icebreakers in the area
- the suitability of available icebreakers to your request

When you request icebreaking services, we must determine if your vessel can navigate safely along its intended route. This policy pertains to:

- ferries
- pleasure crafts
- fishing vessels
- commercial ships

All requests for icebreaker assistance are assessed against established priorities and service standards.

HISTORY OF ICEBREAKING

Great Lakes
In 1842, a commercially owned passenger steamer called the *Chief Justice Robinson* was built in Niagara. It was the first Great Lakes vessel designed for icebreaking.

From 1906 in the Great Lakes, and possibly before, icebreaking requests were dealt with by local chartered tug boats. They managed the clearing of harbour approaches and channels.

East Coast
In 1855, Canada decided to provide support services to shipping off the east coast.

During the fall and spring, they used the *Queen Victoria* and the *Napoleon III* to tow sailing ships between the ice floes for salvage work and supplying lighthouses.

For 4 years, Canada funded these ships, and paid private contractors to operate them. However, this structure failed, and Canada took over the ships in 1859.

Prince Edward Island
Canada has provided icebreaking services off Prince Edward Island since 1873.

The first vessel employed off the coast of Prince Edward Island was the *Northern Light*. The *Stanley* and *Minto*, more capable icebreakers, followed. This ensured the area had a communication link with the rest of Canada during a vital period in Canada's history.

St. Lawrence River

While we were developing the icebreaker service in Prince Edward Island, we were making similar developments in the St. Lawrence River between Québec and Montréal. In this area, annual winter flooding made commercial development difficult.

Ice barriers, or dams, that formed in the narrow points of the river caused flooding. To decrease this flooding, we designed ships to break up the ice at strategic locations in the river and keep the ice moving down the deepest channels. In 1904, we ordered the icebreakers *Champlain* and *Montcalm* from Scotland. They performed this role effectively for many years.

An added benefit of the flood control activities was the ability of the river to be open for winter navigation. Other than a few exceptional days during abnormally severe weather conditions, the river has been kept open year-round as far as Montréal since the late 1950s.

This extension of the navigation season to Montréal increased the demand for icebreaker services throughout the Gulf of St. Lawrence and its ports. Icebreaking became more important in support of safety of shipping and increased the ability of Canada to trade with other maritime nations during the winter season.

Arctic region

In the 1920s we established regular Arctic patrols during the short summer navigation season due to:

- exploration of the Arctic, which peaked in the late 1890s
- the purchase of the *CGS Arctic* from the German government in 1904

We initiated patrols to respond to a number of needs, including:

- re-supplying isolated outposts
- providing services to native settlements
- backing up Canada's claims to sovereignty over the Arctic archipelago

During the 1930s the port of Churchill opened for grain export shipment through Hudson Bay. We provide them with icebreaker services at the beginning and end of each season.

At the beginning of the 1950s we built the first of the modern icebreakers to improve access to the north and supply defense sites and northern communities. This was partially due to the ‘cold war’ tensions at the time.

In 1957, we took over the annual resupply of Distant Early Warning Line sites spread across the Arctic. This added another dimension to the growing need for icebreaker services.

More recently, the extraction of raw materials, such as ores, crude oil and natural gas, has caused increased commercial activity throughout Canadian Arctic waters. This created more demand for icebreakers capable of northern operations.

Modern icebreaking

Since confederation, demand for icebreakers across Canada has steadily increased. As a result, our icebreaking services have evolved and developed to meet that demand.

What started as icebreaking 'between the ice' has gradually increased to include navigating during the entire ice season and aiding Arctic sovereignty.

Now, icebreaking services have shifted from mainly a safety and communications based activity. It now includes activities that directly support Canada's economy by extending the navigation season for continued maritime trade.

CRUCIAL EFFECTS FROM ICE TO VESSELS

Effect on Stability

Low temperatures can cause condensation of water vapour to ice, and icing can lead to additional weight on the hull, which will cause the loss of freeboard and buoyancy. Ice on masts, decks and cargo equipment, and superstructure may raise the center of gravity of the ship. Ships may even experience an asymmetric ice load, which will increase the roll moment and make the vessel excessively roll. It poses a risk to the personnel working on board and even to the ship itself. Besides, the deicing of ships is complex, time consuming and dangerous work. Freshwater ice originates from fog, rain or snow, while the seawater ice is formed generally when the air temperature is below minus 2 ℃ and there are strong winds. When the deck is frozen, people should be careful when moving and working on the ship. It is noteworthy that the ice may be formed on the outer surface of the ship, or in some of the internal space of the ship. Sea wave droplets on deck can usually be reduced by decreasing the speed and changing the course of the ship. Also, the excessive accumulation of ice should be prevented, and the 7 relevant risks should be avoided.

Effects on the Hull

- Material Selection In ships sailing in the environments at low temperature, the hull structure usually requires the selection of hull steel in accordance with the design service temperature. The risk of breaking the structure under small loads will increase if the material is designed to be brittle at the service temperature, and even if there are minor defects, such as welding defects. This danger manifests itself as: The toughness of carbon steel decreases with the decrease of the temperature, resulting in brittle fracture without deformation. To avoid the occurrence of the above brittle fracture, it is necessary to perform the toughness test of the corresponding hull material. The detailed requirements for such tests are usually found in the codes of each classification society (Kurniawan, 2015).

- The Structure and Layout of the Bow In the ice area, the ship's bow is the first point to contact the ice, so the ice design should be considered more. For instance, the transition between the stem post and the shell plate should be as smooth as possible, and the non-destructive testing is performed on the joint to further increase the anti-icing capability.

Merchant ships may need to balance the performance of ships in open water navigation and ice voyages. For instance, the bulb bow is installed to reduce the wave resistance. Yet the maneuverability is poor and easy to damage when operating in the ice area. In the FSICR, the stem post reinforcement is required to extend from the flat plate keel to 0.75m above the loading waterline. This is because the entire stem post area will also encounter ice load when the ship sails on the ice ridge, and even if there is icebreaker 8 assistance. When the ribs in the stem post area are not perpendicular to the shell plate, some tripping brackets are also required to withstand higher impact forces. The structure of the stem area should be properly strengthened in line with the operating requirements of the sailing ice area. It is advisable to have a bollard fitted to the towline on the deck so that the icebreaker can tow in the course of rescue.

- Ballast Tanks At moderately low temperatures, the problem the ballast tanks may be subject to is not the formation of ice on the surface of the ballast water, but the formation of ice in the ballast tank air pipe; During the operation of the ballast water, the risk of damage to the internal structure and accessories caused by the falling of ice suspended in the tank are noteworthy. A heating system is to be provided in the ballast tanks above the water line to prevent the formation of ice from the ballast water and cause damage to the deck and the side shell when the ship is sailing at low temperatures for a long time. For large oil tankers or ships with large ballast tanks, the risk of freezing ballast water will be reduced. Yet heating systems may be provided on the waterline in small tanks or other ballast tanks that are likely to be frozen. The height of ballast water loaded in ballast tanks must be considered. The volume of water produced was changed when the ballast water in the tank is fully frozen in order to avoid damage to the hull structure caused by the increase in volume when water forms ice. Given that the seawater does not fall to the same temperature as air does, the ballast temperature below the waterline will not fall below -5℃. Accordingly, ballast tanks below the water line do not provide a heating system and can also satisfy the winter operations, and generally do not form ice inside the piping system.

Stern Structure and Rudder 9 When cruising in an ice zone, the tail also bears the ice load (Xu, 2002). The rudder is especially susceptible to ice strikes at the tail. Under the large ice load, the rudder rake is required to be reinforced with additional structures.The rudder is both a machine and a hull structure as it needs to meet both of these design requirements. The trim serves as an effective means to reduce such dangers in ships, so that the susceptible hull area is not exposed on the ice. Yet this may cause the rudder stock and the steering gear to yield the additional torque due to the ice impact force. The scale on the rudder angle indicator is noteworthy when the ship is sailing towards the stern. If the angle is offset, the ship should be stopped promptly and then reversed after moving to the bow. Two major operational modes should be determined for ships sailing in ice area, i.e. intact ice and crushing ice. Because the smaller ice is easier to move, the force of the intact ice on the rudder is usually greater than that of the crushed ice. When the ship is sailing on the edge of the channel and ice ridge, it will yield significant ice load and can serve as intact ice. The ice loads must also be considered in full load and ballast conditions. The rudder horn may also face the impact of ice when turning.

- Exterior Coating of the Hull Ice will have a large frictional effect on the shell plate of the ship sailing in the ice area. Thus, a wear-resistant epoxy coating suitable for navigation in the ice area should be employed in the shell plate area of the ship. Yet the abrasion-resistant epoxy paints are difficult to adhere well to the shell plate, and minute cracks will be produced in the coating if the shell plate is a large non-stiffened plate frame. The entire coating system will fail after a period of time, so the greater the stiffness of the plate frame for the coating, the better it will be.

- Hull Attachments 10 Most ships will generally have bilge keels. Yet the bilge keel of a sailing ship in the ice area may be damaged by ice, and the structure connected to the major hull may be damaged under the damage of the bilge keel. To limit the damage caused by the partial loss of the bilge keel, it is optimal to design the bilge keel into several separate box configurations. Also, it is better not to install the keel in the front 1/3 of the ship's length. Likewise, the fin stabilizer will be particularly susceptible to ice damage. When the ships are sailing in ice areas, they are generally limited by ice. As most ships are sailing at low speeds, the use of fin stabilizers is not very obvious.

The Effect of Low Temperature on Engine Room To maintain the safety of the ship and the effective operation of the propulsion and auxiliary systems when the ship enters a cold climate area, the main engine, transmission device, shaft and propeller of ships should also be considered in line with the possible service conditions in the cold areas they serve.

- Main Propulsion System The ability to sail in the ice region depends to a large extent on the ice-breaking capacity of the ship. This is primarily dependent on the power of the main engine. Thus, there are specific requirements on the main engine power in the classification requirements of the classification society (Zhang, 2012) . For instance, the Finnish-Swedish ice class rules have a minimum power requirement on ships sailing in the Baltic Sea. The ice-breaker has a large power and displacement ratio, which is to overcome the frictional resistance of ice to meet the ship's need to break ice and move in the ice. Normally, the joint determination of ice area navigation and open water speeds are the primary driving force of non-icebreakers.

- Impact on Cooling Water System 11 When a ship sails in an ice zone, the blockage of the seawater cooling inlet is easy to cause, which will cause an accident in the absence of cooling water in the ship's main engine or generator. These accidents may lead to the failure of the entire ship's power, or lead to the stranding accidents. Accordingly, some deicing measures must be provided for the sea chest. For instance, a filter can be installed at the suction port, and the filter screen can serve as a filter to prevent ice blockage. A proper heating system can also be arranged at the suction port of the cooling system. The heating system of the sea chest should be inspected from time to time to confirm that it is in good working condition, and it is necessary to ensure that the heating system can run continuously when the ship is sailing in the ice-prone water. Ships sailing at low temperatures will cause damage to the main engine, when the hull is severely over-cooled. The number of chillers in the operation of the main engine should be increased, the cooling temperature should be raised, the load of the air cooler should be adjusted, and the exhaust gas temperature should be monitored to ensure that it is always within the limits. The correct cooling water temperature should be used and all valves and pumps should be checked to ensure that the cooling system is in ice service before the ship enters the ice area when a recirculating cooling system is installed on the ship.

- Propeller The general advantage of a fixed pitch propeller is that the propeller is simple and strong, whereas it is difficult to make a paddle that meets the requirements of the ice zone. The use of controllable pitch propeller helps maintain a constant engine load; yet the disadvantage is that the pitch will decrease at low speeds, which increases the time for the ship to resume sailing in the ice ridge. The use of all-direction propeller and podded propulsor（POD） can increase the maneuverability and reduce the weight and size. It is now applied in plenty of Finnish icebreakers, yet it is expensive. 12 It has been proved practically that the propeller with independent blades is more suitable for the ships in the ice area in comparison with the propeller with integral casting. This is because there may be cases in some damage accidents where only a single blade is damaged while the other blades are still operational. Another benefit of this type of propeller design is that a single damaged blade can be replaced by the trim of the vessel without the ship entering the dock for repairs. In all ballast conditions during the ship sailing, the propeller should be able to be fully immersed under ice. The immersion of the propeller at this time suggests that when there is a minimum tailing and sufficient draft, the distance from the top of the propeller blade to the waterline is greater than the thickness of the ice layer. Yet this may limit the size of the propeller diameter, which results in the design of a double propeller arrangement.

- Bow Thruster If equipped with bow thrusters, ships sailing at low temperature should avoid using under severe ice conditions because ice may cover the thruster’s louvers. Otherwise the water will be prevented from entering the bow thruster system. Additionally, the all-direction propeller unit can be configured to replace the bow thruster as it can be retracted in the main hull while sailing in the ice zone and the shell plate can remain smooth after retraction.

- Generator Ships sailing at low temperatures should ensure that generators and emergency generators and their auxiliary equipment can work normally under the extreme cold conditions. Given the aim of normal operation, an additional heating unit can be provided to protect the coils at extreme cold temperatures from freezing. The emergency generator cylinder liner should be equipped with an electric heater with a temperature regulation function, and it should be ensured that the generator can transmit the load promptly. Also, the additional space heating 13 must be provided in the emergency generator room to ensure that cool air from the ventilation system reaches a certain temperature when entering the generator room. Additionally, the electric heating methods are used in many anti-icing measures for ice navigation. This part of electricity should be considered when the capacity of the generator is calculated, so as to avoid the shortage of generator capacity.

- Cable Cables outside the living area and engine room should ensure that the cable material is not damaged by cold temperatures when they are exposed to cold air. For this purpose, the cable may require the use of a special material housing or covered insulation. For cables on open decks, it may be necessary to install them in galvanized or glass-steel sealed terminal boxes with a drain function. Besides, the distributing box and distribution board located outside of the engine room and living area may require a space heater.

- Compressed Air System If the ice is formed in a common air system, ships sailing at low temperatures may have problems. Air supply equipment onboard can be problematic. It is advisable that all air systems be equipped with dryers.

- Engine Room Ventilation System Vessels sailing at low temperatures may consider stopping all ventilation equipment except the main engine room ventilators to maintain a reasonable design temperature of the cabin. To maintain the normal operation of the boilers, main engines and auxiliary engines, ventilation should be provided to maintain air flow when these devices cannot be provided with independent ventilation ducts. 14 .Yet it should be ensured that the vents of the main unit ventilation system are not directly blown onto the fuel lines and the heavy fuel delivery systems. Also, the pneumatic and manual vent covers should be inspected frequently to ensure they are operating properly to prevent freezing or jamming (Tang, 2014) .

- Emergency Batteries and Battery Compartments The emergency battery of communication equipment should be properly protected to ensure that it is not affected by the extremely low temperatures. Batteries generally do not freeze at low temperatures, but they can be covered with a plastic film to prevent getting frozen.

- Fresh Water Tanks and Distilled Water Tanks In ships sailing at low temperatures, the water in the gauge glass of these tanks should be drained as far as possible when there is no water in the fresh water tanks and the distilled water tanks. All lines in the storage tank should be completely drained if you do not use evaporation equipment. The temperature of the water in the storage compartment should be monitored, and the water entering the storage compartment should be maintained at a suitable temperature. The supply line from the fresh water tank to the booster pump is generally easy to freeze, and precautions should be taken according to its location.

- Lubricating Oil Ships sailing at low temperatures should be determined to use only oil and grease meeting the expected temperature. Diesel can be mixed with kerosene to decrease the melting point.

Impact of Low Temperature on Cargo System

Before entering the cold area, the valve ports of all cargo systems and other auxiliary systems must be inspected to determine that there is no water in the driving gear box and that there is an excellent lubrication. If there is a small amount of water in the gear box and bonnet, it will be frozen with the fall of the temperature, which will adversely impact the valve body, and in extreme cases it will make the valve freeze or even fail to open.

- Deck Piping Deck piping can be affected by low temperatures, and such problems on oil tankers can be especially serious. The low temperature will cause a certain temperature difference between the air and the cargo because there are a considerable number of deck lines on the tanker, which will cause thermal expansion of the loading line. This deformation will be generally smaller in the longitudinal direction than the deformation caused by the sagging and hogging 16 in the ship. Thus, the longitudinal pipeline generally is not required to consider any special design. Yet the design of the fixed support of the transverse deck pipeline should consider the effect of the expansion of the pipeline caused by the temperature difference.

- PV Valves The entire PV valve should be comprehensively inspected before the ship enters the cold area. To avoid the accumulation and growth of ice, Canopy protection or steam heating measures can be used on the line valve. At extremely low temperatures, the canvas cover is more effective than the steam heating protection, yet the use of a canvas cover should ensure that it does not interfere with the effective operation of the PV valve. Quick acting valve base surface enables antifreeze paint to not get frozen in the closed position, which can effectively prevent the formation of ice film.

- Vacuum Circuit Breakers The vacuum circuit breaker of the PV valve should be filled with antifreeze liquid according to the instructions of the manufacturer before the ship enters the freezing temperature. Also, the concentration control of the glycol in the circuit breaker is crucial. When the concentration is too high, it may fail. To ensure that the circuit breaker remains in proper working condition, the concentration of antifreeze should be regularly checked. Once out of the cold navigation zone, the liquid density in the vacuum circuit breaker should be readjusted to the concentration required for operation at normal air temperature conditions.

- Inert Gas Discharge Columns The inert gas discharge column and inert gas line should drain all liquid before the vessel arrives in port. To ensure there is no ice on the fire protection network, fire network should be inspected before loading and unloading cargo. Grease and canvas cover are applied for protection if there are automatic and manual valves on the injection line of inert gas and oil 17 tank. The pipe diameter of the general inert gas discharge column should not be less than 50mm.

- Cargo Pump To avoid the ice removal before unloading and prevent the delay in loading and unloading, the engine and bearing shall be protected by canvas cover if a deep well pump is installed on the deck；Submerged hydraulic pump system, hydraulic oil should be able to work below -25 ℃；When the vacuum system is employed to strip the system, the pump and the water supply tank should be protected to prevent the freezing. Anti-freeze ingredients can be added to the water to ensure the safety of operation according to the manufacturer's recommendation. The freeze-thaw ingredients can be added to the water to ensure safe operation according to the manufacturer's recommendation.

- Cleaning System The water in the seawater washing line should be drained and separated from the drive system. Check the branch pipes of the cleaning system to minimize the amount of residual water in the piping if the cargo compartment needs to be cleaned in a cold area.

- Heating Coils in Cargo Holds Ships sailing at low temperatures should be drained and air dried inside the pipeline if they are not using heating coils. The steam line should be closed to avoid the occurrence of blockages, and it is best to be isolated from the main line.

- Pump Room Ships sailing at low temperatures should minimize the influence of temperature on the pump room. The port of the pump room should be kept as closed as possible to ensure that the temperature in the pump room is minimized by the ambient temperature. Steam lines in pump 18 rooms should be drained, which include those connected to heaters. If a pump room heater is fitted, it should remain on constantly. If there are heaters on different levels of the platform, use at least one on each platform, which help maintain a suitable temperature in the pump room.

- Oil Discharge Monitoring System (ODME) ODME's freshwater supply system and pumps should be drained together in ships sailing at low temperatures. Because the system is susceptible to failure or damage in cold climates, special care should be taken when disconnecting and draining the ODME

Effect on Deck Equipment

All deck equipment should be considered to maintain operational capacity under extreme cold weather conditions and provide appropriate deicing measures and corresponding protection.

- Hydraulic Equipment The operating temperature range of the hydraulic oil should be highlighted by ships sailing at low temperatures, hydraulic equipment on deck, such as winches and lifting equipment. The control box is protected by a canvas cover. The ship should be operated and tested before it enters the sub-zero temperature. And all equipment with heating devices should be carefully checked, such as heating equipment in the crane cab. For a hydraulic drive system, when the ambient temperature is below 0 °C, the system should be continuously cycled to ensure that the hydraulic fluid remains at operating temperature.

-Mooring Line Ice may be formed in unprotected mooring lines and may damage the fibers of the cable at 19 low temperatures. Accordingly, the mooring line is protected by a canvas cover to prevent ice from forming inside the mooring line before use.

-Mooring Arrangement When the ship is sailing at low temperatures, the mooring winches and windlass on the ship in the bow area are particularly easy to freeze. Windlasses and winches can cause severe ice accumulation as they are exposed. Before reaching the port, windlass and winch should be ensured to be operable, which may require additional time to clear the accumulated ice.

- Deck Scupper Ships sailing at low temperature shall employ the anti-freezing measures for the deck scupper to prevent it from being covered by ice and ensure cooperation with the hole plug.

- Other Equipment on the Deck The motor employed to lift the gangway should provide adequate protection against ice accumulation. Also, some small deck fittings may have ice and snow accumulated, and antifreeze and deicing measures should be provided.

Effect of Low Temperature on Lifesaving Equipment

Life Raft All life rafts provided by ships at low temperatures should be ensured to operate safely under anticipated environmental conditions. Snow and ice accumulated on life rafts and landing equipment should be removed frequently to keep them available. 2.6.2 Lifeboats and Rescue Boats

- Hull and Release Device 20 Ships sailing at low temperatures shall employ the deicing measures for lifeboats, rescue boats and their launching devices. Deicing hammers near the life/rescue boat should be easy to be available. The permanent damage to the equipment should be avoided particularly when a deicing hammer is used. The colloidal shell of lifeboats should be checked comprehensively before the ship enters the ice area, especially to ensure the connection between the inner and outer fibers of the gliding shell is intact. If the lifeboat is equipped with a heater, it should always be on during the navigation to ensure that it is not frozen in the closed position.

- Engine The lifeboat engine on board the ship should be ensured to be ready for use at all times, and it can be started within 2 min in the expected low temperature environment. The lifeboat engine start-up procedure may differ from the normal start-up procedures in extreme cold conditions. All personnel who may be involved in starting the engine under low temperature conditions should learn the start-up procedure to ensure that they generally understand the operation. The engine should employ the suitable diesel or kerosene to prevent wax from the fuel system. When the fuel is replaced, the fuel tank and fuel line should be thoroughly cleaned. The engine should be tested and ready for use when the new fuel is replaced.

- Cooling Water System For ships sailing at low temperatures, antifreeze fluid is applied for protection if the lifeboat cooling system is an independent self-circulation system. If the system is not independent, it should be checked regularly to ensure the system is normal.

- Drinking Water Harmless antifreeze measures should be taken for drinking water stored in lifeboats before the ship enters the ice area. 21

- Free Fall Lifeboat It is unsafe to drop the free fall ship in the ice area. It is necessary to use the ship's engine or other methods to perform icebreaking before proceeding.

- Immersion Suits and Insulation Equipment For ships sailing at low temperatures, the operating temperature for the design of the suit usually ranges from -1.9 ℃ to 35℃. Immersion suits should increase the low temperature insulation performance as much as possible. Insulators should also be applied at low temperatures.

- Lifebuoy It should be ensured that the equipped lifebuoy in ships sailing at low temperatures will not be frozen in the storage position and be free to move and use.

- Respirator and Oxygen Treatment Equipment When the oxygen breathing or resuscitation apparatus is employed at low temperature, the possible danger of the freezing of the gas supply valve and the expiratory valve due to the water vapor from the user is noteworthy. Additionally, the low temperature (below -4℃) may cause lung tissue frostbite in ventilator users.

- Helmet The safe use temperature range of the safety helmet provided by the ship must be marked by the manufacturer in the cap under the cold environment. The crew should select a safety helmet that matches the ambient temperature

<u>Effects of Low Temperature on Fire Fighting Systems and Equipment</u>

Due to the accumulation of ice or snow or low temperatures, the design or layout of fire fighting systems must be easy to operate in ships sailing at low temperatures.

- Detection system The exhaust port and vacuum pressure valve of the detection system should be properly protected to prevent the formation of ice and ensure the effective operation of the fire fighting system.

- Portable Fire Extinguishers and Foam Equipment In extremely cold environments, portable fire extinguishers located in exposed areas are susceptible to freezing. The low temperature can easily make the foam fire extinguisher to fail though it is generally considered that CO_2 fire extinguishers can perform safe and effective operations at temperatures above -20 ℃. This is because the foam mixture may not be used due to the low temperature when the foam fire extinguisher is thawed. At these extreme temperatures, the contact with any part of the fire extinguisher or exhaust gas during operation should be avoided to prevent low temperature burns on the human body. Unprotected foam and water fire extinguishers, safe and effective operating temperatures are generally above 1℃. Yet the effective operating temperature of water and foam fire extinguishers can drop to -20℃ if specific additives are used. The operator should refer to the data provided by the manufacturer of the fire extinguisher to check if the use of the fire extinguisher is limited under actual conditions.

- Hoses and Nozzles The safe operating temperature of hoses for general marine fire-fighting systems is above -20℃, and the nozzle is above -25℃. Dedicated hoses can be applied at -40 ℃ and marked by special signs. The vessel selects hoses and nozzles in accordance with the lowest 23 temperatures that may be encountered during the voyage.

- Pipeline When ships sail at low temperatures, to ensure fire-fighting water and foam piping on deck are ready for use, they should be well drained and maintained. Fire hydrants and all other moving parts should be well lubricated and protected with a canvas cover to prevent them from being used immediately due to ice and snow accumulation. Storage tanks for fixed foam extinguishing systems probably need to be heated, or temporary space heaters can be considered to maintain sufficient temperature.

- Fire Hose Box Fire hose box clips, locks and chains should be kept free of ice; water mist nozzles and connections should be well lubricated and dried. All hoses should be completely drained before the storage to avoid damage caused by low temperatures and ensure that they can be used promptly

The Effect of Low Temperatures on the Living Compartment and Channel

The function of the crew cabin must be complete and suitable for living in the low temperature environment. The crew work and the escape passage must also meet the requirements that can be applied in the low temperature environment.

- Insulation To meet the living requirements under low temperature conditions, heating systems should be provided in the cabin, which include the air conditioning systems and the auxiliary heating systems. To reach the design temperature of the cabins in the ice area, outside walls and ceilings of cabins shall be provided with special insulation measures, such as adding 24 insulation layers.

- Channel The safe access to the bow can be protected by a box structure or under deck. Emergency escape routes should also take certain anti-freeze measures to ensure the safety of personnel when passing through.

- Ventilation System The ventilator of the cabin is exposed to the outdoor environment when the temperature of the outdoor environment is very low. The inner surface temperature of the ventilator may be very low through heat conduction. When the inner surface temperature is lower than the dew point temperature of the inner air, a considerable amount of condensate steam will be produced on the inner surface of the ventilator, and the ice will be formed when the water temperature is below zero.

The Influence of Low Temperature on Navigation Equipment

-Navigation Light The navigation light is an essential navigation device, and the side lights and mast lamp must be visible at all times during the navigation of the ship. In the ice area, the navigation light of the ship can cause ice formation due to the spray of the waves, which will pose hidden dangers to the safety during the navigation. Thus, it is also necessary to provide some methods for deicing and snow melting.

- Radar and Antenna Radar and antennas are also important equipment for navigation. Under severe weather conditions, there is also the possibility of icing, which will threaten the safety of sailing ships. 25 Therefore, for radar, satellite communications, and antennas, it is also necessary to use a certain amount of protection.

- The Window of the Bridge The formation of frost and ice on the bridge window can affect the driver's eyes. In the ice area, it is particularly necessary to pay attention to the antifreeze and deicing treatment of the bridge window.

The Impact of Low Temperatures on Personnel

- Damage to Exposed Persons Prior to entering the ice area, the ship should customize and provide a sufficient number of winter clothes, including polar clothing and hats, snow goggles and underwater warm equipment. In order to prevent people from being sunburned, the windows of the bridge should be equipped with a sun filter and should be equipped with a sufficient amount of sunscreen lotion, anti-cracking lipstick and protective cream before entering the ice zone.

- Train The captain and chief engineer should participate in the training of ice sailing courses and have ice sailing experience. If conditions are met, relevant course training may be extended to ordinary seafarers.

- Crew Activities Ships sailing at low temperatures are likely to freeze on the passageway, and personnel should be especially careful when walking on board and should keep one hand free as much as possible. There should be anti-freezing measures or anti-skid treatment on the passages, which can be treated by heating, salting or sanding. 26

- Deck Watcher The deck watchers in cold weather should shorten the shift time and provide appropriate shelter. In the meantime, the deck watchers should try to rest as much as possible in the living area and ensure that hot food and drinks can be supplied directly to avoid the occurrence of hypothermia symptoms.

- Crew Fatigue When the ship is sailing in the ice area and operating at the terminal, duty schedules should be properly established to ensure that all crew members have enough rest periods. 2.10.6 Voyage Planning Ships traveling at a low temperature should develop a navigation plan based on ice information from reliable sources. The reliable and effective ice area information may include navigational warnings, ice distribution maps, Baltic Sea weekly ice status reports, navigation manuals, marine meteorology, etc.

CAUSES AND EFFECTS OF THE SINKING OF THE TITANIC

The Titanic was a White Star Line steamship built in the early nineteen hundreds by Harland and Wolff of Belfast, Ireland. At the time of her construction, she was the largest moving object ever built. With a weight of more than 46,000 tons, a length of nearly 900 feet, and a height of more than 25 stories, she was the largest of three sister ships owned by the White Star Line [Division, 1997]. The Titanic was also equipped with the ultimate in turn-of-the-century design and technology, including sixteen major watertight compartments in her lower section that could easily be sealed off in the event of a punctured hull. Because of her many safety features and a comment by her designer that she was nearly unsinkable, the Titanic was immediately deemed an unsinkable ship [Gannon, 1995].

On April 10, 1912, the Titanic commenced her maiden voyage from Southampton, England, to New York, with 2227 passengers and crew aboard [Division, 1997]. The passengers included some of the wealthiest and most prestigious people at that time. Captain Edward John Smith, one of the most experienced shipmasters on the Atlantic, was navigating the Titanic [Rogers and others, 1998]. On the night of April 14, although the wireless operators had received several ice warnings from others ships in the area, the Titanic continued to rush through the darkness at nearly full steam. A time line of the events that followed is shown in Table 1. At 11:35 p.m., the lookouts spotted a massive iceberg less than a quarter of a mile off the bow of the ship. Immediately, the engines were thrown into reverse and the rudder turned hard left. Because of the tremendous mass of the ship, slowing and turning took an incredible distance, more than that available. At 11:40, without enough distance to alter her course, the Titanic sideswiped the iceberg, damaging nearly 300 feet of the right side of the hull above and below the waterline

The damage caused by the collision allowed water to flood six of the sixteen major watertight compartments. As water rushed into the starboard side of the ship's bow, the ship began to tilt down in front and slightly to the right. By midnight, water in the damaged compartments began to spill over into others because the compartments were watertight only horizontally and the walls extended only a few feet above waterline. By 1:20 a.m., water began flooding through anchor-chain holes. Around 2:00, as the bow continued submerging, the propellers in the stern were lifted out of the water. Flooding progressed until, at about 2:10, the bow of the ship was under water and the stern was lifted out of the water almost 45 degrees. Because of the tremendous weight of the three large propellers in the stern of the ship, the stresses in the ship's midsection increased immensely as the stern was lifted out of the water. At an angle of 45 degrees or more, the stresses in the midsection exceeded the ultimate stresses of the steel and the steel failed [Gartzke and others, 1994]. Stresses at failure were estimated at nearly 15 tons per square inch [Gannon, 1995]. What survivors of the disaster then described was a loud noise that sounded like breaking China or falling equipment [Hill, 1996]. This noise can be attributed to the tearing and disintegration of the Titanic's upper structure. By 2:12, with the bow and stern attached by only the inner bottom structure, the stern angled high out of the water. The bow, dangling beneath, continued to fill with water. At 2:18, when the bow reached a weight of about 16,000 tons, it ripped loose from the stern. Free from the weight of the bow, the stern rose again sharply to an almost vertical position. Slowly filling with water, the stern began to sink into the water. At 2:20, the stern slid beneath the surface. Meanwhile, the bow had been coasting down at about 13 miles per hour (mph). At 2:29, the bow struck the bottom of the ocean. Falling nearly vertical at about 4 mph, the stern crashed into the ocean floor 27 minutes later.

The two pieces of the Titanic lie 2,000 feet apart, pointing in opposite directions beneath 12,500 feet of water. The bow section remains mostly intact, although the damaged portion of the hull is covered with a 35-foot high wall of silt and mud that plowed up when the Titanic hit bottom, so the point of fracture can not be seen. The stern section is a tangled wreck, as implosions occurred during the descent due to air trapped within the structure succumbing to the increased water pressure at greater depths. Between the two sections is a wide field of debris [Hill, 1996].

For 73 years, the Titanic remained undisturbed on the ocean floor. On September 1, 1985, oceanographer Bob Ballard and his crew discovered the wreck of the Titanic about 350 miles southeast of Newfoundland, Canada [Gannon, 1995]. Since then, four more expeditions have visited the Titanic. In 1991, the first purely scientific team visited the site. The dive was called the Imax dive because the purpose was to create a film for Imax theaters. The Soviet submersibles used in the dive were capable of staying submerged for twenty hours and were equipped with 110,000-lumen lamps. With this equipment, scientists were able to take pictures of the Titanic wreck and eventually uncover new evidence into the cause of the Titanic disaster.

CAUSES OF THE RAPID SINKING

On an expedition in 1991 to the Titanic wreck, scientists discovered a chunk of metal lying on the ocean floor that once was a part of the Titanic's hull. The Frisbee sized piece of steel was an inch thick with three rivet holes, each 1.25 inches in diameter [Gannon, 1995]. Since the retrieval of this piece of steel, extensive research has been done to uncover additional clues to the cause of the rapid sinking of the Titanic. The following is a discussion of the material failures and design flaws that contributed to the disaster.

Material Failures

When the Titanic collided with the iceberg, the hull steel and the wrought iron rivets failed because of brittle fracture. A type of catastrophic failure in structural materials, brittle fracture occurs without prior plastic deformation and at extremely high speeds.

The causes of brittle fracture include low temperature, high impact loading, and high sulphur content. On the night of the Titanic disaster, each of these three factors was present: The water temperature was below freezing, the Titanic was travelling at a high speed on impact with the iceberg, and the hull steel contained high levels of sulphur.

The Hull Steel.

The first hint that brittle fracture of the hull steel contributed to the Titanic disaster came following the recovery of a piece of the hull steel from the Titanic wreck. After cleaning the piece of steel, the scientists noted the condition of the edges. Jagged and sharp, the edges of the piece of steel appeared almost shattered, like broken China. Also, the metal showed no evidence bending or deformation. Typical high-quality ship steel is more ductile and deforms rather than breaks [Gannon, 1995].

Similar behavior was found in the damaged hull steel of the Titanic's sister ship, Olympic, after a collision while leaving harbor on September 20, 1911. A 36-foot high opening was torn into the starboard side of the Olympics' hull when a British cruiser broadsided her. Failure of the riveted joints and ripping of the hull plates were apparent in the area of impact. However, the plate tears exhibited little plastic deformation and the edges were unusually sharp, having the appearance of brittle fractures [Garzke and others, 1994].

Further evidence of the brittle fracture of the hull steel was found when a cigarette-sized coupon of the steel taken from the Titanic wreck was subjected to a Charpy test. Used to measure the brittleness of a material, the Charpy test is run by holding the coupon against a steel backing and striking the coupon with a 67 pound pendulum on a 2.5-foot-long arm. The pendulum's point of contact is instrumented, with a readout of forces electronically recorded in millisecond detail. A piece of modern high-quality steel was tested along with the coupon from the hull steel. Both coupons were placed in a bath of alcohol at -1°C to simulate the conditions on the night of the Titanic disaster. When the coupon of the modern steel was tested, the pendulum swung down and halted with a thud; the test piece had bent into a "V." However, when the coupon of the Titanic steel was tested, the pendulum struck the coupon with a sharp "ping," barely slowed, and continued up on its swing; the sample, broken into two pieces, sailed across the room [Gannon, 1995]. Pictures of the two coupons following the Charpy test are shown in Figure 1. What the test showed, and the readout confirmed, is the brittleness of the Titanic's hull steel. When the Titanic struck the iceberg, the hull plates did not deform. They fractured.

microstructural analysis of the Titanic steel also showed the plausibility of brittle fracture of the hull steel. The test showed high levels of both oxygen and sulphur, which implies that the steel was semi-kilned low carbon steel, made using the open-hearth process. High oxygen content leads to an increased ductile-to-brittle transition temperature, which was determined as 25 to 35°C for the Titanic steel. Most modern steels would need to be chilled below -60°C before they exhibited similar behavior. High sulphur content increases the brittleness of steel by disrupting the grain structure The sulphur combines with magnesium in the steel to form stringers of magnesium sulphide, which act as "highways" for crack propagation. Although most of the steel used for shipbuilding in the early 1900s had a relatively high sulphur content, the Titanic's steel was high even for the times [Hill, 1996].

The Rivets.

The wrought iron rivets that fastened the hull plates to the Titanic's main structure also failed because of brittle fracture from the high impact loading of the collision with the iceberg and the low temperature wa A ter on the night of the disaster. Figure 2 shows the Titanic during her construction, with the riveted hull plates of her stern visible. With the ship travelling at nearly 25 mph, the contact with the iceberg was probably a series of impacts that caused the rivets to fail either in shear or by elongation [Garzke and others, 1994]. As the iceberg scraped along sections of the Titanic's hull, the rivets were sheared off, which opened up riveted seams. Also, because of the tremendous forces created on impact with the iceberg, the rivet heads in the areas of contact were simply popped off, which caused more seams to open up. Normally, the rivets would have deformed before failing because of their ductility, but with water temperatures below freezing, the rivets had become extremely brittle.

When the iceberg tore through the hull plates, huge holes were created that allowed water to flood the hull of the ship. As a result, rivets not in the area of contact with the iceberg were also subjected to incredible forces. Like a giant lever, the hull plates transferred the inward forces, applied to the edges of the cracked plates by the water rushing into the hull, to the rivets along the plate seams. The rivets were then either elongated or snapped in two, which broke the caulking along the seams and provided another inlet for water to flood the ship.

Design Flaws

Along with the material failures, poor design of the watertight compartments in the Titanic's lower section was a factor in the disaster. The lower section of the Titanic was divided into sixteen major watertight compartments that could easily be sealed off if part of the hull was punctured and leaking water. After the collision with the iceberg, the hull portion of six of these sixteen compartments was damaged, as shown in Figure 3. Sealing off the compartments was completed immediately after the damage was realized, but as the bow of the ship began to pitch forward from the weight of the water in that area of the ship, the water in some of the compartments began to spill over into adjacent compartments. Although the compartments were called watertight, they were actually only watertight horizontally; their tops were open and the walls extended only a few feet above the waterline [Hill, 1996]. If the transverse bulkheads (the walls of the watertight compartments that are positioned across the width of the ship) had been a few feet taller, the water would have been better contained within the damaged compartments. Consequently, the sinking would have been slowed, possibly allowing enough time for nearby ships to help. However, because of the extensive flooding of the bow compartments and the subsequent flooding of the entire ship, the Titanic was gradually pulled below the waterline

The watertight compartments were useless to countering the damage done by the collision with the iceberg. Some of the scientists studying the disaster have even concluded that the watertight compartments contributed to the disaster by keeping the flood waters in the bow of the ship. If there had been no compartments at all, the incoming water would have spread out, and the Titanic would have remained horizontal. Eventually, the ship would have sunk, but she would have remained afloat for another six hours before foundering [Gannon, 1995]. This amount of time would have been sufficient for nearby ships to reach the Titanic's location so all of her passengers and crew could have been saved.

Important Points for Ice Navigation of Ships

1. Manoeuvring in Ice

Navigating in ice waters can be a real task for ships, as the later moves cracking and smashing through the frozen and frigid seas. While moving towards subzero temperature with ice covered waters, the ship's captain has to be extremely cautious and must pay utmost attention to the type of ice, thickness, and its exact location in the subzero navigation areas. If there's any kind of misjudgment during ice navigation, a detour from the navigable route would lead to additional fuel wastage and might also get the vessel stuck in thick ice leading to dangerous situation and damage.

The existence of ice on seawater corresponds to a major restraint for ships and offshore operations at high latitudes in both the hemispheres. The sea-ice, which on an average is 2–3 m thick, can be pierced only by specially designed ice-strengthened vessels or icebreakers with an appropriate ice class.

Most merchant ships and fishing vessels which are not ice-strengthened must consequently keep away from all ice waters and sub-temperature areas. In many places, where the concentration of ice is maximum and the ice pressure is highest, even the most powerful of the icebreakers have problems with ice navigation.

To avoid such mishaps during ice navigation, an ice pilot and ice breakers are normally provided for commercial vessel operations which help to safely guide the vessels through the ice field to and from their destinations. In addition to the ice pilot being on board and the ice-breaker's relentless assistance, a few other measures must be kept in mind by the vessel's crew during the ice navigation.

First of all, it is imperative to understand that if any alternative route is available for the ship, ice water should be avoided at all costs. However, if ice navigation is inevitable, it should be made at right angles to the leeward edge where the ice is loose or broken. While manoeuvring through ice if a floe cannot be avoided then it should be hit squarely with the stem. Note that a glancing blow may damage the ship's shell plating or throw the vessel off course causing another unavoidable blow.

Entry in ice should always be done at low speeds to avoid any sort of damage. Once into the pack, the vessel’s speed can be increased so as to maintain headway and control so as to never lose all way off and avoid the ice floes to close in on the hull, rudder and propeller.
If the ship is stopped by heavy concentration of ice the rudder should be put amidships and the engines should be kept turning slowly ahead. This will wash away the ice that is accumulated astern and will help the vessel to fall back.
In a close pack during ice navigation, avoid sharp alterations of course and keep the speed enough for steerage way. Full rudder movements should be avoided or used only in cases of emergencies.

1. Manoeuvring in Ice
Always keep vigilant lookout for leads (navigable channel within an ice field) through ice. Additional lookouts should be posted forward or at higher ends for safety concerns. Conning should be carried out from the ship’s bridge to get a better view of the ice accumulation.
Keep in mind that at all times the stern must be observed for rudders’ movement so as to avoid a floe from actually moving the stern towards it. In such cases, it is advised to post men right aft with torches, whistles, walkie-talkies, etc. to make sure that the bridge is informed immediately in case the propeller is in any kind of danger. This is extremely important in twin screw vessels. Reduce speed if the ice goes under the ship.

3. Engine care
During ice navigation, engines should be kept running at all times and under maneuvering conditions in such a way that the ahead and astern movements can be easily carried out without time delay. Similarly, engine movements from ahead to astern and vice-verse should be made cautiously to avoid stressing the engine mechanisms in low temperatures, which could be unfavorable to the ship’s engine parts. Also, when ice approaches the stern of the vessel while maneuvering bursts of the engines should be given accordingly to keep ice from accumulating.

4. Navigation at Night
As far as possible, avoid navigating through ice at night. It is preferred to “heave to” since the leads or lanes cannot be seen. Most ice navigators stop the vessel along the edge of the ice and leave the vessel drifting along with the pack.
At nights, seawater lubricated tail end shafts are in the danger of getting frozen. To avoid from freezing, vessels with single screws should have their aft peak tank filled with water and have it kept warm by means of steam hose injection, or other alternative means. The vessel should keep her engines running with propeller on low RPM so as to avoid seizure by ice.

5. Anchoring
Anchoring in heavy concentrations of ice should be avoided; if ice is moving then its force may break the cable. When conditions permit, anchoring can be carried out and it must be done in light brash ice, rotten ice or widely scattered

floes with the main engine on immediate notice. Anchor should be brought in as soon as the wind threatens to move ice onto the vessel.
Even with the advent of new techniques and technologies for ice navigation such as radar sensor images through cloud cover, infra-red images, and satellite images for a larger view of the surroundings around the vessel, it is vital to understand that ship's operations of any sort under the influence of sea-ice are not only dangerous but also life threatening, and utmost care must be taken while navigating through such ice areas.

OPERATIONS IN ICE

For vessels intended to operate in ice, it is important to be able to distinguish between the different ice types that may be encountered, both for efficiency and or safety. The two most fundamental properties of ice cover are thickness and age, both of which are reported on standard ice charts using World Meteorological Organization (WMO) terminology and symbols, as outlined in Appendix 10, Table 1. Other terminology is also used, particularly for the initial freezing stages, including frazil, grease, shuga, and slush ice.
These are all thin forms of ice cover that will normally be reported as new ice. Ice services use a number of techniques to derive the thickness of ice cover, but all of these are approximate. The symbols on ice charts should always be treated with some caution. Old ice is ice that has survived one or more melt seasons. It encompasses both second-year and multi-year ice, but the term multi-year is frequently applied to either old ice form. Multi-year ice becomes much stronger than first year ice, due in part to its reduced salinity. Floes also tend to have much more variable thickness than younger ice, as they incorporate weathered ridges and other features.
This and other features help experienced ice navigators to distinguish between first-year and multi-year ice. Ice "of land origin" is generally glacial ice, formed over thousands of years by the accumulation and re-crystallization of packed snow. Ice islands and icebergs enter the sea from glaciers and ice sheets, and may in turn 'calve' smaller bergy bits and growlers as they degrade. Glacial ice is very hard, and represents a major hazard for vessels with even the highest level of ice capability. Growlers and bergy bits have small freeboards, and can be very difficult to detect either when part of the general ice cover or in open water with moderate sea states. Due to their origin, they are usually found in proximity to icebergs, whose own presence is a good indicator of the potential risk of encountering these smaller fragments.
Ice cover is very rarely uniform or homogeneous. Near the coast, ice may be 'land fast', anchored in place by the shoreline and possibly by grounded pressure ridges. Land fast ice tends to have relatively consistent properties, but may still include ridges and rubble piles.
At the edge of the land fast ice, shear zones may occur where the free-floating pack and land fast ice collide. The shear zone can be a chaotic amalgamation of ridging and rubbling. It can be both difficult and dangerous to transit, especially if the pack is in motion at the time. Even the most powerful ice breakers have become trapped, and less capable vessels have suffered damage

or been sunk by pressure events in shear zones. Shear zones should be transited, where necessary, with extreme caution.
The general ice pack is typically a mix of ice types, thicknesses and floe sizes at various total ice concentrations. Patches or stretches of open water can be found even in the winter polar pack as floes move relative to each other. In some areas, more or less permanent polynyas of open water exist due to water upwelling. When ice floes move against each other, they may raft, increasing local thicknesses, form rubble, or generate ridging. All of these increase the difficulty of ice transit.
Ridges may have sail and keel heights totaling in the tens of meters which can only be penetrated by repeated ramming. Ice charts consolidate all available information on ice cover using the "ice egg", which in most sea areas will be developed using WMO principles and terminology.
An example of how the ice egg is developed is shown in Appendix 10, Figure 1. Each of the fields is filled out using codes, of which the 'stage of development' code given in Appendix 10, Table 1 is one example. More complete explanations can be found in sources such as the Canadian government's MANICE.

Preparations for Ice

1. Take additional bunkers as an allowance for manoeuvring in heavy weather and deviations due to ice and ice accretion.
2. Maintain a large stock of de-icing salt on board
3. Remember that the ice accretion is possible in cold driving winds.
4. Change to low sea suctions, and provide temporary steam pipes at the intakes, if permanent de-icing connections are not provided.
5. Cover the mooring lines, cable drums etc. with plastic covers and secure.
6. Cover all exposed motors and control stands.
7. In exceptional circumstances, and subject to the vessels stability, due consideration must be given to lowering the ballast tank levels, if there is a risk of the ballast freezing
8. Check the ballast air-pipes for clogging with ice, prior to any ballasting or de-ballasting.
9. If ice accretion is rapid, then maintain steerage away from the spray
10. Keep both anchor shanks slightly out of the hawse-pipe, so that ice formed inside the hawse-pipe holding the anchors can be broken by heaving the anchor.
11. Cover the spurling pipes.
12. Cover the fairlead openings by canvas and wooden templates.
13. Keep crowbars and ice picks ready for use.
14. The Crew are to be clothed according to the recommendations made in NP 100 against the wind chill diagram.
15. The radar scanners are to be kept on stand by if not in use.
16. Keep the bow thruster heater on for about three 3 hours before arrival, and turn them slowly every hour to ensure that the oil is warm.
17. Check electrical insulation.
18. Drain the fire lines, grease their expansion joints.

19. Spread de-icing salt on decks.
20. Cover the boom belt with canvas so that the rollers are not affected by ice accretion.
21. Lower a length of manila rope in the scuppers.
22. The heating coils of the emergency generator are to be on and, the tank maintained at 90% full to avoid condensation.
23. With regard to the engine cooling system the manufacturers instructions are to be adhered to, and the cooling system must be fitted with a solution of water and antifreeze at the recommended ratio to provide protection down to at least, minus 40oC.
24. Maintain the outside air-circulation into the engine room at the minimum required. Keep all WT doors to all spaces and all other accommodation doors closed.
25.
Ensure that the Fore Peak tank manually operated valves are closed, and also that all tank manholes are closed.
26. Turn on the accommodation heating, and ensure that the sanitary and domestic water flow is satisfactory.

Navigation in Ice and safety precautions

The onset of Ice Accretion can be sudden and dangerous. In the North Atlantic Ocean, the transit of a cold frontal system in winter, will rapidly bring down the air-temperature, causing the vessels steel structure to cool. The driving sea spray then adheres to the ships structure, and forms ice which builds up rapidly.

The consequences are:

- Change in trim generally by the head.
- Reduction in stability.
- Blockage of air-vents, ballast tank air-pipes.
- Freezing of pipelines.
- Increase in viscosity of hydraulic oil in the systems,
- Fracturing of exposed castings made from cast iron.
- Icing of bridge windows.
- Blockage of Deck Scuppers.

If there is ice formation on the sea surface, this usually restricts the sea spray, however, ice accretion is still possible where there is high air moisture content. Ice formation of the sea surface severely restricts navigation and the vessel may become ice-bound. Forcing the ship through ice can cause damage to the hull, shipside intake grids and may damage the propeller, if attempts are made to go astern. The cooling water intakes may also become frozen, and the decision to enter an ice bound area has therefore to be carefully considered.
The boundaries of ice, the predicted shift of these boundaries, the type of ice formed e.g. grey ice, pack ice etc are transmitted in bulletins. It must be remembered that the ice boundaries can have moved since the last bulletin, and the proposed routes may be affected. The assistance of an Ice Breaker could also be required, and the vessel may have to join an ice convoy. The Master must engage an Ice Pilot for the area if available.

SAFE MANOEUVRING IN ICE

Rudder and propeller of a ship in ballast and loaded ship are operating in different conditions.

Propeller of a ship in ballast is in constant interaction with the ice – the ship is subjected to vibration – answers the helm poorly and has almost no inertia, and could easily be stopped on entering heavy ice.

Rudder and propeller of a loaded ship are fully submerged in water. It decreases their contact with ice, therefore it is easier to handle the ship and as a result it is easier to pass more difficult ice.

While navigating in drifting ice floes, the ship has to avoid rapid change of course and keep her stern part away from the ice edge while turning.

If it is necessary to enter an ice floe, the ship should approach it at a right angle (90 degrees) with minimum steering way (without inertia), later gradually increasing her speed to keep the initial slow speed until the ice floe is broken. If cracks are no longer made the ship should carefully watch for her speed to be able if it is necessary to return to initial point.

Turning in the lead a ship has to keep to the inner side of the lead, trying to avoid contact of her stern part with the ice edge.

It is especially important to protect her rudder and propeller from the ice damage when the ship is moving astern, when the ice broken by the aft part of the ship. In this case the rudder should always be amidships and the propeller should be rotating until the ship is finally stopped in the ice.

For successful breaking out of the lead the ship should use easy part of the lead with damaged edges and turns. Bouncing effect in the lead could also be utilized for the beginning of breaking out.

It is not recommended to enter the ice compacting area if the ship is proceeding without assistance.

If the ship is still in the compacting area all measures for leaving it as soon as possible should be undertaken.

The ship is advised to steer upwind & avoiding navigation hazards in the area return to friendly ice or open water.

If the ship is beset all measures to protect her rudder and propeller from being blocked by ice should be taken, you should continue movement, inform the ice breaker, keep her engine running and constantly watch for changes in the situation.

If the ship is to be left by the ice breaker in the area of compacting, the ice breaker crashes the ice around the ship, creating some kind of cushion from both sides of the ship.

Reliable use of radar for the ice navigation is possible when deck officers have appropriate experience and within distances not exceeding 5 nm. It is possible to select the way between ice floes only at a distance of 2-3 nm, and type of the ice could be determined only in close proximity to the ship. The ice edge as well as separate ice floes are easily detected on the radar screen. Hummocks are seen as a generic noise on the radar screen. Sometimes, even heavy ice could be mistakenly recognized as open water. To obtain experience of radar usage in ice which could be utilized later it is recommended to use radar in good visibility in different ice conditions.

During the night time the ship uses her search light and deck illumination. Search light is used for the ice edge detection. When the ship is proceeding in convoy, it should be remembered that the light from your searchlight could easily blind the ice breaker or the ship ahead of you. It is recommended to use the Suez canal light to illuminate the ice edge right ahead of your ship.

OVERTAKING

Never ever try to overtake the unassisted ship proceeding in the ice lead ahead of you.

However, sometimes during the unassisted passage it is required to overtake the ship in the ice lead. In such as case you should break out of the ice lead well in advance, and overtake the ship at a safe distance. A safe distance here means distance sufficient to prevent the ice between ships from being broken because of the ship’s motion.

The most dangerous moment is when the bow of the overtaking vessel is approaching the stern of the vessel being overtaken – at this time it is possible to break the ice between ships.

You can change your course to the ship in the ice lead only when you pass half of her length.

MEETING

Sometimes there is a necessity to pass the ship on the opposite course in the ice lead.

In this case, one of the ships uses the existing lead, and the other has to make a new one. Loaded ship is recommended to break out of the ice lead, while the ship in ballast is recommended to use the existing ice lead.

There are two methods of meeting:

1) when the ship leaving lead stops her engine, and

2) when she does not stop her engine.

In the first case the ship leaves the ice canal in the area of friendly ice and waits for the other ship to pass.

As soon as the ship using the ice lead passes more than a half of the ship waiting outside the lead, the latter runs her engines astern and enters the lead again.

The second case when both meeting ships have way is faster and more dangerous. In this case the ice must let the ship leaving the ice lead proceed without getting stuck. Distance between the ice leads must be sufficient to prevent ice from being broken because of the motion of vessels.

Sometimes, it is possible to stop the ship using the ice canal and pass her when she is stopped. In this case it is recommended to enter the lead only after the waiting ship is finally past and clear. However, the use of this method depends on the local ice conditions as the ship in ballast could not have enough power to resume her voyage.

SHIP IN CONVOY FOLLOWING THE ICE BREAKER

When following the ice breaker, the ship is complying with the ice breaker master's orders and usually has to:

- keep the distance;
- keep the speed;
- keep the engine status.

In case of keeping the distance the ship must control the distance both visually and by radar.

In case of keeping the speed it is necessary to watch for the speed and adjust the engine status as required to maintain the ordered speed.

In case of keeping the engine status it is necessary to keep the engine status (e.g., full ahead) until a new order is received from the ice breaker.
In all circumstances constant radio contact between the ship and the ice breaker is essential, all doubts and questions must be clarified with the ice breaker as soon as they arise.
If another ship is following your ship you should inform her about all changes of your speed, especially if your speed is rapidly decreasing.

HOW TO FASTEN THE TOWING LINES

Towing by the ice breaker is used when the engine power of the ship is insufficient for the ice navigation or when navigating in compacting ice. As a rule, close-coupled towing is used. The towing wire is sent through the anchor lead and fastened to the bridle on board the ship. In rare cases towing wire may be fastened directly to bollards.

PROPULSION AND STEERING

In case of close-coupled towing the ship constantly works with her engine and steers by her rudder, trying to keep the ice breaker in line. Constant radio contact with the ice breaker is essential for proper compliance with his orders regarding the engine status, rudder position and in extreme cases for fast release of the towing wire.
While turning in the ice lead the ice breaker may use the vessel being towed as an active rudder. In this case the vessel being towed assists the ice breaker in turning or keeping in the middle of channel by complying with her orders.

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Requirements for Ships Operating in Ice

The propulsion plant and steering gear of any ship intending to operate in ice must be reliable and must be capable of a fast response to manoeuvring orders. The navigational and communications equipment must be equally reliable and particular attention should be paid to maintaining radar at peak performance. Light and partly loaded ships should be ballasted as deeply as possible, but excessive trim by the stern is not recommended, as it cuts down manoeuvrability and increases the possibility of ice damage to the more vulnerable lower area of the exposed bow. Engine room suction strainers should be able to be removed easily and to be kept clear of ice and snow. Good searchlights should be available to aid in visibility during night navigation with or without icebreaker support.
Ships navigating in ice-covered waters may experience delays and, therefore, should carry sufficient fresh water, supplies and manoeuvring fuel, especially vessels which use heavy bunker fuel for main propulsion.

Adverse Environmental Conditions

Ships and their equipment at sea in Canadian winters and in high latitudes are affected by the following:

- low surface temperatures;
- high winds;
- low sea-water injection temperatures;
- low humidity;
- ice conditions ranging from slush ice to solid pack;
- snow, sleet, and freezing rain;
- fog and overcast, especially at the ice/water interface; and

- superstructure icing when there is the great and dangerous possibility of heavy and rapid icing with consequent loss of stability.

Superstructure Icing

Superstructure icing is a complicated process which depends upon meteorological conditions, condition of loading, and behaviour of the vessel in stormy weather, as well as on the size and location of the superstructure and rigging. The more common cause of ice formation is the deposit of water droplets on the vessel's structure. These droplets come from spray driven from wave crests and from ship-generated spray. Ice formation may also occur in conditions of snowfall, sea fog, (including Arctic sea smoke) a drastic fall in ambient temperature, and from the freezing of raindrops on contact with the vessel's structure. Ice formation may sometimes be caused or accentuated by water shipped on board and retained on deck.

Vessel icing is a function of the ship's course relative to the wind and seas and generally is most severe in the following areas: stem, bulwark and bulwark rail, windward side of the superstructure and deckhouses, hawse pipes, anchors, deck gear, forecastle deck and upper deck, freeing ports, containers, hatches, aerials, stays, shrouds, masts, spars, and associated rigging. It is important to maintain the anchor windlass free of ice so that the anchor may be dropped in case of emergency. Constant spray entering the hawse pipes may freeze solid inside the pipe, also anchors stowed in recessed pockets may freeze in place, both conditions preventing letting the anchor go. It is good practice in freezing spray to leave anchors slightly lowered in the hawse pipe in order to free them from ice accretion when needed. It is also advisable to maintain securing claws in place in case of slippery brakes, so that the anchors can be readily released in the event of a power blackout.

Superstructure icing is possible whenever air temperatures are -2.2°C or less and winds are 17 knots or more. It is very likely to take place when these conditions occur at the same time.

In fresh water such as the Great Lakes and St. Lawrence River superstructure icing will occur at 0°C and below, and accumulate faster than in salt water conditions.

Generally speaking, winds of Beaufort Force 5 may produce slight icing; winds of Force 7, moderate icing; and winds of above Force 8, severe icing. Under these conditions, the most intensive ice formation takes place when wind and sea come from ahead. In beam and quartering winds, ice accumulates more quickly on the windward side of the vessel, thus leading to a constant list which is extremely dangerous as the deck-immersion point could easily be reached with a loaded vessel.

Signs of Ice in the Vicinity

When steaming through open water, it may be possible to detect the approach of ice by the following signs:

- Ice blink: this is a fairly reliable sign and may be the first indication that an ice field is in the vicinity. It can usually be seen for some time before the ice itself is visible and appears as a luminous reflection on the underside of the clouds above the ice. Its clarity is increased after a fresh snowfall. On clear days, ice blink is less apparent but may appear as a light or yellowish haze which would indicate the presence of ice. Ice blink can sometimes be detected at night, either from the reflection of moonlight, or from the ambient starlight in clear weather.

- The sighting of small fragments of ice often indicates that larger quantities are not far away.
- Abrupt moderation of the sea and swell occur when approaching an ice field from leeward.
- In northern areas, and in Labrador and Newfoundland, the onset of fog often indicates the presence of ice in the vicinity.

On a clear day there may be abnormal refraction of light causing distortion in the appearance of features. Although the ice field will be seen at a greater distance than would normally be possible without refraction, its characteristics may be magnified out of all proportion – it may even appear as giant cliffs of ice in the far distance, with breaks between them where the open water lies.

The following are signs of open water:

- Water sky: dark patches on low clouds, sometimes almost black in comparison with the clouds, indicate the presence of water below them. When the air is very clear this indication is less evident. When iceblink is visible at night, the absence of blink in some sectors of the horizon may indicate open water but cannot be assumed to be water sky.
- Dark spots in fog give a similar indication, but are not visible for as great a distance as the reflection on clouds.
- A dark bank on a cloud at high altitude indicates the presence of patches of open water below, which could lead to larger areas of open water in the immediate vicinity.

Ships Navigating Independently

Experience has shown that non-ice-strengthened ships with an open water speed of about 12 knots can become hopelessly beset in heavy concentrations of relatively light ice conditions, whereas ice-strengthened ships with adequate power should be able to make progress through first-year ice of 6/10 to 7/10 concentrations. Such ships are often able to proceed without any assistance other than routing advice. In concentrations of 6/10 or less, most vessels should be able to steer at slow speed around the floes in open pack ice without coming into contact with very many of them.

Entering the Ice

The route recommended by the Ice Superintendent through the appropriate reporting system i.e. ECAREG or NORDREG, is based on the latest available information and Masters are advised to adjust their course accordingly. The following notes on ship-handling in ice have proven helpful:

- Do not enter ice if an alternative, although longer, open water route is available.
- It is very easy and extremely dangerous to underestimate the hardness of ice.
- Enter the ice at low speed to receive the initial impact; once into the pack, increase speed gradually to maintain headway and control of the ship, but do not let the speed increase beyond the point at which she might suffer ice

damage. Particular attention should be paid to applied power in areas of weak ice or open leads, pools, etc. where the speed might increase unnoticed to dangerous levels if power is not taken off.

- Be prepared to go "Full Astern" at any time.
- Navigation in pack ice after dark should not be attempted without high-power searchlights which can be controlled easily from the bridge; if poor visibility precludes progress, heave to in the ice and keep the propeller turning slowly as it is less susceptible to ice damage than if it were completely stopped, blocks of ice will also be prevented from jamming between the blades and the hull.
- Propellers and rudders are the most vulnerable parts of the ship; ships should go astern in ice with extreme care, and always with the rudder amidships. If required to ram ice when brought to a halt, ships should not go astern into unbroken ice, but should move astern only in the channel previously cut by their own passage.
- All forms of glacial ice (icebergs, bergy bits, growlers) in the pack should be given a wide berth, as they are current-driven whereas the pack is wind-driven. Large features of old ice may be moving in a direction up-wind or across wind according to the direction of the current.
- Wherever possible, pressure ridges should be avoided and a passage through pack ice under pressure should not be attempted. The ship may have to be stopped in the ice until the pressure event is ended.
- When a ship navigating independently becomes beset, it usually requires icebreaker assistance to free it. However, ships in ballast can sometimes free themselves by pumping and transferring ballast from side to side, and it may require very little change in trim or list to release the ship, especially in high-friction areas of heavy snow-cover.

The Master may wish to engage the services of an Ice Navigator in the Arctic.

Icebreakers

The Canadian Coast Guard has a limited number of icebreakers available for the escort and support of shipping. These icebreakers are heavily committed and cannot always be provided on short notice when requested. Therefore, it is important for the ECAREG CANADA Office or Ice Operations Centre to be kept informed about the position and projected movements of vessels when ice is present. Failure to follow the reporting procedures, by vessels unsure of their ability to cope with prevailing ice conditions on their own, will only add to the difficulties of providing icebreakers and can lead to serious delays.
Canadian Coast Guard icebreakers, many of which carry helicopters for ice reconnaissance, have operated in ice for many years, from the Great Lakes to as far north as the North Pole. Their Commanding Officers and crews are highly skilled and thoroughly experienced in the specialist fields of ice navigation, icebreaking, and ice escort. The fullest co-operation with the Commanding Officer of an icebreaker is, therefore, requested from a ship or convoy under escort. For progress to be made, it is essential that escort operations be under the direction of the Commanding Officer of the icebreaker.

Communicating with Icebreakers

Once a vessel has requested icebreaker assistance, a radio watch should be kept on 2182 kHz and channel 16 VHF (156.8 MHz). Difficulty is often experienced by icebreakers in making initial contact with these vessels, often with the result of lost time and extra fuel consumption. MF and VHF remain as proven communications tools and should be utilised to maintain contact with the icebreakers.

A continuous radiotelephone watch on an agreed frequency should also be maintained on the bridges of all ships working with Coast Guard icebreakers. Ships should be capable of working one or more of the following MF and VHF frequencies:

- 2237 kHz - MF
- 2134 kHz - MF
- 2738 kHz - MF
- 156.3 MHz - VHF Channel 6

Table 8 lists the letter, sound, visual, or radiotelephony signals that are for use between icebreakers and assisted ships. These signals are accepted internationally and they are restricted to the significance indicated in the table.

While under escort, continuous and close communications must be maintained. Communications normally will be by radiotelephone on a selected and mutually agreed inter-ship VHF working frequency. It is vital to inform the Ice Operations Centre and icebreaker of any change in the state of your vessel while awaiting an icebreaker escort.

Table 8: Operational signals to be used to supplement radiotelephone communication between icebreaker and assisted vessel(s)

Code Letters	Icebreaker Instruction	Assisted Vessel(s) Response
WM	Icebreaker support is now commencing. Use special icebreaker support signals and keep continuous watch for sound, visual, or radiotelephony signals	
A	Go ahead (proceed along the ice channel)	I am going ahead. (I am proceeding along the ice channel)
G	I am going ahead, follow me	I am going ahead. I am following you
J	Do not follow me. (proceed along the ice channel)	I will not follow you (I will proceed along the ice channel)
P	Slow down	I am slowing down
N	Stop your engines	I am stopping my engines
H	Reverse your engines	I am reversing my engines
L	You should stop your vessel instantly	I am stopping my vessel
4	Stop. I am icebound	I am stopping my vessel
Q	Shorten the distance between vessels	I am shortening the distance
B	Increase the distance between vessels	I am increasing the distance
Y	Be ready to take (or cast off) the tow line	I am ready to take (or cast off) the tow line
FE	Stop your headway (given only to a ship in an ice channel ahead of an icebreaker)	I am stopping headway
WO	Icebreaker support is finished. Proceed to your destination	
5	Attention	Attention

Signals which may be used during icebreaking operations

Code Letters Icebreaker Instruction Assisted Vessel(s) Response
E I am altering my course to starboard I am altering my course to starboard
I I am altering my course to port I am altering my course to port
S My engines are going astern My engines are going astern
M My vessel is stopped and making no way through the water My vessel is stopped and making no progress through the water

Note: Emergency Stop Signal:
Icebreakers have red revolving lights placed high up at the after end of the superstructure, visible from astern, which will be activated when an EMERGENCY STOP is required by the escorted ship or ships.
The signal "K" by sound or light may be used by an icebreaker to remind ships of their obligation to listen continuously on their radios.
If more than one vessel is assisted, the distance between vessels should be as constant as possible; watch the speed of your own vessel and of the vessel ahead. Should the speed of your own vessel go down, give an attention signal to the vessel following.
The visual signals are seldom used in practice, but are listed in case voice radio communication fails.
The use of these signals does not relieve any vessel from complying with the International Regulations for Preventing Collisions at Sea.

Report Required Before Escort Commences
Before escort or assistance commences, the icebreaker will require some or all of the following information to assess a ship's capabilities while under escort in ice:
- vessel name, type and call sign;
- Lloyds/IMO number;
- owner/agent name;
- country of registry;
- tonnage (gross and net);
- ship's length and beam;
- port of departure and destination;
- cargo type and amount (tonnage);
- ice navigator's name, if embarked;
- open water speed;
- ice class (if any) and classification society;
- drafts - forward and aft;
- number of propellers and rudders;
- shaft horsepower;
- propulsion plant (whether diesel or turbine, and astern power expressed as a percentage of full ahead power) and the type of fuel for the main propulsion (e.g. heavy bunker, diesel, LNG, etc.); and
- radiotelephone working frequencies, communications systems including telephone and/or fax number.

Icebreaking Escort Operations

The following are comments on aspects of icebreaker escort procedures:

a) Track width:

Progress through ice by an escorted ship depends to a great extent on the width of the track made by the icebreaker, which is directly related to the speed of the forward progress of the icebreaker and the distance between the icebreaker and the ship following.

b) Icebreaker beam:

When an icebreaker is breaking a track through large heavy floes at slow speed, the track will be about 30 to 40 per cent wider than the beam of the icebreaker. At high speed, and if the ice is of a type which can be broken by the action of the stern wave (wake), the track may be as much as three times that of the icebreaker's beam.

c) Minimum escort distance:

The minimum distance will be determined by the Commanding Officer of the icebreaker on the basis of distance required by the escorted ship(s) to come to a complete stop, after reversing to full astern from normal full ahead speed. Once this distance has been established, it is the responsibility of the ship under escort to see that it is maintained. If the escorted vessel is unable to maintain the minimum escort distance and is falling back, the icebreaker should be informed at once to avoid the possibility of besetment and resulting delay.

d) Maximum escort distance:

Maximum distance is determined on the basis of ice conditions and the distance at which the track will remain open or nearly so. Increasing this distance creates the possibility of besetment, which would necessitate a freeing operation by the icebreaker. If the escorted vessel is unable to maintain the maximum escort distance, the icebreaker should be informed at once to avoid the possibility of besetment and resulting delay.

e) Maintaining the escort distance:

Masters are requested to maintain the required escort distance astern of the icebreaker to the best of their ability. The progress made depends to a very great extent on the correct escort distance being maintained. This distance is dictated by the existing ice conditions and the risk of collision by the escorted vessel overtaking the icebreaker.

a) Ice concentration:

With 9+/10 concentrations, the track will have a tendency to close quickly behind the icebreaker, thus necessitating very close escort at a speed determined by the Commanding Officer of the icebreaker and the type of ice encountered.

b) Ice pressure:

When the ice concentration is 9+/10 and under pressure, the track will close very rapidly. Progress will be almost impossible because the track, being marginally wider than the beam of the icebreaker, will close and result in the escorted ship becoming beset.

c) Effect of escort on width of track:

When an icebreaker makes a track, it causes outward movement of the floes. The width of the track depends on the extent of this outward movement together with the amount of open water available for floe movement. A longer escort distance allows a longer period of movement that results in a wider track.

d) Speed:

When an icebreaker makes contact with ice floes on either side of the track, they may be forced outward with sufficient momentum to overcome the indraft at the stern; otherwise, some blocks and small floes will be drawn into the broken track. Most tracks made by icebreakers will contain ice rubble, which may also contain floes, which could damage an escorted vessel at excessive speed.

If an icebreaker proceeds at slow speed through ice, floes will slide along her hull and remain intact, with the exception of small pieces that may break away from the leading edges. At high speeds the floes will be shattered into many pieces. The icebreaker will, therefore, proceed at a speed which will break floes into as many pieces as possible, thus reducing the possibility of damage to the ship following in the track.

e) Escorted ship beset:

When a ship under escort has stopped for any reason, the icebreaker should be notified immediately. If the ship is beset, the engines should be kept slow ahead to keep the ice away from the propellers. The engines should be stopped only when requested by the icebreaker.

f) Freeing a beset vessel:

Freeing a ship that has become beset during escort is usually carried out by the icebreaker backing down the track, cutting out ice on either bow of the beset ship, and passing astern along the vessel's side before moving both vessels ahead. To free a ship beset while navigating independently, the icebreaker will normally approach from astern and cross close ahead at an angle of 20 to 30 degrees to the beset ship's course. Such an approach may be made on either side in moderate winds. In strong winds at a wide angle to the track, a decision as to which side the cross-ahead is made will be determined by which of the two ships is more influenced by the wind. On occasion, the icebreaker may elect to pass down one side of the beset vessel, turn astern of her and pass up on the other side, thereby releasing pressure from both sides.

g) Systems of escort:

When a ship becomes beset during escort, the normal procedure is for the icebreaker to back up to free her and then proceed ahead with the escorted ship following. However, when progress is slow, the Free and Proceed system may be used, in which the beset ship is directed to proceed up the track made by the icebreaker while backing up, the icebreaker then following behind. Before the escorted vessel reaches the end of the previously broken icebreaker track, the icebreaker proceeds at full speed to overtake and pass the escorted vessel. This cuts down the number of freeing operations and improves progress.

h) Red warning lights and air horn:

When escorting ships in ice, Canadian Coast Guard icebreakers use two rotating red lights to indicate that the icebreaker has become stopped. In most cases these lights are placed in a vertical line 1.8 metres apart abaft the mainmast and are visible for at least two miles. However, construction restrictions of some icebreakers necessitate that these lights be placed horizontally in roughly the same aft-facing position.

As an additional warning signal, all icebreakers are fitted with and use a zet-horn, facing aft, audible up to 5 nautical miles, which sounds simultaneously with the red warning lights when they are activated. Prior to commencement of escort, all vessels will familiarize themselves with the positioning and operation of these red rotating lights and the zet-horn.

i) Icebreaker stopped:

Whenever the red revolving lights are displayed and the horn sounded, either separately or simultaneously, it signifies that the icebreaker has come to a standstill and is unable to make further progress without backing up. During close escort work, a lookout shall always be kept for the flashing red light. The Master of the escorted ship should treat these signals with extreme urgency and immediately reverse engines to full speed astern. The rudder should be put hard over to increase ice-friction on the hull as long as headway is carried, until all forward motion has ceased, then the rudder must be returned to the amidships position.

j) Icebreaker stopping without warning:

Masters are cautioned that, because of unexpected ice conditions or in other emergency situations, the icebreaker may stop or otherwise manoeuvre ahead of the escorted ship without these warning signals. Masters must always be prepared to take prompt action to avoid overrunning the icebreaker.

a) Towing in ice:

This procedure would only be undertaken in emergencies as there is an inherent risk of damage to both vessels. The Commanding Officer of an icebreaker who receives a request for a tow will judge whether or not the situation calls for such extreme measures. Canadian Coast Guard icebreakers are not equipped for close-coupled towing operations. The Canadian Coast Guard has an online Policy and Operational Procedures on Assistance to Disabled Vessels.

b) Anchoring in ice:

Anchoring in the presence of ice is not recommended except in an emergency, but if such anchoring is necessary, only the minimum amount of cable should be used and the capstan/windlass should be available for immediate use. The engines must be on standby, or kept running, if the start-up time is more than 20 minutes. If the water is too deep to let go an anchor, the ship may be stopped in fast ice (when the conditions permit). When off-shore in deep water, a ship can usually safely stop in the drift ice without an anchor down when darkness or poor visibility prevents further progress. The ship will then drift with the ice and may be turned around by the ice, but will be quite safe if properly placed before shutting down.

c) Convoys:

Convoys of ships may be formed by the Commanding Officer of the icebreaker, after consultation with the appropriate shore authority. During operations in ice, this action will best aid the movement of the maximum number of ships when there are an insufficient number of icebreakers of suitable capacity available to facilitate the escort of ships proceeding to or from adjacent areas or ports.

The Commanding Officer of the icebreaker will determine the order of station within the convoy, to be arranged to expedite the movement of the convoy through the ice (not necessarily on "first come-first served" basis). The ships in the convoy are responsible for arranging and maintaining a suitable and safe distance between individual vessels. The icebreaker will designate the required distance to be maintained between itself and the lead ship of the convoy.
If the ice conditions should change on route, or if some vessels have difficulty in following the vessel ahead, the Commanding Officer of the icebreaker may change the order of convoy station so that ships within the convoy can assist the progress of others less capable than themselves.

Ship Handling Techniques in Ice

Manoeuvres in Different Ice Conditions

Ice is an obstacle to any ship, even an icebreaker, and the inexperienced navigator is advised to develop a healthy respect for the potential strength of ice in all its forms. However, it is quite possible, and continues to be proven so, for well-maintained and well-equipped ships in capable hands to navigate successfully through ice-covered waters. Masters who are inexperienced in ice often find it useful to employ the services of an Ice Advisor for transiting the Gulf of St. Lawrence in winter or an Ice Navigator for voyages into the Arctic in the summer.
The first principle of successful ice navigation is to avoid stopping or becoming stuck in the ice. Once a ship becomes trapped, it goes wherever the ice goes. Ice navigation requires great patience and can be a tiring business, with or without icebreaker escort. The longer open water way around a difficult ice area whose limits are known is often the fastest and safest way to port or to reach the open sea.
For an unstrengthened ship, or for a ship whose structural capability does not match the prevailing ice conditions, it is preferable and safer to take any alternative open water route around the ice even if it is considerably longer. An open water route is always better than going through a large amount of ice. Any expected savings of fuel will be more than offset by the risk of damage, and the actual fuel consumption may be higher by going through ice, even if the distance is shorter.
The following conditions must be met before a vessel enters an ice field:

- Follow the route recommended by the Ice Superintendent via the Marine Communications and Traffic Services Centre (MCTS). This route is based on the latest available information and Masters are advised to adjust their course accordingly if changes are recommended during the passage.
- Extra lookouts must be posted and the bridge watch may be increased, depending on the visibility.
- There must be sufficient light to complete the transit of the ice field in daylight or the vessel must be equipped with sufficient high-powered and reliable searchlights for use after dark.
- Reduce speed to a minimum to receive the initial impact of the ice.
- The vessel should be at right angles to the edge of the pack ice at entry to avoid glancing blows and the point of entering the ice must be chosen carefully (see Figure 49), preferably in an area of lower ice concentration.

- The engine room personnel should be briefed fully as to the situation and what may be required of them, as it may be necessary to go full astern at any time, and engine manoeuvres will be frequent as speed is constantly adjusted.
- The ship should be ballasted down to ice draft, if appropriate, or to such a draft that would offer protection to a bulbous bow, rudder, or propeller (as applicable).
- The ship should be fitted with an internal cooling system for use in the event that the main engine cooling water intake becomes clogged with slush ice.

After Entering the Ice

Once the ice is entered, speed of the vessel should be increased slowly, according to the prevailing ice conditions and the vulnerability of the ship. If visibility decreases while the vessel is in the ice, speed should be reduced until the vessel can be stopped within the distance of visibility. If in doubt, the vessel must stop until the visibility improves. The potential of damage by ice increases with less visibility. If the vessel is stopped, the propeller(s) should be kept turning at low revolutions to prevent ice from building up around the stern.

When navigating in ice, the general rule is:

- use the pack to its best advantage. Follow open water patches and lighter ice areas even if initially it involves large deviations of course.
- in limited visibility, beware following an open water lead at excessive speed, it may be the trail of an iceberg.

Do not allow the speed to increase to dangerous levels when in leads or open pools within an ice field, or when navigating open pack conditions.

Changes in course will be necessary when the vessel is in ice. If possible course changes should be carried out in an area of open water or in relatively light ice, as turning in ice requires substantially more power than turning in water, because the ship is trying to break ice with its length rather than with its bow, turns should be started early and make as wide an arc as possible to achieve the new heading. Care must be taken even when turning in an open water area, as it is easy to underestimate the swing of the ship and to make contact with ice on the ship's side or stern: a glancing blow with a soft piece of ice may result in the ship colliding with a harder piece (see Figure 50).

The ship will have a strong tendency to follow the path of least resistance and turning out of a channel may be difficult or even impossible. Ships that are equipped with twin propellers should use them to assist in the turn. . In very tight ice conditions, a ship sailing independently may make better progress by applying full power and leaving the rudder amidships. This allows her to find the least resistance without any drag from the rudder in trying to maintain a straight course by steering.

Warning:

Avoid turning in heavy ice – seek lighter ice or open water pools.

If it is not possible to turn in an open water area, the Master must decide what type of turning manoeuvre will be appropriate. If the turn does not have to be sharp then it will be better to maintain progress in ice with the helm over. When ice conditions are such that the vessel's progress is marginal, the effect of the drag of the rudder being turned may be sufficient to halt the vessel's progress completely. In this case, or if the vessel must make a sharp turn, the star manoeuvre will have to be performed. This manoeuvre is the equivalent of turning the ship short round in ice by backing and filling with the engine and rudder. Masters will have to weigh the dangers of backing in ice to accomplish the star manoeuvre, against any navigational dangers of a long turn in ice. Care must be taken while backing on each ram that the propeller and rudder are not forced into unbroken ice astern

Backing in ice is a dangerous manoeuvre as it exposes the most vulnerable parts of the ship, the rudder and propeller, to the ice. It should only be attempted when absolutely necessary and in any case the ship should never ram astern. In recent years “double-acting" ice strengthened vessels have been developed which are designed to break ice while moving astern in order to protect their bulbous bows, but only this type of specially designed vessel should attempt such manoeuvres.

The ship should move at dead slow astern and the rudder must be amidships (Figure 51). If the rudder is off centre and it strikes a piece of ice going astern, the twisting force exerted on the rudder post will be much greater than if the rudder is centred. In the centre position, the rudder will be protected by an ice horn if fitted.

If ice starts to build up under the stern, a short burst of power ahead should be used to clear away the ice. Using this technique of backing up to the ice and using the burst ahead to clear the ice can be very effective, but a careful watch must be kept of the distance between the stern and the ice edge. If a good view of the stern is not possible from the bridge, post a reliable lookout aft with access to a radio or telephone.

The danger from becoming beset is increased greatly in the presence of old or glacial ice, as the pressure on the hull is that much greater.

When in pack ice, a frequent check should be made for any signs of the track closing behind the ship. Normally there will be a slight closing from the release of pressure as the ship passes through the ice, but if the ice begins to close up completely behind the ship it is a strong sign that the pressure is increasing (Figure 52).

Similarly, if proceeding along an open water lead between ice and shore, or ice in motion and fast ice, watch for a change in the wind direction or tide as the lead can

To free a beset vessel, it is necessary to loosen the grip of ice on the hull, which may be accomplished in several ways, or it may be necessary to wait for conditions to improve:

- Go ahead and astern at full power while alternating the helm from port to starboard, which has the effect of levering the ice aside. Care must be taken when going astern to ensure that no ice goes through the propeller(s), or if the vessel frees itself that it does not make sternway into any heavy ice. In vessels with twin propellers, they should be alternated with one ahead and one astern for a few minutes, then each changed to the opposite direction, slewing the stern from side to side to create a wider opening in the ice astern.
- Alternate the ballast to port and to starboard to list the ship and change the underwater shape. This method should only be done with knowledge of the possible consequences of an exaggerated list if the ship comes free quickly.
- Alternate filling and emptying of the fore and after peak tanks is a safer manoeuvre than using the ballast tanks, but it is usually only effective in changing the trim for the bow to get a better angle of attack on the ice ahead, or for the propellers to be given a better grip by greater submersion. It can also be

effective in extracting from a ridge, by raising the bow so that the ship slides backwards as the bow is raised.

- In smaller ships it may be possible to swing weights over the side suspended on the ship's cranes or lifting gear to induce a list and break the ship free. This method should only be used with knowledge of the possible consequences if the ship comes free quickly (see (b) above).

Ramming

Ramming is particularly effective when attempting progress through ice that is otherwise too thick to break continuously.

Warning:

Ramming should not be undertaken by vessels that are not ice-strengthened and by vessels with bulbous bows. Ice-strengthened vessels, when undertaking ramming, should do so with extreme caution.

For ships that can ram the ice it is a process of trial and error to determine the optimum distance to back away from the ice edge to build up speed. The optimum backing distance will be that which gives the most forward progress with the least travel astern. It is always necessary to start with short rams to determine the thickness and hardness of the ice. All ships must pay close attention to the ice conditions, to avoid the possibility of lodging the ship across a ridge on a large floe. Floes of old ice which may be distributed throughout the pack in northern waters, must be identified and avoided while ramming.

Ramming must be undertaken with extreme caution because the impact forces caused when the vessel contacts the ice can be very high. For ice-strengthened vessels these forces may be higher than those used to design the structure and may lead to damage. However, if the ramming is restricted to low speeds, the risk of damage will be greatly reduced.

Towing in Ice

Towing in ice on a long wire is possible, although the strain on the tow line is much greater than in an open water tow as the tug or icebreaker is subject to the sudden acceleration/deceleration of icebreaking. The situation can be alleviated somewhat if there is an icebreaker making a track ahead of the towing icebreaker. The Canadian Coast Guard does not usually engage in towing operations except in emergency situations. There is a long tradition of this sort of work in the Baltic, though, where icebreakers are specially designed with a notch in the stern and heavy winches and cables to enable the bow of the towed ship to be brought up against the stern of the icebreaker and secured. This towing method is known as close coupled towing and is considered an efficient method of towing in uniform ice conditions.

Warning:

Close-coupled towing techniques which are commonly used by European icebreakers in the Baltic Sea and in Russian waters of the Northern Sea Route, are not used in Canadian waters

Towing in ice was common in the 1970s and early 1980s in the Beaufort Sea, by anchor-handling supply boats or icebreakers when repositioning drill ships and platforms. Experience has shown that towing in ice requires specialized skills in towing and ice navigation, coupled with appropriate purpose-designed equipment. The towing equipment must be robust and must allow frequent changes in towline length. The use of shock-absorbing springs or heavy surge chains is recommended. Bridle arrangements must optimise manoeuvrability to

allow the towing vessel and tow to be navigated around heavy ridges and ice floes.
It is the recommended practice that the connection between vessels should incorporate a weak link, usually a lighter pendant, which will fail before the tow-line or bridle. In difficult ice conditions the towline should be kept as short as possible to avoid having the towing-wire pass under the ice floes, due to the weight of the wire and the catenary formed by a longer line. In freeing a beset tow, the towing vessel can shorten the tow-line to provide some propeller wash to lubricate the tow, but care must be exercised to avoid damaging the tow with heavy ice wash. Towing in ice is a special application not to be undertaken without the benefit of training and experience.

Speed
In all attempts at manoeuvring or avoiding ice, it must be remembered that the force of impact varies as the square of the speed. Thus, if the speed of the ship is increased from 8 to 12 knots, the force of impact with any piece of ice has been more than doubled. Nevertheless, it is most important when manoeuvring in ice to keep moving. The prudent speed in a given ice condition is a result of the visibility, the ice type and concentration, the ice class, and the manoeuvring characteristics of the ship (how fast it can be stopped).

Ice Management
In situations where an icebreaker is used to prevent ice from colliding with fixed structures, such as drilling platforms, the technique of ice management comes into force. The icebreaking and offshore supply fleet in the Canadian and U.S. Arctic has been involved with work to support drilling operations. Icebreakers either try to break up drifting ice before it arrives at the structure or to push and divert the dangerous floes out of the way so that they by-pass the structure. In ice management, obtaining information about the present and predicted ice conditions is very important, to ascertain the best deployment of the icebreakers.

Close-Range Ice Hazard Detection

Although a careful lookout will help the ship avoid large ice hazards (such as icebergs), there is still a need for the close-range detection of ice hazards, such as small icebergs and old ice floes. Close-range ice navigation is an interactive process, which does not lend itself to traditional passage planning techniques. Two groups of equipment aid in close-range hazard detection: visual (searchlights and binoculars) and radar (both X- and S-band marine radars and the newer enhanced ice radar systems).

Use of Radar for Ice Detection
Radar can be a great asset in ice navigation during periods of limited visibility, but only if the display is properly interpreted. Ice makes a poor radar target beyond 3 to 4 nautical miles and the best working scale is in the 2 to 3 nautical mile range. Radar signal returns from all forms of ice (even icebergs) are much lower than from ship targets, because of the lower reflectivity of radar energy from ice, and especially snow, than from steel. Detection of ice targets with low or smooth profiles is even more difficult on the radar screen,

although the radar information may be the deciding factor when attempting to identify the location of these targets under poor conditions, such as in high seas, fog, or in heavy snow return. For example, in close ice conditions the poor reflectivity and smooth surface of a floe may appear on the radar as a patch of open water, or signal returns from sea birds in a calm sea can give the appearance of ice floes. In an ice field, the edge of a smooth floe is prominent, whereas the edge of an area of open water is not. The navigator must be careful not to become over-confident in such conditions.
In strong winds the wave clutter in an area of open water will be distributed uniformly across the surface of the water, except for the calm area at the leeward edge.
Ice within one mile of, and attached to, the shore may appear on the radar display as part of the land itself. The operator should be able to differentiate between the two if the receiver gain is reduced. Mariners are advised not to rely solely on radar for the detection of icebergs because they may not appear as clearly defined targets. In particular, mariners should exercise prudence when navigating in the vicinity of ice or icebergs. The absence of sea clutter also may indicate that ice is present. Although ridges may show up well on the radar display, it is difficult to differentiate between ridges, closed tracks of ships and rafted ice, as all have a similar appearance on radar.
The effectiveness of marine radar systems will vary with power and wavelength. The optimum settings for the radar will be different for navigating in ice than for open water. As the radar reflectivity of ice is much lower than for ships or land, the gain will have to be adjusted to detect ice properly. Generally, high-power radars are preferred and it has been found that radars with 50 kW output provide much better ice detection capability than 25 kW radars. Similarly, 3-centimetre radars (x-band) provide better ice detail while 10-centimetre radars (s-band) show the presence of ice and ridging at a greater distance - it is therefore recommended that both wavelengths be used.
Warning:
Marine radar provides an important tool for the detection of sea ice and icebergs. However, do not rely solely on your radar in poor visibility as it is not certain that radar will detect all types and sizes of ice and it will not differentiate old ice from first year ice.

Ice Navigation Radars

Conventional marine radars are designed for target detection and avoidance. Enhanced marine radars provide a higher definition image of the ice that the vessel is transiting through and may help the user to identify certain ice features. There are various shipboard marine radar systems enhanced and optimized for ice navigation. Figures 55 to 58 compare images from a conventional x-band radar and an enhanced x-band ice navigation radar used on board a Canadian Coast Guard icebreaker. In the ice navigation radar, the analog signal from the x-band radar (azimuth, video, trigger) is converted by a modular radar interface and displayed as a 12-bit digital video image (1024x1024).
In the enhanced marine radar, the coastline is more clearly defined; icebergs are visible at greater distances, as are the smaller bergy bits and growlers. In the standard radar, sea clutter affects the ability to see smaller targets near the vessel. X-band radars will produce clearer images of the ice at short ranges,

such as under 4 nautical miles, when set to a short pulse. The shapes of ice floes, the ridges and rafted ice and open water leads are also more distinct in an ice navigation radar, particularly when using the short radar pulse length. Experiments with cross-polarized radar have demonstrated that it is possible to enhance radar displays for better detection of old and glacier ice. Advances are also being made in shipboard systems which use passive microwave radiometers to measure the natural emissivity of the ice (the relative ability of its surface to emit energy by radiation), producing radar-like displays which may be colour-enhanced to distinguish between open water and various ice types

Icebergs

Icebergs normally have a high freeboard and, as such, they are easy to detect visually (in clear conditions) and by ship's radar. In poor to no visibility, radar must be relied upon. The radar return from an iceberg with low freeboard, smooth surface, or deep snow cover is less obvious, particularly if surrounded by bright returns from sea or ice clutter. Depending upon their size, aspect and attitude, icebergs may be detected at ranges between four and 15 nautical miles or even further for very large high profile icebergs, detection ranges diminishing in fog, rain, and other conditions affecting the attenuation of radar return. Icebergs may not appear as clearly defined targets but the sector of the radar display directly behind the iceberg may be free of clutter. Iceberg radar targets will sometimes cause a “radar shadow" on the far side, in which other targets will not show. It is sometimes possible to identify an iceberg target lost in the clutter by this shadow extending away from the observer. A large iceberg with a long and gently sloping aspect may not provide enough reflective surfaces to show at all on radar, so it should never be assumed that just because there are no targets in view there are no icebergs around.
Warning:
Do not rely solely on marine radar to detect ice, particularly glacial ice. Observation will reveal the shadow to increase in size on approach to the iceberg, and to swing around as the angle between the ship and the iceberg changes. However, care should be taken in using this technique as the returns from pack ice can obscure the return from the iceberg.
As the vessel gets closer to the iceberg, the size of the radar target reduces and may in fact disappear when very close to the iceberg, in which case only the shadow will remain to warn of the iceberg's presence. For this reason it is important to plot any iceberg (which has not been sighted visually) that the vessel may be approaching, until the point of nearest approach has passed.

Visibility

Operating in restricted visibility is inevitable in, or near, ice-covered waters, either because of precipitation, fog or darkness. Travel through ice may, however, continue at night or in fog, which is common in the Arctic during the open water period, and visibility is often reduced by blowing snow in the Gulf of St. Lawrence during the winter.
All possible effort must be made to minimize the chances of collision with ice in poor visibility and the requirements of the regulation for preventing collisions at sea also apply. These efforts should include:

- maintenance of a constant visual and radar lookout;

- use of searchlights at night (which may be counter-productive in fog or precipitation through reflected glare);
- reduction of speed before entering any ice field in poor visibility and not increasing speed before the threat has been determined;
- reduction of speed in any ice situation where the ratio of glacial and old ice to first-year ice indicates a significant increase in the chance of collision with hazardous ice;
- location of icebergs, bergy bits, and growlers on marine radar before they are obscured by sea or ice clutter, and tracking of these targets on ARPA (Automatic Radar Plotting Aid);
- switching between ranges to optimize the radar for iceberg detection when navigating in pack ice;
- use of radar to detect icebergs and bergy bits by observing their radar shadows in mixed ice cover; and
- recognition of the difficulty of detecting glacial and old ice in open pack ice with marine radar when little or no radar shadow is recognizable.

Many escorts occur in fog, when the escorted vessel must follow the icebreaker and maintain the required distance by radar. If the icebreaker suddenly slows or its position is lost on the radar screen, a collision may occur. It is important in these situations to maintain VHF radio contact and constant monitoring of the radar distance between vessels.

Passage Planning

The purpose of this section is to provide guidance in the procedures to be followed in the acquisition and use of information for planning passages in or near ice. Nothing in the instructions given here, or the processes that follow, either supersedes the authority of the Master or relieves the Officer of the Watch from their normal responsibilities and from following the principles of good seamanship.

Passage planning for routes in ice-covered waters is based on standard navigational principles for passage planning (International Maritime Organization Resolution A. 893(21) adopted on 25 November 1999, Guidelines For Voyage Planning). The presence of sea ice along the planned route adds importance to the traditional practice of passage planning, necessitating the continual review of the entire process throughout the voyage.

Passage planning takes place in two phases,

- Strategic, when in port or in open water, and
- Tactical, when near or in ice-covered waters.

Both Strategic and Tactical Planning involve four stages:

- Appraisal
- Planning
- Execution
- Monitoring.

The Strategic phase may be considered small-scale (large area) and the assumption is that the ship would be outside ice-covered waters, and days or

weeks from encountering ice. The Strategic phase may be revised several times before the Tactical phase is commenced. The Tactical phase may be considered large scale (small area) and is constantly being revised as the voyage unfolds.
Passage planning for open water is a fixed process in which most, if not all, the information is gathered before the ship leaves the dock. The localised nature of some of the information for Arctic passage planning in ice means that information may become available only as the ship moves into Canadian waters. The amount and extent of information is a function of the voyage type, so the more difficult voyages, such as early or late season, are supported with more resources, such as icebreakers, more frequent reporting of current ice conditions, and the appropriate ice forecasts. Passage planning in ice-covered waters, especially in the Arctic, is an evolving process that demands a flexible approach to the planning and execution.

High Latitude Navigation

Navigating in high latitudes requires great care in the procedures and in the use of information. The remoteness of the Arctic and the proximity to the North Magnetic Pole has an effect on the charts that are supplied and the navigation instruments that are used with them. This section discusses some of the effects and limitations on charts and instruments used in the Arctic

Navigational Appliances

The equipment requirements for vessels navigating north of 60° North latitude in Canadian waters in a shipping safety control zone, are contained in the Navigation Safety Regulations. In brief the following are required:

- two radars;
- two Gyro compasses;
- two echo sounders, each with an independent transducer;
- two searchlights with two spare lamps;
- a weather facsimile receiver; and
- a spare antenna.

Canadian Hydrographic Service Navigational Charts and Publications

With respect to the Arctic, due to a lack of modern hydrographic surveys, the quality of charts, including paper charts, Electronic Navigational Charts (ENC) and Raster Navigational Charts (RNC) can be poor. Many charts contain areas that are inadequately surveyed, or are based on old surveys where only spot soundings were collected, or where data was collected only along a single track. Mariners must be aware of these limitations.
There are two areas of concern regarding the use of charts in the Arctic. These are consideration of the different projections used versus southern waters and the accuracy of the surveys. While up-to-date charts and nautical publications are always critical to safe navigation the Arctic requires a special understanding and the mariner should use all sources of updates, including Notices to Mariners and broadcast Notices to Shipping, to be sure paper charts, electronic charts and nautical publications are up to date.
Projections

To compensate for the fact that the meridians converge as they near the pole the scale of the parallels is gradually distorted. In the Arctic, Mercator projections suffer too much distortion in latitude to be used for anything but large scale charts. As the latitude increases, the use of rhumb lines for visual bearings becomes awkward, as it is necessary to add ever-larger convergence corrections.

In the Arctic, the common projections are Lambert Conformal Conic, Polyconic, and Polar Stereographic. Polar Stereographic is popular as it provides minimum distortion over relatively large areas. Roughly 30 per cent of Canadian Hydrographic Service navigational charts in the north use one of these projections. The number of different projections makes it important, when changing charts, to check the type of projection and any cautions concerning distances, bearings, etc. For example, the habit developed with Mercator charts is to use the latitude scale for distance, which is not possible on Polyconic charts. Particular care must also be taken when laying off bearings in high latitudes, as a convergence correction may be needed even for visual bearings. To eliminate the corrections required by the use of compass bearings for fixing positions, three radar ranges of known features can provide an accurate position.

Warning:

In the arctic, as in any other area, check the chart projection before use. Be aware of different projections within the same chart.

Accuracy

The accuracy of charts in the Arctic can vary widely according to the date of survey and the technologies available at that time. The more frequently travelled areas, such as Lancaster Sound, Barrow Strait, and the approaches to Nanisivik, are reasonably well surveyed, but many charts are based on aerial photography (controlled by ground triangulation) combined with lines of reconnaissance soundings or spot soundings gathered as helicopters land at many discrete locations. Today, only 10% of the Arctic has been surveyed and charted to modern standards. That is to say the Canadian Hydrographic Service has acquired continuous bottom profiles and has recorded survey vessel positions using modern radio- or satellite-positioning systems, and meet present-day international hydrographic standards for surveying, including having conducted detailed examinations where the data indicated possible shoaling of the bottom. In general, the more recent the survey, the more reliable and accurate the results. The very latest surveys frequently, but not always, consist of 100% bottom insonification using multi-beam sonar, sweep multi-transducer systems, and airborne laser bathymetry systems.

Even new editions of charts may contain a mix of older and newer data. The appearance of depth contour lines on new charts does not necessarily indicate any new information.

Precautions to be taken when using navigational charts for Arctic areas include:

- checking the projection and understanding its limitations;
- checking the date of the hydrographic survey and reviewing the Source Classification Diagram;
- using range and bearing to transfer positions from chart to chart;
- checking for evidence of reconnaissance soundings;
- using the largest scale chart available;

- checking for the method of measuring distances and taking bearings; and
- updating charts and nautical publications by checking for Notices to Mariners, Notices to Shipping and any other sources for chart corrections.

It is important to note that raster charts are electronic copies of the paper charts, and there is normally no increase in accuracy simply because a charts is digital. Most S-57 ENC and BSB RNC charts are based on the paper chart; however, in the Arctic there are some S-57 ENCs that do not have a paper chart equivalent and they may be based on modern surveys. It is important to examine the meta-data in the electronic chart display to assess this information.

Compasses

The magnetic compass can be erratic in the Arctic and is frequently of little use for navigation:

Note:

The magnetic compass depends on its directive force upon the horizontal component of the magnetic field of the earth. As the north magnetic pole is approached in the Arctic, the horizontal component becomes progressively weaker until at some point the magnetic compass becomes useless as a direction measuring device.

If the compass must be used the error should be checked frequently by celestial observation and, as the rate of change of variation increases as the pole is approached, reference must be made to the variation curve or rose on the chart. In high latitudes, generally above 70°N in the Canadian Arctic, the magnetic compass will not settle unless the ship remains on the same heading for a prolonged period, so it can be considered almost useless anywhere north of Lancaster Sound.

The gyro compass is as reliable in the Arctic as it is in more southerly latitudes, to a latitude of about 70°N. For navigation north of 70°N special care must be taken in checking its accuracy. Even with the compensation given by the latitude corrector on certain makes of compass, the gyro continues to lose horizontal force until, north of about 85°N, it becomes unusable. The manual for the gyro compass should be consulted before entering higher latitudes. The numerous alterations in course and speed and collisions with ice can have an adverse effect on its accuracy. Therefore, when navigating in the Arctic:

- the ship's position should be cross-checked with other navigation systems, such as electronic position fixing devices, where course history could be compared with course steered (allowing for wind and current);
- the gyro error should be checked whenever atmospheric conditions allow, by azimuth or amplitude; and
- in very high latitudes approaching the North Pole, the most accurate alternative to the gyro compass for steering is the GPS, which, if working as it should, can also be used as a check on “course-made-good" over the ground.

Soundings

When in areas of old or sparse hydrographic survey data, the echo sounder should be run so as to record any rocks or shoals previously undetected, although it is doubtful that the sounder would give sufficient warning to

prevent the ship going aground. Even in areas of the high Arctic that are well surveyed, the echo-sounder should be run, as ship traffic in the area is sparse and many of the routes will not have been sailed previously by deep-draft ships.
Many of the navigational charts in the Arctic consist largely of reconnaissance soundings (not done as part of a survey). As a result, it is not likely that a line of soundings would be of much use in finding a position. Additionally, false echoes may be given by ice passing underneath the echo sounder or by the wash when backing or ramming in ice. In heavy concentrations of ice cover, the echo sounder may record multiple returns so that it is impossible to distinguish which one represents the actual depth beneath the keel. When soundings are lost in this manner, it may help to stop the ship in the ice until a stable echo can be discerned amongst the random spurious echoes.

Position Fixing

Problems encountered with position fixing arise from either mistaken identification of shore features or inaccurate surveys. Low relief in some parts of the Arctic makes it hard to identify landmarks or points of land. Additionally, ice piled up on the shore or fast ice may obscure the coastline. For this reason radar bearings or ranges should be treated with more caution than measurements in southern waters. Visual observations are always preferable. Sometimes it is possible to fix the position of grounded icebergs and then to use the iceberg for positioning further along the track, if performed with caution.
Large areas of the Arctic have not yet been surveyed to the same standards as areas further south, and even some of the more recently produced charts are based on reconnaissance data. To decrease the possibility of errors, three lines (range, or less preferably bearings) should always be used for positions. Fixes using both sides of a channel or lines from two different survey areas should be avoided. Because of potential problems, fixes in the Arctic should always be compared with other information sources, such as electronic positioning systems. Reliance on one information source should be avoided.

Global Positioning System (GPS)

The Global Positioning System, or GPS, is a space-based radio-navigation system that permits users with suitable receivers, on land, sea or in the air, to establish their position, speed and time at any time of the day or night, in any weather conditions.
The navigational system consists nominally of 24 operational satellites in six orbital planes, and an orbital radius of 26,560 kilometres (about 10,900 nautical miles above the earth). Of the 24 satellites, 21 are considered fully operable and the remaining three although functioning, deemed “spares". The orbital planes are inclined at 55° to the plane of the equator and the orbital period is approximately 12 hours. This satellite constellation allows a receiver on earth to receive multiple signals from a number of satellites 24 hours a day. The satellites continuously transmit ranging signals, position and time data that is received and processed by GPS receivers to determine the user's three-dimensional position (latitude, longitude, and altitude), velocity and time. Although the satellites orbit the earth in a 55° plane, the positional accuracy all over the globe is generally considered consistent at the 100-metre level. For

a ship at a position 55° north or south latitude or closer to the pole, the satellites would be in a constellation around the ship with the receiver actually calculating the ship's Horizontal Dilution of Precision (HDOP) with satellites possibly on the other side of the pole. With a ship at or near the North Pole all the satellites would be to the south, but well distributed in azimuth creating a strong fix. The exception to this is the vertical component of a position which will grow weaker the further north a ships sails because above 55°N there will not be satellites orbiting directly overhead

There are a variety of sources of error which can introduce inaccuracies into GPS fixes especially in polar regions such as tropospheric delays and ionospheric refraction in the auroral zone. The troposphere varies in thickness from less than nine kilometers over the poles to over 16 kilometres on the equator which can contribute to propagation delays due to the signals being refracted be electromagnetic signal propagation. This error is minimized by accurate models and calculations performed within the GPS receiver itself. The ionospheric refraction in the auroral zone (the same belt in which the aurora borealis / aurora australis phenomena occur) caused by solar and geomagnetic storms will cause some error.

One minor advantage of the drier, polar environment is the efficiency of the receiver to process satellite data. In warmer, marine climatic conditions it is more difficult to model a wet atmosphere.

If the datum used by the GPS receiver in calculating latitude and longitude is different from the horizontal datum of the chart in use, errors will occur when GPS derived positions are plotted on the chart. GPS receivers can be programmed to output latitude and longitude based on a variety of stored datum sets.

Since 1986 the Canadian Hydrographic Service has been converting CHS charts to NAD 83. Electronic charts are typically on NAD83 however it is important to check the electronic chart meta-data to be certain. Information on the chart will describe the horizontal datum used for that chart and for those not referenced to NAD 83, corrections will be given to convert NAD 83 positions to the datum of the chart. The title block of the chart will describe the horizontal datum used for the chart and will give the corrections to convert from the datum of the chart to NAD 83 and vice versa. A note of caution regarding raster charts: the title block, since it is an image taken from the paper chart, may indicate the chart is not on NAD83 however the Canadian Hydrographic Service issues all its raster charts on NAD83 therefore no correction is necessary.

Global Navigation Satellite System (GLONASS)

The Global Navigation Satellite System is a radio-based satellite navigation system operated for the Russian government by the Russian Aerospace Defence Forces. It complements and provides an alternative to the United States Global Positioning System and is currently the only alternative navigational system in operation with global coverage and the same precision. The GLONASS constellation has 24 operational satellites to provide continuous navigation services worldwide, with 7 additional satellites for spares and maintenance.

Radios

Radio communications in the Arctic, other than line of sight, are subject to interference from ionospheric disturbances. Whenever communications are established alternative frequencies should be agreed upon before the signal degrades. Use of multiple frequencies and relays through other stations are the only methods of avoiding such interference.

INMARSAT
Inmarsat owns and operates three global constellations of 11 satellites flying in geosynchronous orbit 37,786 km (22,240 statute miles) above the Earth. Use of INMARSAT services in the Arctic is the same as in the south, until the ship approaches the edge of the satellite reception at approximately 82°N. At high latitudes where the altitude of the satellite is only a few degrees above the horizon, signal strength is dependent on the height of the receiving dish and the surrounding land.
As the ship leaves the satellite area of coverage the strength of the link with the satellite will become variable, gradually decline, and then become unusable. When the strength has diminished below that useable for voice communications, it may still be possible to send telexes. Upon the ship's return to the satellite area of coverage there may be problems in obtaining the satellite signal and keeping it until the elevation is well above the horizon.

Search and Rescue
The Canadian Forces are responsible for coordinating Search and Rescue (SAR) activities in Canada, including Arctic waters, and for providing dedicated Search and Rescue aircraft to aid in marine Search and Rescue incidents. A Search and Rescue service is defined as the performance of distress monitoring, communication, coordination, and search and rescue activities through the use of public and private resources. Any incident requiring assistance must be reported to an MCTS Centre.
The Canadian Coast Guard works with the Canadian Forces to coordinate marine Search and Rescue activities within the Arctic. They search for and provide assistance to people, ships, and other craft that are, or are believed to be, in imminent danger. They provide dedicated marine Search and Rescue vessels in strategic locations. There are no dedicated marine SAR units deployed in the Arctic waters on a year-round basis, however, Canadian Coast Guard units deployed in the Arctic during the navigation season are designated for SAR activities as their secondary role. SAR aircraft are staged into the Arctic from more southerly bases in the event of a SAR incident, or may already be present on training missions.
Rescue Co-ordination Centres, covering all waters under Canadian jurisdiction, are staffed 24 hours a day by Canadian Forces and Canadian Coast Guard personnel. They are located in Victoria, British Columbia, Trenton, Ontario and Halifax, Nova Scotia. The Joint Rescue Coordination Centre (JRCC) in Trenton provides emergency response and alerting systems for Search and Rescue in the Great Lakes and Arctic regions. Visit the Joint Rescue Coordination Centre (JRCC) Halifax website for more information.

Reporting Oil Spills

Any incident involving the spillage of oil or petroleum lubricating products into the marine environment must be reported immediately to NORDREG CANADA. In addition, the operator should report the incident to the 24-hour Spill Report Centre.
Nunavut and Northwest Territories: (867) 920-8130.
Yukon: (867) 667-7444;
Canadian Coast Guard toll-free: 1 (800) 265-0237 (24 hours)

Fuel and water

The ASPPR requires all vessels operating in the Zones to have sufficient fuel and water on board to complete their intended voyages and to leave all Zones. A vessel's capability of making its own fresh water will be taken into account in this regard. There are no refuelling or watering facilities in the Arctic unless the cruise operator makes special arrangements during the planning phase. Transport Canada will require an estimate of fuel consumption anticipated for the full voyage and NORDREG will need to be informed of the volume of fuel on board prior to the vessel entering the first Zone

Environmental Disturbances on Ice Transportation, Birds, Animals and Fish

Environmental effects of a harmful nature are becoming an increasingly important concern in marine navigation. This concern applies to navigation in ice-covered waters where special navigational considerations may have a potential for environmental disturbance. While it is clear that accidents can have a detrimental effect on the environment, even normal marine operations have the potential to affect valued components of the environment. Valued components may include the following:

- rare or threatened species or habitats;
- species or habitats which are unique to a given area;
- species or habitats which are of value for aesthetic reasons;
- species which may be used by local populations; and
- cultural and socio-economic practices of local populations

There are numerous potential effects that are not unique to ice environments; however, the presence of ice, cold temperature, and remote location, may enhance the level of disturbances over similar activities in milder environments.
Some specific environmental disturbances which are unique to ice-covered waters include the possible restriction of on-ice travel of local populations when a track is created in the ice, potential disruption of the formation or break-up process for local ice edges and, in the early spring, disruption of seal breeding on the ice.
Potential disturbances arising from normal operations are generally location specific. In most cases, avoiding sensitive areas and times of the year will mean that disturbances can be avoided. Adherence to navigation practises, as outlined in this manual, will minimize the risk of environmental disturbances from navigation in ice. Navigators should consider how their ship might affect the environment and take measures to minimize the disturbance.

Ice Information

To conduct a sea voyage safely and efficiently, a mariner must have a well-founded understanding of the operating environment. This is especially true for navigation in ice. It is the responsibility of all mariners to ensure that before entering ice-covered waters, adequate ice information is available to support the voyage from beginning to end.

The ways and means of acquiring ice information suitable for navigation vary from one source to another. Content and presentation formats also vary depending on the nature of the system used to acquire the raw data, and the degree of analysis or other form of enhancement which may be employed in generating the final product.

Many information sources are not normally or routinely available at sea, especially outside Canadian waters. In some cases prior arrangements may be necessary to receive particular products. The mariner is encouraged to consider carefully the required level of information, and to make appropriate arrangements for its delivery to the vessel.

Levels of Ice Information

It is possible to distinguish four levels of ice information, characterised by increasing detail and immediacy:

- Background;
- synoptic (summary or general survey);
- route specific; and
- close range.

Background information is primarily historical in nature. It describes the natural variability in space and time of ice conditions for the region of intended operation. It may also describe the relationship of ice conditions to other climatological factors including winds, currents, and tides. It is applied very early in the strategic planning process, but it may also be useful at any time during the voyage.

At the synoptic level, ice conditions are defined for specific regions and time periods. The information may provide either current or forecast ice conditions but, in either case, it is not very detailed. As synoptic information is normally used days or even weeks before entering the ice, and because conditions are often dynamic, its greatest value is as a support tool for strategic planning.

Route-specific information provides a greater level of detail than synoptic information, usually for smaller areas. The detail provided may extend to the identification of individual floes and other features of the ice cover, and is most useful at the tactical planning stage.

Close-range information identifies the presence of individual hazards which lie within the immediate path of the ship. This level of information provides critical support during monitoring and execution of the tactical passage plan.

Environment Canada's Canadian Ice Service (CIS), provides ice information and long-range forecasts to support marine activities. At the synoptic level, the Ice Operations Division of the CIS provides valuable strategic planning information through a series of plain language bulletins, warnings, and short-range forecasts for ice and iceberg conditions. These are broadcast live by marine radio, with a range of up to 320 kilometres. Broadcast frequencies and schedules are listed in the Canadian Coast Guard publication Radio Aids to

Marine Navigation, issued seasonally. Taped bulletins are broadcast continuously from Canadian Coast Guard radio stations with an effective range of 60-80 kilometres. Alternatively, most of this information is available on the CIS website or by subscription through the CIS Client Service section. Extended forecasts (including seasonal outlooks and twice-monthly 30-day forecasts), and daily ice analysis charts, are available through the web, email, mail or facsimile subscription. For further information contact:

Address:
Canadian Ice Service
373 Sussex Drive, 3rd Floor
Lasalle Academy, Block “E"
Ottawa, Ontario
K1A 0H3
Telephone: 1 (877) 789-7733
Fax: (613) 947-9160
CIS website

The most important external source of information available to the ship is the broadcast of ice analysis charts by the CIS. For ships equipped with their own reconnaissance helicopter, aerial visual observations may provide considerably more ice information at the route planning and tactical levels.

Remote Sensing Systems

With special purpose receiving and processing equipment, ships may take advantage of airborne and satellite borne remote sensing systems for complementary synoptic level ice information.

The Canadian Ice Service operates two airborne imaging radar systems for ice reconnaissance, which are able to transmit raw data directly to the CCG Ice Operations Centres. The all-weather systems can penetrate dry snow cover to produce grey-tone images of the ice surface. The level of detail afforded by these systems depends on sensor resolution, which may vary between 25 and 400 metres. The resultant images therefore, are well suited to the tactical route planning process. The higher resolution data may be used in conjunction with visual observations and marine radar at the close range hazard detection level.

Many commercially available systems enable ships to receive direct transmission of weather satellite imagery which may be used to assess regional ice distribution. These systems are designed to receive the VHF (137 MHz) image transmission from various weather satellites via inexpensive personal computer software. Image resolution is in the range of 3 to 4 kilometres, providing suitable information for synoptic level voyage planning. The low cost of these systems (typically in the tens of thousands of dollars) makes them suitable for a larger number of ships transiting ice-covered waters (Figure 61).

Canada has a fully operational imaging radar satellite known as RADARSAT-2, which provides high-resolution (100 metre) global coverage of ice-covered waters on a nearly continuous basis. RADARSAT-2 has the capability to send and receive data in both horizontal (H) and vertical (V) polarizations. Images acquired with the various combinations of polarizations on transmit and receive can be displayed on single channels or in various combinations including ratios and false colour composites.

Canadian Ice Service Ice Charts

Ice charts issued by the Canadian Ice Service (CIS) use standard World Meteorological Organization terms and symbols to describe ice conditions at different locations. The mariner should be aware that these charts are synoptic level information sources, and the ice conditions depicted are averages for the area. There is always the possibility that local ice conditions may differ significantly from those depicted on the chart. Maintaining manoeuvrability for the avoidance of locally heavy ice conditions is an important consideration when using ice charts at the route planning level.
The ice analysis charts issued daily by CIS do not show areas of ridged ice, rubbled ice, or ice under pressure. They do, however, indicate the general drift in miles per day of individual ice-fields, so that developing pressure can be deduced. In using this information, the mariner should consider at all times the potential for ice drift and changes in ice conditions, which is especially important where navigation corridors are constrained by shallow water, and where winds, currents, and/or tides may result in zones of ice convergence.
The ice analysis chart is the primary map product produced at the CIS. It is produced daily at 1800 UTC during the operating season, and represents the best estimate of ice conditions at the time of issue. The chart is prepared in the afternoon so that it may be delivered to users in time for planning the next days' activities.
An example of how to read a daily ice analysis chart is presented in Figure 65. The CIS uses codes and symbols to describe all ice forms, conditions, and concentrations as accepted by the World Meteorological Organization. The ice codes are depicted in oval form, known as the Egg Code, which is completely described in MANICE, and is outlined in this section. The use of codes and symbols varies according to the type of ice chart:

- current daily ice chart: area specific, most detailed
- regional weekly ice chart: smaller scale, less detailed.

The basic data concerning concentrations, stages of development (age), and form (floe size) of ice are contained in a simple oval form. A maximum of three ice types are described within the oval. This oval, and the coding within it, are referred to as the "Egg Code".
The Egg Codes symbols in the code are classed into four categories of ice information:
1) Total concentration (top level)
Ct - Total concentration of ice in the area, reported in tenths.
2) Partial concentrations of ice types (second level)
CaCbCcCd - Partial concentrations of thickest (Ca), second thickest (Cb), third thickest (Cc), and fourth thickest (Cd) ice, in tenths.
3) Ice type corresponding to the partial concentrations on the second level (third level)
Stage of development of the thickest (So), second thickest (Sa), third thickest (Sb), and fourth thickest (Sc) ice, and the thinner ice types (Sd and Se), of which the concentrations are reported by Ca, Cb, Cc, and Cd, respectively.
4) Predominant floe size category for the ice type and concentration (bottom level)
Floe size corresponding to Sa, Sb, Sc, Sd, and Se (when Sd and Se are greater than a trace).

Characteristics of Sea Ice

There are characteristic features and formations associated with individual ice types, which provide useful clues that the mariner can use to recognize and classify ice conditions. It must be remembered that environmental conditions such as darkness, fog, snow cover, ice roughness and surface melt may complicate ice recognition. Additional information on ice type characteristics and terminology is contained in Annex A.

New Ice

New ice is recently formed ice in which individual crystals are only weakly frozen together, if at all. It is frequently found without structural form, as crystals distributed in a sea-surface layer which may exceed one metre in depth, depending on sea state.

New ice may be recognized by its characteristic soupy texture and matt appearance, as illustrated in Figure 67. It may also take the form of spongy white lumps a few centimetres in diameter (termed shuga), which can also result from heavy snow falling into water at about the freezing point.

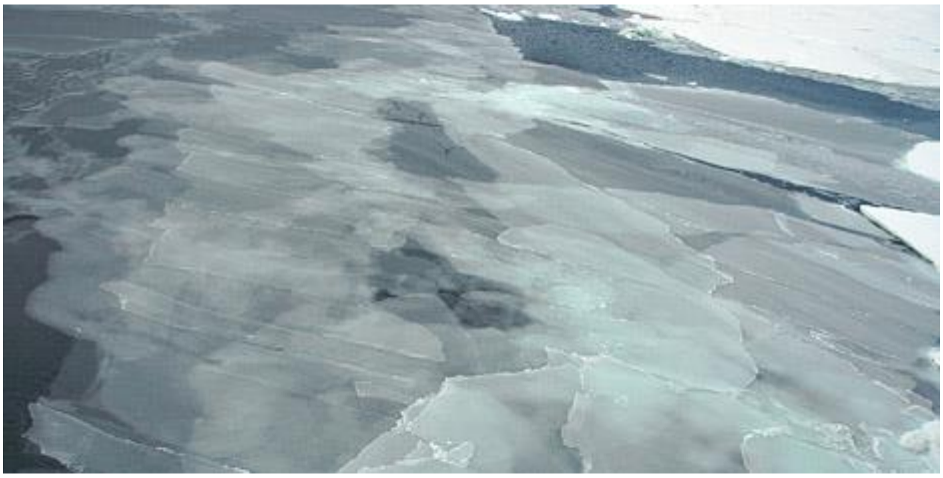
Nilas

Nilas is ice that has developed to the stage where it forms a thin elastic crust over the sea surface. The layer may be up to 10 centimetres thick and is characterized by a dark, matt appearance. Nilas has unique deformation characteristics that make it easy to recognize. It bends easily on a ships wake, often without breaking, and when two sheets of nilas converge they may overlap in relatively narrow fingers (Figure 68). New ice and nilas are not a hazard to shipping

Young Ice

Young ice is ice that is between 10 and 30 centimetres thick. This category includes grey ice (10-15 centimetres thick), and grey-white ice (15-30 centimetres thick). As these names suggest, young ice is most readily identified by its characteristic grey colour. Converging floes of grey ice will overlap, or raft, in wider fingers than nilas ice, and can extend to rafting of very large sheets. Extensive rubble fields are frequently observed, especially in grey-white ice.

Young ice achieves sufficient strength to present a potential hazard to vessels not strengthened for ice and will begin to slow down the speed of advance of low-powered vessels. Figures 69 and 70 are examples of young ice



Old Ice

Old ice is ice that is more than one year old and has survived at least one melt season. This category includes second-year and multi-year ice. During the melt period, puddles form on the first-year ice surface that because of their darker colour tend to absorb more solar radiation than the surrounding patches of white ice. Should the ice not melt completely before the onset of freeze-up, the undulating pattern will become a permanent feature of the ice surface. As the melt-freeze cycles are repeated, the ice grows progressively thicker and the difference between melt ponds and hummocks becomes more pronounced.

It is not always easy to distinguish second-year from first-year ice, as both snow cover and melt-water tend to hide the early stages of hummock growth. The component of the ice cover that is actually second-year ice is normally limited to the upper 50-100 centimetres, with the remainder being first-year ice growth. Thus second-year ice may be recognized when pieces turn on their side, by the presence of a distinct, cloudy boundary between the two layers which is several centimetres thick. Below the boundary, the first-year ice will usually be apparent from its slightly greener colour, and vertical structure of its columnar crystals. Figure 72 shows an example of second-year ice.

Multi-year ice is easier to identify than second-year ice, primarily because the hummocks and melt-ponds become increasingly pronounced. In addition, there is normally a well-established drainage pattern connecting the melt ponds, and floes tend to have a higher freeboard than first-year ice. Where the ice is bare, the colour of multi-year ice may appear bluer than first-year ice**.**

Multi-year ice floes vary considerably in size, thickness, and roughness, depending on their growth history. Even when the surface is hidden by rubble or snow, it is frequently possible to identify these very strong floes by the first-year ice ridging which often forms around their perimeter. Many of these characteristics can be seen in the photograph of a typical multi-year floe, presented as Figure 73. Multi-year ice is the strongest and hardest form of sea ice and represents a serious impediment - indeed a danger - to all ships, as even the most powerful icebreakers will avoid contact with multi-year floes if at all possible.

Icebergs, Bergy Bits and Growlers

Mariners should beware of leads in pack ice, which may suddenly end at an iceberg. Because icebergs project deep into the water column, they are affected more by ocean currents and less by winds than the surrounding sea ice. This may result in differential motion and the creation by the iceberg of an open water track through the pack ice.

Generally, the same comments apply to bergy bits and growlers as to icebergs. However, the smaller size of these hazards means they are often more difficult to detect than icebergs and, therefore, are very dangerous. Special care must be taken in watching out for bergy bits and growlers. They may be well hidden by white caps in the open sea, as shown in Figure 74, or by rubbled ice, as shown in Figure 75. Their shape may make even larger bergy bits difficult to detect using marine radar, when the freeboard is relatively small and if the sides are oriented to deflect radar energy away from the antennae. It is worthwhile to reduce speed while in bergy waters and to add an extra watch keeper to ensure that an adequate look out can be maintained. Bergy bits and growlers are the most dangerous hazards to ships in ice-covered waters.

Marine Observations from Vessels

Observations from vessels on weather, sea, and ice conditions are important sources of information for the Environment Canada Storm Prediction Centres. Vessel observations allow the meteorologist:

- to know where the vessel is and to focus on that area;
- to confirm a forecast with actual data during the forecast period;
- to learn in real time what winds are produced by various pressure patterns in a given area; and
- to learn which forecasting techniques are appropriate for a given area, for example, to forecast sea conditions, vessel icing, and ice motion.

Direct observations from vessels are incorporated on weather maps and analyses. There is a special need for observations from vessels transiting Hudson Strait and Hudson Bay, from fishing vessels in Davis Strait during November and December, and any vessels navigating in the Arctic.

In addition to using vessel observations in current forecasts, the information is stored by the Canadian Climate Centre in Toronto so that meteorologists can analyse it, for example to learn the means and extremes of wind for various marine areas. Engineers use the data to evaluate extreme events expected which could affect vessels and structures; they can develop and refine formulas to compute conditions such as sea state and vessel icing.

Observations can be passed to the appropriate Storm Prediction Centre, listed in Section 1.7, or to the nearest MCTS Centre which will forward the information to the Storm Prediction Centre. No cost is involved. Weather, sea, and ice observations can be added to any position report given; for instance, all vessels operating in Arctic waters must provide a once daily position report. It is most useful to provide weather observations at the regular times of 0000, 0600, 1200, and 1800 UTC so that charts and forecasts can be updated.

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