# Iced Maritime Routes, impact on Stability for Naval Ships

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**ABSTRACT**

Three factors can be pointed out in order to explain the motivation for iced seas or partially iced seas sailing: Climate environment, shortening of commercial route, offshore oil and gas exploitation. It is necessary to prove the ability of a ship to break the ice and to resist to ice shock. A list of laboratory, which can perform those evaluations, is given. The stability is also sensitive to the increase of mass by ice accretion on superstructures, and taken into account by some rules.

**Keywords:** *Ice, Maritime routes, Rules, Laboratories.*

## 1. INTRODUCTION

Three factors can be pointed out to explain the motivations to sail on iced maritime routes:

- Climate conditions,
- Shortening of maritime route and
- Offshore oil and gas exploitation.

Climate conditions involve regions with maritime coast opened on iced sea during most part of the year or which are located around the polar circle. Countries such as Finland, Sweden, Federation of Russia whose coasts are around Baltic sea and Bothnie gulf are telling examples of the first case and countries such as Canada, Norway and the north coast of the Federation of Russia belong to the second one, figure 1.

Such countries must maintain both port and offshore traffic, such as ferry services and must guarantee the security in their own territorial waters with ice-worthy warships needed to patrol.

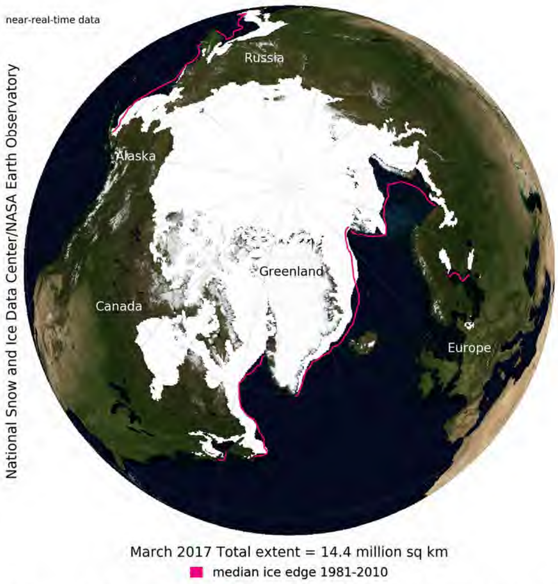


**Figure 1: Extent of ice in Arctic region for March 20017 - Courtesy of the National Snow and Ice Data Center, University of Colorado, Boulder.**

## 2. MARITIME ROUTES

There are two major maritime merchant routes. One route links European ports to those located along the East coast of the United-States, through the Canal of Panama and the other one links European ports to ports on Chinese and Japan coast, figure 2. Alternative maritime routes from Arctic make substantial shortening in term of distance travelled, respectively Northwest Passage and Northern Sea Route, as shown in Table 1.


**Figure 2: Current maritime routes and arctic maritime routes: left Northwest Passage, right: Northern Sea Route, from AMAP, 2012.**

**Table 1: Distance travelled for the major maritime route and their alternative**

| | Current route through The Panama Canal | Alternative route through Arctic, Northwest Passage |
|---|---|---|
| **Maritime routes from Europe to East coast of the United-states** | ≈17000 km | ≈14000 km |
| | **Current route through Canal of Suez** | **Alternative route through Arctic, Northern Sea Route** |
| **Maritime routes from Europe to coasts of China or Japan** | ≈21000 km | ≈14000 km |

The ships which sail along the Arctic routes must be ice-breakers or vessels with the capability to follow ice-breakers, that is to say with a hull and propellers able to resist ice-cube shocks.

Oil resources are important in Arctic region, figure 3, and the exploitation of these resources are under important environmental constraints. The structure of offshore platforms must resist ice pressure and the OSV in charge to supply must be proved to be ice-cube shock resistant and moreover these units have to perform dynamic positioning in iced sea conditions.


**Figure 3: Major areas of oil and gas development and potential development in the arctic and major shipping routes and possible new routes through arctic waters (from AMAP, 2012.**

## 3. EXPERIMENTS IN ICED TANKS

Many establishments are involved in iced sea tests. The main objective is to prove the ability of the future vessel to break the ice, for ice-breakers projects, or to resist ice cube shocks for the other iced-seas going vessels. The ability of the propulsors, propellers or azipod, to ingest iced block without any damage must be demonstrated too. A list of the major test sites which owns an ice model basin is given in Table 2.

To obtain ice layer with the right thickness in a basin and to maintain the right temperature inside the enclosure for the tests may be of high costs, in both energy and time. Establishments involved in iced sea tests, but without appropriate facilities, have developed alternative and innovative methodologies by using artificial ice to perform tests. According to this kind of method, pieces made of polystyrene stand for iced water to study the effects of ice cubes shocks and, more recently, paraffin-based blocks stand for floating ice block to study the ingestion of ice by the propulsors. The former method is used at the University of Pusan (Won-Joon Lee and Moon-Chan Kim, 2013) and the later by MARIN (G.Hagesteijn, 2015).

## 4. ICE ACCRETION

In above section we discussed only about iced sea, but icing phenomenon may occur on the hull and on the superstructure of a iced-sea-going vessel. This kind of icing may occur when sailing in ice free water, the causes of the icing phenomenon is a low temperature and a significant rate of humidity. We can cite as a telling example the frosty fog. Frosty fog is composed of non-frozen droplets in super cooled state. Such a state is a metastable one; the droplets froze as soon as they meet any element of the boat, hull or superstructure. The same phenomenon occurs on in land facilities, involving hot tension wire for example or air traffic when plane flies through an icing cloud. Hull and superstructure icing may be dangerous for the stability of the ship. On the one hand, ice accretion means significant additive weight for the ship, and on the other hand a non-symmetric accretion means the ship heels on her side and the heeling may lead to capsizing.

At sea the main reasons for ice accretion are;

- Freezing spray,
- Super-cooled fog
- Freezing rain or drizzle
- Failing wet snow.

The most probable reason (about 90%) is the freezing spray that is studied below. That can explain why most of the rules consider only ice accretion in the bow area of the ship (one over three front part).

## 5. PREDICTION OF ICE ACCRETION

Many theories exist to predict the ice accretion as Overland. The parameters of those theories are: the freezing point of salt water, the air and water temperature, wind speed and time of exposure in order to determine the risk of ice accretion, PR.

$$PR = V_a\,(T_f - T_a) / (1 + 0.3\,(T_w - T_f))$$

With $T_f$ freezing point of sea water (°C)

$T_a$ air temperature (°C)

$T_w$ sea temperature (°C)

$V_a$ wind speed (m/s)

From this risk, PR, some propose to determine empirically the rate of ice accretion, IR, in centimeter increasing of thickness by hour.

Then, with a time exposure it is possible to estimate the thickness and the mass of ice.

Lozowski propose some more sophisticate theory than the one presented above.

Relying on those theories it is possible to make prediction from usual weather forecast given by most meteorogical centres as NOAA.

## 6. RULES

***Assumptions***

The presence of icing degrades the already very rough environment to which a ship is subjected. The accumulation of ice in the topside harms the stability of the ship. Currently, some simple technologically solutions to effectively combat ice accumulation exist but usually note supposed to be effectiveness for the rules. Main icing abatement are: mechanicals methods (including electro expulsive deicing system, pneumatic or high pressure water jets), thermal methods or chemical methods freezing point depressants or ice-phobic coating.

This is why the French and some foreign navies have sought to determine coherent criteria in order to better understand this phenomenon. Each vessel that is subject to this environment must therefore comply with these criteria. To ensure this, the Navies must make calculations based on multiple assumptions. For IMO, only ships who have to sail in some particular zones (more or less northern then 60°N and southern than 60°S) have to follow specific checks: The ships have to follow intact criteria for extra loads.

As most of the occidental rules, French rules, came from the Sarchin and Golberg work. To propose their criteria for ice accretion they used the feedback of the “wind-class” US icebreakers. The performed an inverse calculation to determine the maximum thickness of ice is acceptable on these ships for usual intact stability criteria. It was this thickness that was proposed for the naval rules criteria. This value matches well with a 20 hours’ time exposure with a small rates of accretion as assumption. This time exposure was determined by 8 years of feedback from a “wind-class” US icebreaker.

### *Comparisons*

In order to carry out the comparison, it is necessary to begin by agreeing on the same definition of hypotheses and criteria. The objective is to make the compared rules communicate better with each other. If the starting assumptions are different from the rules, then it is not possible to compare the results and the criteria. The most severe criterion cannot therefore be determined. Such a divergence in the definition of assumptions raises the question of how they were obtained.

An initial assessment can be made. In order to facilitate understanding, a table summarizing the main assumptions of some navies is given below. The navies appearing there have been selected because they have many differences between them. The values shown vary from one a navy to another, as does the definition of the starting assumptions. It is also observed that the input data (mass of the ice, center of gravity,...) and the output criteria are quasi-identical; which is an important first step towards standardizing assumptions and criteria.

There are almost as many starting assumptions as there are navies. Some prefer to calculate the mass of the ice by considering a certain distribution on the exposed surfaces of the ship, others prefer to consider that it is a function of its displacement. The divergences do not end there; they are also present in the definition of the position of the center of gravity of the ice or the wind speed to be taken into account.

Although the definition of the criteria is similar from one navy to another, the threshold is nevertheless different for some of them. For example, whereas the criterion on the GMt without wind imposes that it is higher than 0.15 m for the BVNR (France), The Royal Australian Navy imposes that it is greater than 0.6 m. The question of the severity of one regulation in relation to another must be raised.

## 7. ACKNOWLEDMENTS

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**Table 2: Characteristics of the major ice model basin**

| Establishment | Length (m) | Width (m) | Depth (m) | Max velocity of the carriage (m/s) | Ice characteristics | Max ice temp. (°C) | Name of the facilty |
|---|---|---|---|---|---|---|---|
| Krylov (Russia) | 102 | 10 | 2 - 4 | 1.5 | Thickness from 10 to 130 mm – Duration of producing: from 1 to 2 days | | Ice basin |
| Aker Arctic Technology (AARC) (Finland) | 75 | 12 | 2.1 | Main carriage 3 Second carriage (lateral) 1.5 | | | Ice Model Test Facility |
| NRC CNRC (Canada) | 90 | 12 | 3 | 4 | Thickness from 5 to 150 mm – rate of growth: 2.5 mm/hour | -30 | Saint Jean de Terre Neuve Facilty |
| NRC CNRC (Canada) | 27 | 7 | 1.1 | | | -20 | Ottawa facility |
| KRISO (Korea) | 42 | 32 | 2.5 | Main carriage 3 Second carriage (lateral) 3 | | -30 | Ice Basin |
| Aalto University (Finland) | 40 | 40 | 2.8 | | Thickness from 20 cm to 30 cm – the ice layer is from a water spray | -12 | Ice Basin |
| NMRI ( Japan) | 35 | 6 | 1.8 | | Thickness 30 cm – rate of growth:40 mm within 15 hours | -35 | Ice Basin |
| ERDC CRRL ( United-States) | 37 | 9 | 2.4 | | Thikness: 15 cm | -24 | Ice Engineering Basin |
| HSVA (Germany) | 78 | 10 | 5 | Main carriage: 3 Second carriage: 3 | Saline ice | -20 | Large Ice Model Basin |
| HSVA (Germany) | 30 | 6 | 1.2 | Recirculating water canal | Saline ice – rate of growth: 2 mm/hour | _16 | AETB – Arctic Environment Test Basin |
| JMUC – Japan Maritime United Corporation (Japan) | 20 | 6 | 1.8 | Upper carriage: from 0.4 to 1.5 Underwater carriage: unknown | Rate of growth: 8 mm/hour | -22 | Ice basin |
| University of Tianjin | 20 | 5 | 1.5 | 0.5 | | -22 | Ice basin |
| Arctic and Antartic Research Institute (Russia) | 35 | 5 | 1.8 | | | | Test Ice Tank |

**Table 3: Comparisons of some rules**

| | | France (Bureau Veritas Naval Rules) | US Navy | Australia |
|---|---|---|---|---|
| APPLICATION | Navigation area | Only for ships sailing north of 65 ° and south of 60 ° or in winter frost zone. | No restrictions | No restrictions |
| | Class of ship | Presence of an additional class, more severe | Presence of an additional class "ICE" | Not applicable for "polar" vessels |
| PARAMETER(S) | Wind | 70% of nominal wind: 100 knots for «unrestricted service» (80 knots for ships not employed in storms). | 70 knots (unrestricted), 45 knots (restricted service) | 70 knots (unrestricted), 60 knots (restricted service) |
| | Mass of ice (t) | - DLnato<1000t, M=10% of full load condition<br>-DLnato>1000 t : 140 kg / m² on the decks on the 1/3 front (Above the exposed deck) and 70 kg / m² on the vertical or oblique walls of the 1/3 front (above the exposed deck), including the side walls but not the masts. | $\Delta^{2}/_{3}$ | 15 cm (950 kg/m3) exposed decks and walls |
| | XG of ice (m/PPAR) | DLnato < 1000t : CoG of considered displacement<br>DLnato > 1000 t : , CoG of ice on the 1/3 front) | 5/6 LOA / PPAr | CoG of ice |
| | KG of ice (m/0H) | DLnato < 1000t : CoG of considered displacement<br>DLnato > 1000 t : , CoG of ice on the 1/3 front) | 1.2 m / exposed deck | CoG of ice |
| | YG of ice (m) | DLnato < 1000t : CoG of considered displacement<br>DLnato > 1000 t : , CoG of ice on the 1/3 front) | 0 m | CoG of ice (0 m) |
| CRITERIA WITHOUT WIND | Area (0°-30°) (m.rad) | 0,051 | - | 0,055 |
| | Area (0°-40°) (m.rad) | 0,085 | - | 0,09 |
| | Area (30°-40°) (m.rad) | 0,033 | - | 0,03 |
| | Gzmax (m) | 0,24 | - | 0,3 |
| | GMt (m) | 0,15 | - | 0,6 |
| | Angle GZmax | 25° >= théta >= 30° | - | 30° |
| CRITERIA WITH WIND | Wind profil | variable | variable | variable |
| | HAwind | variable | variable | variable |
| | théta R | 25° | 25° | 25° |
| | Area A1/A2 | 1,4 | 1,4 | 1,4 |
| | théta C | 30° | 15° | 30° |
| | GZ1/GZmax | 0,6 | 0,6 | 0,6 |