SECOND INTERNATIONAL CONFERENCE ON
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UNIVERSITY OF ICELAND
DEPARTMENT OF ENGINEERING AND SCIENCE

ICING OF SHIPS

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REASONS FOR ICING OF SHIPS

Icing of ships, which is usually due to freezing of sea spray that is blown over the vessel, is a well known problem in northern waters. (Icing refers generally to the formation of ice on ships, aircraft, power-lines, aerials and other man made installations or equipment). The sea spray is partly shipgenerated, and partly derived blown from wave-tops. The formation of ice on ships is often considerable on forecastle deck, on rails, masts and rigging and on other super- structures. Icing is formed by another reason when undercooled fog or rain freezes, thus creating fresh water icing. This type of icing is more common in typical arctic waters, and will not be considered here.

In icing conditions the danger for a ship is, of course, primarily due to the fact, that the ice-accreation increases the top-weight of the vessel, thus moving the center of gravity upwards and reducing its weight stability. At the same time added weight will decrease the freeboard and therefore reduce the form-stability of the ship. Furthermore accumulation of ice in masts, rigging and other super- structure will increase the effective wind area and therefore in- crease the effect from a wind-moment, which would further reduce the stability of the ship. This effect will be evaluated later. Several losses of ships are definitely known to be due to icing, but several other ship losses, are also considered to be due to icing. Many nations have carried out research on icing of ships, the main object often being to study the process of icing, the accumulation rate and external factors influencing icing. The aim of some of these studies has focused on the possibility of predicting icing, that would permit broadcasting the danger of icing with the weather-forecast. For such predictions considerable amount of data has now been collected. Walden (1967) has summarized the effective icing factors from sea water spray (Table 1).

The first item, meteorological and oceanographic conditions, includes primary conditions for the formation of icing. In order to produce icing from sea spray, the spray has to collide at least on parts of the ship, and sea and air temperatures have to be such that part of the sea spray freezes on the ship. Icing will accumulate in shorter period of time and will be more severe, if sea spray is constant and the temperature of sea and air low. However, if the air temperature is below - 18° C, the spray freezes in the air before touching the ship, and therefore does not produce icing. It has been shown, that the salinity of the sea water has no significant influence upon the icing, compared with the temperature of air and sea, and the wind force. The formation of the sea spray and the height it reaches above sea level, is mainly dependant upon the wind force and the state of the sea.

TABLE 1

Factors which influence icing from sea water spray

1. Meteorological and oceanographic conditions	air temperatur water temperature wind force state of sea: height, steepness, number of wave patterns, foam in the air, salinity.
2. The ship	size design load (freeboard)
3. Movement of the ship	course relative to wind and sea, speed
4. Place of measurement on board	height above water position in relation to ship's super-structure and hull

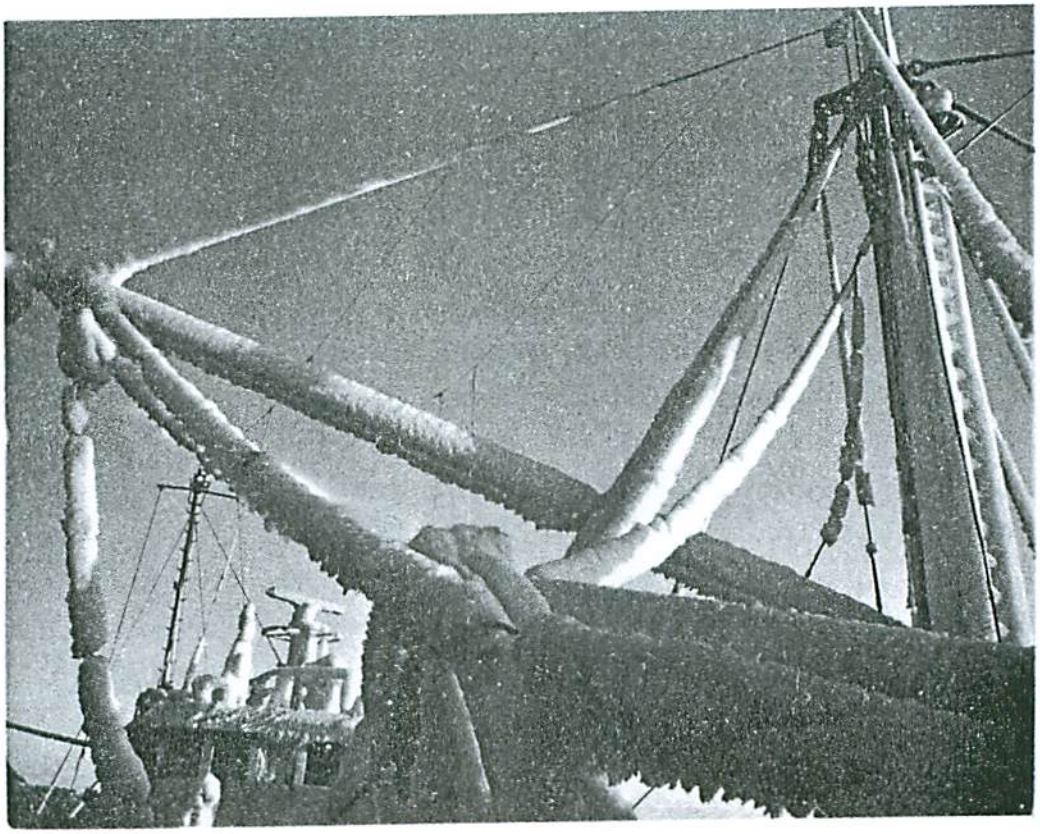

Fig.1. Icing of ships, rigging.

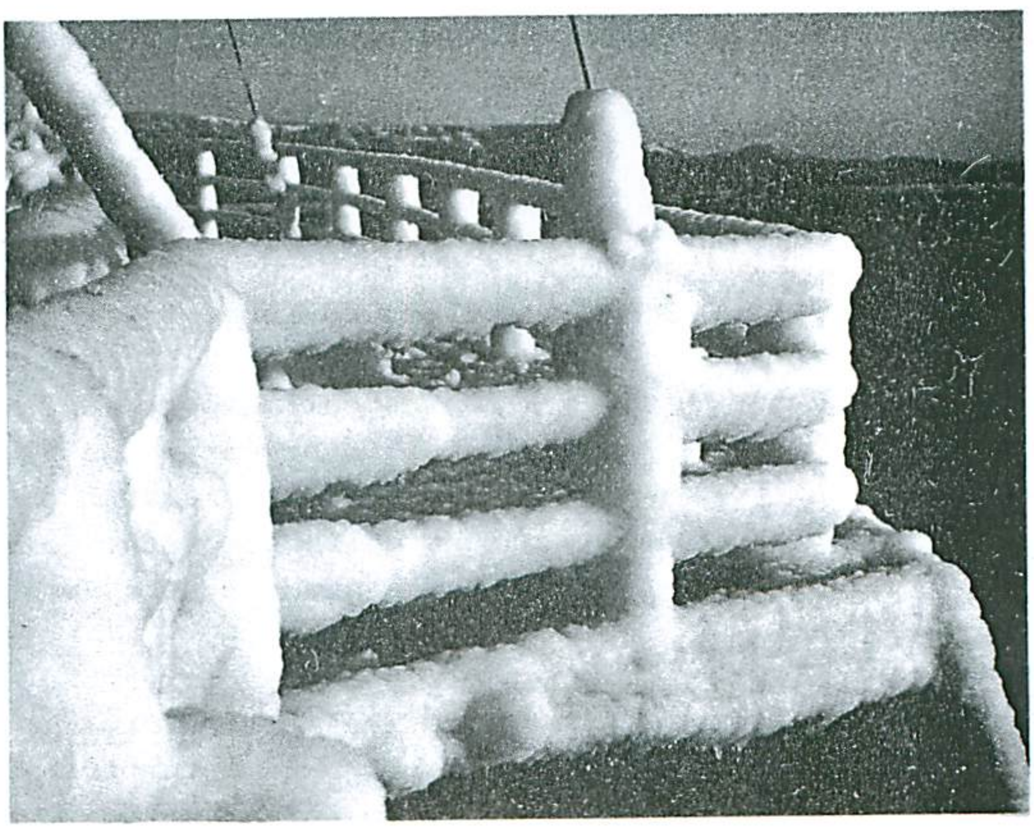

Fig.2. Icing of ships, handrails.

The second and third items, the ship and its movement, are also very important. The size and type of ship is important, but also the way it is loaded and its course relative to the movement of wind and waves. Irregular seas, composed of several wave patterns, will cause irregular rolling of the vessel so the vessel produces more sea spray at higher levels. Besides, the irregular seas themselves will usually produce more sea spray higher over sea level. The size of the ship has great influence on icing, mainly the freeboard. Bigger ships have larger freeboard. Usually the icing on the outside of a smooth hull is not a problem, as the sea breaks ice off again. Ships having a large freeboard have their decks, masts, rigging and other super-structure at a higher level above the sea, and as the sea spray reaches only a limited height above sea level, the icing on such ships is considerably reduced compared with smaller ships with less freeboard. Even on smaller ships, it is often seen that the icing is most severe on the lower parts of the masts and rigging etc., the sea spray not reaching the highest parts.

The thickness of icing on different parts of ships has been measured on Japanese vessels (T.Tabata, S.Jwata and N.Ono, 1963). They carried out measurements of the rate of icing at constant intervals by placing thin pieces of paper on the ice. Thus it was possible to measure the amount of icing at all the different measuring spots during each time interval, and so get a good general impression of the ice-accumulation on the various parts of the ship. The results showed, that the thickness of icing is very different on the various parts of the ship. Certain places on deck are considerable ice collectors, for example corners and rigging. Since 1962 a special icing meter has been used for measuring icing on ships. The icing meter records the weight of the sea spray that freezes on the cylinder of the icing meter, relative to the total amount of sea spray at that point.

However, such icing meter has so far only been used on a few ships. Therefore the results are still limited. Yet it is possible to obtain a rough information on icing from crews of fishing vessels and other small vessels in northern waters. This has been done and still is by several nations. Although the material is still limited, icing forecast with the weather fore-

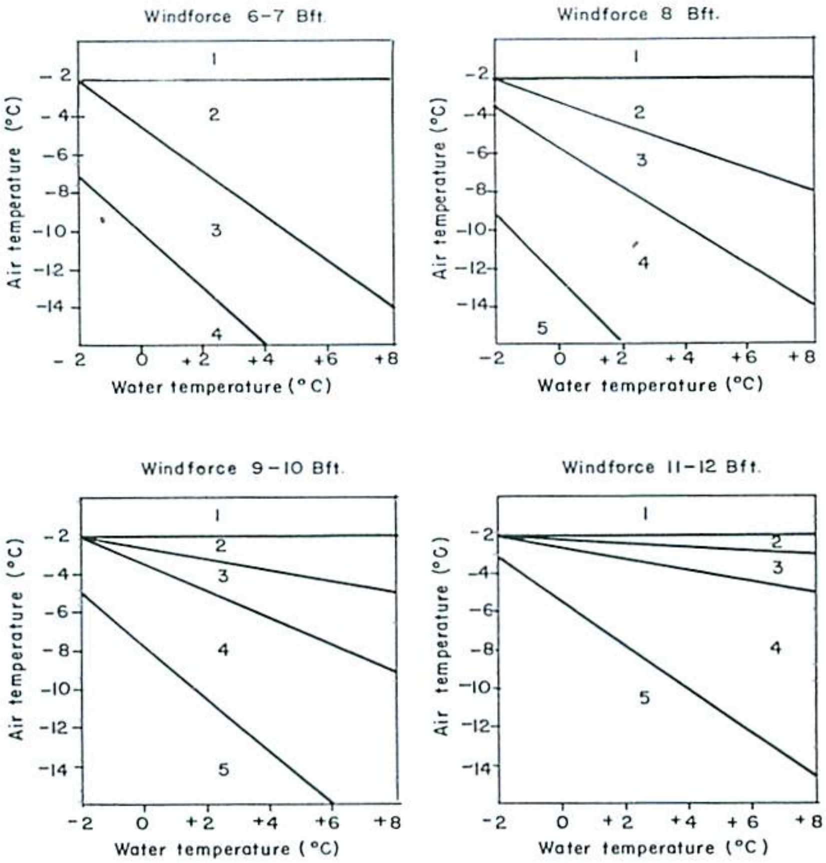

Fig. 3. Diagrams for estimating ice accretion on ships with low speed, as a function of the wind force and air and water temperatures.

Grade of icing –
1 – No
2 – Low 1–3 cm/24 h
3 – Moderate 4–6 cm/24 h
4 – Heavy 7–14 cm/24 h
5 – Very heavy 15 cm/24 h

Example –
Forecast:
windforce 9–10 Bft
airtemperature – 8° C
water temperature + 3° C

Expected icing according to diagrams: heavy icing 7–14 cm/24 h

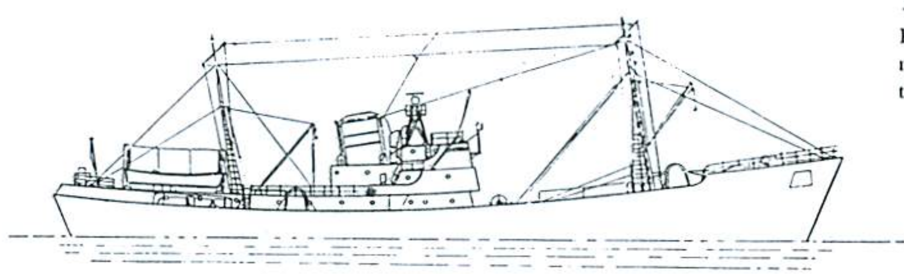

Fig.4.

Rigging arrangement of a British trawler from 1948.

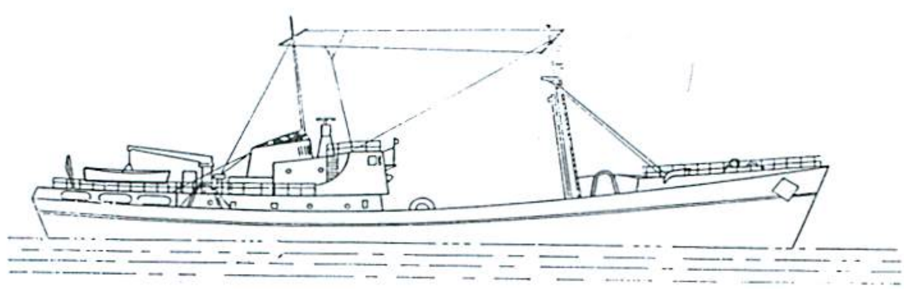

Fig.5.

Rigging arrangement of a British trawler from 1958.

cast can be of great importance for the safety of fishing vessels and other small crafts in areas where icing can be expected. The Icelandic Meteorological Office started therefore during the winter 1968/69 to send out icing forecast for Icelandic waters.

ICING FORECAST
WITH THE WEATHER FORECAST

The icing forecast of the Icelandic Meteorological Office is based on diagrams which express ice accretion on ships with low speed, as a function of the wind force and air and water temperatures. These diagrams have been obtained from MERTINS (1967). The grade of icing is divided into 5 degrees: No, low, 1-3 cm. in 24 hrs., moderate, 4-6 cm in 24 hrs., heavy, 7-14 cm in 24 hrs., and very heavy, 15 cm in 24 hrs. or more.

As an example consider the following weather forecast: Windforce 9-10 Bft. airtemperature - 8°C. sea water temperature 3° C. Expected icing according to diagrams: heavy icing 7-14 cm in 24 hrs.

The diagrams are based on the data collected and observed by Mertins when on German research vessels, altogether about 400 observations of icing on trawlers on the fishing banks of Iceland, Greenland, Labrador and Barentsea. Although not based on measurements with an icing meter, the 400 observations should give a rather reliable result for the vessels concerned. The icing of some Swedish small cargo vessels in the Baltic Sea has been compared with the diagrams and conformity appeared to be reasonably good.

It is of interest to follow predictions of icing of the Icelandic Meteorological Office and compare it with icing on Icelandic vessels. For this purpose the Icelandic State Director of Shipping has in cooperation with the Director of the Icelandic Meteorological Office published a questionaire and distributed it to the skippers of Icelandic fishing vessels in order to provide information needed for this purpose. The skippers are asked to give information about loading condition of the ship, position, date and time when icing started, wind force and direction, state of sea, air temperature, sea temperature, icing forecast, behaviour of ship during icing, amount of ice accumulated (measured in cm), in different places on board. Included are some questions regarding the work to remove the ice, manhours needed etc. The purpose of this questionaire is to collect further data on the actual icing on different types and sizes of vessels. After obtaining such information it is possible to calculate the amount of ice and the approximate raising of the centre of gravity due to the icing, and therefore to reconsider the existing regulations regarding the extra stability needed for safety under icing conditions.

BRITISH RESEARCH ON ICING OF TRAWLERS AFTER THE TRAWLER LOSSES IN 1955.

On the 26th of January, 1955, two British trawlers Lorella and Roderigo were lost with all hands, 40 men, north-east of Hornbjarg, northwestern Iceland. Although icing was well known to be hazardous in northern waters, these losses led to a special research of the nature and effect of severe icing, such as might be encountered by trawlers. The British Shipbuilding Research Association (BSRA) carried out a study of the ice accumulation on 1:12 scale model of a type of British trawlers common in the years 1948 to 1955. The tests were carried out in a climatic chamber at Weybridge. After the tests were finished a very interesting and well known report was published (BSRA 1957). Lackenby (1960) has also discussed the results of this research. Since these reports are available in English, only some of the results and some comments need to be mentioned here. The icing experiments were carried out in climatic conditions thought to be similar to those prevailing when the two trawlers in question were lost. These conditions were obtained by spraying water into the refrigerated chamber by compressed air.

One of the most interesting conclusions reached after these tests includes the variation in the amount of icing of a then commonly rigged trawler with the conventional foremast with fore-stays, rigging, shrouds and derrics and a trawler fitted with tripod mast, with consequent reduction in the number of stays and shrouds. Comparison indicated that because of its lower centre of gravity the loss of stability in the latter type is approximately two thirds of that of the conventionally rigged ship for the same ice accumulation. In the conclusions of the BSRA report, it is also emphasized, that while the removal of ice catching rigging and deck rails will reduce the rate at which ice will accumulate on the ship, the same weight of ice will ultimately be deposited and thus the same loss in freeboard will occur if the vessel remains in icing conditions. Accordingly it is stressed that when icing conditions are encountered the only safe protection for the ship is to withdraw from these conditions as quickly as possible.

The results of this British research led to a general alteration of the rigging of British sidetrawlers. Fig. 4 gives a side view of a typical British trawler from 1948, and Fig. 5 a side view of similar size of trawler from 1958 and later. The freeboard of these trawlers was also increased, to give the vessels increased formstability. It is interesting to note, that when it was decided to build 12 small side-trawlers, 250 GRT, in East-Germany, for Icelandic owners in 1957-58, is was decided to fit these vessels with a tripod mast this being recommended by the Icelandic State Director of Shipping to reduce the danger of icing in conformity with the results of the British research, although these vessels were not intended for distant water trawling. Since this type of masts also proved to be so much better in other respects, almost every fishing vessel in Iceland today, even the smallest, are fitted with tripod masts. But there are still several ice catching structures on fishing vessels, which could be removed or redesigned to reduce icing.

THE DANGER OF ICING AND SHIP LOSSES.

Loss of ships due to icing happens apparently periodically but without regularity. This is to be expected to some extent since the vessels are able to carry a certain amount of ice (provided careful handling and paying due respect to the danger from icing) and the fishing banks in northern waters are often close to arctic weather conditions (areas, with extreme cold in winter). When fishing vessels are located in these waters, they can always expect icing, should the arctic conditions appear suddenly and unexpectedly. Reliable weather forecast and withdrawal from the area as quickly as possible are therefore often the safest, and sometimes the only safe protection of the ship as stated in the British report.

On February 8th 1959, the Icelandic trawler "Júlí" was lost with all hands on the New-Foundland fishing banks. Therefore, no one can tell what actually happened, but there is hardly any doubt, that icing was the reason for that loss. The Icelandic trawler Thorkell Máni was nearly lost at the same time in the same area because of icing and many other Icelandic and German trawlers in the area were in serious danger due to very heavy icing but also storm and drifting ice.

After arrival of the Icelandic trawlers from the New-Foundland fishing banks a sea-court of inquiry looked into reasons for the loss of Júlí and studied the icing on board of the trawler Thorkell Mani (722 GRT in size). These inquiries proved to be very valuable, as it is rare that anyone survives to describe what actually happened when icing is as severe as it was on the New-Foundland fishing banks during these fatal days of February, 1959.

The weather was northwesterly winds, windforce 11 BFT., snowing and frost. On Sunday, the 8th of February, the whole crew of mt Thorkell Mani was continuously occupied in removing ice with axes and other equipment from rigging, forecastle and other super-structure. At 5.30 p.m. the ship has a bad list to portside. The portside life-boat was then removed from the vessel into the sea. After some time the vessel had a bad list to the starboard side, so the starboard lifeboat was also removed. As the crew had difficulties in removing the ice which accumulated very quickly, the first engineer cut away the boat-davits, both on starboard and portside. At the same time everything removable on deck was discharged into the sea, except the inflatable life rafts, which were kept ready, but not inflated. At midnight on the 8th of February the situation was a little better, and the crew had some rest for few hours. But before dawn on Monday the 9th of February, is was again necessary to remove ice, which had accumulated during the night. All members of the crew continued that work on deck during Monday. In the morning another Icelandic trawler, Marz, had succeeded in finding the trawler Thorkell Mani in spite of the icing on all antennae, and was now in sight, prepared for rescue if needed. The work on removing the ice was continued on both trawlers during that day and until 4.30 in the following morning when both trawlers left the New-Foundland fishing banks and sailed at full speed to Reykjavík. There had been altogether 10 Icelandic trawlers on the New-Foundland fishing banks when the bad weather suddenly broke out, and the last trawlers to leave the banks were the Thorkell Mani and Marz.

Icelandic trawlers had already been fitted with inflatable liferafts before the difficulties and loss at the New-Foundland fishing banks, but as a result of this Icelandic rules were altered so, that instead of rigid lifeboats under davits, permanently inflated lifeboats amidships are since then permitted and the vessels are fitted with axes and clubs for the removal of ice.

The recent losses of the British trawlers Ross Cleveland and Kingston Peridot in Icelandic waters in January and February, 1968, and the trawler St. Romanus, most likely in the North sea are still remembered by everybody. At the same time as Ross Cleveland was lost 4th February 1968, near Ísafjörður on the west coast of Iceland, the Icelandic fishing vessel Heidrun 11 was lost with all on board. No doubt icing has been the main reason for these losses although the weather was very bad at that time.

MEASUREMENT OF ICING ON SHIPS WITH ICING-METER.

It was mentioned before, that in Japan an icing-meter was used in icing experiments in 1962 and 1963 (Tabata et al. 1963 and Ono 1964).

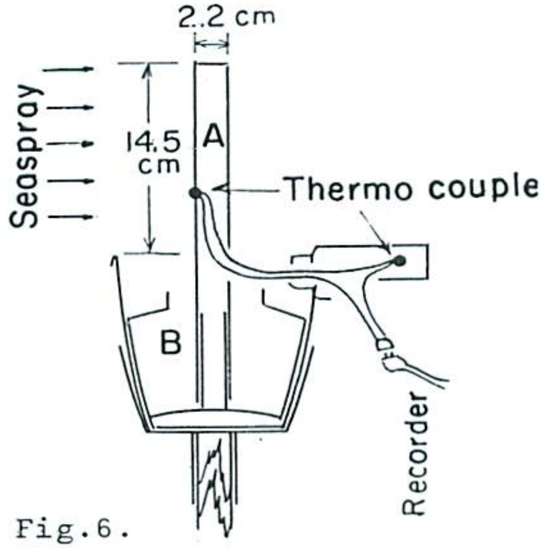

Fig.6.

Icing meter, used to measure the rate of icing.

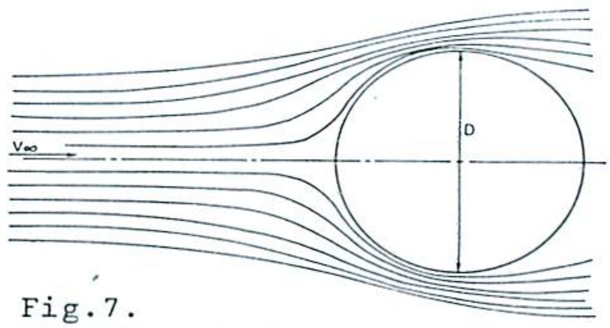

Fig.7.

Streamline airflow around a cylinder.

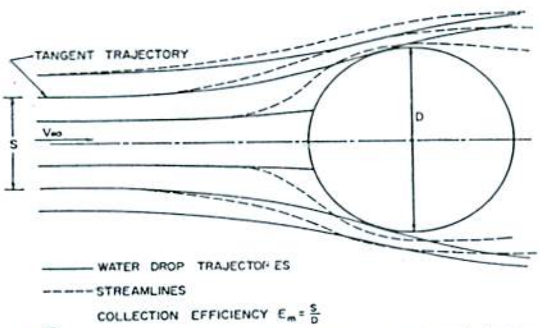

Fig.8. Water drop trajectories in the vicinity of a cylinder.

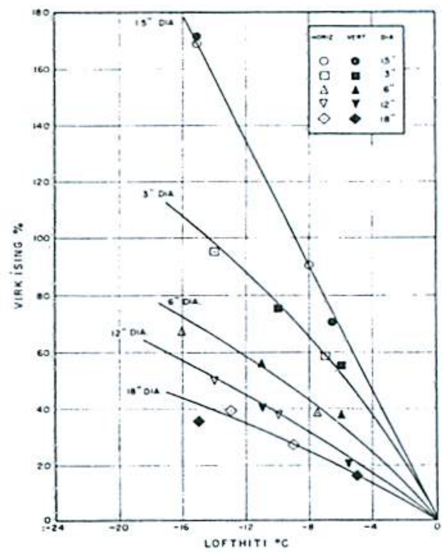

Fig.9. Effect of temperature on the icing efficiency (vertical scale).

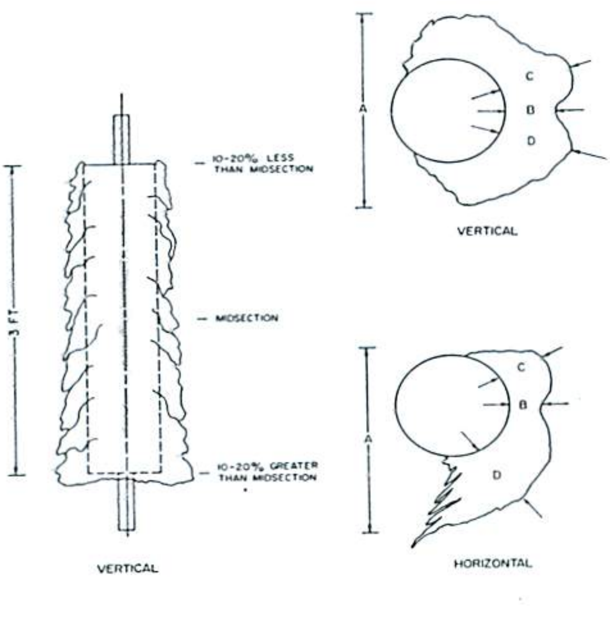

Fig.10.

Ice formed during tests on vertical and horizontal cylinders.

The purpose of the icing-meter is to measure the weight relation between sea water spray at the place of the icing-meter and the icing accumulated on the meter. As sea water spray contains salt, all of it does not freeze. Ice is crystallized from pure water from the sea spray, the unfrozen brine being concentrated which decreases the critical temperature of crystallization. A part of the brine flows down on the surface of the accumulated ice, and a part of it is confined in cracks of the crystallized ice. The accumulated ice is therefore considered to consist of such confined brine and pure frozen water. Due to downward percolation of the brine on the surface of the ice, the amount of accumulated ice is normally less than that of sea water spray which is thrown on the ship. The ratio of the weight of ice accumulation to that of the sea water spray is termed "rate of icing", which can be used as an index to assess the rate of growth of icing. An icing-meter is shown on Fig. 6. Part A of the figure shows a cylinder on which the ice is deposited, and part B a jar which collects the downward percolating brine.

THE ICING OF CYLINDERS IN CONDITIONS OF SIMULATED FREEZING SEA SPRAY.

Many parts on board of ships on which ice is accumulating are cylinders, such as masts, derrics, rigging wires, shrouds, hand rails etc. The British tests on a model of a trawler in an icing wind tunnel referred to earlier, were mainly focusing on loss of stability due to ice accretion. Recently some tests on the icing process of cylinders in simulated freezing sea spray have been carried out in Canada by the National Research Council. (Stallabrass et al. 1967). The streamline air-flow around a cylinder is shown in Fig. 7 and in Fig. 8 the streamlines around a cylinder as broken lines, and also the water drop trajectories in the vicinity of the cylinder. Among interesting results of these tests is, that they have shown that the larger the droplet size, the larger the accumulation (collection) efficiency and the larger the diameter of the cylindrical object the smaller is the accumulation (collection) efficiency. Fig. 10 shows how the ice was formed during the tests on vertical and horizontal cylindrical objects. In spite of the differences in the shape of the ice accretions on a horizontal and a vertical cylindrical objects, no significant difference in icing efficiency was apparent. It was therefore possible to combine the results from all the tests as shown in Figs. 9 and 11. They show the effect of temperature and cylinder diameter on the icing efficiency. The manner in which the icing efficiency increases with decreasing cylinder diameter (size) confirms without slightest doubt the vital necessity to keep the number of rails, stays etc. at minimum, and when possible, one larger diameter strut should replace several smaller ones.

THE INFLUENCE OF ICING ON THE STABILITY OF SHIPS.

Icing of a ship reduces both the weight stability and the form stability. The top weight of the ice accumulation raises the centre of gravity (G) (Fig. 13). The centre of buoyancy is B, in the inclined position. The total weight of the ship being W, the moment GZxW is a righting moment in the left in Fig. 13 and the ship is stable, but in the right in Fig. 13 the moment GZxW is an upsetting moment, thus the ship is unstable. When G moves upwards due to icing the moment arm GZ will decrease until the uprighting moment will not be sufficient to withstand the force of wind and sea, and the ship will capsize. Fig. 12 shows the effect of the raising of the centre of gravity G. The GZ curve will decrease and finally only small external forces will be needed to capsize, the vessel.

But the icing has also other effects on the stability of a ship. Due to the weight of the ice, the freeboard of the vessel will be reduced and therefore also the form stability.

This effect on the GZ curve is shown in Fig. 14. The GZ-curve I is the basic curve. The GZ-curve II a shows the effect of increased freeboard as compared with curve I. Curve II b shows again the effect of raising the centre of gravity. In all

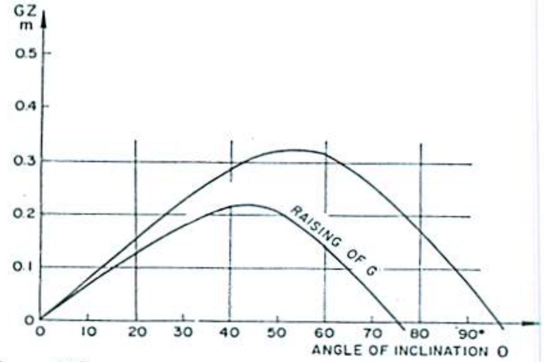

Fig.12. Effect of raising of the centre of gravity, G, on stability.

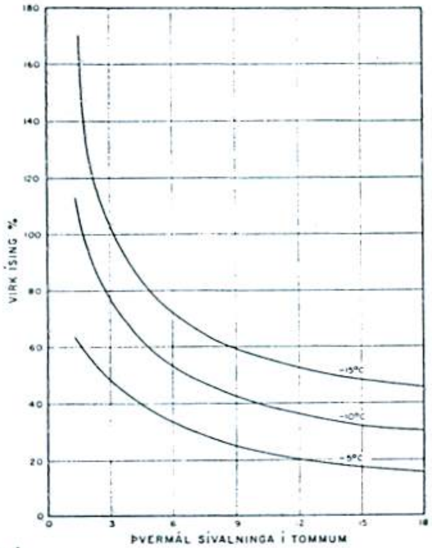

Fig.11. Effect of cylinder diameter on the icing efficiency (vertical scale).

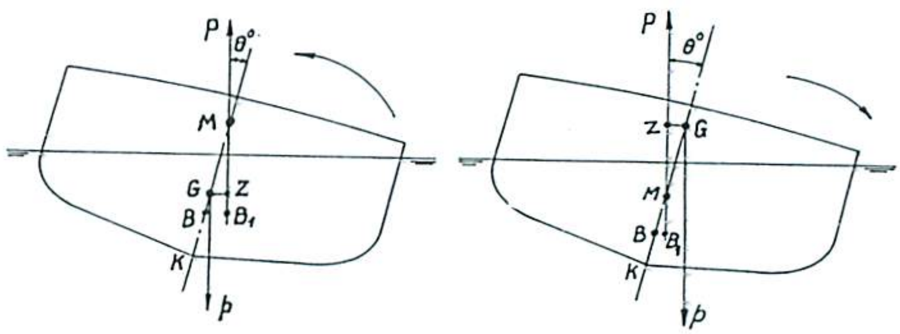

Fig.13. Stable ship and unstable.

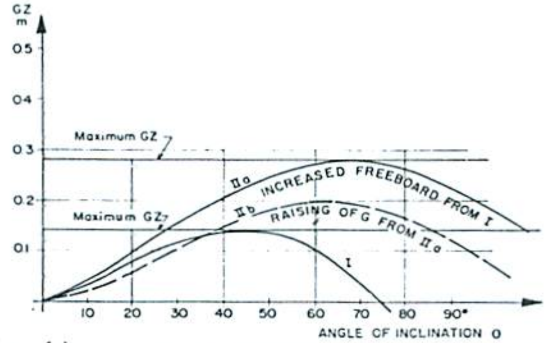

Fig.14. Effect of increased freeboard on the stability.

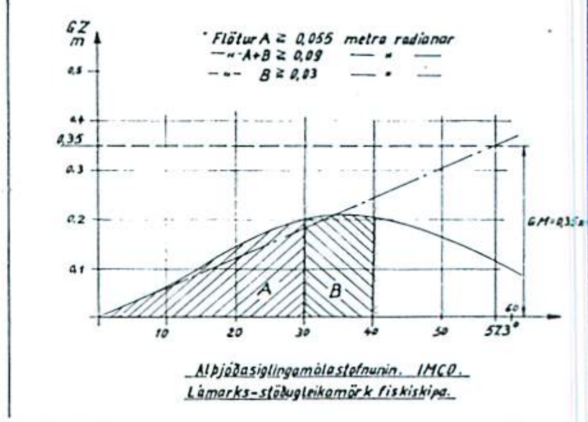

Fig.15. IMCO stability criteria for fishing vessels.

cases the angle 0^{O} is the angle of inclination of the ship. The third effect of the icing on the stability of the ship is the increased wind area of rigging and super-structure, so that a smaller wind gust is sufficient to capsize the ship.

THE IMCO INTACT STABILITY CRITERIA FOR FISHING VESSELS, WITH ICING

A special subcommittee has been working within IMCO. The Inter-Governmental Maritime Consultative Organization in London, on the safety of fishing vessels, especially the intact stability with the aim to work out recommended stability criteria. The results have been published, and are schematically shown on Fig. 15.

The following criteria are recommended for fishing vessel:

(a) The area under the righting lever curve (GZ curve) should not be less than 0.055 metre-radians up to $\theta=30^{O}$ angle of heel (the area A on Fig. 18), and not less than 0.09 metre-radians up to $\theta=40^{O}$ or the angle of flooding θ_f if this angle is less than 40^{O}. Additionally, the area under the righting lever curve (GZ curve) between the angles of heel 30^{O} and 40^{O} or between 30^{O} and θ_f if this angle is less than 40^{O}, should not be less than 0.03 metre-radians. (Area B on Fig. 18).

(b) The righting lever GZ should be at least 0.20 m at an angle of heel equal to or greater than 30^{O}.

(c) The maximum righting arm should occur at an angle of heel preferably exceeding 30^{O} but not less than 25^{O}.

(d) The initial metacentric height GM_o should not be less than 0.35 m.

When calculating the intact stability of fishing vessels it is recommended by IMCO that a certain amount of icing should be included, when considering vessels operating in certain northerly and southerly waters. Weight of ice per square metre of all exposed weather decks and gangways is to be assumed not less than 30 kg/m^2, with the addition of a weight of ice per square metre of projected lateral area of the portion of the vessel above water plane not less than 15 kg/m^2. For vessels operating off the east coast of Canada during the winter months IMCO is recommending that each Administration should give consideration to more severe requirements.

If comparing the IMCO recommendation 30 kg/m^2 on open weather decks with the diagrams in Fig. 3, taking the specific gravity of icing to be 0.85, the thickness of ice on decks will be 3.5 cm, which is "moderate" on the diagrams. To this should be added however the weight of the lateral area icing according to IMCO.

It is of interest to collect more data of icing of ships to see how they compare with these figures. It is not possible to ensure stability of a ship regardless of the amount of icing. Therefore further measurements are needed of the actual icing of ships at sea, to enable a decision to be taken on the reasonable amount of icing to be considered when calculating intact stability.

The specific gravity of icing on a trawler was measured in Reykjavik harbour on January 14th and 15th 1969. The ship received rather heavy icing when passing Reykjanes (Figs. 1 and 2). The mean value of the specific gravity was found to be 0.847 (g/cm^3).

The measurements were carried out by cutting out ice blocks of icing on different places on deck, on wire, ropes etc. These ice blocks were measured, and their volume calculated. Each block was then put in a separate glass container and the content weighted at a laboratory. The salinity was also measured, and found to vary from 9.11 to 17.39 $^o/oo$.

METHODS TO REDUCE DANGER OF ICING OF SHIPS AND EQUIPMENT TO REMOVE ICE

In order to reduce danger of icing of ships, the following is of importance: At the design stage of a ship ice collecting items on deck should be kept at minimum. Wire rope rigging open handrails etc. accumulate considerably more ice than tripod masts and plate bulwarks. The hull form and freeboard should be such, that sea spray is kept at a minimum, and form stability as good as possible. All super-structure should be fitted with watertight closing appliances on main deck. When icing starts to form on a ship, the speed and course of the ship should be such as to keep sea spray at minimum, even though fishing has to be stopped. Nets, derrics, wires and other lose equipment should be lowered, both to reduce topweight, and to reduce icing. Freeing ports should be kept clear and open at all times. All equipment for removing ice should be kept ready for immediate use. It is important to keep an eye on the icing, and start removing it before it has reached any considerable weight.

Besides the ice axes and other direct mechianical means to remove the ice by hand, several other equipment and outfit have been tested and will be tested which are safer and more easy to apply for removal of ice.

Steam- and hotwater pipes and hoses on deck are useful to assist the mechanical removal. Electrical heating of decks, masts and superstructure makes mechanical removal of the ice also easier. By covering areas such as the front of the weel-house with rubber or plastic material, pulsating air-pressure hoses between the flexible covering and the structure can break off the ice, if it has been permitted to form thick enough deposit to be broken but not to yield. Special paints have also been tested in order to find out if it is possible to reduce the adhesion between the structure and the ice which would make mechanical removal more easy.

Doubtless further development of equipment for removal of ice will reduce the danger from icing of ships. More experience in forecasting icing with the weather forecasts, for dangerous icing-areas, will no doubt be of great value to increase the safety of ships in northern waters, but today we still have to keep in mind the views expressed above, that when icing conditions are encountered, the only safe protection for the ship is to with-draw from these conditions as quickly as possible.

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