Proceedings of the 23rd International Conference on
Port and Ocean Engineering under Arctic Conditions
June 14-18, 2015
Trondheim, Norway

STATISTICAL NAVIGATION CONDITIONS ALONG XUELONG ARCTIC CRUISE PATH IN THE SUMMER OF 2012

Zhijun Li [1], Hongwei Han [1], Qingkai Wang [1], Ruibo Lei [2], Bingrui Li [2]
[1] State Key Laboratory of Coastal and Offshore Engineering, Dalian University of Technology, Dalian, China
[2] China Polar Research Institute, Shanghai, China

ABSTRACT

Based on the ship-base observations in 0.5 hours while Chinese RV Xuelong sailed through the Northeast Passage, Arctic during the summer of 2012, environmental conditions affect on the sailing are analyzed from Arctic Navigation purposes. The Chinese RV Xuelong is looked as a research object. While the ice concentration was over 70% and ice floes size over 2km had been found they were limits of RV Xuelong to sail in ice breaking. The percents of the navigated distance to meet the floe ice with more than 70% ice concentration and the ice floes over 2 km are analyzed respectively. Then the ice thickness under the both conditions encountered by RV Xuelong is taken into account for one of key parameters in Arctic Navigation. These results are given in five key navigating areas of Chukchi Sea, East Siberian Sea, Laptev Sea, North of Sevemaya Zemlya and Expedition area.

INTRODUCTION

Polar research in Arctic focuses on the climate change and has potential scientific values in development and utilization of resources and adaptability to the environment. While a hot issue from the latter is the possibility of Arctic shipping along with the rapid decay of summer Arctic sea ice (Gu and Xiao, 2011; Li, 2013; Li et al., 2013). The key problem limiting the Arctic shipping is the improvement of the knowledge on in-situ environmental conditions and the equipment for the voyage. Studies on these issues are now enhanced in whole World (Li et al., 2013; Rothwell, 2012; Lepy, 2013).

After Chinese RV Xuelong and another Chinese commercial ship Yongsheng, belonging to China Ocean Shipping Company (COSCO), travelled cross the Arctic through the Northeast Passage, Chinese realized the advantage of shortened distance but also many uncertain matters. In China ice engineering, the ship capability against ice during sailing in ice-infested water is a main objective although there are many international successful experiences on this issue, especially Finland, Russia and Canada have achieved many goals on ice breakers (Kotovirta et al., 2011; Lubbad and Løset, 2011;Kujala and Arughadhoss, 2012; Zhou et al., 2013). Because of the shortage of Arctic navigation knowledge in China, recent projects funded by the Ministry of Industry and Information Technology of China (MIIT) are trying to shift to practical applications. However, how to improve the ship quality to sail in ice-infested Arctic waters and how to improve the infrastructure along coasts of Arctic Northeast Passage to ensure the transfer, supply, rescue and so on for future shipping, is still the actual problem faced currently.

Due to RV Xuelong has a certain scientific equipments and Yongsheng has not, this paper summarizes the RV Xuelong collected data in 2012.

OBSERVATIONS OF NAVIGATION CONDITIONS IN THE ROUTE

RV Xuelong (see Figure 1) was built in Ukraine in 1993, its ice-strengthened to Class B1. China bought it and refitted it into a polar research vessel since 1994. The main technical indexes of the ship are as follows. Total length: 167.0 m; Moulded breadth: 22.6 m; Moulded depth: 13.5 m; Full draft: 9.0 m; Full displacement: 21025 tons; Maximum speed: 18 knots; Cruising radius: 20000 nm; Main engine power: 13200 kW; Auxiliary engine power: 800 kW $\times 3$; Deadweight capacity: 10225 tons. The vessel is provided with advanced navigational, positioning and automatic piloting systems as well as platform which can accommodate two helicopters, a hangar and necessary equipment. She can continuously break ice as thick as 1.1 m (including 0.2 m thick snow) at a sailing speed of 1.5 knot. On board of the ship, there are labs of marine physics, marine chemistry and biology, and meteorological and clean laboratories as well as a data processing center, covering an area of 200 m^2.

Figure 1. Photo of RV Xuelong.

The technology of ship board observations of sea ice on RV Xuelong is similar with literature reported methods (Hall et al., 2002; Weissling, et al., 2009). The observed contents are sea ice types, ice concentration, melt pond coverage, floe size, ice thickness and some meteorological and hydrological parameters. The ice thickness by naked eyes and videos are obtained by comparing a reference body with the broken ice section. Floe size is observed around Control Bridge in the range of 5 km, its size is obtained by comparing with ship length. The observation interval is 0.5 hours. If there is iceberg in the visual range or in the Marine Radar screen, the iceberg position, members and shape are recorded. Also there are two interval cameras beside Control Bridge to monitor the ice conditions around Portside and Broadside with 5-min interval.

Ice thickness observation

The distance from to water level is around 7 m, and a JVC40G video was installed on the Portside of the main deck. This video recorded the broken ice section while ship broken ice sheet. A reference body (Engineering Plastic Ball) in rang above water surface monitored and recorded with the broken ice section together. Comparing with the known size ball, the ice section of broken thickness was evaluated. Because the icebreaker can not broke ice ridge with normal breaking, the broken section can not to be the thickness section. Therefore, the method is limit to level ice with ice thickness in 50-100 cm. Human observation also recorded the ice thickness from naked eyes, there was a bar to be used as a reference body.

Meteorological observation

Meteorological observation mainly includes international fixed time human observations and continuous machine records. Fixed time human observation included clouds, visibility, weather phenomenon and the wave height and surge height; automatic recorded items were wind direction, wind speed, air pressure, temperature, dew point temperature and relative humidity.

During the navigation, the ship borne Seaspace system received the NOAA-16, NOAA-18, NOAA-19 satellite data and images. The weather conditions were decided by combining with ship based observation records.

Sea ice/marine surface temperature observation

Sea ice/marine surface temperature was measured by using KT19.82IIP infrared radiometer (Heitronics Company, Germany). Its measured the temperature range of -20 °C ~70 °C, the measurement precision is ±0.5°C. Infrared radiometer sampling interval was 1s. The instrument installed near the edge of Control Bridge root. Its lens looked vertical downward, its lens axis left 40 cm out off the edge and the lens coved the circle about 20cm in diameter. The distance between the lens and marine surface is about 40m.

Figure 2 marks the observations on RV Xuelong.

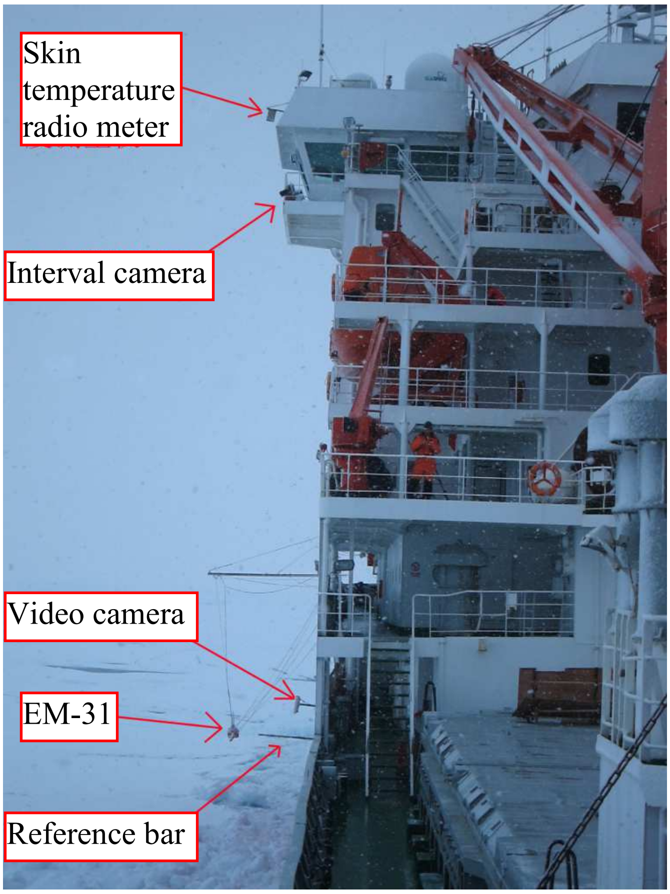

Figure 2. Observation system of sea ice conditions on RV Xuelong.

OBSERVATION RESULTS

The RV Xuelong expedition voyage during 19 July and 8 September, 2012 is shown in Figure 3. The inbound trip was along the Northeast Passage and return trip was higher latitude Arctic Expedition because the ice conditions were lighter in the summer of 2012.

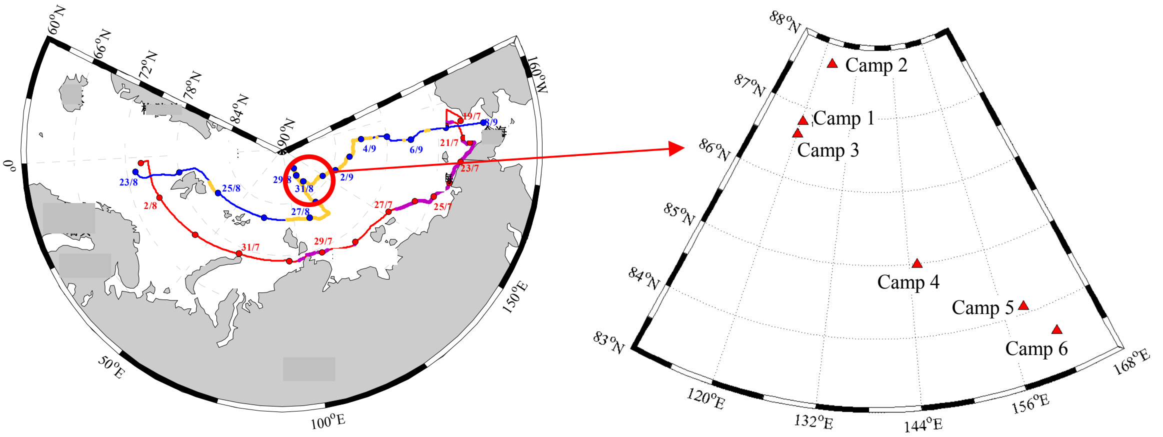

Figure 3. The RV Xuelong voyage in 2012 summer (red line is Northeast Passage and purple line is the sea ice covered line in the Northeast Passage and blue line is higher latitude return trip and yellow line is the sea ice covered line in the return trip). The right side figure is the 6 ice camps in 2012.

The Arctic navigation conditions have spatial-temporal changes and Northeast Passage can be used for sailing while whole passage reaches navigable conditions. For statistics easily, the RV Xuelong voyage in 2012 is divided into five parts, see Figure 4. Part 1 is Chukchi Sea; Part 2 is East Siberian Sea; Part 3 is Laptev Sea, Part 4 is North of Sevemaya Zemlya and Part 5 is Expedition area.

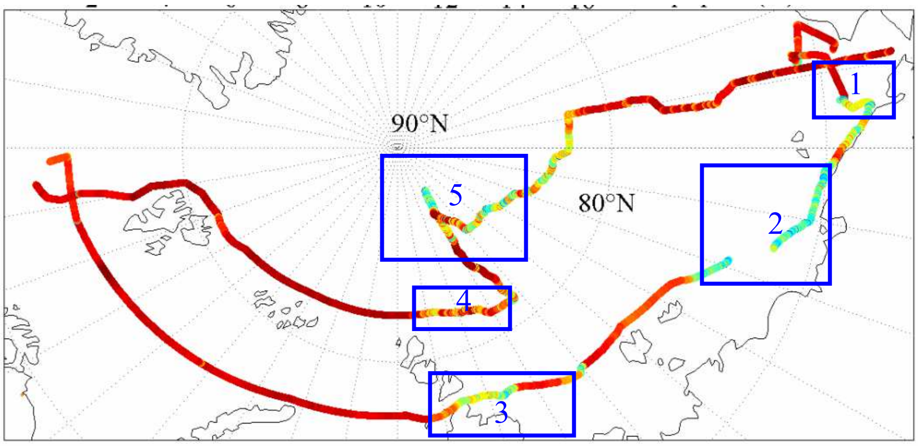

Figure 4. The sections of navigation conditions in the voyage of RV Xuelong in 2012.

Ice navigation does not depend on sea ice concentration and thickness, but also depends on melt pool coverage, ice floe size, distribution state of ice ridges and leads. For example, in spit of higher sea ice concentration and thicker ice thickness in the area with many melt pools, the overall strength of ice floe is still lower, and the ice sheet is shear failure easily under the action of an icebreaker; If the ice sheet is lager than several ship length, it is difficulty to sail in ice and is have to meet ice ridges; In addition, even the lead coverage is same, ship goes easily in the area of leads in liner distribution channel, not in the area of lead in spark distribution.

Sea ice concentration
Actually sea ice concentration controls how ship breaking ice and ice responds broken forms. Shibata (2013) gave three levels of navigation difficulties based on the classification of WMO (1970)'s sea ice concentration. They are easy navigation with 0~30% in ice concentration, difficulty navigation with 30%~70% in ice concentration and very difficulty navigation with 70%~100% in ice concentration.

During whole navigation, the ice conditions were recorded following ASPeCt rules in the interval of 0.5 hours. In the statistics, they are two cases for the sea ice concentration over 70% in a longer distance. One is ice concentration is over 70% and the ice floe size was over a kilometre and the another is ice concentration is over 70% and the ice floe size was smaller. In the first case, RV Xuelong needs breaking ice for navigation and in the second case, RV Xuelong sails without ice effect. Therefore, the statistics did not account the times of occurrences over 70%, but considering the effective navigation distance between two observations in half-hours. The "zigzag" navigation and "ramming" time in ice ridge and multi-year thick ice was ignore. In fact, they were not many and no effect in statistical results. The encountered ice concentration and its percent of occupied distance with total navigation distance are listed in Table 1.

Based on Table 1, the ice concentration over 70% will limit ship navigation in breaking ice. In 2012 summer, the ice concentration over 70% in the Northeast Passage was less, about 7% of total route in Arctic where ice need to break for navigations.

Table 1. The encountered ice concentration on the RV Xuelong Northeast Passage in 2012.

Ice concentration/%	0	10	20	30	40	50	60	70	80	90	100
Navigation distance/mile	2318	1120	544	509	557	271	437	479	469	312	93
Occupied percent/%	32.6	15.8	7.7	7.2	7.8	3.8	6.2	6.7	6.6	4.4	1.3
Occupied percent in Part 1/%	7.52	3.81	1.53	2.18	0.69	0.15	0.19	0.46	0.16	0.18	
Occupied percent in Part 2/%	2.22	0.78	1.07	1.89	2.13	1.14	1.78	1.87	1.89	1.22	0.32
Occupied percent in Part 3/%	4.29	3.11	0.71		0.21	0.16	0.08				
Occupied percent in Part 4/%	11.93	2.80	1.67	0.74	1.03	0.95	0.74	0.50	0.33		
Occupied percent in Part 5/%	6.66	5.26	2.68	2.33	3.77	1.37	3.36	3.92	4.21	2.99	0.98

Sea ice thickness

Ice thickness is one of the key factors affecting Arctic navigation, the recorded ice thickness in 2012 summer is divided as the five statistical parts and only the ice thickness where ice concentration over 70% is analyzed though Figure 5's data analysis. The results are given in Table 2. Because most ice concentration in Part 4 is below 70%, the ice thickness in Part 4 is neglect.

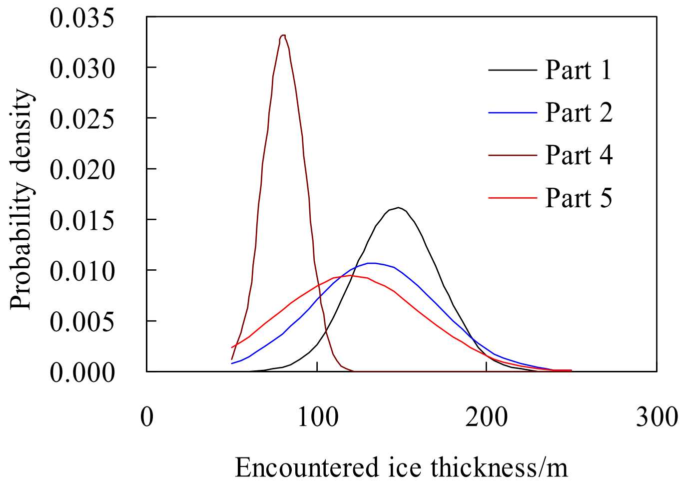

Figure 5. The probability density of ice thickness encountered in 2012.

Table 2. The encountered ice thickness on the RV Xuelong Northeast Passage in 2012.

Section of the passage	Part 1	Part 2	Part 4	Part 5
Middle ice thickness/cm	150	130	80	120
Maximum ice thickness/cm	180	190	100	200
Speed range/knot	9.04	6.83	12.41	8.52

Ice floe size

One of the other factors affect navigation is floe size. In navigation, the floe size is a relative length between ice floe and ship length. It can reflect the ship-ice relative mass, relative velocity, relative broken ice crack in an ice floe. The observations in 2012 found that only the ice floe size in kilometers, it made RV Xuelong sail in breaking ice.

Table 3. The encountered ice floe size on the RV Xuelong Northeast Passage in 2012.

Floe size code	0	1	2	3	4	5	6	9
Floe size range/m	Pan cake ice	<2	2-20	20-100	100-500	500-2000	2000-10000	iceberg
Relative ship length		0.01	0.1	0.2	1	6	12	
Encountered distance percent/%	35.3	1.2	12.2	24.4	20.6	4.8	1.3	0.2

The total length of RV Xuelong is 167.0m, 22.6m in width, 10250 t in weight, 21025t in water draft. If ice floe size is greater than 6 times the ship length, the action of RV Xuelong is breaking ice continuously.

The statistical floe size which RV Xuelong encountered in the summer of 2012 through the Northeast Passage is summarized in Table 3. Because the ice concentration also controls the ship breaking distance percent in the total route, Table 5 does not need to statistic in five parts.

Icebergs
There were icebergs both along the Northeast Passage and along the route of higher latitude. The higher latitude area had iceberg more, and only 3 icebergs encountered along the Northeast Passage. Total of 75 icebergs were met. In these icebergs, there were two "table mountain" icebergs, and others were broken "towering" icebergs with 100 meters in long axis and only two icebergs with 1000 meters in long axis. These smaller icebergs comes from mountain glaciers where is in west of Part 4.

Because the shallow water, most icebergs can not enter Northeast Passage area. RV Xuelong only once met 9 icebergs on the marine radar screen in 6 nm at same time. These icebergs did not affect RV Xuelong's speed. But the iceberg density had not any connection with sea ice concentration or fog, it is necessary that mate operates Ship Borne Marine Radar any time even there is not sea ice and fog.

Visibility
There is much fog and cloudy over Arctic area. The visibility in Arctic is often much lower. During the 16 days shipping along Northeast Passage, the visibility was lower than 1 km in 7 days and was lower than 300 meters on 25 July. Along the route of higher latitude, the lowest visibility was 100 meters. The lower visibility affects RV Xuelong's speed much. It was not easy to following the guided icebreaker and lost the broken open channel. In the high ice concentration area, the lower visibility affects to find natural open leads to sail.

Data statistics found that if the visibility was lower than 400 meters, RV Xuelong should sail in lower speed. Based on Table 4, there was 2% navigation distance was in lower visibility under 400 meter.

Table 4. The encountered low visibility on the RV Xuelong Northeast Passage in 2012.

Visibility/m	Encountered distance/mile	Encountered distance percent/%
100	3.7	0.1
200	39.6	0.6
300	66.4	0.9
400	28.8	0.4
500	243.9	3.4
600	23.6	0.3
700	21.2	0.3
800	114.1	1.6
1000	302.3	4.3

Air temperature, marine surface temperature and swell

Usually the air temperature and marine surface temperature are little higher than sea water freezing point. It is easy to have icing on ships while the humidity is higher or the swell breaking water on ship. During 2012, there were some cases that the marine surface was frozen in night; the melt ponds were frozen in night and some icing on RV Xuelong desk, weather equipments. These phenomena did not affect RV Xuelong navigation much.

CONCLUSIONS AND DISCUSSIONS

Only the ice concentration over 70% makes RV Xuelong sails in breaking ice and ice thickness is important to evaluate ice resistance on ship. In 2012 summer, the ice concentration over 70% in the Northeast Passage was less, about 7% of total distance needed to break for sail. If floe size is over 6 times of RV Xuelong's length, it also makes RV Xuelong sail in breaking ice.

There were smaller icebergs with 1000 meters in long axis along the Northeast Passage. They mostly come from mountain glaciers and no effect on RV Xuelong's speed. But the iceberg density had not any connection with sea ice concentration or fog, it is necessary that mate operates Ship Borne Marine Radar any time even there is not sea ice and fog.

There was 2% navigation distance was in lower visibility under 400 meter in 2012, the lower visibility affected RV Xuelong's speed much.

The Air temperature, marine surface temperature and swell in Arctic summer can make some icing on RV Xuelong desk, weather equipments. But these phenomena did not affect RV Xuelong navigation much.

Although Meng et al. (2013) and Zhao and Yang (2013) studied Chinese Arctic navigation from other aspects, there is still much empty space to study Arctic environments, ocean and offshore engineering in Arctic, and other scientists and engineers' experiences, achievements from different countries.

ACKNOWLEDGMENTS

We sincerely thank the crew of the RV Xuelong for providing excellent logistic supports. The Fifth and Sixth Chinese National Arctic Research Expeditions in 2012 and 2014 were organized by the Chinese Arctic and Antarctic Administration. The fieldwork was supported by the Polar Research Institute of China. After the expedition, the data analysis and research were supported continuously by National Basic Research Program of China (973 Program) (No.2015CB953901) and National Natural Science Foundation of China (41376186). We also try to transfer the understandings to Arctic navigation in summer under the support of High Technology of Ship Research Project of the Ministry of Industry and Information Technology (2013417-01). Parts of international cooperation actions are supported by International Science and Technology Cooperation Program of China (2011DFA22260), Public Science and Technology Research Funds Projects of Ocean (201205007-05).

REFERENCES

Gu, W., Xiao, Y., 2011. Arctic sea ice changes and the prospect of ship navigation. Marine Technology, 2011(3): 2-5 (in Chinese).

Hall, R. J., Hughes, N, Wadhams, P., 2002. A systematic method of obtaining ice concentration measurements from ship-based observations. Cold Regions Science and Technology, 34: 97-102.

Kotovirta, V., Karvonen, J., von Bock und Polach, R., et al., 2011. Ships as a sensor network to observe ice field properties. Cold Regions Science and Technology, 65: 359-371.

Kujala, P. and Arughadhoss, S., 2012. Statistical analysis of ice crushing pressures on a ship's hull during hull–ice interacti on. Cold Regions Science and Technology, 70: 1-11.

Lepy, E., 2013. The recent history of Finnish winter navigation in the Baltic Sea. Polar Record, 49(248):33-41.

Li, R., 2013. American experts: the Arctic s ea ice will melt and be navigable in 2050. China Ocean-China Network, http://ocean.china.com.cn/ 2013-03-06 (in Chinese).

Li, Z., Yan, L., Xu, M., et al., 2013. Evaluation of Arctic route's navigation environment. Computer Engineering and Applications, 49(1):249-253 (in Chinese).

Liu, Z., 2013. The “Yongsheng” ship of COSCO successful maiden voyage Arctic Northern Passage. http://money.163.com/13/0916/16/ 98THF5AR002540BQ.html (in Chinese).

Lubbad, R. and Løset, S., 2011. A numerical model for real-time simulation of ship–ice interaction. Cold Regions Science and Technology, 65:111-127.

Meng, S., Li, M., Tian, Z., et al., 2013. Characteristics of the sea ice variation in the Arctic Northeast Passage. Marine Forecasts, 30(2): 8-13.

Rothwell, D. R., 2012. International straits and trans-Arctic navigation. Ocean Development and International Law, (43)3: 267-282.

Shibata, H., Izumiyama, K., Tateyama, K., et al., 2013. Sea-ice coverage variability on the Northern Sea Routes, 1980–2011. Annals of Glaciology, 54(62):139-148.

Weissling, B., Ackley, S., Wagner, P., et al., 2009. EISCAM — Digital image acquisition and processing for sea ice parameters from ships. Cold Regions Science and Technology, 57:49-60.

Zhao, J. and Yang, M., 2013.Study on the key sea area and ice condition information of the Northeast Route of Arctic. China Maritime Safety, 2013(7):53-54.

Zhou, L., Riska, K., von Bock und Polach, R., et al., 2013. Experiments on level ice loading on an icebreaking tanker with different ice drift angles. Cold Regions Science and Technology, 85: 79-93.