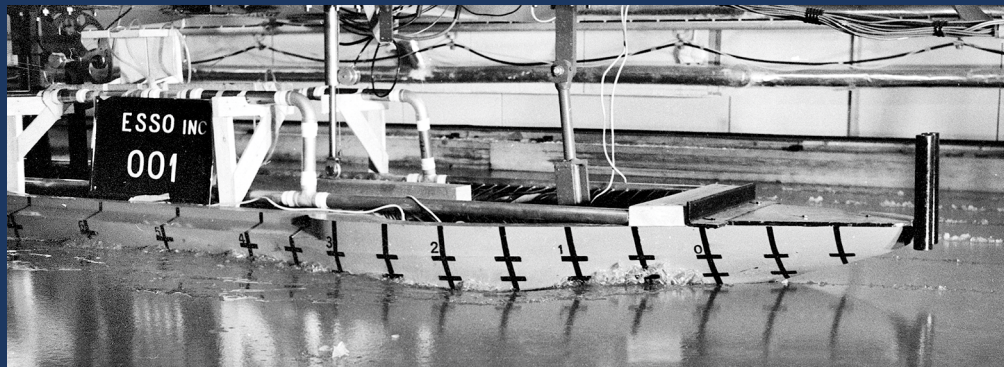


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Aker Arctic
A Success Story
of Finnish Technology
years of ice model testing



The Ice Technology Partner

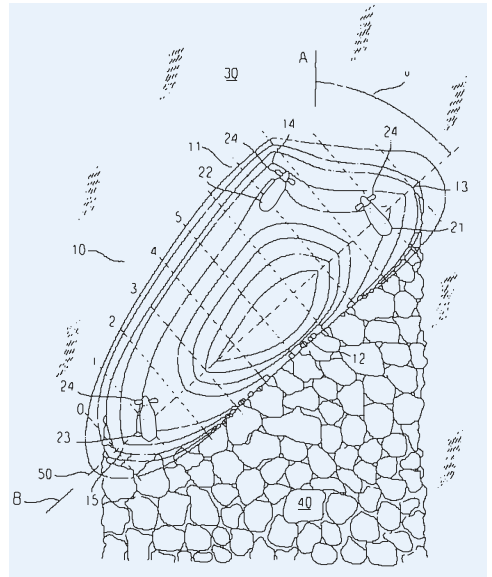
Creating a Testing Platform for Inventive Designs

Year 2019 marks 50 years since the first ice model testing project in Finland which revolutionized the design process of ice-going vessels.

The first ice model testing series have proven to be essential to the design process of ice going vessels and the operation in the first provisional facility was continued. The following model testing facilities were dedicated to ice model testing which is crucial design tool in ice technology.

Many development projects which initially sounded unrealistic would not have been possible without ice model testing. For example, the DASTM concept, the Oblique icebreaker, or the Arctic LNG carriers could not have been realized without extensive verification of the ideas' feasibility through model tests. Currently, one of the most important aspects of ice model testing is to optimize the hull of ice-going ships to minimize ice resistance. These optimization efforts result in lowering the emissions and the fuel consumption of the ship.

In addition to ship design and model testing services, Aker Arctic strives to improve its other services. Design and delivery of ice propellers and shaft lines, and ice simulator development, are good examples of these successful efforts.



In the 1990s there arose a need for an icebreaker which would create a wide channel for assisting ships in ice. The Kvaerner Masa-Yards design team came up with the idea of an asymmetrical hull shape. In 1997 the idea was patented, and it also won The International Golden Award for the most innovative idea. Extensive marketing efforts eventually lead to an order in 2011 and icebreaker Baltika was built. She is the first ship ever built for operation in ice with an asymmetric hull that allows her to operate not only ahead and astern, but also sideways with a large angle of attack. In this way the relatively small oblique icebreaker is capable of opening a wide channel in ice for large merchant ships.

The Beginning of Ice Model Testing



SS Manhattan navigating in the Arctic

The history of modern icebreaker design and construction in Finland began in the late 1930s with the diesel-electric icebreaker, *Sisu*. Until the development of ice model testing, icebreakers were built based on the designer's experience with previous vessels, and the primary way to evaluate the hull form was through full-scale experimental tests.

In the mid-1960s, studies indicated that oil found in the Alaskan North Slope could be feasibly transported to the market through the Northwest Passage. A decision was taken to modify an existing 106,000 DWT tanker, *SS Manhattan*, for this purpose by retrofitting it with a new icebreaking bow. Built as an ordinary tanker in 1962,

the tanker was refitted for the arctic voyage with an icebreaker bow in 1968–69. Wärtsilä provided support for the project since the Finnish shipyard had previous experience from building icebreakers both for the subarctic and arctic conditions. During the retrofit process, the oil company Esso (Humble Oil) suggested to study the performance in ice of the newly designed bow in model-scale in an ice model basin, before making decision to start an expensive conversion.

That is when Esso decided to invest in construction of the first ice model testing facility in Finland. It was built in an old underground bomb shelter in Helsinki.

Wärtsilä Icebreaking Model Basin (WIMB), 1969-1983

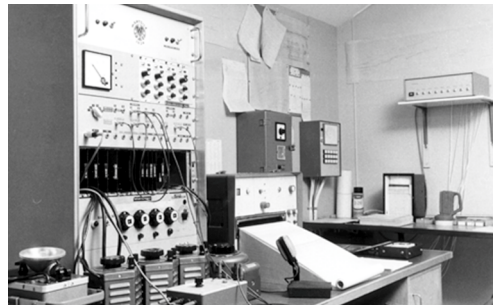


The first ever ice model test conducted in Finland was a resistance test in level ice of SS Manhattan.

The first ice model test basin in Finland was ready for testing at the end of 1969. The technique to create the model ice was adopted from Arctic and Antarctic Research Institute (AARI) in Leningrad, USSR.

At that time, model ice was made by spraying a layer of fresh water on the surface of the high saline basin water (salinity 1-2%). The fresh water first formed small ice crystals on the surface of the saline water. The crystals then started to grow vertically downwards to form the bulk of the ice sheet.

The method resulted in a 2-3 mm thin, hard upper layer of ice with a 10-60 mm thick layer of softer ice below. The maximum ice thickness that could be grown daily was 65 mm.



Instrument room in WIMB

The model tests were conducted by towing the model ships and the data was recorded on paper with an oscillograph.

Soon after WIMB was constructed, two other new facilities were also built: one in Germany and one in the United States.

The dimensions of the world's first ice model test basins

Year	Location	Owner	Length (m)	Width (m)	Depth (m)
1955	Leningrad, USSR	Arctic and Antarctic Research Institute	13.4	1.85	1.1
1969	Helsinki, Finland	Wärtsilä Helsinki Shipyard	50.0	4.8	1.15
1970	Columbia, USA	Arctec Inc.	18.3	2.4	1.2
1971	Hamburg, West Germany	Hamburgische Schiffbau-versuchsanstalt	30.0	6.0	1.2



Wooden model of Atle/Urho-class icebreaker



Atle/Urho-class icebreaker, Sisu, in operation

The first years in the new model testing facility were a time of calibration. WIMB had results of six vessels tested in both model scale and full-scale. Correlations between these results have significantly improved performance predictions of ice-going vessels.

Between 1969-1983, some 100 test series were performed. Simultaneously, the full-scale activity continued, and some 65 test programs were carried out in different parts of the icy world.

Concurrent with the calibration period, the development of new icebreaking hull forms was in full speed. In the 1970s and 1980s, many new icebreaking vessel designs were developed and tested through model tests in ice.

The first icebreaking vessels developed and built utilizing the results of ice model tests were the five Atle/Urho-class icebreakers, which were built for Maritime Administrations of Finland and Sweden in 1974-1977.

Icebreaking vessel designs developed utilizing ice model testing in WIMB

Years of model testing	Class name	Type of the vessel	Number of vessels built
1971-74	Atle/Urho	Baltic icebreaker	5
1974	Kapitan Sorokin	Polar icebreaker	4
1975	Kapitan Chechkin	River icebreaker	6
1977-78	Mudyug	Sub-Arctic icebreaker	3
1979-82	Kapitan Evdokimov	River icebreaker	9
1979-82	SA-15, Norilsk	Arctic cargo ship	19
1980-81	Otso	Baltic icebreaker	2
1981-82	Taymyr	Nuclear icebreaker	2

In addition to the icebreaking vessels, model testing was efficiently used in development of number of other ice-going vessel types, including:

- tankers,
- ferries,
- LNG carriers,
- anchor handling vessels,
- tugs,
- bulk carriers,
- RO-RO carriers,
- coast guard cutters,
- LASH/container carriers,
- fishing vessels,
- coastal road ferries, and
- dredgers

The research projects carried out at WIMB explored numerous important topics of ship-ice interactions, such as:

- friction between ice and ship hull coating,
- air bubbling system development,
- propeller loads,
- operational docking tests,
- offshore structures, and
- modelling development.

However, in 1980, WIMB no longer met the scientific and technical standards of the day and Wärtsilä decided a new, more advanced facility was necessary.



Shallow-draft nuclear-powered Taymyr-class icebreakers, Taymyr and Vaygach



SA-15, Norilsk-class Arctic multipurpose cargo ship



Icebreaker Otso assisting another vessel.



Kapitan Sorokin-class polar icebreaker, Kapitan Nikolaev



*Shallow-draft river icebreaker
Kapitan Evdokimov*



River icebreaker Kapitan Chechkin

Wärtsilä Arctic Research Centre (WARC), 1983-1989, (Kvaerner) Masa-Yards Arctic Research Centre (MARC) 1989-2005

The knowledge gained from the WIMB was used to build an improved modern facility, the Wärtsilä Arctic Research Center (WARC). A new type of model ice was also developed at the same time and the new laboratory was intended to be a comprehensive research centre rather than only an ice model test basin.

The new facility was inaugurated in February 1983. The timing was excellent; an arctic boom started in the beginning of 1980s and the Northern Sea Route (NSR) was increasingly attracting interest in the shipping industry.

The new fine-grained (FG) model ice was significantly different from all other model ice types used at the time. The ice was made by spraying saline water in the air, and as the freezing droplets fell on the water surface, they created a layer of slush.

To accomplish the layering, a spraying carriage travelled back and forth along the basin length until the target ice thickness was achieved. The ice was then hardened by freezing overnight. A wide range of mechanical properties could be achieved by varying the freezing time and temperature.

The advantages of the FG model ice were:

- better control of model ice properties,
- better brittleness / higher elastic modulus, and
- ice breaking into realistic-sized pieces.

The FG model ice was further developed in 1986 by adding the possibility to alternate between layers of saline and fresh water ice (FGX). The layering lowered the elasticity of the ice further to better correspond to sea ice.



In the 1980's, operational model tests were often conducted manoeuvring the model manually. Model of icebreaker Otso, assisting another vessel in heavy brash ice, is steered by her future captain, Atso Uusiaho.



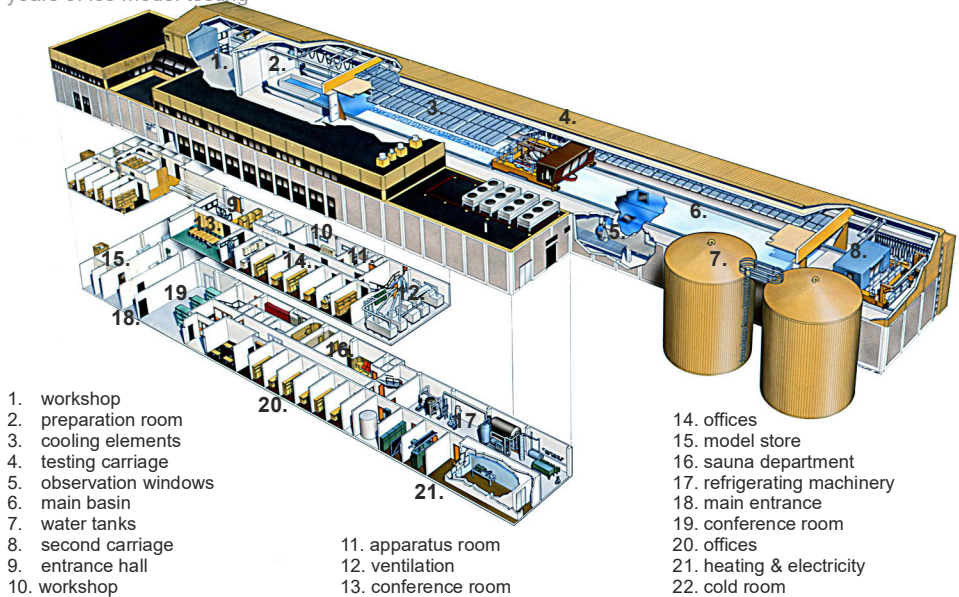
The FGX model ice proved to model sea ice remarkably well and the technology was adopted in two other laboratories, Arctic Offshore Research Center (AORC) of Helsinki University of Technology and Krylov Shipbuilding Research Institute (KSRI) in St. Petersburg, on license agreement.

MARC also planned and supervised the modernization of the ice model testing facility at KSRI, including delivery of the spraying system and testing equipment.

Measuring ice density in the 1980's. A piece of ice is submerged and the ratio between the ice and water density is determined from the submerging force



Model outfitting at WARC



Layout of Wärtsilä Arctic Research Centre.

The test basin of the facility was 77.3 m long, 6.5 m wide and 2.3 m deep.

The main activities conducted in the new research centre were:

- basic research projects, e.g. post graduate studies,
- Finnish government funded research quota,
- Wärtsilä's own research and development projects, and
- commercial projects.

One of the key research objectives was to gain a better understanding of the entire icebreaking process by studying many aspects of ship-interactions. Some key experiments involved bow shapes, the influence of friction using friction panels on the Finnish icebreaker Otso, and removable icebreaking bow.

Additionally, many resources were invested in improving the model ice to achieve better correlation between the results in model- and full-scale. The goal was to remove the use of scaling correction factors in full-scale predictions. The ice trials of ships, such as icebreakers Otso and Kontio, and Kapitan Evdokimov-series river icebreakers, were all important sources of full-scale data.

One particular project on level ice resistance resulted in the formulation of the "Lindqvist equation", which is still widely used to this day for predicting level ice resistance.

The advances made in the understanding of ship-ice interactions from this period enabled significant improvements in design of ice-going ships though the optimisation of the hull forms.



Innovative icebreaker bow shape was studied by measuring forces between the removable bow and the tug hull both in model-scale and in semi-scale (1:2). The results of this study can still be seen in the icebreaker bow design today.

A crisis in the global marine industry led Wärtsilä to pool its marine resources with Valmet, resulting in the establishment of Wärtsilä Marine in 1986. WARC became a part of Wärtsilä Marine Arctic Technology, which was a unit of Helsinki Shipyard. The emphasis on the research continued until the

bankruptcy of Wärtsilä Marine near the end of 1989. At this time, most of the activities were related to in-house development projects for vessels intended to be built at Wärtsilä's own shipyards. During the 1980s, the annual number of test days in the ice model test basin varied between 130-190.

The most significant development projects conducted at WARC in 1982 - 1988

Year	Project
1982-83 (1986)	Development of FG (FGX) model ice
1986-87	Wärtsilä Bow shape development which resulted in changes in bow on IB Kapitan Nikolaev
1985-86	Ice model tests of a 100,000 DWT tanker for IHI Corporation
1983-87	Friction panel research project to define the friction correlation between the model ice and model, and sea ice and ship
1985-87	Ice-deflecting bottom ribs for shallow draft vessels
1987-88	Cylindrical bow research project aiming for reduction of ice resistance
1987-88	Multi-purpose research and resupply ship Aurora Australis
1987-88	Supply and research ship James Clark Ross
1988	Lake Saimaa icebreaker Arppe
1987-93	Small icebreaker for IHI Corporation
1987-88	Mingeo research icebreaker
1987-88	IB Karhu nozzle and open propeller model and full-scale tests. First high-quality full-scale videos of interaction between ice and propeller and nozzle
1988	First Azipod ice model tests

In the early 1990s, there was a dramatic slump in the shipbuilding industry in Finland due to break up of the Soviet Union. As a result, the future of the ice laboratory was very uncertain. However, a new shipbuilding company Masa-Yards was established to continue the operations of Wärtsilä Marine. Kvaerner group took over Masa-Yards in 1991 and created Kvaerner Masa-Yards Technology Group. Due to this change in ownership, the research and development work in the ice laboratory decreased dramatically and practically all work in the facility, now called Kvaerner Masa-Yards Arctic Research Centre (MARC), was commercial.

During the 1990s, MARC was very actively studying ice conditions for various oil companies, and many expeditions, especially in the Russian Federation, were organized. The main locations of interest were Sakhalin, Pechora Sea, Gulf of Ob, and Kara Sea. The main objective was to learn as much as possible about the ice environment to enable development of new offshore operations and to design the best possible vessels for the specific areas. Numerous ice model test series of various offshore structures, operational scenarios and double-acting ships were conducted in the facility.



Tempera and Mastera were the first built double acting tankers (DAS™). The hull shape was studied in numerous model test series in 1995-2000.

Azipod development



The first Azipod unit was installed to fairway supply vessel Seili.



The first double acting concepts were converted product carriers Uikku and Lunni.

In late 1980s, Wärtsilä, ABB and the Finnish Maritime Administration started the development of a new azimuthing podded propulsion unit, Azipod. The first prototype was installed onboard the ice-going fairway supply vessel, Seili. After the full-scale tests of Seili, the development of a high ice class Azipod for the Finnish Maritime Administration continued with the design project, Tarmo II.

In 1992, a team dedicated to developing the commercial Azipod was established within the ice laboratory. This allowed designers access to the model test basin to perform extensive model tests for the new Azipods. The main principles of the Azipod design are still based on the ice model and open water tests from the

1990s. The invention of the Azipod created many new possibilities in icebreaking practices. One of the most significant concepts is that of the Double Acting Ship (DAS™), where a ship is designed to advance ahead in open water and thin ice, and to use the stern to proceed in heavy ice conditions.

The real breakthrough for the Azipod, and the DAS™ concept occurred with the conversions of the ice-going tankers Uikku (1993) and Lunni (1994) which were fitted with a DNV ICE 10Azipod unit during their retrofit to replace the conventional propulsion system. Uikku and Lunni proved the advantages of both the Azipod propulsion and the DAS™ concept in the years to follow.

The most significant model testing projects conducted at MARC in 1989 - 2005

Year	Project Name
1989-90	Ice rubble formation for Chuchki Sea. Construction and protection of artificial islands
1989-90	Early concepts for Sakhalin drilling platforms
1991-92	Next generation Baltic Icebreaker. Development of the first Double Acting Vessel Tarmo II
1993	Azipod in ridges. Confirmation of excellency of Double Acting concept
1993	Development of river icebreaker Röthelstein. First constructed Azipod icebreaker
1994	Ice model tests of USCGC Healy based on MARC concept. Initial and final ice model tests were conducted at MARC
1995-2000	Development and ice model tests of the first Double Acting Tankers later resulting in Tempera and Mastera
1996	Offloading in the Arctic. Testing of different concepts. A Joint Industry Project with several oil companies
1996-98	Development of Oblique Icebreaker. Innovation patented in 1997 resulting in oblique icebreaker Baltika built in 2014
1997	Development of icebreaking support/supply vessel Arcticaborg. Two Caspian icebreakers were constructed in Helsinki shipyard
1998, 2002	Great Lakes Icebreaker (GLIB) project. Assistance in ship design and ice model tests resulting in icebreaker Mackinaw
2003, 2005	Development of double acting arctic container vessel Norilskiy Nickel. Concept design including ice model tests
2003-05	Finnish-Swedish ice class tests for tankers, multiple projects
2003	Development and ice model tests of double acting icebreaker Fesco Sakhalin
2005	Development and ice model tests of double acting Pirazlomnoye Shuttle Tankers

With the approach of the new millennium, the future of the testing facility seemed uncertain as Kvaerner was facing difficult times. Fortunately, the facility managed to secure orders of ice class model tests which guaranteed continuation of the testing business. In 2004, Aker Finnyards, owner of the Rauma shipyard, took over Kvaerner's shipbuilding industry. In 2006, the company changed its name to Aker Yards.

Up until the early 2000s, the ice model testing and the related consulting was an integral part of the different shipbuilding companies. However, following the turbulent shipyard ownership changes, a decision was made to establish a new independent company focusing on design of ice breaking vessels. A brand-new state of art testing facility was built to support the design development process.

Aker Arctic Technology Inc (2005-)

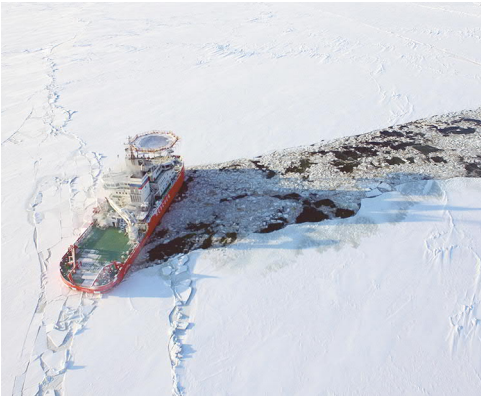


Aker Arctic building in 2018 when solar panels were installed on the roof of the ice model test basin.

The new technology company, Aker Arctic Technology Inc, was founded in January 2005. The site for the construction of the next generation ice model testing facility was chosen next to Vuosaari Harbour in Helsinki. The new facility was inaugurated in February 2006. At this point the company employed about 20 persons, consisting of 12 employees from the old facility and a group of ship design engineers from the former design department of the Helsinki Shipyard. Over the years, as the business of arctic shipping expanded, the number of personnel steadily increased to be approximately 50 people in 2018.

Dimensions and model ice features of Aker Arctic's ice model test basin

Length total	75 m
Length of ice sheet	60 m
Breadth	8 m
Water depth	2.1 m
Test carriage speed range	0 - 3 m/s
2nd carriage speed range	0 - 1.5 m/s
Model ice thickness range	15 - 150 mm
Model ice flexural strength range	15 - 100 kPa
Young's modulus and flexural strength ratio	> 1500



Baltika is the first asymmetric icebreaker ever built.



Icebreaking platform supply and standby vessel Fesco Sakhalin



Photo: Courtesy of USCG

The double acting Great Lakes Icebreaker Mackinaw was developed for United States Coast Guard.



Photo: Courtesy of USCG

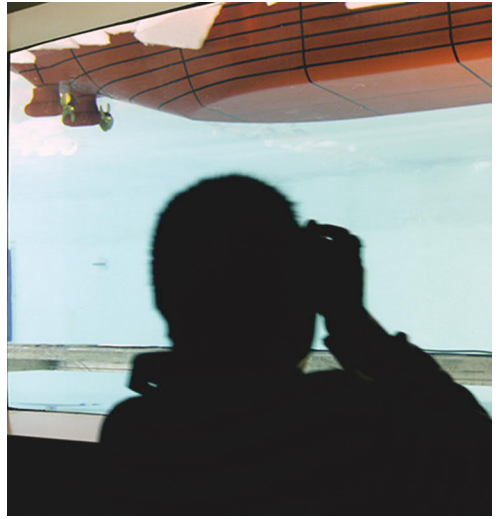
USCGC Healy is the United States' largest and most technologically advanced icebreaker. Hull form development and propulsion line engineering by MARC were based on the Finnish diesel-electric icebreaker Otso.



Icebreaking support/ supply vessel Arcticaborg in the Caspian Sea



River icebreaker Röthelstein, breaking ice and pushing barges on the Danube river.



The current ice model test basin is unique in several respects. One of the outstanding features includes glass bottom of the test basin allowing viewing and video shooting of the tests from below. In addition, there are observation windows on both sides. From these the amount of ice gathering under the model can be seen.

The Vuosaari facility has two carriages moving along the same rails. The first carriage is used for test measurements. The second carriage is used for spraying during ice-making process, measuring ice properties and producing different ice

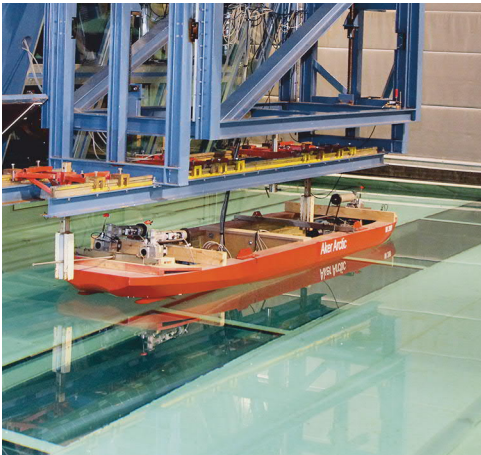
conditions. Experience proved that the FGX model ice was very reliable and it is still used today. One of the great advantages of FGX model ice is that four ice sheets can be prepared within a working week.



Spraying process in progress.



The ship model is connected to the test carriage where all the measurements are conducted. The model is fitted with its own propulsion and the carriage follows the model during the test.

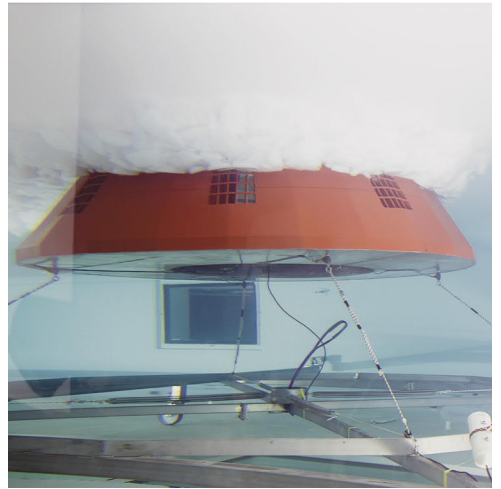


Typically, the model vessels are made in scale 1:40 to 1:10 for testing. Originally, the models were made of abachi wood, which does not absorb water easily. The models were shaped manually using plywood forms. Occasionally, models were also made from fiberglass.

In the 1990s, the tropical wood was replaced with PVC foam which is easy to work with and has excellent mechanical properties. Nowadays the final shape is milled with a CNC machine.



Milling of the model surface



Semi-submersible drilling unit Arctic S was tested both in gravity based (left) and floating (right) mode.

While the 1990s only saw between 35 and 70 test days per year, the opening of the new facility coincided with a boom in the shipbuilding market. The oil exploration activities around the world increased and so did demand for Aker Arctic's services. During the best years the number of ice model test days exceeded 100. The new Arctic exploration activities changed the requirements for the supporting icebreakers, ultimately leading to many new developments in vessel design.

The customers ranged from world's biggest oil companies to shipyards and shipowners. To meet the market demand, new test types were developed:

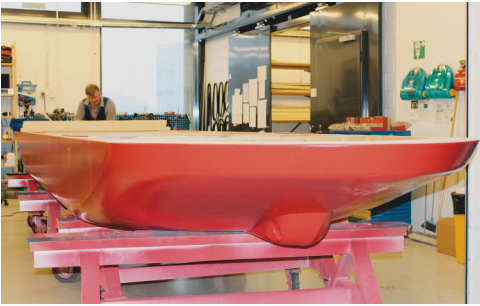
- fixed offshore structures,
- floaters,
- drillships,
- artificial islands,
- harbour ice melting system,
- new ice management methods, and friction tests.

Vessel types tested during 2007 - 2017

Vessel type	% of total number of ice sheets
Icebreaking LNG carriers	17 %
Icebreakers	16 %
Offshore structures	13 %
Offshore service vessels	12 %
Ice class tankers	11 %
Research and development	9 %
Cargo vessels	7 %
Drill ships	7 %
Arctic cruise ships/ferries	4 %
Coast Guard/Naval vessels	2 %
Antarctic research vessels	2 %

The most significant model testing projects executed in 2005 - 2018

Year	Project Name
2006	Modification of drillship Frontier Discoverer
2006	Modification of drilling platform Kulluk
2006-08	Concept development and model tests of an Arctic Ore Carrier for iron mines in Baffin Island
2008	Jack-up model tests
2008	North Star Arctic island model tests
2008-09	Model tests of Aurora Borealis research and drilling vessel, EU project
2008-09	Model testing and hull development of an Arctic platform support and anchor handling vessels
2009	Basic design and model tests of Caspian 50t tug. Five vessels built 2010-2011, Mangystau 1-5
2009-2015	Model testing of an icebreaking emergency and evacuation vessel for Caspian Sea
2009-2014	Arctic drillship and ice management tests for several clients
2010-2011	Icebreaking trimaran research and development tests
2010	Model tests of final version of the Oblique icebreaker Baltika
2010-2018	Model testing and design development for numerous coast guard and navy projects
2011-2017	Yamal LNG Arctic Carriers development and testing for several clients. Series of 15 vessels built
2012	Polar Research Vessel Xue Long 2 design and testing for Polar Research Institute of China (PRIC)
2013-2014	Design and model testing of icebreaker Polaris
2013-2014	Ice encroachment and protection tests with Kalamkas and Kashagan artificial islands
2014	Yamal LNG heavy module carriers Audax and Pugnax design and model testing
2014	Yamal LNG Port icebreaker Ob and icebreaking tug design and testing
2014	Design and testing of icebreakers Aleksandr Sannikov and Andrey Vilkitsky for Novy Port
2014	Novy Port Arc7 40k tankers testing and support
2014-2015	Ice model tests of different kinds of windmill towers
2015	Ice model tests and support of the French Polar Research Vessel L'Astrolabe
2016	Design and model testing of Yamal LNG Condensate tanker Boris Sokolov



Arctic module carriers Audax and Puganax were developed for the transport of massive LNG plant modules to the Yamal Peninsula. With a length of 206.3 m, a 43 m wide cargo deck, and PC3 ice classification, the heavy cargo ships are designed to navigate in exceptional ice conditions.

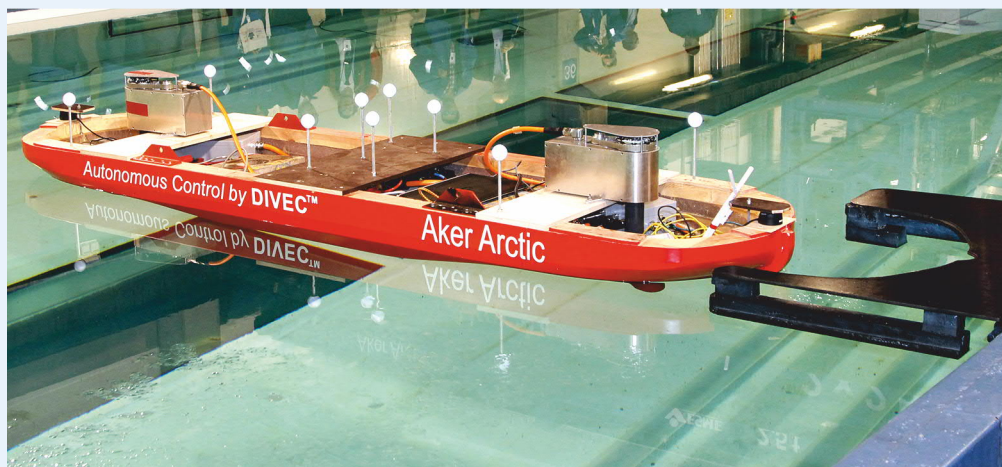


Polaris, built in 2016, is the most powerful icebreaker ever to fly the Finnish flag and the first icebreaker in the world to feature environmentally friendly dual-fuel engines capable of using both low-sulfur marine diesel oil (LSMDO) and liquefied natural gas (LNG). It has excellent manoeuvrability due to the two Azipod units in stern and one in bow.



Aker Arctic has been leading the development of Arctic LNG carriers over the years resulting in Yamalmax icebreaking LNG carriers. The vessels are based on the DAS™ concept and capable of operating independently without icebreaker escort along the Northern Sea Route. The hull form has been extensively tested in Aker Arctic ice model test laboratory. The first Yamalmax carrier, Christophe de Margerie, was delivered in 2016.

The Future of the Ice Model Testing



Computer controlled ship model approaching docking on quay.

Aker Arctic is constantly striving to improve its model testing services to give customers the best designs of ice-going vessels and structures.

The company has developed a model propulsion system that is capable of full computer control of the model ship. In addition to standard model testing, the new propulsion system can be used with dynamic positioning, autopilot and other external control systems. This system also serves as part of a testing platform for autonomous vessels, which are currently in active development in maritime world. Aker Arctic's system allows testing of full-scale control systems in a safe, model-scale environment.

Model tests are also used to support the development of Aker Arctic's simulator model. The data collected from model tests in ice can be used in the simulator's database to more accurately portray the ship's response in ice.

Creating realistic simulator models in the early stages of the building process enables crew training prior to launching the ship. One aim for the future of the simulator is to estimate the effects of different hull features on the ship's ice resistance. The optimization of the hull form could then be started before the model tests.

Aker Arctic has a cooperation agreement with Aalto University to perform commercial ice model tests in Aalto Ice Tank after the renovation in 2019. Being square, and the largest ice tank in the world, it is suitable for conducting maneuvering and turning tests, which are not possible to conduct elsewhere.

The quality of Aker Arctic services is ensured by the continuous study of model ice. Equally important for maintaining the company's market position is the development of new model testing techniques and to be able to flexibly react to customer's needs.



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Aker Arctic

A Success Story
of Finnish Technology

years of ice model testing

Aker Arctic Technology Inc
Merenkulkijankatu 6
FI- 00980 HELSINKI, Finland
Tel.: +358 323 6300
Fax: +358 323 6400
Info@akerarctic.fi
www.akerarctic.fi

The Ice Technology Partner

