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ARCTIC DRILLSHIP DESIGN FOR SEVERE ICE CONDITIONS

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ABSTRACT

This paper presents an Arctic drillship concept design developed by Aker Solutions and Aker Arctic for a MODU (Modularized Offshore Drilling Unit) with capabilities to perform extended season drilling in waters with sea ice. The design was developed starting 2012 and it`s station keeping capabilities in ice was investigated during an ice model test performed at the Aker Arctic ice model testing facility (Helsinki) in 2013.

In Arctic waters, like the Kara Sea, Chukchi Sea and Beafourt Sea, the open water season is sometimes limited to only a few months and a conventional drillship may therefore have a very short drilling season. The objective of the performed drillship design is to propose a concept that may extend the drilling season in these areas by having capability to perform drilling operations during interaction with sea ice.

Starting with a functional specification the drillship design focus have been on the elements that enables these operations as design of the drilling topside for low air temperature, capability of performing drilling operations through a forward located turret moonpool, perform internal handling when having a forward located turret moonpool position and design optimization of hull lines and turret position for sea ice interaction.

The design work has been performed through sizing of the hull, drilling, turret and station keeping system. General arrangement drawings have been developed for each deck level and the technical work has been documented through development of an outline specification.

The cost for the drillship has been developed based on the outline specification (Yard cost estimate) and the Aker Solutions internal cost database for mooring, turret, anchor, thruster and Living Quarter.

DESIGN BASIS

A design basis was developed for the design and is presented in the following section (and in Table 1). The criteria`s set in the design basis were governing for the design of the unit and the consequences of these will be discussed in the later sections. The design basis is not project or area specific and was proposed with the objective of an Arctic MODU for operations in waters with ice with a minimum of icebreaker assistance during operations. In that sense the work performed is generic with the objective of estimating the cost for such unit.

It is assumed in the design that there is a risk/uncertainty in ice management efficiency and therefore the MODU is designed for survival in an as thick intact ice cover thickness to the extent reasonable (with the main objective to avoid disconnection) when considering cost and operations. This includes design of hull lines for effective ice breaking, a forward turret position to reduce the ice load during change of ice drift direction and station keeping system (mooring system) with a high restoring capacity.

The MODU is intended to operate in late ice season, summer season and early ice season. The design ice condition assumed (for survival – before mooring disconnect) was a mooring load equivalent to interaction with 1.5 m intact level ice cover during ice drift change[1].

Table 1. Arctic drillship sizing parameters

General sizing parameters	
Operational water depth	70m - 1500 m
Days of operations without re-supply	120 days
Personnel on Board (PoB)	160
Drilling in ice	Station keeping by mooring (< 400 m)
Drilling in open water	Station keeping by DP
Total well depth	7500 m
Ambient air temperature	
Design air temperature	-40^{0}C
Transit capabilities	
In 1.5 m intact level ice cover	3 knots
In open water (calm)	13 knots
Station keeping Operability	
Drilling in ice	Ice conditions equivalent to 1.5 m level ice, 90 % concentration with floe size 150-200 m
Drilling in open water[2]	80 % operability for North Atlantic scatter diagram
Dynamic Positioning system	DP3
Station keeping survival	
Survival in ice	Ice conditions equivalent to intact ice cover with 1.5 m level ice thickness
Offset restrictions for riser angle (to the vertical)	
Drill string connected - Drilling operations	Offset corresponding to 2 degrees for riser
Drill string connected - Survival	Offset corresponding to 6.5 degrees
Turret diameter limitations	Offset corresponding to 10 degree riser angle
Disconnection capabilities	
Mooring disconnection by turret buoy drop	Yes
Mooring disconnection by single line drop	Yes
Classification	
DNV +1A1, DRILL (N), CRANE, HELDK-SH,F-AM, EO, DP Class 3 (DYNPOS AUTRO, POSMOOR ATA, Classification for operation in ice: PC5, DAT(-40°C) Classification notation, Russian Maritime Register of Shipping (RMRS): KM() Arc6 [1] A1 DYNPOS3-2	

[1] Previous performed model testing indicates that an ice ridge interaction head on with the MODU with a consolidated layer thickness of 1.5 m and keel depth equal to baseline of the MODU will give the same load level as found for the level ice condition.

[2] The North Atlantic scatter diagram covers the Haltenbanken area (Norwegian Sea) and is considered to be conservative for estimation of the operability in open water.

The drilling design basis includes capabilities to perform exploration well drilling, coil tubing, wireline operations and running and pulling x-mas tree. A 1 ½ conventional triple stand derrick with single well centre and offline stand building capacity was assumed for design. The MODU should include space to accommodate two 18 3/4" 15000 psi BOP (Blow Out Preventer) stacks.

MAIN PARTICULARS

Designing the drillship for operations in sea ice and low temperature impacts the design when comparing to existing drillships. The main challenges for the drillship design introduced by the Arctic environment are:

- Design the mooring system for potential sea ice interaction
- Disconnection and re-connection of the mooring system in sea ice
- Design the drilling facilities for low air temperatures
- Evacuation in ice
- Marine operations in sea ice

An important item based on above recognition was therefore to design the hull lines to reduce the global ice load on the hull in all phases of operation to 1) reduce the size of the mooring system with respect to mooring handling and turret size and 2) reduce MODU resistance in ice during marine operations. Based on the experience from previous Arctic floater concept design the following items were prioritised in the design of the unit:

- Hull lines optimised for ice interaction:
    - Bow shape (reduce possibility of potential sub-surface transport of broken ice towards the drilling riser)
    - Length of reamer on the hull side (length of sloping hull side)
    - Stern shape
- Turret position (drill centre position) evaluation:
    - Performance in ice vs performance in open water (forward vs centre turret)
    - Material handling from two sides (centre drilling turret) vs. handling from one side (forward turret drilling)
    - Living Quarter (LQ) location (aft vs forward of turret)
- Turret mooring disconnection system
- Handling system:
    - From supply vessel to drillship and internal handling
- HVAC design (Heating Ventilation Air Conditioning system design for the ambient air temperature specified)
- Cladded drilling topside and derrick design

Based on the performed design a drillship (see Figure 1) with the following main particulars (see Table *2*) was developed:

Table 2. Arctic drillship main particulars

Main particulars	**[-]**
Length Overall (LOA) / Length between perpendiculars (LPP)	232 m/212 m
Breadth / Breadth in area with reamer	42 m/48 m
Operating displacement	89000 tonnes
Operating draft	13 m
Depth moulded	22 m
Total power generation	51 MW (6x8.5 MW)

Figure 1. Arctic drillship

GENERAL ARRANGEMENT AND CAPACITIES

The main MODU General Arrangement (GA) drawing is shown below (see Figure 2), dividing the MODU into its different main areas.

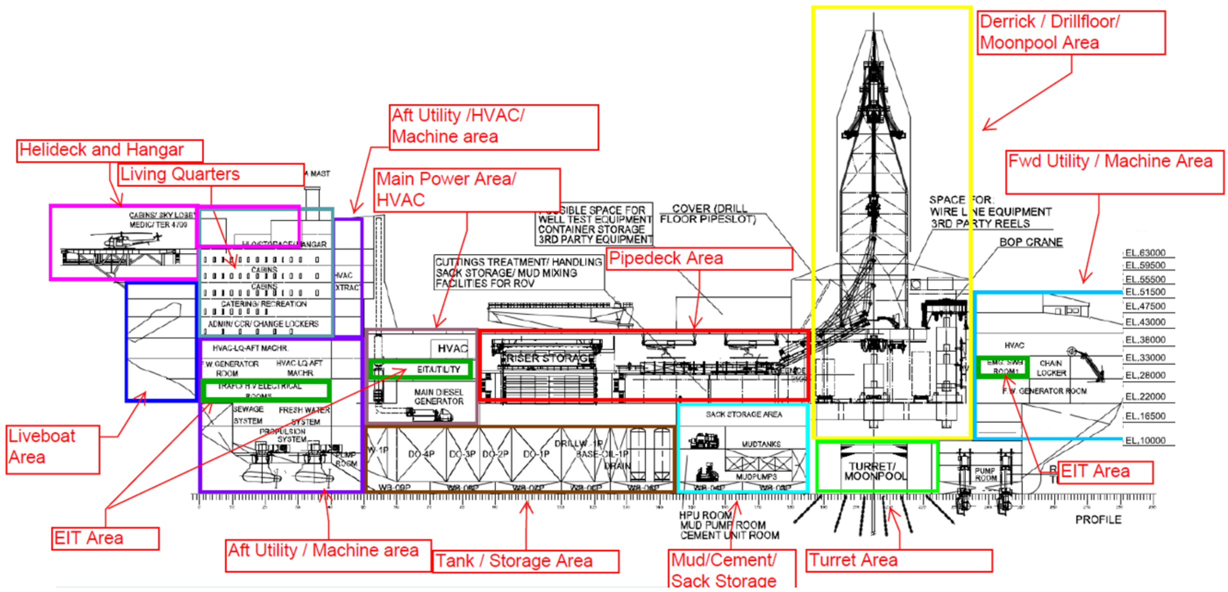
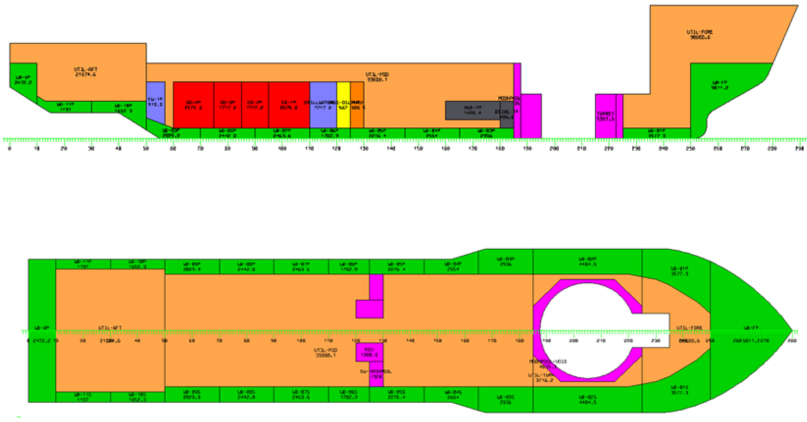


Figure 2. General arrangement

The forward position of the drilling turret is limited by the location of the forward retractable thrusters and the forward collision bulkhead. A study was performed to investigate the feasibility of having the LQ forward of the turret (with the objective of reducing hull length) but the results indicated that the consequences of such design would be that the turret would have to be relocated minimum 20 m to the aft, giving a less preferred turret position with respect to operations in ice. The GA shows clearly the one-side handling system for riser, casing and drill pipe into the derrick area through the conveyor belt system.

TANK ARRANGEMENT AND STORAGE CAPACITY

The storage capacity is sized according to the design premises. The design basis requirements set on days of operations without resupply and air temperature design is driving the large diesel storage capacity. At full load (utility tanks at full capacity) only 3 % of the ballast capacity is used to maintain even keel and no heel. At minimum load (utility tanks at 10 % capacity) the ballast system is used to achieve draught at 13 m and maintaining even keel and no heel (60 % of the ballast capacity is used). The ballast tanks location is designed to minimize the amount of ballast water above the waterline to reduce the potential heating needed of ballast water to avoid freezing in the tanks. The operating draft of the unit is 13 m but a transit draft of 11.5 m without impact the vessel stability is feasible. The tank plan and storage capacities for the unit are shown below for fluids (see Figure 3).



Capacities	[-]
Diesel oil (red)	16500 m^3
Fresh water (blue)	1700 m^3
Drill water (blue)	3300 m^3
Base oil (yellow)	1100 m^3
Brine (black)	950 m^3
Mud (black)	2700 m^3
Drain (orange)	1200 m^3
Ballast water (green)	61000 m^3

Figure 3. Tank plan and storage capacities

In addition there are tanks for bulk material (8x150 m^3), mixing (2x35 m^3), charge suction pump (4x65 m^3), reserve (3x100 m^3), pill/slug (2x30 m^3) and cuttings storage (ISO tanks - 825 m^3). The pipe storage capacities on main deck are 6000 m of casing, 7500 m of drill pipe and 1500 m marine riser.

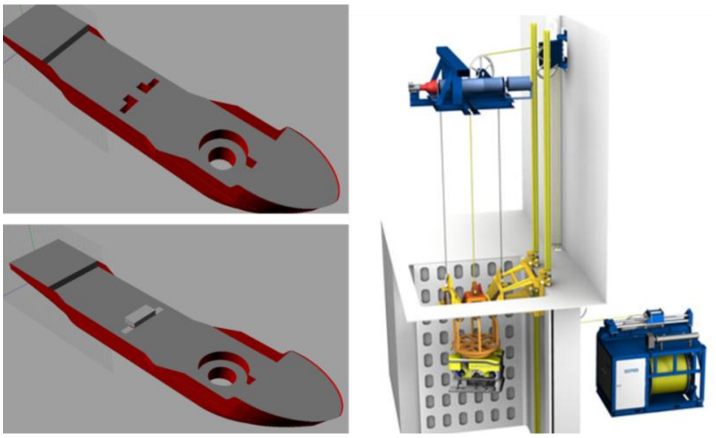
INTERNAL HANDLING AND CRANE CAPACITY

Three Knuckle boom Cranes which are electro hydraulic driven are proposed for handling of containers, sacks, drill pipe/casing in bundles and drilling riser. The main hook capacity of the cranes is 85 tonnes SWL (Safe Working Load). The max radiuses of the cranes are 46 m giving access (and visibility for crane personnel) to all laydown areas and hatches for handling.

For handling into the LQ area there is a hatch in front of LQ and a laydown area on the starboard side. An elevator in the central core in front of the LQ is used for distribution. Three laydown areas on the starboard and port side are used for handling of all pipe, containers and sacks. The pipes are further handled by forklift to their storage area while sacks and equipment are transported to an elevator at same level for transport to tanks and storage areas lower in the hull.

For pipe handling into the derrick area the overhead cranes above the pipe deck will lift the pipes and place them on the conveyor belt which takes them into the derrick area. In the derrick area the conveyor crane handles the pipes into the derrick (40 tonnes capacity). On the starboard side in the derrick area there are two side doors with loading platforms to be used for handling of X-mas tree (and BOP parts if any repair/modifications). The X-mas tree is further skidded into position.

The BOP (Blowout Preventer) is positioned in the derrick area and is handled in position by BOP crane and skidding. For handling of the BOP the BOP overhead crane has a capacity of 450 tonnes, while the BOP transporter crane capacity is 225 tonnes (2 off). In the forward part of the unit there are hatches for retracting the forward thrusters for any modifications/repair.



ROV (remotely operated vehicle) handling in ice is challenging as the ROV cannot be handled over the shipside through the sea ice. The ROV is therefore launched and recovered through an internal moonpool, see Figure *4*. The ROV moonpool is positioned close to mid-ship and the ROV hangar and control room is located on the main deck.

Figure 4. ROV moonpool/hangar location (left) and ROV handling (right)

DERRICK AND DRILL FLOOR AREA

The derrick is designed with a 15x15 m base and x 52 m clear work height with a 750 tonnes crown load, set back capacity of 600 tonnes, travelling equipment with 750 tonnes hook load and top drive capacity of 750 tonnes. The drillstring heave compensator has a capacity of 750 tonnes static load and 7.5 m (25 feet) stroke while the maximum riser tensioning load is 1160 tonnes. The rotary table has dimensions 60 ½” with capacity 750 tonnes. There are 5 double shale shakers for mud return. The handling and storage arrangement for BOP are designed to handle BOP stacks with up to 7 cavities.

The tubular system in the derrick consists of 2 remote/local operated hydraulic powered roughnecks on the drill floor. One for well centre and one for stand building. The derrick is equipped with fingerboards for the following set-back capacity (drilling tubular in set-back):

- 7500 m , 5 ½” – 6 5/8” drill pipe, 260 stands
- 270 m 9 ½” drill collars, 10 stands
- 6000 m 9 5/8” casing, 250 stands

MACHINERY

The machinery consists of six 8.500 kW diesel engines driving the electrical generators arranged in three separate engine rooms in the aft part of the drill ship. Two 2.500 kW emergency diesel engines with emergency switchboard are located in the forward part.

WINTERISATION

The unit is designed for operations in the low temperatures by enclosing the drilling topside. In order to maintain the requirements set below there are several HVAC (Heat Ventilation Air Conditioning) units located in the MODU including channels. The heating of the ventilation air is based on WHRU (Waste Heat Recovery Unit) from the power generators. The back-up heating of the heating medium is arranged by diesel fired heaters/boilers. For cooling of the LQ chilled water is used while warm extract air from the accommodation is used to keep the lifeboat entrance free of ice.

The ambient HVAC temperatures set for design are:

- Air: -40^{o}C C-100% and +16^{o}C C-80 % RH
- Seawater: -2^{o}C to 16^{o}C

The HVAC design wind speed was set to 30 m/s, 10 m above sea level. The MODU has air intakes on each side of the unit with heating elements. The following area design has been performed for the given air temperature intervals:

- General process and utility areas, riser/casing/drill pipe storage area, electrical rooms: minimum 5^{o}C and maximum 35 ^{o}C
- Manned control rooms: min 20^{o}C and max 24 ^{o}C

The following ventilation rates were designed for:

- Rooms with diesel engines: Minimum 6 ac/h (air changes/hour)
- Classified and natural ventilated areas: Minimum 12 ac/h

HULL LINES

The hull lines are designed for sea ice interaction with the objective of 1) reducing the global ice load on the hull and 2) avoid/reduce amount of broken ice being transported under the baseline of the hull towards the drilling riser.

The hull is designed with an icebreaking bow shape which breaks ice by bending downwards in order to reduce horizontal ice loading. The underwater part of the bow is plough-shaped to enforce broken ice blocks to drift sideways over the sides of the hull instead of drifting below the baseline towards the moonpool and turret area.

The part of the hull side extending from the bow area has a sloping surface in the waterline (reamer). The hull lines are designed for minimized ice load and to maximize heading control (i.e. “ice vaning”) in drifting ice. The reamer (expanded and sloped section at the bow) and long sloped stern at waterline significantly improve the turning capability in varying ice drift directions. Transom at water line is also sloped to bend ice downwards, which is important feature, especially in case of occasional 180 degrees ice drift changes (i.e. ice drifting towards the stern). These features are illustrated in the Figure 5 and Figure 6.

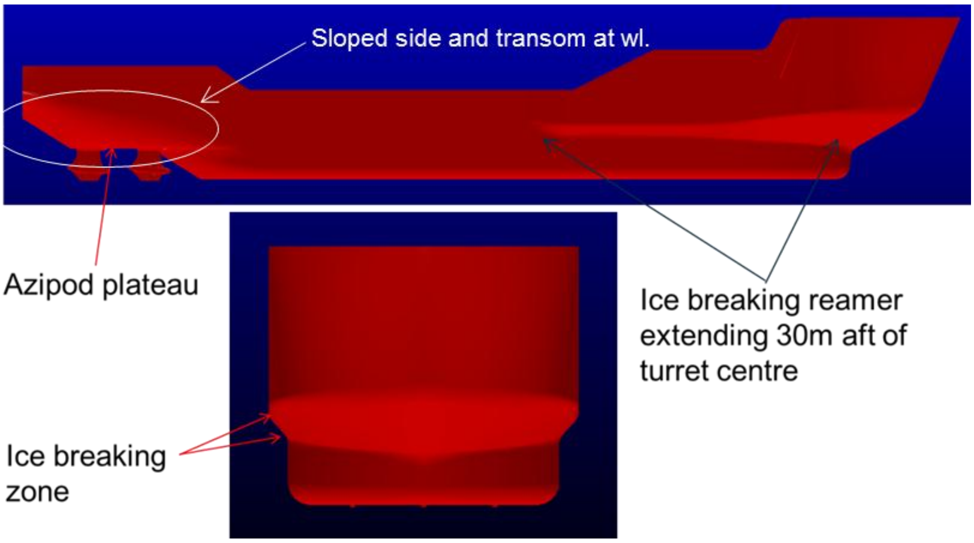


Figure 5. Hull lines (side view)

The underside of the hull is shown below with the thruster positions. For the ROV moonpool and sea water inlet the actual opening is indicated in blue. The Azipod thrusters are located at a plateau below the sloping hull side in the waterline and can be used to flush the broken ice away from the baseline area during hull rotation in ice.

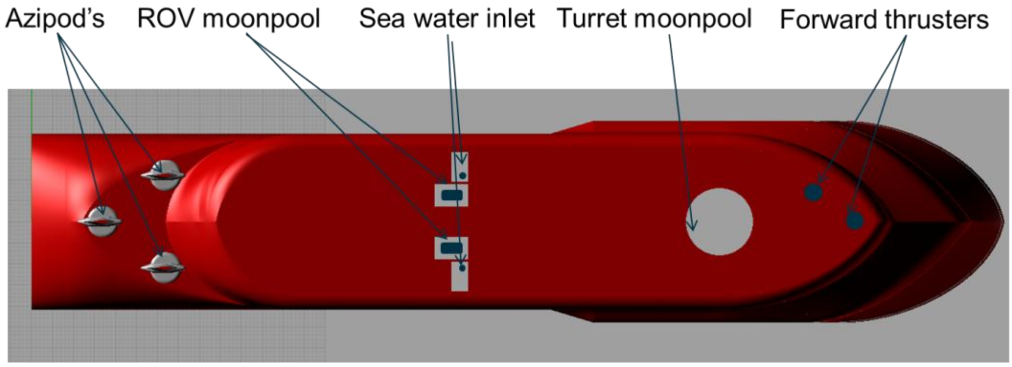


Figure 6. Hull lines (below view)

HULL STRUCTURAL DESIGN

A dual class design complying with both RMRS (Russian Maritime Register of Shipping) ARC 6 and PC 5 (Polar Class) has been performed. The following guiding is used for the two class requirements:

- RMRS ARC6: Medium first-year ice (up to 1.2 m thickness) for summer navigation and thick first-year ice (up to 1.5 m) for winter navigation
- PC-5: Year-round operation in medium first-year ice which may include old ice inclusions

These class requirements are considered suitable, having a reasonable balance between operating capabilities and cost/weight, for the proposed ice conditions. The impact on the structural steel weight of designing for these ice classes are considered to be small compared to only structural design for open water operations.

STATION KEEPING SYSTEM AND TRANSIT CAPABILITIES

The thrusters are used for both transit and station keeping. There are a total of 5 azimuting thrusters:

- Aft: Three open podded thrusters each 9.5 MW suitable for operation in ice
- Forward: Two nozzle retractable thruster each 3.5 MW, to be retracted in ice

For drilling in open water the 5 thrusters provide DP3 capability while for drilling in ice the turret mooring system will be used for station keeping assisted by aft thrusters during rotation in ice (forward thrusters will always be retracted when operating in ice).

Two different turret mooring alternatives have been developed for the drillship. Both can accommodate between 12 and 18 mooring lines. The turret solutions are partly based on known solutions and components, and partly contain new solutions. Both turret solutions have an internal diameter of 16 m.

The MODU is designed with own position capacity for operation in the proposed ice conditions. However, the uncertainty in ice conditions during operation warrant a disconnect ability. A disconnection can be performed by either mooring buoy release or release of individual lines. A major factor for design of this system is the corresponding re-connect ability. The mooring buoy disconnect will need one pull-in operation to reconnect while disconnect by individual lines will need a reconnect by pulling in individual mooring lines.

The turret alternatives proposed are shown in Figure 7.

- Alternative 1: Buoy turret
  - Disconnection by:
    - Release of mooring buoy or,
    - Release of individual lines
- Alternative 2: Fixed turret:
  - Disconnection is based on release of individual lines

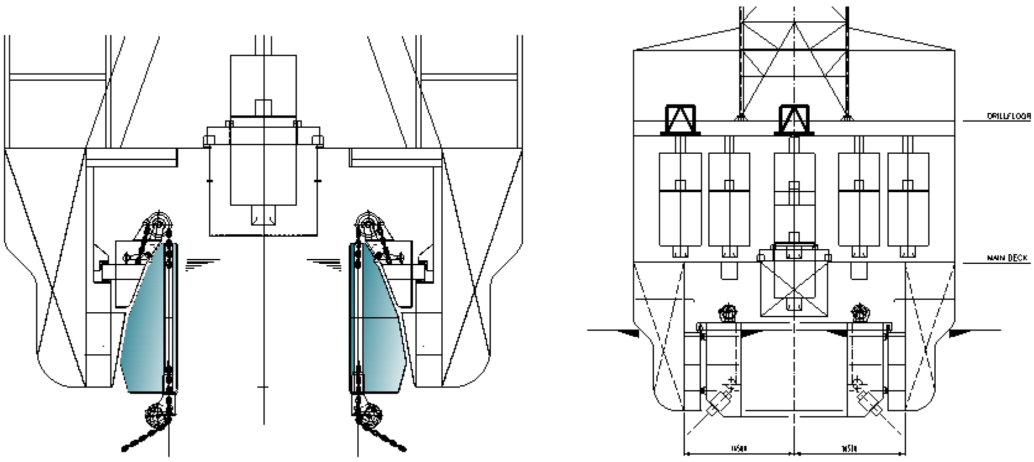


Figure 7. Turret alternative 1 (left) and alternative 2 (right)

Two different symmetric mooring systems are proposed and sized for two different water depths (see Table 3).

Table 3. Mooring system particulars

Water depth		**100m**	**400m**
Bottom chain (R4), 120mm	Length [m]	800	500
Wire, 134mm	Length [m]	220	
Fibre Rope, 219mm	Length [m]		500
Platform chain (R4), 120mm	Length [m]	100	100
Midline buoy	Net Buoyancy [t]	20	
Weight one line	[t]	313	171
Length one line	[m]	1120	1020
Pretension	[t]	100	200
Anchor type		Drag (21t Stevshark Mk5)	Vertical load (18m2 Stevmanta)

The mooring lines will have spring buoys to avoid wellhead contact during disconnection (release of either turret buoy or individual mooring lines). The capacity for different load cases for the two proposed mooring systems are shown in Table 4.

Table 4. Mooring system capacity

Water depth	Criteria, Intact system	12 Lines	18 Lines
100 m	Drill string connected offset 6.5 deg SF 1.9	16MN	24MN
	Mooring capacity SF 1.5	25MN	39MN
400m	Drill string connected offset 6.5 deg SF 1.9	17MN	25MN
	Mooring capacity SF 1.5	22MN	33MN

EVACUATION

The evacuation means for the drillship are consisting of free-fall and davit launched TEMPSC (Totally Enclosed Motor Propelled Survival Craft) approved for Arctic duty. The total number of crafts is 4 to achieve 160 POB + stranded helicopter. 2 MOB (Man Over Board) boats are also planned for. In addition there are self-contained containerized escape chute system approved for arctic duty with the following location:

- Aft corners of the LQ: 2x100 % capacity
- In front of the derrick: 1x50 % design (for stranded/isolated personnel)

These evacuation alternatives are originally developed for evacuation in open water conditions. They are further developed for Arctic application but currently there are no (to author`s knowledge) proven alternatives for a quick evacuation of personnel (similar to free fall for open water) when the drillship is surrounded by sea ice.

ICE MODEL TEST

The drillship concept was tested in design ice conditions at the Aker Arctic ice model test facility in Helsinki in 2013. The objective of the model test was to verify the hull lines and mooring design for the proposed design ice conditions. The sensitivity of the following features were also investigated with basis in the main concept for the design case when ice shifts drift direction with 175 degrees:

- Length of reamer on hull side impact on global ice load
- Mooring loads from intact level ice vs. mooring loads from managed level ice (variation in floe size and concentration)
- Use of thruster during drillship rotation in level ice (impact on rotation time and global ice load)
- Rotation in level ice with drillship having already created a wake (most rotation tests in level ice are performed without the wake behind the unit)
- Combination of above two items

The model scale used was 1:39. The choice of the model scale was governed by the basin width vs length of the drillship with the objective to have at least 40 m (full scale) between the basin side and the drillship during rotation in ice to–avoid any impact on loads due to confinement of the model ice.

The hull model was made of Airex structural foam and the surface of the model was treated with standard Aker Arctic painting to obtain the target friction properties. A grid was painted on the model to quantify depth and extension of sub-surface ice transport and broken floe size.

The model was attached to a carriage using a universal joint (cardan shaft). The universal joint was attached at the baseline in the turret position (mooring attachment point/fairlead in turret).

The model was free to roll, pitch, yaw and heave and fixed in surge and sway. The ball joint was greased properly before testing to avoid any friction. The model was also equipped with two azimuthing stock propellers at the aft. The model particulars are listed in Table 5.

Table 5. Model particulars

Particulars	[-]	Full scale	Model scale
LOA	[m]	218.2	5.57
LPP	[m]	207.6	5.3
Breadth	[m]	42/48	1.07/1.22
Depth	[m]	22	0.56
Draught	[m]	14.5	0.37
Turret position from AP	[m]	160	4.08
GM	[m]	3	0.076

A general view of the tested model is shown in Figure 8 and Figure 9.

Figure 8. General view of model – Bow (Reamer 1)

Figure 9. General view of model – Stern with thrusters (Reamer 1)

Before the test campaign the model geometry, bollard pull of the thrusters and eigenfrequency of the carriage was measured. Before each test the model draft and GM (inclination test) were measured.

The measured model parameters during each test were Fx. Fy and Fz at the universal joint connection point, carriage position and speed, model motions, thruster angle and RPM. The motions were measured with an infrared motion measuring device (Qualisys system). Four cameras were attached to the model during testing (2 above water view and 2 below water surface view) to observe the ice failure mode and behaviour of broken ice under the hull. In addition two cameras were recording from the side of the basin (one above waterline and one below waterline). A synchronisation signal was used in all tests (for synchronisation of videos and recorded time series).

The following ice properties were measured each test day: ice thickness, flexural strength, compressive strength, Young`s modulus, floe size, ice concentration and ice density. Some additional ice property measurements were performed during the test period as ice rubble buoyancy, ice-ice friction and ice-model friction. The ice field was photographed before the tests and the photographs were combined into one picture. The ice concentration and floe size were determined from these pictures (see Figure 10).

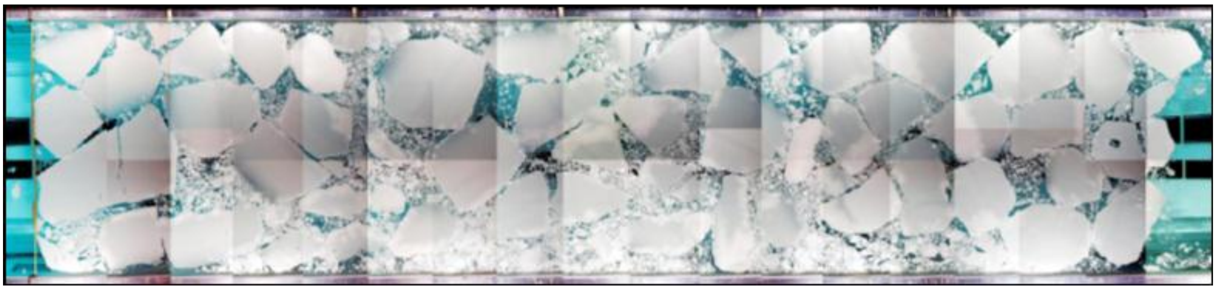


Figure 10. Typical photo used for determination of ice concentration

The test matrix is presented below (see Table 6). All the tests were ice drift reversal tests (see Figure 11) performed with ice drift velocity equal to 0.2 m/s except three tests which were performed head on with different velocities. All tests were performed with:

- Target level ice thickness of 1.5 m
- Target ice concentration of 90 % (except for tests done in intact level ice)
- Target GM of 3.0 m
- Thruster only used in tests 4.4, 5.1 and 5.3

Table 6. Model test matrix

# Test	Reamer	Floe size [m]	Comment
1.1/2.1/3.1	Short/Long/Long	200*200	
1.2/2.2/3.2	Short/Long/Long	200*200	
1.3/2.3/3.3	Short/Long/Long	100*100	
1.4/2.4/3.4	Short/Long/Long	100*100	
4.1	Long	Intact level ice	
4.2	Long	Intact level ice	Head on test
4.3	Long	Intact level ice	Head on test
4.4	Long	Intact level ice	Test with wake behind model
4.5	Long	50*50	
4.6	Long	50*50	
5.1	Long	200*200	
5.2	Long	200*200	Head on test
5.3	Long	200*200	Test with wake behind model

Figure 11. Model during ice drift reversal (left) and sub-surface ice transport (right)

The results of the tests performed document the following regarding responses of the unit in the tested ice conditions:

- No broken ice was transported under the baseline of the unit in the tests
- The measured ice load (peak loads) was reduced with almost a factor of 50 % when comparing tests with broken ice conditions with tests with intact ice conditions
- When including the wake behind the model and use of thruster for support of rotation in ice a further reduction in loads were observed

Based on the findings from the model test additional optimisations of the MODU were performed;

- Draft reduced to 13 m
- Stern shape optimised

OPERABILITY OF DRILLSHIP

Pre-simulations of the ice model test were performed by using a numerical model developed by Aker Solutions for floater interaction with intact level ice (see Figure 12.). The model was corrected towards the ice model test results and further used to perform post-simulation with the target ice properties for the intact ice condition. When comparing the measured results with the simulation performed with measured ice properties a good correlation was found.

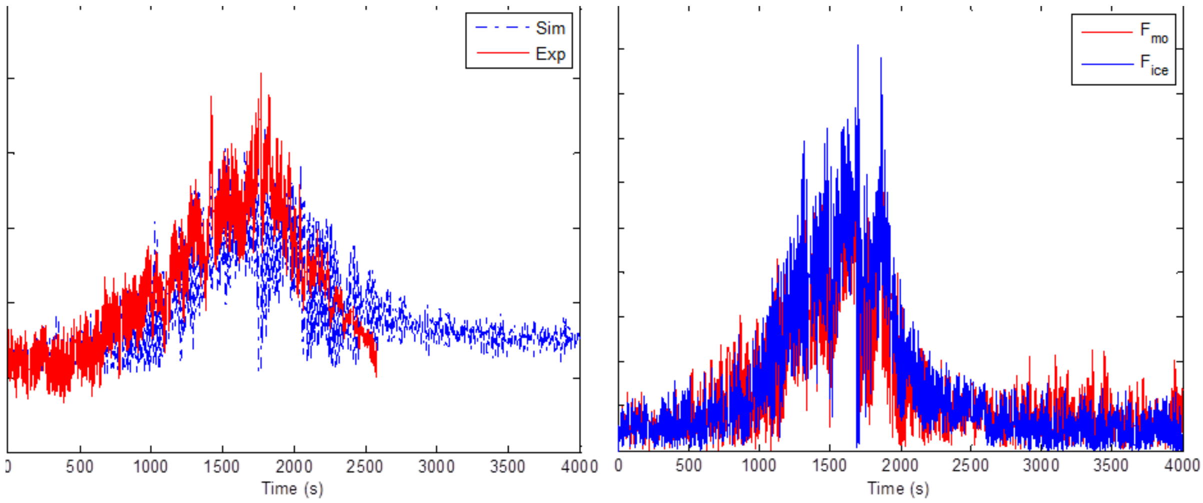


Figure 12. Simulated compared with measured loads using measured ice data (left) and mooring load and ice load estimated with corrected simulation model and target ice properties

The ice model test results including the post simulations (with the corrected simulation model) indicate that:

- For a 12 line mooring system the mooring system can resist 1.5 m intact level ice in the survival condition (ice drift reversal case)
- For a 18 line system the drillstring can be connected when operating in intact 1.5 m level ice (ice drift reversal case)
- Broken ice will not be transported under the hull when interacting with 1.5 m level ice

Analytical ice ridge load estimation indicate that an ice ridge with consolidation 1.5-2 m and keel depth equal to the baseline of the MODU will give a load level in the same range as the ice drift reversal event with 1.5 m level ice.

It should be noted that the MODU mooring system is sized for intact level ice. The objective with this approach is to avoid disconnection of the unit to the extent possible. For managed ice the measured peak load levels were 50 % of what was measured for intact level ice. This indicates that if including an ice management system the MODU can operate in thicker ice than the target ice thickness for the performed design.

It should also be noted that the numerical simulation model and the ice model testing results are not correlated towards full scale results.

The operability in open water was investigated by estimating the drillships operability by comparison with the North Atlantic scatter diagram (similar to areas as Haltenbanken / Norwegian Sea). Such comparison is considered conservative as the Hs for this area is more severe compared to areas like GoM/Brazil/Africa. For the present turret position an operability of 75 % was estimated.

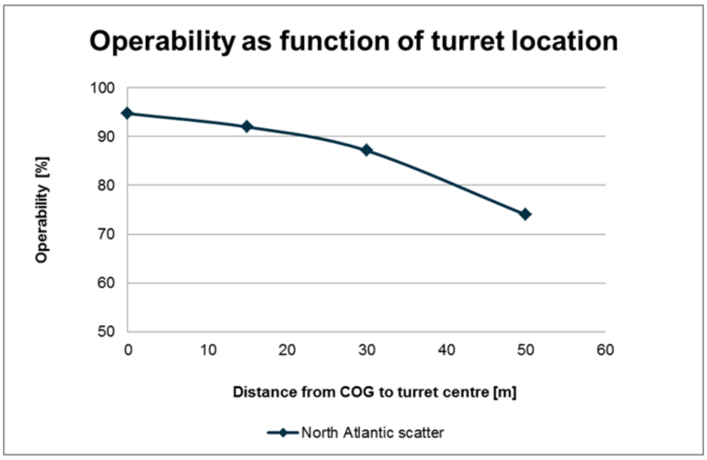


Figure 13. Open water operability as a function of turret position

The transit capability in open water Beaufort 6 (Hs 4.4m – Ws 12.6 m/s – Cs 0.5 m/s) was found to be 13 knot with the present thruster configuration. Transit capabilities in level ice was investigated during the ice model test and for transit in 1.5 m intact level ice a speed of 4 knots is achievable using only the aft thrusters.