THE DESIGN OF A PURPOSE BUILT GLOBAL CAPABLE EXPEDITION YACHT
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SUMMARY
During the last year, Damen has developed a purpose-built globally capable expedition yacht - the SeaXplorer. Designed specifically for the expedition market, this yacht has faced the challenges of accurately defining the operational profile of an expedition vessel, implementing Polar Code requirements in the core design, optimizing the hull shape, defining the ice breaking capability, propulsion system and other purpose-specific requirements...all without compromising the safety and comfort of the yacht in any way. Damen Shipyards wanted to develop the idea of a vessel which will fill a gap in the market for a robust, strong, versatile and comfortable expedition yacht. Together with EYOS Expeditions and their extensive experience, the operational profile of the SeaXplorer was carefully defined, developed and implemented in the design. Optimized hull shape has been successfully verified with an array of HSVA model tests which helped define the ice strengthening regions along the hull with respect to the Polar Class demands. In addition, special expedition features have been incorporated, such as extra-large provisions, spare parts and equipment spaces, a zero discharge management system, a hydraulic lift helicopter hangar, internal storage for multiple tenders and a comprehensive complex dive area. Beside functionality, styling is a very important issue in the Yachting industry, Azure Yacht Design and Naval Architect were challenged to design the exterior lines of the SeaXplorer. Damen has developed a range of SeaXplorer expedition yachts in 65 meter, 90 meter 100 meter variants, each of which meet different sets of expedition requirements while sharing the benefits of a common lineage. The following paper describes the development of the SeaXplorer 90 meter.

1. INTRODUCTION
When designing a vessel that will sail deep into ice-covered regions, designers and engineers must take well into account the full suite of potential operational scenarios that may be encountered. Every purpose built expedition yacht at its essence should be a safe, strong and ice-capable vessel which maintains all the comfort of a luxurious yacht. In that respect, no aspect of the core design features should be compromised in any way.

Damen Shipyards builds up to 150 ships a year, from small workboats to patrol boats, research vessels, offshore ships, icebreakers, superyachts and military vessels. This broad proficiency in designing, engineering and building such a variety of ships provides them with the expertise and engineering dexterity to develop a new type of vessel for a specific new market. A cross-pollination of Damen Offshore division, with its focus on commercial and industrial builds, and the Amels Yacht division with its focus on high quality luxury builds, has combined to create the initiative of a true expedition yacht, the SeaXplorer.

Despite the extensive expertise in yachting and offshore, Damen was lacking operational knowledge in the expedition industry. This led to the establishment of a partnership with EYOS Expeditions Ltd, the foremost provider of yachting expeditions in the world. Having taken dozens of superyachts to some of the most remote parts of our planet over a collective several hundred polar and tropical expeditions, they have a foundation of practical experience that is unparalleled. To capitalize on this experience, EYOS Expeditions was engaged as a design partner and became the ‘virtual client’ for the SeaXplorer design.
Styling is always of high importance in the yachting industry, and while Amels has a great deal of experience in this regard, parent company Damen wanted to provide the SeaXplorer with a look that is ‘outside the (yachting) box’. Damen engaged with Azure Yacht Design specialists and gave them a free hand; the result is the SeaXplorer’s signature expedition yacht aesthetics; bold, ‘ruggedized’, modern, strong and versatile.

Damen’s vast shipbuilding knowledge together with EYOS’s operational experience has resulted in a development of a design brief with an extensive scope of topics to be tackled:

- Operational profile
- Ambient conditions
- Polar code
- Hull shape
- Ice breaking capability
- Expedition logistics
- Special expedition features
- Styling

2. DESIGN CONDITIONS

A global capable expedition yacht should be able to operate comfortably and efficiently in both tropical and polar conditions and therefore requires the ability to function within an operational ambient temperature gradient of -10°C to +45°C. The wide thermal operating range needs to be complemented with excellent sea-keeping ability since a true expedition vessel often has to traverse broad areas of turbulent water in order to access these rarely visited regions. The SeaXplorer needs to be as comfortable in the Southern Ocean or the North Atlantic as she is in remote Micronesia or Madagascar.

The best times to access the Polar Regions are in the spring and early summer when the light has returned and the wildlife is abundant. Temperatures are not at their most extreme and ice is already reducing from its winter maximum, but conditions are still ‘polar’ with pack ice drifting about and late Spring storms are always possible. In general, polar expeditions take place along the coastal fringe, where the interactions with wildlife is most intense.

Ice conditions generally consist of either sea ice or glacial ice. Sea ice, which forms each winter (and dissipates during summer) is very commonly encountered by vessels operating in the polar regions and typically expedition yachts will sail more in broken ice with low to medium ice concentrations rather than full cover ‘fast ice’. However, changing wind can result in pack ice being blown downwind and collecting at natural ‘choke points’ such as narrow bays. Maneuvering through these bays, or needing to traverse through a band of pack ice to reach open sea is a common occurrence. It is at these times that ice-breaking capabilities are most advantageous and where a vessel’s capabilities can define the success of the voyage/mission. As ice class increases, so, too, does the safety of the vessel as well as its ability to extend its operating area and cruising season. Glacial ice is a much more serious proposition, being incredibly dense/hard and also more difficult to see. Even a small block of ice (a ‘growler’) measuring 1 cubic meter will weigh 1 tonne and can do a great deal of damage to a poorly designed/constructed yacht. In conditions of heavy swell and fog, these growlers pose significant risks to non/low ice-classed vessels. The safest vessels are those with strong ice reinforcing, protected or retractable appendages and accoutrements such as ice-radar.
Tropical conditions can also be challenging with high temperatures, high relative humidity and high UV radiation. Good insulation and special windows with heat reflection layers can reduce the capacity of the air conditioning. Dust filters have to be fitted in the air intakes when crossing the Red Sea.

2.1 Operational profile

A typical operational profile for a privately operated expedition yacht, developed with EYOS, can be found in the following tables. Table 1 represents a typical yearly route for such a vessel including different time frames, locations and weather conditions whereas Table 2 gives an overview of such an operational profile in terms of days spent in certain segments of the expedition.

<table>
<thead>
<tr>
<th>November - February</th>
<th>Antarctic expeditions</th>
<th>Typical expeditions are 4 weeks but the season can be extended to 16 weeks. Some passages from South America to Antarctica encounter severe weather. Mainly operating in open water with a maximum of 10% coverage. In some cases pack ice (up to 1 m thickness) or high ice concentrations are experienced. In total 1 day out of a week</th>
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<tbody>
<tr>
<td>March</td>
<td>Re-locating</td>
<td>Long ocean crossings. Many hours, sometimes rough weather at higher latitudes</td>
</tr>
<tr>
<td>April-May</td>
<td>Tropical expeditions</td>
<td>8 weeks available for tropical expeditions (French Polynesia, Melanesia, Indian Ocean). Good weather, many diving activities and use of submersibles and toys</td>
</tr>
<tr>
<td>June</td>
<td>Relocating</td>
<td>Long ocean crossings. Many hours, sometimes rough weather</td>
</tr>
<tr>
<td>July-August</td>
<td>Arctic expeditions</td>
<td>8 week expedition window eg. the North West Passage, Greenland, Svalbard, Northern Sea Route etc). Mainly operating in open water with a maximum of 10% coverage. In some cases level ice (up to 1 m thickness) or high ice concentrations are experienced. In total 1 day out of a week</td>
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<tr>
<td>September</td>
<td>Cote d’Azure</td>
<td>4 weeks Cotes d’Azure. Nice weather, a lot of fun with the toys on board</td>
</tr>
<tr>
<td>October</td>
<td>Re-locating</td>
<td>Long ocean crossings. Many hours, sometimes rough weather</td>
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Table 1 [Operational profile of an expedition yacht]

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<thead>
<tr>
<th>Percentage [%]</th>
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<tr>
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<td>Tropical/Cote d’Azure cruising (84 days)</td>
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What can be observed from the given numbers is that she is at sea with or without guests for 60.3 % of the time and finally only for 5.5 % can be found in real ice. This realization is an interesting point from a designer’s perspective: where to put the emphasis? Will it be the ice breaking capability, the sea-going behaviour or perhaps a combination of the two? Since our clients aren’t keen on accepting compromises and limitations, Damen was faced with the challenge of incorporating the requirements of the Polar operations into the design, regardless of the relatively short amount of time actually spent in ice.

3. **POLAR CODE FOR THE SEAXPLORER**

An increasing number of ship movements within the Polar regions, particularly the offshore operations in the Arctic Region, encouraged the IMO to develop and implement the Polar Code. In order to protect the environment, stringent rules have been established for ships entering the Polar Regions to prevent disasters with oil spills in this fragile area. From January 2017 the IMO Polar Code will be in force and thereafter all the ships travelling to the Polar regions will have to comply with its demands.

The Polar Code consists of three divisions: Polar Code A (defined as year round Polar operations), Polar Code B (summer operations in first year and multiyear ice) and Polar Code C (for everything less than B). Importantly, the Polar Code is a risk based regulation i.e. in order to obtain a Polar Code certificate, the operator has to make an operational and risk assessment based on a certain planned itinerary. The more ice that is likely to be encountered (the further one wants to go into the ice, or the earlier in the season one wants to sail), the higher the risk. On the other hand, the higher the ice class is, the more the risk is mitigated. The whole risk assessment process is to be found in POLARIS, the Polar Operational Limit Assessment Risk Index System.

When we take our operational profile into consideration, Polar Code B is the most suitable one for the SeaXplorer. Polar Code A is excessive for a private yacht design; it will create an “ice breaker” which is not only very expensive to build but also to operate with regard to fuel consumption. Additionally, icebreakers have poor seagoing behaviour and comfort due to their hull form. On the other hand, if a POLARIS risk assessment is to be carried out for a Polar Code C with a light or a non-ice class, the expedition outcome risks being disappointing as the vessel would not be able to traverse any areas of significant pack ice. This is the common scenario at present; expeditions have to be curtailed in order to fit within the vessel’s limited ice capabilities.

Polar Code B is the best option to choose for a globally capable expedition yacht:

- Serious ice strengthening to operate safely in the variable boundary between the open sea and the ice.
- Ice capability that will not adversely affect seagoing behaviour (as it does with Polar Code A vessels)
- Optimised performance for summer operations in first year ice; the typical operating environment of an expedition yacht
4. OPTIMIZED HULL SHAPE AND PROPULSION WITH RESPECT TO THE ICE CAPABILITY AND AHEAD SEAGOING BEHAVIOUR

4.1 Hull shape

As discussed, the SeaXplorer requires exceptional seagoing properties in order to provide a high level of comfort in inclement conditions and heavy seas, yet also needs to be capable of breaking the ice when the situation requires. In order not to diminish either of these core attributes, Damen has defined a double-acting hull with the blunt and vertical stem (now well known as ‘the Axe bow’) and an ice-breaking stern.

The Axe Bow concept has been founded by Lex Keuning at Delft University of Technology and has resulted in numerous Damen vessels designed with the patented license of the Axe Bow. They continue to show improved operational profiles, comfort and safety. Together with its lower resistance, which leads to lower fuel consumption and less emissions, the Axe Bow is an excellent choice for the operational profile of the SeaXplorer.

The ice breaking stern is equipped with podded propulsion units and is expected to operate in ice going conditions stern first, having the capability to bend and break ice as it advances through it. Successful stern-first ice-mode operation has been achieved with an appropriate deadrise angle of the aft body, which enables faster movement of the broken pieces of ice towards the sides of the hull, accompanied with the movement of the podded propulsion units. Slow oscillation of the propulsion units between 160° and 200° helps the ice sheet to break faster and enhances the icebreaking capabilities significantly. Each headbox generates an initial crack in the incoming ice sheet, with medium-sized ice pieces formed in between which are rapidly washed away from the hull by the wake of the propellers.

The double acting hull gives the SeaXplorer all the necessities for an operation in a predetermined route which is supported by icebreakers but doesn’t require their assistance, ensuring the complete autonomy of the vessel on her expedition.

4.2 Propulsion

The vessel is equipped with a diesel electric propulsion system consisting of diesel powered generator sets, electric frequency converters, electric motors, azimuthing thrusters and bow thrusters. The two azimuthing thrusters have a controllable pitch, pulling propellers with a diameter of 3 m and a speed of 200 rpm. Each azimuth thruster has a 3000 kW electric power input and a steering motor enabling the 360° steering capability. This enhances not only the ice maneuverability, but also the dynamic positioning together with the bow thrusters, both of which are important for the vessel’s operational profile. In addition, the propeller fin has to be strong enough to withstand the interaction with the ice debris which can still induce damage even though they will be partially milled by the propeller.
4.3 Model tests - HSVA

In order to get a better insight into hull and propulsion operations in ice, model tests have taken place in HSVA facilities in Hamburg, Germany. Given their expertise in dealing with the ice-breaking hulls, valuable suggestions have been obtained on how to enhance the lines plan. Keeping the width of the stern the same as the beam of the vessel improves the ice-breaking capability due to the fact there is no ice-crushing on the vertical side plating (which can generate significant added resistance). It was also necessary to give attention to modifications near the headbox of the azimuthing pulling propulsors (see Figure 3). By adding a wedge-shaped structure, earlier ice fractures will be obtained while going astern, allowing the ice to break and separate before reaching the headboxes of the azimuthing propulsors. This prevents impacts with larger ice pieces and helps avoid and minimize any possible damage to the pods.

Tests were carried out in the HSVA’s large basin consisting of seven test runs astern in 70 cm ice and five test runs ahead in 50 cm ice. A representative example of one test run is given below, illustrating the obtained results for all the test runs.
4.3 (a) *Initial turning astern in level ice, PD = ca.100%*

The vessel managed to initiate the turning circle successfully, accelerating a few meters in straight astern motion before rotating the thrusters about 45°, resulting in a turning rate of 5.14°/min with a corresponding turning radius of 417 m.

Figure 4 [HSVA model test – *Initial turning astern*]
The results of the test run consisting of its speed, total thrust, torque, rpm and angle of the pod is given in the graph below.

Figure 5 [HSVA model test – graphical results]
The test runs have taken place in varying ice-coverage scenarios including: 100% ice-coverage, 95% compacted rubble and a range from 85% - 65% managed ice coverage.

![Figure 6](image1.png)

Figure 6 [HSVA model test - different ice-coverage]

Propeller ‘ice milling’ only occurred when sailing astern in ice flows and rubble field where features thicker than the original ice sheet; a result of debris accumulating into multiple layers of ice. When sailing astern towards a compact ice sheet (ie. solid pack-ice), the tip of the blades were below the ice sheet and therefore ice milling was avoided. The vessel showed a very good performance in both ahead and astern motions, in both solid pack ice and in less concentrated floes. A velocity of 5 kts was easily reached and maintained in 80% ice concentration. Any potential difficulty in maintaining forward headway during fast course changes (where the vertical bow impacts the ice) did not occur at higher velocities as the bow simply cleaved through the ice. Together with a very good turning capability and the excellent ice breakout while going astern, the model tests have demonstrated the achievement of the desired performance and safety levels of the SeaXplorer double acting hull. This is the world's 1st private yacht with a double acting hull.

5. ICE STRENGTHENING

In order to break ice, the SeaXplorer has to be designed to withstand additional global and local structural loads. A polar class notation ‘PC6’ or ‘PC7’ (from the Polar Code ‘Category B’ definition) is required by vessels contemplating navigation and operations in thin/medium first year ice. The first step is the division of the hull into four different areas depending on the magnitude of the load: bow (highest strength), bow-intermediate, mid-body and stern. The latter three are further divided vertically into the bottom, lower and ice-belt regions (see Figure 7).

![Figure 7](image2.png)

Figure 7 [Ice strengthen hull regions]
These divisions have been the subject of many discussions with class, due to the hull characteristics specific to a yacht. These rules are originally made for cargo vessels, where a flat of side is extending for almost 70% of the ship length (a feature which is absent in the SeaXplorer hull lines), so definition of the bow shoulder area for the application of the ice class rules was difficult. Furthermore, an issue is the extent of the non ice-strengthened area of the midship body, which is defined where the frame forms an angle of 7 degrees. Compared to the common flat bottom of a cargo vessel, the SeaXplorer has a larger deadrise angle, which makes the bilge boundary unclear. With the help of the model tests carried out in the HSVA model basin, it has been possible to check the effective ice pressure together with the flow along the ship and therefore determine the most reasonable choice for the area extents. (see figure)

![Figure 8](image)

Figure 8 [Ice strengthen hull regions of the SeaXplorer 90m]

As shown in Figure 8, the bow and bow-intermediate regions are shifted to the stern and vice versa. This is due to option of operating the vessel astern in heavy ice. The ice strengthening will be thus mainly be gathered in the aft area, rather than in the so-called ice belt.

![Figure 9](image)

Figure 9 [Ice frame of the SeaXplorer 90m]

This reinforced region runs almost along all the ship length and extends about 1m above and below the waterline. Figure 9 illustrates the detail of the ice frame; the ice belt is made up by three girders, namely the upper ice, lower ice and intercostal stringers. The positions of these girders are related to the position of the upper ice waterline and the lower ice waterline, determined by the maximum and minimum draught respectively. In terms of additional weight there is an additonal increment of about 10% to the total lightship weight.
6. STABILITY WITH ICE ACCRETION AND EXTENDED ICE DAMAGE

In addition to the normal stability requirements of SOLAS, the Polar Code demands further calculations in order to ensure sufficient safety while sailing in ice regions in both intact and damaged conditions.

With respect to the intact stability, the loading conditions that have to fulfill the IS Code, are affected by an increase of weight resulting from ice accretion. Added topside weight can make the ship vulnerable, causing a rise of the vertical center of gravity and increasing the rolling moment. Accordingly to the Code, 30 kg per square meter is taken into account on exposed weather decks and gangways, 7.5 kg on the projected lateral area of each side of the ship above the water plane, which together result in 70 tonnes more on 13 m high on top of the standard loading conditions of the SeaXplorer.

Moreover, the vessel has to be able to withstand flooding resulting from hull penetration due to ice damage, additionally to the passenger ships criteria of the IMO (i.e one compartment damage and probabilistic damage criteria). The ice damage extent prescribed in the code is longer if centered forward of the maximum breadth of the ship, while the transverse penetration shall be always 760mm normal to the shell. This criterion can be more onerous than the other IMO damage criteria since the damage is applied at any position along the shell, and not anymore between two watertight bulkheads as prescribed by the deterministic damage stability of SOLAS. This will lead to a two-compartment damage scenario. For typical icebreakers and cargo ships, the double hull arrangement should not require any subdivision design changes. However, for a yacht like the SeaXplorer, the double shell is not an option when the main design target is the meticulous optimization of the available space. The outcome of the calculation can show serious issues if either the big compartments at midship are simultaneously flooded, or when the buoyancy of the aft ship compartments is lost leading to significant trim angles. To avoid these situations, a solution which would not seriously compromise the general arrangement was required. As a result, few watertight voids, at least long as the damage extension in that location, are placed across the watertight bulkheads. Figure 10 illustrates this configuration. The idea is to flood at most a big watertight compartment together with one of the void, but never two big watertight compartments at the same time.

![Figure 10](Tank plan of the SeaXplorer 90m)
7. EXPEDITION LOGISTICS

Expedition logistics are often overlooked in vessel design and typically only become apparent during the operational phase. By joining forces with an experienced expedition operator, Damen has been able to bring logistical considerations into the very core of the design. Three major areas of logistical design where considered:

Firstly, the designers considered the need to get all guests from the interior out through a transitional area and on to a zodiac, tender or helicopter. The transitional area, often referred to as a ‘mud room’ is a dedicated space where guests can suit up for the region/activity; in a polar region this is boots, outerwear and lifejacket. On return to the vessel, guests again pass through this area and are ‘decontaminated’ before passing through into the interior spaces; wet outerwear is removed for drying, boots are removed for cleaning and guests are welcomed back with a towel and a beverage.

Secondly, the designers considered the need for rapid transitions from key interior spaces out to activity craft (zodiacs, tenders, helicopters etc.). It is common on expedition voyages for opportunistic activities to present themselves with little warning e.g.: sighting of key wildlife species such as whales and polar bear. Good conduits from the interior spaces to the mudroom and beyond is important, as is access to the bridge, observation lounge and outdoor decks.

Thirdly, expedition vessels are the platforms from which expedition activities are launched. The ability to operate multiple activities simultaneously relies on well-maintained expedition equipment being available for launch and activation with minimal interference to other activities. Wherever possible redundancy is incorporated into the critical systems e.g. submersible launch and recovery.

7.1 Special expedition features

The design of an expedition yacht has to go far beyond the features of a conventional luxury-purpose vessel. In order to make the SeaXplorer suitable to reach the wildest places on the planet and capable for true luxury expeditions, a wide set of features have been implemented during the design process of the boat. First, it can perform at full operational service for over 40 days of autonomy (operations without a port call) thanks to large fuel tanks capacity up to 600m³ of total volume. At the same time the lower decks are arranged with massive stores for provisions, spare parts and equipment, a workshop and a zero discharge waste management system. Looking at the aft part of the ship (see figure 11), a large hangar can accommodate a helicopter (14 meters), two large tenders (12 meters), two medium tenders/zodiacs, two deep diving (1000m) submersibles and various other tenders and ‘toys’.. A fast launching system is provided for the expedition tenders, on which the guest can step in through a boarding gate just above the waterline. Diving experiences are possible thanks to the private submersibles together with a fully equipped dive center including a decompression chamber, a dive-technician workshop and a wetsuit drying room. The two lifeboats can double as ‘limo-tenders’ for close range operations when at anchor off ports of call.
Without having to leave the yacht, the passengers can enjoy the scenery of the polar regions from the comfort of being inside. There are two main lounges on the guest decks: the Sky Lounge, and especially the Observation Lounge (figure 12) which mainly represents the blend between the expedition behavior of this yacht and the comfort guaranteed by a luxury vessel.

Finally, on the bridge deck, 360 degrees of visibility is ensured by the wheelhouse with its enclosed bridge wings. With this configuration, the crew can safely maneuver the SeaXplorer through the ice in below zero conditions.

**STYLING**

Damen included Azure Yacht Design and Naval Architects for the esthetical design of the SeaXplorer. The greatest challenge was to reach the exact right balance between the two contrasts this ship represents: the traditional superyacht or classic ‘white boat’ and a rugged commercial or military offshore vessel. The main design brief idea was to accomplish strong and recognizable looks as well as blending in the Damen heritage. The layout of the SeaXplorer with a large helicopter hangar on the aft makes it even more difficult to achieve a balanced design. After careful consideration, Azure’s final shape of the lines resulted with a profile shown in Figure 13.
Their excellent design was recognized by many potential customers, yacht specialists and press after the SeaXplorer’s successful launch at the 2015 Monaco Yacht Show introduction.

9. CONCLUSION

An increasing demand for remote coast expeditions, and particularly the Polar Regions, signaled that a large number of existing yachts intended for that purpose are not going to be able to comply with the Polar Code. In addition, few vessels engaged in expedition activities were ever designed with expedition in mind; most are either refits/conversions or traditional ‘white boats’ that have been pushed to the limits of their design envelopes by their increasingly adventurous owners. The SeaXplorer is a pioneer design of a true expedition yacht that has been purpose built to fill this growing niche and its design team had to overcome numerous challenges in order to develop their innovative ideas. Damen, in collaboration with its partners, managed to find excellent solutions to enable the design of an expedition yacht, the first private yacht to comply with the Polar Code and a remarkable vessel that will ensure the safe and comfortable travel anywhere around the globe. SeaXplorer will be able to explore more of the planet than any other vessel design, and with minimal effect on any of the pristine environments her ambitious owners seek to visit.

REFERENCES
