Polar expedition ships:

Ultimate passenger safety and comfort with Azipod® propulsion

Whitepaper by
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Abstract

The growing popularity of the Arctic and Antarctic as destinations for tourists has brought a spike in orders for passenger ships capable of operating in icy waters. Ensuring the safety of passengers and crew in such inhospitable regions is no mean feat. Additional risks must be considered right from the start, when the vessel and its propulsion system are at the design stage.

ABB's Azipod propulsion offers major safety benefits for ice-going vessels and has built a strong track-record across the sector, as demonstrated by the fact that it already satisfies IMO's Polar Code requirements and is available with Polar Class notations suitable for a range of ice conditions. This level of confidence stems from past performance, with more than 60 vessels now in operation or ordered working in icy waters, including Arctic areas such as Pechora Sea, Kara Sea, Ob Bay, and Yenisei River.

In addition to ice-going ships, today around 60 cruise ships are fitted with Azipod propulsion, including the world's largest such vessels – Royal Caribbean's Oasis class. In fact, due to better vessel maneuverability, improved passenger and crew safety, greater fuel efficiency and lower total cost of ownership, Azipod units have largely superseded conventional shaftline propulsion in combination with rudder steering across the cruise market.

Given the strength demonstrated by Azipod propulsion in these distinct markets, it came as little surprise that PC6 classed Azipod propulsion was selected for polar discovery yacht Scenic Eclipse – the world's first passenger vessel to be constructed explicitly to Polar Code standards – and for three Endeavor class ships which will be the world's largest expedition yachts with ice class.

Taking all this into account, it is fair to consider the Azipod technology as the natural starting point for new generation cruise ships crossing polar and sub polar waters.

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Kimmo is a product manager of compact-sized Azipod propulsors at ABB's Marine & Ports business. He has worked with Azipod propulsion over 10 years together with wide range of customers from variety of vessel segments. Combining his broad expertise including ice classes, hydrodynamics and electrical propulsion and his experience in front-end propulsion sales, his role in defining the product requirements have been an integral part for the strong success of the new Azipod D series launched in 2015.

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Fig 1. Gearless Azipod propulsion is available for all polar ships from lighter expedition vessels to heavy icebreakers.

Increasing cruise traffic and regulation for polar waters

Forecasts and recent newbuilding contracts indicate an upward trend in cruise traffic in polar waters. Navigating in such areas must be considered from the start in terms of ship design and the propulsion system selection, as it presents additional risks compared to normal open water shipping. The risks are recognized and have been well understood at the IMO, which has adopted a set of regulations, known as the Polar Code, "to increase the safety of ships' operation and mitigate the impact on the people and environment in the remote, vulnerable and potentially harsh polar waters"[1].

These regulations entered into force on 1 Jan 2017. The Polar Code makes direct reference to IACS Polar Class (PC) requirements, which set out in detail structural and machinery requirements for ships "intended for independent navigation in ice-infested polar waters"[2]. The required Polar Class notation is defined by the ice conditions and the season in which a ship will operate (see Table 1).

No. 1 propulsion in ice-going vessels

In terms of propulsion systems, ABB's Azipod propulsion is the current global market leader both in independently navigating ice-going vessels and in cruise ships. This makes Azipod propulsion a natural starting point in the design of any cruise vessel intended for independent operation in ice-infested polar waters or nearby sea areas. Azipod units fulfil all applicable Polar Code requirements and are available with Polar Class notation suitable for the intended operation area, season and ice conditions.

The highest Polar Class vessel built so far is the Azipod-equipped Finnish icebreaker Polaris, accorded PC4 Icebreaker(+) notation by Lloyd's Register (see Fig 2). Polaris can break level ice 1.8m thick at 4kts and is also the world's first LNG fueled icebreaker.[3]

The next Polar Class icebreaker newbuilding worthy of note will be for the Polar Research Institute of China. With an even higher Polar Class notation, PC3 Icebreaker, she too will also be equipped with Azipod propulsion.

Also the world's first vessel confirmed to comply with new Polar Code requirements is equipped with Azipod propulsion. Shuttle tanker Shturman Albanov, owned by Sovcomflot Group, received her Polar Ship Certificate issued by Russian Maritime Register of Shipping (RMRS) on Dec 2016 and is capable of operating in the Arctic all year-round at temperatures down to –45°[4] (See Fig 3).

In fact, Azipod propulsion is the system most commonly selected for independently operating ice-going ships. The reasons are clear: the dimensioning principles developed for Azipod units, which consider ice interaction loads, have proved to be very robust: since the first delivery in 1990, Azipod units have operated in ice without a single instance of structural damage due to ice loads. This includes operation in ice covered Baltic Sea, Caspian Sea, Great Lakes, Okhotsk Sea and Arctic Sea. Currently there are more than 60 very high-ice class Azipod vessels in operation or ordered. Most of these vessels operate in Arctic waters including Pechora Sea, Kara Sea, Ob Bay and Yenisei River. Several Azipod-equipped cargo vessels have sailed the Northern Sea Route (North East Passage) – a handful completed their voyage without icebreaker assistance.

Polar Class	Ice descriptions (based on WMO Sea Ice Nomenclature)
PC 1	Year-round operation in all polar waters
PC 2	Year-round operation in moderate multi-year ice conditions
PC 3	Year-round operation in second-year ice which may include multi-year ice inclusions.
PC 4	Year-round operation in thick first-year ice which may include old ice inclusions
PC 5	Year-round operation in medium first-year ice which may include old ice inclusions
PC 6	Summer/autumn operation in medium first-year ice which may include old ice inclusions
PC 7	Summer/autumn operation in thin first-year ice which may include old ice inclusions

Table 1. Definition of IACS Polar Class operation area and season.[2]

Among the latest high-ice class Azipod vessels are a series of LNG carriers (LNGC) being built for the Yamal LNG project in the Russian Arctic. The first of the series, Christophe de Margerie, launched in January 2016, is both the world's most powerful LNGC and the world's first LNGC that can navigate thru ice. She has ice class Arc7 by RMRS, comparable to Polar Class 3.

In addition to establishing a solid record of accomplishment and an extensive reference list, ABB Marine's Azipod dimensioning principles have been systematically verified by three full-scale Azipod load measurement projects. The Azipod units in question were equipped with numerous load sensors to gain uniquely detailed data on ice loading in different ice conditions, including harsh Arctic winter operation (See Fig 4).

Fig 2. The Finnish icebreaker Polaris accorded PC4 Icebreaker(+) notation by Lloyd's Register and equipped with Azipod main propulsion is currently the highest Polar Class ship. Credit: Arctech Helsinki Shipyard.

Fig 3. Arctic shuttle tanker Shturman Albanov equipped with Azipod main propulsion is the first vessel certified to comply with Polar Code requirements.

Fig 4. Ice load measurement campaign onboard Norilskiy Nickel included Azipod strain gauges calibration at Helsinki Shipyard and subsequent astern operation through harsh ice ridges in the Kara Sea in the Arctic Ocean.

The cruise connection

Fig 5. The world's largest cruise ship is currently Harmony of the Seas launched in 2016 and equipped with Azipod main propulsion – just like several previous cruise ships holding "the world's largest" title before her.

The first cruise ship to be equipped with an Azipod was launched in 1998. Today Azipod units are the most common form of propulsion found on cruise ships, in use on 60 such vessels, including the Oasis class ship series owned by Royal Caribbean International and currently the world's largest passenger ships (See Fig 5).

1st in Polar Class passenger ships

The world's first Polar Class passenger vessel will be the Azipod-equipped Scenic Eclipse with PC6 ice class notation granted by Bureau Veritas (See Fig 6). Scheduled to launch in August 2018, Scenic Eclipse is a discovery yacht able to navigate in both Arctic and Antarctic waters.[5]

Another Azipod-equipped Polar Class passenger ship series will be three Endeavor class mega-yachts for Crystal Cruises with PC6 notation. They are designed for operation in the Arctic, Antarctic and also in the Tropics. These 20,000 GT newbuildings will be the world's largest expedition yachts with ice class and the first passenger ships to be classified according to the new DNV GL rules.[6,7]

Why are Azipod units safer than shaftline-rudder propulsion?

There are certain fundamental benefits in Azipod propulsion that explains why it has almost completely superseded conventional shaftline-rudder propulsion in both cruise and independently ice-going vessels over the last decade. These benefits mainly relate to crew and passenger safety, but also have a bearing on environmental protection, performance in both ice and open water operation and total-cost of ownership.

Precise maneuvering with 150% more side thrust

With Azipod propulsion the full propeller thrust can be directed freely in any direction, whereas in fixed shaftline-rudder arrangements thrust decreases rapidly as helm angle increases. Generally, a conventional rudder can produce only about 40% side thrust compared to maximum ahead bollard pull thrust. The figure for flap rudders is up to 60%.[8] With a 360-degree freely turning Azipod, however, full thrust can be precisely applied in any direction, giving 150% more side thrust than a conventional rudder. Furthermore, Azipod propulsion makes it possible to navigate astern and sideways simultaneously, which is difficult to achieve with a rudder since negative propeller speeds reduce the effectiveness of a rudder considerably. Full thrust in any direction is a great benefit when maneuvering ships amid icebergs and in ice fields, as well as when approaching either ice-covered or open water ports.

Superior safety with 38% smaller turning circle

In the case of collision avoidance maneuvers, whether the risk is another vessel in the Bahamas or a floating iceberg in North Atlantic, an Azipod-equipped vessel is more likely to avoid collision than a vessel with conventional shaftline-rudder arrangement. This is because conventional rudders typically require tunnel thrusters at stern to assist weak maneuvering. However, tunnel thrusters do not work effectively at higher ship speeds, whereas the superior steering capability of Azipod units is effective throughout the ship's speed range. Furthermore, Azipod units eliminate the need for stern tunnel thrusters, thus providing greater flexibility and simplicity in ship design and general arrangement. More effective and safer turning capability of Azipod propulsion have been verified, for example, by full-scale and full-speed turning circle tests between sister-ships MS Fantasy with conventional propulsion and MS Elation with Azipod propulsion which recorded 38 % reduction in tactical diameter[10], see Fig 7. Similar results have been obtained also from model experiments with wider set of ships, see Fig 8.

Captain William Wright, Master of Oasis of the Seas: "The Azipod units allow me to direct the power exactly where I want it, giving me the confidence to maneuver within a decimeter of where I want"[9]

Fig 6. The Scenic Eclipse discovery yacht has PC6 ice class and Azipod main propulsion. The vessel is set to launch in 2018.

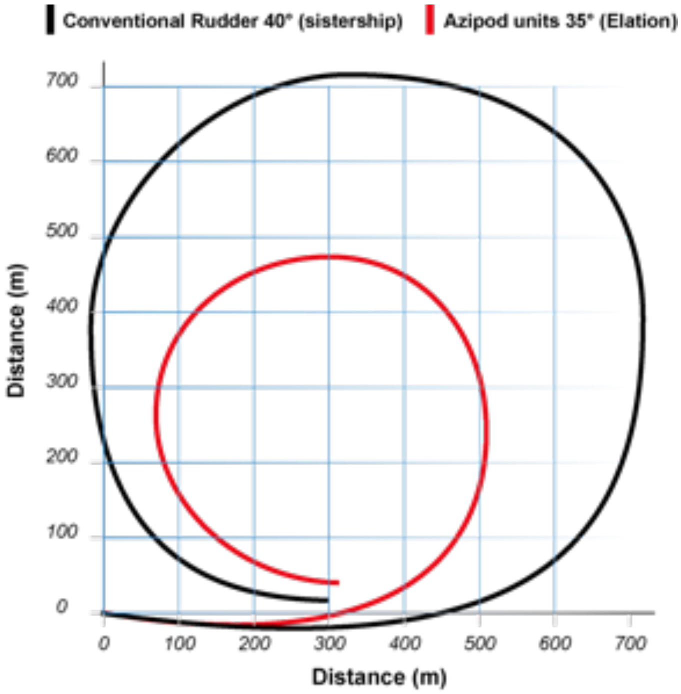


Fig 7. Full-speed steering tests from MS Elation show the superiority of Azipod steering compared to her Fantasy class rudder equipped sister vessel.

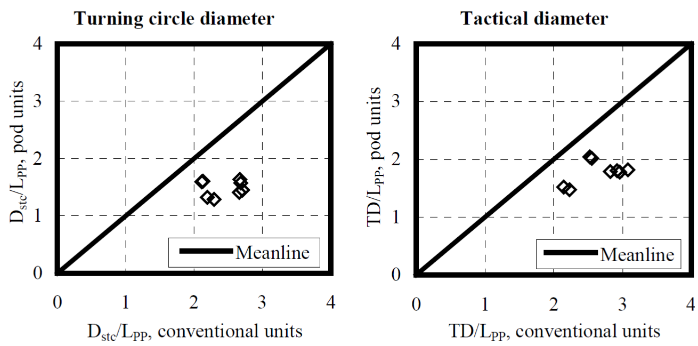


Fig 8. Turning circle data of ship models equipped with podded or conventional propulsion units.[11]

50% shorter crash-stop distance with full heading control

With traditional rudder steering, an emergency crash-stop is accomplished by reversing the propeller rpm from positive to negative. This is time-consuming as the ship power generating machinery must go from full power to zero power and then ramp up again to full power in the opposite direction. In practice the vessel operating with a rudder will also lose her heading control during the crash-stop as the rudder will not work efficiently unless the propeller is producing thrust for it – and at negative propeller rpm there is a little thrust available for the rudder at all. This means that ship heading and direction during the crash-stop are effectively at the mercy of the elements – determined by prevailing environmental conditions, i.e. current, wind and waves, which especially becomes a factor in heavy seas.

In Azipod vessels the crash-stop can be accomplished in the "pod-way" by steering the Azipod units outwards 180 degrees and keeping positive propeller rpm during the whole crash-stop. This shortens the crash-stop distance considerably – typically by at least 50% (see Fig 9). Moreover, during the crash-stop, Azipod units can generate enormous side force to any desired direction irrespective of ship speed. This gives the captain full control to decide the heading and direction of the vessel during the whole crash-stop even in heavy weather conditions. The combination of 50% shorter crash-stop distance and full heading control is a huge advantage in onboard safety when considering worst-case scenarios – especially in ice infested waters.

Captain Grant Thompson: "On sea trials [Azipod-equipped] MY Kogo went from full ahead to a crash stop in 2½ times her length. Not only is this a remarkable feat but it was totally controllable and resulted in us changing the way we performed man overboard drills, as we could literally just stop and back up to the victim whilst the rescue boat was being launched."

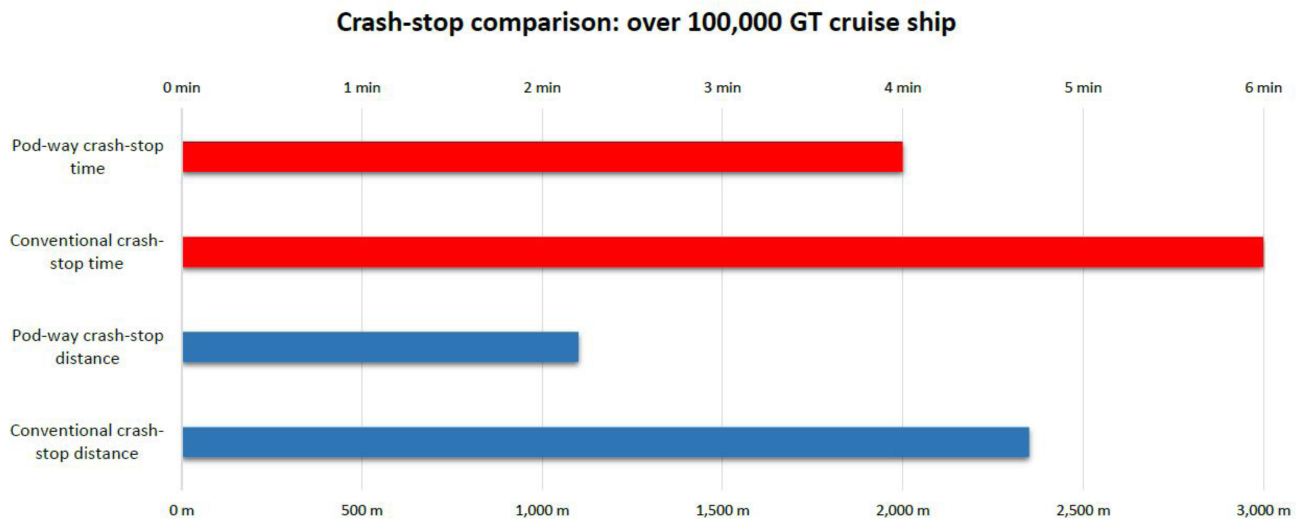


Fig 9. Full-scale comparison between "pod-way" and conventional crash-stops from full speed.

Stuck in ice?

One danger of operating in polar waters is the risk of getting stuck, for example, in compressed ice fields. Among other benefits, Azipod propulsion makes possible double acting ship (DAS) designs, as pioneered by Aker Arctic Inc., which greatly improves a vessel's maneuvering capability in ice fields. A DAS design ship can navigate stern first in ice conditions which offers several benefits, including:

- Propulsor thrust lubricates the sides of the ship hull, reducing ice friction caused by compressed ice fields
- Azipod unit(s) can be rotated 360 degrees to flush and break ice ridge if impeding vessel progress
- Safer and more efficient maneuvering in ice fields thanks to the ability to produce full thrust from Azipod units in any direction
- Considerably less installed power (for example 40% reduction) required to achieve ice-going capability compared to a non-DAS ship- History of performance, condition, and intervention performed on the systems

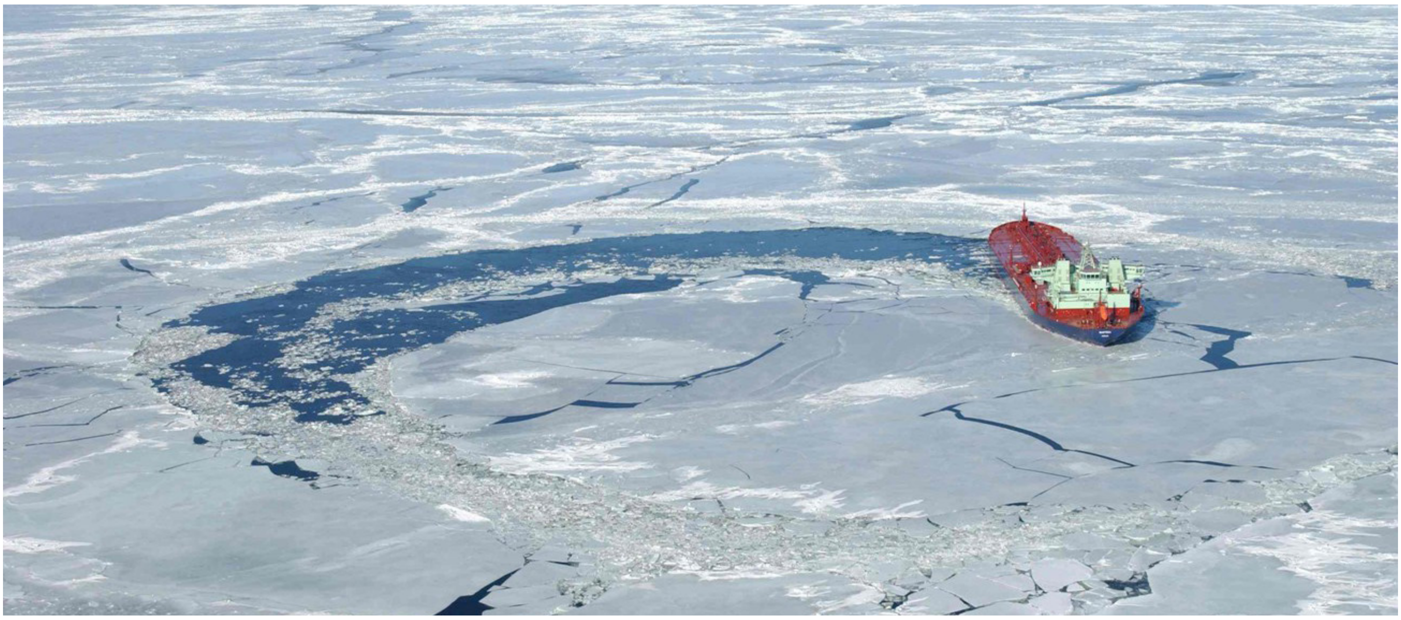


Fig 10. Even large tankers can be handled efficiently in ice with DAS design as demonstrated by Azipod equipped MT Mastera. Credit: Neste

Ultimate strength and robustness against ice loads

Within the Azipod, the electric motor is installed directly on the propeller shaft making the drivetrain extremely simple and robust against any ice loads hitting the propeller. In contrast to mechanical Z- or L-drive azimuthing thrusters, there are no mechanical gears so the Azipod shaftline can withstand both bending and high torque peaks under heavy ice loading.

For extreme ice classes, the Azipod electric motor and ship power plant can be configured to provide an over-torque capability that ensures the propeller rotates even in heavy ice interactions. This prevents ice blocks hitting static propeller blades from an unfavorable direction while a vessel is proceeding under her own inertia. Over-torque ensures that rotation of the propeller is constant and thus the angle of attack is favorable from the perspective of blade strength.

In comparison to shaftline propulsion, a further Azipod safety feature derives from its steering system, which is set to yield and absorb extreme impact loads on propeller side blades. This sort of extra protection cannot be achieved with the blades of the conventional fixed shaftline propeller. This phenomenon has been verified by full-scale measurements in extreme Arctic ice conditions.

Fig 11. Azipod propulsion motor is integrated onto propeller shaft making the drive train gearless and robust.

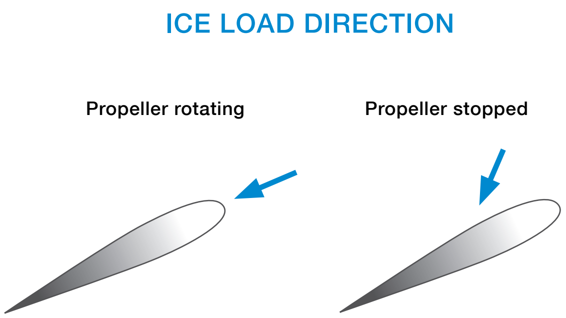


Fig 12. Azipod over-torque capacity ensure rotating propeller and ice loads coming to propeller blades from favorable direction in extreme load cases.

The world's best passenger comfort

Most modern Azipod-equipped cruise ships are classified according to strict Comfort Class 1 requirements regarding onboard noise and vibrations levels. This is one reason Azipod propulsion features so commonly as a solution on large cruise ships as Comfort Class requirements are easier to fulfill than would be the case with conventional shaftline-rudder propulsion arrangements. There are no noise-generating gears and the pod motor and its shaft are located completely outside the ship hull. More importantly, the Azipod unit's pulling propeller receives a steady undisturbed wake field, which gives propeller designers greater scope to optimize propellers for silent operation compared to a conventional pushing propeller with rudder (see Fig 13).

In addition, disturbing vibration caused by maneuvering in ports with high rudder angles are avoided as the Azipod propeller and its housing rotate as a single unit, meaning there is never a high angle of attack between them. Noise and vibration caused by stern tunnel thrusters are avoided as these are no longer necessary when adopting Azipod propulsion.

Captain Eddie Cooney: "Recent sea trials have confirmed that the use of electric Azipod units for the propulsion of Grace E has made for exceptional quietness and comfort while navigating. There is little evidence that the boat is underway unless you are looking out the windows and actually witnessing the changing landscape. We expect that this will be a very much appreciated asset to guests cruising aboard."

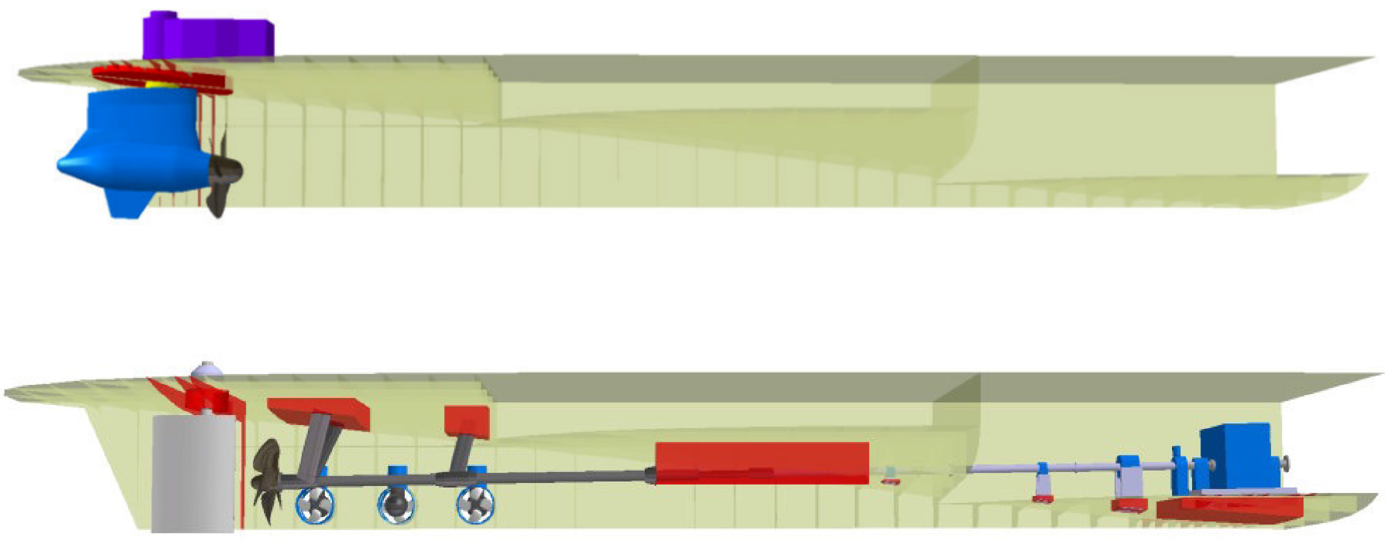
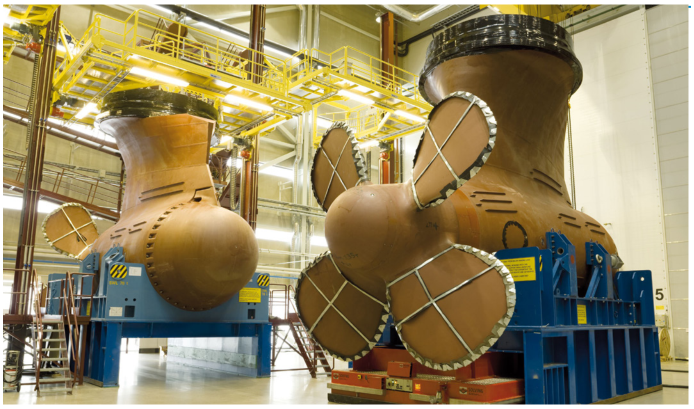


Fig 13. Thanks to lack shaftline, supporting brackets and tunnel thrusters, the pulling Azipod propeller receives extremely steady incoming water flow to propeller resulting less noise and vibrations and better efficiency.

Environmental protection

Azipods fulfil Polar Code[1] requirements for environmental protection and are the best-in-class propulsion system in terms both of risk of oil leakages and overall propulsion energy consumption. The main feature is the U.S. Vessel General Permit (VGP)[12] approved shaft seal design which doesn't have any oil-water interface. The amount of oil used in a gearless Azipod unit is only a fraction of that found in geared mechanical azimuthing thruster or traditional shaftline propulsion. Furthermore, the fully electric Azipod propulsion with its small footprint for vessel general arrangement makes it easier for ship designer to utilize alternative power sources, such as LNG, batteries or fuel cells – or leave space aside for these for conversion at a later date.



Pete Towning, Build Chief Engineer: "Marine national parks often impose understandable speed and anchoring restrictions to protect their marine ecology; [Azipod-equipped] MY Grace E, with her DP capability and speed control, is fully prepared to slowly navigate or hold a fixed position indefinitely if required, and provide the owner with the best possible vantage point to appreciate the surroundings. The captain will also be thankful for the infinite maneuverability available to him when operating the vessel in busy marinas and navigationally restrictive areas, with the increased safety of being able to stop quickly in an emergency and efficiently compensate for tidal currents and wind effects."

Get the job done

- Azipod units are the most common propulsion system for polar ice-going ships and for large cruise ships. Both the world's first Polar Class icebreaker and passenger ship are equipped with Azipod propulsion.
- Azipod propulsion enables more efficient ship designs which can navigate independently and safely thru polar waters and are less prone to getting stuck and being delayed due to ice. Similarly, in open water, even the world's largest cruise ships can navigate independently in rough seas to distant harbors thanks to the high maneuverability and efficiency offered by Azipod propulsion.
- The gearless drivetrains used in Azipod units are extremely robust against ice loads, providing ship owners reliability they can count on even in demanding ice conditions. At the same time, Azipod propulsion delivers the best onboard comfort with lower vibration and noise compared to other propulsion systems for Polar Class passenger ships.
- When operational safety, robustness and passenger comfort are topped with the fact that Azipod propulsion offers lower energy consumption in both open and ice-covered waters, it is the natural choice for any expedition vessel intended for polar waters – from luxury yachts touching Antarctica to heavier ships intended for a full North Pole expedition. (See Table 2 for the availability of Polar Class Azipod products.)

Recommended propulsion for polar expedition ships

ABB's recommended starting point for Polar Class expedition ship propulsions is the gearless Azipod DO series covering power range from 1.5 MW to 7.5 MW per unit. Azipod DO propulsors are best-in-class in both hydrodynamic and overall efficiency. Available in several frame sizes, the Azipod D product platform can be tailored to reach the best possible match for each vessel hull and ice class.

In the case of an expedition cruise ship with Polar and Comfort Class notations, expected installed propulsion power saving with twin Azipod DO installation is about 10% compared to twin shaftline installation with electric propulsion. Azipod DO products are available up to PC 5 ice class (see Table 2).




	Azipod DO	Azipod XO	Azipod ICE	Azipod VI
Power (MW)	1.5 – 7.5	8 – 22	2 – 5	6 – 17
Max Polar Class	PC 5	PC 5	PC 2	PC 1

Table 2. Available Azipod series with Polar Class and their respective power range. Azipod DO series is recommended starting point for polar expedition ships.

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[8] Mehldau, J., Station Keeping with High Performance Rudders, presentation at Dynamic Positioning Conference 9-10 Oct 2012, slide 5, http://dynamic-positioning.com/proceedings/dp2012/design_control_mehldau_pp.pdf, visited 15 Nov 2016

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