Faster, safer, cleaner
Azipod® propulsion for ferries

The latest addition to the Azipod® propulsor family, the mid-range Azipod® series, can help shipowners reduce emissions, lower the total cost of ownership and provide improved operational safety and flexibility.

The new Azipod® mid-range podded propulsorh-hzv, 'M' series, covers three frame sizes in the power range from 7.6 MW to 14.5 MW per propeller, and is based on the straightforward, robust and easy to maintain design principles that have seen Azipod® propulsion selected across 25 vessel types over close to three decades.

A ferry or a RoPax design with the inclusion of the new Azipod® mid-range series offers several ad-vantages compared to conventional shaft-line-rudder propulsion:

- Faster port approaches and departures
- Improved on-time performance of sailings
- Better resilience to weather
- More payload and more room for alternative energy sources
- Competitive vessel newbuilding price
- Improved passenger comfort
- Improved operational safety

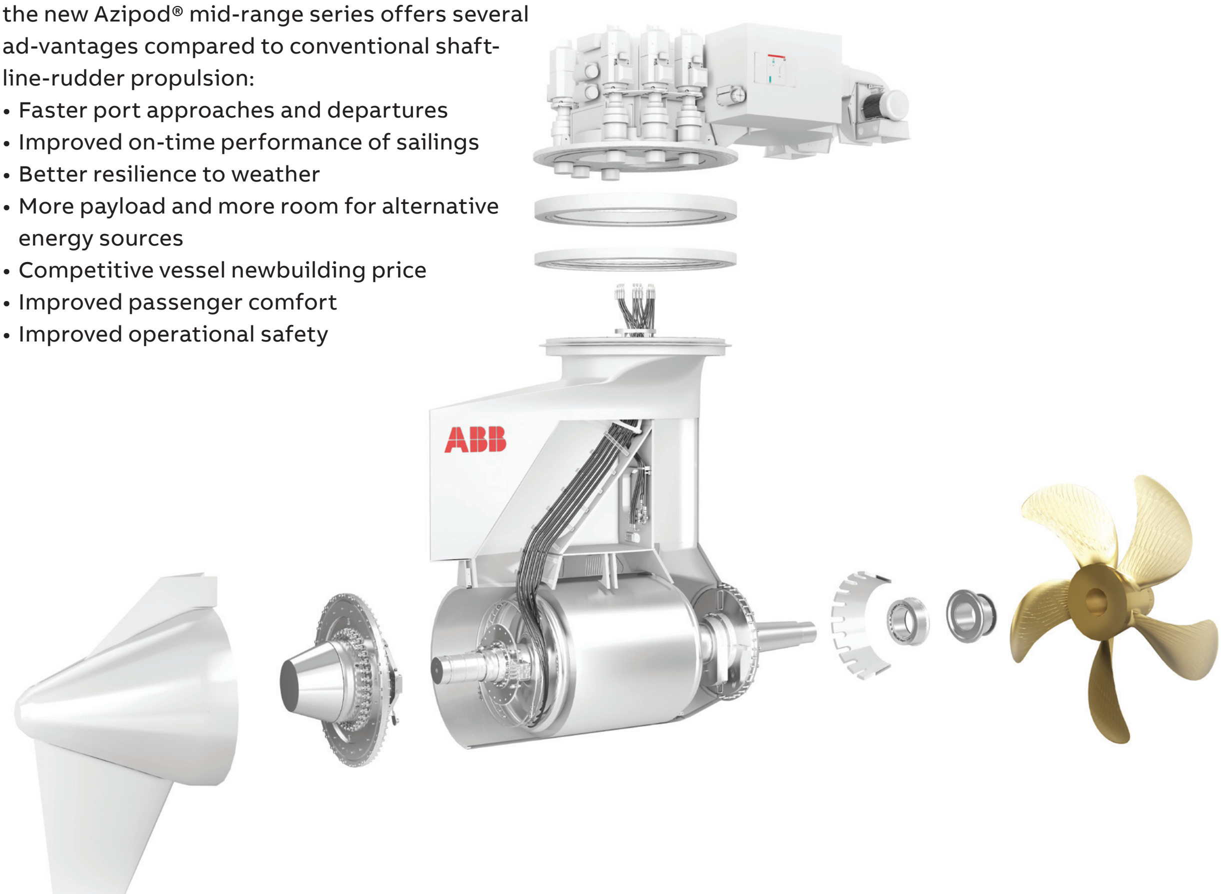

Figure 1: Azipod® propulsor

Faster port approaches and departures

Ships equipped with Azipod® propulsion have superior manoeuvrability with the 360° steerable main propellers. Turning of the ship, crabbing, steering while decelerating and stopping are more effective, accurate and faster compared to conventional shaftline-rudder propulsion. Figure 2 shows an example from a simulator run, where turning in a dock with a 200-meter RoPax was six minutes faster with Azipod® propulsion.

For newbuilding projects, port and vessel specific time savings in manoeuvring can be estimated in ABB’s deck simulator facility in Helsinki, Finland. Customer representatives can make runs in a variety of different ports and see the differences between Azipod® and shaftline vessels for themselves.

Resilience to weather

Harsh weather conditions can pose challenges during docking or approaches in tight channels. The ability to use full thrust from the main propellers in any direction improves control of the ship in extreme wind conditions, as well as the crabbing capability of the vessel.

Better resilience to weather improves on-time performance and allows the schedule buffer to be reduced. Time saved can be further used to decrease the maximum ship speed in transit or to increase number of sailings per day. Decreasing maximum ship speed reduces fuel costs (OPEX) and enables a lower installed power requirement and cost for newbuilds (CAPEX).

Precise manoeuvring with 150 percent more side thrust

Generally, a conventional rudder can produce only about 40 percent side thrust compared to maximum ahead bollard pull thrust. The figure for flap rudders is up to 60 percent[1]. The 360-degree rotating Azipod® delivers 150 percent more side thrust than a conventional rudder. Full thrust in any direction is a significant benefit when maneuvering ships in tight and busy channels.

57 percent better crabbing capability

Marine consultancy Deltamarin Ltd. has performed a detailed case study of a mid-range Azipod®-equipped RoPax vessel compared to a vessel with a conventional shaftline-rudder design, including crabbing performance. The propulsion and vessel details of the comparison are given in Table 1. According to the study, Azipod® propulsion improves the crabbing capability of a 225 m long RoPax by as much as 57 percent, as shown in Table 2. Tailwind conditions are especially challenging for conventional shaftline propulsion, whereas Azipod® propulsion excel in tail winds.[2]

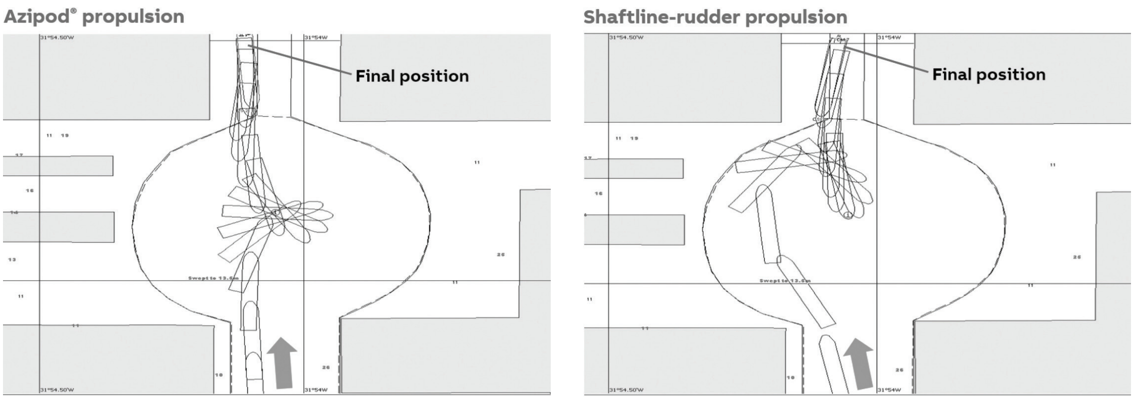

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Figure 2: Example berthing tracks of RoPax dockings by professional captains in a bridge simulator. On average, the left maneuvre with Azipod® propulsion was 6 min faster compared to right one with conventional shaftline propulsion

Length^{OA} 225 m, breadth 34 m, draught 6.7 m

Azipod® ship thruster setup			Shaftline ship thruster setup		
	Power	Pcs		Power	Pcs
Azipod® units (FPP)	10.6 MW	2	CPP with flap-rudder	10.6 MW	2
Fwd tunnel thursters	2 MW	3	Fwd tunnel thrusters	2 MW	3

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Table 1: Thruster setup of propulsion alternatives[2]

Wind direction	Max. Allowed wind speed [m/s]		Improvement with Azipod®
	Azipod®	Shaftline	
15°	34	33	**3 %**
30°	24	23	**4 %**
45°	21	20	**5 %**
60°	22	21	**5 %**
75°	22	20	**10 %**
90°	23	20	**15 %**
105°	24	19	**26 %**
120°	25	18	**39 %**
135°	26	17	**53 %**
150°	33	21	**57 %**
165°	41	27	**52 %**

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Table 2: Maximum allowed wind speed for crabbing for the propulsion alternatives[2]

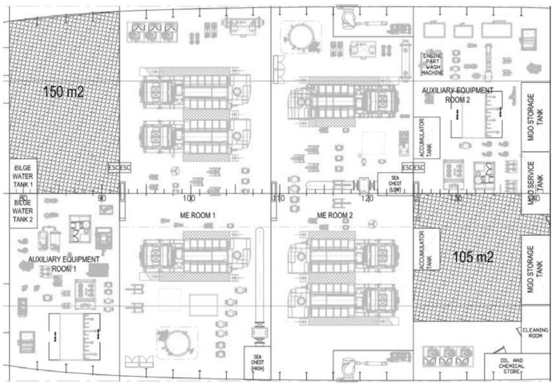

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Figure 3: Rearrangement of the case vessel's tank top plan with Azipod® propulsion freed total 255 m2 foot-print[2]

More payload, more room for alternative energy sources
Azipod® propulsion enables a flexible machinery arrangement that is easy to design for the vessel's specific requirements and priorities. In the case study, Azipod® propulsion motors installed outside the vessel hull, without long shaftlines, saved 255 m² of machinery footprint compared to conventional diesel-mechanical shaftline propulsion, see Figure 3. Lack of fixed shaftlines gives more freedom for locating propulsion and power plant machinery, enabling re-arrangement for higher payload, and clearing additional space needed for alternative energy sources such as LNG tanks, batteries or fuel cells. Table 3 demonstrates some benefits of rearranging the general arrangement for the case vessel.[3]

Similar space savings were also achieved by ship designer Foreship Ltd., who concluded that Azipod® M propulsion would enable main engine rooms to be located in one watertight compartment aft, saving at least 10 m compared to mechanical propulsion for Safe Return to Port (SRtP) designs, as seen in Figure 4. This would leave more space in the forward part of the vessel for additional stowage, LNG tank rooms or lower trailer holds.[2]

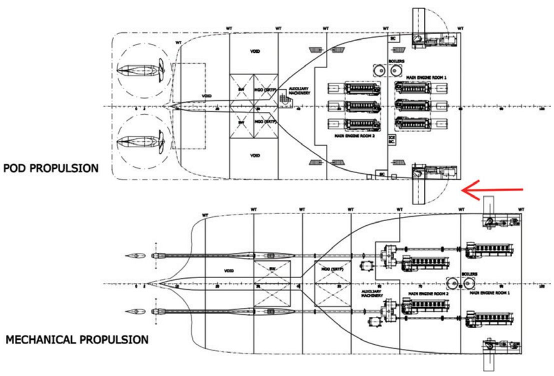

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Figure 4: Azipod® arrangement allows more valuable space in front of engine rooms[4]

Utilization	Effect	Impact
Rearranging GA and MA for extra passenger cabins	The total extra income depends on each individual case. An average price for an A-class cabin per trip is €80. The vessel would have one round trip per day. The price is an average of seasons and cruise types.	Yearly increased income of +€700 800/a
vvRehhharranging GA and MA for extra cargo space (cars, trailers, etc.)	The total extra income depends on each individual case. An average price per car per trip is €32. The vessel would have one round trip per day.	Yearly increased income of +€1 168 000/a
Increased LNG capacity	The total extra autonomy depends on each individual case. For case vessel, the consumption at design point is 106.0 t/d. The total extra volume is around 1000m^3, which utilised in C-type cylinderical LNG tanks is around 750m^3 (due to filling rate, cofferdam, etc.)	Autonomy capacity increase of 3.2 days in case vessel
Increased MGO capacity	The total extra autonomy depends on each individual case. For case vessel, the consumption at design point is 121.6 t/d. The total extra volume is around 1000m^3, which utilised in MGO tanks would be around 800m^3 (due to filling rate, cofferdam, etc.)	Autonomy capacity increase of 5.9 days in case vessel

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Table 3: Examples of utilization of freed space[2]

Effect on hull resistance		
	Shaftline	Podded
Interceptor	-2,00 %	-2,00 %
Bow thruster tunnels	4,00 %	4,00 %
Shaft arrangement	7,00 %	0,00 %
Rudders	2,00 %	0,00 %
Headboxed	1,00 %	0,00 %
Recesses for stabilizer fins	0,50 %	0,50 %
Bilge keels	1,00 %	1,00 %
Total	13,50 %	3,50 %
Difference	10,00 %	

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Table 4: Effect of appendages on hull resistance[2]

Comparison at 22kn		
	Shaftline version	Azipod® MO1800
Diameter [m]	5,1	5,1
Speed [rpm]	139	139
Power [kW/unit]	10274	9045
Propeller / Azipod® unit efficiency	0,686	0,708

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Table 5: Delivered power requirement for the case vessel at 22 kts[2]

$1,700,000 annual savings in fuel and energy consumption

The main fuel consumption advantages with a twin Azipod® vessel stem from lower vessel re-sistance and better propulsion efficiency. As shown in Table 4, the difference in resistance was only 10 percent because the shaftline alternative was not equipped with stern tunnel thrusters, which typically increase resistance.

Savings with podded propulsion increase further compared to shaftline propulsion due to undisturbed water flow to the propeller and optimum propeller angle towards the inflow which both increase propeller efficiency, Figure 5. According to the case study, the savings on delivered power (P_D) at 22 kts was 12.0 percent with Azipod® propulsion, see Table 5.

Taking into account mechanical losses (3.5 percent) for shaftline propulsion employing 10 bearings and a gearbox on a mechanical drive train, and electrical losses of Azipod® propulsion drive train (9 percent) including propulsion motor, transformer, frequency converter and generators, the savings in engine power (P_B) with Azipod® propulsion is 6.6 percent.

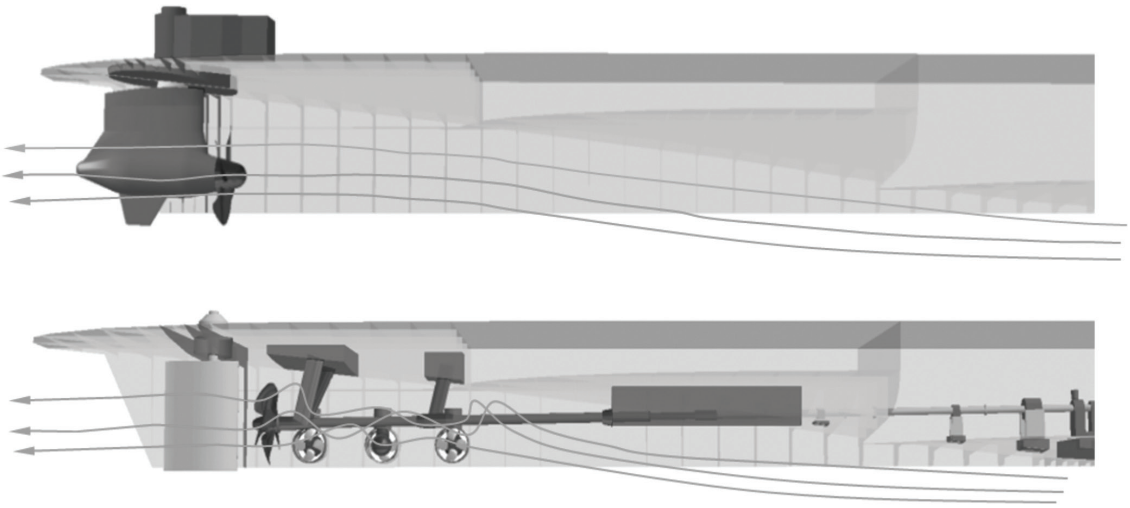

Figure 5: Due to lack of shaftline, supporting brackets and tunnel thrusters, the pulling Azipod® propeller receives steady incoming water flow, resulting in less noise and vibration, and better efficiency

Route	Consumption [t/a] (LNG)		Difference [t/a]		Econ. savings	Consumption [t/a] (MGO)		Difference (MGO)		Econ. savings
	Diesel-mech.	Azipod® M	[t/a]	[%]	$	Diesel-mech.	Azipod® M	[t/a]	[%]	[$]
Puttgarden - Rodby	18 437	15 638	-2 799	-15.2	1 399 500	20 406	17 796	-2 610	-12.8	1 448 550
Rostock - Gedser	22 146	20 178	-1 968	-8.9	984 000	23 065	23 065	-2 300	-9.1	1 276 500
Kiel - Gothenburg	22 269	18 482	-3 787	-17.0	1 893 500	24 662	21 085	-3 577	-14.5	1 985 235
Rosslare - Cherbourg	24 373	20 588	-3 785	-15.5	1 892 500	27 320	23 573	-3 747	-13.7	2 079 585
Fredrikshavn - Oslo	21 225	17 173	-4 052	-19.1	2 026 000	23 477	19 651	-3 826	-16.3	2 123 430
Turku - Stockholm	20 752	17 968	-2 784	-13.4	1 392 000	23 255	20 479	-2 776	-11.9	1 540 680
Amsterdam - Newcastle	18 982	16 102	-2 880	-15.2	1 440 000	21 060	18 347	-2 713	-12.9	1 505 715
Average	21 169	18 000	-3 169	-15.0	1 575 357	23 649	20 571	-3 078	-13	1 708 528

Table 6: Fuel oil cost saving with Azipod® M propulsion compared to conventional shaftline propulsion[2]

Due to a lower total engine power and thus utilised energy consumption, the M&R costs are lower. For these example routes, the energy consumption decrease is about 32,000 MWh as an average. An average price of diesel-engine spares is about €2/MWh. An average work amount of diesel-engine maintenance is about 0.044 h/MWh/a and price onboard around €35/h.	Savings of €64 000/a + €49 000/a = €113 000/a
Due to lower total engine power and thus utilised energy consumption, the lubrication oil costs are lower. The lubrication oil price is about. 0.8 g/kWh. For these example routes, the energy consumption decrease is about 32,000 MWh as an average. Price of lubrication oil is about €1000/ton.	Savings of €25 600/a

Table 7: Savings due to less ME maintenance and lower lubrication oil costs[2]

These savings were further simulated for seven existing ferry routes relevant for this size of vessel. The simulation also considered the fuel oil consumption advantage of electrical power plant in partial loads. The resulting fuel oil cost saving with Azipod® M propulsion is on average $1.7 M per year for the seven routes presented on Table 6. The monetary values are based on prices for LNG of $355/ton and for MGO $555/ton.

In addition to savings in energy consumption, Azipod® M propulsion saves on other operational expenses. For example, lower installed power on main engines requires less engine maintenance and lower lubrication oil consumption. Estimated savings from these are listed in Table 7.

Superior safety with 38 percent smaller turning circle

In collision avoidance manoeuvres, 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 stern tunnel thrusters to assist in manoeuvring. 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.

The more effective and safer turning capabilities of Azipod® propulsion have been verified by full-scale and full-speed turning circle tests on sister ships MS Fantasy with conventional propulsion, and MS Elation with Azipod® propulsion. A 38 percent reduction in tactical diameter[4] was recorded, see Figure 6. Model experiments with a wider set of ships have shown similar results, see Figure 7.

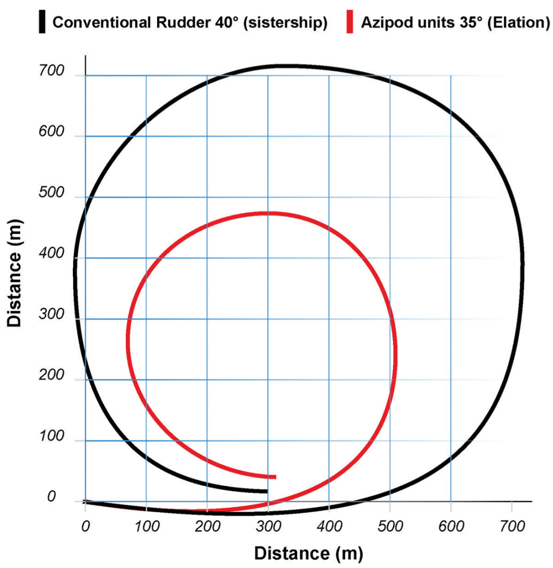

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Figure 6: Full-speed steering tests from MS Elation show the superiority of Azipod® steering compared to her Fantasy class rudder-equipped sister vessel.

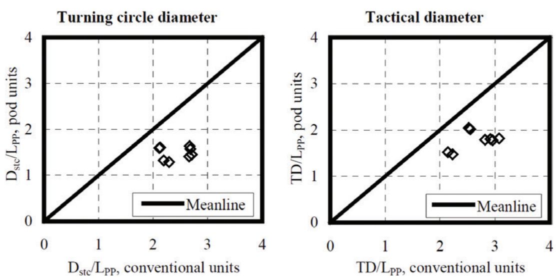

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Figure 7: Turning circle data of ship models equipped with podded or conventional propulsion units[5]

Shorter crash-stop distance with full heading control

With traditional rudder steering, an emergency crash-stop is accomplished by reversing the propeller pitch or rpm from positive to negative. Especially changing rpm from positive to negative direction is time-consuming, as the ship's power machinery must go from full to zero power and then ramp up again to full power in the opposite direction. In practice, any vessel operating with a rudder will also lose control of heading during the crash-stop, as the rudder does not work efficiently unless the propeller is producing thrust, and negative propeller pitch or rpm generates very little thrust for the rudder. This means that ship heading and direction during the crash-stop are effectively at the mercy of current, wind and waves, a condition exacerbated in heavy seas.

In Azipod®-equipped vessels, crash-stop can be accomplished by steering the Azipod® units 180° and keeping positive propeller rpm during the entire procedure. This shortens crash-stop distance considerably – typically by about 50 percent (see Figure 8). Moreover, during the crash-stop, Azipod® units can generate enormous side force in any desired direction irrespective of the vessel's speed. This gives the captain full control over the heading and direction of the vessel during the entire crash-stop, even in heavy weather conditions. The combination of short crash-stop distance and full heading control is an extreme advantage in onboard safety when considering worst-case scenarios.

Robustness suitable for ice classes

The mid-range Azipod® propulsors are also available with ice class up to 1A Super and PC 6 – or even higher if power is de-rated. Inside 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.

The world's best passenger comfort

Most modern Azipod®-equipped cruise ships are classified according to strict Comfort Class 1 requirements governing onboard noise and vibrations levels. There are no noise-generating gears and the pod motor and shaft are located outside the ship's hull. More importantly, the Azipod® unit's pulling propeller receives an undisturbed wake field, as shown in Figure 5, giving propeller designers greater scope to optimize propellers for silent operation compared to a conventional pushing propeller with rudder.

Vibration caused by manoeuvring in ports with high rudder angles is also avoided, as the Azipod® propeller and motor housing rotate as a single unit, meaning there is never a high angle of attack between them. Stern tunnel thrusters are not needed with Azipod® propulsion, thus eliminating associated noise and vibration.

Environmental protection

All Azipod® designs are best-in-class propulsion products in terms of both risk of oil leakages and overall propulsion energy consumption. The main feature is the U.S. Vessel General Permit (VGP)[6] approved shaft seal design, eliminating any oil-water interface. The amount of oil used in a gearless Azipod® unit is only a fraction of that in geared mechanical azimuthing thrusters or traditional shaftline propulsion. Furthermore, fully electric Azipod® propulsion, with its small footprint for vessel general arrangement, makes it easier for ship designers to utilize alternative power sources such as LNG, batteries or fuel cells, or leave space aside for conversion at a later date.

Azipod® M series

At the core of the Azipod® M product line are the latest 4th generation permanent magnet (PM) motors developed by ABB. These motors are structurally as sound as the well-proven Azipod® C and Azipod® D series PM motors, but are optimized further with today's mass-computing capacity and evolutionary algorithms to a) maximize electrical efficiency and b) minimize the use of expensive rare-earth elements needed to build strong permanent magnets. For the ship owner this means that Azipod® M with 4th generation PM motor will have extremely high electrical efficiency, typically 98 percent, at a competitive price.

The Azipod® M series features additional technical solutions that provide benefits for ferry and RoPax owners and operators. These include:

- Low onboard height. The Azipod® M unit, including its auxiliary units, have been designed for low onboard height to allow placement under the car deck of RoPax vessels, ensuring more intact loading and unloading, as well as enabling the maximum number of lanemeters.
- Tailorability. The strut height of the underwater propulsion module can be selected for each project to achieve the best possible propeller diameter, efficiency, and tip clearance. The location of auxiliary units onboard (in the pod room) is easily adjustable in order to get the best fit for tight aft-ship designs.
- Simplicity. Designed to be as simple as possible, ensuring robustness, reliability and easy maintenance for the crew, with all the active auxiliary components easily accessible in the pod room.

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[1] 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 4 Nov 2018

[2] Foreship Ltd., FS2939: Ferry Pod Feasibility, 8 Nov 2017, Confidential

[3] Deltamarin Ltd., Report for Project 7107: Marine Study on Azipod M® – Comparison of Azipod and diesel-mechanical shaftline propulsion systems, 5 June 2018, Confidential

[4] Kurimo, R., Sea Trial Experience of the First Passenger Cruiser with Podded Propulsion, Practical Design of Ships and Mobile Units, 1998, page 743

[5] Toxopeus, S. and Loeff, G., Manoeuvring Aspects of Fast Ships with Pods, 3rd International EuroConference on High-Performance Marine Vehicles HIPER'02, Bergen, 14-17 Sep 2002, page 398, http://www.marin.nl/upload_mm/6/e/2/1806690851_1999999096_Manoeuvring_aspects_of_fast_ships_with_pods.pdf, visited 4 Nov 2018

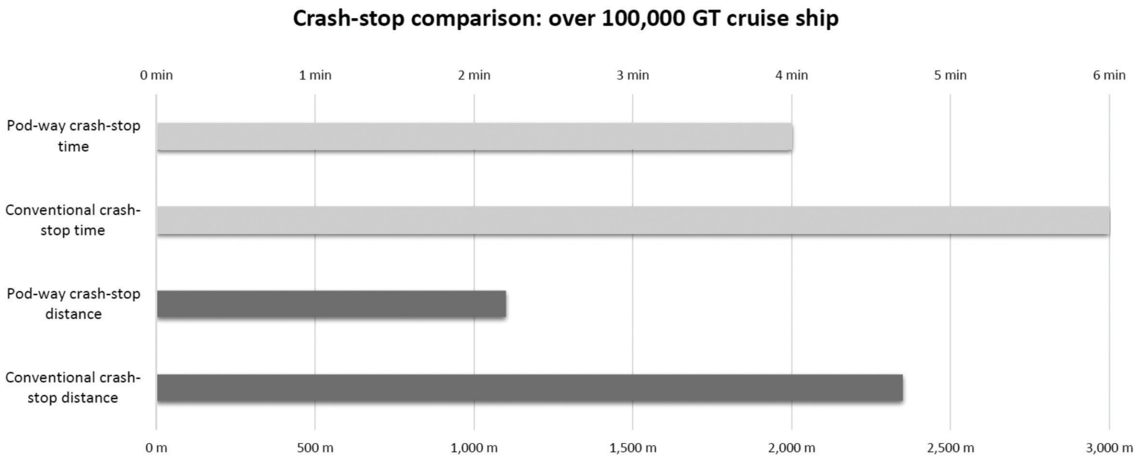

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Figure 8: Full-scale comparison between 'pod-way' and conventional 'negative rpm' crash-stops from full speed