

## **Future-Proof Propulsion Technology for Polar Research Vessels**

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### **ABSTRACT**

To operate safely and responsibly in the toughest ice conditions on the planet, the toughest technology is required. Podded propulsion solutions have been developed to meet the stringent requirements for polar vessels, offering effective, clean and quiet operations, together with superior maneuverability and reliability. Harsh environments, ice conditions, regulatory requirements and lack of infrastructure are key challenges in building research icebreaking vessels operating in the Polar waters. System redundancy and equipment reliability are critical for the safety of the crew and the vessel.

The awareness and concerns related to the impact of ship traffic on arctic fauna and marine life are growing. Limiting underwater noise, emissions, and any waste such as lube oil, is critical. Underwater Radiated Noise (URN) is the noise generated by ship operations that passes through water, potentially disturbing marine life and interfering with sensitive measuring instruments. ABB recently completed a full-scale validation of the prediction method for URN that can be efficiently applied to any new project.

To break ice in the most challenging conditions, vessels powered by Azipod® propulsion navigate stern first. Propellers mill the submerged part of the ice ridge to open a passage, while water flow generated by the propeller flushes the hull, allowing the ship to move with ease in demanding ice conditions. The double-acting ship (DAS) concept allows research ships to operate without icebreaker support, keeping ice channels open more effectively and enabling vessels following behind to reduce their fuel consumption. Podded propulsion systems have also proven highly effective in carrying out operations including research, environmental response, and search and rescue (SAR) in ice-infested waters.

Typical future-proof sustainable solutions include Onboard DC Grid™; a modular power system platform that enables simple, flexible, and functional integration of energy sources and loads.

This paper will discuss recent studies on underwater noise mitigation of electric propulsion system in icebreaker operation and latest development on ice class podded propulsion. Operational experience from Icebreaking Research vessel Xue Long 2 will be also presented.

**KEY WORDS:** Icebreaker, Underwater radiated noise, Onboard DC Grid™, Azipod®

## **HISTORY OF RESEARCH ICEBREAKERS**

The history of Polar exploration is full of not only success and glory but also expeditions that ended up in disasters, resulting in losses of human lives and equipment. The early expeditions clearly revealed the need for careful preparation and self-contained operation in the most remote areas of the world. In the beginning the polar expeditions relied on sailing ships and quite a few vessels were lost in the polar waters.

Operation of sailing ships in ice conditions is very difficult due to maneuverability issues, in particular the lack of ability to back the ship created problems and rowing boats were often used to pull the ship backwards.

The advent of the steam engine solved some of the challenges of the sailing ships and later expeditions used combinations of steam engines and sails. The long transit voyages to the polar regions used sails for propulsion, saving the fuel for the boilers during the ice transit.

After the Second World War the diesel engines started to dominate maritime transportation.

Most of the nations that have permanent research bases on Antarctica have dedicated logistic support vessels to serve those bases. Some of these vessels can also serve as Polar research vessels as a secondary mission.

Much of the space inside these vessels is occupied by containerized cargo and fuel for the bases, leaving less room for scientific equipment and laboratories. The rotation crew for the base is also carried onboard.

The propulsion system of these vessels was normally geared diesels or icebreaker type diesel electric. The growing interest in the Polar regions prompted the development of dedicated Polar research vessels where the logistic support played a much smaller role. In these vessels focus is on the research work with large open deck area and numerous probe winches as well as several well-equipped laboratories. A relatively large number of scientist cabins is provided.

Diesel-electric propulsion is predominant and hybrid technology with fuel cells and battery packs together with "green" fuel is emerging

Dynamic Position requirements pave the way for azimuthing propulsors.

In recent years the cruise business has expanded into the Polar regions in the form of exploration cruise vessels. Some of these vessels have high ice class and good icebreaking capability. *Le Commandant Charcot*, owned and operated by Ponant Cruises, was in fact the first vessel built to ice class PC2. The vessel has demonstrated its icebreaking capability by reaching the North Pole single-handed, without icebreaker assistance. In the Antarctic *Le Commandant Charcot* broke free and assisted the British RRS *Sir David Attenborough* that got stuck in heavy ice conditions during its assignment.

*Le Commandant Charcot* has excellent icebreaking capability, particularly going astern due to its Double Acting design. In this case Double Acting means that the bow is designed for economic open water performance and moderate icebreaking whereas the stern is designed for more serious icebreaking.

## **POD PROPULSION TECHNOLOGY FOR POLAR RESEARCH VESSELS (PRV)**

Azipod® is a gearless steerable propulsion system where the electric drive motor is in a submerged pod outside the ship hull. Azipod propulsion improves vessel safety, design flexibility, energy efficiency, manoeuvrability, high levels of ice-breaking performance, greater uptime and reduced construction and maintenance costs. Since 1990, two of three new icebreakers have used podded propulsion systems. There are evident benefits of an electric Azipod propulsion system in Polar research vessels:

1. Flexibility in the vessel design and general arrangement resulting added space available for cabins, research facilities or other equipment. An alternative is to build a shorter and more compact vessel with the same capacity which results more compact and efficient design.
2. Excellent icebreaking capability & safety
3. Superior maneuverability, especially at low speeds, in harbor and in research operation mode
4. Reduced level of propeller induced pressure pulses resulting minimized noise and vibrations onboard and underwater.
5. Inbuild system redundancy and excellent Dynamic Positioning (DP) operation capability
6. Lower total fuel consumption due to the power plant principle and improved hydrodynamical efficiency.
7. Vessel building schedule and yard costs can be optimized with the modular construction of the propulsion system.
8. Project risks are also further reduced by the fact that there are fewer vendors, interfaces, and installation trades to schedule.

For polar research icebreaker, selection of Azipod propulsion shall eliminate the need of rudders and steering gears, shaft lines, gear box, stern tube and seals, lubrication system, inboard propulsion motors, retractable aft thruster, and Controllable Pitch (CP) propellers. It will further minimize the propulsion system complexity, maintenance, fuel consumption and different equipment suppliers and interfaces at the same time maximizing reliability and performance.

### **Azipod operational performance**

The maneuverability of a vessel equipped with Azipod propulsion is superior compared to a conventional vessel. This makes tactical ice navigation, following of the leads and several other ship duties in ice much more efficient.

Azipod propulsion thrust can also be used to clear ice between the pier and the ship. This will result in considerably faster berthing of an Azipod system -equipped vessel in ice infested ports. There are several possibilities for other ice management tasks that can be efficiently performed with the use of the wake of Azipod propulsion e.g. clearing ice-free 'lake' for safe

operation of ROV. Ice ridge and ice rubble penetration capacity is far better going astern than with traditional bow-first operation.

Compared to the classic icebreaker with shaft line propellers and rudders, the improvement of turning capability in ice using podded propulsion is remarkable. Figure 1 depicts the turning circle of various vessels plotted against a given ice thickness. It clearly shows how podded icebreakers can turn in much tighter circles than conventional vessels. To further enhance the icebreaker turning capability propulsion arrangement with combined Azipod units in the bow and two units in the aft will provide unrivalled manoeuvrability. Result of Icebreaker Polaris turning in spot and Azipod orientation is shown in Figure 2.

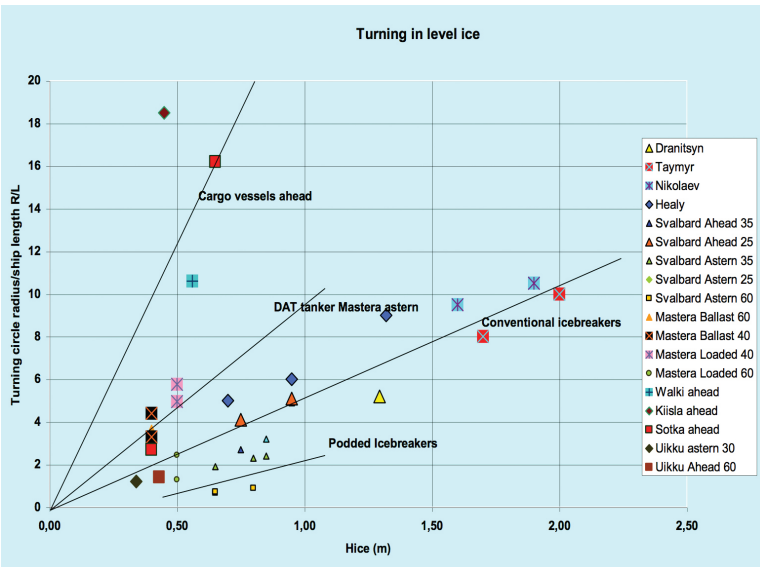


Figure 1. Different icebreaking vessel turning capacity in ice

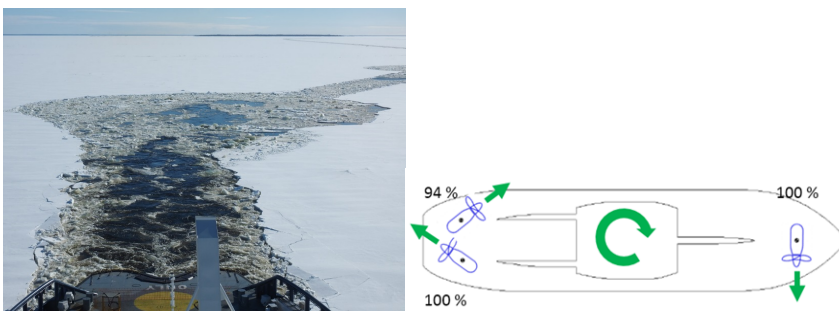


Figure 2. IB Polaris turning in place and thruster orientation.

### **Research operation in astern mode**

Research icebreaker with Azipod propulsion can be operated in low-speed science/silent mode running the vessel astern. The ship hull and propeller stream work as noise barriers for scientific towing equipment, while keeping the vessel course stability and maneuverability. This can also further extend the overall scientific work operating window, even in the presence of ice.

### **OPEX cost**

Icebreakers with podded propulsion are more fuel-efficient than conventional driveshaft vessels, due to the efficient hull design and the system's reduced power requirement, which can in some cases lead to a substantial improvement in efficiency, reducing fuel costs and increasing endurance.

Modern power systems together with podded propulsion can be designed to operate at variable frequency, which allows the machinery system to run at varying RPMs in response to changing demand. This has two benefits. It can deliver substantial fuel savings compared to conventional power distribution systems and it allows the engines to run at optimal levels in relation to fuel economy and long-term durability while still delivering outstanding performance. This is especially important in the constantly changing conditions that research icebreakers encounter while operating in ice.

### **CAPEX cost**

As exciting as many new marine technologies are, they must also be viable in an industrial manufacturing environment. It is essential to consider production attributes early in the design and acquisition cycle, especially in cases where the equipment faces unique demands, as is the case for research icebreakers. Podded propulsion systems like Azipod propulsion have proven themselves in terms of ease of installation: the single lift requires cuts the time in drydock and reduces schedule risk for the shipyard.

Project risks are also reduced by the fact that there are fewer vendors and installation trades to schedule. Furthermore, the podded system eliminates the need for gearbox, thrust bearing, shaft-line, stem tube and seals, lubrication system, rudder and steering gear, stern thrusters and an interior electric motor.

Improved performance and propulsion efficiency may allow reduced power rating of the whole powerplant and propulsion, resulting smaller propulsion motor, drives, generators and main engines.

### **UNDERWATER RADIATED NOISE (URN)**

The main contributors for underwater radiated noise from Azipod propulsion is the hydrodynamic noise from the propeller and the electro-magnetic noise from the electric motor of the Azipod unit. The electric motor is located outside the ship hull and cannot be isolated from radiating acoustic energy to the underwater environment. The electric motor is

the main contributor to the underwater noise from Azipod units in non-cavitating conditions, and equally important source to the propeller in cavitating conditions.

The propeller design for arctic research icebreakers is driven by the bollard pull condition, i.e. the ship at zero-speed. The ship must be able to operate safely in harsh ice conditions. The propeller is designed to absorb full power available from the electric motor, and to give as much thrust as possible at zero ship speed. The propeller loading is adjusted according to the performance requirement in bollard pull and the blade area ratio is adjusted to avoid thrust breakdown due to cavitation. The heavy ice class propellers typically have zero or very moderate skew to be more resistant against heavy ice loads. The thickness of the blades is determined based on the ice loads acting on the propeller blades. The heavy ice class propeller blades are then easily recognized for their symmetric outline and relatively large blade area ratio as shown in [Figure 3](#).



Figure 3. A photograph of heavy ice class Azipod VI1600 units.

In addition to the bollard pull condition, the research ice vessels have transit and research modes. The propeller efficiency should be reasonable in transit mode although it is compromised since the design point is in the bollard pull condition and blade profiles are thick compared to propellers designed to open water.

In the research mode, acoustic emissions of the propulsion are restricted in research vessels. Many classification societies have their limits for underwater noise emissions. The limits are based on the vessel types and their mission. The first underwater noise level was set in the ICES 209 (Mitson, 1995) which gave recommendation for underwater noise levels for fishery vessels. Regarding arctic research vessels, the noise levels are determined for low ship speeds, typically around 10 knots in research missions.

## Hydrodynamic noise

As discussed earlier, the propeller design is very much focused on the bollard pull condition. The means to affect the underwater noise levels in transit are then limited by propeller designer. The needed power level near 10 knot vessel speed is only 10-30 percent of that required at the bollard pull condition. The propeller blade loading is then relatively low due to the high blade area and the margin against cavitation inception is usually reasonable. The ship wake field at the propeller plane is very smooth in icebreakers equipped with Azipod units, which also helps to avoid cavitation at low ship speeds. The hydrodynamic noise emitting from non-cavitating propellers is usually clearly below the relevant noise limits at low speeds.

The prediction methods for hydrodynamic underwater noise levels from propellers still rely on empirical or semi-empirical methods, or measurements in model tests. There are attempts to simulate hydrodynamic noise using a combination of CFD and acoustic analogies (Viitanen et al. (2018), Lidtke et al. (2022)), but proper full-scale validation of the approaches are still missing. The noise measurements in model tests are subject to background noise, influences of the measurement system, and scale effects. The results of the model test measurements are available at very late stage of the propeller design process.

ABB uses tools and methods developed within the CRS community (Cooperative Research Ships, <http://www.crships.org>) to predict hydrodynamic noise from propellers. The Boundary Element Method (BEM) code Procal is used to calculate the flow field around propeller blades. The Procal code calculates the propeller performance, the pressure field, and sheet cavitation extent around the propeller. The output of the BEM simulations is used by the Empirical cavitating Tip Vortex (ETV) method (Bosschers, 2018). The semi-empirical ETV model calculates the noise emitting from cavitating tip vortices. CRS community developed a Matlab implementation of the semi-empirical method predicting broadband noise from cavitating bubbles emitting from propeller sheet cavitation (Matusiak, 1992). The MatusiakLab simulations also use output from the Procal code.

## Electromagnetic noise

Sound emission from an electrical motor can be considered as a sum of three types of sources acting simultaneously: 1) Cooling noise, 2) Mechanical noise and 3) Magnetic noise due to magnetic interaction between stator and rotor (airgap). In this case the magnetic noise is of importance. The rotating magnetic field in the motor is never fully sinusoidal (slots, saturation, pole shape, voltage waveform etc), which means that also harmonic field components are generated to some extent. These harmonic field components are the main cause for magnetic noise. The flux harmonics generate rotating force waves having distinct frequency  $f$  and wavenumber  $r$ . Some examples of magnetic force waves are shown in [Figure 4](#).

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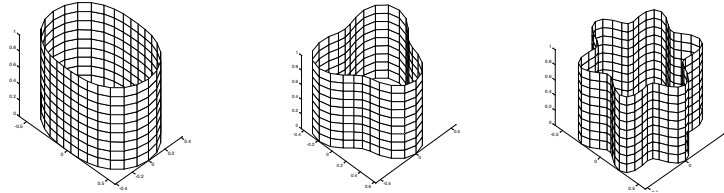


Figure 4. Rotating force waves, from left to right  $r = 2, 3,$  and  $6$ .

An electrical motor operating with sinusoidal supply voltage (DOL=Direct-On-Line) is typically very silent. This is due to two reasons: 1) The motor is running with constant speed making the vibroacoustic design more straightforward with respect to structural- or acoustical resonances 2) The voltage waveform produces an airgap flux with low total harmonic distortion, THD. In the case of frequency converter supply (VSD=Variable Speed Drive) the previous two aspects fail to hold true. Especially, as the voltage waveform is not sinusoidal anymore, the airgap flux THD increases heavily. Increased distortion in airgap flux manifests itself in a form of increased magnetic noise level. For a standard industrial induction motor the increase of noise level in some circumstances can be as high as 30 dB.

Considering electrical motors operating in underwater conditions such as Azipod units, the experimental determination of sound radiation properties of the unit alone is practically impossible.

For this reason, the electromagnetic noise studies rely on simulation models the validation of which is carried out in two steps as follows:

#### Step 1: Airborne tests during Factory Acceptance Test (FAT)

The airborne electromagnetic noise emission of an Azipod unit can be measured easily at a factory testbed using the designed converter supply together with correct shaft loading. Sound intensity-based methods are favored due to their ability to exclude the extraneous noise from the results (factory background noise & noise from the loading machine). Once the airborne noise figures are obtained, validation of the magnetic field simulation model and structural dynamics together with airborne noise radiation takes place. Step 1 is especially important for structural damping estimates.

#### Step 2: Underwater noise simulation using coupled models

To get reliable underwater noise predictions, the Fluid-Structure-Interaction (FSI) approach is essential. In short it means that the pod structural vibrations and underwater sound radiation are solved simultaneously to include the water inertial (attached mass) and dissipational (radiation damping of the structure). FSI-based methods are computationally heavy, but the reward comes in form of improved underwater noise radiation accuracy. The coupled analysis method is then validated during sea trials. A boundary mesh of a pod unit is shown in Figure 5.

## Example of simulation chain

Essentially, the simulation workflow consists of following steps:

1. The coupled mechanical-acoustical FE-model using unit-wave excitations (radial & tangential,  $r = 0, 5, 10$  and  $12$ , for example) is solved to obtain unit-wave sound power of the pod at the selected range of frequencies (typically 10-3000 Hz for large pods). Structural analysis uses complex material model (hysteretic damping).
2. Multiplying the unit-wave power responses with magnetic excitation force waves are obtained from electromagnetic field simulation.

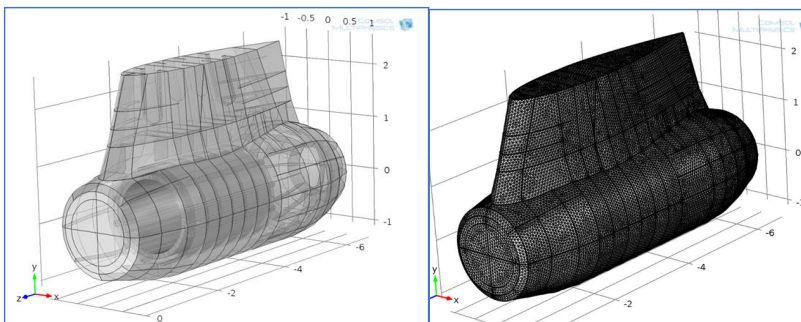


Figure 5. Azipod unit geometry and boundary mesh for underwater electromagnetic noise.

The hydrodynamic noise prediction is then added to the electro-magnetic noise prediction to have the total noise level of Azipod propulsion. When measuring URN levels in full scale, the other noise sources from the ship are also present in the noise spectra. Careful analysis of the measurement data is needed identify all sources present in the underwater noise spectra.

An example of noise spectra from the simulated hydrodynamic and electro-magnetic noise sources, and the sum of the sources for a vessel designed without noise restrictions are given in Figure 6. The far field measurement results and RINA Transit noise limit are also given in the figure for reference. It is seen that the peaks present in the far field measurements noise spectrum are well captured by the ETV model and the electro-magnetic noise simulations.

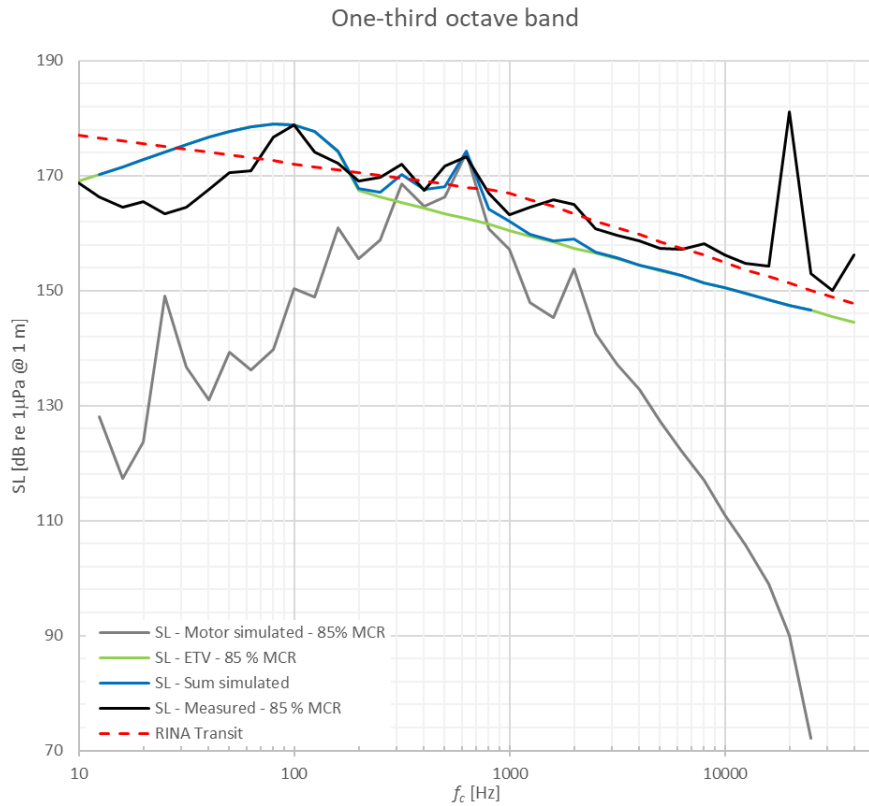


Figure 6. Simulated hydrodynamic noise (ETV), simulated electro-magnetic noise, and sum of simulated noise sources for a ship without noise restrictions. Far field measurement results and RINA transit level are given for reference.

### SOLUTIONS TO MITIGATE ELECTROMAGNETIC URN

As a conclusion, propeller hydrodynamic noise is highly dependent on the load and rotational speed, and it can be reduced if propeller is carefully designed according to speed and load situations. Main concern still lies with electromagnetic noise of motor inside the pod. To smooth out the output voltage waveform of converters, one simple and cost-efficient solution could be to use passive filters between motor and the drive, Figure 7. Filter size in this case will depend on the switching frequency of the converter and may not be suitable for cases where drives typically operate at switching frequency of few hundred Hz.

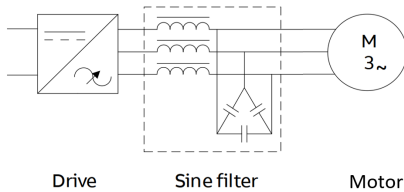


Figure 7. Sine (passive) filter between propulsion drive and Azipod motor to reduce harmonic content in voltage waveform

Active harmonic filters could be a more compact solution to be used with low switching frequency converters, however this may require additional power source and comes with a price tag.

Another possibility is to use propulsion transformer with two voltage levels on secondary side, such that, 100% voltage is available for normal operation with first tap, Figure 8. While 100-x% voltage is available via second tap, which will result in reduced DC link voltage in the drive. This will inherently bring down the air gap flux THD level in the Azipod motor. The x% voltage reduction can be selected based on characteristic of propulsion system. Operation with reduced voltage will also limit the available power and therefore this methodology is not suitable for ice breaking operation and not in general to mitigate URN of ships in general. This is suitable only for silent operation where the vessel operates at reduced speed.

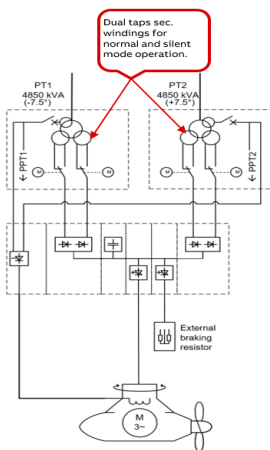


Figure 8. 24-pulse propulsion solution with dual taps on secondary side of propulsion transformers

## OPERATIONAL EXPERIENCES

The modern research icebreaker Xue Long 2 was delivered for Polar Research Institute of China (PRIC) in 2019. PRIC icebreaker is equipped 2 x 7.5 MW Azipod® propulsion units will enable the vessel to continuously break through ice up to 1.5 meter thick plus snow up to 0.2 meter at the speed of 2-3 knots, moving ahead or astern, Figure 9.



Figure 9. Research icebreaker Xue Long 2 for Polar Research Institute of China

Rong Huang, Chief Engineer and Designer of the Polar Research Institute of China states “Two key goals for the Xue Long 2 were maximum flexibility and durability. The proven Azipod propulsion system ensures that the new vessel will be able to carry out her missions in varying Arctic and Antarctic ice conditions with the highest possible regularity.”

## CONCLUSIONS

This paper presented recent studies on underwater noise mitigation of electric propulsion system in icebreaker operation and latest development on ice class podded propulsion. Operational results from Icebreaking Research vessel Xue Long 2 was also discussed. Azipod propulsion represent the modern technology that can elevate the operational capability of icebreaking research vessel to a completely new level, while maintaining low level of URN. Even in the harshest ice conditions the vessel with Azipod propulsion will have unrivalled icebreaking performance.

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