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Digitally Signed 28-Oct-2021

DOC:	REV:	FILE:	DATE:
19136-000-13	A	19136.01	27 October 2021

References

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3. *Basic Ship Theory*, E.C. Rawson and K.J. Tupper, Volume 2, 1979.
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Executive Summary

A feasibility study was undertaken to explore an optional propulsion system enabling reduced underwater radiated noise (URN) in open water missions.

A strategy for a hybrid, triple propulsor system was identified during the development of the concept design propulsor study (Reference 5). The advantages of this type of system for open water missions are lower levels of URN and possibly increased efficiency, however at increased capital and maintenance costs.

The strategy for this system is as follows: a conventional fixed shaft propeller with an electric drive motor is installed on centerline. The propeller, drive train, and motor are optimized for low URN. Twin ABB Azipod propulsion units are mounted port and starboard. The Azipod units are to be the primary propulsors in ice and dynamic positioning operations, but will function at low power levels to provide needed steering forces during quiet open water missions.

Azipods are being considered over Z-drives for this strategy due to the Azipod having lower URN at reduced power compared to gear mesh noise from conventional geared right angle drives.

ABB modeling of the Azipods in a low power steering mode shows promising results for achieving low URN. Required steering forces are met with the units operating at 900-1400 kW (16-25% power) with estimated URN levels below ICES 209 levels.

In this strategy only the centerline propeller would be optimized for noise. Efficiencies of ice rated propellers optimized for cavitation-free operations can be as low as 41%. It is proposed that the propellers on the Azipods be optimized for thrust and thus have a higher open water efficiency. The propellers on the Azipod units will still need to be cavitation free at the low

power and low rpm needed for steering forces. Careful design of these propellers relative to caviatation will be needed. For long open water voyages where URN is not a concern, the Azipods could be the primary movers with just enough power on the centerline propeller to prevent appendage drag. This would improve open water efficiency over a twin screw option where both propellers would need to be optimized for noise.

The capital cost of the triple screw arrangement is estimated to be approximately $10M more than the twin screw Azipod arrangement.

Key findings of the feasibility study are:

- Low URN, possibly within ICES 209 requirements, may be possible with the triple propulsor arrangement.
- Some open water transit efficiency gains may be possible during non-URN-sensitive voyages.
- An increase of vessel length on the order of 10 ft is required to accommodate the Azipods and the additional propulsion motor.
- This propulsor arrangement adds approximately $10M to the capital cost of the propulsors.
- Operating cost increases are on the order of $0.5M for a ten-year maintenance cycle.
- Depot spares should consider a spare centerline propeller.

Purpose

The existing concept design (Reference 1) assumes a twin azimuthing propulsor system for reasons of improved maneuverability and functionality in ice conditions, compared to a conventional propeller-rudder configuration. One disadvantage of azimuthing drives, either geared right angle drives, or podded electric propulsors, is the amount of noise that is transmitted to the water.

The goal of this study is to investigate the feasibility of a hybrid triple propulsor system that can achieve lower URN levels for noise-sensitive open water missions.

The feasibility of the triple propulsor system is evaluated for impacts to the current concept design. Impacts to vessel size, power, and costs are reported.

Impacts to Current Concept Design

Arrangements

A partial arrangement plan was developed to show how the triple screw propulsor configuration would fit within the existing concept arrangement (Figure 1). The arrangement shows a large Thruster Room between Frames 135 and 158. The upper Azipod units are shown at 14 ft off centerline port and starboard, providing adequate clearance for the lower units when they are facing directly inboard (recommended minimum spacing is ½ of a propeller diameter). The separate Motor Room shown in the current concept arrangement (Reference 2) is eliminated and that space is combined with the Azipod Thruster Room. The elimination of the Motor Room results in slightly more interior volume being available, which is utilized by enlarging the Hold and lower Winch Room.

The upper Thruster Room requires more space than was allocated for the upper Drive Room of the Z-drive arrangement. The Z-drive configuration separated the Motor Room from the Thruster Room by a transverse watertight subdivision bulkhead at Frame 144. The elimination of this subdivision bulkhead is necessitated in the Azipod arrangement to provide enough space for the air handling units.

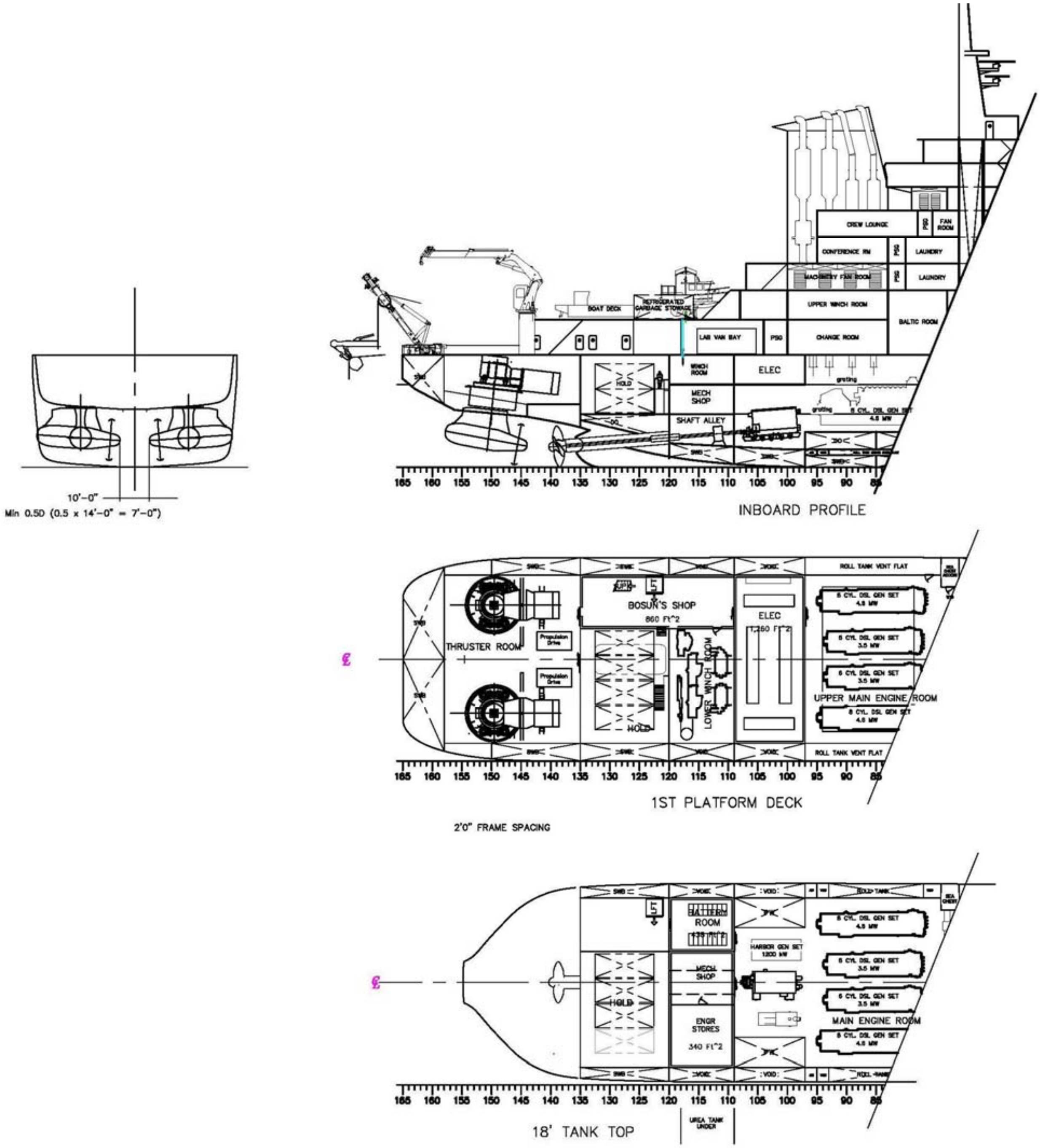

Figure 1 Partial general arrangement showing triple propulsors

The additional compartment volume results in damage stability requirements not being met. Figure 2 shows a comparison of the Z-drive arrangement (top) and the Azipod arrangement (bottom). It is estimated that an additional ten feet (10'-0") of vessel length will be required for the Azipod arrangement to meet damage stability requirements.

The arrangement of the added centerline fixed propulsion system can best be seen on the inboard profile shown above in Figure 1. The system comprises:

- A 7.2 MW resiliently mounted drive motor located in the lower Machinery Room.

- A 14-ft diameter fixed pitch stainless steel propeller optimized for zero cavitation through 11 knots. The stern geometry around the centerline propeller requires careful development to achieve relatively good flow to the propeller. A gondola stern pod is recommended.
- A drive train consisting of propeller shaft, stuffing box, thrust bearing and resilient coupling at the motor interface.

Reaching a lower URN goal will require that diesel generators be double resiliently mounted. Double resilient mounting requires an additional weighted mass for each foundation. The existing concept shows two 3.6 MW generator sets and two 4.8 MW generator sets. We propose that the two smaller generator sets be double resiliently mounted, providing 7.2 MW for a quiet running mode.

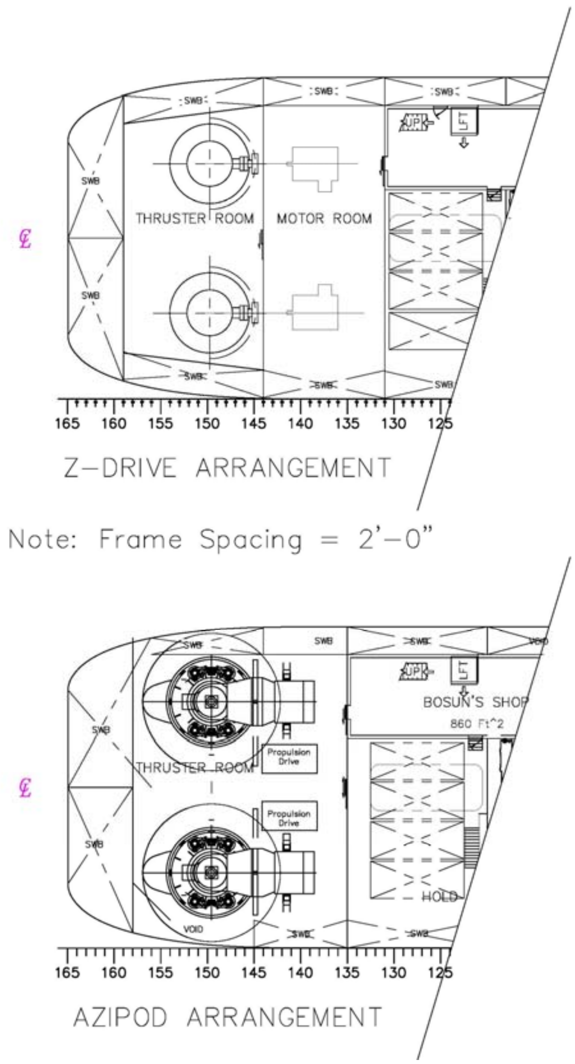

Figure 2 Comparison of Existing Z-Drive arrangement and Azipod arrangement

The impact of adding ten feet of length to the vessel results in negligible increases to open water and ice resistance. Increases in power levels beyond what is currently described in the concept design report (Reference 1) will not be necessary for this option. The additional 10 ft of length, assuming it is added at the midbody, results in an approximate increase of 500 LT of displacement (approx. 5%). This increase in length and displacement may allow for increased area in the main Machinery Room to compensate for the space lost to the centerline drive motor.

The increase will also compensate for the added lightship weight from the additional length, including the additional weight of the weighted mass and resilient mounts for the two 6-cylinder diesel generator sets, as well as some modest increase to fuel capacity. Depending on where the added length is incorporated, berthing space may also be added.

Steering Forces

Required steering forces were estimated by assuming a conventional twin spade rudder arrangement suitably sized for the concept design. Each rudder has an approximate lateral area of 154 ft^2. Steering forces for this rudder were estimated using an empirical analysis (Reference 3). A maximum rudder angle of 25 degrees was assumed for the quiet mode missions since extreme rudder angles beyond this would presume extreme environmental conditions where sea state noise may dominate. The estimated forces from a conventional rudder are:

- At 5 knots, max steering forces at 25 degree rudder are 50 kN.
- At 11 knots, max steering forces at 25 degree rudder are 242 kN.

ABB conducted a computational fluid dynamics (CFD) analysis of the 5.5 MW model VI1600 unit at power levels between 900kW and 1400kW to determine steering forces and predicted URN levels (Reference 4). The following table shows the predicted steering forces at 5 and 11 knots along with the assumed power levels. As can be seen in the table the required steering forces can be met at the reduced range of power levels.

Table 1 Predicted steering forces and assumed power levels at 5 knots and 11 knots for 5.5 MW Azipod model VI1600 (Reference 4)

Inflow		Propeller			Ship Coordinate sys.	
$V\,[knot]$	θ [°]	$n\,[rpm]$	$Q\,[kNm]$	$P_d\,[kW]$	$Fx\,[kN]$	$Fy\,[kN]$
5.0	-5.0	101.3	96.2	1020.85	171.8	-49.1
5.0	-10.0	69.0	32.0	231.4	45.6	-50.2
5.0	-20.0	42.8	2.4	10.7	-14.4	-50.1
5.0	-25.0	36.4	-2.1	-8.1	-25.2	-50.2
11.0	-5.0	227.7	485.9	11587.7	886.1	-242.1
11.0	-10.0	149.8	145.7	2285.5	210.5	-242.0
11.0	-20.0	93.7	9.1	89.2	-71.7	-241.9
11.0	-25.0	79.4	-12.8	-106.7	-124.2	-241.9

ABB notes that at 5 knots the power consumption reduces rapidly above 5 degrees of rudder angle, and the required 50 kN steering force can be met with a windmilling (non-powered) propeller at approximately 20 degrees (Reference 4). At 11 knots the power consumption also reduces rapidly above 5 degrees of rudder angle, and the required 240 kN steering force can be met with a windmilling (non-powered) propeller at approximately 22 degrees. However, keeping some low power on the units versus windmilling will offset the appendage drag and provide a positive forward propulsion component.

URN

ABB estimated the noise signature of the Azipod unit (withing an error band of +/- 4 dB) to be below the ICES 209 URN levels at 5 and 11 knots, as can be seen in the ABB graphic below (Reference 4). Low noise levels from the centerline propeller and drive train will need to be carefully considered during further development of this option but acceptable results are reasonably possible.

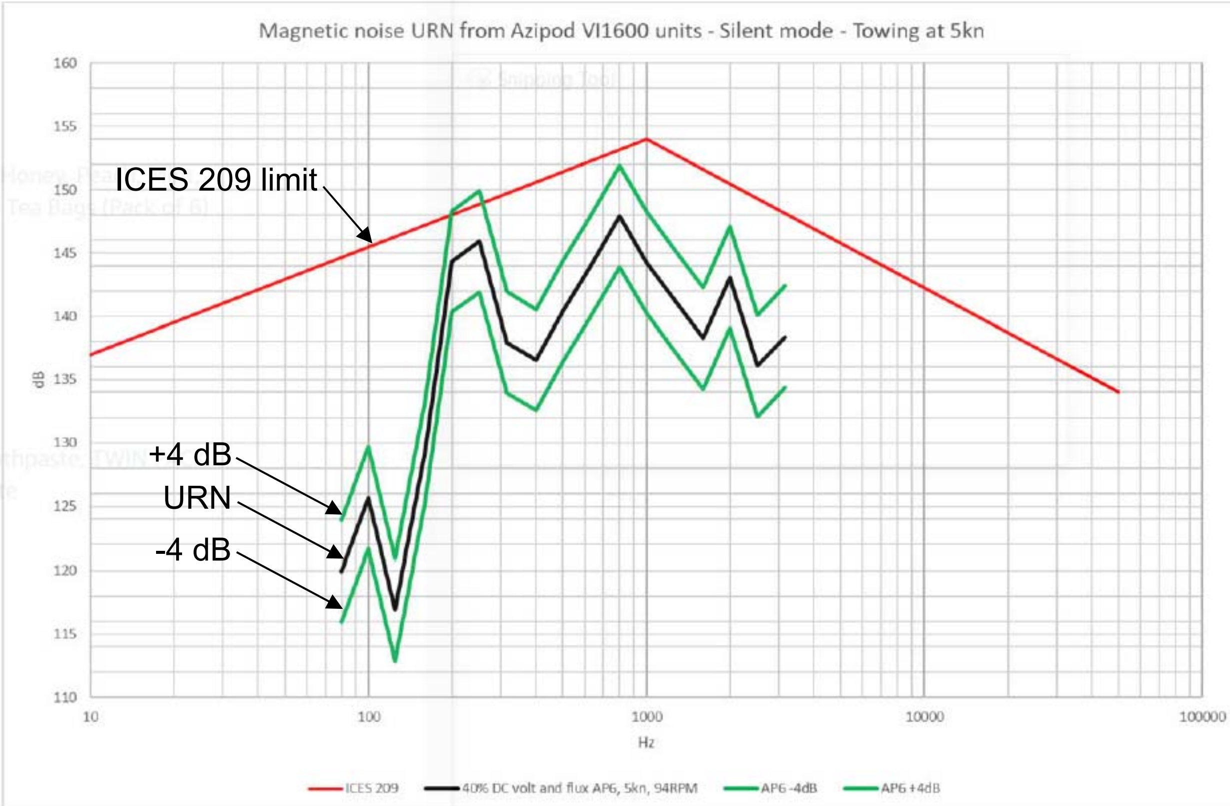

Figure 3 Estimated Azipod URN compared to ICES 209 levels at 5 knots, showing error band of +/- 4 dB Azipod operating at 94 RPM / 900 kW (Reference 4)

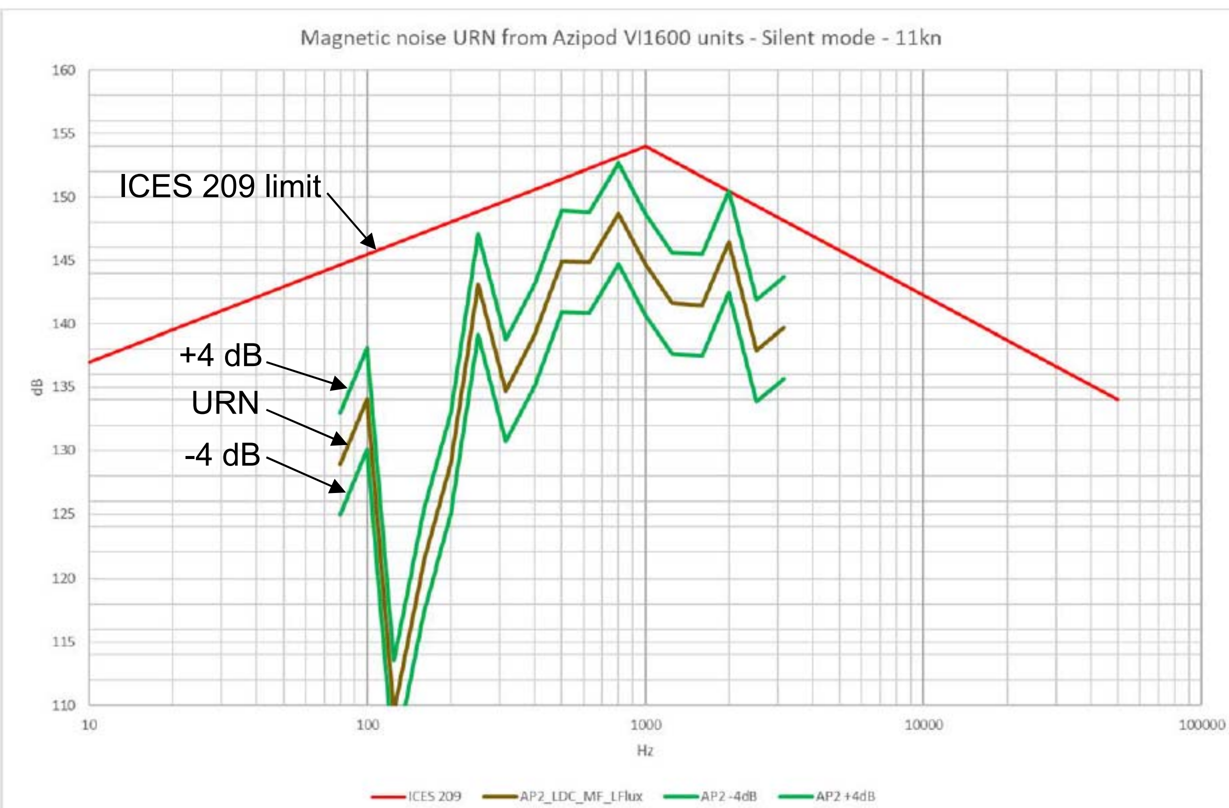

Figure 4 Estimated Azipod URN compared to ICES 209 levels at 11 knots, showing error band of +/- 4 dB Azipod operating at 94 RPM / 900 kW (Reference 4)

Efficiencies

In the triple propulsor strategy, only the centerline propeller would be optimized for noise. Optimizing for noise requires a cavitation free propeller through the speed range of interest which, for ICES209 for example, is 0 to 11 knots. A cavitation free, ice rated design will impact the efficiency of the propeller. As was found on the *Sikuliaq* (cavitation free through 8 knots), efficiencies of ice rated propellers optimized for cavitation-free operations can be as low as 41% versus approximately 65% for a cavitation free open water propeller. However, since the Azipod propellers will be operating at low power and RPM while in the open water steering mode there may be fewer design constraints on these propellers, allowing them to be designed for higher thrust efficiency for the icebreaking mode where they will be the primary propulsors. For long open water voyages where URN is not a concern, the Azipods could be the primary movers with just enough power on the centerline propeller to prevent appendage drag.

In the twin screw arrangement where the Z-drives or the Azipods are the primary propulsors in both open water and ice, the propeller design will need to consider the 5-8 kts "Quiet" mode operations outlined in the Underwater Radiated Noise Requirements Study (Reference 6). This implies an ice rated propeller design that is cavitation free through 8 knots and therefore a reduced efficiency as low as 41%, which will impact the amount of power needed to achieve ice breaking thrust requirements. Whereas in the triple screw arrangement the Azipod propellers could achieve a significantly higher propulsive efficiency resulting in improved fuel economy.

These options, and particularly the challenge of designing Polar Class 3 propellers with low cavitation, must be considered in more detail during preliminary design before estimating actual efficiency gains and fuel savings of the triple propulsor option.

Costs

It was determined that modifying the Azipod propellers concept design arrangement to accommodate the triple propulsor arrangement would add significant collateral costs not accounted for in the propulsor study report (Reference 5). That report estimated the triple propulsor option costs as follows:

- A capital cost increase of $3M for the centerline drive train.
- Maintenance cost increase, 10 years, approximately $0.5M.

The following additional costs were determined by this feasibility study:

- Vessel length increase of ten feet, $5-6M.
- Double resilient mounts with weighted mass for two diesel generator sets, $1M.

Total added cost for the triple propulsor option is approximately $10M over and above the baseline Azipod option of $15M.

Summary

The following key findings result from this feasibility study:

- Low URN, possibly within ICES 209 requirements, may be possible with the triple propulsor arrangement.
- Some open water transit efficiency gains may be possible during non-URN-sensitive voyages.
- An increase of vessel length on the order of 10 ft is required to accommodate the Azipods and the additional propulsion motor.

- This propulsor arrangement adds approximately $10M to the capital cost of the propulsors.
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