Antarctic Research Vessel (ARV)

Engineering Report: Transducer and Centerboard Trade-Off Study

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1. Executive Summary

The Antarctic Research Vessel is a state-of-the-art ice capable research vessel supporting a broad suite of sonars and acoustic systems collecting water column data and conducting seafloor mapping. As with other research vessels, bubble sweep down over the sensors is a concern and the hull design continues to be optimized to improve this performance. The ARV hull design also has a unique challenge protecting and operating these precision systems while still maintaining good sea keeping and ice breaking characteristics. Transducers in the ice breaking hull must be protected behind ice windows or retracting into the hull during ice breaking to protect them from damage. Ice windows range in material type from titanium to high tech composites depending on the size and operational frequency of the transducers being protected.

A Box Keel was designed to house the hull mounted transducers and shaped to resist bubble sweep and ice tumble that can affect the performance of these systems. Some transducers however, particularly higher frequencies, have reduced or ineffective performance when mounted behind ice windows, so a Centerboard was also designed to house transducers without ice protective windows. The Centerboard can be raised into the hull of the ship and a closure in the hull will protect the vulnerable transducers during ice breaking activities. The Centerboard base can be flush with the hull bottom or can be extended to positions below the hull bottom to further improve resistance to bubble sweep down when operating in open water.

This study discusses the transducer mounting strategy and details the design and sizing of the centerboard as well as the prioritization and selection of the transducers placed on it.

1.1. Acronyms

ADCP	Acoustic Doppler Current Profiler
ARV	Antarctic Research Vessel
ASC	Antarctic Support Contractor
CAD	Computer-Aided Design
G&C	Gibbs & Cox, a division of Leidos
KUTI	Kongsberg Underwater Technology Inc
MAC	University-National Oceanographic Laboratory System Multibeam Advisory Committee
MRU	Motion Reference Unit
NACA	National Advisory Committee for Aeronautics
NSF	National Science Foundation
P-Spec	ARV Performance Specifications
SBP	Sub-Bottom Profiler
UNOLS	University-National Oceanographic Laboratory System
VFI	Vendor Furnished Information

2. Analysis Methodology

The analysis methodology for the Antarctic Research Vessel involves multiple layers of review and integration of information to ultimately create the best transducer arrangement for the ship's missions. The objective notional transducer suite from the P-Spec, listed below in Table 1, was reviewed for both operational frequency and known performance behind ice windows and the most effected transducers were identified and prioritized for arrangement on the Centerboard. This is used as the foundation for the design of the transducer suite and its arrangement. The design was iteratively improved until the requirements were all met including requested systems, levels of protection and interference mitigation.

After the transducer configuration and AutoCAD modeling was completed the design was reviewed by the transducers manufacturer, KUTI and by the UNOLS - Multibeam Advisory Committee (MAC) to confirm arrangement feasibility and any potential interference. The UNOLS MAC is a community-based effort with the goal of ensuring consistent high-quality multibeam data is collected across the U.S. Academic Research Fleet. As the design converges towards completion, transducer positioning will continue to be refined and reviewed by the design team, manufacturer, and subject matter experts.

2.1. Modeling Approach

The modeling approach for the transducer arrangement includes the use of Computer Automated Drafting (CAD) tools. The overall dimensions of each transducer foundation as well as installation instructions was provided by the vendor. The dimensions were then taken into AutoCAD and modeled onto the hull form outline of the vessel. Each transducer is shown on a drawing set that will represent its placement on different plan and elevation views of the ship. Some of the more sensitive transducers will need to be mounted to a retractable hull centerboard. A partial plan drawing will show the centerboard in greater detail and will also be included in the drawing set. Other sensors and transducers not mounted to the centerboard will be placed on the box keel and behind protective ice windows to keep them safe during normal ship function. Both the box keel and centerboard will be modeled as part of the AutoCAD hull form model of the ship to ensure transducer dimensions fit within the design and are accessible to the desired degree.

2.2. Assumptions & Constraints

The required transducer suite for the ARV is defined in the P-Spec and listed below in Table 1. All efforts were made to support the objective level for all of these systems and constraints from the different systems drove their placement and priority.

The EM-124 deep water multibeam sonar has a large receive array and the requirement for orthogonal placement to the transmit array heavily constrains its potential location. Fortunately, its demonstrated performance behind titanium ice windows makes this 26 foot array appropriate for placement on the box keel where it defines the widest part of the box keel.

The EM-712 shallow water multibeam sonar has titanium reinforced transducers, but they do not provide the strength and protection required for the ARV's ice breaking capability. Due to performance issues they also cannot be mounted behind ice windows. For this reason it was selected for placement on the Centerboard. The size of the transmit and receive arrays, along with the orthogonal placement requirement is the main driver for the size and width of the

Centerboard. The alternative solution was the use of a 10 ton gate valve in the hull to retract the EM-712 through for protection but this solution was not favored by the team.

The EK-80 bio-acoustic sonars are known for reduced or ineffective performance when mounted behind ice windows. This is especially true for the higher frequency bands. For this reason the EK transducers were selected for placement on the Centerboard and their arrangement was clustered to facilitate an efficient calibration process. All five objective frequencies are accommodated on the Centerboard, and due to its smaller size, the design team believes they can also accommodate an additional 333 kHz transducer, if a sixth frequency provides additional scientific value. It is also recognized that the 18 kHz and 38 kHz transducers can function satisfactorily behind ice windows, if necessary, but separating the EK transducers will increase the calibration time required and every effort will be made to keep them clustered on the Centerboard.

The ADCP sonars are known to function well with minimal strength loss from behind composite ice windows. This functionality along with the significant physical size of the 38 kHz transducer drove the selection of the ADCPs to be mounted forward on the Box Keel.

2.2.1. Sonar Protective Design

In consideration to the main objective of this ship to perform scientific studies in the Antarctic, it was decided early on that a box keel design should be considered. A box keel is a permanent appendage of the ship that protrudes from the hull. The hull design of a traditional icebreaker is poorly suited to the operation of sonar equipment. The long slant of the icebreaker's bow tends to push ice and disturbed water down and along the centerline of the hull. This disturbed water represents the potential for bubble sweep-down and ice tumble interference.

To mitigate this property of the icebreaking hull form, a centerline keel appendage is formed aft of the ice knife. The near vertical of this box keel serves to form a pressure field that excludes the surface water that has been disturbed by the passage of the ship. It is generally understood that without a box keel design of some kind the transducer suite is vulnerable to interference from bubble sweep down and ice tumble. This protective feature of the box keel allows the transducer suite to sit lower in the water from the hull of the ship which, in combination with certain geometry of the design, acts as a barrier channeling large ice and bubble sweep-down away from the transducers housed on it. This is elaborated further in Reference 2 Bubble Sweepdown Analysis and Reference 3 Hull Form Trade Off Report.

The centerboard is extendable from the box keel bottom and allows for three operational positions and a servicing position with a bottom closure. It's location on the Box Keel allows for it to take advantage of the Box Keel performance in a flush to the bottom position and also includes positions 3ft and 10 ft below the Box Keel for increased resistance to bubble sweepdown in open water and increasing sea states. When retracted a closure provides protection from ice during heavy ice breaking operations and a servicing position allows it to be raised above the water line for maintenance access.

2.2.2. Precision Survey and Benchmark Systems

A challenge with the Centerboard movement is repeatable placement and alignment of the Centerboard with respect to the ship's precision benchmark. This is particularly important for systems requiring heading inputs such as ADCPs and multibeam mapping systems. Mechanical locks at the operating positions can improve this functionality but to mitigate this issue, a Motion

Reference Unit (MRU) will be mounted on the Centerboard. This issue was also noted and communicated to the design team by the UNOLS Multibeam Advisory Committee (MAC) which has found this to be problematic on other research vessels using centerboards without MRUs.

2.2.3. Systems Maintainability

The centerboard cannot be removed from the ship. For this reason, the centerboard can be elevated within the hull to a "maintenance" position, allowing access to the instruments within while at dock, or even while at sea. This allows for the permanently mounted transducers as well as future or mission specific transducers in the two spare wells to be serviced or changed out without the need for dry dock facilities. It also allows for the forward looking camera to be cleaned and maintained for optimal performance in identifying bubble sweepdown.

The sonar installations on the box keel may be serviced in drydock but will also include exterior bolt pattern on the round transducer wells to accept a diver installed "soft patch" or "blanking plate", similar to other UNOLS research vessels. This can be used to facilitate transducer change out in a dockside setting.

The HiPAP is a vulnerable acoustic array that must be lowered below the ship's hull when in use. To facilitate this the HiPAP is mounted on the end of a spar that can be pulled up through a gate valve in the hull for protection and servicing.

The HiPAP system has a dedicated trunk, allowing retraction of the HiPAP for protection. Also, through a series of hatches through the upper decks of the ship and through the roof of the pilothouse, the HiPAP may be removed for replacement or major service.

Having the ability to access and maintain systems that are part of the centerboard, without the need for dry dock offers key advantages for servicing fixed systems and also allows for temporary installation of mission specific systems or to provide critical redundancy for certain missions. Hull mounted camera systems often foul shortly after testing and sea trials rendering them useless to detect bubble sweep, but Centerboard mounted cameras are easily maintained.

The Centerboard transducer foundations will be machined into a removable shoe. Machined foundations offer more precise position than assembled weldments with more consistent dimensional tolerance. This machined application allows for a tight fit of instruments on a high impedance foundation. This removable shoe approach has proven valuable in supporting future systems and arrangements where a prefabricated shoe assembly can be replaced in drydock to support a different transducer arrangement.

3. Evaluation Criteria

3.1. Sonar Suite

Evaluation of the quality of the sonar system design must consider several factors. Manufacturability, installation, ship and sensor maintenance and repair, position precision, ice protection and future capabilities are among the factors that were considered by the design team. First, sonars installation, alignment, and benchmarking are a time-consuming task that must occur in conjunction with several other shipyard tasks. It is important that the sonar systems should have sufficient space for technicians to install the equipment, groom the cables, route and watertight the cable penetrations and terminate in the transceiver cabinets. Ease of inspection and troubleshooting is of paramount consideration, and the team continues to develop and improve this system.

In addition to access and maintenance of the sonars, the ship itself must be maintained without the sonars creating more challenges. Keel blocking in drydock of a ship with sonar systems is a principal challenge. The ship's large sonar flat diminishes the area available for blocking. Without proactive consideration, this lack of available area for blocking may lead to heavy loads on blocks local to the sonar flat. This design must be carefully considered and planned for in advance to avoid costly rework in construction phase.

Repair and replacement of transducers is of critical concern because the ARV's drydock availability is limited. It is important to ensure as many sonar suite interventions as possible occur during regular dockside visits. Exact requirements to perform this work continue to evolve as does the understanding of the trade space. There is sufficient space in the design to allow for continued improvement of this capability.

Transducer and sonar systems requiring heading information must be referenced to the ship's benchmark survey. Due to the movement and tolerances of the Centerboard, it will include an MRU to ensure the required accuracy is met.

Sonars are sensitive instruments and not all systems and frequencies perform well behind protective ice windows. These constraints drive the final location of each transducer with the most vulnerable or affected transducers prioritized to the Centerboard.

On a ship with a lifespan such as the ARV, pre-planned product improvements must be considered in the earliest phase. The scientific sonar systems are among the most critical of these considerations. Ease of upgrade, replacement, reconfiguration, and improvement must all be nascent in the design. Spare transducer wells allowing installation of mission specialized or future instruments must be provided according to the P-Spec. Available space for incorporation of additional permanent installations should be reserved for integration of yet undetermined and undesigned capabilities. Space is currently available to support additional spare wells on the box keel for future or additional systems.

The objective transducer suite requirements for the ARV science mission is defined in the P-Spec and listed in Table 1, below. The ARV P-Spec preserves the opportunity to provide redundant instruments, or an additional range of sensors if the design allows and the science capability is expanded. With the baseline transducer suite specified the focus of the design shifts to ensuring the proper function of this equipment. All equipment must be installed in accordance with the manufacturer's recommendations for the best quality data and in such a way that transducers are not damaged by the harsh environments or conditions.

Additionally, the ARV P-Spec notes a few other distinct requirements for the transducer arrangement design. The ARV requires two spare transducer wells on the box keel for installation of mission specific equipment. These spare transducer wells are to be use for a potential guest scientist or future sonar equipment requirements. The current design includes two 22 inch spare wells but space is available on the sonar flat for additional wells, if desired. To accommodate a wide range of equipment and as there are no defining specifications for the dimensions of this specialized mission equipment, 22in diameter mounting plates has been used for each of the spare transducer wells on the box keel. The design also includes UNOLS standard 19in diameter mounting plates on the centerboard to offer a higher objective level of reconfigurability.

Table 1: ARV Performance Specifications – Notional Transducer Suite

Transducer	Details
Deep Water multibeam 10-8,000 m	Threshold: Kongsberg EM 124 (or equal) 1°x°1
Shallow water multibeam 3-3,600 m	Threshold: Kongsberg EM 712 (or equal) 1°x°1
Acoustic Doppler Current Profilers	Teledyne RDI ADCP (or equal) Threshold: 38, 75 kHz Objective: 38, 75, 150 or 300 kHz
Sub-bottom profilers	Threshold: Kongsberg SBP 29 (or equal)
Marine biology echo sounders and sonars	Simrad EK80 (or equal) Threshold: 38, 120, 200 kHz Objective: 18, 38, 70, 120, 200 kHz
USBL	Threshold: Kongsberg HiPAP or Sonardyne Ranger 2 (or equal)
Acoustic release transponder	Threshold: (1) x 12 kHz
Hydrophones	Threshold: (2) x hydrophones
Forward looking camera	Intent of camera is to be able to see bubble clouds as they pass under the hull Threshold: (1) Forward looking camera preferably in a drop keel
Forward looking sonar	Forward looking sonar may be used for navigation Threshold: (1) forward looking sonar

3.2. Sonar Self Noise

The Performance Specifications for ARV details levels of self-noise the sonar transducer locations shall not exceed as seen in Table 2 below. These self-noise levels are for the systems mentioned during a minimum sustained speed of 8 knots. Compliance with these limits shall be demonstrated during underway Sea Trials. An exception to this will be the self-noise hydrophone in the plane of the propulsors during a Sonar Self-Noise Survey.

Table 2: ARV Performance Specifications – Sonar Self-noise Level Requirements

Equipment	Frequency of Band	Spectrum Noise Level Limit
Multibeam survey system	40-100 kHz 12 kHz	35 dB 49 dB
Single beam survey systems	12 kHz 38 kHz 120 kHz 200 kHz	49 dB 40 dB 32 dB 32 dB
Sub-bottom profiler	2 kHz - 9 kHz 15 kHz- 20 kHz	9dB – 27dB 47 dB
Acoustic Doppler Current Profilers	38 kHz 75 kHz 150 kHz	40 dB 32 dB 32 dB
Acoustic navigation and tracking system	20 kHz- 30 kHz	47 dB

4. Results

4.1. Box Keel

The box keel's design considers all the parameters previously explored in this trade-off study and can be seen in Reference 4 Scientific Electronic Systems Arrangement Drawing. The shape of the box keel is designed to minimize bubble sweep-down, ice impact on equipment, and maximize transducer array performance. This design allows for inclusion of all transducers and features required by the P-Spec with considerations to future potential modifications.

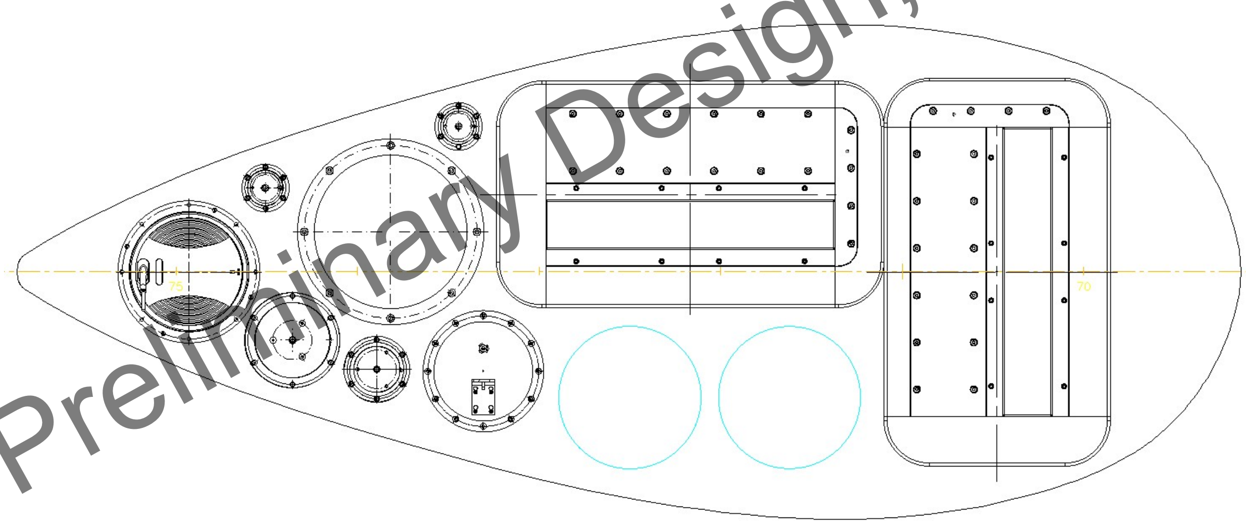
The circular transducers in the most forward part of the box keel include a speed log, acoustic release transponder, spare equipment wells, and a suite of ADCPs. Placing this equipment as the forward most of all transducers prevents potential bubble sweep-down and cavitation being likely to affect these systems as it allows for their placement to be close to the box keels centerline. This is true of all transducer arrays on the box keel but is notable due to the large area required by the multibeam arrays and SBP. The sub-bottom profilers and deep water multibeam are the largest. Placement of the transmitter both (sub-bottom profilers and deep water multibeam) is forward of the EM 124 receiver which stretches the width of the box keel. This configuration is recommended by the manufacturers material and allows for the EM 124 deep water multibeam to act as the receiver for both systems. The placement of the centerboard and HiPAP (near frame 75) is due to both systems extending past the surface of the box keel as needed. Place both the centerboard and HiPAP aft of the rest of the transducer arrays allows the telescoping systems to move without creating any potential forward interference.

It should be noted that it is important to minimize the risk of bubble sweep down and cavitation created by hull irregularities or openings forward of the transducer arrays. For this reason, the centerboard and HiPAP systems are "downstream" and aft of the box keel sonar flat. Negative effects reducing performance of any system is minimal at lower speeds and increases as the ARVs operating speed and/or sea state increases. This consideration is part of a comprehensive design approach, at the current stated speed of 8kts during the specific transducer operating condition there has been indication of reduced sonar operational performance with the current design. Details about the bubble sweepdown performance of the hull form and the transducer arrangement can be found in more detail at Ref 2 Antarctic Research Vessel (ARV): Bubble Sweepdown Analysis. This will continue to be evaluated as the design progresses.

4.2. Centerboard

The P-Spec suggests the utilization of a “drop keel” or centerboard to house certain electronics and transducers. The Centerboard on ARV provides three key functions. It provides a maintenance position where transducers can be accessed and changed out without the need for dry dock facilities. In the raised position the transducers can be protected from ice damage during ice breaking operations. Lastly, operational positions allow for placement of the transducers up to 10 feet below the hull of the ship for improved resistance to bubble sweep down as sea state increases. Our team has developed a single centerboard, which houses a complete suite of EK-80 fisheries sensors, EM 712 send and receive array, and two spare sonar installation flats.

Figure 1: Centerboard Partial Plan View



In certain conditions, such as when holding station in dynamic positioning or when navigating a track line, it may be necessary for the ship to “crab” at a bearing with an angle of attack to the actual direction of track through the water. This angle of attack presents a possibility that the flow over the centerboard may begin to stall or cavitate. To minimize this concern, the centerboard’s foil section is considered. There are myriad foil sections to choose from, those with low drag, or high lift, or special shapes as needed for special functions. ARV needs a shape that will quietly maintain attached flow at larger angle of attack. For this purpose, the NACA four-digit series has been in use for over 70 years and has proven reliable and low risk.

With the profile decided, the designer must look to the arrangement of sonars to determine the area required on bottom of the foil. The foil must be of sufficient width and length to support installation of all the sonars, subject to the profile selected.

The NACA four-digit series is defined by a formula of a non-dimensional curve, with the width of the foil as the dependent variable. The final two numbers of the NACA four-digit series are the factor in this formula by which the width is defined. For instance, a NACA 0012 foil 1000mm long will have a breadth of 12%, or 120mm on each side of the centerline of the foil. The current centerboard design utilizes the NACA 0021 series profile which provides a centerboard with a 42% L/B ratio. If more space is required, expanding the width of the centerboard up to a NACA 0022 remains a low-risk foil selection.

It is worth repeating that there are numerous foil profiles with special properties, as the ARV design continues it is possible that a foil profile that provides more capability and a larger installation will come to light, however the current NACA 0021 is a conservative selection from a hydrodynamic and space planning standpoint and recommended for this phase of development.

5. Conclusions and Recommendations

Operations of the sonar instruments on the ARV are of paramount importance to the ship's science missions. Their sustained operations and performance are a critical component of the ship design. Toward this end, the design team has studied and created a box keel appendage that will sweep aside entrained bubbles to maintain sonar system operations in increased sea states. This box keel will house the largest sonar instruments and provide bubble free bottom surface that may be utilized for future missions and for yet to be implemented sonar systems.

The centerboard system allows for removal and installation of sonar systems without drydock or use of divers, allows for repeatable alignment, and includes an MRU. Centerboard positions include a retracted position for protection in ice and three operational positions designed to provide increasing resistance to bubble sweep down in open water and increased sea states. The required sonar suite was reviewed and ranked based on its performance behind ice windows and affected transducers were prioritized on the Centerboard. The current Centerboard design accommodates all objective sonars but the ranking process has identified the most important transducers for consideration. The HiPAP USBL system utilizes a retractable pole and gate valve to facilitate servicing and protects it from damage during ice breaking.

This trade off study will facilitate the design process as it continues to evolve and be refined through collaboration with KUTI and other subject matter experts. Prioritization for Centerboard placement has been established and the various constraints have been identified with the shallow water multibeam and EK sonars being of highest importance to successfully support the science mission. The design team will continue to engage the UNOLS MAC and other subject matter experts as the final design matures.

6. References

1) ARV Performance Specifications, Rev. Change 01, 24 August 2022.
2) 5E1-050-R101: Antarctic Research Vessel (ARV): Bubble Sweepdown Analysis, P2
3) 5E1-051-R001: Antarctic Research Vessel (ARV): Hull Form Trade Off Report, P2
4) 5E1-301-D101: Antarctic Research Vessel (ARV): Scientific Electronic Systems Arrangement Drawing