Antarctic Research Vessel (ARV)

Engineering Report:

Science Systems Report

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Prepared by:

Christopher Townsend	Christopher Townsend	12/30/2022
Signature	*Print Name*	*Date*

Christopher Townsend, Principal Naval Architect, Gibbs & Cox

Checked by:

Andrew Johnson	Andrew Johnson	01/04/2023
Signature	*Print Name*	*Date*

Andrew Johnson, Principal Engineer, Gibbs & Cox

Engineered/Managed by:

Joy Carter Minor	Joy Carter Minor	01/11/2023
Signature	*Print Name*	*Date*

Joy Carter Minor D74 Department Manager, Gibbs & Cox

Approved by:

Joe Barbano	Joe Barbano	01/11/2023
Signature	*Print Name*	*Date*

Joe Barbano, EG Manager, Gibbs & Cox

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1. Executive Summary

Over the past year the ship design team has collaborated with the Leidos ASC team, the National Science Foundation, the Science Advisory Sub-Committee and numerous collaborating systems vendors and technical advisors. This foundation is necessary to take the next steps of Preliminary Design Review (PDR). This preliminary design has focused on the science missions and how these are to be incorporated into an extremely capable Antarctic icebreaking ship. This Science Systems Report (SSR) details how a flexible science workflow has been integrated into every system and function of the ARV.

The National Science Foundation's (NSF's) science operations are the primary objective of the ARV and the design and integration of science systems are divided into these design areas:

- Overboard Handling Systems
- Science Laboratories
- Science Support Spaces (Holds, Lockers, Shops)
- Science Network Infrastructure
- Scientific Sonar Suite
- Centerboard Design
- Science Seawater Systems
- Lab and Storage Van Support
- Science Work Boats

This report summarizes the National Science Foundation's Antarctic Research Vessel's science systems design and integration including the hierarchical process for design integration and requirements verification, design space trade-offs made during the design process, and measures implemented in the science systems design to adapt to future technologies.

In the subsequent pages, the overboard handling systems will be described in detail. The ship's science capabilities are closely related to these handling systems and efficient and safe operation of these systems is paramount. Throughout the preliminary design process, the overboard handling systems have been a primary design driver, and in this final round of design, the ship's arrangements have reached an appropriate level, and the detailed winch reeving plan development is under way. The efficient reeving and multiple functionalities of the winch and handling systems is a major accomplishment that will help to ensure science mission efforts are speedy and safe. Man-rated davits and cranes allow science missions to deploy fully loaded, without additional operations along the hull side.

The locations and relationships between science laboratories and science support spaces have been studied extensively, in cooperation with science advisors, the Science Advisory Sub-Committee (SASC), NSF, and the Leidos Antarctic Support Contract (ASC) team. While many details remain to be resolved in final design, the overall sizing and position of the labs has been established. They meet and exceed the requirements and provide a safe foundation for study and collaboration.

The Science Network Infrastructure has been developed to an appropriate level at this phase of design. This is a rapidly evolving field, and the design trade space remains open for integration of future technologies.

The scientific sonar suite and centerboard design are tightly integrated with the ship hull design as bubble sweepdown, and ice impact are critical concerns to this equipment and are factors principally influenced by the ship's hull shaping. The centerboard can carry all sonars that perform poorly under ice windows, and all the requirements for the sonar suite are met. The hull design requires additional study, as the bubble sweepdown performance has room for improvement. The opportunity to further fine-tune the hull design may also result in improved open water efficiency, although range and endurance requirements are currently being met.

Science seawater systems are essential to good science and tight integration with ship systems and, with the science laboratory arrangement, are of paramount importance. The ARV science seawater system provides for two parallel systems: one for high volume delivery of scientific seawater, and the other for lower volume. The low volume system in particular has a de-bubbler and low shear type pump that will help to prevent damage to sensitive organisms within the seawater. The ship has multiple sea chests, to allow for access to scientific seawater in a variety of operational conditions.

Lab and science support vans are an essential component of the ARV's science capabilities. Problems with stowage of these vans in the Research Vessel (RV) Gould and RV Palmer have been noted, and the ARV's science hold will include guided roller tracks and International Standards Organization (ISO) locks for moving and securing of these containers. In total, 20 standard 20ft ISO vans can be readily accessed on the ARV with additional opportunity to exceed requirements by stacking containers. The ARV includes a van garage which allows science team members to access three of the vans from within the climate-controlled interior of the ship.

The science work boats have been integrated into the ARV design without compromising the science workflow. These boats will bring tremendous capabilities to the science parties and may be launched from dedicated davits or from the port main crane. The davits and cradles from these workboats can be reconfigured to support other workboats depending on Science Mission Requirements (SMRs).

The design and integration of science systems into the overall vessel design supports the successful science mission execution and performance as specified in the ARV SMR. The science systems integration is guided by the Performance Specification (PSPEC) and through consultation with science advisors, the SASC, NSF, and the Leidos ASC team. Gibbs & Cox (G&C) employs an interdisciplinary and iterative design spiral methodology for science system design integration. Particular attention is given to design areas that impact multiple engineering disciplines and different areas of the vessel including workflow between science handling systems and science laboratories, science underwater sensor integration with the hull form and hull structure, and inter-compartment systems such as the science seawater system, science wireways, and science network infrastructure.

The design team uses input from various experts including equipment vendors, design team members with past experience (operational field experience and similar previous designs), customer comments and recommendations, input from the academic community (NSF SASC and science and technical advisors), the ASC Science Advisors, and specific subject matter experts and committees. Working group meetings are sometimes used to coordinate design inputs among multiple stakeholders. G&C also works closely with equipment vendors throughout the design process to ensure that equipment integration with the vessel systems is a fully functional design and that the design is reliable, serviceable, and able to operate in the extreme environmental conditions specified in the PSPEC. As the ARV design continues to mature, and Vendor Furnished Information (VFI) is available, the design and integration of the science systems will continue.

Risks and areas of non-compliance are also noted for specific design areas. Critical areas of concern include:

- Bubble Sweepdown
- Icebreaking while towing
- Impact of side frame foundation on wet lab and aquarium
- Personnel transfer to ice shelf
- Personnel transfer to small boats
- Personnel access to water surface for glider/Autonomous Underwater Vehicle (AUV) recovery
- Locating incubators in non-shaded area
- Centerboard deployment and retrieval method
- Aft Deck Working Crane

The concern over bubble sweepdown performance is further detailed in the model test results and, in the bubble sweepdown analysis, but can be summarized by stating that bubbles from the free surface of the water have a significant risk of sweeping down the current hull design and impinging upon the performance of the EM-124 receive array. This risk will be further studied in the Post-PDR phase and the hull design will be adjusted to obtain better performance.

In icebreaking model testing, there was substantial ice impact with the propulsors and significant ice impinging upon the clear channel astern of the ARV. This would interfere with operations of towed array, seines, or other equipment while in heavy icebreaking conditions. This concern may be best addressed by adding a downrigger at the stern which will allow a lower rigging point for any towed instruments or equipment. This is also commonly addressed by biasing the azipods outboard to blow the channel clean. Finally, the current hull redesign work related to bubble sweepdown has the potential to address this concern. In the next round of hull studies this towing in icebreaking will be further considered.

The starboard side A-frame foundation has not been designed. It is anticipated that this foundation will be tightly integrated with the ship's house structure. This foundation design may encroach upon the area accounted for within the wet lab and aquarium. It may be necessary to reduce the staging bay area to continue to meet requirements for the wet lab and aquarium.

The details of access from the ship to the water or ice surface remain to be addressed. There are a number of solutions, including a hull side access, a landing platform, and gangway that all have strengths. These will be vetted and integrated into the final design.

Deck incubators may be supported in several non-shaded areas of the ship deck. Specific solutions are subject to trade space with the main cranes and with the science workboat storage. This requirement will be supported with high volume scientific seawater, and the details of this design will be addressed in final design.

Specifics of the system for raising and lowering the centerboard have not been provided. There are a number of suggested solutions on the table, but this detail will be constrained within the builder's spec, and implemented by the builder, so this has not been taken to a higher level of design.

The SMR and PSPEC call for the smaller aft deck working crane to be "portable". This crane currently calls for a 40 ft reach and a 4000 lbs. safe working load in Sea State 5. Generally, these requirements are incompatible with the requirement to be portable. In the post-PDR phase, these requirements will be reviewed with the NSF and ASC teams and a suitable crane will be designated.

From the concept design and the SMRs, the foundations have now been built beneath them that will support the science requirements. In final design these risks will be retired and the level of detail of the design will be completed and prepared for construction design.

2. Acronyms

ADCP	Acoustic Doppler Current Profiler
ARV	Antarctic Research Vessel
ASC	Antarctic Support Contract
AUV	Autonomous Underwater Vehicle
CCB	Configuration Control Board
CCP	Configuration Control Plan
CPVC	Chlorinated Polyvinyl Chloride
CTD	Conductivity-Temperature-Depth
DRM	Design Reference Mission
G&C	Gibbs & Cox
HVAC	Heating, Ventilation, and Air Conditioning
IPT	Integrated Product Team
ISO	International Standards Organization
KPP	Key Performance Parameter
KVM	Keyboard, Video, Mouse
LARS	Launch and Recovery System
MMO	Marine Mammal Observatory
NSF	National Science Foundation
PCS	Piston Coring System
PDR	Preliminary Design Review
PSPEC	Performance Specification
RHIB	Rigid-Hull Inflatable Boat
RIG	Research Infrastructure Guide
ROV	Remotely Operated Vehicle
RV	Research Vessel
SASC	Science Advisory Sub-Committee
SMR	Science Mission Requirements
SOC	Science Operations Center
SSR	Science Systems Report
TCB	Technical Control Board
TMC	Trace Metal Clean
UNOLS	University National Oceanographic Laboratory System
USBL	Ultra-Short Baseline
USCG	United States Coast Guard
VFI	Vendor Furnished Information
WLL	Work Load Limit

3. Analysis Methodology

The analysis methodology for the NSF's ARV science systems design and integration is a hierarchical process. The hierarchy employed by G&C, is to design and develop a vessel concept, including design and integration of science systems, which satisfies the principal Key Performance Parameters (KPPs) for an oceanographic research vessel serving the NSF Antarctic science operations in accordance with the specified SMR, Reference 1). The NSF science operations are the primary objective of the ARV. The requirements that need to be verified by evaluation are the 90 days endurance using a Design Reference Mission (DRM) and the various modes of operation defined in the DRM and meeting the Range of 17,000 NM at ≥11 kts in calm water. The requirements that will need to be proved by test during sea trials are a sustained cruise speed of ≥11 knots and a maximum speed of ≥14 knots in calm water.

As the science capabilities of the ARV are of paramount importance, meeting the science needs is the foundation of the ship's arrangement design. Beginning with the aft working deck, and side working deck, the capability to support a minimum 40m piston core, with an objective of a 50m piston core is a driving concern. Other constraints on the working deck design are van storage, workboat storage, and science hold access. Additionally, all these systems must be accommodated while concurrently encouraging excellent visibility and communication. This large aft and side working deck are one of the primary constraints driving the overall length of the ship.

Many of the science labs require ease of access to the main and side working decks. The staging bay, marine tech shop, changing room, lab vans and carpenter shop all need ready access to the main deck. The Baltic room, wet lab, aquarium and staging bay all should have immediate access to the side working deck. The placement of these labs near the working decks also presents the opportunity to service them all with the main cranes. This also is an essential consideration in the overall arrangement of the decks.

Science lab and storage vans will need to be accommodated in the science hold and on deck. These locations all must work with the main cranes and without interfering with the other critical science mission operations. Vans may be accommodated in a designated location provided with ISO container locks or may be located in non-designated locations with an ISO lock adaptor plate using the deck bolt pattern. On locations with a dedicated in deck ISO lock, the lab and storage vans may be double stacked, so this also should be considered as a limiting constraint/capability.

Efficient flow of scientists, proximity of samples and supplies, and safe working environment were the primary drivers influencing the science laboratory arrangements. Heavy samples or supplies may need to be moved between labs, or from the science storeroom. Chemicals and reagents will need to be hand carried between the labs and the science HazMat locker. Similarly, working quantities of liquid nitrogen will made on the main deck LN2 plant to support needs in the science labs. All these considerations and more must go into the layout of the labs.

The hierarchically indentured objectives that fall under this primary objective are the design and integration of science mission equipment and outfitting such as:

- Overboard Handling Systems
- Science Laboratories
- Science Support Spaces (Holds, Lockers, Shops)
- Science Network Infrastructure
- Centerboard and Box Keel Design

- Scientific Sonar Suite
- Science Seawater Systems
- Science Support Boats
- Lab and Storage Vans

The design and integration of science systems into the overall vessel design supports the successful science mission execution and performance as specified in the ARV SMR in compliance with the NSF Research Infrastructure Guide (RIG), Reference 2). The hierarchical methodology continues into a prioritized parent/child organization of the requirements in the ARV PSPEC, Reference 3), such that scientific mission spaces are finalized in a sequential fashion by priority and by family (i.e., parent/child groups). Requests for changes to the requirements or baseline design will be processed through the ARV Configuration Control Board (CCB) and/or Technical Control Board (TCB) in accordance with the ARV Configuration Control Plan (CCP), Reference 4), and the ARV Performance Requirements will be amended, as needed.

The ARV KPPs are for the vessel to:

- Be classed Polar Class 3
- Break through surface ice that is ≥ 4.5 feet thick at ≥ 3 knots
- Operate at sea for ≥ 90 days without reprovisioning, refueling, or needing maintenance beyond the organizational level in compliance with the Design Reference Mission
- Accommodate on board living spaces and support for the ARV’s 29 crew and for at least 55 scientists and technical personnel
  Additional priority requirements
- Steam at cruise speed (≥ 11 knots) for at least 17,000 nautical miles (nm)
- Dock at Palmer Station, Antarctica
  Have excellent bubble sweepdown performance supporting low sonar self noise for sonar systems operation
- Capable and maneuverable ice breaker able to gain access to previously inaccessible areas of scientific interest
- Modern multi-role scientific winches and handling systems to support broad scientific efforts including over the side handling and towing requirements
- Provide scientists with a modern ice breaking research vessel capable of concurrently executing multiple scientific research missions.

In this second tier of the hierarchical approach, the design trade space is examined for compartment size and location – to examine trade-offs in the overall vessel design and arrangement, integration of and location between different science spaces, and for compliance with the individual compartment size, location, and outfitting requirements. Simultaneously, G&C employs an interdisciplinary and iterative design spiral methodology for compartment arrangement to evaluate and balance design space tradeoff decisions for electrical and mechanical systems integration. The design team uses input from various experts including equipment vendors, design team members with past experience (operational field experience and similar previous designs), customer comments/recommendations and input from the academic community. Also, working group meetings are sometimes used to coordinate design inputs among multiple stakeholders. G&C works closely with equipment vendors and technical subject matter experts throughout the design process to ensure that equipment integration with the vessel systems results in a fully functional design and that is reliable, serviceable, and able to operate in the extreme environmental conditions specified in the Performance Specification, Reference 3). Adaptability for future technologies is provided in the design as part of the required design margins in accordance with the Performance Specification, Reference 3), and equipment removal studies.

Throughout the Preliminary Design Phase, the SASC, NSF, and Leidos ASC team have provided input on design elements and the design has been revised in response to this input.

If customer requirements change, the interdisciplinary design team evaluates the need to update the design drawings as part of the ARV CCP and also as new or updated VFI is received. Problem areas and the status of the evolving ARV design maturity will be evaluated for potential risks (and associated mitigation measures). Throughout the design process, G&C uses a regular screening process to ensure that the ARV design is compliant with the configuration-controlled requirements. The regular design screenings ensure that during the Preliminary Design Phase, the ARV design reflects the available VFI and design convergence is achieved across all drawings.

4. Science Systems Integration/Approach

The science systems integration is guided by the Performance Specification, Reference 3), the SMR Reference 4 and design methodology described in Section 3.

The science operations have been studied and discussed continuously throughout the design process. The specific workflow of various science operations has been considered in the layout and positioning of all of the science labs and their supporting spaces and equipment. Safety and efficiency of these operations is a driving consideration in the design and layout of the science systems.

The handling equipment and compartment location is designed to meet the requirements while optimizing functionality and facilitating the movement of scientific samples across the working decks and throughout the main deck laboratories.

The main working deck is large and multi-functional, supporting over boarding operations off the stern and starboard side utilizing capable A-Frames on the fantail and mid ships. The aft working deck has direct access from the main passageway and adjoining change/mud room, the Staging Bay and Marine Tech and Carpentry Shops with ample room for Lab Vans, containers and deck equipment. The starboard working deck has direct access to the Staging Bay, Aquarium Room, Wet Lab and Baltic Room. The main deck incorporates standard UNOLS 2’x2’ bolt pattern and removable bulwarks to provide flexible support solutions for unique, mission specific and future deck systems.

The main deck passage way provides wide unobstructed access without turns through the science laboratories, from the working deck all the way to science stores in the fore peak. All primary science labs are located on the main deck along with critical support spaces, shops and storage for laboratory equipment and chemicals. The aft winch control station, located above the Staging Bay, can support all science winch operations with a clear view of the stern and starboard working decks.

The Baltic Room is sized to support excellent access to the Conductivity-Temperature-Depth (CTD) rosette for all concerned scientists and provides an observation window from the ship reception area on the 01 Deck. The CTD winch control station provides a clear and unobstructed view of the entire starboard waterline as well as a view inside the Baltic Room, allowing for coordinated cast preparation and safe deployment of the CTD Launch and Recovery System (LARS).

The 01 weather deck supports science support small boats and has seawater supply to support deck incubators in a protected location off the main deck. The forward Aviation Deck and Hanger support a wide range of fixed and rotary wing aerial drones for both science support needs and ice reconnaissance. The deck can support several Lab Vans to support atmospheric sampling or other mission specific needs and has sea water supply to support deck incubators. The 01 deck and forward aviation deck are also fitted with the standard UNOLS 2’x2’ bolt pattern.

The integration of science handling equipment and science spaces, particularly location, also improves the overall design of the science wireways and multi-cable transits between compartments.

Additional details are included in the sections below for the design integration/approach, trade-offs, and risks for specific aspects of the ARV science systems, including compliance with the PSPEC, SMRs, and in process ECRs.

5. Design Integration/Approach

5.1 Overboard Handling Systems

The ARV science overboard handling systems are located in four areas of the vessel: Aviation Deck, Main Working Deck, Starboard Working Deck, and the Baltic Room, on the starboard side forward of and adjacent to the starboard working deck. The ARV overboard handling systems integrate winches, A-frames, cranes, and LARS to comply with the PSPEC, Reference 3), SMR, Reference 4, and Appendix B of UNOLS Research Vessel Safety Standards, Reference 9). Details of the ARV overboard handling systems are included below and the arrangements are shown on the drawing 5E1-403-D001 Handling Systems and Scientific Package Development Drawing, Reference 5).

5.2 Winches

The science winches are located in two winch rooms. The Lower Winch Room is located aft of the Main Engine Room below the main deck on the First Platform. The Upper Winch Room is located on the 01 Deck, starboard side aft of the Baltic Room and directly inboard of the Side A-Frame. The permanently installed science winches are located in either the Upper Winch Room or Lower Winch Room, as detailed in Table 1. In addition to permanently installed winches, portable and mission specific winches may be mounted on the working deck area using the standard UNOLS 2’x2’ deck bolt pattern. All the winches will have a wire washing system in compliance with Appendix A of UNOLS Research Vessel Safety Standards, Reference 9).

The CTD Winch is an active heave compensated, direct drive hydrographic duty winch designed specifically to support CTD rosette operations from the Baltic Room. It is located forward in the Upper Winch Room and directly serves the CTD LARS located overhead in the Baltic Room. The drum is currently planned to carry UNOLS standard Rochester .322 EM cable (10,000+ m), but level wind and shells can be adjusted to support future CTD strength member solutions, as they are developed. The CTD winch is the most highly utilized of the science winches supporting CTD rosette casting for all science users.

The Hydrographic Winch is an active heave compensated direct drive winch for general hydrographic sampling serving the Starboard A-Frame. It is located in the Upper Winch Room and will be matched with the CTD Winch for spares commonality. It will have the capability to be re-rove to the CTD LARS in the Baltic Room, in order to back up the CTD Winch. It will also be able to be rove to support the stern A-Frame, for lighter towing needs astern. The drum is currently planned to carry UNOLS standard Rochester .322 EM cable, but level wind and shells can be adjusted to support a strength member between ¼”-1/2” (10,000 m).

It has been noted that the Hydrographic winch fills a quite necessary role backing up the CTD winch and supporting general vertical casting needs on the starboard side, but it is often under-utilized over the life time of the vessel. In order to improve overall performance and reliability the CTD and Hydrographic winches will be matched and co-located in the upper winch room on turn tables. This will allow the winches to share spares and consumables while being easily re-rove to support either starboard A-frame or Baltic Room operations. Primary application of each winch can be rotated to balance the use and wear of both winch and strength member, over the operational life time of ARV

The Coring Winch is an actively heave compensated single storage drum traction winch system. It is located in the Upper Winch Room and primarily serves heavy piston coring operations at the Starboard A-Frame. It is currently planned to carry 7,000 to 10,000 m of ¾” synthetic rope with a nominal break strength of 100,000 lbs. It can also be re-rove to serve the Stern A-Frame to better support deep water rock dredging operations that are currently poorly supported on steel wire rope.

The Oceanographic Winch, located in the Lower Winch Room, is an active heave compensated, double storage drum, traction winch system. The current design employs two storage drums and slack line compensators serving a double drum traction head. The double drum traction head can switch drive between the two traction heads while the strength members remain rove. This will allow easy switching between operations without the need to re-rove a traction head, if the other strength member is required. The Oceanographic winch serves primarily the stern A-frame and can also be rove to the Starboard A-Frame or utilize the Port Main Crane for over boarding. The two drums are currently planned to carry the UNOLS standard strength members 9/16” 3x19 torque balances wire rope (12,000 m) and Rochester .680 EM/FO cable (10,000 m), however traction and reeving sheeves can be switched out to support future or unique mission specific strength members of different diameters, as required.

All winches are driven by electric motors, which may be used as generators to recover energy as the load is being lowered.

The Hydrographic and CTD winches are matching, and the Hydrographic winch may be mounted on a turntable so that it can also support operations utilizing the Aft A-Frame and also the Starboard Main Crane.

Both the Oceanographic and Piston Coring Winches include a traction winch and uptake reel. In the case of the Oceanographic winch, a second traction winch, slackline compensator, and uptake reel may be supported.

The Oceanographic Winch may be led to the Aft A-Frame and also may be reeved to the Starborad A-Frame or Port Main Crane.

The Coring Winch may be reeved to the Starboard A-Frame, Aft A-Frame, or Starboard Main Crane.

Table 1: Science Winch Types and Quantity

Type	Quantity	Capacity	Notes
Hydrographic Winch	1	• Coaxial electro-mechanical (EM) cable or fiber-optic cable, 10,000 meter (m) length, 0.25-inch to 0.50-inch diameter	• Located in Upper Winch Room • Serves either Baltic Room LHS or Side A-Frame • Active Heave Compensated • Serves as backup to CTD Winch • Can also serve Aft A-frame
Oceanographic Winch	1	• Torque balanced wire rope, 12,000 m length, 9/16-inch diameter 3x19 wire rope, or • Fiber-optic cable, 10,000 m length, 0.681-inch diameter, or • Coaxial EM cable 10,000 m length, 0.680-inch diameter • Slack Line Compensator to support operations in up to sea state 4.	• Located in Lower Winch Room • Serves Stern A-Frame and portable LARS on the aft working deck crane(s) via a sheave tower with instrumented sheave • Active Heave Compensated • Traction winch with slack line compensator and level winds • Two storage reels with level winds, one for each wire, each reel is supported by its own traction winch and slack line compensator • Selectable dual drive drum allows both strength members to remain rove while switching between strength member in use
Conductivity-Temperature-Depth (CTD) Winch	1	• EM cable, 10,000 m length, 0.322-inch diameter	• Located in Baltic Room • Integrated with Baltic Room LHS/docking head • Active Heave Compensated
Coring Winch	1	• Cable (steel or synthetic), 7,000 m threshold or 10,000 m objective length, ¾-inch diameter, 100,000-pound (lbs.) nominal breaking strength	• Located in Upper Winch Room • Serves Side A-Frame to support coring loads • Capable of 80,000 lb line pull • Traction winch with slack line compensator and level winds • Active Heave Compensated • May be rove to Stern A-Frame or Starboard Main Crane

5.3 Cranes

The ARV is fitted with four (4) knuckle boom cranes: Port Main Crane, Starboard Main Crane, Aft Working Deck Crane, and the Forward Crane.

The Forward Crane supports stores loading operations from hold to shore, and also supports operations on the Aviation Deck and Forward Hangar including light duty over the side science operations. In order to facilitate aviation operations, create efficient structural load paths, and present a clean look, the Forward Crane is integrated with the forward house structure. The Forward Crane is personnel rated for lifting.

The Starboard Main Crane is located on the aft end of the starboard side of the pilot house. It is able to reach from dockside to the Cargo Hold Hatch, carrying a lab van of over 25,000 lbs. The working radius of the Starboard Main Crane and Port Main Crane overlap so that loads may be transferred over the entire Main Working Deck or the Starboard Working Deck. This crane is used in conjunction with the Piston Core LARS system to deploy the piston core handling truss. The Starboard Main Crane is personnel rated for lifting.

The Port Main Crane sits at the aftmost extremity of the Port side house. In order to take advantage of existing ship design structure the crane sits tangent to the aftmost bulkhead of the house, centered on a longitudinal bulkhead. The Port Main Crane can support over boarding operations on the port side of the ship, and services the Boat Deck on the 01 Deck as well as the Lab Van Garage and the Science Hold Hatch. The Port Main Crane is personnel rated for lifting.

Both of the Main Cranes may be reeved with cable from the winches which will allow for active heave compensation, a capability that the two cranes otherwise do not possess.

The Aft Deck Working Crane is a light weight utility crane that is required to use the main deck bolt pattern to secure it to the working deck. Given the range and sea state requirements currently, making this a portable bolted crane is a design issue that has not been resolved at this time. This crane is designed as a versatile mission specific solution for staging deck gear and sampling systems between sampling operations. It is also capable of supporting the over boarding of light science packages and cargo loading and unloading from small boats alongside. Due the proposed portable bolted aspects of this crane is will not be personnel rated for lifting

Table 2: Crane Types and Capacities

Type	Quantity	Capacity	Notes
Port Main Crane	1	• SS5-SS6: 20,000 lbs. / 40 ft. • In Port: 67,200 lbs. / 65 ft.	• Located Aft Working Deck, Port Side • Personnel Rated
Starboard Main Crane	1	• SS5-SS6: 20,000 lbs. / 40 ft. • In Port: 67,200 lbs. /65 ft.	• Located Starboard Working Deck, Starboard Side • Personnel Rated
Aft Working Deck Crane	1	• SS5: 4,000 lbs. / 40 ft.	• Portable Crane attaching to deck bolt grid pattern • Located Aft Working Deck, Starboard Side • Portable, attaching to deck bolt pattern *
Fwd. Working Deck Crane	1	• SS5: 4,000 lbs. / 40 ft.	• Located Fwd. Flight Deck, Starboard Side

*Subject to vendor design and regulatory approval

5.4 A-Frames

The ARV is fitted with two (2) A-Frames located on the main deck to serve the Aft Working Deck and Starboard Working Deck.

The Stern A-Frame supports all over boarding and towing operations astern and is primarily served by the Oceanographic Winch, in the Lower Winch Room. The Stern A-Frame will support a wide variety of science activities with 30 feet of vertical clearance and strength members up to 120,000-lb break strength. These activities include operations such as benthic and mid-water net tows, light coring operations, piston coring operations, dredging or dragging operations and the deployment and recovery of seismic, geo-technical drilling, Remotely Operated Vehicle (ROV)/AUV systems and oceanographic moorings. It will also include a "servicing position" to facilitate block maintenance and change out, without the need to go aloft. The A-Frame will have integrated tugger/utility winches to support load trading, over boarding and deck operations. Although primarily served by the Oceanographic Winch, the stern A-Frame is also able to support coring and hydrographic warps rove from Upper Winch Room.

The Starboard side A-Frame supports general over boarding and towing from the starboard side deck. It also serves as a back-up load handling solution for the Baltic Room LARS supporting the CTD or Trace Metals Rosette. The A-Frame will support a wide range of vertical casting and towing operations on the starboard side. It is noted that side towing in ice conditions can often be impractical. The Starboard A-Frame is able to be served by the Coring Winch, the Hydrographic Winch or the CTD Winch. The location and rating of the Starboard side A-Frame is particularly driven by the need to support up to a 50m Piston Corer on the starboard working deck using a large diameter synthetic strength member.

Details for the ARV A-Frames are included in

Table 3. As the ARV design continues to mature, and VFI is available, the design integration of the A-Frames will continue. This is in accordance with the Performance Specification Reference 3 and includes evaluation of load cases and environmental conditions, evaluation of the inboard and outboard reach including winch-wire routing, and evaluation of controls and control panel locations.

Table 3: A-Frame Types and Capacities

Type	Quantity	Capacity	Notes
Stern A-Frame	1	• 40,000 lbs. through full motion • Cables up to 1-inch diameter with 120,000 lbs. nominal breaking strength	• Located at the transom, Aft Working Deck on centerline • 20.5 ft. clear width • 30 ft. vertical clearance (attachment point of block to deck) • Structural stops at the outboard reach position and 12 ft. inboard reach position • Angular range of motion to be developed with A-Frame vendor including outboard reach position and inboard maintenance position
Side A-Frame	1	• 40,000 lbs. through full motion • Cables up to 1-inch diameter with 100,000 lbs. nominal breaking strength	• Located Starboard Working Deck, aft of Baltic Room at Frame 94 • 15 ft. clear width • 25 ft. vertical clearance (attachment point of block to deck) • 10 ft outboard reach position • Variable speed up to 2 degrees per second (deg./sec.)

5.5 Baltic Room LARS Hydroboom

The Baltic Room is located on the Main Deck, starboard side, forward of the Side A-Frame and Starboard Working Deck. The size of the Baltic Room LARS Hydroboom is a key design driver for the size of the Baltic Room compartment. The Baltic Room/CTD Launch and Recovery System is a positive capture articulating boom assembly, located in the Baltic Room overhead and designed specifically for the CTD rosette. It is primarily served by the CTD Winch, but can also be served by the Hydrographic Winch, both located in the Upper Winch Room. The CTD LARS will have a Work Load Limit (WLL) of 20,000 lbs. with a docking head that can swing out of position to facilitate traditional reeving to support other science payloads. The CTD LARS is capable of supporting a side load up to 6,000 lbs.,

This is in accordance with the PSPEC Reference 3) and includes evaluation of load cases and environmental conditions, evaluation of the inboard and outboard reach including winch-wire routing, and integration with other Baltic Room outfitting including controls and control panel locations.

Table 4: CTD LARS Type and Capacity

Type	Quantity	Capacity	Notes
LARS Hydroboom	1	• SS5: Maximum working load of 20,000 lbs. • Safe working load of 6,000 lbs in the towing configuration. Design loads applied at angles of up to 50 degrees from vertical.	• Minimum Extension over the side of 12 ft. • Maintains positive control of CTD through range of motion extending to the water surface • Over-the-side equipment shall have a 12 ft. clear vertical height over the Main Deck • Capable of positioning the design package from full inboard to full outboard locations in less than 30 seconds

5.6 Piston Core-Handling Launch and Recovery System (LARS)

The ARV is fitted with a substantial Piston Coring System (PCS) to support marine geology and geophysical missions.

The Piston Coring LARS consists of a truss system, to support the length of the core barrel, and a handling system to maneuver the truss between vertical and horizontal, as well as inboard and outboard. The Piston Coring LARS is located just aft of the Baltic Room on the Starboard deck. The LARS and the Starboard Main Crane are used to rotate the truss from horizontal to vertical and then the LARS moves the truss under the Starboard A-frame to pick up the Piston Corer and then moves the truss forward away from the Piston Corer for deployment. The process is reversed for recovery and the LARS decouples and supports the Piston Corer head weight while the core liner is extruded forward into the Baltic Room.

The design point for the LARS is a piston corer minimum rigged length of 6 meters and maximum rigged length of 50 meters with a design weight of 22,000 lbs. The LARS supports four positions: Position 1 (Vertical), Position 2 (Outboard Horizontal), Position 3 (Inboard Horizontal), and Position 4 (Stowed). The piston core LARS truss is modular and can be broken down into sections that fit onto a 20ft flat rack for stowage on main deck or within cargo hold. As the ARV design continues to mature, and VFI is available, the design and integration of the LARS will continue. This is in accordance with the PSPEC Reference 3) and includes evaluation of load cases and environmental conditions, and winterization details including protection from ice abrasion at the ice line and heating when stored on deck. Once the truss is stowed inboard the LARS will be used to de-couple the head weight to facilitate core extrusion forward in the shelter of the Baltic Room and on to the Main Lab.

6. Science Laboratories

Per the ARV PSPEC, Reference 3), there are outfitting and arrangement requirements that apply to all science laboratories and specific requirements for individual compartments. All laboratories, except for the Cold Storage Laboratories, are located on the side-shell of the vessel fitted with dual portholes to the maximum extent possible for natural light – this includes the Aquarium Room which exceeds the area minimum requirements. Flexibility is provided by the laboratory outfitting and arrangement for the ARV to adapt to future technologies. Outfitting furniture and shelving designs leverage modular design to optimize arrangement within each compartment. This optimization facilitates replacement, allows for adjustable workbench and shelving heights, and provides tie-down or securing arrangements on decks, workbench tops, and bulkheads for onboard equipment configurations that vary voyage-by-voyage.

Strong efforts were made to locate the main science working spaces on the main deck with a continuous and unobstructed passage way running from the forward science stores to the working deck. The passageway is wide enough to accommodate a standard pallet jack to facilitate movement of samples, equipment, and supplies fore and aft. Spaces were arranged moving forward from the working deck placing the wettest spaces starboard and aft, and the driest spaces port and forward. Proximity was also considered to ensure an efficient and smooth movement of science samples. Access to the working deck utilizes large watertight double.

Details of the ARV science laboratories outfitting and arrangement are shown on the drawing 5E1-601-D001 Science Space Arrangement Drawing, Reference 6). Maximum customization of the laboratories for different science missions will be provided using Unistrut outfitting of the labs on the bulkheads and in the overhead along with a 2x2 grid of deck sockets. All labs are of size and equipage that meets or exceeds ARV PSPEC Requirements.

The Science Operations Center (SOC) is the central hub of active data collection and able to monitor science operations underway. It is sized to support stand up meetings of the entire science crew during watch change. It supports a large wall of monitors and the science systems racks, with a central watch desk position flanked by CTD and mission specific workstations and a large display/chart table. It will also support a Multi Beam work Station and modular bench top stations for science party members on that watch to have laptops and/or displays. The SOC allows the Chief Scientist and Watch Leads to monitor and direct active science operations. It is adjacent to the Main Lab, and is near the Microscope Room, the Main Elevator, and the stair tower. It's central location near the Hydro and Bio Labs, Electronics Tech Shop, Computer Lab, Server Room, Transceiver Room and Science Stores make the SOC the nerve center of the Science Mission.

The Main Lab has been arranged to also optimize piston core extrusion workflow. The double doors into the Baltic Room align with the Baltic Room's double doors to the Starboard Working Deck to facilitate the movement of long core sections through the Baltic Room into the Main lab for description and sub-sampling and then across the central passage way into the Cold Lab for storage. The Main Lab has been designed to be readily reconfigurable, with two large fume extraction hoods and sinks along the sides of the lab, and modular work tables arranged along the interior of the lab. The sink supplies and drains supporting the interior workbenches may be disconnected and made flush to the floor in case they are not needed in the preferred lab arrangement, depending upon the mission.

The Bio/Chem/Analytical Lab is on the port side between the Hydro Lab and the Electronics Lab. This lab supports a variety or disciplines in a configurable space but it is also located furthest from the live animal/wet spaces to better isolate fixatives and other chemicals. It also two large fume extraction hoods.

Numerous commenters have found that the Electronics Tech Lab, which is just forward of the Biology Lab, is larger than needed, and the Biology Lab may be enlarged as volume is removed from the Electronics Tech Lab.

The Hydro Lab has close proximity to the Baltic Room, Main Lab and Bio/Chem/Analytical Labs, The science seawater system serves the Water Wall with fixed flow through sampling instrumentation and contains a climate-controlled space for a Salinometer Room. . Attention was spent to ensure that the space was large enough to accommodate both current and future flow through instrument needs as well as mission specific instruments while maintaining a configurable lab space. It also has both a small and large fume extraction hood. Based upon comments, the Hydro Lab has been designed larger than the PSPEC's minimum area requirement.

Both the Hydro Lab and the Biology Lab have direct access to the large central hallway with direct access to the aft Science Reagent and Hazardous Material Storage Locker.

The Computer/Electronics Lab is on the port side, opposite the SOC, and has easy access to the Main Lab and to the central hallway. The Computer/Electronics Lab is a configurable dry space to support scientific electronics, instruments and sensor assembly, servicing and trouble shooting. It has bench space to support CTD assembly, battery charging, acoustic release servicing, camera/video systems and other housed assemblies. Workbenches are modular and may be used to secure workpieces. It also has printers and over-sized plotters along with a video/photo editing works station and a 3-D printing workstation.

The Microscope Room has space for three microscopes, including a Keyboard, Video, and Mouse (KVM) to support each. A small Chem locker is provided for reagents and other chemicals., and the Microscope Room is directly adjacent to the central hallway with immediate access to the exterior HazMat locker. The microscopes will be installed on vibration isolation tables. The room is located in a place of minimal motion and with the ability to darken the space for fluorescence or photographic needs.

The Baltic Room is accessed by a 6ft double door into the Wet Lab, the Main Lab, and also onto the Starboard Working Deck. It is the primary deployment and recovery area for water sampling rosettes. The CTD LARS is deployed through a door through the hull side. The Baltic room is expected to be a wet space, and as such has substantial deck drains, washdown facilities, as well as the standard 2' x 2' bolt down grid. There is an overhead viewing area for the Baltic Room in the ship's reception area, and the space available has been optimized for many hands to access the CTD concurrently when it is recovered. The CTD LARS and CTD winch may be operated from the Baltic Room Control, which has unobstructed view of the starboard waterline as well as a commanding view of the Baltic Room operations. Backup controls for the CTD LARS and CTD Winch are available from the main winch control cab.

The Wet Laboratory is located aft of the Baltic Room for transfer of scientific samples from the Side A-Frame and Starboard Working Deck. The wet lab has oversize drains and may be equipped with a sill-less roll up door aligned with the Starboard A-Frame to facilitate operations involving the Starboard Working Deck, including trace metal operations utilizing a portable trace metals winch with specialized sheaves. The other laboratories are located on the port and starboard side of the vessel forward of the Baltic Room. All of the main deck labs are designed to facilitate accessibility for disabled science crew members. Double doors to facilitate equipment loading/unloading are provided for all science spaces located on the main deck. As required, the laboratories listed below are located on the main deck with access to the working deck area and a 72-inch-wide longitudinal passageway for access between the working deck area and the science spaces.

The Aquarium is aft of the Wet Lab, with a 6 ft double door connecting them. The Aquarium also has a 6 ft door accessing the Starboard Working Deck. It is the wettest space accommodating large and small free flowing aquaria with large direct access to the starboard working deck and service from the science and incubator seawater systems. It will have a grated deck and sediment traps for efficient drainage during sampling and processing efforts.

All the equipment required by PSPEC is installed. As with the Wet lab, the space is expected to be muddy, and is designed with the intent to be easily cleaned.

There are two identically sized cold labs, measuring 8ft wide and 20ft deep. Each have work benches, seating, and shelving for storage of samples. Both may be cooled as low as -20F.

The Atmospheric Lab is on the 03 Deck forward, underneath the flight deck. Tubing runs from sampling locations on the Atmospheric Mast, directly above, to the atmospheric lab. The Atmospheric Mast is far forward on the ship, in clear air. The Atmospheric Mast includes a small platform with a 2’ x 2’ bolt pattern to support installation of scientific equipment as necessary. The detail design of the mast will occur in the Final Design Phase, and its exact height will be determined then, after the Stack Gas Analysis Study. The tubing routing from Mast to sampling equipment length and turns are minimized and tubing is easily accessed for cleaning either through mechanical means or by provided compressed air.

The Meteorology Laboratory is located on the 07 Deck above the Bridge collocated within the Marine Mammal Observation Room; this location is in close proximity of the main mast, minimizing the length and number of turns for routed cables and piping for sampling. Additional wireways are installed for installation of equipment on a mission by mission basis.

There are some areas of the laboratory outfitting and arrangement that will be further developed but these items are not of concern at this stage of the design, and will be developed as the design matures and VFI is available. Examples of areas that are still under development include the size of fixed counters and cabinets and details of modular sink installations and hood exhaust details.

In all, the Science Laboratory Arrangement has been designed to maximize communication and collaboration among scientists, and to ensure safety and efficiency of the work done in them.

7. Science Support Spaces

Details of the ARV science support spaces outfitting and arrangement are shown on the drawing 5E1-601-D001 Science Space Arrangement Drawing, Reference 6). At this stage of the design, no significant design trade-offs are required to integrate the science support spaces in the ARV design and there are no risks identified or areas of non-compliance related to these compartments. These Science Support Spaces have been arranged to provide ease of access from required Laboratory spaces, and effective isolation from Laboratories as necessary for safety and function. All of the Science Support Spaces meet SMR and Performance Specification requirements for area, volume and outfitting.

The Science Main Deck is served by the Main Centerline Hallway which reaches from the aft working deck to the large door accessing the Science Stores Area. The hallway is designed to allow mobility of a pallet jack from bow to stern of the ship. The large Science Stores space is provided forward of the collision bulkhead. The entrance to the Science Stores is adjacent to the Science Office.

The Electronic Technician Shop is located on the main deck. It provides work station/office and bench space and tooling for Electronic Technicians to test trouble shoot and repair sensitive electronic sensors, instruments and systems for both standard shipboard and mission specific needs. It is equipped with static dissipative mats or deck coatings and specialized electronic tools and test equipment.

The Liquid Nitrogen plant is located aft of the Cold Storage/Labs next to the stack. This location separates it from the Labs due to noise, but keeps it on the Main deck to improve safe and efficient movement of working quantities of liquid nitrogen.

The Server Room is oversized for the current electronics compliment. This space will not be wasted, rather it provides storage for electrical and electronics supplies but also provides space for anticipated future growth of the ship's server compliment.

The Sonar Transceiver Room is situated above the Sonar Cable Trunk. The space supports the large transceivers and provides ample wireways for both transducer cabling and power and network cabling. Additional wire trays are available to support temporary sonar installations or growth in the ships transducer and transceiver compliment. Several comments have directed that the Transducer Room should be moved to the 01 Platform. In the PDR phase this will be a primary goal as the exact requirements for fuel tankage and provision storage are refined.

The Autosal room is currently in the Hydro Lab and provides a dedicated steady controlled temperature space for salinometer sample processing and sample bottle storage. This space is in consideration to be moved to the Bio/Chem/Analytical Lab when the Transceiver Room is moved to the 01 Platform. This would further increase the size of both Hydro and Bio/Chem/Analytical Labs.

The Staging Bay is aft of the Aquarium Room on the starboard side of the ship, it has large doors accessing both the Starboard Working Deck and the Aft Working Deck. The Staging Bay provides a sheltered location to stage and maintain equipment between deployments. It can also be used to shelter mission specific equipment such as Trace Metal Clean (TMC) rosettes, gliders and small AUVs, drifters and mooring gear. This space has large lockers for rigging and lifting gear. The door to the Working deck is sized such that either of the large workboats may be partially brought through the door for maintenance or equipment installation on the Science Workboats in inclement weather. Both large doors into the Staging Bay are supported by the Starboard Main Crane.

The Changing Room is on the interior of the ship, on the port side of the Main Centerline Hallway. It includes large lockers and drying racks as well as benches, hanging hooks and cubbies. It is set up in a “locker room” style layout, allowing crew to move about without interrupting other crew who may be gearing up more slowly or coming off the deck. Two toilets are adjacent to the changing room. It is equipped with boot and glove driers.

A passage extends behind the Changing Room providing access to the Lab Van Garage. Here three Lab Vans are supported by a weather resistant vestibule. This allows each of these Lab Vans to be accessed without going onto the weather deck. A sill is provided forward of the van door openings and oversized scuppers are provided to evacuate any deck water that flows underneath the Lab Vans. The Lab Vans are protected from the weather by an 8ft overhang overhead. The Lab Van Garage provides a flexible and modular solution to support mission specific science processing or sampling needs.

The ARV is required to accommodate at least 20 scientific and laboratory vans. The current van storage plan includes two (2) positions forward on the aviation deck, eight (8) vans double stacked in the hold and ten (10), or more, positions on the main working deck. The Lab Van Garage is located in a sheltered location forward on the main working deck and can accommodate three (3) lab vans with direct access into the ship. This can support mission specific laboratory or storage needs, but Rad Vans or Cesium source Vans can only be supported on the main working deck, without direct access to the ship, to prevent potential contamination. Active Lab vans would only be supported on deck, however vans stored in the hold will have access to end doors and refrigerator Vans will have electrical service. The containers are served with ample space within the hold about their perimeter, and a folding catwalk allows access to both the foreward and aft end of each container.

The vans stored within the Science Cargo Hold are served through the Science Cargo Hold hatch. Once the vans are stacked two high and dogged together, they will be elevated on the van roller track, and tugged to the port or starboard side. Once in position, the roller track will be lowered locally, allowing the two containers to be captured by the hold’s ISO locks. This process will be repeated for storage of all eight Science Cargo Hold containers.

This same passage provides access to the Marine Tech Shop and the Carpenter Shop, both on the port aft corner of the ship’s house. Both of these shops have direct access to the weather deck, and both have a 4ft overhang protecting these entrances from weather.

The Marine Tech Shop opens directly onto the main working deck and contains equipment and tooling to support the over-boarding, maintenance and repair of oceanographic systems and their associated rigging. Large gear lockers contain lifting, rigging and lashing gear. Tooling for repair and light fabrication is arranged within this space.

The Carpentry Shop opens directly onto the main working deck and contains tools and stock for fabrication in wood and plastics including field repairs/modifications, crate building for science samples, and other mission specific support needs. This space will have a dust collection system.

The Marine Mammal Observatory (MMO) is located on the 07 Deck, above the Bridge and includes the Meteorological Lab within. The MMO also includes an AloftCon station which when not in use provides adjustable captain’s chairs allowing a wide field of view forward. From within the MMO, a full 360 degree view of the ocean is provided.

8. Science Network Infrastructure

The Science Mission Network Infrastructure is a collaboration of the Cybersecurity Integrated Product Team (IPT) and Network Design Working Group to integrate the relevant ARV Performance Specifications, Reference 3), science mission needs, and lessons learned from prior vessel network designs. The Science Mission Network Infrastructure design is shown on the Shipwide Network Diagram. The network diagram is the primary design artifact for the ARV network design with the Science Mission Network being one of three networks overseen, in addition to the Vessel Network and the Guest Network.

The Science Mission Network electronics racks are co-located with the vessel electronics racks in the included in Servers and Server Heating, Ventilation, and Air Conditioning (HVAC) Room located on the main deck between Frames 13 and 18. Based on customer feedback, the electronics racks are located on the main deck in the vicinity of the Science Laboratories and Science Support Spaces to facilitate workflow and science wireway routing between the Science Mission Network electronics racks and science spaces. The size and arrangement of the Servers and Server HVAC Room will be evaluated in more detail as the ARV design matures.

9. Scientific Electronic Systems

The Scientific Electronic Systems are required by the ARV Performance Specifications, Reference 3), to support the ARV science mission. Many of the Science underwater sensors that perform poorly through ice windows were prioritized for the centerboard along with two large spare well to support future or mission specific transducer needs. The transducer foundations will be machined into a removable base or “shoe” attached to the bottom of the center board. This also better facilitates future arrangements or new systems as they become available. The centerboard design is described in more detail in Section 9.1. The arrangement of the underwater sensors is shown on the drawing 5E1-301-D101 Scientific Electronic Arrangement Drawing, Reference 7). There are several spare sonar transducer ports on the box keel and there will be space reserved within the transducer cable trunk for the installation of additional, redundant or future sensors. The hull includes a box keel which mitigates bubble sweepdown and ice tumble and reduces self-noise. This box keel redirects surface air ingested into the sea by wave action and the icebreaking bow shape away from the sensors and around the hulls waterline.

The underwater sensors located on the hull plating are on the box keel,behind ice reinforced windows.. Additional underwater sensors are mounted on the centerboard which is able to be retracted and closed to protect the transducers from ice damage.. The Bottom Mapping Transceiver Room is located on the main deck, port side, directly above the Transducer Room. The location of the Transceiver Room is vertically aligned with the Deep Water Multi-Beam transducers to minimize the cable run length and cable bends required for routing between the transducers and the transceivers; this arrangement is in accordance with the manufacturer recommendations. The science underwater sensors are listed in Table 5. Descriptions of the sensor systems are in the following paragraphs. The desire to move the Transceiver Room to the First Platform is noted, and this will be a primary investigation as requirements for fuel and provisions are further refined.

As the ARV design continues to mature, and VFI is available, the science underwater sensor arrangement will be evaluated, including a hull form trade study and bubble sweepdown analysis to validate the sensor locations.

Below specific makes and models of these sensors are specified for reference; however, these manufacturer and models may be updated as new products become available.

9.1 Multi-Beam Echo Sounders

The multi-beam echo sounders include both deep water (10-8,000 m) and shallow water (3-3,600 m) multi-beam models.

The deep-water multi-beam echo sounder is the Kongsberg EM 124 one degree by one degree transmit and receive arrays. The EM 124 transducer arrays are fitted with titanium ice windows for protection from damage when the vessel is operating in ice-covered waters.

The shallow water multi-beam echo sounder is the Kongsberg EM 712 one degree by one degree transmit and receive arrays. The EM 712 is ice strengthened but is not capable of sustaining heavy ice breaking. For this reason the EM 712 is to be installed on the retractable centerboard, which will further increase its performance in open water conditions. The centerboard and the EM 712 may be deployed 10ft below the ship baseline, 3 ft below baseline, flush with the hull bottom, or protected inside the ship with a closure.

9.2 Sub-Bottom Profilers

The sub-bottom profilers are Kongsberg SBP 29 model which is a narrow beam, multi-beam profiler with a primary application to do sub-bottom imaging of sediment layers and buried objects under the sea floor. These profilers constitute a system that has a wide bandwidth (2-9 kHz) and narrow beams giving it improved penetration, cleaner data, and good angular resolution. The SBP 29 utilizes the EM 124 receive array so that only the SBP 29 transmit array is required. This allows the system to operate with wider beams when desired.

9.3 Acoustic Doppler Current Profilers

The Acoustic Doppler Current Profilers (ADCP) are Teledyne RDI for 38, 75, 150, and 300 kHz frequencies which can collect detailed maps of the distribution of water currents and suspended materials through the water column at depths 1000m and deeper. This sensor suite is helpful in applications including climate studies, mid-ocean frontal mapping, fisheries research and others. These sensors are clustered near each other on the box keel. Each are protected underneath a custom ice window that mimics water properties and allows low loss transmission of the ADCP through its protection. ADCP's perform well with minimal signal loss from behind composite ice windows and are suitable for placement in the Box Keel.

9.4 Marine Biology Echo Sounder/Sonar

The marine biology echo sounders and sonars are a suite of Simrad EK80 models. This suite includes individual 18, 38, 70, 120, 200, and 333 kHz transducers and is well suited for applications such as assessment of fish biomass and distribution, species identification and discrimination, plankton research, habitat mapping, behavioral studies, environmental research, and oil and gas detection. Notice that this installation exceeds PSPEC objective by including the 333 kHz transducer. This is included within this study for reference that the space is available for such an installation and may be eliminated if desired. These sensors are clustered on the bottom of the centerboard and are not provided with ice windows, as these sonars are sensitive to ice windows, and substantial resolution is lost.

9.5 Ultra-Short Baseline System

The Ultra-Short Baseline (USBL) system is the Kongsberg HiPAP 502P, a High Precision Acoustic Positioning System, designed for optimal positioning in both shallow and deep water of subsea objects such as AUVs, towed bodies or fixed seabed transponders. The ARV configuration for the USBL system uses a Classification Society approved gate valve to lower the USBL transceiver below the vessel keel when the system is operating and retract the transceiver inside the hull when the system is not in use to reduce drag, protect the system from ice damage, and for maintenance or repair. The system offers a wide range of transponder channels and cNODE transponder models for depths rating down to 11,000m.

9.6 Other Underwater Sensors

The hydrophones are Simrad PI Trawl model hydrophones and microphones dedicated for bottom and pelagic readings to communicate with deployed wireless sensors. The hydrophone monitoring system reception has a 50^o horizontal beam and 30^o vertical beam.

The ARV is also fitted with two (2) speed logs and a forward-looking sonar used for navigation and a forward-looking camera which may be used to observe bubble sweep down.

The centerboard has been designed to support installation of side looking sonars if these are desired. This capability is not required but may have added value.

As the centerboard will not be readily accessible for post-delivery modification, there are two spare transducer ports, presenting opportunity to install special purpose mission sensors.

Table 5: Science Underwater Sensors

Description	Quantity	Model No.	Manufacturer	Notes
Deep Water Multi-Beam	1	EM 124	Kongsberg	Box Keel Mounted, Transmitter
Deep Water Multi-Beam	1	EM 124	Kongsberg	Box Keel Mounted, Receiver
Shallow Water Multi-Beam	1	EM 712	Kongsberg	Centerboard Mounted, Transmitter
Shallow Water Multi-Beam	1	EM 712	Kongsberg	Centerboard Mounted, Receiver
Acoustic Doppler Current Profiler (ADCP) 38 kHz	1	RDi	Teledyne	Box Keel Mounted
ADCP 75 kHz	1	RDi	Teledyne	Box Keel and Centerboard Mounted
ADCP 150 kHz	1	RDi	Teledyne	Box Keel and Centerboard Mounted
ADCP 300 kHz	1	RDi	Teledyne	Box Keel and Centerboard Mounted
Sub-Bottom Profiler 3.5 kHz	1	SBP 29	Kongsberg	Centerboard Mounted
Marine Biology Echo Sounder/Sonar 18 kHz	1	EK80	Simrad	Centerboard Mounted
Marine Biology Echo Sounder/Sonar 38 kHz	1	EK80	Simrad	Centerboard Mounted
Marine Biology Echo Sounder/Sonar 70 kHz	1	EK80	Simrad	Centerboard Mounted
Marine Biology Echo Sounder/Sonar 120 kHz	1	EK80	Simrad	Centerboard Mounted
Marine Biology Echo Sounder/Sonar 200 kHz	1	EK80	Simrad	Centerboard Mounted
Marine Biology Echo Sounder/Sonar 333 kHz	1	EK80	Simrad	Centerboard Mounted
Ultra-Short Baseline Transceiver	1	HiPAP 502P	Kongsberg	Box Keel Mounted
Speed Log	2	379814A	Kongsberg	Box Keel and Centerboard Mounted
Spare	4	TD50VLF	TBD	TBD Mounted
Acoustic Release Transponder 12 kHz	1	cNode	Kongsberg	Centerboard Mounted
Hydrophone	5	PI Trawl	Simrad	Box Keel and Centerboard Mounted
Forward Looking Camera	1	V-90	Dropshot 20/20	Centerboard Mounted
Forward Looking Sonar	1	SN-90	Kongsberg	Centerboard Mounted
Side Looking Sonar*	2	SN-90	Kongsberg	Centerboard Mounted

*Unrequired additional capability

9.7 Centerboard Design

The centerboard and centerboard trunk are required by the ARV PSPEC, Reference 3), to support the ARV science mission. The centerboard allows the scientific underwater sensors to be deployed below the vessel keel outside of the turbulent flow created by the vessel while underway to improve the functionality of the sensor readings. This arrangement also allows the underwater sensors to be raised above the vessel keel inside the centerboard trunk for protection from ice damage for vulnerable transducers when the vessel is operating in ice-infested waters.

These scientific underwater sensors are housed in the ARV centerboard:

Shallow Water Multi-Beam EM 712

- Marine Biology Echo Sounders 18, 38, 70, 120, 200, 333 kHz
- Speed Log
- Hydrophone
- Side Looking Sonar, Konsgsberg SN90
- Forward Looking Sonar, Konsgsberg SN90
- Underwater Forward-Looking Camera, Dropshot 20/20 -V90 or equivalent

The arrangement of the centerboard is shown on the drawing 5E1-301-D101 Scientific Electronic Arrangement Drawing, Reference 7). Notice that the side looking sonar and 333 kHz EK80 exceed requirements. If these are not installed at the time of delivery, it is recommended that the space and access should be reserved for this pre-planned product improvement.

The centerboard is designed to be deployed while the vessel is underway for science operations; therefore, the drag created by this appendage is important to consider with the overall vessel speed and resistance requirements for science operations. The overall size of the centerboard must be balanced to allow for adequate spacing of the transducers while minimizing overall drag. The NACA 0021 foil section was selected as the design point for the ARV centerboard – this foil section presents a low risk of stalling at the angles of attack expected when tracking a straight line over ground with a vessel crabbing angle. The underwater scientific sensor arrangement was optimized to have a footprint as small as possible with minimum required spacing between sensors to minimize obstruction and potential offset errors of the sensor readings. Based on the optimized sensor arrangement, the centerboard has a chord length (longitudinal direction) of 162 inches and thickness (transverse direction) of 56 inches.

The centerboard is raised and lowered within the centerboard trunk using a mechanical system with designed stops. The centerboard trunk will be larger than the centerboard. The centerboard is designed for three (3) down positions and one (1) maintenance position. The maximum deployed position of 10 ft. below the keel and to be retracted within the centerboard trunk so that the bottom fin position is no less than 35 ft. above baseline, and no less than 7 ft. above the waterline to allow for access for maintenance and calibration of the sonars. The centerboard trunk is fitted with an ice door to minimize damage from ice to the centerboard and underwater sensors when the centerboard is in the stowed and maintenance positions. The centerboard trunk is located adjacent to other multi-deck trunks such as the propulsion exhaust casing, lift trunk, and stair towers; this grouping of trunks minimizes the overall impact of the trunks on interior arrangements.

As the ARV design continues to mature, and VFI is available, the centerboard design and underwater scientific sensor arrangement will be developed in more detail.

9.8 Science Seawater System

The Science Seawater System consists of two (2) Scientific Seawater Pumps and two (2) Incubator Seawater Pumps installed to provide ambient temperature seawater to science laboratories, laboratory van sites, incubator locations, and the Aquarium Room as required by the ARV PSPEC, Reference 3). The location of the Science Seawater System components including the pumps, temperature probes, and Scientific Seawater Instrument Room is still under development at this stage of the design. The arrangement of the ARV Science Seawater System piping is shown on drawing 5E1-524-D001 Science Seawater Diagram, Reference 8). As the ARV design continues to mature, and VFI is available, the system design will be developed in more detail including location of key system components and verification of pump sizes based on the system arrangement.

The Science Seawater System materials must be corrosion resistant in seawater and as chemically neutral as possible to deliver science sampling water that is closely matched to ambient seawater conditions of the vessel when other scientific samples and data is collected. To improve the quality of the science sampling water relative to the ambient conditions, G&C is exploring the option to use debubblers (large debubblers at the intake manifolds or smaller debubblers within each science space), and also investigating ice separation systems. The piping material for the Science Seawater System is chlorinated polyvinyl chloride (CPVC); this material is immune to corrosion that results in pipe leaching for enhanced corrosion protection. Insulation is fitted for the science seawater system to limit the temperature change of water to 2 degrees Fahrenheit (^{o}F) or less from the inlet to point of use and insulation is fitted for the incubator seawater system to limit the temperature change of water to 1^{o}F or less from the inlet to point of use.

An audible/visual alarm system will be provided for the deck incubator system and live aquarium tanks.

10. Workboats

The ARV will support four science support small boats. Two 6-7m Rigid-Hull Inflatable Boats (RHIBs), one 10 m Science Survey Boat and one Landing Craft.

The diverse makeup of the small boat complement on ARV is necessary to support a broad range of scientific activities and observations off ship. The small boats are the primary method of access to water, land and sea ice for off ship scientific endeavors. The smaller RHIBs need to be simple, open, multi-use platforms that maximize space available for science equipment and personnel. The Scientific Work Boat will be outfitted with sampling and survey equipment and sonars with a requirement for a 12-hour endurance. The Landing Craft Work Boat will need to be a robust and capable solution, as it is the only method of transporting bulky science cargo from ship to shore.

Alternatives to traditional solutions should be considered that may better support operation in the rough and cold seas of Antarctica and the unimproved landing sites around the continent. Significant lessons learned have been realized in the program while working to improve small boat capability and access in the Palmer Station area. This experience has shaped and influenced capability, operation and maintenance of the small boats directly supporting US scientists and their efforts collecting scientific data on the water in Antarctica.

The ARV Project can leverage the knowledge and experience to date, from what is arguably the most diverse and capable scientific small boat program across Antarctica, in order to identify the safest and most effective small boat support solutions for the next generation Antarctic Research Vessel.

10.1 Science Small Boat characteristics

10.1.1 7m RHIBs open boat (2ea)

The ARV is equipped with two 7m RHIB support boats. These are particular useful in recovering gliders, tagging ceatations and for dive operations. These boats will be propelled by inboard diesel, outboard diesel, or electric drives. No gasoline engines will be required.

One of these RHIBs will be supported by a dedicated man rated launch and recovery davit. The other will have a deck cradle, which may be stowed on the 01 Boat Deck, or may be stowed on top of one of the Science or Stowage Vans and will be supported by the Port Main Crane.

10.1.2 Key 7m RHIB features and capabilities

- Matched/Interchangeable Hulls
- Air collar or similar fendering system for safety
- Consider diesel outboard, diesel hybrid or electric drive (no gasoline outboards)
- Multi-task role moving Pax and science support equipment on water, to sea ice or shore
- Open boat plan, bolt pattern, lashing points
- Low dead rise for improved beaching, multi-chined for maneuverability
- Aluminum hull with close scantling spacing and beaching pads for rocky and rugged landings
- Personnel lift rated
- Antennae arch for VHF/AIS/GPS antennae
- Simple low-profile control/steering station to maximize open cargo capacity
- Able to accept a removable bow pulpit for tagging, biopsy and close approach

10.1.3 Scientific Science Survey Launch

The Scientific Survey RHIB is the workhorse of the off-ship science operations. This includes a winch and A-Frame for towed operations, a sonar transparent well where sonar systems are installed, several scientific workstations, and a foam filled inflatable collar surrounding the hull's gunwale. This will be a twin engine boat, with either an inboard diesel, outboard diesel, or electric drive. The Scientific Survey Launch RHIB is highly maneuverable by virtue of its twin propulsors and is capable of being fitted with a Dynamic Positioning System. The RHIB will carry a suite of scientific instruments on its mast, including a cellular antenna for line-of-sight telemetry with the ARV and a StarLink or equivalent for over the horizon telemetry. The 10m RHIB is supported by a dedicated launch and recovery davit system located in a sheltered pocket on the 01 Boat Deck. The Scientific Survey Launch RHIB will have an onboard head and climate controlled cabin.

10.1.4 Science Survey Work Boat Features and Capabilities

- Air collar or similar fendering system for safety
- Consider diesel hybrid drive or electric (no gasoline)
- Research winch and stern a-frame (electric drive preferred) for towing and casting science packages. Plankton nets, Bongo nest, ECO rosette CTD
- Survey capability, multi-beam mapping (near shore/uncharted) capable
- Bio-acoustic survey, micro scale, (2-3 band EK-80) 38&120 kHz minimum
- Seismic support Chirp/Sparker, stream, survey grade GPS
- Full Nav Suite, Radar/Fathometer/AIS
- Cabin heat/head/fold down workstations for survey party/techs
- 2 crew 4 science/techs. Total of 6
- Bolt pattern and lashing points
- Keel cooler, no raw water in the boat to freeze
- Shore power/comms (boat power, block heaters, data line)
- Sonar well/ice window for transducer protection
- Cradle for storage when not in handling system
- On water support for glider ops, USV ops, close approach

10.2 Landing Craft Work Boat

The ARVs 10m Landing Craft is stowed on the 01 Boat Deck and is launched and recovered by the Port Main Crane. Its cradle may be installed on the top of one of the Science or Stowage Vans. The Landing Craft will have twin engines, either inboard diesel, outboard diesel, or electric drive. It will have onboard winches and a forward deploying launch gate. The pilot house will be set aft so as to support deployment of snow machines from the launch gate.

10.2.1 Landing Craft Features and Capabilities

- Air collar or similar fendering system for safety
- Consider diesel hybrid drive or electric (no gasoline)
- Transition challenge on an icy lee shore
- Consider non-traditional solutions to a traditional landing craft or augment with a transition solution
- Able to move bulky science equipment and portable sampling systems ashore (or sea ice)

- Able to move ashore equipment to establish a short-term Field Camp
- Able to transport science and tech pax and samples to and from shore

The ARV will support four science support small boats. Two 6-7m RHIB open boats, one 10m Science Survey Boat and one Landing Craft. The diverse makeup of the small boat complement on ARV is necessary to support a broad range of scientific activities and observations off ship. The small boats are the primary method of access to water, land and sea ice for off ship scientific endeavors. The smaller RHIBs need to be simple, open, multi-use platforms that maximize space available for science equipment and personnel. The Scientific Work Boat will be outfitted with sampling and survey equipment and sonars with a requirement for a 12-hour endurance. The Landing Craft Work Boat will need to be a robust and capable solution, as it is the only method of transporting bulky science cargo from ship to shore.

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11. Design Trade-Offs

Two design trade-offs are described in more detail below to integrate the underwater sensors into the ARV design: hull form analysis, and centerboard design. At this stage, no significant design trade-offs are required to integrate other areas of the science systems.

11.1 Hull Form

The ARV is capable scientific research ship with icebreaking capability. Traditional hull forms for icebreaking are typically not desired for optimal performance for science operations (enhanced seakeeping at slow speeds, reduced bubble sweepdown for sensor performance). The design trade space for the ARV hull form therefore has two competing and opposed criteria that must be balanced as the design progresses. G&C has analyzed six (6) hull form variations to effectively balance hull form parameters of the ARV design with the competing criteria of icebreaking and science operations. Based upon additional understanding of the hull's icebreaking, bubble sweepdown, and open water performance, a further study of additional hull forms will be conducted in the post-PDR phase that will inform further testing.

11.2 Centerboard Design

To ensure optimum performance of the scientific sonar instruments, the team considered integrating a centerboard and centerboard trunk in the ARV design. G&C selected a single centerboard design over a twin centerboard design due to cost considerations and the added interior volume required to accommodate two separate centerboard trunks. A twin centerboard design may increase the total number of sensors capable of lowering below the keel, but the current single centerboard design satisfies the requirements, and this configuration is considered adequate.

12. Technical Risks, Areas of Non-Compliance, and Mitigation Measures

Bubble Sweepdown performance of the hull remains sub-optimal. This will be addressed in the Post-PDR phase of design with further CFD analysis and model testing.

The portable Aft Deck Working Crane is required to be installed on the Working Deck bolt pattern. This requirement has been called into question by our crane vendor and structural design team. This installation may require recertification by regulatory bodies each time it is moved. Additional vendors will be engaged in the Post-PDR phase to more thoroughly vet this requirement.

The two main cranes are currently sized to support significant lifts at maximum reach in sea state 5+. There is concern that this is a requirement for capability that will never be utilized in actual operations. Substantial weight and expense can be saved if this requirement is moderated.

Details of the working boats requirements have not been finalized and will be better fleshed out in the post-PDR phase.

13. Conclusions and Recommendations

The design and integration of science systems into the overall vessel design supports the successful science mission execution. The science systems integration is guided by the Performance Specification. As the ARV design continues to mature, and VFI is available, the design and integration of the science systems will continue and this report will be updated.

The ARV PDR design provides a significant advance in capability over current vessels across the spectrum of requirements. The ARV can explore previously inaccessible regions due to it's icebreaking capabilities and range. The Science Space Arrangements meet and exceed the requirements, provide for future growth, and provide for safe workspace, efficient workflow, and close proximity of workplaces. This carefully considered design allows for less fatigue, less risk of injury, and improved collaboration.

The deck equipment design allows for excellent accessibility, maintenance, and operability. The CDT and Piston Core LARS systems provide capabilities without precedent. A thorough examination of the winch requirements and limitations has led to a safe, efficient, and capable reeving arrangement. Active heave compensation is available on all of the winches, and through good reeving design, that capability may be extended to the Main Cranes. The man-rated cranes allow for deployment of crew of differing abilities onto the ice or into the workboats.

The compliment of Science WorkBoats are easily and safely deployed even in significant sea states, and the capabilities and efficiency of these workboats continues to evolve.

The ARV Preliminary Design has laid the foundation upon which the vision of an efficient, safe, and capable research ship may be realized. This design is poised make a significant advance is the scientific research capabilities of the National Science Foundation.

14. References

1) ARV Science Mission Requirements
2) NSF Research Infrastructure Guide (RIG)
3) ARV Performance Specifications
4) ARV Configuration Control Plan (CCP)
5) G&C Drawing No. 5E1-580-D001, Handling Systems and Scientific Package Deployment Drawing
6) G&C Drawing No. 5E1-601-D001, Science Space Arrangement Drawing
7) G&C Drawing No. 5E1-301-D101, Scientific Electronic Arrangement Drawing
8) G&C Drawing No. 5E1-524-D001, Science Seawater System Diagram
9) University – National Oceanographic Laboratory System (UNOLS) Research Vessel Safety Standards 11th Edition, November 2021