Antarctic Research Vessel (ARV)

Trade-Off Studies Report

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Revision History

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P0	September 30, 2022	All	C. Townsend L. Marion	Initial draft for ASC peer review
P1	December 30, 2022	All	C. Thompson	Revision to answer NSF, SASC, and Leidos ASC comments

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1. Executive Summary

Trade-off studies and assessments are routinely performed to identify and inform key design decisions at the start of any ship design. Several major trade-off studies have been undertaken in accordance with the ARV preliminary design scope of work, including assessment of hull form and hull size, as well as propulsion system options. The findings of these trade-studies have been documented in standalone reports which are identified in Section 2 of this report.

This report provides a synopsis of the other trade-off study opportunities accomplished as part of the design development process across numerous disciplines. A summary of these assessments and findings are presented in this report.

1.1. Acronyms

ABL	Above Baseline
ARV	Antarctic Research Vessel
ASC	Antarctic Support Contractor
DR2	Design Review #2
DR3	Design Review #3
DR4	Design Review #4
ECR	Engineering Change Request
KPP	Key Performance Parameter
LAN	Local Area Network
MT	Metric Tons
NSF	National Science Foundation
OSV	Offshore Supply Vessel
PC	Polar Code
P-SPEC	Performance Requirements
RMRS	Russian Maritime Register of Shipping
SME	Subject Matter Expert
SWBS	Ship Work Breakdown System
TBD	To Be Determined
VCG	Vertical Center of Gravity

2. Trade-Off Studies

Trade-off assessments and studies are a key tool for evaluating the cost and capability of design alternatives for the Arctic Research Vessel (ARV) and have been performed across all ship design disciplines. Trade-offs that substantially influence ship size and design have been documented in related ARV reports as illustrated in Table 1.

Table 1 – Trade-Offs Documented in ARV Deliverables

Trade-Off Topic	Report
Hull Form Dimensions	5E1-051-R001 Hull Form Trade-Off Study
Transducer and Centerboard Arrangements	5E1-052-R201 Transducer and Centerboard Trade-Off Study
Structural Framing Scheme	5E1-061-R001 Structural Design Report
Main Propulsion Selection	5E1-062-R001 Propulsion System Report
Dedicated Harbor Generator	5E1-062-R101 Electric Propulsion Architecture Trade-off Study

Other trade-offs not identified in Table 1 are documented in this report to capture the history of assessments and evaluations for easy reference in later phases of design. Trade-off summaries are organized by SWBS group.

3. Hull Structure (Group 1)

No additional trade studies in Group 1 are identified at this time.

4. Propulsion Plant (Group 2)

4.1. Bow Tunnel Thruster Size and Quantity

At least one bow thruster is needed to achieve the required maneuvering and dynamic positioning capability per the ARV Performance Specifications, Reference (1). The baseline hull form includes a single large bow thruster, fitted to the main portion of the hull above the forward

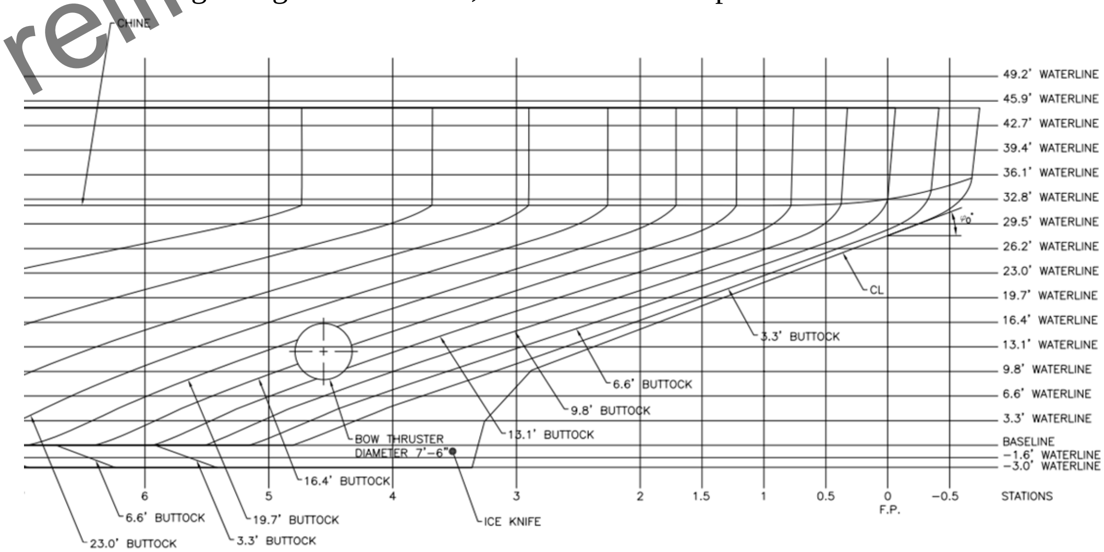


Figure 1 – Baseline Tunnel Thruster Illustration

ice knife appendage as shown in Figure 1. While the size and location of this thruster is nominally compliant with dynamic positioning requirements as demonstrated by initial capability plots, the intersection of the thruster tunnel with the side shell results in geometry that may be impinged by ice when icebreaking.

One option being considered is the inclusion of a drop down bow thruster. Such thrusters are not Polar Class rated. However several vendors have experience with a drop down thruster functioning as a tunnel thruster and obtaining a PC3 rating, while retaining the ability to drop down and perform as an Ice Class rated azimuthing thruster.

The ARV Ship Design team is considering alternative arrangements for tunnel thrusters, including increasing the quantity of thrusters to three and decreasing the size of each thruster to permit installation in the ice knife appendage. Expected benefits of this arrangement include a reduction in the risk of ice impingement, improved dynamic positioning, and the potential to reduce radiated noise from the bow thruster(s) which could interfere with underwater sensors. Further study is needed to determine if:

- compliant dynamic positioning capability can be achieved with smaller bow thruster units, since dynamic positioning ability is significantly impacted by the bow thruster force and moment
- there is a risk of short-circuiting of thruster flow (resulting in reduced thruster and poor performance) due to the short tunnel length if installed in the ice knife
- there is sufficient vertical clearance to fit the thruster tunnels and supporting structure
- there is sufficient horizontal width within the ice knife to accommodate the thruster body and electric motor
- satisfactory noise/interference performance with sonar and other sensors can be achieved

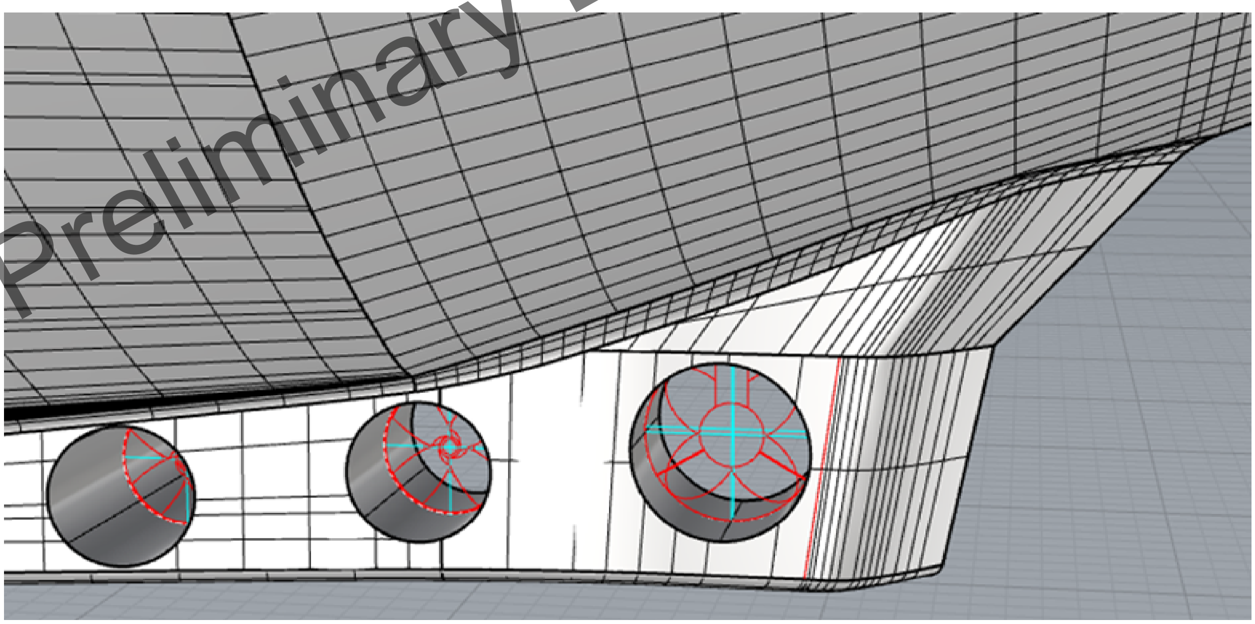


Figure 2 – Tunnel Thruster Alternative Configuration

A summary of bow thruster tunnel and size options is presented in Table 2 below.

The single large tunnel thruster configuration shown in the lines plan submitted for DR2 is currently being evaluated in model testing. A recommendation on a final thruster configuration for ARV will be provided in a future revision of this report.

Table 2 – Bow Thruster Alternative Impacts

	Single large tunnel thrusters, mounted in main hull above forward ice knife	Multiple (three) tunnel thrusters installed in ice knife	Drop down Bow Thruster (with tunnel thruster capability)
Benefits	• Generates largest steering force due to position and size of thruster • Generous space within hull to accommodate tunnel, thruster, and supporting structure	• Provides a level of redundancy in the event of a thruster failure • Shorter tunnels improve thruster performance • Tunnels are installed lower in ship which minimizes their proximity to broken ice • Lower ship resistance due to shape of tunnel intersection with ice knife	• Outstanding azimuthal control of thrust. • Improved DP performance • Excellent isolation of vibration source from ship structure.
Disadvantages	• Tunnel intersection with side shell subject to ice strikes, tunnels may tend to collect ice and clog	• Insufficient thrust from smaller thrusters to satisfy performance requirements • Thruster flow could short-circuit due to insufficient tunnel length • Limited vertical and horizontal space within ice knife may present challenges in supporting and installing thrusters, thruster motors, and tunnels	• Custom configuration required (medium risk). • No PC3 thruster available • Thrusters generally have a nozzle (poor for in-ice performance)
ARV P-SPEC 070.7 Dynamic Positioning Capability	• Compliant	• Further analysis needed	•
ARV P-SPEC 070.7 Noise	• Will be evaluated in baseline analyses	• Further analysis needed	•
ARV P-SPEC 070.7 Vibration	• Will be evaluated in baseline analyses	• Further analysis needed	•
ARV P-SPEC 070.7 Bubble sweepdown	• Will be evaluated in baseline analyses	• Further analysis needed	•

4.2. Bow Azipod

While tunnel type thruster(s) have been proposed for installation at the bow on ARV to provide required maneuverability and dynamic positioning performance, an alternative configuration using a bow azipod has been considered. A bow azipod installation could provide optimal maneuverability for ARV and reduce the amount of installed power required to achieve desired icebreaking capability (and associated reduction in equipment and lightship weight).

Bow azipod provide several valuable advantages to icebreaking performance, but also come with several drawbacks as described in Table 3. In general, these comparisons are made against a typical two-azipod solution with a fixed bow tunnel thruster.

Table 3 – Azipod Arrangement Alternative

Azipod Arrangement	Benefits	Drawbacks
Three Azipod Two at stern, one at bow	• Bow azipod reduces icebreaking resistance due to induced flow in bow region moving broken ice away, reduces installed power required • Improves propulsive efficiency and results in installed power savings of 14% compared to a two-azipod option • Reduction in installed power could result in selection of smaller thrusters, saving weight (bow azipod replaces bow tunnel thruster(s)) • Superior open water and ice-breaking maneuverability • Superior icebreaking performance when transiting ice ridges, brash ice, and re-frozen rubble fields • Proven installations on ships up to PC 4	• Acquisition and lifecycle cost (maintenance) for three azipod expected to be greater than for two azipod with tunnel thruster(s) • Added weight and lost buoyancy at bow o Net buoyancy change may be negligible with removal of tunnel thruster(s) • More complex hull geometry and hull structure (including foundation) in way of bow azipod • Installed on recently delivered PC 2 and PC 3 ships; insufficient evidence to prove durability and operability

Numerous existing icebreaking vessels feature bow azipod (some vessels with one bow azipod, others with two). The sub-type of vessels where bow azipod are common include escort icebreakers, harbor icebreakers, and OSV-type icebreakers. Most of these vessels are Russian, with some built for Nordic countries. Until recently, bow azipod have not been installed in icebreaking vessels with Polar Class (PC) notation greater than PC 4. In the last four years, the icebreaker *OB*, designed to Russian Maritime Register of Shipping (RMRS) Icebreaker 7 (equivalent to PC 3) as well as sister ships *Aleksander Sannikov* and *Andrey Vilkitsky*, designed to RMRS Icebreaker8 (equivalent to PC 2) have been put into service, all featuring at least one bow azipod (two bow azipod are fitted to the *OB*).

Figure 3 shows the notional outboard profile with hull lines illustrated for the PC 4 icebreaking vessel *Polaris* (delivered 2016), featuring two stern azipod and one bow azipod.

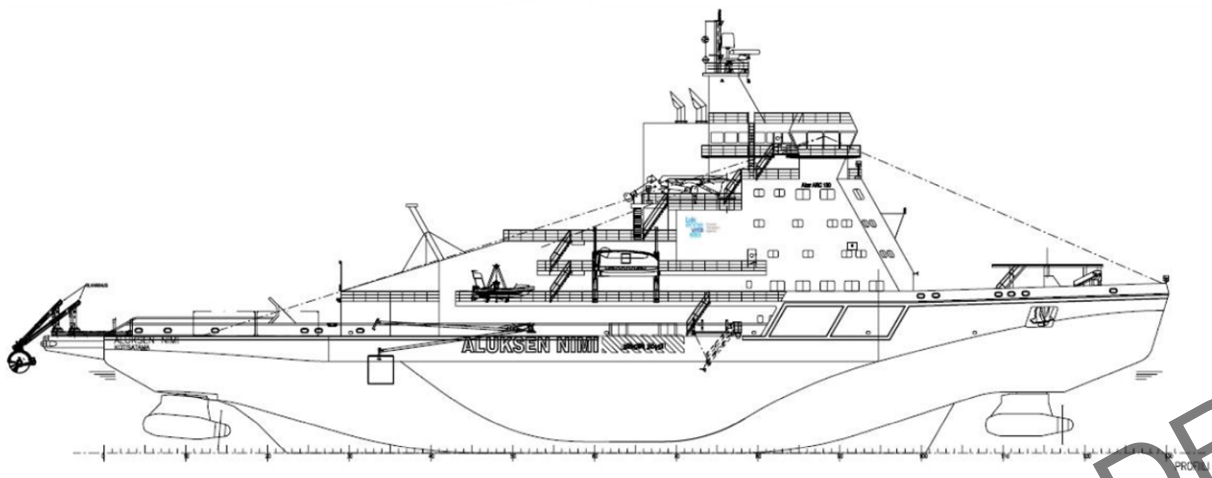


Figure 3 – PC4 Icebreaking Vessels Polaris with bow azipod

Market research shows that no icebreaking vessels that have been designed primarily for research missions feature a bow azipod. Although there are several attractive benefits as outlined in Table 3, a bow azipod arrangement may not be suitable for ARV for several reasons:

1. In accordance with Section 073.3 of Reference (1), the “hull and appendages shall minimize bubble sweepdown interference with sonar transducers” to ensure it can execute its research mission effectively. On the ARV, the bow azipod installation would be in a region where bubbles form, and even when not in use presents a risk of poor bubble sweepdown characteristics. No other vessel with sonar sensor performance and bubble sweepdown avoidance requirements has a bow azipod.
2. There is insufficient data on performance and reliability of bow azipod installations for vessels rated PC 3 or higher.
3. The ARV KPPs are consistent with an icebreaker design of modest capability and do not include extreme icebreaking performance requirements, which is when bow azipod would provide the most advantage.
    a. As described in Table 3, bow azipod offer superior performance in challenging ice conditions, which escort-type vessels must be able to handle. However, as ARV has the flexibility to navigate around challenging ice features including ridges, brash ice, and re-frozen rubble fields, a bow azipod is not needed to achieve desired icebreaking performance.

However, the most valuable benefit ARV could achieve with a bow azipod is a reduction in propulsor weight. The ARV Ship Design team is performing an assessment to identify the potential weight savings of a three azipod installation. If the expected weight savings is 40 MT or more, these findings will be shared with the wider ARV team to determine if further evaluation of design rolldown including bubble sweepdown and cost impacts for a three azipod solution is warranted.

Results of the weight assessment and any further trade-off analysis of bow azipod will be provided in the next revision of this report. If results suggest a significant enhancement to ARV capability is possible with a bow azipod, the ARV Ship Design team will brief all appropriate stakeholders.

5. Electric Plant (Group 3)

5.1. Harbor Generator

Whether or not to implement a harbor generator has been widely discussed. There is concern among several advisors that the actual power requirements for harbor generation are lower than predicted. If this is the case, there is a risk that the smallest primary genset will be operating at a very low utilization level, which is known to provide sub-optimum fuel economy. On older power plants this condition could also lead to "slobbering" which can cause damage to the mechanical systems of the engine and excessive engine oil consumption. This specific concern has been discussed with the Wabtec technical representatives and reviewed by Gibbs and Cox specialists. Both agree that the concern for "slobbering" does not apply to plants utilizing the Wabtec EGR technology. The team has also reviewed the engine's fuel consumption map, and while there is a measurable loss in efficiency at lower power demand, this is not an extended condition, and the diminished efficiency has been considered in the Range and Endurance calculations.

In addition to the preceding considerations, the ARV is to be equipped with a substantial battery bank. Through using the battery bank to sustain in port power demand, the diesel power plant may be shut down entirely. When the batteries are depleted to a preset level, the smallest primary engine may be brought online, recharging the house battery bank while sustaining in port power demand. This will allow the engine to operate at peak efficiency and loading until such time as the battery bank is recharged to the recommended level. At such time, the engine will be taken off line, and the battery will again support all in port power demands. Through use of such a power management plan, the power plant will operate at peak efficiency while minimizing pollution and waste energy.

No additional trade studies in Group 3 are identified at this time.

6. Command and Control (Group 4)

No additional trade studies in Group 4 are identified at this time.

7. Auxiliary Systems (Group 5)

7.1. Working Deck Heating

Reference (1) Section 517.2, line item 2047, requires that "A waste heat glycol heating system shall be used to heat the main working deck." This requirement is consistent with the findings of the ASC Research Vessel Replacement Program Deck De-icing Systems Study, Reference (2). It is expected that there will be sufficient waste heat capacity from the ARV machinery plant to provide deck heating, however this type of system is not recommended for the ARV due to the complexity, weight, and cost of such a system and a trade-off assessment has been performed to identify a more suitable deck heating approach.

The ARV team includes Polar operations subject matter experts (SMEs) with experience on the design and operational performance of deck heating systems on other ice-capable vessels. This knowledge includes familiarity with recommendations from the US Army Corps of Engineers on

Icing Management for Coast Guard Assets, Reference (3), the ABS Guide for Vessels Operating in Low Temperature Environments (ABS LTE), Reference (4) as well as lessons learned from the design of the NSF ice-capable research vessel SIKULIAQ. This knowledge base has been used by the ARV Ship Design team to prepare an assessment of deck heating alternatives.

Reference (3) concludes that there are three practical ways of heating decks, which include:

1. Electric heat tracing
2. Heated air circulation (in channels below deck)
3. Anti-icing mats

Because little detail is provided in Reference (3) on the heated air circulation option and based on the complexity of routing and supplying heated air in channels below the deck (creating challenges with routing other distributed systems) this option is not given further consideration.

It is understood that a waste heat glycol system was originally a requirement for the SIKULIAQ but design and cost estimates for the system revealed numerous technical, producibility, and programmatic challenges that ultimately resulted in changes to the SIKULIAQ requirements to permit the use of electric deck heating.

Furthermore, Leidos SMEs with direct experience maintaining the electrical heat trace system on the SIKULIAQ affirm the ease of maintenance and repair. SMEs with experience working with the glycol loops on the Palmer have expressed concerns over the weight and cost to maintain such a system. Both of these real world experiences serve to validate the recommendations of Reference (3).

The benefits and drawbacks of various deck heating options described above, including guidance from Reference (4), are described in additional detail in Table 4 – Deck Heating Options.

With prior experience on the SIKULIAQ demonstrating that the size and complexity of a waste heat glycol system for heating of the aft deck was a significant weight and cost driver resulting in selection of a different deck heating system, this type of deck heating system should not be used for ARV. There are similar challenges with an oil circulating system, with the added concern of possible spills for a vessel working in sensitive areas. Of the other options evaluated, anti-icing mats have also been eliminated from consideration because they cannot be used on working decks. Therefore, the ARV Ship Design team recommends that electric heat tracing is used to heat the main working deck. Programmatic steps are being taken to prepare an ECR to propose changes to Reference (1).

Table 4 – Deck Heating Options

Approach	Benefits	Drawbacks
Waste Heat Thermal Fluid (water with anti-freeze) All-welded C-channel distribution fitted to underside of deck(s)	• Heat source is exhaust gas flow from diesel-electric generators, no need to burn additional diesel • Minimal pollution concern from leaks	• ARV minimum outdoor air temperature of -49 F requires high concentrations of ethylene glycol (~57.4%) or propylene glycol (~58.5%) to protect hydronic system fluid from freezing • High concentrations of glycol required reduces the fluid's capacity to transfer heat (~21% loss) • Increased flow rate of fluid to offset reduction in heat transfer will require larger pumps, larger deck channels, and excessively tax the heat exchangers • From SIKULIAQ lessons learned; complexity of system results in significant cost (materials and labor to fabricate and install channels) and weight penalties compared to other options. SIKULIAQ was ultimately built with electric dead heating.
Waste Heat Thermal Fluid (oil) All-welded C-channel distribution fitted to underside of deck(s)	• Heat source is exhaust gas flow from diesel-electric generators, no need to burn additional diesel	Per the ABS Guide for Vessels Operating in Low Temperature Environments, Reference (4) • Thermal oil is a substitute for steam systems as the oil will not freeze in low temperatures if suitable oil is chosen. • The thermal capacity of oil is less than water, so a greater volume of oil is required to be pumped. • Protection from release of oil into the environment must be considered with thermal oil systems. Also: • Complexity of system results in significant cost (labor to fabricate and install channels) and weight penalties compared to other options
Electric Deck Heating (Heat Tracing) Flexible electric heating elements are fitted to the underside of deck(s)	• Heat generated is readily increases or decreased to suit demand • Lightweight compared to fluid circulation type systems • Lower material and installation cost compared to fluid circulation type systems	• Requires dedicated electrical power and electrical distribution components to generate heat, resulting in additional fuel consumption
Anti-Icing Mats Electrically heated, fastened to top side of deck(s)	• Removable for deck maintenance • Lighter in weight and lower cost compared to fluid circulation systems	• Standard shapes may make complete deck coverage challenging • Mat-type equipment has been used in the offshore environment, but durability and lifecycle cost are unknown • Not suitable for aft main deck due to expected damage due to handling of cargo and other heavy equipment • Mats trap moisture between pad and deck, encouraging corrosion

8. Outfitting and Furnishings (Group 6)

8.1. Aloft Control Station

An Aloft Control Station is a small, enclosed space located high above waterline and well above the bridge, typically fitted on the main mast trunk, which provides enhanced visibility and is minimally outfitted for several crew to direct ship operations. Similar spaces are occasionally found on other types of ships (especially fishing vessels), but Aloft Control Stations are frequently fitted to icebreaking vessels and are used finding leeds when navigating in ice.

Inclusion of an Aloft Control Station (also called the AloftCon or Ice Bridge) in the ARV design is desirable if the associated weight and vertical center of gravity (VCG) impact can be absorbed within ship weight and stability limits.

A meeting was held on April 20th, 2022, with members of the Leidos ARV team hosting numerous subject matter experts (SMEs) on Aloft Control Station arrangements and functionality, including:

- NSF stakeholders
- Glosten ARV Concept Design Team
- Operators, Logistics, and Design personnel associated with the following icebreaking vessels:
    - *KRONSPRIS HAAKON*
    - *ARRV*
    - *HEALY*
    - *SIKULIAQ*
    - *POLAR SEA*
    - *POLAR STAR*
    - *SIR DAVID ATTENBOROUGH*
    - *NATHANIEL B PALMER*

The agenda for the meeting was discussion of Aloft Control Station particulars of other comparable ships, and an assessment of their features, benefits, and drawbacks. As a result of the meeting and subsequent discussions, a draft set of requirements for the proposed Aloft Control Station were developed. The ARV Aloft Control Station is intended to provide full control of the vessel during ice operations and provide a birds-eye view of ice fractures in accordance with the below requirements.

Draft Requirement: An Aloft Control Station shall be provided (AloftCon or Ice Bridge)

- Space and seating for minimum two 95th percentile males dressed in extreme cold weather gear shall be provided.
- Electric heating may be provided to satisfy heating requirements.
- AloftCon floor shall be provided with electric heat strips.
- There are no other Air Conditioning or Climate Control requirements.
- Access to AloftCon shall be provided by an inclined ladder with appropriate de-icing, fall protection, etc.
    a. Objective: AloftCon shall be accessed by exterior stairs with appropriate de-icing, fall protection, etc (low)
    b. Objectives: Interior stairs (high)

- AloftCon shall provide clear view forward and aft, with a view of no less than from 160-200 degrees aft and 300-60 degrees forward
    a. Objective shall be 360-degree field of view.
- AloftCon shall provide windows such that broken ice along the waterline of the ship is visible as practicable based upon sightlines over the house structure.
- AloftCon shall provide appropriate lighting, including dimmable night lighting
- AloftCon shall include redundant comms with bridge, ice radar repeater, chart plotter repeater, and floodlight control.
    a. Objective: provide full ship controls within AloftCon. These controls may be locked out from the main centerline bridge station.
- Top of AloftCon immovable structures shall be no higher than air draft restriction.
- AloftCon shall be as high above water as practicable, but in no case should the eye level be greater than TBD ft above the eye level of the Marine Mammal Observatory space.
- Other objective requirements:
    a. AloftCon shall serve as an additional science observatory. LAN drops and Wi-Fi capability shall be provided.
    b. Top of AloftCon deck shall support 2'x2' equipment bolting grid for occasional support of installation of scientific equipment (maximum size and weight are restricted to TBD dimensions and weight)

The weight and VCG impact of the Aloft Control Station is being investigated as part of the Design Weight Estimate. An assessment of the feasibility of including the Aloft Control Station will be provided in a future revision of this report.

Configuration Change/Waiver Request ECR-005 has been initiated to formally develop Aloft Control Station requirements and if approved, incorporate the change in Reference (1).

8.2. Exhaust Stack Location

A single centerline exhaust stack was initially selected for the ARV design and was shown on revision P1 of the General Arrangement drawing, Reference (5).

The single centerline stack was a result of selection of Fairbanks Morse (FM) engines during the DR2 design spiral to suit the high-power generation needs of the ARV and the available Machinery Space area and Engine Room footprint.

During development of the Machinery Arrangement, the ARV Ship Design team determined that there was a sub-optimal amount of overhead clearance above the FM main diesel generators as illustrated in the left-hand side of Figure 4. Due to this clearance issue, there was concern that there would not be enough space to properly route the Exhaust ducting all the way to the port side. As such, the stack was moved to the centerline to allow for optimal routing of exhaust and to allow sufficient space for other required Engine Room services installed in the overhead (engine room ventilation ducting, combustion air ducting, firefighting, chain hoist, etc).

NSF comments on the DR2 General Arrangement drawing (revision P1) identified two arrangement concerns associated with the centerline stack: (1) restricted aft visibility from the Marine Mammal Observation Space, and (2) sub-optimal lab arrangements and access on the Main Deck. It is noted that typical icebreaking and research vessels have a single port-side exhaust stack, which is motivated in part by the importance of the over-the-side working deck arrangements on the starboard side of the vessel, as well as the aft visibility and lab arrangement preferences noted above. Exiting DR2, the ARV Ship Design team undertook the task of identifying and implementing the necessary design changes to move the exhaust stack to the port side of the vessel.

Entering DR3, the stack has been successfully relocated to the port side of the ship to improve lab arrangements and aft visibility. Relocation of the stack was facilitated by a change in diesel generator selection to shorter Wabtec units, which improves overhead clearance in the existing machinery space as illustrated on the right-hand side of Figure 4.

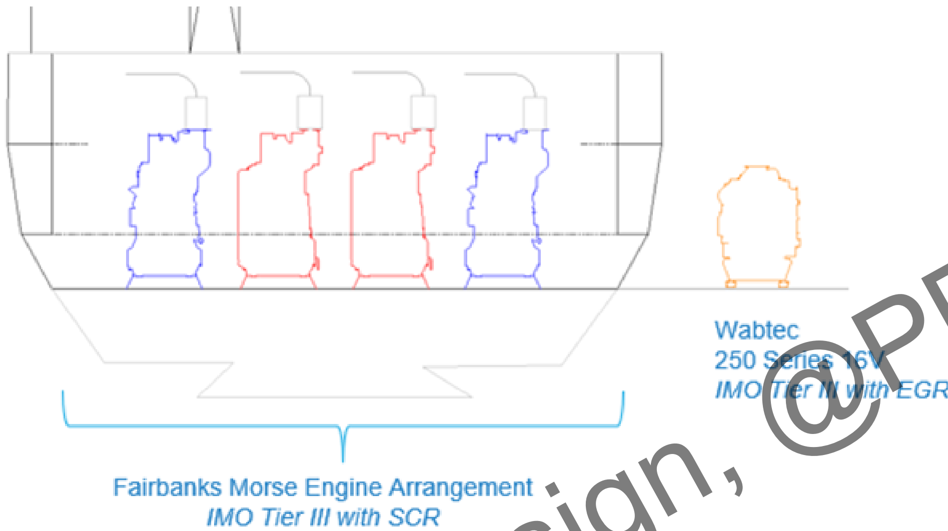


Figure 4 – Diesel Generator Arrangement Concepts

Additionally, deck to deck clearance has been increased which ensures exhaust piping can be routed to the port-side stack and provides sufficient space for other required Engine Room services.

9. Science Mission (Group 7)

Science Mission Trade Studies have been covered in other reports. Examples include the centerboard and transducer trade study, bubble sweepdown study, battery study, topside arrangement design, handling system design, and general arrangement of the ship, including science space arrangement design.
No additional trade studies in Group 7 are identified at this time.

10. Engineering (Group 8)

10.1. Aft Deck Freeboard

Reference (1) Section 0.44.2.2.1 requires that freeboard at the aft working deck not exceed 10.0 feet. Results from initial stability assessments indicate this is insufficient freeboard to satisfy applicable stability requirements without changes to the principal dimensions of the ship or stability requirement waivers.

The ARV Ship Design team has investigated several alternatives that increase the watertight envelope of the ship by adding freeboard or adding watertight volume above main deck to improve stability limits. A summary of these options is provided in Table 5. Option 1 was presented to the wider ARV team as the preferred approach in August 2022. Illustrations showing the extent of the proposed changes are provided in Appendix A.

Table 5 – Freeboard and Watertight Envelope Alternatives

Configuration	Description	Improvement to Stability Limits
Post-DR2 Baseline	38 ft Main Deck + Watertight up to 01 Level Forward of Frame 81	N/A
Option 1	43 ft Main Deck, no Watertight Buoyancy above Main Deck	Good
Option 2A	Stepped Main Deck (38 ft to 43 ft) + Watertight up to 01 Level Forward of ~Frame 81	Better
Option 2B	43 ft Main Deck + Watertight up to (Raised) 01 Level Forward of ~Frame 81	Best

An initial assessment of the benefits and drawbacks of these options has been prepared and these findings are presented in Table 6.

Table 6 – Benefits and Drawbacks of Watertight Envelope Alternatives

Configuration	Benefits	Drawbacks
Post-DR2 Baseline	• Minimizes structural discontinuities in way of deck heights • Retains existing arrangement and “flow”	• Lowest stability limits • Additional stability improvement measures necessary
Option 1	• Minimizes changes to DR2 Baseline • Retains functionality of existing arrangement • Minimal watertight structure above Main Deck • Increases Engine Room overhead height and volume	• Shifts entirety of ship structure above Main Deck up 5 ft; increases ship's VCG • Additional stability improvement measures likely necessary
Option 2A	• Isolates increases to ship structure height to ~forward Frame 81 • Mostly allows for retention of 50 ft ABL 01 Level height • Increases Engine Room overhead height and volume	• Results in structural "discontinuity" in way of Main Deck transition from 38 ft ABL to 43 ft ABL (stepped or sloped deck) • Likely requires appreciable arrangement modifications • May require false floors/decks
Option 2B	• Greatest stability limits • Likely permits for unballasted Full Load and Mid-Voyage conditions • Increases Engine Room overhead height and volume	• Increase in structural weight due to larger watertight envelope

During the presentation of these options in August, some stakeholders were in favor of increasing freeboard to reduce deck wetness in heavy seas, while others were concerned that greater freeboard would make it more difficult to deploy and retrieve equipment over the side and over the stern.

It was determined that a freeboard increase to 13.0 feet should be evaluated, with all stakeholders understanding that adding some watertight volume above the main deck is also likely to be required to achieve desirable stability limit improvement. Weight and stability assessments are in progress.

The science advisors and design team see drawbacks to the 13.0 ft freeboard currently required by the ship's design. This is seen as a key area of study in the Post-PDR design. A small craft landing or side handling niche are envisioned. Vendors for such products and examples of working designs have been identified and will be investigated in detail in the Post-PDR phase.

Once the stability assessment is complete and a final recommendation on changes to the maximum allowable freeboard and/or changes to the extent of watertight envelope of the ship is ready, findings will be presented to the ARV team and an ECR will be prepared to change Reference (1), if required.

11. Conclusion

Trade-off assessments are a key tool in developing the ARV preliminary design to ensure all options are considered and presented for the wider team's consideration so that the best solution for the design can be selected.

This initial revision of the Trade-Off Studies report documents the assessments and studies of six (6) different design features in five (4) different SWBS groups. A status and summary of the path forward to close out all trade studies is presented in Table 7.

Table 7 – Status and Path Forward for Trade-Off Studies

Trade-Off	Status	Path Forward
Bow Tunnel Thruster Size and Quantity	**Open** – Assessments in Progress	• ARV Ship Design team to re-evaluate bow thruster arrangement after initial model testing
Bow Azipod	**Open** – Assessments in Progress	• ARV Ship Design team evaluating potential weight savings
Working Deck Heating	**Open** – Recommendation Ready	• Propose changes to Reference (1)
Aloft Control Station	**Complete** – ECR-005 submitted	• Assist in approval of ECR-005
Exhaust Stack Location	**Complete**	• None
Aft Deck Freeboard	**Open** – Assessments in Progress	• Complete stability and weight updates for 13' freeboard option

Updates to existing trade-off studies and newly identified trade-offs will be documented as design development continues and when this report is revised prior to DR4.

12. References

1) 1913.01 ARV Performance Specification
2) 19136-000-09 ASC Research Vessel Replacement Program Deck De-icing Systems Study, Glosten, 29 April 2021
3) 2013 USACE report ERDC/CCREL TR-13-7 *Icing Management for Coast Guard Assets.*
4) ABS Guide for Vessels Operating in Low Temperature Environments, September 2021
5) G&C Drawing No. 5E1-001-D001, General Arrangement Drawing

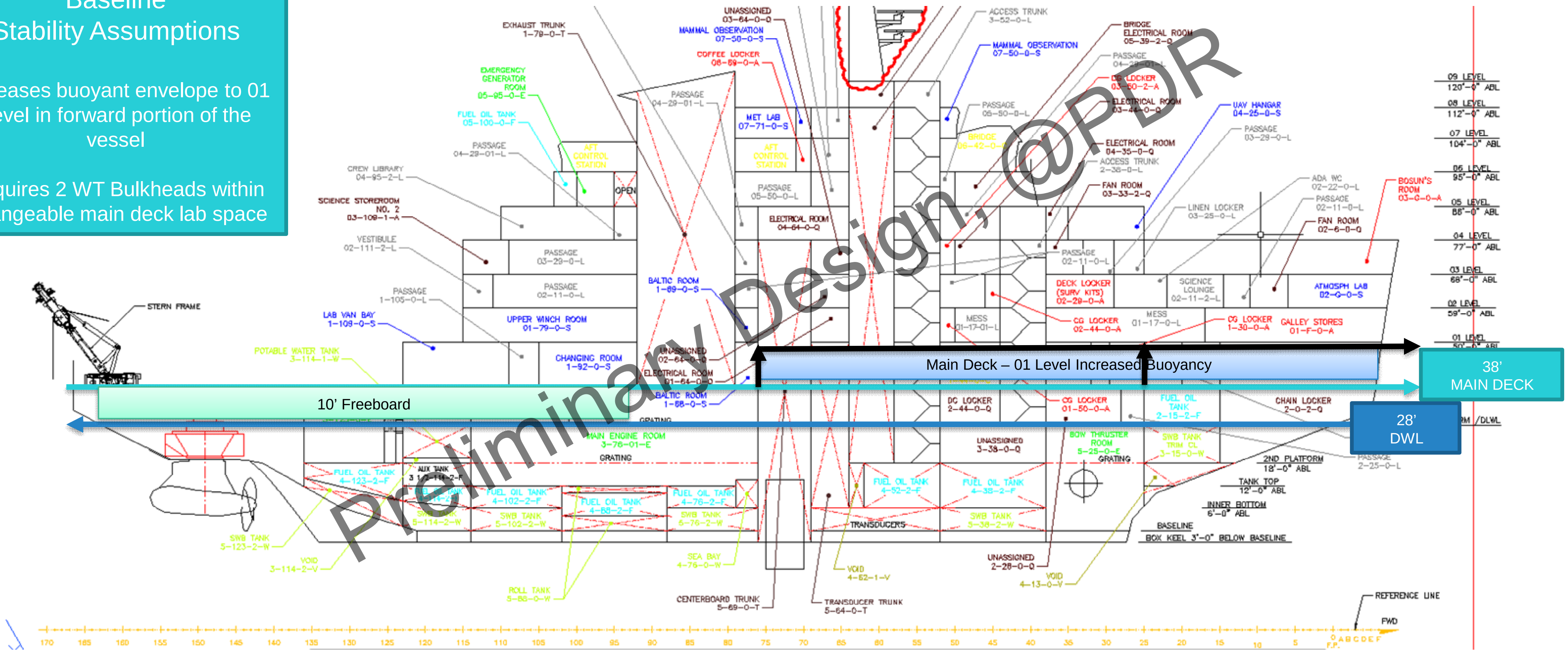
Appendix A – Watertight Envelope Alternatives

Aft Freeboard Deck – Post-DR2 Baseline

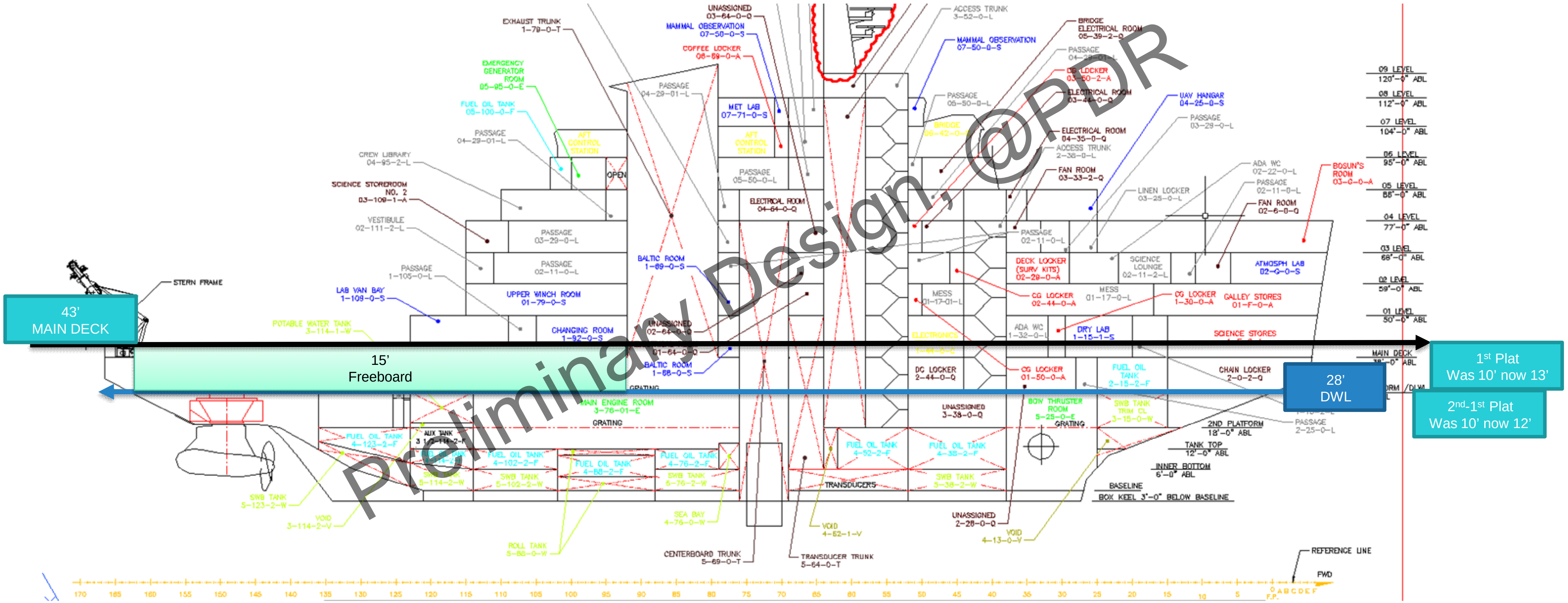
Baseline Stability Assumptions

Increases buoyant envelope to 01 Level in forward portion of the vessel

Requires 2 WT Bulkheads within arrangeable main deck lab space



Aft Freeboard Deck – Option 1



Aft Freeboard Deck – Option 2A

Potential Path:

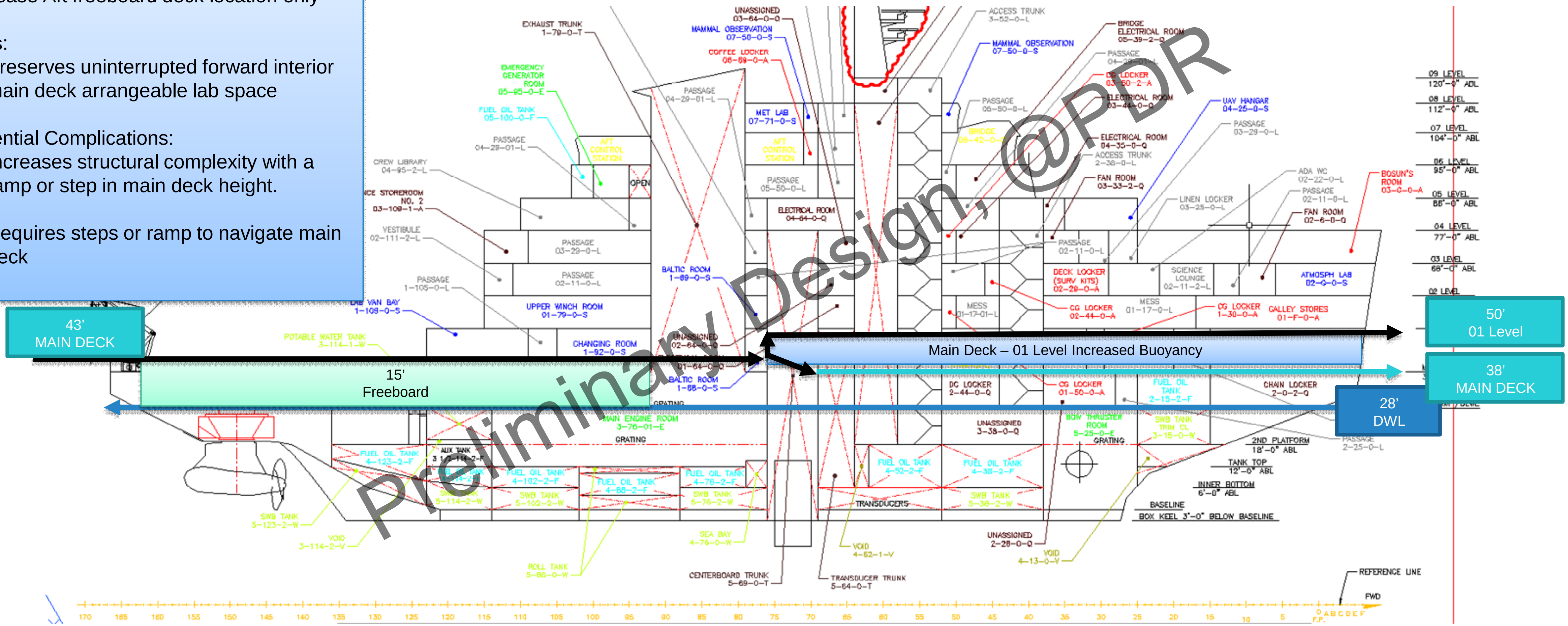
Increase Aft freeboard deck location only

Pros:

- Preserves uninterrupted forward interior main deck arrangeable lab space

Potential Complications:

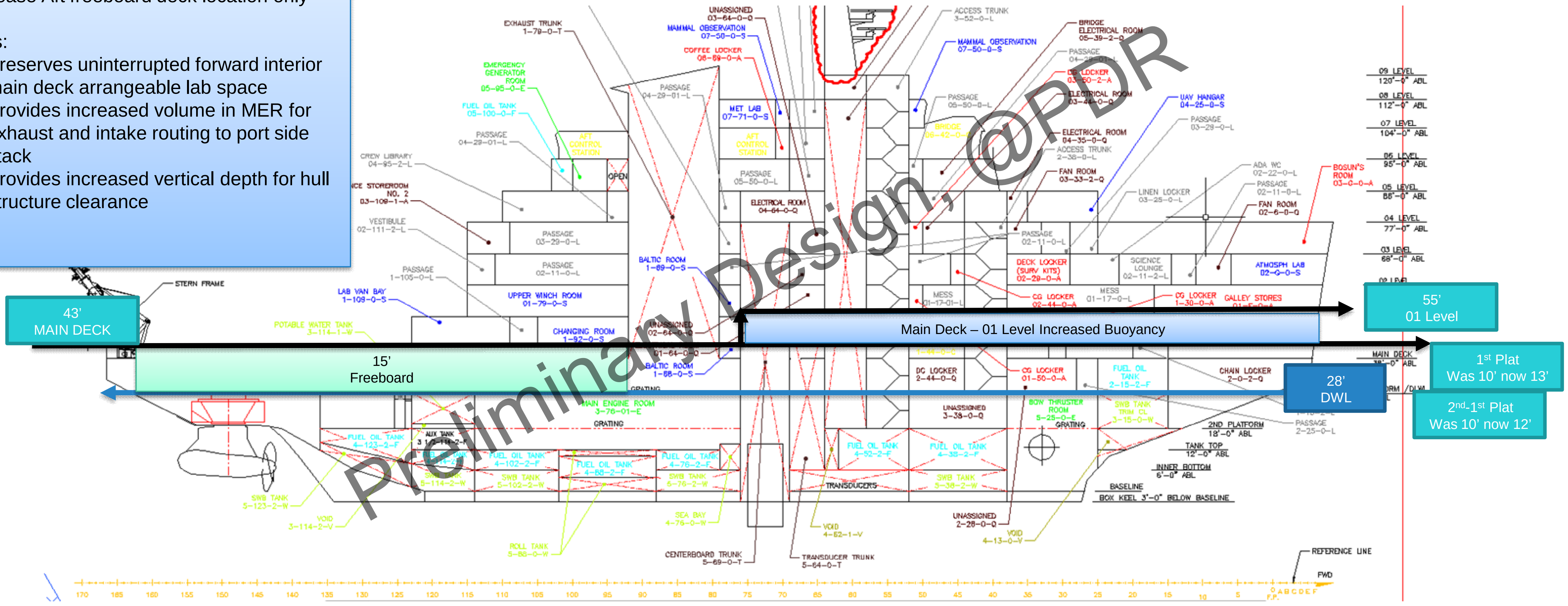
- Increases structural complexity with a ramp or step in main deck height.
- Requires steps or ramp to navigate main deck



Aft Freeboard Deck – Option 2B

Potential Path:
Increase Aft freeboard deck location only

Pros:
- Preserves uninterrupted forward interior main deck arrangeable lab space
- Provides increased volume in MER for exhaust and intake routing to port side stack
- Provides increased vertical depth for hull structure clearance



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