ASC Research Vessel Replacement Program
Autonomous Vehicle Handling Study

PREPARED FOR: Leidos, ASC Centennial, CO			BY: Steven P. Bargh, PE PROJECT ENGINEER	
Glosten 1201 WESTERN AVENUE, SUITE 200 SEATTLE, WASHINGTON 98101-2953 T 206.624.7850 GLOSTEN.COM			CHECKED: Dirk H. Kristensen, PE PRINCIPAL APPROVED: Timothy S. Leach, PE PRINCIPAL-IN-CHARGE	
DOC: 19136-000-08	REV: -	FILE: 19136.01	DATE: 7 May 2021	Digitally Signed 07-May-2021

References

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2. *IBRV Performance Specifications*, Glosten, File No. 19136.01, Rev. P2, 9 June 2020.
3. *Rules for Building and Classing Marine Vessels*, American Bureau of Shipping (ABS), 2020.
4. 46 CFR (US Code of Federal Regulations), *Shipping*, 2020.
5. *Standard Guide for Shipboard Use of Lithium-Ion (Li-ion) Batteries*, ASTM, Standard No. F3353-19, 2019.
6. *Technical Reference for Li-ion Battery Explosion Risk and Fire Suppression*, Det Norske Veritas Germanischer Lloyd (DNVGL), 2019.
7. *Design Guidance for Lithium-ion Battery Installations Onboard Commercial Vessels*, US Coast Guard (USCG), CG-ENG-Policy Letter No. 02-19, 2 October 2019.
8. *Research Vessel Safety Standards*, University-National Oceanographic Laboratory System (UNOLS), 10th Edition, July 2015.
9. *Lithium Battery Safety Procedure*, Woods Hole Oceanographic Institute (WHOI), 23 February 2011.
10. *ARV Concept Design General Arrangement*, Glosten, Drawing No. 19136-000-01, Rev. -, 26 April 2021.

Abbreviations

ABS	American Bureau of Shipping
ABS MVR	ABS Rules for Building and Classing Marine Vessels (Reference 3)
ARV	Antarctic Research Vessel
ASTM	American Society for Testing and Materials
ASV	Autonomous surface vehicles
AUV	Autonomous underwater vehicle
CFR	US Code of Federal Regulations
CSSF	Canadian Scientific Submersible Facility
CTD	Conductivity, temperature, depth
DNVGL	Det Norske Veritas Germanischer Lloyd
LARS	Launch and recovery system
NFPA	National Fire Protection Association
ROV	Remotely operated vehicle
VTOL	Vertical Take-Off and Landing
UAV	Unmanned aerial vehicle

USV	Unmanned surface vehicle
UNOLS	University-National Oceanographic Laboratory System
USBL	Ultra-short baseline
USCG	United States Coast Guard
WHOI	Woods Hole Oceanographic Institution

Executive Summary

This study produced the following recommendations for updating the Antarctic Research Vessel (ARV) Performance Specifications to improve the functionality of autonomous vehicle handling:

1. The Unmanned Aerial Vehicle (UAV) Deck should be located forward of the superstructure.
2. The UAV Deck should have a means of de-icing.
3. The UAV Deck should have a 2 ft by 2 ft grid of deck sockets in addition to tie down sockets.
4. The opening from the UAV Hangar to the UAV Deck should be at least 12 ft wide to accommodate large, fixed wing UAVs.
5. The opening from the UAV Hangar to the UAV Deck should be more substantial construction than a roller curtain door currently in the specification, such that it can adequately handle the wind and wave loads on the forward side of a superstructure.
6. There should be at least 20 ft of clear space in the Autonomous Underwater Vehicle (AUV) Hangar to accommodate long AUVs.
7. A portion of the aft working deck should have reinforced structure to accommodate large AUVs and remotely operated vehicles (ROVs) and their accompanying launch and recovery systems.
8. The freight elevator in the AUV Hangar should be sized to accommodate a 3ft x 3 ft pallet.
9. The aft working deck should have a means of moving heavy AUVs/ROVs from the exterior deck into the covered AUV Hangar. This could be in the form of a bolt-in rail system utilizing the tie-downs.
10. The aft working deck should be provided with a 50 Hz power supply for equipment developed to use 50 Hz, avoiding the need for a transformer.
11. Two fuel drum storage locations for autonomous/unmanned surface vehicles (ASVs/ USVs) or UAV use should be added to exterior decks. This storage solution shall allow for fuel drum jettison over-the-side if needed in the event of an onboard fire.
12. A means should be provided to move heavy lithium batteries from the AUV Hangar onto the aft working deck, and from the aft working deck to the transom and overboard.
13. The AUV Hangar and UAV Hangar should be designed to meet the requirements of the ASTM *Guide for Shipboard Use of Li-ion Batteries* (Reference 5).
14. The AUV Hangar and UAV Hangar should be provided with seawater from the fire main and a rapid means of deployment for use in the event of a lithium battery fire.

Purpose

Per the Glosten proposal for this phase of work (Reference 1), the scope of the Autonomous Vehicle Handling Study was as follows:

> "The use of autonomous vehicles for research activities is increasing, including the use of undersea, surface, and aerial vehicles. This study will review handling systems to support the efficient launch and recovery of multiple vehicles.

> In addition to handling autonomous vehicles, this study evaluated the requirements for the storage and charging of their batteries, power requirements, and regulatory obstacles. Storage and charge of vehicle batteries is an important topic due to space and arrangement requirements."

Methodology

The first phase of this study involved gathering information and knowledge related to all types of autonomous vehicles used in the science community. Internet searches were performed to create a database of ASVs, AUVs, ROVs, and UAVs that could potentially be used on the ARV. This research is compiled in Appendices A–D. The specifications of each vehicle were documented to guide the rest of the study. While it is difficult to predict which exact autonomous vehicles will be used in the future, examining a range of vehicle types allows us to design flexible spaces which will be able to handle unknown future needs.

Discussions were held with industry experts to obtain knowledge on how these vehicles are currently being operated on research vessels:

- UAVs: Luc Lenain, Scripps Institution of Oceanography.
- ROVs: Hans Thomas, Monterey Bay Aquarium Research Institute.
- ASVs: Andrew Ziegwied, ASV Global.

The second phase of the study was a review of the Performance Specifications, as currently written (Reference 2), to develop recommendations for improvement based on the knowledge gained in Phase 1. We reviewed the following details in the specifications for each type of autonomous vehicle:

- Deck space available for operation.
- Storage space and maintenance considerations.
- Handling systems for launch and recovery.
- Considerations for vehicle power sources.

The final phase of the study was a review of current regulations and industry best practices regarding autonomous vehicle power sources (batteries and gasoline). The information gathered from these sources allowed us to make recommendations for items to be added to the specifications in order to be compliant with regulations and best practices.

Findings

Aerial Vehicles

Overview

UAVs come in two main types, multi-rotor and fixed wing. A third type currently in development is the vertical take-off and landing (VTOL) fixed wing hybrid. This hybrid technology is still in its infancy but will be able to operate on the ARV when it arrives as the ARV will be able to accommodate multi-rotor and fixed wing UAVs.

A typical multi-rotor UAV is shown in Figure 1. Multi-rotor UAVs are small, inexpensive, and easy to operate but have limited endurance and speed. A typical mission using a multi-rotor AUV lasts between 20 and 30 minutes. These characteristics make multi-rotor UAVs useful for small-scale aerial photography or videography, but large-scale applications are not viable. Batteries are the primary power source for multi-rotor UAVs as gasoline engines cannot handle the need for fast and high precision throttle changes.

Figure 1 Multi-rotor UAV Cinestar [courtesy of Freefly]

A typical fixed wing UAV is shown in Figure 2. Fixed wing UAVs utilize wings like an airplane, allowing them to cover much larger distances and operate for longer timeframes (upwards of ten hours). Fixed wing UAVs lose the ability to hover in place and have a more difficult take-off and landing procedure. Gasoline engines are a viable power source for fixed wing UAVs in addition to batteries.

Figure 2 Fixed wing UAV Scan Eagle [courtesy of Boeing]

Hybrid VTOL fixed wing UAVs are an attempt to blend the best characteristics of multi-rotor and fixed wing UAVs. These hybrid vehicles will combine the hover capability and ease of take-off and landing of multi-rotor with the endurance and speed of fixed wing. A current example of a hybrid UAV is shown in Figure 3.

Figure 3 Hybrid VTOL fixed wing UAV [courtesy of Amazon]

Deck Space

The ARV specifications call for a UAV Deck. The location of this deck has been brought into question, either forward or aft of the superstructure. The impetus of this question was the desire to determine if clean air forward of the superstructure or sheltered air aft of the superstructure is better for UAV performance. Industry expert Luc Lenain from Scripps Institution of Oceanography determined that the clean air forward of the superstructure is the best location for the UAV Deck as the sheltered air aft of the superstructure will create large amounts of turbulence.

Figure 4 shows the forward half of the ARV concept design, which illustrates a possibility for a forward-located UAV Deck. The size of this deck, 34 ft by 54 ft, is more than adequate for UAV operations and allows for flexibility of mission type. Threshold clear deck sizes are 24 ft by 33 ft to allow for vertical take-off, catapult launch, and helicopter winching operations. In addition to this clear area, it is anticipated that a 20 ft ISO van could be located on this deck to support UAV operations. This van would be located outside of the recommended clear deck area.

The Performance Specifications currently require tie down sockets on the UAV Deck. A 2 ft by 2 ft grid of deck sockets should be added to the UAV Deck in addition to the tie down sockets.

The control center for UAV operations can be located in two locations, depending on weather conditions. If weather permits, the UAV control center can be located in the UAV Hangar which is adjacent to the UAV Deck. If inclement weather prevents the UAV Hangar door from being open, the control center can be moved to the Bridge. The bridge has a clear view of the UAV Deck and is sheltered from the elements.

The UAV Deck should have weatherized data feed boxes and wireless receiving capability for scientist access to the ship network.

The weather in the Antarctic can be harsh and unpredictable. It is possible that a mission will begin in fair weather but deteriorate before the UAV returns. Because of this possibility, the UAV Deck needs to have a de-icing system to allow for safe UAV recovery.

The UAV Deck should be fitted with a means of fall protection around the perimeter of the open deck.

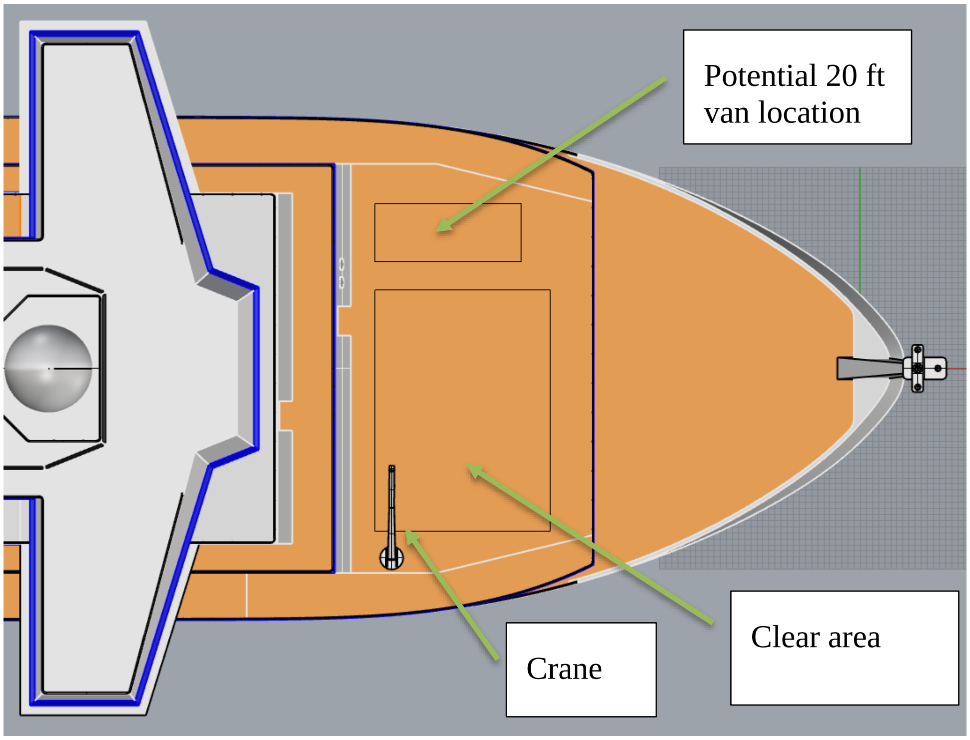


Figure 4 04 Deck forward, ARV concept design UAV Deck

Storage and Maintenance

The ARV specifications, as currently written, require the UAV Hangar to be adjacent to the UAV Deck on the forward end of the superstructure. The specifications require the hangar to be 450 ft^2 and contain a workbench, cabinet, and tools. The size and furnishings of this hangar are adequate.

The specifications call for an 8 ft wide roller curtain door to open directly onto the UAV Deck. There are two issues with this requirement. First, the popular UAV 'Scan Eagle' is over 10 ft wide when assembled. The opening from the UAV Hangar to the UAV Deck should be increased to 12 ft wide to accommodate fixed wing AUVs. Second, the door is on the forward side of the superstructure on a vessel operating in the Southern Ocean. A roller curtain door will not survive the vessel's operational profile. The door between the UAV Hangar and the UAV Deck should be designed to withstand the anticipated wind load and green water.

The UAV Hangar should be provided with clean power and a minimum number of receptacles should be specified.

Handling Systems

UAVs are generally small and lightweight (less than 50 lb takeoff weight); therefore, they do not require lifting devices to maneuver around the ship. If a lifting device is required, the forward stores crane is located adjacent to the UAV Deck and UAV Hangar and has a capacity of 4,000 pounds. The launch and recovery of multi-rotor and fixed wing UAVs are described below.

Multi-rotor UAVs require only a small amount of deck space for take-off and landing. The area above this space needs to be free and clear of any obstacles. Advancements in technology are enabling multi-rotor UAVs to take-off and land without any involvement by an operator.

The launch and recovery of fixed wing UAVs is a more involved process. Depending on the size of the vehicle, take-off requires either a runway or a catapult system. Landing usually entails a high-speed catch using large net on the aft working deck, requiring a large amount of clear space. Landing fixed wing UAVs poses a risk of damage of ship structure, equipment, or personnel.

Powering

Multi-rotor UAVs are powered by lithium batteries. Fixed wing UAVs are powered by lithium batteries or gasoline/jet fuel. The use of hydrogen fuel cells is being developed for use in UAVs but is not mature technology at present. It is assumed that if hydrogen is used storage will be brought on the vessel as needed. See the ‘Autonomous Vehicle Power Sources' section for further discussion.

Subsurface Vehicles

Overview

AUVs and ROVs are the main types of subsurface vehicles used in the science community.

AUVs are untethered vehicles that mostly resemble torpedoes in shape. Typical lengths range from under 10 ft to over 20 ft. Weight ranges are from several hundred pounds to several thousand pounds. AUVs carry equipment such as cameras, sonar, and depth sensors and mostly operate independently. Normally, the data collected by an AUV is stored on the vehicle until it is recovered at the conclusion of a mission. Some AUVs transmit data to the ship via satellite link. AUVs are primarily powered by batteries. A typical torpedo- shaped AUV is shown in Figure 5.

Figure 5 Teledyne Marine Osprey AUV [courtesy Teledyne Marine]

ROVs are normally box-like in shape, ranging in size from a microwave oven to a car. Large ROVs can weigh upwards of 10,000 pounds and require specialized launch and recovery systems (LARS). ROVs are connected to the ship via a tether which allows for power, data transfer, and operator control. Most ROVs carry equipment such as still cameras, video cameras, lights, cutting and grabbing arms, and water sampling tools. A large ROV is shown in Figure 6.

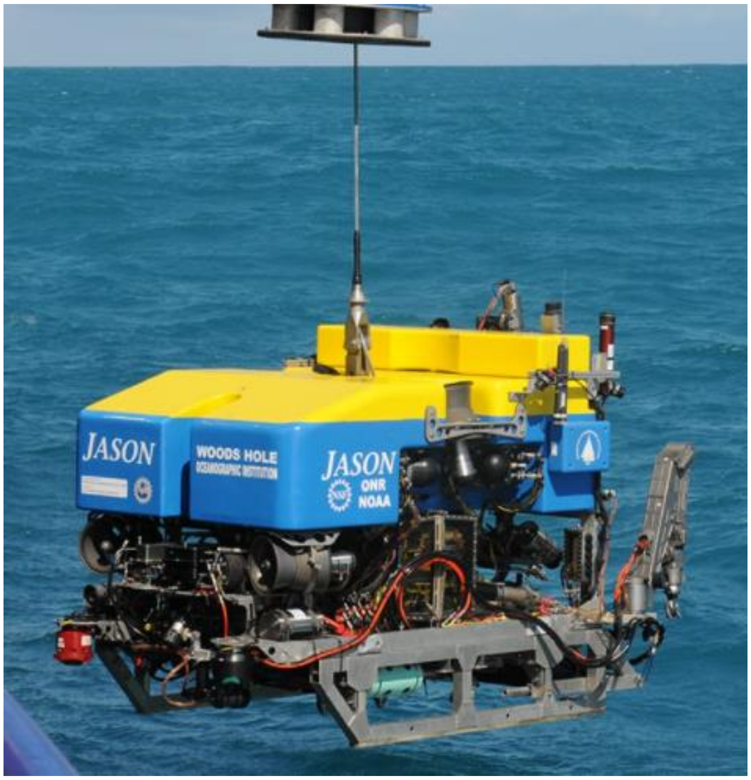


Figure 6 ROV Jason [courtesy of WHOI]

Section 715.1 in Reference 2 specifies that the ARV will have an ultra-short baseline (USBL) underwater system positioning transponder. In this system, a transceiver is mounted in the vessel and a transponder is located on the AUV or ROV. This combination allows the location of the subsurface vehicle to be tracked by operators.

Deck Space

Operations using AUVs and ROVs are typically conducted from the aft working deck. Most science operations will be conducted at the transom and along the starboard side of the vessel. Either the port or starboard side of the aft working deck may be used for the launch and recovery of AUVs and ROVs. Figure 7 shows the Main Deck on the ARV concept design. The control center for the aft working deck is located to have an unobstructed view of both the aft and side working decks. The aft working deck space spans the entire beam of the ship at 68 ft-7 inches and has a length of 50 ft on the port side and 94 ft on the starboard side. There is adequate space for AUVs and ROVs on the aft working deck.

Some ROVs require 40 ft containers. There is adequate space on the aft working deck to accommodate a 40 ft container.

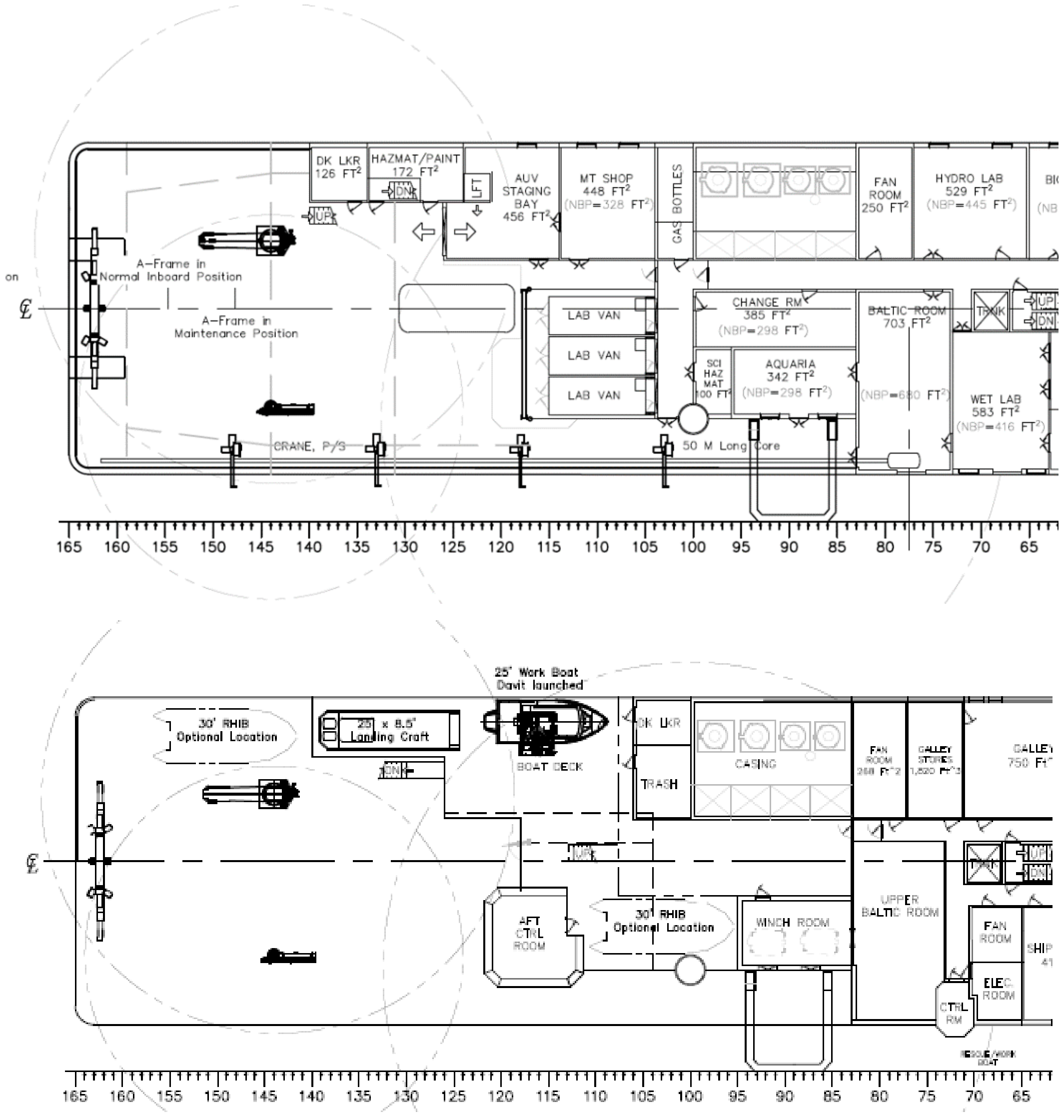


Figure 7 ARV concept design Main Deck, showing aft working deck space [via Reference 10]

Storage and Maintenance

The ARV concept design has a dedicated AUV Hangar, labeled as the AUV Staging Bay in Figure 7. The Performance Specifications currently require the AUV Hangar to open directly to the aft working deck via a roller curtain door. The AUV Hangar should be considered a wet space. A freight elevator within the hangar provides access to both levels of the Science Hold (1st platform and tank top). This elevator should be large enough to accommodate a 3 ft. x 3 ft. pallet. Note that this elevator would require a sill while at sea, making it more difficult to use. AUVs can also be stored on the aft working deck.

The specifications currently call out 450 ft^2 for the AUV Hangar but do not give exact dimensions of the space. AUVs can be up to 20 ft in length so the specifications should require the AUV Hangar to be at least 20 ft long.

The AUV Hangar contains a bench with tools and is adjacent to the Marine Tech Shop. The Marine Tech Shop will be fully equipped for mechanical work including welding. A dedicated support van (for AUV or ROV work) could be located in the lab van area seen in Figure 7.

There is no space dedicated to ROV storage and it is assumed that ROVs will be stored on the aft working deck. Some ROVs may also come with their own LARS that, combined with the weight of the ROV, can be a substantial load on the deck. It is recommended that a section of the aft working deck is required to be reinforced to accommodate large ROVs and their corresponding LARS. If an ROV needs a sheltered environment, the AUV Hangar or storage vans may be able to accommodate ROVs of certain sizes.

The AUV Hangar should be provided with clean power and a minimum number of receptacles should be specified.

Handling Systems

Large AUVs and ROVs need to be moved between their storage area and mission area for launch and recovery. To handle these moves, the ARV concept design has three cranes that serve the aft working deck. The working deck large crane has a capacity of 20,000 pounds and reach that encompasses most of the aft working deck and beyond the port side shell (Figure 7). The starboard aft portable crane has a capacity of 4,000 pounds and a reach that encompasses the starboard rail and of the aft working deck. The amidship heavy lift crane has a capacity of 30,000 pounds and a reach that encompasses the lab van area and the forward, starboard portion of the aft working deck (Figure 7). Both the large crane and amidship heavy lift crane can access the Science Hold.

The Performance Specifications currently state that cranes shall "all to be operable through Sea State 5". The heavy lift crane may be more difficult to control at sea given the weight of the boom, but the heavy lift crane is not designated for deploying to the water. The Aft Working Deck Large crane and the portable crane will be used for deploying to the water. It will be preferable to use the portable crane as it can be located closer to a side rail for better view of the process, and a reduced reach.

These cranes can handle moves that begin and end on the working deck, but they cannot retrieve or place vehicles into a covered space (AUV Hangar). An in-deck fixed-rail system could be incorporated to help move large AUVs and ROVs from the aft working deck to covered storage and workshop areas. However, this may be problematic due to icing and could further complicate de-icing systems. It would also be possible to utilize the bolt-down fittings to temporarily add rails where needed.

Once the AUV or ROV has been moved from its storage location, launching can be accomplished using the ship’s equipment or dedicated LARS provided with the vehicle. The ARV has two over-the-side handling frames that can accommodate vehicle launches: the stern A-frame and the side A-frame.

The stern A-frame has a safe working load of 40,000 pounds, 30 ft of vertical clearance, 18 ft of horizontal clearance, 12 ft of reach forward and aft of the transom, and 180 degrees of motion ranging from parallel to deck to parallel to sea surface. The side A-frame has a safe working load of 40,000 pounds, 25 ft of vertical clearance, 15 ft of horizontal clearance, and 10 ft of reach over the starboard side of the vessel. These frames are generally configured to run a wire overboard and would need specialized lifting equipment to handle the launch of AUVs and ROVs. The inclusion of specialized lifting attachment should be revisited in the next design phase in the builder’s specification and bid design.

The cranes can also perform over-the-side launching, provided they too have the correct lifting heads. Further investigation should be performed to determine if specialized lifting devices should be required.

The recovery of AUVs and ROVs is more challenging than the launch. The ship must be able to maneuver to the location of the AUV and have a means to obtain the retrieval attachment, and the lifting device (frame or crane) must have the correct attachment. As previously stated, the frames and cranes serving the aft working deck should be supplied with lifting attachments that will allow recovery of AUVs and ROVs from the water.

Some AUVs and ROVs come with their own LARS that must work within the constraints of the vessel. As mentioned in the ‘Storage and Maintenance’ section, the scantlings of the aft working deck and the tie-down arrangement must be able to accommodate the large combined load of the ROV and LARS. The specifications call out a removable bulwark on the aft working deck that will help facilitate dedicated LARS use.

Not all portable LARS will be designed for cold temperature operations, particularly electro-hydraulic systems. The ability to provide ship’s hydraulic power to portable LARS should be considered.

The launch and recovery of some AUVs and ROVs requires the use of a small surface boat to coordinate. In the event that the AUV or ROV has a dedicated LARS that renders one crane or lifting frame unusable, there is redundancy in the array of lifting devices to still be able to launch a boat.

Powering

AUVs are currently powered by lithium batteries and will be for the foreseeable future. The use of hydrogen fuel cells is being developed for use in AUVs but is not mature technology at present. ROVs receive power via the tethered connection to the ship. See the ‘Autonomous Vehicle Power Sources’ section for further discussion.

Some AUVs require a 50 Hz power supply. The aft working deck should be provided with a 50 Hz power supply.

Any autonomous vehicle stored on deck should have the ability to connect to power and data cables. These data cables should connect to lab spaces for long term connectivity.

Surface Vehicles

Overview

ASVs (also referred to as USVs) operate on the surface of the water without a crew. Some ASVs resemble surfboards in shape, but this style ASV are simple and do not impact ship design. Larger ASVs resemble workboats or rescue boats in shape and can range from 5 ft to 30 ft in length. Weight ranges are from several hundred pounds to several thousand pounds. ASVs can perform bottom mapping, hydrographic work, and tend to buoys. ASVs can be controlled remotely from the parent ship or operate fully autonomously. Figure 8 shows a typical ASV.

ASVs are not highly utilized by research vessels to date, but the coordinated use of aerial, subsurface, and surface vehicles to conduct research is likely to increase in the future.

Figure 8 C-Worker 6 ASV [courtesy ASV Global]

Deck Space

Operations using ASVs will likely be conducted from the aft working deck on the Main Deck level (Figure 7). The aft working deck space spans the entire beam of the ship at 68 ft-7 inches and has a length of 50 ft on the port side and 94 ft on the starboard side. Either the port or starboard side of the aft working deck may be used for the launch and recovery of ASVs.

Storage and Maintenance

If the ASV comes in a containerized package, the container could be stored in the lab van area on the aft working deck as shown in Figure 7. If the ASV rests within a dedicated LARS, this could be located in an open area by the side shell on the aft working deck. Similar to an AUV or ROV LARS, the scantlings of the deck would need to be strong enough to support the weight and loads associated with its use.

Handling Systems

The handling systems for ASVs will be similar to those for AUVs and ROVs. Ship's equipment (cranes and lifting frames) can be used with specialized attachments or a dedicated LARS that comes with the ASV can be integrated with the vessel. As described in the 'Subsurface Vehicles' section, recovery will be a more difficult process than launch.

Powering

ASVs can be powered by battery banks, solar panels, marine diesel fuel, or regular diesel fuel.

Simultaneous Use of Multiple Autonomous Vehicles

ARV operations may include missions where multiple autonomous vehicles are operated simultaneously. In these scenarios, the concept design is adequate for several reasons. Separating the UAV Deck from the aft working deck provides ample space for each type of autonomous vehicle. The aft working deck has multiple cranes and frames that can handle over-the-side operations. The aft working deck also has the strength to handle vehicle specific launch and recovery systems.

The simultaneous use of autonomous vehicles places more constraints on mission planning. ARV operators will need to be aware not to 'overbook' the vessel. A sample scenario is as follows: an autonomous vehicle is to be used on the ARV that has a dedicated LARS installed at the transom. This LARS renders the A-Frame unusable during that mission. Any other autonomous vehicles must be capable of launch and recovery over-the-side.

The simultaneous use of autonomous vehicles creates an increased requirement for communication to and from the ship. This increased communication capacity, data streams for example, should be investigated in the future during design of the communication systems.

Autonomous Vehicle Power Sources

The power sources identified for use by autonomous vehicles on the ARV are:

- Gasoline
- Diesel
- Jet Fuel
  - JP-5
  - JP-8
- Lithium Batteries
  - Lithium Metal
  - Lithium-Ion
  - Lithium Polymer
- Hydrogen
  - Fuel Cells

Gasoline, Diesel, and Jet Fuel

Regulatory References

Applicable rules for storage of flammable liquids can be found in the ABS *Rules for Building and Classing Marine Vessels*, commonly referred to as the ABS Marine Vessel Rules (ABS MVR; Reference 3):

- Section 4-1-1/1.9.4
- Section 4-6-1/3.23
- Section 4-8-4/27.3.3

Plan of Action

The small amount of gasoline, diesel, or jet fuel required to power fixed wing UAVs or ASVs can be stored in 55-gallon drums. These drums should be stored in racks on an exterior deck that allow for overboard jettisoning if needed in the event of an onboard fire. The location of the rack should be chosen to avoid any potential impacts on ship operations and should be enclosed with a containment coaming. Two stations should be provided: one forward near the UAV Deck and one aft on the Main Deck.

Batteries

Regulatory References

The following references concern lithium-ion battery usage onboard vessels. These regulations currently apply to large lithium-ion battery installations for shipboard propulsion or ship service power. These references should be monitored throughout the design life of the ARV for updated applicability to portable lithium-ion battery usage:

- ABS MVR (Reference 3) – Section 4-8-3/5.9.
- 46 CFR (Reference 4) – Section 111.15.
- *Standard Guide for Shipboard Use of Lithium-Ion (Li-ion) Batteries,* ASTM Standard No. F3353 (Reference 5).
- *Technical Reference for Li-ion Battery Explosion Risk and Fire Suppression,* DNVGL (Reference 6).
- *Design Guidance for Lithium-ion Battery Installations Onboard Commercial Vessels,* United States Coast Guard (USCG; Reference 7).

Current Practice References

The following references are produced as guidelines for operators:

- *Research Vessel Safety Standards,* University-National Oceanographic Laboratory System (UNOLS; Reference 8).
- *Lithium Battery Safety Procedure,* Woods Hole Oceanographic Institute (WHOI; Reference 9).

Overview

UNOLS separates lithium batteries into two categories (Reference 8):

- Primary lithium batteries (lithium metal).
    - Non-rechargeable, containing lithium metal.
    - All primary lithium batteries must be treated as hazardous material while aboard a vessel.
- Secondary lithium batteries (lithium-ion and lithium polymer).
    - Rechargeable, containing no lithium metal.
    - In a lithium-ion battery, the lithium is in a liquid state.
    - In a lithium polymer batter, the lithium is in a plastic state.

Identification

Any planned use of primary lithium batteries needs to be identified during cruise planning. The chief scientist must provide the crew with a list of all primary lithium batteries to be used and their characteristics.

No special inventory or identification is required for secondary lithium batteries.

Handling, Stowage, and Use

Primary lithium batteries must be handled with care during loading, unloading, and while in use.

It is recommended that primary batteries are stored in their protective case on an open deck, or as close as possible to the exit to an open deck if they are stored in an enclosed area. Batteries vary in size and shape and can weigh over 1,000 pounds. A means should be provided to move heavy batteries to the deck and overboard in the event of a fire. Any space that will be used to store primary lithium batteries must meet the provisions set out in Reference 5. These include but are not limited to:

- Temperature control and monitoring in the space
- Gas monitoring
- Exhaust ventilation
- Structural fire protection
- Fixed firefighting capabilities
- Battery management system

These characteristics result from the potential for a lithium fire involving the battery and are described further in the 'Emergency Procedures' section below. Both the AUV Hangar and UAV Hangar should meet the requirements set out in Reference 5.

Secondary lithium batteries have no special handling, stowage, or use guidance beyond the typical avoidance of high temperatures. Secondary lithium batteries may remain installed in their respective equipment.

Charging

Primary lithium batteries are non-rechargeable.

Secondary lithium batteries should only be charged with the dedicated charger in accordance with manufacturer instructions. Large secondary lithium batteries should be charged on an open deck to mitigate consequences in case of a fire.

Emergency Procedures

A fire involving a primary lithium battery will persist until the entirety of the lithium or all the oxygen in the space is depleted. While the fire is burning, significant heat and toxic fumes will be produced. To limit the amount of heat generated, large amounts of water should be applied to the battery. The water will not extinguish the fire but will help to control a 'runaway' temperature. The large amount of water needed to control the temperature of the fire can overwhelm a vessel's bilge system, so the water used to control the temperature should be diverted overboard. Protective masks should be worn to avoid inhaling the toxic fumes.

For the reasons described above, it is preferred to fight a battery fire on an open deck. If the temperature of the fire cannot be controlled, it is recommended to jettison the battery overboard. If the battery that is on fire is within a vehicle, the entire vehicle including the battery should be jettisoned overboard.

The AUV and UAV Hangars should be supplied with seawater from the fire main system and a means of rapid availability, whether it be a deluge system or dedicated hose station.

For large secondary batteries, the emergency procedures are the same as primary batteries, described above.

For small rechargeable batteries, a portable ABC extinguisher should be used in the event of a hot cell or fire. A class D extinguisher should not be used. Secondary lithium batteries may be jettisoned in case of an onboard fire.

Portable ABC extinguishers shall be provided in any space where equipment with batteries may be used.

Hydrogen

Hydrogen fuel cells are starting to emerge as a viable alternative to lithium batteries to power AUVs and UAVs. This technology is not widely developed or mature, but companies are investing in its development. Hydrogen fuel cell company Plug Power has developed a multi-rotor AUV and is currently conducting real world testing. Plug Power claims that their hydrogen fuel cells will allow for significantly longer flight times than a lithium polymer battery. This is a promising technology that should be monitored over the coming years.

Specification Changes

Recommended Changes

Section 044.2.2 – Working Decks and 0.44.2.8 – Unmanned Aerial Vehicles Support

The recommended action is the UAV Deck should be located forward of the superstructure. The tradeoff from this recommendation is that modern ice breaker designs have the superstructure forward to help reduce ice accumulation. Should the specification:

- **Require UAV deck to be forward (threshold requirement, no objective).**
- Express preference for UAV Deck forward? (UAV deck is threshold, forward is objective).
- Require UAV deck, remain silent on location? (threshold only).

Section 130.1 – Working Deck

The recommended action is a portion of the aft working deck should have reinforced structure to accommodate large AUVs and ROVs and their accompanying launch and recovery systems. The tradeoffs from this recommendation are that the deck may not need any further strengthening and the location for possible strengthening is not known currently. Should the specification:

- Require specific reinforced areas? Will need to give loads and sizes that are known for existing equipment, this may or may not capture future equipment. (could develop threshold and objective requirements).
- **State assumed ROV system to be used, remain silent on deck space and flag as item to pay attention to during design reviews?**

The recommended action is the aft working deck should have a means of moving heavy AUVs/ROVs from the exterior deck into the covered AUV Hangar. This could be in the form of a bolt-in rail system utilizing the tie-downs. The tradeoffs from this recommendation are tripping hazards and maintenance. Should the specification:

- Require the designer to develop a notional rail system that utilizes the bolt down pattern? (Would need to develop parameters for the system. Thresholds and objectives.).
- State desire for rail system, assuming this would be passed on to shipyard for detailed development?

Section 320 – Heat Tracing

Add text stating 'UAV Deck shall have a means of de-icing'.

Section 660.3.2 – AUV Hangar

Add text stating 'Freight elevator should be sized to accommodate a standard pallet'.

The recommended action is that there should be at least 20 ft of clear space in the AUV Hangar to accommodate long AUVs. Should the specification:

- Require a minimum space in way of the AUV Hangar (threshold requirement, no objective)?
- **State largest AUV to be assumed, remain silent on deck space and flag as item to pay attention to during design reviews?**

The recommended action is a means should be provided to move heavy lithium batteries from the AUV Hangar onto the aft working deck, and from the aft working deck to the transom and overboard. The tradeoff from this recommendation is the arrangement of the AUV Hangar has additional constraints. Should the specification:

- Require a specific means to move specified weight of compromised batteries to the deck and/or over the side)?
- **Discuss use of primary LI-Ion batteries and require designer to consider safety precautions in development of spaces where stored, including fire protection and handling**?

This specification change also applies to the following recomendations:

- The AUV Hangar and UAV Hangar should be designed to meet the requirements of the ASTM Guide for Shipboard Use of Li-ion Batteries.
- The AUV Hangar and UAV Hangar should be provided with seawater from the fire main. A rapid means of deployment of this seawater should be provided.

Section 660.3.3 – UAV Hangar

The recommended action is the opening from the UAV Hangar to the UAV Deck should be at least 12 ft wide to accommodate large, fixed wing UAVs. The tradeoff from this recommendation is the cost of door and mechanisms to handle structure weight for forward facing door. Should the specification:

- Require a door size (threshold requirement, no objective)?
- State largest UAV to be handled, remain silent on door size?
- **Remain silent on door size and flag as item to pay attention to during design reviews?**

The recommended action is the opening from the UAV Hangar to the UAV Deck should be more substantial construction than a roller curtain door currently in the specification, such that it can adequately handle the wind and wave loads on the forward side of a superstructure. The tradeoff from this recommendation is the cost of door and mechanisms to handle structure weight for forward facing door. Should the specification:

- **Describe door as solid construction to handle environmental loads (no threshold defined)?**
- Remain silent on door type and flag as item to pay attention to during design reviews?

Section 710.2 – Stern Frame and 710.6 – Aft Deck Cranes

The recommended action is that the stern and side frames as well as the two cranes serving the aft working deck (aft working deck large crane and aft working deck portable crane) should be provided with the ability to support special lifting attachments to aid in the launch and recovery of autonomous vehicles. Extra hydraulic lines should be run to the lifting points of each device to facilitate easy use of specialized lifting attachments. The tradeoff from this recommendation is making the cranes more complicated. Should the specification:

- Require lifting attachments for specific cranes (threshold requirement, no objective)?

- **Require that at least two of the cranes be fitted with hydraulics to lifting points (threshold requirement, no objective)?**
- Remain silent on fittings for cranes?

New Section

A new section should be added to the specification concerning gasoline storage and include the following text:

> "A fuel drum storage location should be added to an exterior deck. This storage solution shall allow for fuel drum jettison over-the-side if needed in the event of an onboard fire."

Required Owner Decisions

There are no required owner decisions other than approving or disapproving the above recommended specification changes.

Appendix A Example UAVs

Scan Eagle

https://www.boeing.com/defense/autonomous-systems/scaneagle/index.page

https://www.insitu.com/information-delivery/unmanned-systems/scaneagle#5

Property	Description	Notes
Manufacturer	Boeing / Insitu	
Length	5.6 ft / 1.71m	
Width (wingspan)	10.2 ft / 3.11m	
Height		
Storage size	1.71m x 0.45m x 0.45m	Packed into single storage container
Weight (max takeoff)	48.5 lb / 22 kg	
Power Source, General	Gasoline	
Power Source, Detailed	Gasoline / JP-5 or JP-8	
Power Source, Size	4.3 kg of fuel	

Astro

https://freeflysystems.com/astro

Property	Description	Notes
Manufacturer	Freefly Systems	
Diameter	4.62 ft / 1.41m	Unfolded, including propellers
Height	1.18 ft / 0.36m	Unfolded
Storage size	0.51m x 0.18m	Folded size, diameter x height
Weight (max takeoff)	18.5 lb / 8.38 kg	
Power Source, General	Battery	
Power Source, Detailed	Lithium Polymer	
Power Source, Size	22.2V	
Charging Requirements	Freefly Smart Charger	

PD-1

https://ukrspecsystems.com/pd-1-vtol

Property	Description	Notes
Manufacturer	UKR Spec Systems	
Width (wingspan)	13.12 ft / 4m	
Payload Capacity	10 kg	
Weight (max takeoff)	88 lb / 40 kg	

Property	Description	Notes
Power Source, General	Gasoline	
Power Source, Detailed	Gasoline	
Power Source, Size	12 liter	Fuel tank size

Appendix B Example AUVs

Sentry

https://ndsf.whoi.edu/sentry/

Property	Description	Notes
Manufacturer	WHOI	
Length	9.7 ft / 2.9m	
Width	7.2 ft / 2.2m	
Height	5.8 ft / 1.8m	
Storage size		
Weight (max takeoff)	2,750 lb / 1,250 kg	
Power Source, General	Battery	
Power Source, Detailed	Lithium-Ion	
Power Source, Size	375 A/h	
Charging Requirements		

Hugin

https://www.kongsberg.com/maritime/products/marine-robotics/autonomous-underwater-vehicles/AUV-hugin/

Property	Description	Notes
Manufacturer	Kongsberg	
Length (max)	21 ft / 6.4m	
Width	2.46 ft / 0.75m	
Height	2.46 ft / 0.75m	
Storage size		
Weight (max takeoff)	3,417 lb / 1,550 kg	
Power Source, General	Battery	
Power Source, Detailed	Lithium Polymer	
Power Source, Size	24 kWh pack	
Charging Requirements		

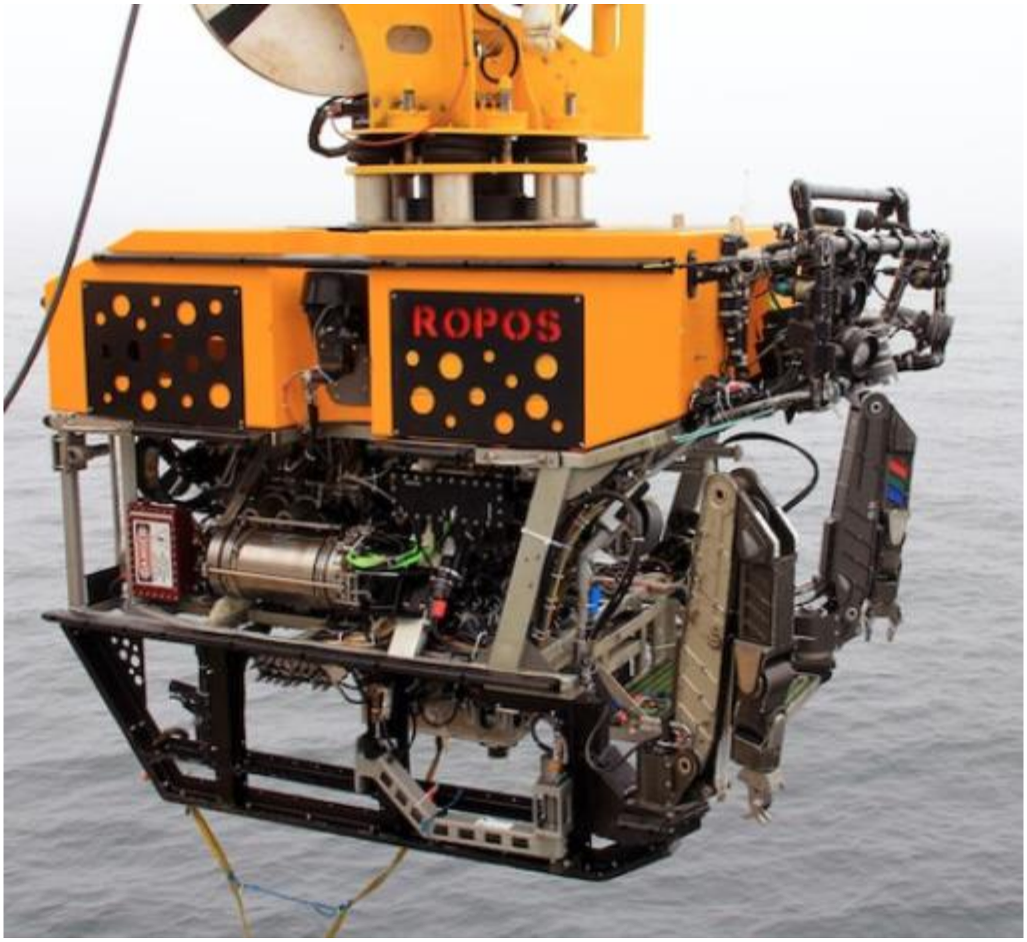
Appendix C Example ROVs

Jason

https://ndsf.whoi.edu/jason/

Property	Description	Notes
Manufacturer	WHOI	
Length	11.2 ft / 3.4m	
Width (wingspan)	7.3 ft / 2.2m	
Height	8 ft / 2.4m	
Storage size		
Weight (max)	11,000 lb / 4,990 kg	
Power Source, General	Ships power	Umbilical

ROPOS



https://www.ropos.com/index.php/ropos-rov

Property	Description	Notes
Manufacturer	CSSF	
Length	10 ft / 3.05m	
Width (wingspan)	5.38 ft / 1.64m	
Height	7.12 ft / 2.17m	
Storage size		
Weight (max)	7,480 lb / 3,393 kg	
Power Source, General	Ships power	Umbilical

Appendix D Example ASVs

C-Worker 5

https://www.asvglobal.com/product/c-worker-5/

Property	Description	Notes
Manufacturer	ASV Global	
Length	18.04 ft / 5.5m	
Beam	5.58 ft / 1.7m	
Draft	2.95 ft / 0.9m	
Weight	2,976 lb / 1,350 kg	lightship
Power Source, General	Diesel Fuel	
Endurance	7 days	At 7 knots

C-Enduro

https://www.asvglobal.com/product/c-enduro/

Property	Description	Notes
Manufacturer	ASV Global	
Length	15.58 ft / 4.75m	
Beam	7.28 ft / 2.22m	
Draft	1.71 ft / 0.52m	
Weight	2,006 lb / 910 kg	lightship
Power Source, General	Solar Panels	
Endurance	30+ days	Depending on latitude, time of year