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Title:
DESIGN CONSIDERATIONS FOR LAUNCH & RECOVERY OF AUTONOMOUS SYTEMS FROM SHIPS, INCLUDING COAST GUARD ICEBREAKERS

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Proposed Content, including problem statement or introduction, outline of key points, and summary of conclusions/recommendations:

A worldwide operational priority for the Navy is to improve mission effectiveness by increased use of autonomous systems, including autonomous aircraft (UAVs), autonomous surface vessels (USVs), and autonomous underwater vehicles (UUVs). Harsh environmental conditions in high latitude environments, such as arctic Alaskan coastal areas, are particularly favorable for deployment of autonomous systems to augment operations. While use of autonomous systems includes critical issues relating to communication of command/control and data information, there are operational considerations that begin with having appropriate unmanned vehicle launch and recovery systems (LARS), and protocols for LAR that include procedures for situations when things go wrong. The Coast Guard operates the US heavy icebreaker fleet to provide all federal agencies, including the Navy, access to high latitude seas, and should consider evaluation of LARS capabilities for autonomous systems for both existing and future icebreaking ships. In the following we address ship design considerations for LARS for UAS, USVs and UUVs, as well as hybrid ROV-AUV and manned-unmanned systems.

First we note that deployment and retrieval of autonomous aircraft (UAS) for research purposes may not pose particular problems for USCG icebreakers: ship users from the science community have primarily expressed an interest in use of small autonomous aircraft such as the ScanEagle, which has been used extensively from Navy and some NOAA ships. A ScanEagle launch unit takes up roughly 5'x15' of ship deck space that is best located with rail access on an upper deck. The so-called 'tetherball' recovery procedure for a ScanEagle uses a hook at the end of the UAS wing for recovery on a cable hung off the side of the ship from a crane which can suspend a line 10-15' away from the ship roughly 40' above sea level from an upper deck is required. However this recovery method needs no deck space and avoids the need for UAS recovery methods using hangars, nets, or in-water retrievals involving small boats. Ship design and use considerations must still include space for storage of both the UAS LARS system, and the UAS themselves, typically shipped in a 20' container, although smaller modules can be managed on pallets if required.

Ship systems needed for LAR for most currently used autonomous (unmanned) surface vessels (USVs) likewise have relatively minimal requirements. Robokayaks (http://www.maribotics.com/) are relatively small and lightweight ASVs which have been extensively tested by the Navy, and can be deployed manually by two individuals. Likewise Navy and CG are considering use of similarly modest-sized and weight WaveGlider USV (http://www.liquidr.com) for surface communication nodes for UUVs, and for studies of whale tracking and ocean acidification. Currently these systems can be deployed by a small deck force with a small crane, or potentially even by hand if required. Similar sized USV systems now under development by the Navy include a 12' and 33' Wave Adaptive Modular Vessels (WAM-V, c.f. http://www.wam-v.com) for which ship LAR systems may require different methods, still being discussed. Plans for WAM-V ship LARS warrant monitoring because the Navy is developing WAM-Vs which themselves launch and recover small autonomous/unmanned underwater vehicles (UUVs), and these combined USV-UUV systems may be deployed in tandem in the future. There are advantages of using a

WAM-V to deploy and recover a UUV versus having a ship directly deploy and recover a UUV, including the fact that UUVs are often difficult to control in close proximity to a ship, and risk damage from contact when close enough for retrieval unless small (manned) boats are used as part of the LAR process. When a WAM-V is used to recover a UUV, then as part of the WAM-V the UUV is protected by the WAM-V pontoons. Further, because the WAM-V hulls react independently to waves, waves reflected from a ships' hull will not cause excessive motion in the main USV superstructure from which a LAR attachment would be connected to a ships' crane, thereby simplifying one of the key problems in UUV or USV recovery. The size of a WAM-V however presents its' own challenges for shipboard LARS which will require further consideration.

Recovery of USVs and UUVs can probably best be accomplished using recently developed so-called nodding boom technology which incorporates real-time ship roll damping capabilities, and includes a single-point attachment boom which articulates all the way to the sea surface and avoids UUV swaying during LAR. Such systems are now deployed on a number of research vessels around the world for scientific package deployment and recovery, and should work equally well for UUVs. Finally, it should be noted that considerations for ship design for autonomous vessel LARS must include some discussion of the fact that some programs combine ROV-UUV systems, where the ROV functions as a tether management system (TMS), from which a UUV may be attached by a long fiber optic cable. ROVs can also best be deployed by nodding boom systems, but may require higher weight capacity than for USVs or UUVs. Small underwater human occupied vessels (HOVs), such as the Deepworker (http://www.nuytco.com/products/deepworker.html), continue to be widely used, and may be deployed in combination with unmanned vessels. LARS design considerations for such small HOVs have an additional person-safety rating requirement which is therefore also relevant for ship design discussions. LARS for diver or ice deployments (eg platforms bearing either divers into the sea or personnel onto the ice), frequently used on many ships including CG icebreakers, have similar person-safety rating requirements which complement LARS design considerations needed for unmanned vessels.

INTRODUCTION

A worldwide operational priority for the Navy is to improve mission effectiveness by increased use of autonomous systems, including autonomous aircraft (UAVs), autonomous surface vessels (USVs), and autonomous underwater vehicles (UUVs). Harsh environmental conditions in high latitude environments, such as arctic Alaskan coastal areas, are particularly favorable for deployment of autonomous systems to augment operations. While use of autonomous systems includes critical issues relating to communication of command/control and data information, there are operational considerations that begin with having appropriate unmanned vehicle launch and recovery systems (LARS), and protocols for LAR that include procedures for situations when things go wrong. The Coast Guard operates the US heavy icebreaker fleet to provide all federal agencies, including the Navy, access to high latitude seas, and should consider evaluation of LARS capabilities for autonomous systems for both existing and future icebreaking ships. In the following we address ship design considerations for LARS for UAS, USVs and UUVs, as well as hybrid ROV-AUV and manned-unmanned systems.

SHIPBOARD UNMANNED AIRCRAFT LAUNCH AND RECOVERY SYSTEMS

Deployment and retrieval of autonomous or unmanned aircraft systems (UAS) for research purposes should not pose significant problems for ships. UAS users from the science community have primarily expressed an interest in use of small autonomous aircraft such as the ScanEagle, which has been used extensively from Navy and some NOAA ships. Use of these aircraft from Coast Guard vessels should be able to follow similar setups and protocols. A ScanEagle launch unit takes up roughly 5'x15' of ship deck space that is best located with rail access on an upper deck. The so-called 'tetherball' recovery procedure for a ScanEagle uses a hook at the end of the UAS wing for recovery on a cable hung off the side of the ship from a crane which can suspend a line 10-15' away from the ship roughly 40' above sea level. This requires the availability of a crane on an upper deck but minimizes the need for significant recovery deck space, and avoids the need for UAS recovery methods using hangars, nets, or in-water retrievals involving small boats. Ship design and use considerations must still include space for storage of both the UAS LARS system, and the UAS themselves. These systems are typically shipped in a 20' container, although smaller modules can be managed on pallets if required. Deployment of launch and recovery systems for a ScanEagle UAS are shown in Figures 1 and 2.

Other UAS systems are also being used from ships. One very lightweight system is the “Resolution” UAS made by Airborne Technologies, Inc. under NOAA SBIR funding. The Resolution UAS has been used by NOAA for reconnaissance of marine mammals and ghost drift nets around the Northwest Hawaiian Islands (NWHI) to facilitate recovery of these nets before they become grounded on the reefs in the NWHI National Marine Monument. These very lightweight UAS (5kg for a 2m wingspan system) provide only digital camera and/or video data streams, are not intended for particularly long distance or duration or distance flights with additional higher power and weight requiring sensor systems. Typical flight times are >1.5 hours to several hours. The Resolution can drop a SAT-201 GPS satellite marker buoy to allow re-location of ghost drift nets (or other items of interest) by vessels intending to retrieve the nets or otherwise engage with the object of interest. The Resolution’s camera and video capabilities also enable use for reconnaissance of marine mammals, sea turtles, spilled oil or search and rescue cases. Cameras on Resolution aircraft can easily incorporate multi-spectral recording where this is desired. The small size of the Resolution facilitates LAR from smaller ships (30’ and up). The launch system design is similar to the ‘slingshot’ system used for ScanEagle, but given the reduced weight and size of the Resolution is smaller in size and weight, requiring only about a 6’x6’ footprint on deck using a rail-mount. The Resolution system uses no fuel, being entirely battery powered, and is fully waterproof and buoyant, as necessary for water-based recovery which is required using small boats. Replacement parts are readily exchangeable if need be. These UAS are easily transported in modestly sized cases (similar in size to an electric guitar case), and require little additional support equipment on deck, being controlled primarily through a laptop computer. Their low cost (@$15K) also means that multiple UAS can be taken to sea, and if any are lost, a program’s goals and funding are not seriously compromised. The Resolution and launcher are shown in Figure 3 on the deck of the NOAA ship OSCAR SETTE off the Northwestern Hawaiian Islands in 2008. Figure 4 shows recovery of a Resolution UAS using a RHIB (rigid hull inflatable boat).

Several other UAS systems are worthy of note due to their use within the oceanographic community. The Manta UAS developed by Advanced Ceramic Research (now BAE Systems) is in use by the Scripps Institution of Oceanography and NOAA’s PMEL (Pacific Marine Environmental Lab) in Seattle for studies of atmospheric gases and particulates, including black carbon. Manta aircraft have a demonstrated ability to fly in formation, allowing multiple airframes to make measurements at different altitudes directly above each other, and to dynamically profile the air column as desired while maintaining vertical spacing among airframes. The Manta system requires shipping in several packing cases, and has a launch frame is similar to that of ScanEagle, but slightly larger, as shown in launch from the Navy Stiletto stealth vessel in Figure 5. The airframe has been reconfigured (strengthened) to permit the type of ‘tetherball’ recovery mechanism developed for ScanEagle.

A smaller UAS also from BAE Systems is the Silver Fox. This UAS has been deployed from a Coast Guard 110’ Coastal Patrol Boat off Hawaii in 2006, from the relatively small launcher located near the bridge, as shown in Figure 6, with later recovery using a small boat. An alternative is a net recovery system mounted on a yard arm to the side of the ship as shown in Figure 7, which requires more storage aboard for the recovery system, as well as the logistical complications of mounting and bracing the yardarm setup, and having a mechanism to retrieve the UAS from the net once recovered. It is worth noting that the Silver Fox UAS can be deployed from a C130 aircraft via standard Sonobuoy, FLIR or Self-Locating Data Marker Buoy (SLDMB) tubes, with the option of using a ship only to retrieve the airframe.

Another UAS which has been used in the arctic for many years is the Aerosonde system, now a part of Boeing. The airframe is similar to that of Manta, but smaller and lighter weight, as shown in Figure 8. It has not yet been used from ships, and does not yet have a ship recovery system. Because of its’ use in high latitude environments it is designed to be recovered by landing directly on ice or runways. It has been used with laser altimeters as well as camera systems for studies of sea ice and glaciers, but may see further use from ships in the future, at least for launching with sea ice retrievals.

Finally, it should be noted that the Navy’s late 2009 demonstration use of the Ion Tiger suggests a broad potential for use in the future from ships as well. The Ion Tiger UAS has the advantage of using a fuel cell battery instead of a conventional battery. This means it has a greater range than other battery powered UAS, and is also very quiet, which is often an advantage over other UAS. Flights with a six pound payload for >24 hours were achieved, with the requirement of high pressure hydrogen storage tanks. To date launch and recovery efforts have only been demonstrated from land, but the hydrogen fuel cell technology is commercially available from Protonex Technology Corporation, and can easily be adopted into airframes already designed for maritime use.

There are also two types of vertical ascent/descent UAS which are being considered for maritime use. There have been earlier UAS systems which used counter-rotating propellers contained in an airframe (the ‘Flying Washing Machine’ designs, such as Aurora Flight Sciences’ GoldenEye), but the cost and complexity of maintaining these counter-rotating propeller systems, and the range limits restricted the broad use of those UAS systems. An alternative being pursued is offered by quad-rotor aircraft, which allow launch, and automatically controlled recovery on rolling ship decks, achieved by variable powering of their four (or more) rotors. Control of the multiple rotors in real time is what allows these aircraft to respond to pitch and roll of a ship deck below them and land automatically. NOAA has already purchased several quad-rotor UAS for marine mammal surveys which require relatively silent and stationary operation (to avoid scaring animals). The quad-rotor UAS provide a vertical platform which can take photographs to document animal abundance for such things as walrus populations on ice floes where their limited range and endurance are adequate. The commercially available Draganfly quadrotor airframe shown on the left in Figure 9 is similar to those now used by NOAA for census of beached elephant seal populations. Navy programs are now planning tests of these quad-rotor aircraft for use from small unmanned surface vessels to take advantage of their automatic launch and recovery capabilities. Finally, there is some interest in use of Coanda effect UAS for ship use due to its’ similar vertical launch and recovery capabilities. The Coanda effect generates lift from airflow along and around a curved surface, as in the EMBLA company airframe shown on the right in Figure 9, developed with funding from the UK Department of Defence. The intended use of these airframes will most likely be for limited range missions where vertical reconnaissance provides an advantage, similar to requirements for quad-rotor systems.

One additional UAS airframe, with rather unique capabilities, is the Flying Fish developed with Defense Advanced Research Project Agency funding at the University of Michigan. This system is being further developed, but has undergone sea trials in Monterey Bay, California. The Flying Fish is actually a floatplane or ‘flying buoy’ developed as an aid to navigation, or as a positional marker, particularly for use in seasonally ice-covered waters where standard Aid-To-Navigation (ATON) buoys are impractical. The aircraft has a GPS sensor, and will take off and land automatically to remain within a certain positional range. Aircraft endurance depends on the range restriction and altitude to which it flies before repositioning. One scientific use of Flying Fish is to obtain vertical profiles of atmospheric conditions at sea in the near surface boundary layer to heights of typically 1000-1500’ that are difficult to obtain with manned aircraft. The second generation of a Flying Fish UAS is shown in Figure 10.

In summary, UAS launch methods typically use a catapult style launch system, which is best when there is rail access from an upper deck location with a footprint on the order of 10’x15’. Recovery methods which involve the use of small boats can limit operational use of UAS to sea states where small boat launch and recovery are advisable. The requirement for additional manpower for small boat recoveries of UAS also limits the appeal of this type of recovery system. For this reason there has been a trend toward use of the ScanEagle style ‘tetherball’ recovery system, which requires only an upper deck crane which can suspend a line some distance from the ship hull. These systems can be, and have been, employed on ships as small as 37’, but are easier from larger vessels. Net recapture systems are possible for lighter weight UAS, but logistical complexities and footprint for this recovery system limits its’ appeal. Currently many of the UAS with payloads other than simply camera systems still use fuel, and LAR operations and safety considerations can include a several person fire response party on standby. The need for fire party deployment can be minimized in future through use of battery or fuel cell power systems, as these become more broadly available as part of UAS systems.

SHIPBOARD UNMANNED SURFACE VESSEL LAUNCH AND RECOVERY SYSTEMS

A number of unmanned surface vessels (USVs) have been developed for a variety of research and military purposes. These include use of a single USVs used to deploy sensors or markers, or act as sensor or marker platform for hydrophones or other sensors themselves. USVs can also act as communication nodes to convey data from unmanned underwater vehicles (UUVs) to ships or aircraft. When three or more USVs are deployed in formation they can convey information via underwater acoustic modems to allow precise positioning of a UUV, an important function for precisely determining the location of objects of interest detected by UUVs, whether whales, ship or airframe debris, or mines. USVs differ in their speed, range and power requirements. We will review several key types now being broadly used first, and then discuss considerations for different launch and recovery methods

The initial types of USVs were those developed for carrying sensor systems for use in river, lagoon, harbor or other shallow sea or littoral areas. A typical example would be the Searobotics Unmanned Survey Vessel catamaran with inflatable hulls shown in Figure 11. Another Searobotics USV is a self-righting monohull vessel intended for multibeam survey work, which has 10 hours endurance at 2 knot speeds shown in Figure 12 (upper portion), intended for operation in rougher waters. Multihull USV designs have also been made by this company, including those with high speed capabilities which however have endurances limited to hours (also show in Figure 12, lower portion). To date these systems have primarily reflect designs intended for shallow water or shore launch and recovery rather than ship based LAR. Another quite different USV system growing in popularity for both military and scientific use is the Wave Glider USV manufactured by Liquid Robotics, shown in Figure 13. This USV is unique in relying on a surface float beneath which an underwater airfoil is used to harness wave energy used to power the propulsion of the USV. The underwater airfoil acts as something of a sea anchor, ensuring the vessel operates well in high seas, which since it is wave powered actually improve its performance. While the endurance of a Wave Glider is thus relatively unlimited (on the order of several months or more), it is normally limited to speeds of typically two knots or a bit more. Sensors tested on a Wave Glider have included fluorometers used for monitoring oil spills (see http://www.liquidr.com), hydrophones used for marine mammal detection and tracking (Wiggins, et al., 2010), and marine meteorological systems (McGillivary, 2008; Smith, et al., 2009). Additional sensor options can be incorporated for ocean observing system parameters (McGillivary and Hine, 2007), and inclusion of echo-sounders can permit seafloor mapping (McGillivary, et al., 2007). These sensors and those for measuring ocean acidification are now being incorporated into Wave Gliders where their power is derived from batteries and/or solar panels. The weight of these vessels was designed to allow them to be deployed by small cranes or, where necessary, man-handled over the side of a ship with a minimum of two people. Wave Glider systems transmit their positions and data every minute via Iridium burst communications, which can include surveillance camera information. The communications link also allows them to be controlled in near-real time, when needed.

Deployment of WaveGliders and unmanned underwater vehicles is also possible via another type of USV, the WAM-V, or Wave Adaptive Modular Vessel, produced by Advanced Marine Research. It was fairly quickly learned by those working with UUVs that retrieving UUVs by having them return directly to a ship for recovery could have unfortunate consequences if the control systems on the UUV were not quite in synch with those of the ship. To avoid ship collisions, as well as to protect UUVs on recovery, a 12' WAM-V was developed under Navy funding. This system, now being tested, is shown in Figure 14. The advantage of a WAM-V is that it is very fuel efficient, and can move more rapidly than many other USVs due to its' minimal in-water hull friction, which increases its range/endurance. Additionally, the design characteristic of having each hull move independently on both sides as well as fore and aft provides extreme stability in high seas, while maintaining the relative stability of the central instrument and communications platform. WAM-V systems are just now being brought into use for research and military purposes, including proposed surveillance and patrol uses (McGillivary and Tougher, 2010; Tougher and McGillivary, 2011). A hybrid WAM-V/Wave Glider system is being considered which incorporates the underwater airfoil of a Wave Glider as a portion of the WAM-V which could be raised and lowered as needed. This would allow a WAM-V to rapidly deploy to a site using motors, but then after lowering the underwater airfoil, it could remain on site or slowly patrol using only wave power, raising the underwater airfoil when a quick return under engine power was desired. In the scenario where a WAM-V was used to deploy and retrieve a UUV, the complementary capabilities of such a hybrid USV system would be very useful. One key thing about a WAM-V is that it requires relatively little deck space for system storage because it is designed to fold up for shipping, with both the rear motors canting inward, the front pontoons folding up, and the frame separating the two catamaran hulls collapsing. It has the ability to unfold on deployment automatically, and refold on recovery automatically as well. This not only protects any UUV payload suspended between the hulls, but reduces the size and reach of cranes needed deploy the WAM-V over the side of a ships' hull. These aspects are shown for the 33' WAM-V in the series of illustrations shown in Figure 15.

The ability of a WAM-V to automatically unfold itself on deployment, and refold itself for recovery, is made possible due to the design of the structural frame, and also the way the motors are designed. Use of water-jet motors facilitates this capability (although other motors are possible). What this means is that for launch and recovery of this type of vessel, cranes and deck handling equipment need not be as large or reach as far out to lift or lower this USV. For the 12' WAM-V being now developed for UUV LAR, it fold up into a very compact space, requiring little more than 6'x4' of deck space for stowage. One of the other advantages of this specific hull design is that it has not been possible to flip the vessel, because the rounded pontoon hulls simply slide down waves, and the flexible front of the pontoons do not pierce waves, but simply bends up and floats atop them. Moreover, and most importantly for LAR operations, the fact that the hulls move independently, both on each side and fore and aft on each side, means that the WAM-V is largely immune to waves reflected from the hull of the ship, and the central platform from which recovery connections may be made, retains a high degree of stability rather than wildly pitching in the seas.

One other USV, the Scout or 'Robo-kayak' was developed at MIT and is available from Maribotics, Inc.. It has been used in a number of Navy demonstration projects,. This USV was developed specifically with the capability to be deployed as multiple interacting units to provide capabilities such as the permit precise GPS location of UUVs via underwater modem acoustic communication with the UUV (Curcio, et al., 2005). It can conduct coordinated patrol formations for sensor deployment, for uses which have included marine mammal location and tracking, marine meteorological measurements, and vertical oceanographic profiles obtained by means of a CTD raised and lowered from a small winch within the hull (Curcio, et al., 2008 and 2006). The small size and light weight of the SCOUT Robo-kayaks make them relatively easy in terms of LAR requirements. Launching and some sensor systems on SCOUT Robo-kayak USVs are shown in Figure 16.

SHIPBOARD UNMANNED UNDERWATER VESSEL LAUNCH AND RECOVERY SYSTEMS

As noted above there are new technology options for launch and recovery of UUVs using USVs. The traditional launch and recovery of UUVs has been performed by a variety of means however. There are several classes of UUVs which have different characteristics which influence their LAR needs and mechanisms. These have been classed as: 1) profiling drifters; 2) gliders; and, 3) propeller driven. The first group is often simply not retrieved, and for systems like ARGO floats (c,f, http://www.argo.net/), and Global Ocean Observing System (GOOS) drifters (c.f. http://www.aoml.noaa.gov/phod/dac/index.php), they are simply thrown over the side of a ship. Gliders have been classified in three popular groups, including Slocum Gliders, Seagliders, and Spray gliders (Curtin, et al., 2005). To this could be added the recently developed SOLO-TREK (Sounding Oceanographic Lagrangian Observer-Thermal RECharging) gliders which use temperature-buoyancy 'engines' (http://solo-trec.jpl.nasa.gov/SOLO-TREC/ ; http://www.jpl.nasa.gov/news/news.cfm?release=2010-111). These systems use buoyancy engines for propulsion, and typically are easily deployed (Fig. 17), with retrieval involving small boat operations.

Propeller driven UUVs include a variety of systems ranging from smaller units which can be deployed over the side by two people (such as the Gavia or Remus), to medium-sized units which require cranes, winches and significant deck space (as shown in Figure 18, with these systems alongside SCOUT Robo-kayaks). Still larger UUVs can conduct long-range underwater mapping, surveillance and data collection, and because of their cost, size, and weight have different LAR requirements. Many of these large UUVs are designed to operate from a 20' container, which can include an extensible launch apparatus telescopes out over the side of a ship to the water, as shown in Figure 19 for a C&C multibeam mapping UUV. Because of their size and cost small boat operations are routinely part of UUV recovery efforts. More specialized deployments for multiple UUVs or specialized UUVs such as the Scripps Flying Wing design, shown in

Figure 20, require even more deck space, and for the Flying Wing designs considerable care in launch and retrieval when A-frames are just large enough for these operations.

LARS ON SHIPS INCLUDING ICEBREAKERS

Three components of LARS on icebreaking ships are appropriate for review regarding their applicability on other ships as well. First, is the requirement for cranes which meet 'man-safety' requirements; second, is the growing recommendation, often required, for winches and cranes capable of meeting new safety and best practices standards which include use of nodding booms and tension monitoring and response winches. Finally, for icebreakers and other ships operating at high latitudes, there are requirements for systems to operate at low temperatures.

In terms of general system launch and recovery, icebreakers share with many other ships requirements for launch and recovery of small boats and dive teams. As noted earlier, small boats are often routinely used as components of recovery for autonomous vessels. However, but insofar as these are standard components of ship systems, we will not explicitly deal with small boat LARS here. We must, however, note that for dive team and transfer of personnel to the ice using personnel platforms lowered by crane, the use of 'man-safe' cranes for deployment is essential to ensure compliance with recognized safety standards. A 'man-safe' crane is generally defined as having a magnetic shut off marker along the wire above their human platforms, and a corresponding sensor at the top of the crane which activates an automatic shut-off to the winch system to prevent the personnel compartment from becoming tube-locked. Man-safe cranes requirements include regular inspection protocols. Additionally, the human passenger compartments (diver platforms and similar personnel carriers lowered by cranes) must pass safety standards to ensure they can withstand being dropped some distance onto a deck without collapsing and injuring their passengers due to collapse. Articulated or knuckle-boom cranes are generally employed for over-the-side deployment of diver or over-the-side platforms lowering personnel to the water or ice. These systems must meet the requirements above, and in addition there must be a data logger for winch systems associated with the crane to comply with established safety standards. A recent set of standard guidelines for this in the US is provided by the University National Oceanographic System [UNOLS, the national academic fleet] guidelines provided by the National Science Foundation at URL: http://www.unols.org/publications/reports/lhsworkshop/LHSFunctionalRequirements-Jul08.pdf .

In addition to these guidelines there are also international guidelines codified by Germanischer Lloyd (GL) as part of their "Rules for Underwater Technology" which may be accessed at http://www.gl-group.com/infoServices/rules/pdfs . Within this guidance there is specific guidance in Part 1 Marine Ships, Chapter 22 Polar Class Ships which includes sections on finite element modeling guidelines. Part 5 of this document also includes specifications and recommendations for manned submersibles and UUVs to depth ratings of 6000m. These considerations are supplemented in Chapter Three for requirements for Naval Vessels.

The key components of systems requirements for UAS, ASV and UUV deployment are use of two systems mentioned above: so-called nodding booms, and tension monitoring and adjusting winches. The requirements for tension monitoring winches are intended to allow for monitoring in real-time of conditions cables are exposed to. These are evaluated in accord with well-documented methods of study which take into account the diameter of sheaves used for systems deployment and retrieval. Records are now required to monitor cable exposure to such stresses, and there are limits to stresses cables are supposed to be exposed beyond which safety is considered at risk. Time-integrated records of exposure to high strain rates are required to evaluate the safety of cables based on exposure to such strains. These records are to be used to evaluate which replacement of cables is required to ensure safe operations. Guidelines specifying these requirements are contained in the UNOLS Research Vessel Safety Standards, RVSS, 9th edition, Appendix A, scheduled to go into effect on June 1, 2011. These requirements, as specified for the R/V SHARP, may be found at: http://www.unols.org/publications/reports/lhsworkshop/index.html, and the general safety recommendations may be found at: http://www.unols.org/publications/manuals/saf_stand/contents.htm in Appendix A.

Newer winches have the ability to adjust to tension levels in real time, slacking off cable if tension levels are exceeded, or increasing the rate of cable uptake if tension levels fall precipitously. These systems of adjusting winches are now being installed as routine parts of shipboard systems, and their use adds greatly to safe operations as part of LARS for autonomous vessels.

In addition to the safety requirement for all winches to monitor cable conditions, there is also an ongoing movement, based on recent shipboard system safety requirements, toward use of so-called nodding booms. These crane systems are intended to minimize strain loads on load-bearing cables by adjusting to tension, and can operate in conjunction with tension-adjusting winches as well as independently when tension-adjusting winches are not a component of ship systems. Nodding boom technology is usually composed of several components. First, systems being deployed are generally not simply hanging, but instead are 'docked' into the top of the crane/boom, typically with a shock-absorbing head (rather like an inner tube) which reduces strains from 'snap-loading' while preventing the system being deployed from swinging in response to the pitch and roll of a ship. This alone adds a component of safety because it eliminates the need for multiple personnel on deck to hold guide lines, thus improving safety for humans involved in the launch and recovery operations, while also reducing their numbers. Further, most nodding boom systems have an extensive 'reach' allowing the system being deployed to be lowered directly into the ocean, as is required to preclude lowering cable to allow the package to reach the sea or ice surface without risk of swinging in response to ship movements. Finally, a nodding boom system typically includes use of hydraulic or other systems which adjust to the tension on the system due to ship roll, and 'nods' as the name implies to reduce or increase tension in response to ship rolls as necessary. Initially deployed on Japanese research vessels, as shown in Figure 21.

Nodding boom systems are now recommended for all U.S. research (and other) vessels to ensure safety not only of humans working on deck, but also of expensive autonomous system payloads. A video of nodding booms in operation from two UNOLS vessels can be seen at:
http://137.229.104.41/researchvessels/sharp/deploy/deploy.html , and,
http://137.229.104.41/researchvessels/sharp/winchme/winchme.html .

For icebreaking ships in the United States most deck systems are required to operate in temperatures as low as -50oC. The same requirement would normally be anticipated to be required for LAR systems as well. Recently the American Bureau of Shipping (ABS) set up a new Arctic Technical Advisory Committee within the International Maritime Organization (IMO), which is managed from Helsinki. This Committee agreed in October, 2009, to work with the Harsh Environmental Technology Center at Memorial University in Canada to amend low temperature system requirements as new technologies became available. Further, because the use of both ASVs and UUVs typically requires communication from the ship using underwater acoustic modems, it is worth mentioning that especially in high latitudes where the sound channel is right at the surface where communication with UUVs in particular is problematic, especially as they approach a mothership, new ship noise standards were established January 1, 2010 by the Acoustical Society of America in ANSI/ASA Standard S12.64-2009/Part 1. As noted earlier, it has been found that communication with UUVs in particular as they approach motherships for recovery has been problematic at times in the past, and this has led to consideration of the option of using ASVs for UUV recovery instead. Acoustic ship noise interference with UUV communication is not going to disappear until ship noise reduction methods are incorporated into new ship designs, but these considerations should be part of design for autonomous vessel LARS in the future.

SUMMARY

Launch and recovery of unmanned aircraft, surface and underwater vessels should be incorporated into considerations for the operation of these systems on existing vessels, and incorporated into design considerations for new ships in the future. First among the desired requirements is deck space on upper decks for control and maintenance vans as well as for deployment of autonomous aircraft. Deck space for a 20' van, and rail access with clearance for a roughly 10'x15' area is needed to accommodate the range of autonomous aircraft now in use. The movement toward 'tetherball' recovery systems for unmanned aircraft means that a crane with a reach roughly 15' from a ship and 40' above the sea surface from the upper deck of a ship is recommended.

For launch and recovery of autonomous surface vessels, deck space for a 20' operations van is also recommended, along with an articulated crane, which should include tension monitoring and nodding boom capabilities and a tension adaptive winch as well. Improved methods for recovery of these systems which do not require use of small boats would be useful in the future.

Similarly LARS for UUVs should incorporate similar winch and crane system requirements for safety of both humans and the UUV. Deployment and recovery of UUVs using ASVs such as the WAM-V are one option in the future which can improve the probability of safe recovery of a UUV, while also improving the facility of deployment and recovery by eliminating the need for small boat operations. This not only eases routine operations, but can extend them into sea state and weather conditions where more traditional methods would be problematic or unsafe.

One additional recommendation for LAR of autonomous systems is ensuring that cranes have significant reach. These systems are not simply being dropped into the water; when being recovered it is problematic if they approach a ship too closely. Most autonomous systems are not as heavy as many of the moorings and buoys routinely deployed from ships, the weight of which usually means that cranes deploying them cannot sustain great reach away from a ship. The weight of autonomous systems is not usually great, but they do benefit from cranes reaching as far from a ship as possible. Ship design for LARS with this in mind as an option is useful. Finally, inherent in the LAR of autonomous systems is the ability of ship systems to be modular to incorporate and transform to permit aft and upper decks spaces to be used as needed. This capability is particularly important for the aft deck when large UUVs may be deployed. Many ships have incorporated back decks which can be lowered in part to provide ready access to the water for retrieval of large UUVs (or ASVs). Such back deck transformation to allow a ramp which can deploy a UUV closer to the sea surface is a valuable addition to ships deploying these systems, and well worth incorporation into new ship designs.

Autonomous systems of all kinds are increasingly essential components of oceanographic research, Coast Guard, and naval vessels. While there are different requirements for LARS for aircraft, surface and underwater autonomous vessels, there can be little question that ships which can readily deploy these systems in compliance with existing safety recommendations, and recommendations for operations at high latitudes, will be important in the future.

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Figure 1. Launch of ScanEagle Unmanned Aircraft in 2009 from NOAA Ship McARTHUR II in Bering Sea for study of ice seals.

Figure 2. Recovery of ScanEagle Unmanned Aircraft in 2009 from NOAA Ship McARTHUR II.

Figure 3. Airborne Technologies Resolution Unmanned Aircraft Launched from NOAA Ship OSCAR SETTE off Northwestern Hawaiian Islands, 2008.

Figure 4. Resolution UAS recovery by small boat from NOAA Ship OSCAR SETTE in 2008.

Figure 5. The Manta unmanned aircraft developed by Advanced Ceramic Research (now BAE Systems) has been tested in the arctic off Norway and elsewhere for studies of atmospheric chemistry by a NOAA PMEL and university researchers. Shipboard launch and recovery systems are similar to those used by ScanEagle, but require a somewhat larger launch frame, shown here on the Navy Stiletto vessel.

Figure 6. Shipboard launch system for Silver Fox on a Coast Guard 110’ Coastal Patrol Boat off Hawaii in 2006 mounted on upper deck.

Figure 7. Net-based recovery of a BAE Systems Silver Fox UAS using a yardarm net system.

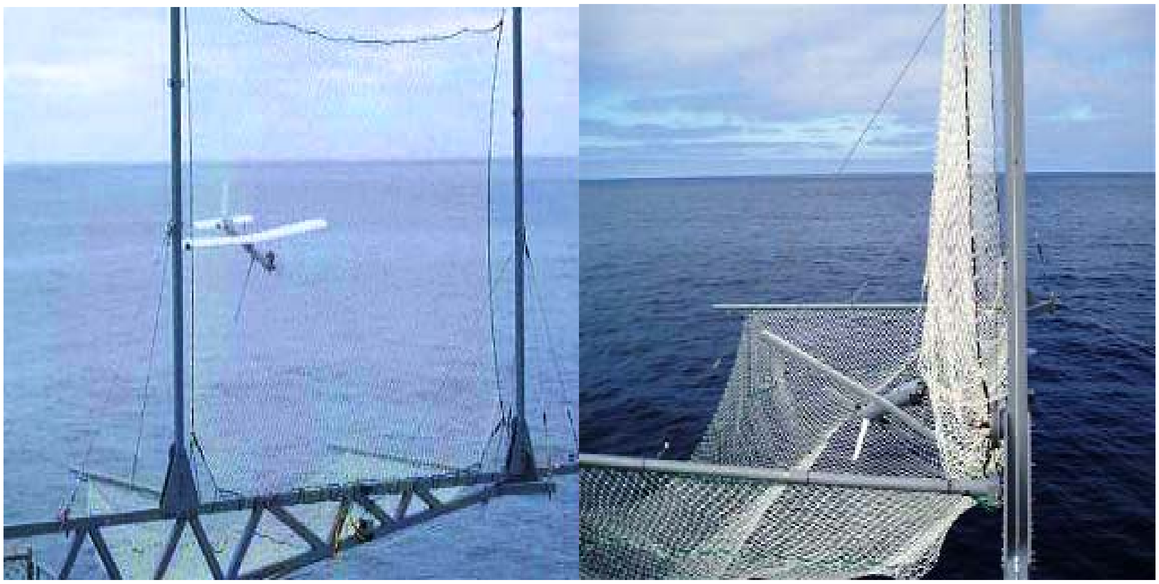

Figure 8. The Aerosonde UAS has been used for high latitude reconnaissance missions including studies of sea ice and glaciers, but to date has been launched only from land, with recovery on ice or sandy beaches. The broad array of sensor packets developed for it may soon see it used from ships at high latitudes including icebreakers, while continuing to rely on sea ice or beach landing and recoveries.

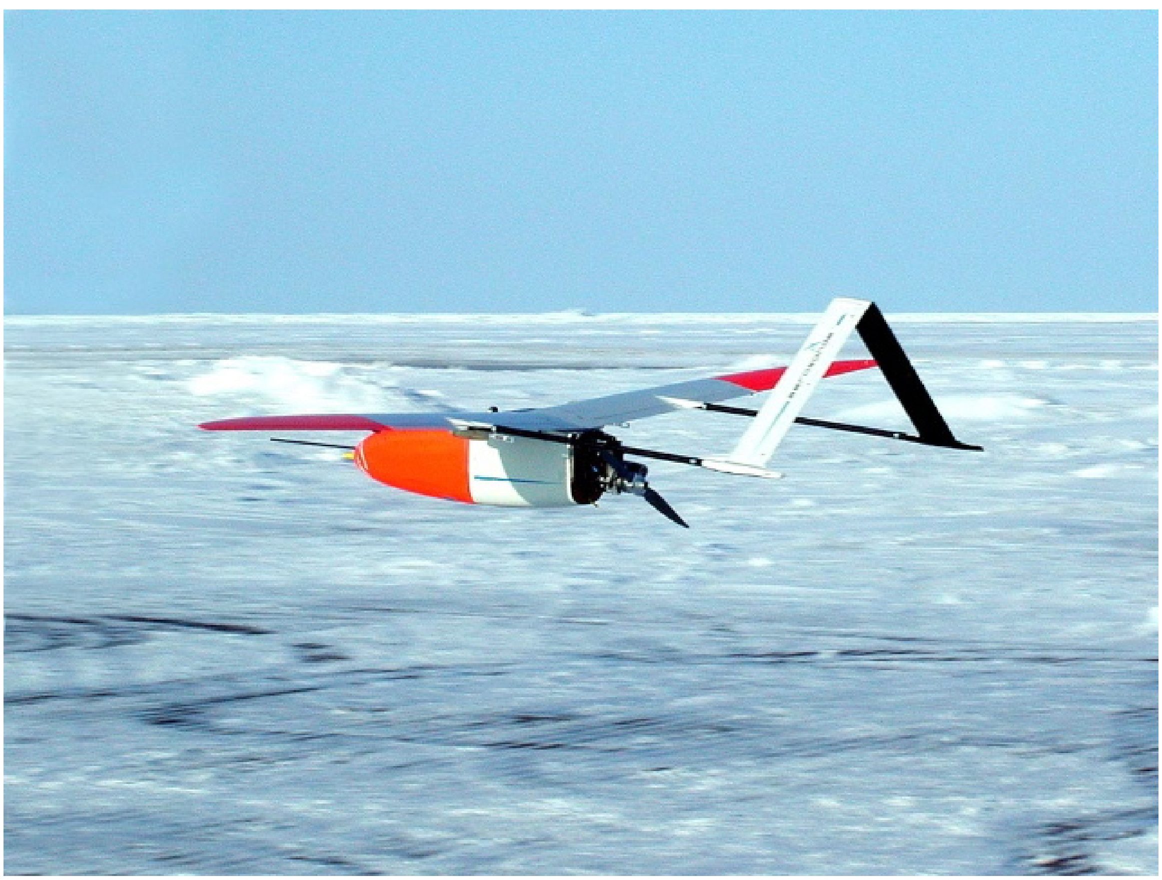

Figure 9. Vertical take-off and landing UAS systems planned for maritime use include Quadrotor aircraft such as the Dragonfly, which automatically senses and facilitates landing on rolling decks, and EMBLA Coanda aircraft with similar capabilities, which while not widely used in the US at this time, but may have options for specialized use from ships or unmanned surface vessels in the future.

Figure 10. The Flying Fish UAS developed at the University of Michigan to serve as a navigational buoy for seasonally ice covered areas, and/or conduct profiles of the atmosphere to heights of typically 1000’ or so for air-sea flux or meteorological model validation.

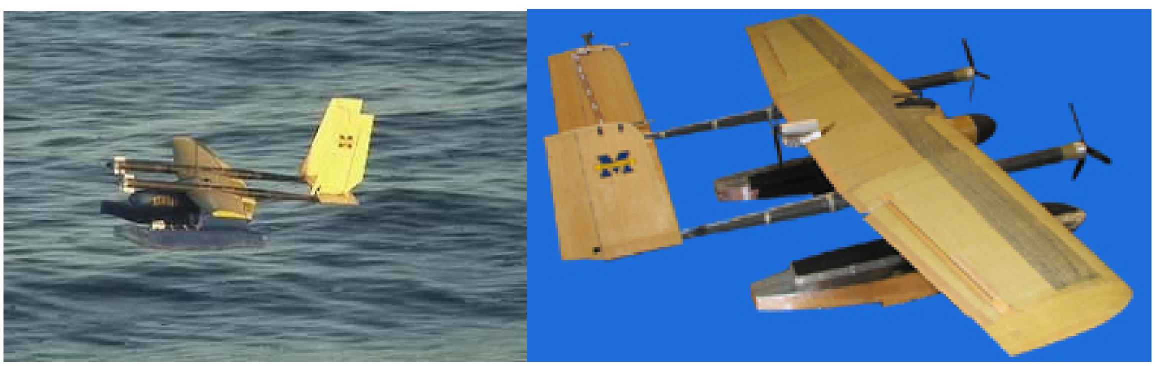

Figure 11. The Searobotics Unmanned Survey Vessel (left) is intended for riverine and coastal surveys, while the Self-Righting Monohull (right) is intended for multibeam surveys in rougher waters.

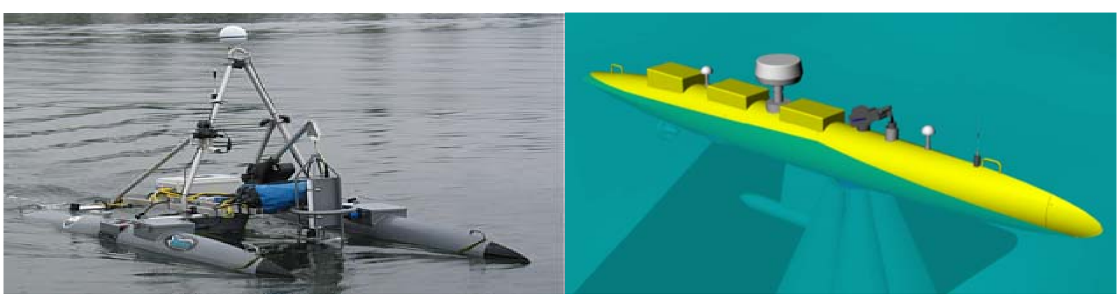

Figure 12.   In addition to catamaran and monohull USVs, Searobotics also makes a multi-hull high speed USV which can be used for mapping or other purposes, but which has endurance limited to several hours.

Figure 13. The Wave Glider Unmanned Surface Vessel manufactured by Liquid Robotics is now becoming widely used by the Navy is designed to be deployed and recovered by two individuals or through use of a small shipboard crane or small boat. Versions with marine meteorological sensors (top) and surveillance camera systems (below) are among several that have been developed.

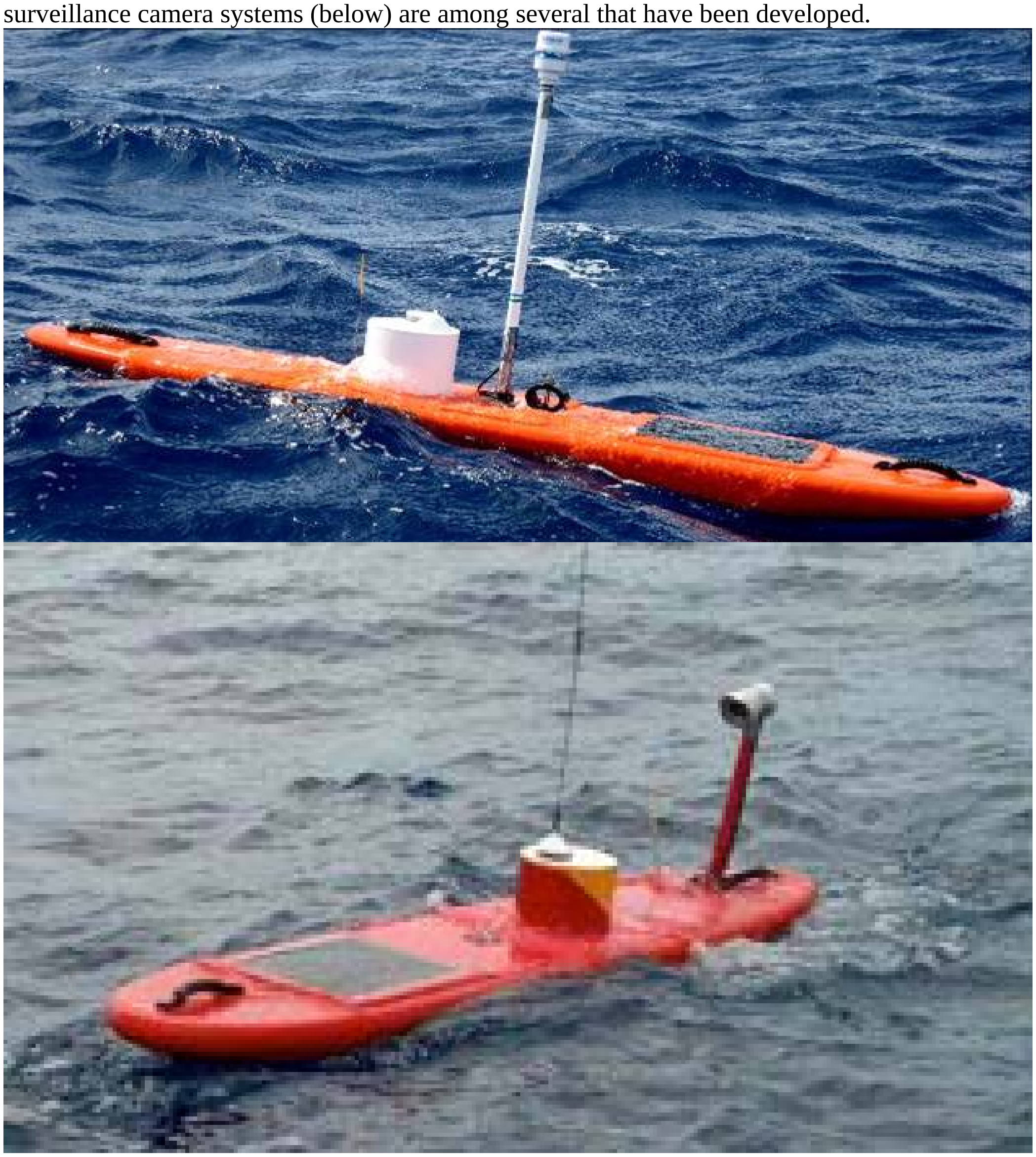

Figure 14. A 12' WAM-V (Wave Adaptive Modular Vessel) made by Advance Marine Research

Figure 15. Sketches of 33' WAM-V (Wave Adaptive Modular Vessel) carrying UUV for deployment (top), folded for launch and retrieval (center), and folded for shipping into a 20' shipping container (bottom).

Figure 16. SCOUT ‘Robo-kayak’ USVs have been launched at sea (upper left) for various purposes, especially for coordinated multiple vessel operations, with sensors including a CTD for vertical profiling deployed from winch within kayak frame (upper right), marine meteorological sensors (below), and underwater hydrophones and acoustic modems.

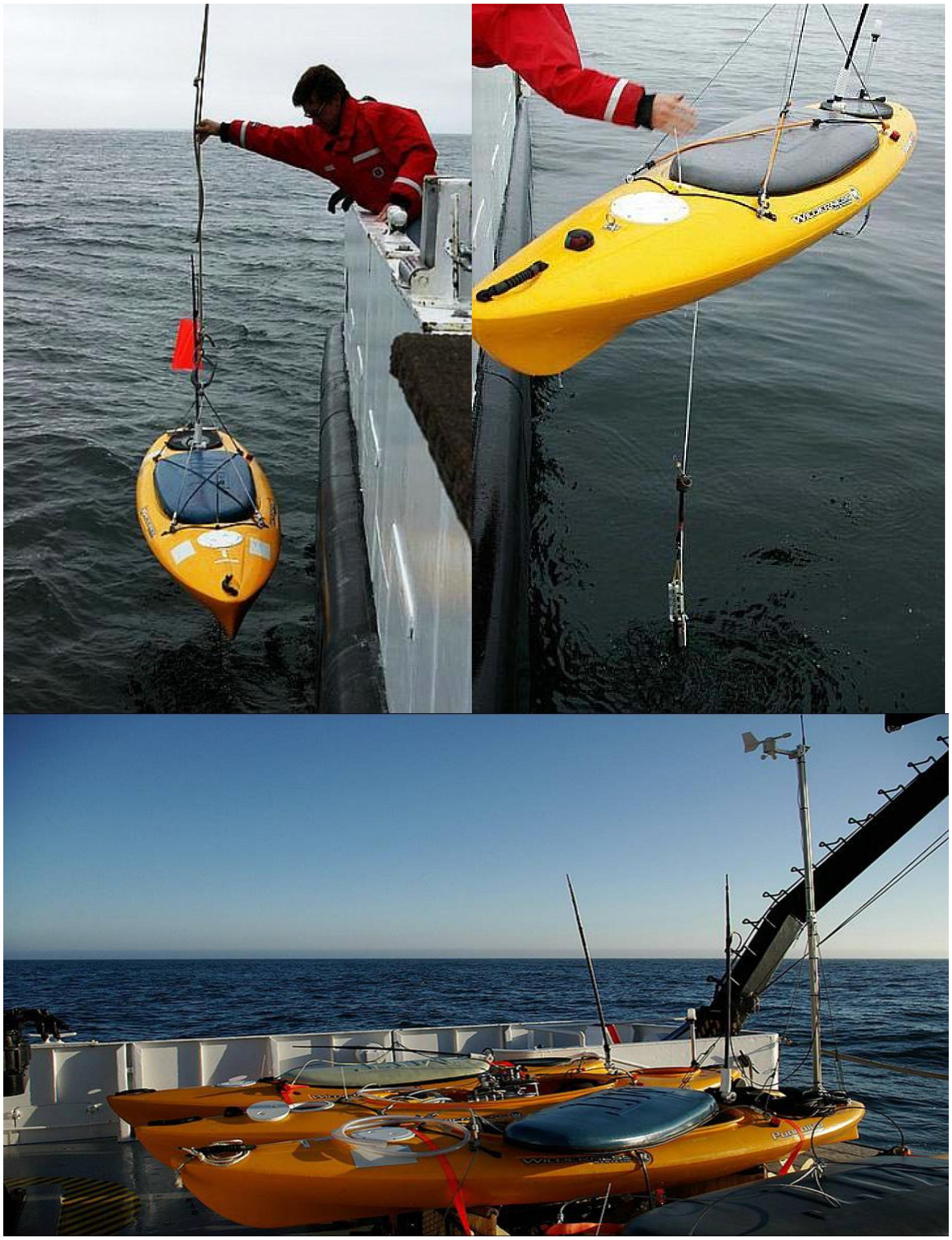

Figure 17. Glider launch and recovery both involve deck operations, but retrieval involves small boat operations to 'lasso' the glider prior to winching aboard (USCGC HEALY glider launch 2009).

Figure 18. Bluefin Robotics UUVs and SCOUT Robo-kayaks on deck prior to a multi-UUV/USV deployment.

Figure 18. C&C and ISE AUVs are large systems typically housed in their own 20' transport and launching vans, ideally with back deck space for the van, and a deck relatively close to the sea surface. Retrieval includes small boat operations, which are less burdensome than for smaller UUVs, due to the longer endurance of these larger systems.

Figure 20. The Scripps Flying Wing style UUV, built for the Navy, requires not only considerable deck space for storage, but also care in launching and small boat retrieval and recovery.

Figure 21. Nodding boom with tension adjusting winch shown on Japanese research vessel.