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LAUNCH AND RECOVERY SYSTEM LITERATURE REVIEW

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ACRONYMS

ABS	American Bureau of Shipping
AUV	Autonomous Underwater Vehicle
DD(X)	Future Destroyer
DoD	Department of Defense
GPS	Global Positioning System
INS	Inertial Navigation system
JAUS	Joint Architecture for Unmanned Systems
LAR	Launch and Recovery
LARS	Launch and Recovery System
LCS	Littoral Combatant Ship
LPD	Landing Period Designator
LPI	Landing Period Indicator
NVR	ABS Naval Vessel Rules
RAHS	Remote Anchor Handling System
RHIB	Rigid Hull Inflatable Boat
STANAG	NATO Standardization Agreement
UAV	Unmanned Air Vehicle
USV	Unmanned Surface Vehicle
UUV	Unmanned Underwater Vehicle
UV	Unmanned Vehicle

ABSTRACT

This report discusses the current state of unmanned vehicle launch and recovery through a literature review of articles published since 2005. The launch and recovery systems addressed are loosely grouped into ramp/slipways, crane-like, intermediate device, and catapult. This report also covers associated fields of interest: decision making aids, simulation, environment, and safety. Gaps in technology and research are identified. Though the focus is unmanned vehicles, this report does overlap with launching manned surface, manned rotorcraft, and manned fixed wing aircraft.

ADMINISTRATIVE INFORMATION

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INTRODUCTION

This report presents the current state in launch and recovery systems (LARS) and associated technologies. The report also identifies perceived gaps in research and understanding. The launch and recovery systems are typically tailored to specific vehicles and vehicle type. This report will attempt to focus on the launch and recovery systems in a generic sense, and less on the specific vehicles. Additionally, vehicles can launch in one manner and recover in another; for instance, a catapult-launched Unmanned Air Vehicle (UAV) that recovers in a net.

The launch and recovery systems are broadly grouped into four categories: ramps/slipways, cranes, intermediate device, and catapults. These categories have some overlap with each other, as for example, some intermediate devices use a crane. Also, the actual vehicle types can use different systems, for example, Rigid Hull Inflatable Boats (RHIB's) can be ramp or davit launched. Therefore, the presentation will focus on the four main categories with the understanding the separating line is somewhat blurred.

In addition to specific systems, there are associated fields of interest in decision aids, simulation, environment, and safety. Decision aids are often related to a specific launch and recovery system, but can be applied to others. Simulation, environment description and safety apply to all systems, though the specific details and implementation vary.

Previous work by Shienberg et al. [1] provides a quick overview of stern ramp and other systems around 2003. The time frame for this literature survey begins in 2005. The literature survey examined publicly available documents. A good number of the references are from presentations at conferences, without an actual paper or article, but are included in the conference proceedings. In these cases, the source is denoted as “(presentation)” in the references.

RAMP/SLIPWAY

The ramp/slipway category covers stern ramps, slipways, well decks, moonpools, and other systems that are integral to the ship design. The vehicles most likely to use a ramp or slipway are surface vehicles, RHIB's, and Unmanned Surface Vehicles (USV's). Often intermediate capture devices incorporate a ramp as part of the process.

Launching a vehicle using a ramp/slipway involves opening the stern gate, if present; lowering the ramp, if needed; and releasing the vehicle. The vehicle then slides down the ramp under its own weight. Once clear of the mother ship, the vehicle can drive away. It is best to judge when to launch so as to avoid a drop off the ramp into the water.

The recovery process is more involved. The recovery must also be timed to avoid ramp tip emergence. During recovery, either the vehicle is driven up the ramp and quickly secured before sliding back down, or a line is made fast to the vehicle at some distance from the mother ship and the vehicle is winched aboard. The former is most common for RHIB's; while the latter is more common for USV's.

Much effort has been spent working on a latching system to aid surface vehicle recovery. A latching system useful for RHIB's would be useful for USV and Unmanned Underwater Vehicle (UUV) recovery as well. Cosmo [2] describes the design of a passive latch to capture a towline for RHIB recovery. The towline should be brightly colored and incorporate a compliant member to reduce loads and damage to the latch. Petersen [3] investigates a bolt-on, external latch and an internal latch for similar towline capture appliances. He also investigates a probe-receiver device to secure an USV for towing. Galway [4] deals with the design considerations of a towline capture latch including jerk, tow, and design loads. Kilbourne [5] describes a number of possible latch designs used to snag a towline trailing from the mother ship.

Selecting a ramp/slipway type LARS has arguably the largest ship design impact of all the LARS examined. The design includes ramp size, angle, door, door type, fendering, and water management. Many investigators used scale model testing as a means of improving the ramp design. Dallinga [6] describes the use of model testing to assess ramp design, including ramp angle, water management, and best heading. Morriseau [7] describes the addition of a stern notch with garage door on a patrol boat, noting the need for rub rails to reduce damage and a redesigned tow post on vehicle or patrol boats. Sebastiani and Lauro [8] deal with incorporating a 7m stern ramp into a small patrol boat, 54m length. In this case, the bottom half of the stern door folds down to become the ramp end. Hackett et al. [9] also used model testing to evaluate different door configurations: barn door, garage door, and sliding door. The barn door was selected due to the extra funnel effect and increased headroom.

As an example of a stern ramp design, Dudson and Avis [10] address the extending ramp installed on the Sea Fighter and supporting model tests for water management. Russell [11] details the advantages of an internal ramp to a bolt-on ramp design, specifically the reduced risk of damage. Another design, the DD(X) stern ramp, has three sections: pivoting, fixed, and extendable [12]. The pivoting part rises from the deck during LAR operations. The extendable part is submerged with "goalpost" floats. Having a large cut out in the extendable part reduces stern flow disturbance.

Ramp designs need to be evaluated in operational scenarios. Situations where the stern ramp is moveable and depressed into water for operations can alter the water flow around the stern of the ship with unexpected results. The altered flow can create a suction force on towed vehicles causing them to impact the stern [13].

On the vehicle component of the ramp LARS, Ulak et al. [14] recommend a wrap around transom collar where possible to reduce stern submergence and entry angle when launching. Ullman [15] stresses an intuitive human-vehicle interface to reduce coxswain mental strain and avoid task saturation. The intuitive interface encompasses a better seat, obvious button layout, and a more direct connection between control movement and desired action.

CRANE-LIKE

The crane-like category includes all manner of side davits (J, L, Miranda), cranes (boom, knuckle, extending, A-frame), anchor handling, or any other similar mechanism with boom and winch. The vehicles mostly likely to use a crane are UUV and surface vehicles. Interestingly, UAV's can be recovered using a crane after ditching in the water near the ship. Cranes are often used in conjunction with cages or other intermediate devices.

The launch process using a crane typically involves the attachment of the crane's hook to the vehicle or intermediate device after which it is hoisted up via winch and moved slowly over the side of the surface platform, lowered to the water, and released. Automated and remote control technology allows the crane to let go of its subject in a variety of ways. It can be slowly winched down and unhooked via operators in a RHIB, remotely, or automatically. Depending on the vehicle or cage design, it can even be dropped from its original suspended height remotely or automatically. Spring-applied, hydraulically releasing latches are common.

The recovery process involving cranes is almost exclusively used when pulling a vehicle or intermediate device onboard. They can be used in the actual capture of UAV's after ditching in the water near the ship. Remote operated systems often allow for reduced manning at the site of recovery, making the process safer.

Olav et al. [16] stresses the importance of remote operation through the Remote Anchor Handling System (RAHS). The system uses remotely operated arms that are essentially an extension of the user's own arms. Using this, the operator can perform anything from buoy recoveries and attaching tow cables to large vehicles, to aiding in underway USV refueling operations.

In comparing davits and slipways, Gelling [17] concludes that davit systems have the advantage as they have a higher percentage of successful recoveries at higher sea states and do not sacrifice volume below deck. Davits are limited by sea state as far as launch processes are concerned and there is a loss of some deck space. Arguably davit operations can be considered more risky. The paper, which covers what type of LARS customers like better, determined that the customers like the system that they use, while the typical naval architect might prefer a slipway.

An A-frame is employed for recovery using the CALISTE capture device, Artzner [18]. It rotates down toward the cage during recovery and rotates back up to lift the cage

and its Autonomous Underwater Vehicle (AUV) onboard. This design protects the AUV by separating it from the ship's heave during capture or launch. The cage and AUV are then put directly onto the deck or a working cradle.

INTERMEDIATE CAPTURE DEVICE

The intermediate capture device is intended to launch and recover a vehicle at a distance from the ship to minimize collision damage and relative motion. Once the vehicle is safely inside the intermediate device, the entire package is then recovered or launched with a crane or ramp. As such, the intermediate capture device category includes cages, sleds, cocoons, nets, slings, and wires. Any type of vehicle can use an intermediate capture device. USV and UUV's typically use cages, sleds, and cocoons far from the ship. UAV's are captured close to the ship in nets or by snagging a wire.

Intermediate capture devices can be used in both launch and recovery operations. In these operations, often the capture device is merely used as a cradle-like device for the subject vehicle for safely moving it to and from the surface platform.

The CALISTE concept uses a cage that attaches to an AUV via a tow line then uses a funnel-shaped device that leads the AUV and lines it up with the cage [18]. After the AUV is docked and locked into the cage, it can be lifted on board. Less sophisticated cages act as temporary housing while the vehicle is being lifted to or from the water.

Mulhern [19] describes various towed underwater bodies that would provide an attachment point for UUV and USV recovery. These tow bodies are maneuverable and are steered to recover stopped UV's, rather than the vehicle maneuvering to meet the tow body.

The Soft Rail Launch and Recovery System uses a sled to travel up and down the wire railing for use with launch and recovery by way of winching. To keep the rails in tension, a depressor and drogue are used to submerge the system and provide a stabilizing drag force to keep the depressor at a fixed depth and aligned with the ship's axis [20]. This sled and rail system can be used for moving surface vehicles and UUV's from land to water or from ship to water. Goldie [21] suggests a sled or cart recovery system for use with UAV's on the Littoral Combatant Ship (LCS) and other small deck navy ships. While the UAV would engage the arresting cable, the cart would then match the UAV's deceleration and the UAV would land on the cart. This would aid in deceleration of the UAV and provide easy removal of the vehicle. Sleds are also used in ramps and slipways for the launch and recovery of RHIB's and other similar vehicles.

Nets are almost exclusively used for UAV recovery. They are set up perpendicular to the flight path of the subject vehicle and often capture them via a folding mechanism. As presented by Berzins et al. [22], nets are ideal for use anywhere. They are generally lightweight and easy to set up. This mobility allows for use in almost any setting including on land, buildings, and oil platforms. They are excellent for recovery of UAV's on ship's flight decks, small craft, and even RHIB's.

Wires are generally also used for the capture of UAV's, and as mentioned earlier, can be used in conjunction with sleds in a most unconventional way. Pate et al. [23] describes the technology and control logic needed for an arresting gear recovery suitable

for UAV's. ScanEagle's Skyhook Recovery System employs the use of a boom assembly with a vertical capture rope in tension to pull ScanEagle out of the air [24].

CATAPULT

Catapult launchers impulsively launch or fire the vehicle down a rail or tube, similar to a speargun, crossbow, or ballista rather than trebuchet. The quick launch helps UAV's attain the needed velocity for flight and quickly escape local ship airwake boundary effects. Torpedo tube launched UUV's are also impulsively launched to ensure a clean exit from the tube.

Advances in catapult technology are not always in the system itself, but its computer monitoring system. McRae et al. [25] state that their Advanced Launch Control System for steam catapults will better enable the user to diagnose issues when they arise by way of better monitoring by the system.

Electro Magnetic Kinetic Integrated Technology (EMKIT) [26], allows for control of the launch speed, gives a shorter launch length, and allows for a range of masses at the highest launch speed. This system is generic and scalable, so can be used on many different platforms. In the future, it is hoped that this will replace steam catapults and launch UAV's from a wide variety of vessels and even remotely from land. Other future considerations include launching of torpedoes.

OPERATOR AIDS

Operator aids are those tools used to help operators know when it is the best time to launch or recover and manage the vehicles shipboard. Much work has been done in this field with manned vehicles, especially helicopter landings. One of the main issues in helicopter landing is knowing when the deck motions are quiet enough to land. Landing Period Indicators (LPI) attempt to signal the pilot when it is appropriate to land. The same technology can be used for RHIB coxswains, USV, UUV, and autonomous vehicle recovery.

Ferrier et al. [27] use an energy index corresponding to deck force components to identify quiet landing times. Ferrier et al. [28] discusses pilot comments on enhanced visual clues for a helicopter landing trainer. More visual cues are better, as is using higher resolution graphics.

McCue and Bassler [29] demonstrate using finite time Lyapunov exponents with a single degree-of-freedom roll model to identify quiescent periods. This approach is non-empirical. Gray [30] uses measured motion data as input to a real time simulation to determine a safety index for embarked helicopters. This approach avoids the assumptions used in a purely numerical simulation method.

Sherman [31] evaluates quiescent period detection methods and uses a system dynamics approach to helicopter landing to gain greater understanding of LPI benefits in reducing pilot stress and risk. Sherman et al. [32] discuss the assessment of LPI operational benefits. With proprietary algorithms and the lack of clearly defined metrics, the authors propose a simplified Benchmark Safety Index for comparison of landing aids.

The same sensor technology that would help a human operator launch and recover a vehicle can be used for autonomous control. Garratt et al. [33] have integrated a visual

tracking system and Light Detection and Ranging (LIDAR) to determine range and deck attitude for autonomous UAV landing. Nabaa and Saraniero [34] suggests a combined system of millimeter wave radar, differential Global Positioning System (GPS), and Inertial Navigation System (INS) can be used for autonomous UAV launch and recovery. In addition, autonomous control requires a more sophisticated controller than a simple autopilot. Ashrafiuon and Muske [35] have demonstrated at model-scale a sliding-mode controller that will drive a USV to a specified moving point, i.e., the stern ramp on a mother ship. Spano [36] approaches the problem from non-linear dynamics and synchronizing motions using a single degree of freedom model. Further work would be required to investigate this approach with more degrees of freedom.

Unmanned vehicles require a control function in addition to being able to launch and recover. The control function involves the operator station, data links, and deck handling. It is possible to control an UAV on deck for taxiing using visual signals [37]. Branthoover and Moulds [38] share lessons learned in the development of an Open Unmanned Mission Interface (OpenUMI) control station following STANAG 4586 and Joint Architecture for Unmanned Systems (JAUS) standards for the control of multiple UV's. Leen [39] describes a software solution to planning and scheduling the use of multiple UV's including maintenance time, asset location, and conflict identification.

SAFETY

Vehicle launch and recovery can be a dangerous task, especially at higher sea states. The process can be made safer with a well thought out process, a well designed vehicle, and a well designed LAR device. As part of increasing safety, LARS designs are reviewed and are certified as safe for use.

The safety certification takes many forms and is performed by different agencies and governing bodies. The military has a series of Military Standards (MIL-STDs) to follow for the various components. Demmick [40] outlines the Defense Safety Oversight Council promotion of Programmatic Safety Precepts, Operational Safety Precepts, and Design Safety Precepts in Unmanned Systems Safety Guide for DoD Acquisition.

Bednarek and Nowak [41] trace the challenges in moving to Commercial-Off-The-Shelf equipment for crane/davit launch and recovery. The governing specifications for davits changed from MIL SPEC 17762B [42] to American Bureau of Shipping (ABS) Naval Vessel Rules (NVR) [43], which presently do not cover stern launch and recovery. The use of water bags for davit/crane load testing is an improvement.

Johnson [44] gives an overview of the certification process for installing a fixed wing UAV, ScanEagle, on U.S. Navy ships. The certification process includes a clearance assessment, fuel usage and storage, LAR equipment storage and handling, and extensive review to minimize risk.

Independent organizations, such as the American Bureau of Shipping, also certify LARS. Ashe et al. [45] describes the ABS LARS certification process – request for certification, design drawing review, and construction survey. Ingram et al. [46] describes how ABS requirements work with the owner's requirements and statutory compliance to generate a safe, effective LARS design. ABS is concerned with the

physical attributes, structural and mechanical, of the LARS. Statutory bodies or government agencies determine safety of life and environmental protection.

Dag [47] discusses in general the safety aspects of various LARS used for fast rescue craft in the oil industry. The author provides a list of traits for an optimal LARS. Of special concern is the need for a fast, safe winch, a latch/hook mechanism, and controlling vehicle pendulation during lifting.

Schulze [48] reported on UAV accidents and how to avoid them. The author found a lost communication link, inadequate maintenance, inadequate emergency procedures, and poor pilot status cues to be contributing factors.

SIMULATION

The virtual simulation of launch and recovery is useful for operator training, controller evaluation, and design requirement evaluation. The simulation can include the geometry of the system, an environmental description, propulsion system, and multi-body interaction effects. Sandberg et al. [49] list even more challenging aspects such as unsteady flow, body-fin interaction, deformable bodies, and 3D flapping motion.

There is also more than one simulation approach – ranging from a single simulation capable of multiple bodies or a federated combination of simulations to a collection of probability density functions for a Monte Carlo simulation. Each of these approaches has different levels of fidelity and applicability. Kery [50] discusses the inclusion of swell for a more accurate seaway description in a time-domain simulation of UUV recovery. Gordis et al. [51] use a simplified UUV and ship excitation model to examine vehicle pendulation in the time-domain. Baker and McCarty [52] discuss the requirements of a davit launch and recovery trainer including the control interface and required model fidelity to be of use for training.

Much more work has been done in helicopter and UAV landing compared to other vehicles. One of the key parts of helicopter or UAV landing is the dynamic interface of the moving deck, moving aircraft, and air wake. Multiple authors have examined the simulation of the entire UAV LAR process. Langlois and Scribner [53] approached the problem using probability density functions for each step in the process and ran a Monte Carlo simulation to determine availability. Dietze [54] used a federated high level architecture approach to provide simulation and predictions up to 15 sec in the future for use as an UAV Landing Period Indicator (LPI). Kachman [55] developed a pilot model and compared simulations to pilot-in-the-loop results. The pilot model could be extended to an enhanced autopilot or autonomous controller.

Yang et. al. [56] use a modified auto-regressive exogenous model and measured data to predict future heave motion. The authors suggest this could be applied to UAV and landing guidance systems. Polsky [57, 58] numerically calculates ship air wake and compares to wind tunnel and full-scale data. Air wake is spatially and time varying, which make a purely stochastic model of limited value. The time varying air wake was integrated into flight trainers to evaluate air wake realism, though validation data are needed.

Wong et al. [59] used a hardware-in-the-loop Monte Carlo simulation to investigate factors involving UAV recovery. Specifically, slower frigate speeds and

higher UAV speeds were better. Ferrier et al. [60] also used hardware in the loop as part a federated simulation to assess weather effects on helicopter landings. Wilkinson et al. [61] discusses the requirements for simulation in use for helicopter operations training stressing high visual and air wake fidelity. Colwell et al. [62] compares time domain and frequency domain simulations of helicopter securing probe loads in uni-directional and multi-directional waves. The agreement between time and frequency domain is good for lateral loads, and lateral and vertical motions, where the motions are mostly linear. The vertical loads are non-linear due to the helicopter securing probe and landing gear design, and do not agree as well.

ITEMS FOR FURTHER INVESTIGATION

Simulation of USV and UUV LAR is just beginning and it not to the level associated with helicopter and UAV operations. It is thought an approach similar to UAV simulation could be used for USV and UUV. More work is needed in quantifying the important tasks or components to include in the simulation to increase fidelity. High fidelity RHIB, USV, and UUV simulations will enable cross training with enabling UAV/helicopter technology.

Operator aids for RHIB and USV LAR could be developed using the same methodology as helicopter and UAV landing period designators. This would require a better understanding of the limiting motions and their interaction with respect to recovery. Large or full-scale testing would be useful to determining those limiting motions. Of specific interest is maneuvering performance and seakeeping and importance of local flow phenomenon, e.g., sloshing.

There is a lack of validation data for helicopter landing operations to compare with simulators and trainers. Presently, the simulation components are individually validated, though to different levels, with no overall fidelity rating.

Current research points to almost exclusive use of nets for UAV recovery. The successful use of nets with air vehicles should be investigated with UUV's. In the same way, more research should be considered for UUV's with respect to catapult type launches underwater. There is vague mention of such technology but no actual pursued goals.

Davit or crane launching manned vehicles requires the vehicle to connected and disconnected from the hook. Making that attachment process more automatic, safe, and consistent would be helpful. Crane LARS that reduce vehicle swinging during a lift should be pursued.

CONCLUSION

This report summarized the current state in launch and recovery systems published since 2005. Launch and recovery systems were categorized into four areas for discussion: ramps/slipways, crane, intermediate device, and catapults.

There are many successful ramp designs in existence today around the world. Many navies and coast guards routinely use ramps to conduct their small boat operations. Ramp and slipway design elements of ramp angle, size, stern door, and fendering have been well investigated. Water management inside the ramp well has been identified as an

area of concern and is being actively investigated. Another field of active investigation is that of an automatic latching mechanism to catch a towline to reduce operator risk. This technology can be applied to unmanned and autonomous vehicles as well.

Launch and recovery system designs are routinely evaluated and certified for safety by statutory and independent organizations. The focus appears to be on the design and construction of the LARS. Avoiding bad environmental conditions often mitigates operational safety and hazards. Market trends are already heading towards increased vehicle utility, and not merely checking a safety box. A possible area of effort would be improving the LAR operational process to maintain the same risk levels in worse environmental conditions. Additionally, failsafe and emergency procedures for unmanned and autonomous vehicles need further work.

Launch and recovery simulation is a needed and useful tool for design and training. The entire process can be modeled using a federated approach of individual simulators or Monte Carlo simulations depending on the eventual use. A federated approach is more useful for trainers; Monte Carlo simulations for design. There is a general need for validation data of the individual component simulations and the entire process. This varying degree of validation and fidelity makes it difficult to assess the fidelity of the entire simulation for training purposes. A RHIB, USV, or UUV simulation of comparable fidelity to helicopter trainers would allow the same technologies and methodologies used for helicopter LAR to be used for RHIB, USV, and UUV LAR.

Operator aids to help launch and recover aircraft are in common use within the naval community. They have been shown to improve the pilot's ability to safely land. There are different approaches with varying levels of empiricism to identify the quiescent landing periods. All the approaches use measured data with real-time calculations to make the prediction of future ship motions. The same methodology could be applied to surface and underwater vehicle LAR.

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