DRDC-RDDC-2016-N044

Kevin McTaggart, Defence Research and Development Canada
Sietske Hendriks, Royal Netherlands Navy
Ian Nimmo-Smith, United Kingdom Ministry of Defence
Arild Øydegard, Norwegian Navy
John Pattison, BAI Incorporated
Norbert Stuntz, Bundeswehr Technical Center, Ministry of Defence, Germany

Considerations in Development of Naval Ship Design Criteria for Launch and Recovery

ABSTRACT

The NATO Seaway Mobility Specialist Team is developing new ship design criteria to ensure that ships are capable of supporting launch and recovery operations over their life spans. This paper describes factors that must be considered in the development of these new design criteria, with an emphasis on frigates and destroyers with associated displacements of 3000 to 10000 tonnes.

INTRODUCTION

The evolution of naval priorities combined with rapid technical advances make this a very exciting time in the field of launch and recovery. Among naval missions, search and rescue (SAR) of migrants along with humanitarian aid and disaster relief (HADR) have become increasingly important in the current geopolitical landscape. These missions dictate a requirement for safe transfer of both military personnel and civilians from smaller boats to ships. Counter-piracy and drug interdiction missions require rapid deployment of boarding parties, which can have 12 or even more personnel. Helicopter operations continue to be an integral part of naval ship missions. Unmanned vehicles, both autonomous and remotely piloted, are being increasingly used for air, surface, and underwater operations.

The increasing importance of launch and recovery within navies has stimulated much related activity. The LAURA Joint Industry Project, which has been in progress for several years, is developing various designs for launch and recovery of waterborne vehicles from ships using cranes [1]. Navies have been collaboratively sponsoring additional work by industry on launch and recovery of waterborne vehicles. The European Defency Agency has performed work on unmanned maritime systems, including launch and recovery.

Among ship operators worldwide, the United States Coast Guard appears to have the most experience with launch and recovery of waterborne vehicles. Fortunately, the US Coast Guard has been very willing to share its experience and knowledge in the open literature, with several references cited later in this paper. It should be noted that there is significant overlap between missions of the US Coast Guard and international navies, thus making lessons learned highly valuable.

Due to rapidly evolving missions and technologies associated with launch and recovery, it can be challenging to design ships that will be suitable for launch and recovery operations throughout their long lives. To address this problem, the NATO Seaway Mobility Specialist Team is developing new ship design guidelines with the goal of supporting launch and recovery operations through ship life. The new guidelines are assimilating lessons learned to date and are also aiming to anticipate future developments that will impact on design for launch and recovery operations. This paper intends to share the foundations for new ship design guidelines and also to encourage feedback that will enhance these guidelines.

SIDE LAUNCH AND RECOVERY USING LIFTING APPLIANCES

Launch and recovery of waterborne objects from the sides of ships is commonly done using lifting appliances, which can include davits, boom cranes, and articulated cranes. A review of side launch and recovery has been performed to provide information for development of associated ship design guidelines.

Review of Side Launch and Recovery

Figure 1 shows a wave buoy being launched from the side of a Royal Canadian Naval Maritime Coastal Defence Vessel using a boom crane. The launch and recovery of the wave buoy is a relatively simple operation for the following reasons:

- The ship and buoy are both moving with minimal speed;
- No personnel are being lifted as part of the launch and recovery operation;
- The shape and size of the buoy make it easy to handle for personnel on deck.

There are several factors that contribute to the success of launch and recovery operations with this combination of ship and crane:

- The deck at the crane location is a suitable distance above the water, in close proximity yet sufficiently high to prevent deck wetness;
- Personnel on the bridge (not shown) have excellent views of the crane;
- The crane is relatively simple;
- There is adequate space in the vicinity of the crane for movement and storage of objects;
- Although the crane is located at the stern of the ship, the vertical motions of the crane relative to the water surface are generally acceptable due to the moderate length of the ship (49.0 m length between perpendiculars).

Figure 1: Launching of Wave Buoy from Side of Ship Using a Boom Crane

Further insight can be gained by considering the launch and recovery of boats, such as that shown in Figure 2. A crane is connected to the boat at a conventional single lift point on the boat. The interface between the crane and the boat significantly influences engineering aspects of both the ship and boat, and also greatly influences launch and recovery operations. Configurations with a single lift point, such as that shown in Figure 2, are widely used because of their simplicity, versatility, and proven reliability. In such configurations, a painter line usually runs from the bow of the boat to a point forward on the ship deck. Personnel on the ship deck often use tag lines connected to the bow and stern of the boat to maintain desired yaw orientation of the boat during launch and recovery. When performing launch and recovery of a boat using a single lift point, it is imperative that the lift point be located sufficiently high on the boat to ensure roll and pitch stability.

More sophisticated lifting appliances can limit yaw motions of the small craft, with the benefit of reducing the need for tag line hanlders. Figure 3 shows a lifting appliance that includes restraint of the the boat in yaw using a rigid lift connection. Such connections are usually designed to allow some initial yaw of the boat during the connection process. Another common approach for restraining yaw is to use a dual point lift system, such as that shown in Figure 4. The lifting appliance has two cables connected to fore and aft points on the boat.

The selection of connection type between the lifting appliance and boat is often the subject of much deliberation. A conventional single lift point on the boat enables usage of a relatively simple lifting appliance, such as a boom crane or articulated crane. A rigid lift connection requires a more sophisticated lifting appliance and a tailored connection on the boat. A dual lift point system also requires a sophisticated lifting appliance. Operational experience

Figure 2: Boat Attached to Crane with Single Lift Hook (courtesy of Welin Lambie)

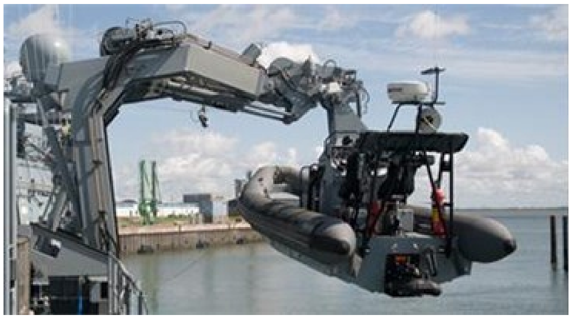

Figure 3: Boat Attached to Davit with Rigid Lift Connection (courtesty of Vestdavit)

Figure 4: Boat Attached to Davit with Dual Lift Points (courtesty of Vestdavit)

with dual lift point systems has highlighted dangers associated with unintentional release of one connection point while the other connection point is still attached to the lifting appliance; thus, care must be given to ensure that both connection points are released simultaneously, and only when expected. A single point connection has proven to be adequate for launch and recovery at lower speeds (e.g., 6 knots and less). Experience of the United States Coast Guard [2] has led to modification of the National Security Cutter to use dual point davits for side launch and recovery, enabling operations at higher ship speeds.

The painter line plays an important role in side launch and recovery at forward ship speed. When the boat is attached to the lifting appliance and has contact with the water, the painter line should normally be connected. Operational experience has led to increasing usage of a lateral boom such that the fore end of the painter line is attached to a point extended laterally from the side of the ship. The usage of a boom helps to maintain a suitable gap between the boat and the side of the ship during launch and recovery. Good directional stability of the boat is important for maintaining this gap and overall safety during launch and recovery.

Figure 5 shows a boat launch and recovery system situated within an alcove on a ship. Ship stealth and protection of crew from harsh environments are among the reasons for situating a launch and recovery system within an alcove. The limited space available within an alcove can introduce challenges for design and operation.

Launch and recovery systems continue to evolve rapidly. To reduce risk to personnel, automated mechanisms are being increasingly used for connections between lifting appliances and objects being launched and recovered. This rapid evolution of systems highlights the importance of ships having the ability to be refitted with new systems during their lives.

Figure 5: Boat Launch and Recovery System Inside Alcove on Ship (courtesty of Vestdavit)

Preliminary Ship Design Guidelines for Side Launch and Recovery

Table 1 gives main areas for ship design guidelines to facilitate side launch and recovery. Each area is discussed in greater detail below.

Ship motions will be dependent on the ship itself and also on the location onboard ship selected for launch and recovery. Table 2 shows RMS ship motion limits developed by the United States Coast Guard [3]. Note that the originally published values were given as significant single amplitudes, which have been divided by 2.0 to give RMS values, which are commonly used by NATO. Fortunately, ship motions at launch and recovery locations can be reliably evaluated using available numerical tools.

Deck wetness events can pose significant hazards to personnel during launch and recovery operations. Consequently, it is proposed that a very low incidence of deck wetness in-

Table 1: Main Areas for Ship Design Guidelines for Side Launch and Recovery

Ship motions
Deck wetness
Proximity to water
Visibility for launch and recovery system operators
Communication with bridge
Space for launch and recovery appliances and personnel
Ability to move objects away from launch and recovery area

Table 2: United States Coast Guard RMS Ship Motion Limits for Side Launch and Recovery

Roll angle	4.0 deg
Pitch angle	1.25 deg
Vertical acceleration	0.1 g
Lateral acceleration	0.1 g

cidence be specified (e.g., 0.1 deck wetness events per hour). The evaluation of deck wetness incidence is challenging due to the influence of steady scattered waves arising from ship forward speed, radiated waves, and diffracted waves. To account for modelling errors, a possible approach is to specify that the deck wetness incidence criterion be satisified for a location at a specified distance below the actual deck level (e.g., 1.0 m below deck level).

Launch and recovery operations become more challenging if the distance between the ship deck and water is large. As this distance increases, launch and recovery times increase. In addition, there will be greater variations in the clearance distance between the boat and the side of the ship. To mitigate such problems, a maximum distance could be specified for the height of the deck above the water (e.g., 15 m).

Good visibility for launch and recovery system operators is essential for safe operations. Achievement of this requirement could be challenging on ships with launch and recovery systems confined to alcoves.

Communication between the bridge and launch and recovery area is required for a variety of reasons, including ensuring that the ship travels at appropriate speed and heading for operations. Visual line of site, electronic video transmission, and audio transmission can all contribute to successful communications. Shipborne aircraft operations have provided valuable lessons in this area.

Area on deck for a launch and recovery system must include clearances for all operational and maintenance envelopes. In addition to the main launch and recovery area, additional space forward can be required for booms or other equipment used to handle painter lines. When designing a new vessel, consideration should be given to future equipment that might require more space than original installations.

It is recommended that a ship have the ability to move objects away from launch and recovery areas as required. For example, if a boat becomes unexpectably inoperable, then the ship should ideally be able to move the inoperable boat away from the launch and recovery system and move an operable boat to the launch and recovery system. A crane with 3 translational degrees of freedom (DOF) (e.g., boom crane or articulated crane) can be well suited to this task. If the main launch and recovery appliance has limited degrees of freedom (e.g., rigid attachment system of Figure 3 or dual point system of Figure 4), then addition of a separate crane with 3 DOF should be considered.

STERN LAUNCH AND RECOVERY USING WELL DOCKS AND STERN RAMPS

A well dock or stern ramp is often used for launch and recovery from the stern of a ship. Sheinberg, Minnich, Beukema, Kauczynski, Silver and Cleary [4] give an overview of stern launch and recovery systems.

Figures 6 and 7 show well docks with craft inside them. Most well docks are designed to operate with landing craft. A well dock can typically accommodate a wide variety of organic vehicles, including subsurface vehicles. A major disadvantage of a well dock is that it has a drastic influence on the size and design of the mother ship. Furthermore, launch and recovery operations from a well dock are usually time consuming and require many trained personnel.

Figure 8 shows a stern ramp with a RHIB. Stern ramps are commonly used to provide fast launch and recovery of organic vehicles, most commonly RHIBs. A stern ramp is usually

Figure 6: Landing Dock During Operations with Landing Craft and Rigid-Hulled Inflatable Boat

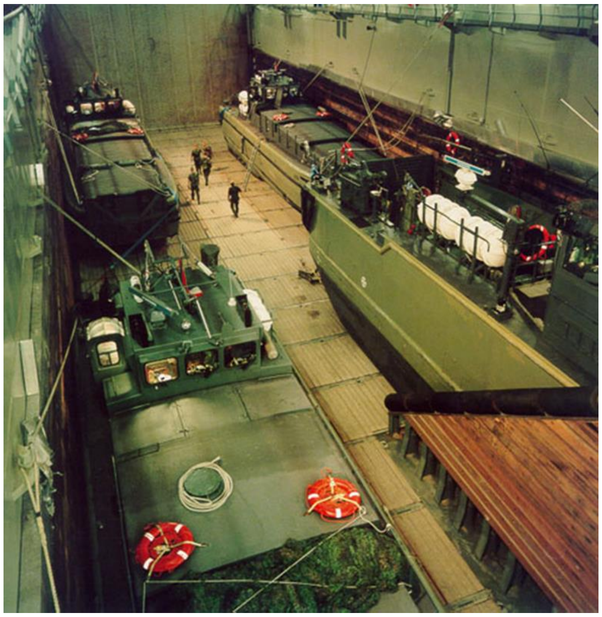

Figure 7: Landing Dock in Dry Condition with Landing Craft

Figure 8: Stern Ramp with Rigid-Hulled Inflatable Boat

designed for a specific vehicle, but can often handle other vehicles of similar or smaller size. Much progress has been made recently in development of automatic systems for launch and recovery from stern ramps. Note that automated capture mechanisms are often only operational with very specific vehicle geometries. To facilitate operation in colder climates, the sill of the stern ramp can be placed above the waterline to prevent ice entry. Operations using such designs can utilize a hinging stern door or cradle to ensure safe recovery. A stern ramp will be a major driver in the design of the mother ship due to demands for space, weight, and specific placement.

Operational Guidelines for Stern Ramps

For launch and recovery using a stern ramp, the recovery operation is generally the limiting factor. Horizontal motions and relative vertical motions of the stern ramp strongly influence operations. These motions are dependent upon various aspects of the mother ship, including size, speed, heading, and motion control systems. Operational limits are typically Sea State 5 or lower.

Stern launch and recovery usually occurs in head seas at speeds between 3 and 6 knots. For launch and recovery of RHIBs with waterjets, the operational speed may be higher due to directional stability concerns with the RHIB.

Preliminary Ship Design Guidelines for Stern Ramps

Many of the factors relevant to side launch and recovery (Table 1) are also relevant to stern ramps. Stern ramps introduce additional challenges that must also be considered. References by Sheinberg, Minnich, Beukema, Kauczynski, Silver and Cleary [4] and Sheinberg, Cleary, DeBord, Thomas, Bachman, St. John and Minnich [5] provide useful guidance regarding design of stern ramps.

The ramp sill depth (the submerged depth at the aft end of the ramp) will determine the ramp availability time in a seaway. A minimum availability time (the time the water level at the sill is high enough for the vehicle to enter the ramp) is needed for a safe recovery. A greater sill depth gives higher ramp availability time and therefore greater operability in waves; however, the transom immersion associated with a greater sill depth can adversely affect ship resistance.

The shape of the ramp opening should be designed to prevent damage to the organic vehicle during entry and exit, and must consider factors such as the limited durability of the inflatable portion of a RHIB.

The slope of the ramp must be sufficiently steep for the organic vessel to overcome its own static friction for launching, but flat enough to ensure that the organic vehicle is able to power itself up far enough during recovery. The ramp surface plays a role in overcoming the static friction of the organic vehicle, with low friction material being benefical. Low friction material will also reduce forces during recovery when the organic vehicle is driven into the ramp.

The clearances around the organic vehicle play an important role in the safety of the crew on board. Sufficient overhead clearance is critical, and must account for wave induced motion of both the mother ship and organic vehicle. The side clearance must be large enough to have some tolerance on both sides, but should restrict excessive lateral motions. When the stern ramp is designed for a variety of organic vehicles, adjustable side fendering should be considered.

The stern doors or gates must be designed such that they do not impede safe operations. For example, overhead clearance is important for upward hinging gates. For downward hinging gates, the ability to withstand wave loads is critical.

A water management system can contribute greatly to safe operation of a stern ramp, especially in higher sea states. The water management system should mitigate hazards, such as waves rolling up the ramp and flushing out the organic vehicle. Wave damping and water dissipation are proven solutions.

The capture of the organic vehicle can be done automatic or manually. When a vehicle is operated from a stern ramp that was not designed for that vehicle, the automatic system will probably not work; thus, a capability for manual capture should always be available.

Roll, pitch, vertical acceleration and lateral acceleration of the mother ship will influence stern ramp launch and recovery. These motions must be considered when evaluating ramp availability time.

AIR VEHICLE LAUNCH AND RECOVERY

Modern frigates and destroyers include the capability to launch and recover helicopters. Many ships include sophisticated mechanical systems that include a cable with automated tension between the helicopter and flight deck, increasing the operational envelope for launch and recovery operations [6].

Typically, the flight deck on a frigate or a destroyer is at the stern, behind the deckhouse and all of its mounted equipment, as shown in Figure 9. As the helicopter approaches to land, it encounters a complex air wake behind the superstructure. The air wake contains time-varying combinations of turbulence, vortices, shear flow and downwash, for which the pilot must compensate to keep the helicopter under control. The ship is also rolling and pitching in response to the seas it is encountering.

Figure 9: Helicopter on Approach to Land on Destroyer

Flight test launches and recoveries are done for every combination of helicopter and ship in order to assure that these operations will be safe. The ship is driven at various speeds and headings relative to the wind and sea in order to find relative wind limits beyond which the test pilots determine it would be unsafe to take off or land. The pilots are given a workload rating scale to rate each launch and recovery as to its difficulty. The results are used to generate ship-helicopter operating limits (SHOL), in terms of relative wind speed and direction, that the ship operators and helicopter pilots can use. A typical envelope is shown in Figure 10. During the test flights, the deck crew take readings from the ships inclinometers of pitch and roll amplitudes. At the limits of relative wind, the maximum pitch and roll amplitudes are cited as guidance for the ship operators.

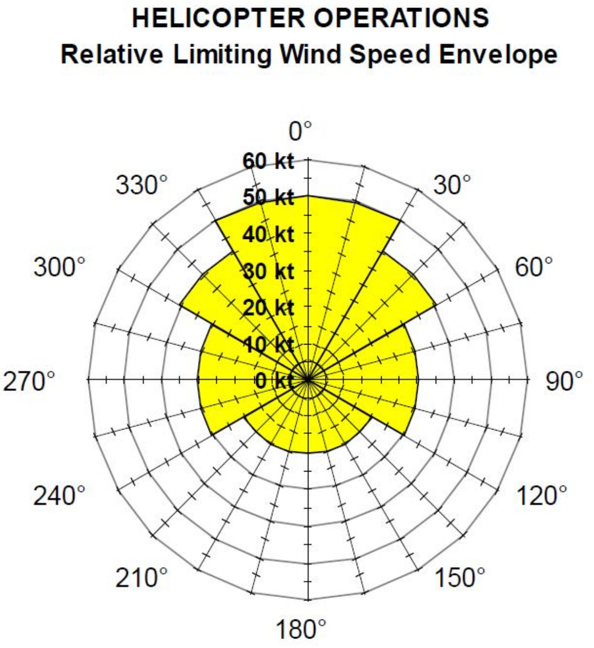

Figure 10: Typical Ship-Helicopter Operating Limits (SHOL)

Over the years, as shipboard helicopter operations expanded, it became apparent that the ship designer needed sets of relative wind and motion limits to assure that new ships would be safe for these operations. Subject matter experts from seven NATO nations assembled to produce an updated seakeeping standard [7] including more detailed treatment of air operations. The document contains limiting ship motion criteria for a variety of missions. The document also references ship motion prediction programs that can be used to determine which sea states will cause limiting motions to be exceeded. For a ship that is required to carry out a specific set of missions, the designer can use sets of the criteria to refine the ship design for best performance in the ocean wave conditions that the ship might encounter in selected operating areas of the world.

For fixed and rotary-wing aircraft launch, recovery and handling, the NATO seakeeping standard contains generic limiting motion criteria and generic relative wind envelopes. For specific aircraft and ship combinations, each with its unique limiting motion and relative wind characteristics, the ship designer has to rely upon the results of dynamic interface sea trials on existing aircraft and ship combinations, and hope that he or she can find combinations that are close enough to those of the new ship being designed.

In the discussion which follows, fixed-wing helicopter operations will be used to show where improvements can be made to the guidance given in the existing NATO seakeeping standard. Limits for vertical and short take off and vertical landing (VTOL and STOVL) operations are based on an air capable ship comparison by Comstock, Bales and Gentile in 1982 [8] in terms of generic criteria, which could be used as default values for any design study. Specific criteria were not publically available for many combinations of aircraft and ships. Thus, generic criteria were presented in terms of limits for roll, pitch, vertical velocity and relative wind (see Table 3). These limits are defined to permit launch and recovery of aircraft within established operational envelopes. Observations during sea trials suggested that, on an approach to landing, vertical acceleration of the flight deck is of more concern than roll or pitch. Indeed, vertical acceleration is a manifestation of heave, roll and pitch and the distance from the center of gravity of the ship.

Table 3: Generic Helicopter Launch and Recovery Criteria Limits

Operation	Performance limitations
Launch	Roll 2.5^o RMS
	Pitch 1.5^o RMS
	Relative wind (Figure 10)
Recovery	Roll 2.5^o RMS
	Pitch 1.5^o RMS
	Vertical velocity 1.0 m/s RMS at flight deck
	Relative wind (Figure 10)

The generic envelope shown in Figure 11 represents the limits of relative wind speed, with respect to relative heading, into which the aircraft may be launched or recovered. Launch or recovery outside of the safe envelope results in unacceptable crosswind or turbulence for safe and efficient operation. By mapping this envelope into the plane of possible ship speeds and headings for the ambient winds associated with each sea condition, wind envelopes satisfying the relative wind requirements can be defined. Figure 12 shows an example of this mapping for mid Sea State 5 with a mean ambient wind speed of 22 knots. The operating envelope is the non-shaded region.

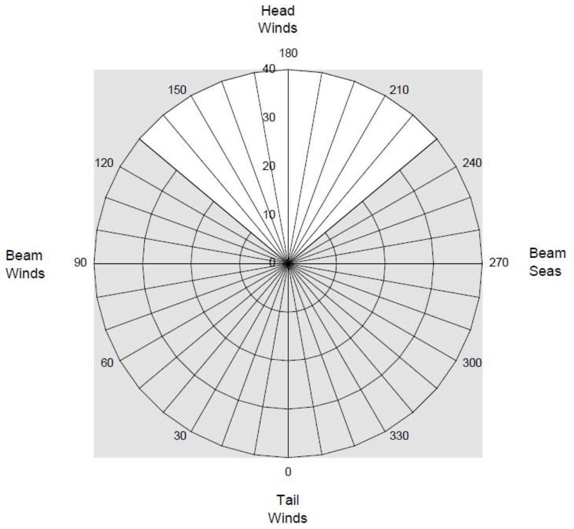

Figure 11: Generic Helicopter Relative Wind Envelope

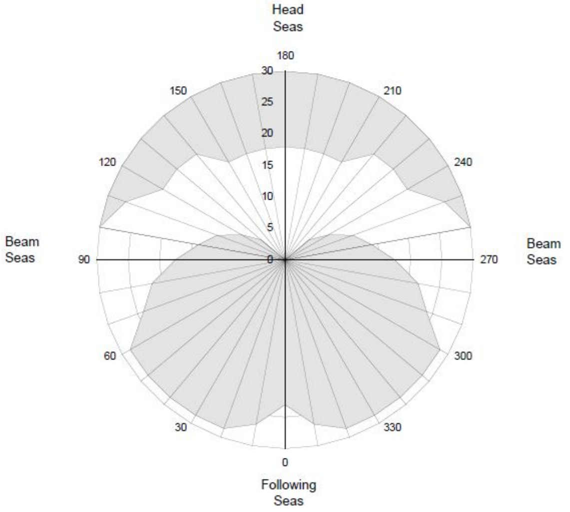

Figure 12: Generic Helicopter Wind Operating Envelope for Sea State 5 with Mean Ambient Wind of 22 knots

During the time since writing of the NATO seakeeping standard [7], computational methods have been developed to determine the effects of various ship topside design features upon the ship's air wake, and in particular various features of the air flow over the flight deck as an incoming aircraft would encounter it. This includes combinations of turbulence, downwash and shear flow for different ship speeds and headings relative to the ambient wind. Aircraft aerodynamics have been coupled to the ship's air wake in such a way that control margins and variances, and thus pilot workload, can be predicted. Model tests have been used to check the results and to help refine the computational methods. Though more work needs to be done to validate the methods, the results have been used successfully in flight simulators to predict the relative wind envelopes for a few new combinations of aircraft and ships, even in early design stages before physical models were built and tested.

Since 2002, three successive research task groups from the NATO Applied Vehicle Technology (AVT) Panel have assessed various aspects of the evolving science and technology of aircraft launch and recovery in a ship air wake environment. The third of these, NATO RTG AVT-217, completed its program of work in December 2015, and submitted a technical report on *Modeling and Simulation of the Effects of Ship Design on Helicopter Launch and Recovery* [9] to the NATO Collaboration Support Office for final editing before publication. The focus of this work was on critical technical areas where details of ship design would affect the performance of helicopter launch and recovery from a flight deck at the stern of the ship. Critical technical areas included:

- Air wake – an evaluation of the methods available to compute features of the air flow behind the ship superstructure and its interaction with the aerodynamics of the helicopter, including shear flow, downwash and turbulence. As to the design of the superstructure, for the methods used, it is possible to model the shape of the deckhouse and all appendages including antennas, stacks, and weapon systems. It is also possible to evaluate flow control devices such as turning vanes and fences.
- Anemometer placement – an assessment of the methods employed to locate anemometers on the ship superstructure in order to reliably determine relative wind speed and direction for helicopter operations.
- Ship exhaust – an evaluation of the effects of stack gas, including increases in temperature, on power margins in the helicopter and ways to mitigate the effect by better placement and design of stacks and possible redirection of the gas plume.
- Ship motion – an assessment of the ability to predict the motions of the flight deck and their effects on launch and recovery of different combinations helicopters and ships.

The NATO RTG AVT-217 technical report also included an assessment of the capability to incorporate the findings of each of the critical technical areas into integrated modeling and simulation of the effects of ship design on the launch and recovery of helicopters. Once the final draft of the technical report is approved for release to NATO nations, it will be used to prepare an Allied Naval Engineering Publication (ANEP) on ship design guidance for safe launch and recovery of helicopters. The ANEP will supplement guidance presented in the NATO seakeeping standard [7] in order to refine the flight deck wind and motion limits for a variety of new aircraft and ship combinations.

APPLICATION OF MODELLING AND SIMULATION

Modelling and simulation (M&S) can be very useful when designing ships that will perform launch and recovery operations. The maturity of available tools depends largely on the complexity of phenomena being investigated.

M&S for Ship Motions

Ship motion predictions are routinely performed to support ship design and operation. When applying ship motion predictions to ships performing launch and recovery, the complexities of ship motions are somewhat simplified because operational conditions normally dictate relatively small forward speed Froude numbers (e.g., $U/\sqrt{g\,L} < 0.2$, where U is ship forward speed, g is gravitational acceleration, and L is ship length between perpendiculars) and moderate wave conditions (e.g., significant wave height rarely exceeds 7 m).

Frequency domain strip theory [10] is widely used and gives good results for slender ships (e.g., length-to-beam ratio $L/B > 6$) in typical launch and recovery conditions. For non-slender ships, three-dimensional methods for predicting hull forces [11] will give noticeably better motion predictions than strip theory. Due to challenges predicting viscous roll damping, vertical plane motions are easier to predict than lateral plane motions [12].

M&S for Relative Vertical Motions between Ship and Ocean Surface

Relative motions between the ship and the ocean surface have a profound influence on launch and recovery of waterborne objects. For side launch and recovery, relative motions are a major driver for locating launch and recovery systems near midships. For stern launch and recovery, experience has shown that operations with longer vessels can be challenging due to high relative motions at the stern.

When evaluating relative motions at a location on a ship, it is common practice to consider the rigid-body ship motions and incident waves, but to ignore the radiated and diffracted waves caused by the motions and presence of the ship. Beck and Loken [13] provide insight into the influence of radiation and diffraction on relative motions. The current high level of interest in launch and recovery will likely stimulate new work examining relative motions in greater detail. Note that many ship motion prediction methods use simplifying assumptions when modelling the influence of ship forward speed on the free surface. Although these simplifying assumptions are quite acceptable for predicting ship rigid-body motions at moderate forward speed, their adverse influence on relative motion predictions are likely more pronounced.

Multi-body Simulation

Capabilities continue to progress for simulating multi-body complex systems, such as launch and recovery of an object from a ship. Complex physical phenomena can be modelled, including hydrodynamic interactions and collisions between entities. Henry, McTaggart, de Kraker, and Duncan [14] describe a simulation of a launch and recovery system for a NATO submarine rescue vehicle which is deployed from the stern of a ship using an A-frame. Söding and Reppenhagen [15], McTaggart, Roy, Steinke, Nicoll, and Perrault [16], and Carette [17] describe simulations of launch and recovery from the side of ships.

Multi-body simulation presents various challenges, including the interoperability of various simulation entities. Validation of multi-body simulations is challenging, with the transient nature of launch and recovery being a contributing factor. Fortunately, progress continues to be made due to the high priority of launch and recovery work among navies. Figure 13 shows a recent simulation of a RHIB being launched from a frigate. Multi-body simulations can provide insight into various phenomena, including crane loads and RHIB motions.

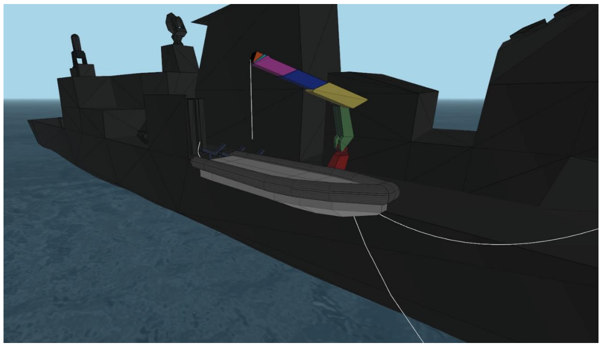

Figure 13: Simulation of RHIB Being Launch from a Frigate

M&S for Air Vehicle Launch and Recovery

The NATO AVT-217 Technical Report [9] discusses the state-of-the-art in modeling and simulation of manned and unmanned helicopter launch and recovery, and how it is being used to offer ship design guidance. M&S provides the designer with the potential capability to evaluate a new ship design in terms of its impact on the aircraft and pilot workload, including the effects of air wake, ship exhaust and ship motion.

Many different types of ship-aircraft simulations exist, including computational, experimental and flight simulation methods. These methods are at varying stages of development and verification and require different levels of resources (computational, temporal, and financial) to execute them.

M&S can be used as a risk reduction tool for ship design by identifying potential problems for aircraft operations prior to ship build. Currently, the available tools can inform the design process when used as part of an iterative design cycle. For example, comparative analysis of a new platform compared to an existing platform can be used to estimate whether an improvement to the air wake has been achieved with a certain design change.

Post ship build, simulation can be used to identify limiting wind conditions to potentially reduce the time required for Ship-Helicopter Operating Limits (SHOL) testing. Although this process has yet to be fully validated, it could be used in the near-term to inform the SHOL process and assist in test planning.

CONCLUDING REMARKS

The NATO Seaway Mobility Specialist Team continues its efforts to develop a new standard to ensure that ships are able to support launch and recovery operations throughout their lives. These efforts will be supported by experiences shared by others and also by new work, including application of modelling and simulation. Ongoing dialogue with the naval launch and recovery community will be essential during development of the new standard.

REFERENCES

[1] F.G.J. Kremer and E.H. Takken. Development overview of a launch and recovery system standardization. In *Launch and Recovery Symposium 2014*, Linthicum, Maryland, 2014.

[2] M. Haycock. Overview of launch and recovery onboard U.S. Coast Guard cutters: Requirements, state-of-the-art and future developments. In *Launch and Recovery Symposium 2014*, Linthicum, Maryland, 2014.

[3] C. Cleary. In-service launch and recovery panel discussion. In *Launch and Recovery Symposium 2014*, Linthicum, Maryland, 2014.

[4] R. Sheinberg, P. Minnich, T. Beukema, W. Kauczynski, A. Silver, and C. Cleary. Stern boat deployment systems and operability. *Transactions, Society of Naval Architects and Marine Engineers*, 111:1–32, 2003.

[5] R. Sheinberg, R. Bachman, C. Cleary, F. DeBord, W.L. Thomas, J. St. John, and S. Minnich. Operational evaluation of stern boat deployment systems. *Transactions, Society of Naval Architects and Marine Engineers*, 118:222–243, 2010.

[6] R. Langlois and P. Keary. Methodology for ensuring safety of an embarked helicopter securing system probe installation. In *Congress of the International Congress of Aeronautical Sciences*, Toronto, Canada, 2002.

[7] North Atlantic Treaty Organization. *Common Procedures for Seakeeping in the Ship Design Process*, 2000. Standardization Agreement No. 4154, Edition 3.

[8] E.N. Comstock, S.L. Bales, and D.M. Gentile. Seakeeping performance comparison of air capable ships. *Naval Engineers Journal*, 94(2):101–117, April 1982.

[9] North Atlantic Treaty Organization STO-TR-AVT-217. *Modeling and Simulation of the Effects of Ship Design on Helicopter Launch and Recovery.* In final editing.

[10] N. Salvesen, E.O. Tuck, and O. Faltinsen. Ship motions and sea loads. *Transactions, Society of Naval Architects and Marine Engineers*, 78:250–287, 1970.

[11] A.D. Papanikolaou and T.E. Schellin. A three-dimensional panel method for motions and loads of ships with forward speed. *Schiffstechnik (Ship Technology Research)*, 39(4):147–156, 1992.

[12] K.A. McTaggart. Verification and validation of ShipMo3D ship motion predictions in the time and frequency domains. In *International Towing Tank Conference Workshop on Seakeeping: Verification and Validation for Non-liFar Seakeeping Analysis*, Seoul, Korea, 2010.

[13] R.F. Beck and A.E. Loken. Three-dimensional effects in ship relative-motion problems. *Journal of Ship Research*, 33(4):261–268, December 1989.

[14] G. Henry, K. McTaggart, K. J. de Kraker, and J. Duncan. NATO virtual ships standards. In *SimTecT 2008*, Melbourne, Australia, 2008.

[15] H. Söding and M. Reppenhagen. Simulation of boat launching and hoisting in a seaway. In *27th International Conference on Offshore Mechanics and Arctic Engineering*, volume 6, pages 89–97, Estoril, Portugal, 2008.

[16] K. McTaggart, A. Roy, D. Steinke, R. Nicoll, and D. Perrault. Simulation of small boat launch and recovery from a ship with a crane. In *Launch and Recovery Symposium 2012*, Linthicum, Maryland, 2012.

[17] N. Carette. Model tests and time domain simulations for launch and recovery systems with manned and unmanned vehicle. In *Launch and Recovery Symposium 2014*, Linthicum, Maryland, 2014.

AUTHOR BIOGRAPHIES

Kevin McTaggart is a Defence Scientist at Defence Research and Development Canada. He has a Ph.D. in civil engineering from the University of British Columbia. His research interests include ship motions in waves, ship maneuvering, and distributed simulation of ship systems. He chairs the NATO Seaway Mobility Specialist Team, which is producing standards for ship maneuvering, seakeeping, and ship design for launch and recovery.

Sietske Hendriks is a hydromechanical engineer at the Dutch Defense Materiel Organisation. She graduated with a master of science in maritime technology from the Technical University of Delft. Her work includes research on ship motions in waves, including fast small planing craft and launch and recovery. She is the national delegate to the NATO Seaway Mobility Specialist Team and is a member of JIP LAURA.

Ian Nimmo-Smith Ian Nimmo-Smith is a naval architect with the United Kingdom Ministry of Defence. He works in the Naval Authority Group providing technical assurance for construction, stability and hydrodynamics to the Royal Navy and wider defence community. He has masters degrees in civil engineering and naval architecture and is the UK delegate to the NATO Seaway Mobility Specialist Team.

Arild Øydegard is the head of the Naval Architecture Section in Norwegian Defence Material Agency. He has a bachelor's degree in military technology from the Royal Norwegian Naval Academy and master's degree in marine hydrodynamics from the Norwegian University of Science and Technology. He is the Norwegian delegate to the NATO Seaway Mobility Specialist Team.

John Pattison is a senior scientist and engineer part time with BAI Incorporated in Alexandria, Virginia, USA. In 2003, he retired from the Naval Sea Systems Command where he was the director of ship hydrodynamics technology. Since then, he has consulted with the Office of Naval Research in their work with the NATO Applied Vehicle Technology Panel in evaluations of the science and technology for shipboard aircraft operations.

Norbert Stuntz is head of the hydrodynamic branch at the Bundeswehr Technical Center of the German Ministry of Defence. He is responsible for the hydrodynamic aspects of the German Navy ships from initial design to end of life.