Capable, Adaptable, Flexible: The Design of a Cost-Effective Naval Platform with Focus on the Increasing Use of Off-Board Assets

Richard Irvine, CEng, MRINA

Babcock International, Bristol, UK
Corresponding author email: richard.irvine@babcockinternational.com

Synopsis

In many areas in the innovation of remote and autonomous systems, miniaturisation is leading to a huge increase in the available range of devices and their prevalence in everyday life. In Defence and particularly the naval domain however, the key area of progression is in the opposing direction. Rather than miniaturising, the remote and autonomous systems used in Defence are getting progressively larger in order to provide for increased payload, range and endurance.

Navies may often find that they require their platforms to have the ability to cater for both large and small remote and autonomous systems, while also catering for the traditional operations of the navy with use of organic boats and helicopters. Such platforms, with the ability to support an increasingly wide variety of these off-board assets, will be significant for navies in increasing their capability and diversifying into different roles.

With provision of sufficient allowances in the design, an adaptable design has the ability to be customised in its configuration. A flexible design has the ability to be reconfigured to fulfil a variety of roles, including those that utilise off-board assets. Allowances are also desirable to enable accommodation of future capability of unknown future high-tech systems so that the navies are able to maintain and increase a strategic technological advantage.

This paper examines some of the aspects relevant to operating off-board assets in the design of a cost-effective naval platform that is capable, adaptable and flexible. Particular focus is given to the development of a hullform, seakeeping, general arrangement issues, upper deck arrangements, mission spaces, payload areas, the launch/recovery systems and interfaces.

Keywords: Unmanned; Off-Board; Launch; Recovery; Hullform

1. Introduction

The design of a naval platform must be cognisant of the range of Off-Board Systems (OBS) that will be available through the operating life of the vessel. Likewise, the design of an Unmanned Vehicle (UxV) for operating off (and onto) a naval platform must be cognisant of the constraints that a naval platform may provide.

In the coming decades there is likely to be a significant shift towards optionally manned or unmanned aircraft operating from naval platforms [1]. In addition, the use of tactical Unmanned Air Vehicles (UAV) will continue to increase to provide Intelligence, Surveillance, and Reconnaissance (ISR) as well as providing small tactical ordnance delivery capability [1]. Similar trends are likely with Unmanned Maritime Systems (UMS), above and below water.

This paper looks at trends in UxV development, their Launch and Recovery System (LARS) requirements, and the implications on the naval architecture and hullform design of moderately sized naval platforms such as OPVs, MCMVs, frigates and destroyers.

2. Historical and Modern-Era UAVs

Effective UAVs have operated from naval ships since the early 1960's. The Gyrodyne QH-50 DASH (Drone Anti-Submarine Helicopter) was an effective Vertical Take-Off and Landing (VTOL) UAV specifically designed for operating from ships with relatively small flight decks, providing long range Anti-Submarine Warfare (ASW) capability (conceived to deliver a nuclear depth bomb). The initial pre-production model QH-50A, as shown in Figure 1, was a co-axial unmanned helicopter capable of carrying a single homing torpedo. The production model QH-50C had a more power-dense engine and therefore capable of carrying two torpedoes. Unfortunately, despite hundreds of QH-50C being built, the limited range of sonar detection aboard the ships did not justify the need for such off-board capability at range.

The later QH-50D was however yet more capable and now enabled the deployment of sono-buoys and depth charges, therefore dramatically increasing the ship's influence. Other payloads were fitted to variants of the QH-50D including trainable minigun, real-time trainable reconnaissance camera and over-the-horizon radar.

Author's Biography
Richard Irvine is a Principal Naval Architect at Babcock International and works within the Concept Design Team on both concept ships and on the further development of innovative new ship designs. Richard has previously been naval architecture design authority for the Al Shamikh Class Corvette and has been a Principal Hydrodynamicist for Vosper Thornycroft with contribution to the design, development and evaluation of vessels including the Dauntless Class Destroyer and the Queen Elizabeth Class Aircraft Carrier.

http://doi.org/10.24868/issn.2515-818X.2018.068

Since the DASH there have been few UAVs designed specifically for naval operations. One of the primary successors to the DASH is the Northrop Grumman Fire Scout, as shown in Figure 2, which adopts a helicopter airframe (Bell 407). With military ambitions for larger UAVs to provide for increased payload, range and endurance, the adoption of helicopter airframes for UAVs is likely to continue.

Figure 1: Gyrodyne QH-50A DASH, 1961
(Credit: U.S. Navy)

Figure 2: Northrop Grumman Fire Scout MQ-8C
(Credit: U.S. Navy)

As modern-era UAV uptake and development continues it is anticipated that a substantial area of growth will be in optionally manned aircraft [1]. Platforms already operating organic helicopters may see these replaced with, or upgraded to, optionally piloted variants. This will undoubtedly increase capability with reduced threat to personnel, but also increase support requirements that should be integrated at an early stage of platform design.

At the opposite end of the scale, micro/nano UAVs are becoming much more prolific. As they tend to only offer low altitude short range (line-of-sight) capability their use is more commonly associated with army operations. Micro/nano single-rotor, co-axial rotor and multi-rotor (e.g. quadcopter) UAVs are simple to operate and, in terms of Space Weight and Power (SWaP) provision, the platform integration requirements are almost negligible for such small devices. Even a swarm launch of fixed-wing micro/nano UAVs for offensive or defensive operations would require limited SWaP provision for the launcher system in comparison to other shipborne effectors.

The benefit of VTOL UAVs (single or multi rotor), of any size, is that they can be readily launched and recovered from a standard helideck; if not a more confined space. Most VTOL UAVs are however very limited in payload, range and endurance. To provide range and endurance for ISR navies currently adopt fixed-wing UAVs which require some form of 'fling and snatch' LARS arrangement. The stowage requirement for the LARS equipment often exceeds that of the UAV, and the manning requirements to rig/derig for each evolution are significant. LARS equipment for fixed-wing UAVs include [2]:

Launching:	Recovery:
- Rocket Assist	- Net (as shown in Figure 3)
- Bungee Cord Catapult	- Arrestor line
- Hydraulic Rail	- Skyhook
- Pneumatic Rail	- Windsock
- Parasail	- Parasail

Figure 3: Net Recovery of Pioneer Fixed-Wing UAV (Credit: U.S. Navy)

3. Future UAVs

3.1. Fixed-Wing VTOL

An area of development that will significantly benefit the naval domain by enabling fixed-wing take-off and landing from a confined space, without need for additional LARS equipment, is fixed-wing VTOL. Two distinct areas being developed are ‘tiltrotors’ (such as the Bell HV-911 Eagle Eye, Bell V-247 Vigilant and NASA Greased Lightning GL-10; as shown in Figure 4) and ‘tail-sitters’ (such as Northrop Grumman TERN; as shown in Figure 5). Combined with auto landing systems, adoption of these types of UAVs will reduce preventable loss or damage to UAVs that can commonly occur during snatch recovery of a conventional fixed-wing UAV.

The development of fixed-wing VTOL UAVs will aim to provide increased payload, range and endurance; and potentially replace fixed-wing tactical ISR vehicles, thereby offering freedom from cumbersome LARS equipment for UAVs.

Figure 4: NASA Greased Lightning GL-10
(Credit: U.S. NASA)

Figure 5: Northrop Grumman TERN
(Credit: U.S. DARPA)

3.2. Multi-Environment UxVs

UxV are by and large, in terms of operating environment, distinctly categorised as: Air (UAV/UAS); Sea Surface (USV); Underwater (UUV); or Land/Ground (UGV/UGS). However, there is growing focus on combining operating environments either by combining UxVs in a System of Systems (SoS), e.g. a UUV launched from a USV, or by providing a UxV with multi-environment capability.

Examples of multi-environment UxVs include amphibious vehicles; marine recoverable UAVs (with water landing capability); aquatic UAVs (with water take-off and landing capability); and submersible UAVs (unmanned vehicle able to navigate both in flight and submersed) such as the ‘Naviator’, as shown in Figure 6, developed by Rutgers University. Benefits brought by these UxVs include reduced susceptibility to damage in the marine environment and the ability to retrieve the vehicle from the water without need for snatch recovery.

Figure 6: Naviator Submersible UAV (Credit: U.S. Navy)

4. Unmanned Maritime Systems (UMS)

USVs may be utilised for a wide variety of operations. Many small units, less than 5m in length, are utilised in operations requiring a moderate sensor payload such as for oceanography, ISR, Mine Countermeasure (MCM) detection, ASW detection, diver detection and communication relay. Larger USVs may engage in heavier payload tasks that include deployment of sensors, ordnances and/or UUVs (SoS). USVs that may be practical to operate from naval vessels tend to go up to around 12m in length and 12 tonnes displacement, such as Atlas Electronik ARCIMS, Thales Halcyon, ASV C-Sweep and Elbit Seagull. Larger USVs much above this become increasingly impractical to operate from moderately sized naval platforms and tend to have better range, making them more suitable to operate as a separate platform independent from a naval ship.

UUVs are used for a diverse range of tasks including oceanography, ISR, ASW, MCM, swimmer delivery and underwater inspection and maintenance. UUVs are generally torpedo shaped 'gliders' wherever there is a need to transit away from the launch/recovery location, as shown in Figure 7. Sizes of UUVs vary significantly depending on the payload range and endurance required for the operation. A significant payload such as swimmer delivery, ordnance delivery or delivery of other UxVs in a SoS may drive the size of a UUV up to as much as 7m in length and 4 tonne displacement. Larger UUVs are less prevalent but may need consideration in the platform design and provision of LARS.

Figure 7: RRS Discovery with 'Glider' Marine Autonomous Systems
(Credit: National Oceanography Centre [3])

The normal operating transit speed of a UUV, optimised for range and/or endurance, may only be somewhere between 2 and 6 knots. For some UUVs a boost speed may be in the region of 10 to 12 knots. The relative low speed of UUVs makes recovery by a naval platform particularly difficult when sea conditions are unfavourable.

Typical mechanical methods for launch and recovery of UMS are with a crane, davit or stern ramp. Although davits, cranes and stern ramps are well proven as LARS for manned boats, their use with UMS is often hindered by the unmanned connection methods. For recovery of UMS the lack of a crew member aboard the vessel under recovery to enable hooking-on means that an alternative engagement method is required. As expressed by Alldis at INEC 2016 [4], 'the lack of efficient launch and recovery of USVs … must be solved if USVs are to be an adaptable, active addition to a navy'. Unmanned connection methods for UMS include the following [2]. All of these methods are relatively simple in theory; less so while in a seaway and in the dark:

- Direct lift onto USV, manned boat or naval platform at sea level (if man-portable UMS)
- 2-axis or 3-axis mechanical davit, with mating connector on UMS
- Catch-pole mechanism (in cradle/sledge or on stern ramp), with catch-hook on UMS
- Funnelled receiver (in cradle/sledge), with probe on UMS
- Lasso line with catch-hook on UMS
- Tether connection (sometimes aided by boat-hook), with catch-hook on UMS

Adoption of stern ramps for littoral waters is increasing as their use becomes proven in naval operations and lessons are learnt. The adoption of stern ramps on large naval platforms is however particularly slow; partially because the operating environment is more blue water, and with a larger ship the wave induced motion of the mother craft and daughter craft differ substantially. Notable naval platforms with stern ramps include USN Freedom class, RNLN Holland Class, and RDN Knud Rasmussen Class [5].

With a tethered recovery of a UUV, USV or manned boat on to a stern ramp, the vehicle under recovery may want to maintain steerage and control while under approach. For this the author suggests the use of an active compensating winch to maintain tension-only on the recovery wire until the vehicle is within the 'recovery zone', i.e. the zone where the most significant stern wave and aerated water will affect the vehicle seakeeping and powering (usually within 10m of the transom).

It has previously been suggested by Morrow [5] that what is required is a connection from the recovering vessel that is stable in the reference frame of the vessel under recovery. The aforementioned author was referring to a 3-axis mechanical connection from the recovering vessel, which in this author's opinion may be highly effective but also relatively complex and expensive. Although the payload may be cumbersome, it is conceivable that in the future a multi-rotor UAV may perform the connection task, station-keeping with the vehicle under recovery, delivering a 'drogue' line that connects to a probe on the vessel before initiating recovery.

5. General Arrangement of Naval Platform for OBS

There is an increasing tendency for moderately sized naval platforms to be specified with capabilities that are to be provided by UxVs, sometimes as core assets but more often as embarked assets or future upgrades. The design of the vessel must be capable of accommodating the most onerous payload as well as being flexible for utilising the same spaces, and LARS, to operate alternative OBS (as otherwise dedicated spaces would be redundant for much of the time). For the purposes of this paper an assumed realistic future fit for a frigate is shown in Table 1, with the resulting practical arrangement of the most onerous payload shown in Figure 8.

	OBS Type	OBS Description	Quantity	SWaP requirements	LARS requirements
AIR	UAV	VTOL Single-Rotor (heavy payload)	1	10.5m x 2m (2.75t)	Flight Deck
	UAV	VTOL Multi-Rotor Octocopter (line-of-site)	1	1.2m x 1.2m (16kg incl. payload)	Open Deck Area
	UAV	Fixed-Wing VTOL	1	15m x 4m (8t) Lilly-pad landing or embarked in lieu of organic helo	Flight Desk
	UAV	Fixed-Wing ISR	1	2m x 1.5m (1t) (folded, stowed with LARS)	Flight Deck
	Helicopter	Organic Helicopter (manned or optionally manned)	1	13.5m x 3m (6t)	Flight Deck
SEA SURFACE	USV	Small USV	1	3m x 1.25m (500kg) stored on mezzanine	Engage at moderate speed
	Manned Boat	Organic Safety Boat	1	8m x 2.75m (3.5t)	Engage at moderate speed
	Manned Boat	Mission Ops Boat	2*	11.5m x 3.25m (8.5t) *(embarked in lieu of Large USVs)	Engage at moderate speed
	USV	Large USV (SoS) (optionally manned)	2*	11.5m x 3.6m (12t) *(embarked in lieu of manned boats)	Engage at moderate speed
SUBSEA	UUV	Man-Portable Glider	3	125cm x 15cm (20kg) stored on mezzanine	Engage at low speed
	UUV	UUV Glider (sensor payload)	1	4m x 1m (1.25t) stored on mezzanine	Engage at low speed
	UUV	Swimmer Delivery Vehicle (SDV)	1	7.5m x 2m (3.5t) embarked in lieu of Large USV	Engage at low speed
	N.A.	20ft TEU Containers	2	6.0m x 2.5m (15t)	N.A.

Table 1: Summary of an OBS Requirement Set for a Frigate Design

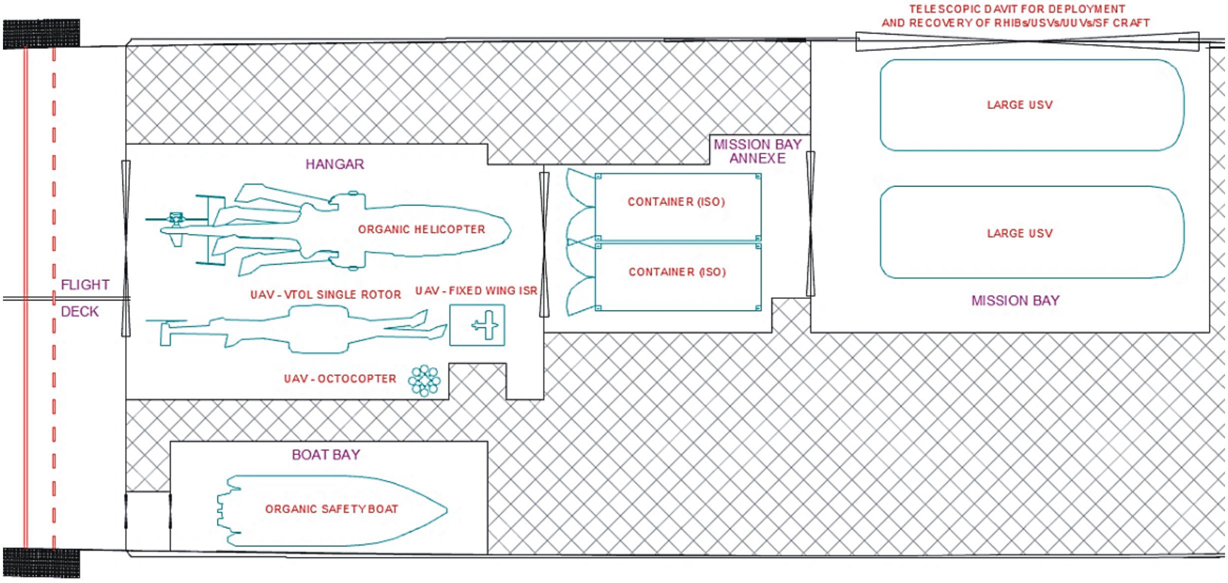

Figure 8: Realistic Example Arrangement of OBS for a Frigate Design – 1-Deck (Arrowhead 120)
(OBS as listed in Table 1)

Oceanographic research vessels will typically launch/recover OBS from working decks at heights not exceeding 4m above the waterline, established as an ideal height through practical experience. Naval vessels, with hostile damage survivability requirements, cannot readily provide large externally opening mission spaces at such low levels (below the damage control deck). Radical designs may emerge to overcome this issue, however what is likely to happen in the author's opinion is the emergence of two ship types; traditional naval platforms with a pragmatic extent of compromise for the adoption of UxVs (which this paper explores further) and stand-off support vessels dedicated to the transportation of UxVs.

Support ships such as HNLMS Karel Doorman, as shown in Figure 9, can deliver substantial off-board capability with the provision of a flight deck, a well-dock and side davits under the flight deck; but this is a very large amphibious warfare ship that also provides substantial lane metres for transporting land vehicles and accommodation for troops. Stand-off support ships dedicated for unmanned warfare may be significantly smaller; perhaps more akin to SD Northern River chartered by the UK Royal Navy, as shown in Figure 10.


Figure 9: HNLMS Karel Doorman (Credit: Kees Torn [6])


Figure 10: SD Northern River (Credit: Mark Harkin [7])

Similar allocation of off-board assets onto support ships is already well established in the superyacht industry whereby those seeking the ultimate in luxury can have an uncompromised palatial yacht followed by a bespoke support vessel for the crew and effects (helicopter, mini sub, jet skis, speed boat, ski boat, tender, etc). In the military domain support vessels operate as naval auxiliaries and therefore, in order to deliver the off-board assets directly into a hostile area, the vessel may need to be entirely unmanned and fitted with substantial defence countermeasures.

In the present and near future, however, for moderately sized naval platforms the survivability requirements push the mission space high within the hull, and hence, coupled with aviation requirement for organic helicopter and/or UAVs, the ubiquitous midship mission bay emerges. Additional mission space is provided at the stern with a ramp. The stern mission space is however limited in length by the need to provide aft buoyancy, again for hostile damage survivability requirements, and limited in height in order to accommodate a flight deck above. The location of these mission areas drive up the overall VCG of the platform and increase the wind profile, which places additional demands on platform design in terms of stability. The need for greater stability, in addition to increased payload, inevitably results in the design of a hullform that is beamier and more voluminous; however still operationally required to have a relatively fast top speed. With many of these design requirements conflicting with one another, demanding so much from a platform without compromise ultimately results in a design become larger, more complex and exorbitantly more expensive. The key decision that navies need to make is, if they wish to constrain budgets, which platforms should accommodate which UxVs and what compromises may be made?

6. Hullform Design for LARS

With the increasing demand for greater payload and launch and recovery of UxVs, Babcock embarked on a two year hullform development programme with MARIN, generating the 'Arrowhead 120' design as a basis for Babcock's 120m frigate design (as shown in Figure 11). Priority was placed on through life costs (e.g. fuel efficiency) and provision of a stable platform for launch/recovery of OBS.

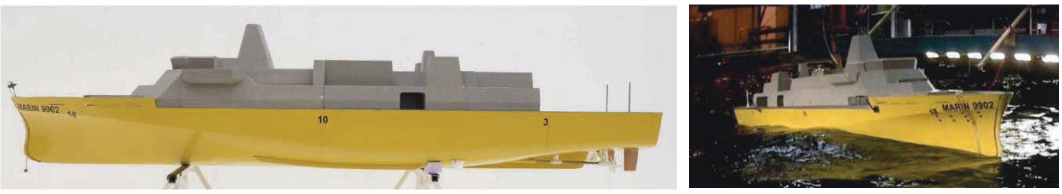
Figure 11: Arrowhead 120 Seakeeping Model in MARIN Seakeeping and Manoeuvring Basin, Wageningen

In developing a hullform for a naval platform there are two fundamental areas considered for LARS. Firstly, in order to provide a stern ramp there is need to provide just enough transom immersion depth for the stern ramp sill in the lightest seagoing condition, but not so much that may then cause significant detriment to resistance at high speed. The second area of consideration is the general seakeeping characteristics. L, B and GMT are balanced to: provide the internal volume and deck space for helicopter, boats, and UxVs; provide suitable stability and seakeeping characteristics; and maintain adequate speed and manoeuvrability characteristics.

Numerous design iterations were assessed, including bow designs with and without bulbous bow. The use of CFD allows fast exploration of variants. Systematic variations of a bulbous bow design were explored, with 5 lengths, 5 widths and 5 heights considered (125 variants in all). For this hullform the width parameter was found to be most significant with a narrow bulb most beneficial for slow speed wave pattern, and a wider bulb most beneficial for high speed wave pattern.

As this design has been developed independent of a customer and not influenced by explicit requirements, the priorities were set for good seakeeping and efficiency based on a conservative speed profile. In other words, the design would not be overtly compromised in order to provide marginal gain on top speed capability. A narrow bulb was therefore considered to provide better overall performance compared to other bulb designs.

Starting with an overall ship length constrained to circa 120m, in order to maintain the vessel operating at top speed in the region of Froude 0.35, it was chosen to have a high LOA/LWL ratio. Operating much above this would be increasingly ineffective as a disproportionate increase in power would be required to enable a small incremental increase in speed.

Following optimisation, the hullform incorporating bulbous bow was found to have only a marginal benefit (circa 2%) in terms of total resistance at low speeds, and comparable to the design without bulb at high speed. In order to provide improved seakeeping the design without bulb was taken forward for development. Characteristics include a fine angle of entry, hard chine and bow flare at around 2m above waterline, and moderate aftship deadrise to reduce stern slamming. The choice to prioritise seakeeping above top speed has not been particularly detrimental as seen by comparison of Admiralty Coefficients (used as a simplistic efficiency measure), as shown in Figure 12. This is probably due to early stage incorporation of hull characteristics and appendage features for an optimal design in terms of arrangement, seakeeping and OBS launch/recovery, thus allowing further effort to be concentrated on optimisation for resistance.

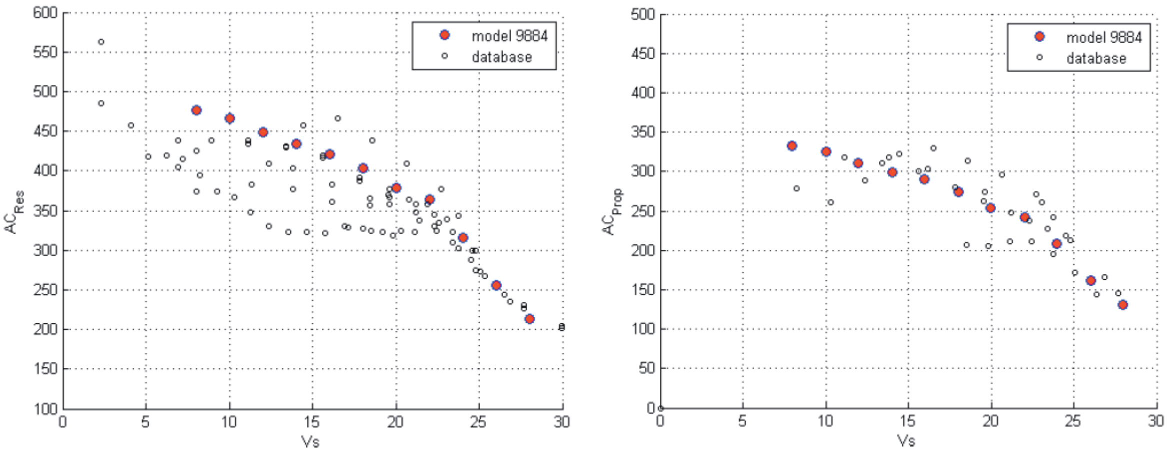

Figure 12: Comparison of Admirality Coefficient (Resistance and Propulsive) against Similar Vessels

Through various iterations of CFD and tank testing of the hullform, the wave elevation along the hull was estimated at both low speeds (8 to 12 knots) and high speeds (18 to 28 knots), as shown in Figure 13. It was important to ensure that any design iterations (e.g. for appendage optimisation) did not have any significant detrimental effect upon the ships wake for wave making resistance and for side/stern LARS. This was also carried out in order to help inform future development and tank testing that will concentrate in detail on the stern ramp integration and LARS.

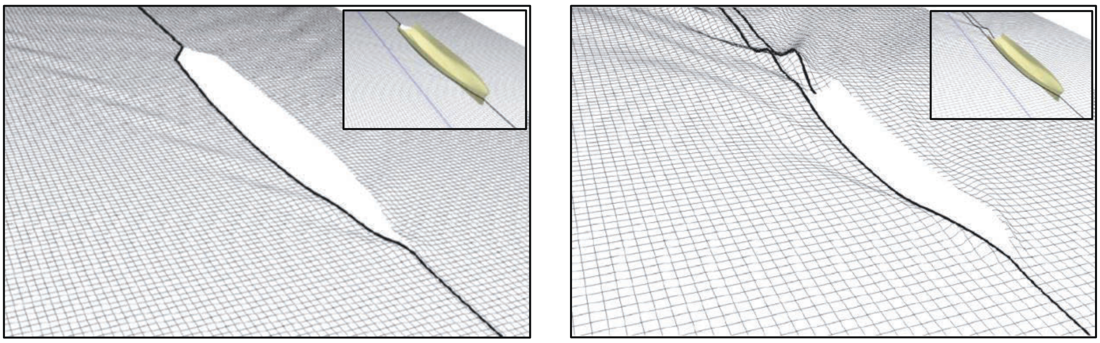

Figure 13: Comparison of CFD Predicted 3D Wave Patterns at 12 knots (left) and 24 knots (right)
(3D wave heights magnified 2.5 times for visualisation)

Results derived indicate that wave heights in way of the stern launch/recovery position are minimal at the optimal speeds for OBS launch/recovery (i.e. 6 to 8 knots), as shown for stern of transom in Figure 14. It is also clear to see, from tank test observation and measurements (as shown in Figure 15) that at higher speeds (particularly above 12 knots), as flow separation at the transom increases, higher stern waves will impair the ability to recover utilising a stern LARS arrangement; therefore limitation on speed of the vessel is essential during recovery regardless of the speed capability of the OBS. Side LARS is less effected by the hull generated waves; and can therefore operate at moderately higher speeds, however other aspects must be taken in consideration such as seakeeping (mention in following section) and the suction effect of the two bodies transiting in parallel.

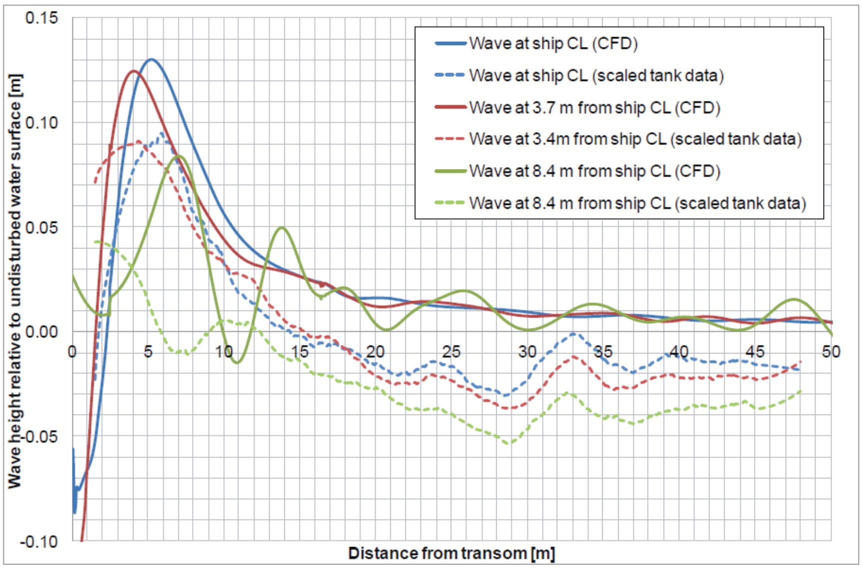

Figure 14: Comparison of CFD and Tank Testing Stern Wave Heights at 8 knots

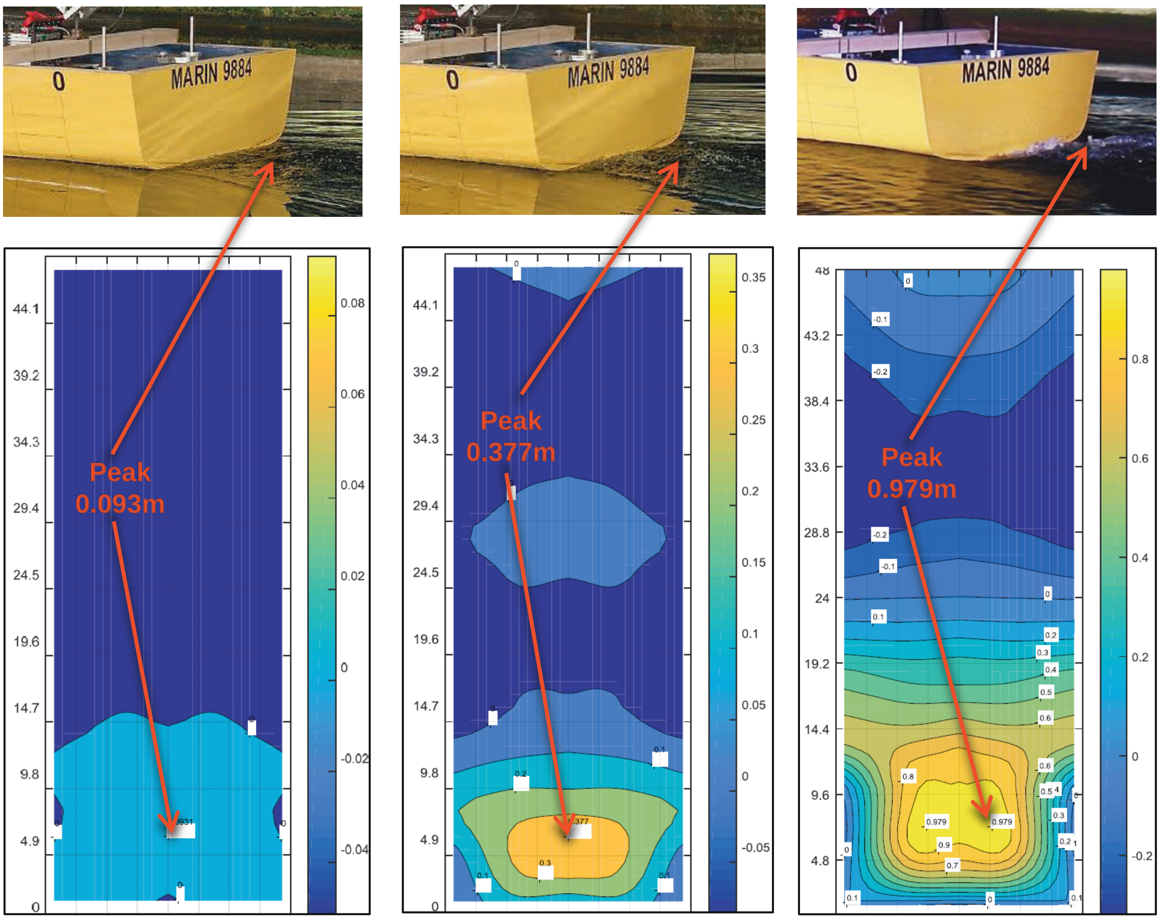

Figure 15: Photographs and Comparison of Measured Tank Testing Stern Wave Height Contours
at 8 knots (left), 12 knots (centre) and 18 knots (right);
distance [m] from transom indicated left of contour plots;
wave height [m] relative to undisturbed water surface (scale) indicated right of contour plots (n.b. with differing scales)

Both active and passive methods have been considered for influencing the wake pattern and further improving the stern wake in order to increase the operability of a stern LARS arrangement. As a passive method the use of a stern hydrofoil, such as the Hullvane® retrofitted to RNLN Holland Class [8], may significantly improve the stern wake. The stern hydrofoil also provides some pitch damping that adds to seakeeping capability. In the appendage optimisation of ‘Arrowhead 120’ it was determined that a stern wedge was of no benefit with the operating profile assumed. Without a stern wedge the design will therefore be able to accommodate a stern hydrofoil with maximum effect [8], either in-build or as retrofit, without any modification to the hull geometry.

As an active method, in order to postpone the flow separation at the transom and to prevent stagnant and reverse flow (i.e. eddies) in way of the stern ramp opening, a High Pressure Sea Water (HPSW) deluge system washes down the stern ramp; a system that will be investigated further in the stern ramp optimisation phase. This will prevent the transom and stern ramp sill from running dry, which could otherwise result in excessive impact between the UUV, USV or manned boat on recovery.

7. SEAKEEPING FOR LARS

Seakeeping capability at LARS locations has been assessed using a combination of STANAG criteria for RMS Roll and RMS Pitch along with USCG criteria for Accelerations in Y-axis and Z-axis. Only slow ship speed (6 knots) has been fully assessed as it has already been determined as the most likely operating condition for safe OBS recovery. Against these criteria the use of side LARS and stern LARS are both within limits for most headings in upper Sea State 5 except for bow and bow-quartering seas, where the vertical accelerations exceed the guideline criteria, as shown in Figure 16. In the author’s opinion this is a very good window of operability for a ship of this size, and it should also be noted that the criteria are guidelines. Operator competence and methods used for recovery will hugely affect the safe operation of OBS regardless of the conditions.

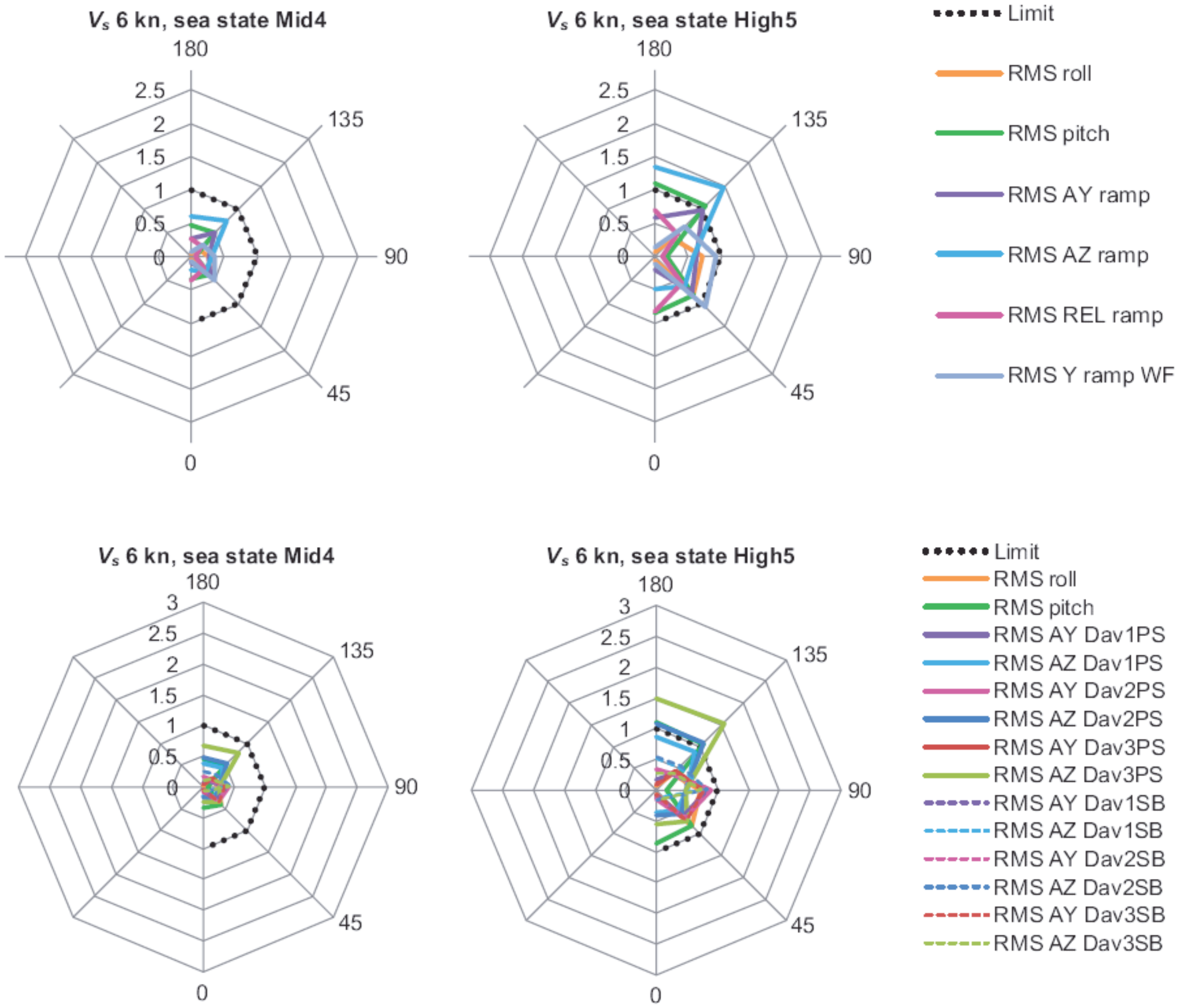

Figure 16: Operability Plots (*non-dimensional) of Seakeeping Criteria for Stern Ramp (top) and Side Davits (bottom)
*[Criteria exceeded in ship headings where value is above 1.0]

8. CONCLUSIONS

It is concluded by the author that, for a relatively low level of compromise in traditional warship requirements, the design of the platform may be greater optimised to allow for greater utility of a range of UxVs (UMS in particular). In providing a platform suitable for operating a variety of OBS the key areas of consideration must include:

- Allowance for volume, deck space and payload capacity for OBS
- Impact on stability resulting from the arrangements for OBS
- Prioritisation of seakeeping to limit motions at launch/recovery locations
- Hullform features to provide adequate transom immersion depth and reduced wave patterns at low speed in way of UMS recovery locations

In most circumstances the recovery of UMS must be undertaken at slow speed and for this more credence should be given to wake systems and seakeeping. In due course the author will undertake further studies on how these can be altered to improve launch/recovery of OBS, manned and unmanned, via a stern ramp.

Acknowledgements

The author would like to acknowledge:

- Babcock International – Concept Design Team, Bristol, UK, for contributions in the development of the Arrowhead 120 frigate design and Arrowhead 120 hullform;
- MARIN (Maritime Research Institute Netherlands), Wageningen, NL, for undertaking hullform research and development including CFD and tank testing.

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