

Counting the ASW Calories: Maximising Sonar Performance under Weight and Size Constraints

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Abstract — What is the optimal ASW sonar performance that can be achieved on a small manned or unmanned vessel? Unmanned maritime platforms range from small, low cost systems that network together as swarms/squads to provide wide area coverage, through to large scale platforms (that can be partially manned) capable of carrying high power, long range sensors with performance and endurance similar to traditional ASW. The optimal ASW sonar solution will harness the benefits that unmanned systems bring, including:

- flexibility; transportability; low costs; covertness; safety and efficiency, whilst still offering operationally viable ASW that requires:
- wide area coverage; persistence; low FAR; detection and classification; tracking; methods of response to a target (defensive/offensive) and self-protection.

This paper looks at the system trades-offs required to minimise weight and space and maximise sonar performance in a littoral threat detection environment. Sonar parameters such as operational frequency, source level and directivity are assessed alongside practical aspects such as payload size, deployment/recovery mechanisms and platform endurance. The possibilities offered by current small, unmanned systems and sensors are explored but also emerging technologies are considered that may change the trade-off space such as energy sources, sensing technologies and communications.

It is concluded that a slimmed down Active sonar fitted to a compact surface vessel capable of either manned or unmanned operation can be an attractive and viable solution for several ASW scenarios in its own right. Furthermore the solution could also act as a key enabler for small low cost systems and integrating link with the wider force.

1 What is the opportunity of using small manned or unmanned vessels for ASW?

For many countries, the submarine threat is both real and local. Mini-subs with limited range, operating in shallow, congested waters may be used to threaten infrastructure and shipping, gather intelligence, or simply to present a strategic threat against neighbouring countries. The operational environment may be non-military, open sea lanes with high levels of commercial traffic and typically in the littoral zone with often shallow waters.

The US Navy's Task Force ASW's document on concepts of operations for the 21st century [1], written in 2005, describes how the foreseen areas of operation are mostly coastal, expecting asymmetric threats. They expect operations in the future to "be centred on dominating near-land combat, rapidly achieving area control despite difficult sound propagation profiles and dense surface traffic" [2]. Furthermore, the expectation is that most enemy submarines are foreseen to be "conventional (diesel-electric) and designed for local or regional coastal defense" [3], allowing for smaller submarines, which can submerge close to home ports, resulting in asymmetric warfare with the objectives of (1) hold enemy forces at risk, and (2) secure friendly manoeuvre areas.

The three main operational scenarios used when discussing the use of unmanned systems in ASW are titled in the USN master plans [2][3] as 'Hold at Risk', 'Maritime Shield', and 'Protected Passage'. NATO NIAG

Study 232 goes on to further define these three scenarios as:

- Protected Passage:** clear the way for a task group or High Value Unit (HVU) to proceed at speed to a destination of choice while minimizing the risk of submarine attack.
- Sea Shield:** clear a static area of operations around an expeditionary task force or other HVU for a sustained period, minimizing the risk of submarine attack.
- Hold at Risk:** monitor a choke point, maximizing the probability that passing submarines are successfully detected and classified.

By operating as a stand-alone capability or as a force multiplier, unmanned systems have the potential to increase effectiveness in high risk choke points and persistent picket-fence operations around a HVU. For area-constrained operations such as these the alternative approach of using unmanned systems with ASW sensors could offer a search-effective and cost-effective solutions.

There is an opportunity to exploit the benefits of cost-effective sensors capable of detecting submerged submarine, mini-submarine and large diver delivery vehicles at sufficient range such that a potential attack can be countered.

Unmanned systems also enable a shift in ASW from 'platform-intensive' to 'sensor-rich' operations, applying network-centric warfare to dominate the environment by

using unmanned vehicles, common operating pictures, and standoff precision weapons, sensors & networks over weapons & platforms.

The aims of ASW relevant to unmanned systems are to:

- Constrain freedom of action
- Scare the threat away
- Render the threat ineffective
- Degrade effectiveness

New capabilities that unmanned ASW have the potential to deliver:

- Autonomous, semi-autonomous and unattended operation
- Sensor netting and cooperative engagement
- Swarms of systems, increasing coverage and providing sensor redundancy

This paper looks at the system trade-offs required to minimise weight and space and maximise sonar performance in a littoral threat detection environment. Sonar parameters such as operational frequency, source level and directivity are assessed alongside practical aspects such as payload size, deployment/recovery mechanisms and platform endurance. Acoustic sensor options are considered, giving a choice between Active and Passive systems. The possibilities offered by current small and unmanned systems and sensors are explored in the context of the trade-off space for unmanned vessels.

2 What unmanned systems offer ASW capabilities?

Unmanned maritime platforms range from small, low cost systems that network together as swarms/squads to provide wide area coverage, through to large scale platforms (that can be partially manned) capable of carrying high acoustic power, long range sensors with performance and endurances similar to traditional ASW. The optimal ASW sonar solution will harness the benefits that unmanned systems bring, including:

- flexibility; transportability; low costs; covertness; safety and efficiency,

whilst still offering operationally viable ASW that requires:

- wide area coverage; persistence; low FAR; detection and classification; tracking; methods of response to a target (defensive/offensive) and self-protection..

2.1 Unmanned/Autonomous Underwater Vehicles (UUV/AUV)

AUVs are seen to have great potential for military applications, reducing risk to manned forces, allowing access to previously inaccessible areas, performing covert operations, and providing force multiplication. The potential to launch AUVs from a submarine is a unique feature that could be used in some scenarios.

AUVs are successfully used in MCM operations [4] however currently available AUV technology is generally

thought to be too limited in payload, speed and endurance to be effective in ASW [5]. Communication back to the parent vehicle can also be challenging. Hold at Risk may be a feasible scenario for the application of small to medium AUVs.

2.2 Underwater gliders

Besides propelled autonomous underwater vehicles, there are also 'gliding' vehicles that slowly move through the water column changing their buoyancy and pitch [6]. These vehicles are optimised for endurance, trading in speed, navigation and payload capabilities. Typically they are fitted with few, low-energy sensors and data is stored on-board, not processed or transmitted back to the mothership. Although the endurance can be remarkably long, it should be noted that their speed is limited, typically 1 Knot. As with AUVs data transmission is limited by being submerged and low power.

2.3 Unmanned Surface Vessels (USV)

Ranging from 2m up to 40m there are a vast array of USV emerging onto the market for multiple autonomous system roles. At the small, energy harvesting end of the market similar limitations as for AUVs apply around power, payload and speed. At the largest size of USV endurance, power and payload become close in capability to traditional assets but the flexibility to forward transport by land, sea and air is lost. There is also an argument that a platform of comparable size to a frigate could be made unmanned. At this size the USV would match the sensor capabilities, speed, endurance and sea-keeping of traditional ASW delivery platforms. However, such a large platform will also have the same limitations around shallow waters, manoeuvrability, flexibility and above all costs.

Driven by MCM, there is a medium class of USVs that are 10-13m in length that offer:

- Useful payload capacity – 2-4 tonnes
- Endurance 12-48 hours
- Speeds: transit >20knots, operations 5-10knots
- Launch & Recovery from mothership/shore and land/sea air transportability – 10-15 tonnes all up weight
- Shallow water operation and manoeuvrability
- High bandwidth comms
- Operation up to 60NM from safe haven
- Manned and unmanned operation options.
- On-board power 10kW- 20kW to drive sensors and comms
- Cost effective in both capital procurement and manning

2.4 Sensor Options for USV/UUV/AUV

Sonar sensors are typically either hull mounted or towed off-board. In order to be effective an acoustic sensor must be located below the waterline, ideally permanently, be physically large enough to provide a

useful array gain, be located where receive flow noise due to water passing over the sensor is not limiting and be separated from the noise and cavitation from the propulsion system. It is difficult on a smaller USV and AUV to find a mounting location on the hull that meets any of these criteria when the USV or AUV is underway therefore towed off-board sensors are generally considered the most suitable solution.

To detect today's quieter submarines passively requires an array design with characteristics that drive larger rather than smaller aperture length and diameter. The size or diameter of the acoustic aperture that is required to achieve useful sensitivity, within the likely bandwidth of interest, affects drag that in turn affects vehicle endurance and controllability. An option is to use large quantities of small passive sonar systems to cover an area, for this they need to be low cost. With this solution comes logistic challenges of launch and recovery and the question of how gathered data is transmitted and managed. ASW sensors currently require an operator in the loop to provide detection performance. Passive sonar systems require a greater skill level to interpret data and identify targets from sonar Time-Bearing and LOFAR displays. Automated contact followers are available but the presence of many contacts, such as in commercial shipping lanes, degrades performance and progress has been limited in reducing the reliance on highly skilled operators.

Active sonar systems provide more consistent and clearer contact data, particularly in cluttered environments and thus offer greater potential for automation. Operators or expert systems are typically presented with automatically generated tracks, and their role is to monitor the track behaviour to filter out unwanted tracks and highlight the threat-like ones. The operating frequency is a key factor in determining the detection performance, acoustic power requirement, size and tow load of the sonar. Low-power, small platforms like AUVs have been deployed with high-frequency active sonars for mine hunting [7], but operational ranges are rarely suitable for ASW. Lower frequency active sonars have been favoured on ASW frigates due to the long range detection possibilities because sound absorption in sea water is dependent on frequency. However, this generally comes at the price of large acoustic projector and larger receive aperture with a high weight, size and power demand. Scaling up the size of the USV to accommodate a lower frequency sonar may be the answer for independent blue water ASW operations, effectively replicating the capabilities traditionally offered by an ASW frigate. It is a relatively expensive solution however and does not necessarily address the littoral or shallow water challenges and loses some of the other benefits of a smaller USV such as mobility and transportability for rapid redeployment. A trade off to find the most suitable active operational frequency band is clearly required, which is discussed further in the next section.

For non-covert operations, USV active sonar systems should bring a step up in detection ranges compared to passive but sensor systems still need to be scaled up sufficiently to provide the acoustic power needed for viable ASW roles; this limits their potential for use on AUVs, gliders and small USVs. An AUV could carry an active sonar source (free flooded ring transducer for example) but it would be fitted outside of the AUV itself, for example at the underside of the AUV hull, to avoid internal reflections. However, this external mounting will increase the hydrodynamic drag of the vehicle and reduce its endurance and speed; its ability to be submarine launched will also be compromised.

Medium and large USVs can be fitted with active source dipping sonars or towed active source, towed passive arrays, depth sounders and effectors like a torpedo launcher, countermeasure launchers or other expendable sensors. All off-board towed systems will require some form of handling or deployment system that enables fast transit to the search area before deployment of the sensor. A dipping sonar usually needs to be stationary whilst deployed to ensure a stable acoustic aperture limiting it to sprint and drift operations where the sensor is unavailable during sprint. USV dipping sonars have been found to have lower area coverage overall compared with a USV towed array sonar due to the need to be stationary when sensing combined with its comparatively lower detection range [8]. A hydro-dynamically stabilised towed system provides greater flexibility as it allows patrol capability whilst the system is deployed as well as the ability to conduct classic sprint and drift.

Considering these available options and the current state of the art, we conclude that a medium sized USV (10m to 13m) with an endurance of 12 to 48 hours fitted with an active towed sonar system offers the optimum trade-off of unmanned vehicle and sensor system combination for utility in ASW. This solution will provide continuous detection, classification and localisation (DCL). Further trade-offs within the sonar solution space are covered in the following sections.

3 Key Characteristics of USV ASW Sonar

3.1 Operational Frequency, Source Level and Directivity

The size and weight constraints of the acoustic transmission system are a key factor in determining the overall system solution. In general terms, for a given frequency and projector type an increase in source level of 3dB implies at least a doubling in weight and size of the projector and associated power amplification. Similarly for a given source level an octave move lower in frequency implies at least the same increase in weight and size. The methodology and analysis utilised during the assessment and trade-offs of low frequency active sonar systems in the early nineties [9] remain broadly valid when considering USV based sonar systems, but the severe size and weight

constraints lead to a quite different conclusion with regards to the choice of the optimum frequency and source level. For example, the curves in ref [9] figure 7, show the nominal source level required for a sonar to achieve detection at a specified range, as a function of frequency. These graphs use the standard active sonar equations, detection theory and assumptions for noise and attenuation described in [10].

As a typical rule of thumb for a keen, weight-optimised design, the designer would likely choose an operating frequency close to, but just beyond, the upward turn in any given absorption curve. If designing a system to achieve significant detection range in open water, unconstrained by troublesome coast lines and sea mounts, one can easily see the argument for designing to a lower frequency and scaling up the size and weight of both the sonar and host platform accordingly, but this would tend to move us away from what can be practically integrated into the medium class of USV discussed earlier. However, in shallow or littoral water where extremely complex acoustic propagation and reflection conditions are in play, it is discrimination and flexibility, rather than detection range that becomes the key design parameters. A medium frequency sonar would seem a more suitable selection for this environment and is certainly more optimised for a medium sized USV platform. Furthermore for a given frequency one can clearly see that increasing source level to achieve greater detection range suffers from a law of diminishing returns due to absorption loss and reverberation, so the extra weight gain from power amplification and additional projectors again may be not worth the extra calories.

The directivity of the receiver array is determined by the size of the acoustic aperture and the frequency of operation by the spacing and configuration of the hydrophones. Assuming a neutrally buoyant towed array, the drag is determined by the length and diameter of the array. For a given frequency of operation, the longer the length of the array the higher the value of directivity achieved. Thus, for a given array length, as the frequency is increased so the directivity is improved.

When the array is not deployed its dry weight becomes the issue as it needs to be accommodated within the vessel payload capacity. Therefore a very long, densely packed receive array is undesirable.

To recap, our weight optimised ASW solution suitable for a medium sized USV would be operating in the medium frequency range at relatively low source level with wide bandwidth and with a relatively short receive array optimised for active detection. It is worth highlighting that traditional bow or hull mounted sonars typically fitted to larger ASW vessels are often designed with these same broad characteristics however we have earlier discounted mounting the sonar to the hull of the USV due to concerns over flow-noise and self-noise, as well as space constraints, and instead favoured a towed variable depth arrangement. This variable depth arrangement may also

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provide advantages in exploiting the acoustic environment compared to a hull mounted sonar, which will be explained briefly in the next section.

3.2 Outboard Characteristics

A USV deploying a variable depth towed sonar gives the flexibility of continuous operation with the sonar deployed; in this case the speed will be limited by three main factors:

- i. The tow capacity of the USV with the tow body deployed to an operationally useful depth. Endurance also comes into play here as the USV needs to be operating at an efficient fuel usage rate to provide mission endurances in the range of 12-48 hours;
- ii. The flow noise effect on the receive array;
- iii. The mechanical strength of the tow winch, connectors and cabling when there is a need to also keep system weight as low as possible.

Typically the operator of an active variable depth sonar will seek to place the towed body at the best possible depth within the vertical water column to achieve the most favourable acoustic conditions to detect the threat. This will be dependent upon the sound speed profile and the likely threat depth, but will often be as deep possible, subject to the water depth, in order to be below the thermocline if one exists as shown in figure 1 in order to have an opportunity to exploit the so called "SOFAR" duct [11]. This is particularly important in tropical climates where the isothermal layer is often very shallow and tends to limit detection coverage at shallow depths.

The towed body needs to be deployed at the "ideal" depth for acoustic detection conventionally taken to be at the transition between the thermocline and the deep layer; this depth differs in the various seas and oceans of interest.

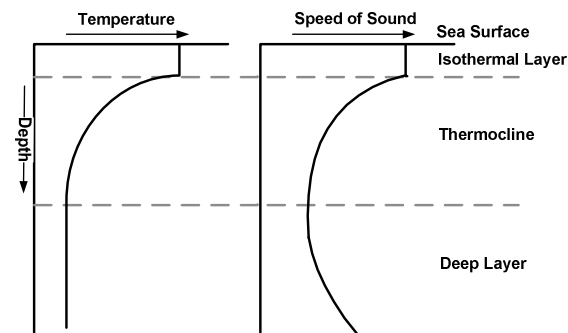


Figure 1, Idealised temperature / depth and velocity / depth profiles

Maximum depth for a given tow scope will occur at minimum speed through the water such that the sonar hangs close to vertically below the vessel. As the speed increases, which may be operationally essential, the tow will tend to stream further behind the vessel and move to a more shallow depth determined by the weight and drag in the tow system. This may not necessarily compromise the

acoustic attributes of the sensor provided it is designed hydro-dynamically such that the required horizontal and vertical orientation of acoustic sensor is not significantly altered. However the change in depth may affect significantly the acoustic propagation conditions, so there is a clear trade between operational patrol speed and achievable depth. The trade-off extremes are minimised by very careful attention to the drag, weight and downward forces applied to the tow with the ideal being a system that tows vertically down at all speeds. The downward force is not easy to achieve with a simple line array and the optimal solution is considered to be a low drag hard body, housing the active transmit system, with a horizontal receive array attached to the rear. This solution comes at the expense of an increased drag force normal to the tow cable, which translates to higher drag at the USV, and therefore the effect on endurance has to be carefully considered.

Alternatively, the USV can transit at a higher speed to the search location and only then deploy the tow to depths whilst stationary or at very slow forward speed (1-2knots), limited effectively by either the tow cable length and/or the available water depth. This 'sprint and drift' type of operation is similar to a dipping sonar. In coastal waters the available water space would rarely be greater than 200m, so to limit weight a maximum cable length of 200m would seem appropriate.

There are however practical issues with towing at very low speeds. The tow may snag or wear on the vessel and it can become hydro-dynamically unstable and unpredictable due to the lack of flow. Careful consideration of the USV propulsion and the deployment mechanism can eliminate these issues. Furthermore, in wind driven waves the slack-snatch loads on the tow system are at their most severe when the tow is near vertical, which can fatigue the handling system and tow components, particularly the tow cable. Strengthening the handling systems and tow to accommodate these cases again drives either weight or possibly expense if lighter materials or more complex fabrication is required. The slack-snatch loads can also severely affect stability of the USV unless carefully considered in the vehicle design and deployment method otherwise the range of sea states in which the system can be used may be severely constrained. The robustness of the catamaran hull, for example, to surge, heave and sway provides significant advantages.

At the other extreme, a patrol high speed through the water may be operationally desirable if, for example, a barrier patrol is being performed or if the vessel is required to keep pace with a larger flotilla. This also drives a trade between weight and propulsion size, endurance (considering the weight of the additional fuel) and tow strength.

Another active transmitter option is an in-line active source offering lower drag, lower weight and fully reelable deployment, which are on the face of it considerable advantages, but with two main disadvantages:

1. omni-directional transmissions are not possible meaning it either takes at least three times as long to achieve 360° search coverage, or the system is limited to searching in only specific directions at any one time.
2. The lack of a natural depressor limits the operational depth that can be achieved for a given speed and tow scope compared to a hard body solution.

3.3 Detection, Classification and Localisation (DCL)

The primary requirement for ASW is the DCL of underwater threats and key to this is the operational frequency and resulting detection range of the sonar. We have already discussed that the very large, low frequency sonars deployed from primary ships are not suitable for medium sized USV and concluded that medium frequency, may be an optimal range to aim for; what performance and compromises does this offer?

3.3.1 Detection Range

The Figure of Merit provides a measure of the ability of an active sonar to detect a signal in noise. By employing a medium frequency, it has been shown in section 3.1 and 3.2 that the sonar can be more compact and thus deployable and towable from a USV whilst still providing useful detection ranges. An ideal performance is with vertically arranged transducers providing omni-directional transmissions; the size of which is in proportion to that of a 10-12m USV.

3.3.2 System False Alarm Rate and Miss Rate

The System False Alarm Rate (FAR) and Miss Rate (MR) effectively measures of the rate at which the ASW Operator reports an incorrect threat classification decision up the chain of command. Operator classification plays an important part in interpreting and filtering the output from the sonar automatic tracking detection process. Complementary sensor data and situational information is expected to be available to the operator to allow a further improvement in these parameters.

In practice FAR and MR are dependent upon:

- a. **The operational environment** – the use of unmanned ASW systems in shallow and noisier waters will make interpreting and filtering the output more of a challenge. New tools will need to be developed to aid operators in classification.
- b. **The operator competency** inclusive of skill and training – The ASW picture from unmanned systems will be more complex due to the increased numbers of systems and sensors collaborating to search the area, and the resulting need to 'mesh' together the data. Automatic tools and AI will be key to supporting operators in the future.
- c. **The operator's workload** including the ergonomics of the system displays and fatigue - Even in cases where small ASW platforms are manned by 2-4 crew, it is expected that the sonar

data will be transmitted off-platform in real-time to sonar operators at a central command location, on ship or shore. Automatic tools and AI will be key to supporting operators to manage and analyse the sonar images.

- d. **The effectiveness of the sonar tracking** in bringing to the operator's attention those tracks that are behaving in "a threat-like" manner and suppressing others. Tools for this purpose will need to be tuned and trained to pick out tracks in congested and noisy environments and to resolve data about the same track coming from multiple sonar contacts.
- e. **The sensitivity of the sonar** in detecting and displaying to the operator signals above noise - By employing medium rather than low frequency the performance in noisier littoral environments may be improved but as a result detection ranges are shorter. Multiple unmanned ASW system can be employed to work collaboratively to give the required signal above noise across the search area.

3.3.3 Expected Time to Classification

The speed at which the system, including the operator, can classify determines the speed at which an operator can investigate or prosecute the threat. The time required to react is based upon:

- a. The likely range from the sensor at which the initial detection occurs. For USV borne sensors, this range will be shorter than for traditional LF ASW sensors, giving the operator less time to investigate and react. The ASW net can be widened and detection achieved earlier by deploying the unmanned system further out or, increasing the number of systems. Limitations in communications ranges can be overcome with the use of mesh networks and Unmanned Aerial Vehicles (UAV) data relays to achieve high bandwidth communications beyond line-of-sight. The more cost-effective each system can be made, the more scalable and therefore capable the overall coverage becomes provided that each USV can be made sufficiently compact to be readily deployed from the protected assets in sufficient numbers.
- b. The separation between the USV and the protected asset. Here the effectiveness is measured by the endurance and speed of the USV. The faster that the USV can transit to the required patrol location and the longer it can operate at that location the greater the separation that can be maintained.
- c. The threat weapon effective range. This range essentially reduces as the combined effectiveness of a. and b. increases.
- d. The threat speed. The underwater threats have the potential to outpace an unmanned ASW system. At initial detection the threat is likely to be travelling slowly to be as stealthy as possible and thus at a speed that unmanned systems could detect and track. By utilising active detection, the threat will know it has

been detected, if it does then speed up to evade tracking the aims of 'Constrain freedom of action' and 'Scare the threat away' have been achieved.

- e. The Investigate and Prosecution time – With a small number of USV sensors deployed, operators may face a reduced time for investigation and prosecution due to the more limited detection ranges. That said, in shallow, noisier waters a medium frequency sensor offering wider bandwidth is likely to have greater discrimination improving the effectiveness of the tracker making the operators job easier. As the techniques for sensor netting and cooperative engagement in ASW mature this will further aid operators and enhance investigate and prosecution of the threat.

3.3.4 Localisation Accuracy

The localisation accuracy determines the accuracy with which the system can direct the investigation and prosecute team to the threat. The required localisation will depend strongly upon the required cueing accuracy of the effectors that will be deployed against the threat.

A key difference in the command chain when using USV ASW is that the investigating operator is not co-located with the sensor and may not be co-located with the prosecute team. Although it is possible to deliver some prosecution weapons from an unmanned system (light weight torpedo for example), prosecution may also come from a cued major platform or aircraft. To benefit from the potential of unmanned ASW a clear command structure and reliable, secure communications channels are needed.

The localisation accuracy that can be achieved by the sonar is dependent upon a wide range of random factors and fixed biases such as:

- Signal to Noise Ratio (SNR) of the detection,
- transmit timing synchronisation,
- range of the detection,
- beamwidth (or bearing resolution),
- range resolution,
- tracking accuracy,
- track stability, and
- locational accuracy of the sensors.

Increasing the bandwidth can improve the range resolution and longer receive apertures can improve bearing resolution.

4 Wider Considerations for Adopting Unmanned ASW

4.1 Mission Planning for USV ASW

The aim of mission planning is to make the best use of time and increase the probability of threat detection through adopting search patterns optimised for the use of unmanned/small ASW systems. Tools are needed for the

prediction of time, trajectory, performance and effectiveness of completing the unmanned ASW task.

Factors that influence the mission effectiveness are: search patterns, sonar type, speed, direction, starting point and numbers of systems.

The patterns used in traditional ASW are not necessary the most effective when employing unmanned systems, particularly as there are likely to be a higher number of UxVs involved in a single search. The factors that most greatly influence the search pattern are:

USV Speed: speed has a direct bearing on endurance of the USV (via fuel/power consumption) and on the threat detection range.

Sonar Type: The current market choice of sonars for USVs is dipping vs towed, leading to two very different search methods. Dipping employs sprint & drift allowing very fast transits but with the platform stationary when the sonar is deployed. Towed arrays offer continuous sonar operation but at reduced speeds.

Number of USVs: the number of systems available to search the area and their ability to collaborate will have the greatest impact on the time to search. Multiple systems will have different start points and may overlap their search areas to increase probability of detection.

Evolutionary type search pattern, shown in figure 2, using more than one USV with a towed sonar, have been shown to be more effective than 'sprint & drift' with dipping sonar [8].

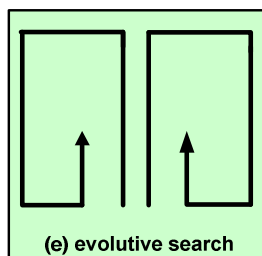


Figure 2, Evolutionary search pattern.

4.2 Logistics

The logistics in operating unmanned systems imposes limitations on how capable they are in achieving the expected performance. These limitations include fuel consumption (endurance), maintenance, system launch and recovery, sensor deployment and communications.

USVs can operate safely at distances of up to 60NM from a base port or ship (safe haven), when crewed, in accordance with Maritime safety guidelines. As an unmanned system, the current achievable line of sight communication range for the high data rates needed for operations is driven by achievable base station mast height and radio power.

Typical transit speed (without the sensor deployed) is 15knots. With the towed body deployed, the system can operate for up to 18hrs. Re-fuelling and crew rotation (if manned) need to be considered to achieve persistent patrol with the system.

Depending on the operational location, the system needs to be transported into area and launched and recovered from a transport/mother ship or from shore. At 12-15tonnes, this class of USV has been designed to fit existing boat bays and is suitable for launch and recovery by davit or stern ramp. Initially existing platforms will need to be employed, which have been shown capable of carrying two to four 11m USVs. In the future new platforms, specifically designed to forward deliver unmanned system into theatre will be introduced with a much greater capacity.

4.3 Non-equipment enablers

The introduction of a new method for delivering ASW will have significant impacts across the non-equipment aspects of operations. Operational experimentation in the UK and overseas would demonstrate the wider benefits realised through using unmanned ASW mission packages. The key focus of investigations and development should be:

- Defining target organisational structure to include unmanned systems usage in the ASW component of the warfare branch and developing concepts, doctrine and tactics to transform ASW capability.
- Conducting a full manpower assessment of numbers, types and skillsets of personnel required for operation and maintenance of unmanned vehicles and how these can be achieved within the existing liability structures and numbers.
- Assessing the cost savings associated with a mixed traditional and unmanned ASW force.
- Conducting operational profiling activities to understand the numbers of systems required to maintain availability on task and deriving infrastructure requirements for unmanned ASW systems, to cover storage, maintenance, training and administrative infrastructure.
- Learning lessons of equipment performance in different environmental conditions and understanding information assurance, exchange requirements and issues associated with 'smart' off-board systems vulnerability.

4.4 ARCIMS-SeaSense Underwater Threat Detection

ARCIMS-SeaSense is a market ready example unmanned ASW USV solution that uses an Active Towed Array Sonar System that provides the capability to detect, classify and locate underwater threats such as submarines, mini-sub and large diver delivery vehicles from an 11m

USV. The Sonar System has been specifically configured to provide a simple and flexible capability for operations within shallow and warm water, but it is highly capable in colder or deeper waters also.

ARCIMS has been designed by AEUK as medium surface vehicle to enable manned or unmanned operations with minimal operator intervention. The ARCIMS-SeaSense system deploys a towed acoustic source and a towed receive array operating in the medium frequency band.

The active source can be deployed at variable depths and allows the selection of pulse bandwidth, duration, and source level. High Source Levels can be achieved although, at shallow deployment depths, lower source levels need to be selected to avoid the risk of cavitation.

A modelling study was carried out on ARCIMS-SeaSense in 2018 that looked at the ability of the system to protect a task group in three scenarios against a threat submarine: For all three scenarios employing more than one system, provided useful performance.

6 Conclusions

It is concluded that a slimmed down Active sonar fitted to a compact surface vessel capable of either manned or unmanned operation can be an attractive and viable solution for several ASW scenarios in its own right. Furthermore the solution could also act as a key enabler for those small low cost systems and an integrating link with the wider force.

This study indicates that ARCIMS-SeaSense has utility in providing a portable and scalable ASW barrier for operations where the need to remain covert is not required. ARCIMS-SeaSense could be deployed singularly or in multiples, and as a system of systems with other ASW assets.

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