The Coastguard Submarine: Covert Maritime Security

Abstract — The challenges that a modern Coastguard faces are complex and evolving. The increasing prevalence of low-profile vessels and semi-submersibles require new and innovative solutions for the maritime security role. Naval submarines have been used in these operations for many years, including the migrant crisis, anti-piracy and anti-smuggling operations. They provide an unparalleled intelligence-gathering asset, but this distracts expensive warfighting vessels that are only using a fraction of their capability.

BMT explores the impact of requirement change on a submarine design by utilising the WYVERN SSK as a baseline and modifies the design for a purely coastguard role. The adversary's low technical ability allows for the removal of high-end sensors and effectors from the design, whilst optimising those needed for surveillance and data sharing. A credible capability to coerce and enforce in low-level engagements is needed, with the emphasis being on the ability to provide a show of force.

The design aims to demonstrate that a small SSK can operate in a dedicated coastguard role, providing the required Intelligence, Surveillance & Reconnaissance (ISR) capability without the high-end warfighting systems. This would provide the benefits of a submarine but without the associated burden of using a naval submarine.

From the development of this coastguard design several opportunities arose that may be applicable to all submarine designs. These include a low-level method of providing force, the design considerations of modular systems and the impact of naval requirements.

The paper opens up an unexplored concept design space whilst still tackling common challenges such as equipment integration. By questioning the overheads of naval design, the paper investigates how design simplification can lead to an attainable submarine for a maritime security role.

1 Introduction

1.1 The Coastguard's Role

The world's coastguards conduct many varied operations, each tailored to match their parent nation's needs [1]. The United States (U.S.) Coast Guard categorises their mission as [2]:

- Protect those on the sea;
- Protect the Nation against threats delivered by sea, and;
- Protect the sea itself.

These categories reflect some of the most complex global challenges faced today and would be familiar to any coastguard or border force.

Nothing embodies the need to protect those on the sea more than the ongoing migrant crisis in the Mediterranean, where close to 1.4 million refugees have arrived in the European Union by sea between 2015 and 2016 [3]. The sea crossings are extremely hazardous with approximately 14,924 fatalities between April 2014 and March 2019, and 289 deaths in the first 79 days of 2019 alone [4].

The Italian Operation Mare Nostrum (OMN) took responsibility for people in need of rescue and protection in the Mediterranean from October 2013 to October 2014 [5]. Throughout the operation, the Italian Coast Guard co-ordinated efforts with the goals of safeguarding lives at sea by contributing to Search and Rescue (SAR), and to fight against the trafficking of human beings [6].

Closely linked to human trafficking is the smuggling of illegal goods and items that pose a threat to a nation's economy or citizens. For the past 30 years, the U.S. Coast Guard has forward deployed assets off Central and South America to defend against a '*torrent of illegal drugs and other illicit goods*' [1].

Anti-piracy is another common operation, with the U.S. Coast Guard being requested to conduct at-sea interception and supporting warfare tasks in key theatres [1]. There were 174 reported incidents of piracy worldwide from January to November 2018 [7].

Estimates for worldwide losses due to Illegal, Unreported and Unregulated (IUU) fishing are between $10 billion and $23.5 billion [8]. This highlights why protecting the marine environment and living marine resources (such as fisheries) is also a key operation for so many coastguards.

1.2 Naval Submarines in a Maritime Policing Role

A navy's operations can be summarised by three '*modes of action*'; maritime security, defence engagement and warfighting [9]. The maritime security mode often overlaps with coastguard or border forces although the other modes add additional requirements to what a coastguard faces.

Materiel derived from the other modes of action is frequently utilised for maritime security operations. Submarines are a good example of this; designed primarily with the warfighting mode in mind, they have proven

themselves in conducting defence engagement and maritime security.

In the maritime security mode, submarines have been used for anti-piracy operations off the horn of Africa [10], anti-smuggling operations in the Irish Sea [11], SAR in the Indian Ocean [12] and to combat human trafficking in the Mediterranean (see figure 1).

Fig. 1. Italian Navy submarine ITS GIANFRANCO GAZZANA-PRIAROGGIA conducted surveillance on human traffickers [13]

Submarines provide a powerful Intelligence, Surveillance and Reconnaissance (ISR) capability whilst remaining covert, allowing them to gather evidence that would be concealed if adversaries knew that they were being observed. In 2012, the then Netherlands Minister of Defence, J.S.J. Hillen, lauded the anti-piracy efforts of the Dutch submarine HNLMS DOLFIJN, which provided intelligence that led to the rescue of 12 hostages. Hillen stated that '*a frigate or a helicopter cannot move silently*' and '*satellites are hampered by weather conditions*'; these limitations leave a large gap in the operational picture - HNLMS DOLFIJN filled that gap [14].

Naval submarines are particularly effective at sea denial by deterring or constraining the operations of surface fleets [15]. This deterrent effect can be extended to the maritime security mode, where careful advertisement of a submarine in the area may be enough to deter illegal operations. The adversaries would be unable to know if they are being monitored, limiting their ability to avoid or deceive security forces.

Despite these successes, it should be remembered that naval submarines are designed to conduct a much broader range of operations, including Anti-Submarine Warfare (ASW), Anti-Surface Warfare (ASuW), force protection, land attack and Special Forces insertion [16]. It is only the ISR elements of the design that are used for the majority of operations in the maritime security mode, and therefore the additional capabilities are underutilised.

1.3 Evolving Challenges

The challenges facing a coastguard continue to evolve. The use of Low-Profile Vessels (LPVs) (figure 2), semi-submersibles (figure 3), and submarines (figure 4) for drug trafficking has steadily increased since the first semi-submersible was confiscated in 1993 [17]. Between June and September of 2017, cocaine worth $306 million was seized from seven interdicted LPVs [18].

Fig. 2. Low-Profile Vessel (LPV) [19]

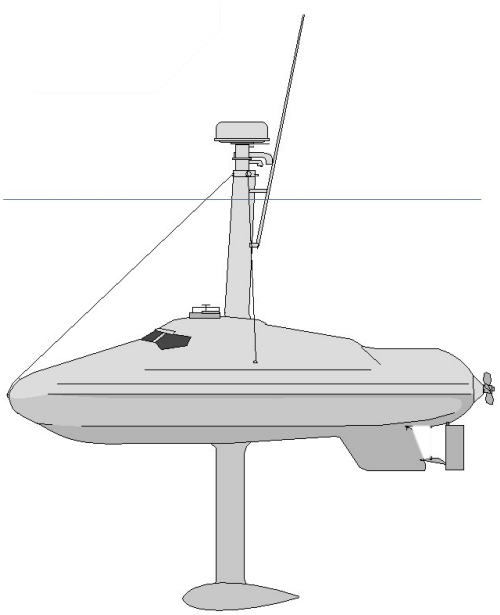

Fig. 3. Semi-submersible [20]

Fig. 4. Drug trafficking submarine [21]

One way to combat these evolving challenges is a dedicated coastguard submarine, particularly as naval submarines have already been used to counter the vessels mentioned above. Captain M.F. Morris, USN, notes the

following assessment; '*American operations analysis shows that given good intelligence of a drug event and a patrol box of a certain length and width, a surface vessel operating alone has only a 5% probability of detecting (PD) that event. A surface vessel with an embarked helicopter increases the PD to 30%, and by adding a Maritime Patrol Aircraft to the mix, the PD goes up to 70%. Analysis by the Colombian Navy shows that adding one of their submarines to the mix raises the PD to 90%'* [21].

It is unclear from that description whether the submarine replaces some of the other assets, but it does show that a submarine can significantly increase operational effectiveness to a level where the vast majority of illegal activity is detected (within the bounds of the scenario). Therefore, the concept of adding a dedicated submarine to a coastguard's assets is worth investigating.

2 Concept of Operations (CONOPS)

2.1 The Role of a Coastguard Submarine

A coastguard submarine would operate in a similar manner to a naval submarine in a maritime security mode. Primarily, the submarine would be leveraging its ISR capabilities and relaying information to more conventional assets, such as surface vessels and aircraft. However, if the situation arose, the submarine would also need the ability to surface and carry out an interdiction independently.

It is envisaged that a coastguard submarine's main operations would be:

- Anti-piracy;
- Anti-trafficking (humans, drugs and illicit items);
- Exclusive Economic Zone (EEZ) and Fisheries Protection;
- SAR (including downed aircraft and vessels lost at sea).

The majority of these operations require the submarine to counter asymmetric adversaries who have little or no-way of combatting a submerged submarine. The submarine can make use of its deterrent ability against these opponents, as they have no ASW capability. This extends the deterrent capability well beyond the line-of-sight deterrence offered by a surface ship.

ISR missions would be possible in all weathers although a submarine's inherent seakeeping performance may sometimes limit surfaced operation.

2.2 Requirements Overview

The coastguard submarine would be required to conduct ISR of coastal facilities, offshore platforms, surface vessels, semi-submersibles and sub-surface craft through a variety of means including acoustic, visual and electronic. SAR operations would require similar methods of surveying the vicinity of the submarine. The sensor performance may be below that of a naval submarine depending on the individual user's preference, so there should be the ability to tailor the sensor suite to the customer's needs.

It would still be necessary to conduct missions covertly although the acoustic requirement and diving depth would be less strenuous than for a naval submarine. Similarly, the submerged endurance could be reduced to cover only the time spent monitoring the adversaries in daylight hours. Snorting or even surfaced operation would be sufficient in darkness.

Communications are key as they allow the submarine to pass on information in a timely manner to those who can best act on it. They also allow the submarine to receive information and act as a node in a wider network. This is likely to involve conveying large amounts of information, although the adversary is unlikely to be able to detect, locate or decrypt signals.

The capability to interdict and forcefully stop those conducting illegal acts is required to allow the submarine to act independently. However, there is no requirement to be equipped with sophisticated weaponry, as would be the case for a naval submarine due to the adversary's limited offensive capability.

The likelihood of intensive combat is low, with the submarine having the inherent ability to remove itself from the situation by submerging. However, a target might surprise the submarine resulting in a short surface engagement. It is assumed that the adversaries do not have the ability to damage the submerged submarine and there is no requirement to withstand shock from an underwater explosion.

It is anticipated that there will be a need to transfer crew to and from the submarine at sea, such as for boarding parties or ship-to-ship transfer.

3 Baseline Design

3.1 Use of a Baseline Design

In order to investigate the technical feasibility of a coastguard submarine design, it is useful to start with a baseline design, which is used to measure the impact of changing requirements. Once the solution space has been bounded, the solution characteristics can support capability assessments and be evaluated against constraints such as cost, infrastructure and the political environment.

3.2 Changes to Key User Requirements

The specifics of the coastguard role discussed in Section 2 result in different user requirements to a naval submarine. These are summarised as:

- Reduced submerged endurance;
- Reduced signatures requirement;
- Reduced lethality;
- Reduced survivability;
- Reduced diving depth;
- Option for reduced underwater sensors;
- Increased operation time on the surface;
- Increased ability to enforce and coerce;
- Increased launch, recovery and stowage of small boats;

- Option for increased communications.

3.3 Impact to the Design

The changes in user requirements are reflected by a change in equipment. As equipment is removed from the design, it can be traded for new items and other benefits to the design such as increased tankage, maintenance envelopes, or habitability. If the desired additions are greater than the removals then the submarine's size must be increased, or if they are much less, then the submarine can decrease in size.

The torpedo tubes are no longer required for a coastguard submarine that is facing low-threat, asymmetric adversaries, particularly as torpedoes do not provide a sensible means of firing a warning shot, thus limiting the ability for enforcing and coercing.

As the requirement for submerged endurance is reduced, there can be a corresponding reduction in the size of the batteries or Air Independent Propulsion (AIP) system. The removal of the torpedo tubes and a smaller submerged power source can be traded for changes to the hull form for increased surface operations, the addition of a deck gun for low-level enforcement and an inflatable boat stowage.

In addition to the major equipment changes, there are benefits from an increased maintenance envelope created by the removal of shock mounts, and the stability gains by trading equipment for solid ballast.

4 BMT WYVERN SSK

4.1 As a Concept

BMT's WYVERN SSK design (see figure 5) is a naval submarine concept design with a surfaced displacement of 720 tonnes. The design places considerable emphasis on a simplistic design approach and allows for a flexible equipment specification, which affords a high level of design tailoring in a cost effective package.

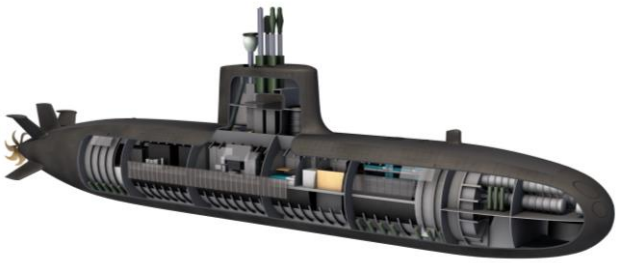

Fig. 5. BMT WYVERN SSK [23]

4.2 As a Baseline

WYVERN offers a good reference point for investigating the feasibility of a coastguard submarine as it is a mature concept that is balanced in terms of hydrostatics and power. It is also positioned towards the lower end of the capability spectrum - the simplicity of the design limits the amount of surplus capability to be removed.

The existing design meets the ISR requirements whilst the inbuilt flexibility of the design provides the best opportunity to accommodate new capability. Table 1 gives the general particulars of the baseline WYVERN design and a coastguard variant of the design.

Table 1. Baseline BMT WYVERN general particulars [23]

	WYVERN Baseline	**Coastguard Variant**
General Characteristics		
Surfaced Displacement	720 tonnes	718 tonnes
Submerged Displacement	860 tonnes	857 tonnes
Length Overall	46 metres	47 metres
Deep Diving Depth	210 metres	150 metres
Range and Endurance		
Crew	15 plus capacity to surge to 21 men	[No change]
Endurance	20 days (4 days on Stirling Air Independent Propulsion (AIP))	22 days (no AIP)
Maximum Speed	18 knots	17 knots
Range (Snorting)	3000 nautical miles	[No change]
Armament		
Weapons	4 Swim Out Heavyweight Torpedoes	1 25mm Autocannon
	4 Countermeasure Launchers	[Option to include]
Payload	up to 6 embarked military forces	[No change]
	Forward access route/trunk	[No change]
Combat System		
Sensors	Cylindrical Bow Array	[No change]
	Planar Flank Array	[Option to include]
	Distributed Array	[Option to include]
	Mine Object Avoidance	[Option to include]
	Fwd. and Aft Facing Fin Arrays	[No change]
	Intercept Array	[Option to include]
	Echo Sounder	[No change]
	Towed Array (clip-on configuration)	[Option to include]

	WYVERN Baseline	Coastguard Variant
Modular Non-Penetrating Masts	Optronics (Attack)	[No change]
	Optronics (Search)	[No change]
	Integrated Communications	[No change]
	Electronic Support Measures (ESM)	[No change]
Command and Control	6 Military-off-the-Shelf Multi-Function Consoles on Shared Processing Architecture	[No change]

5 WYVERN Coastguard Variant

5.1 Changes to the WYVERN design

The WYVERN design was evolved into the coastguard variant shown in figure 6 by trading equipment to meet the modified requirement set, whilst retaining a hydrostatically balanced design.

Fig. 6. WYVERN coastguard variant

As part of the evolution, the torpedo tubes and AIP system were removed, which eliminated a considerable amount of complexity and weight from the design. When these removals were combined with reduction in pressure hull weight due to reduced diving depth, then a weight margin is created that was traded for new equipment.

Whilst the baseline design meets the ISR and communications requirements, the requirement to enable a low-level threat of force had the greatest impact on the design. Adding a deck gun is the best way to meet this requirement.

MSI Defence Systems were consulted and the SEAHAWK LW25M A2 25mm autocannon was selected from their range as it balances the necessary stopping power with size. The 25mm gun has the ability to damage larger vessels such as trawlers and has a greater effective range than smaller calibres.

Whilst the gun can withstand being immersed in seawater, there were concerns about the effect of pressure, due to depth, on the gun mechanisms and ammunition. For these reasons, it was necessary to integrate the gun into a pressure-tight stowage from which it can be remotely raised and operated for surfaced operations.

The outer hull was modified to include a hydrodynamic fairing for the deck gun stowage with space for fore and aft access (see figure 7) and a flared bow for directing sea spray away from the casing and gun.

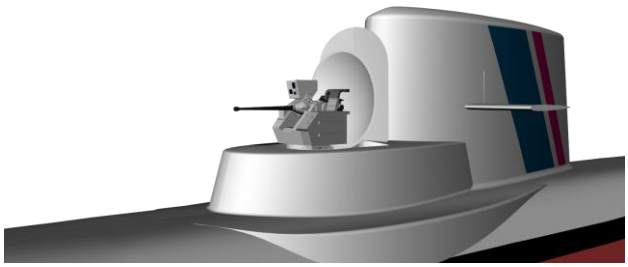

Fig. 7. WYVERN coastguard variant's deck gun

The modifications to the outer hull increase the resistance of the submarine. However, some of this energy is reclaimed by replacing the low-signature baseline propeller with a more efficient propeller. Additional external fuel can be stored in the outer hull. The result is a 1 knot reduction in top speed, a similar range but an increase in total patrol endurance.

Available space inside the bridge fin was re-designated as a stowage for inflatable boats and supplemented by areas under the casing.

5.2 WYVERN Coastguard Variant Concept of Employment (CONEMP)

The flexible sensor and communication options present in the baseline design fulfil the ISR requirements and can be further tailored to meet specific needs. The acoustic, visual and electronic data can be interpreted and reviewed in the submarine's control room (figure 8) before the most relevant data is conveyed to other assets in a timely manner.

Fig. 8. WYVERN coastguard variant's control room

The coastguard variant is designed to act as part of a network alongside surface, airborne and shore assets with the primary role of providing intelligence that other, more

conventional, assets can act on. However, in a real-world scenario, it may be the case that the other assets are not in a suitable position to interdict a suspect vessel.

If the submarine is required to apprehend a vessel alone, then it can covertly track a target and manoeuvre into a suitable position to interdict. Utilising the element of surprise, it can surface and remotely deploy the deck gun. As the speed of the submarine is below that of most high-speed craft, the deck gun can coerce the target into stopping and obeying commands by firing warning shots if necessary.

Once the suspect vessel has been stopped then the submarine either waits for support or readies a small inflatable boat to transfer a boarding party.

5.3 Comparison with Current Coastguard Assets

A comparison of the WYVERN coastguard variant and other current coastguard assets is given in Table 2, showing that a coastguard submarine offers a good trade-off within the range of existing capabilities whilst also surpassing others.

Table 2. Comparison table of current coastguard assets

	WYVERN Coastguard Variant	127m Cutter[a]	42m Cutter[b]	Maritime Patrol Aircraft (MPA)[c]
Covert ISR	Yes	No[d]	No	Yes
Ability to Interdict	Yes	Yes	Yes	No
Crew	15	128	18	5-7
Endurance	22 days	55 days	14 days	>20 hours
Speed	17 kts	28 kts	26.5 kts	320 kts
Range	3,000 nm	12,000 nm	1,500 nm	4,900 nm

Maritime Patrol Aircraft (MPAs) and other airborne assets provide the majority of current ISR capabilities for coastguards [25]. However, to remain covert the MPAs need to operate outside of visual range and rely on their onboard sensors to track the target. A submarine has the ability to get much closer to the target without the risk of counter-detection whilst retaining a long-range, over-the-horizon detection and surveillance ability. Sonar detection ranges can be over 30 nautical miles [11] and in some cases well over 100 nautical miles [26]. A submarine also provides a persistent presence and is able to gather information over a much greater period than a single airborne asset.

The WYVERN coastguard variant offers a reduced interdiction capability compared to a conventional surface asset, such as a large coastguard cutter. However, this is a reflection of the submarine's primary role of ISR.

The maximum speed, range and endurance meet that needed to fulfil the CONOPS whilst keeping the size of the platform to a minimum. It is envisaged that the submarine would operate from a homeport or forward base and patrol the adjacent coastline.

Now that a feasible concept design has been developed, it can be used as a tool to investigate what needs to be done in the wider aspects needed to achieve the operational capability. This would include looking at the crewing of the submarine, the infrastructure required to maintain it, and the doctrine of how the submarine would operate.

5.4 Cost

The cost of a submarine acquisition is highly variable and based on many factors that are unknown for this study. These include the build yard (and their experience), combat system manufacturer and the required number of vessels, as well as the effect of the wider aspects required to deliver the capability [27]. However, cost goes hand-in-hand with size and complexity. As the design strives for simplicity and size has been kept to a minimum, then the relative cost will be much lower than a naval submarine.

The relaxation of naval requirements, the removal of equipment and the reduction in system complexity will lead to improved maintainability, improved reliability and availability and lower cost of ownership.

It is recognised that the cost effectiveness of a dedicated coastguard submarine capability would depend on its utilisation. Similarly, it is recognised that the coastguard variant does not additionally offer wider warfighting capability. However, at a national budget level a Coastguard variant submarine potentially offers a more cost-effective means of conducting maritime security operations than using a naval submarine. A full cost-benefit analysis can now be conducted, based around the WYVERN coastguard variant.

a. Based on the USCG Legend Class high endurance cutters [28].
b. Based on the UK Border Force 42m Customs Cutter [29].
c. Based on the USCG C-130J long-range surveillance aircraft [30].
d. Unless supplemented with an unmanned air system (UAS), which would have a limited range and sensor ability below that of an MPA.

6 Wider Opportunities and Observations

6.1 Submarine Deck Guns

The development of the coastguard submarine highlighted several wider opportunities applicable to all submarines, the first of which is the benefits of a deck gun. Deck guns seem consigned to history and the last Royal Navy submarine to be fitted with one was HMS ANDREW (P423) (figure 9), which was built with a gun fitted and then removed during modernisation. However, the gun was re-instated in 1964 to counter blockade-runners [28], emphasising a deck gun's usefulness against low-threat adversaries.

Fig. 9. HMS ANDREW (P423) [28]

A submarine may find itself in a situation where it is not possible to submerge, such as when conducting a surfaced transit of a harbour choke point or canal. During these periods, the submarine is vulnerable to threats that it is normally immune to, for example small arms fire or explosive boats. The attack on the USS COLE [32] and more recent attacks off Yemen [33] show how devastating these attacks can be.

In these scenarios, the defensive capabilities of a deck gun with greater stopping power could provide a useful addition to the standard force protection fit. For these instances, it might be better suited to have a temporary arrangement that can be installed before a high threat surface transit and then removed for normal operations.

A concept for a submarine mast-mounted recoilless gun was patented in 2007 [34]. Although there has been no recent public development of the system, it emphasises that the author is not alone in investigating methods of providing low-level force. The mast-mounted system was not thought practical for integration onto a coastguard submarine due to an assumed lack of accuracy and range based on its mounting location and recoilless nature, although it was not possible to investigate this in detail.

6.2 Integration of Modular Systems

The coastguard variant's deck gun is stored in a pressure tight stowage as shown in figure 10. For other variants, this stowage could be repurposed and turned into a container for modular systems whilst retaining the original option for a gun, similar to a Vertical Payload Module (VPM) [35] or other modular stowages [36].

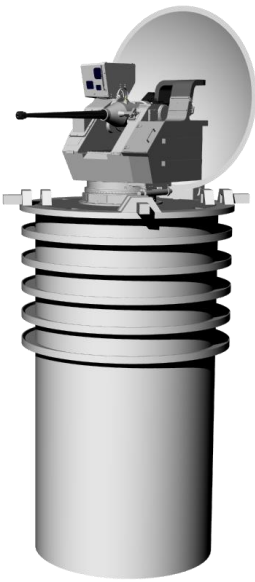

Fig. 10. Deck gun stowage design

This would add a high level of flexibility and capability to any naval submarine, allowing the gun to be swapped out for other payloads such as missiles, unmanned vehicles, or diver equipment. However, the integration of the gun into the WYVERN coastguard variant has demonstrated the design impact of such containers.

The impact to the rest of the design was significant and only possible in the case of the WYVERN coastguard variant by trading other capabilities (AIP and torpedo tubes). This trade-off may not be acceptable for other designs, especially if the complexity of the stowage increases in order to accommodate other capabilities. A good example of this would be additional tankage used to compensate for submerged missile firings. Where integration is not as straightforward then a possible option is the use of a hull plug [37].

6.3 The Benefits of Relaxing Naval Requirements

The development of the coastguard variant has provided a useful comparison between the requirements of a naval and coastguard submarine. As discussed in Section 3, many of the requirements are reduced compared to what would be expected in a naval design, particularly in the following areas:

- Survivability;
- Lethality;
- Signatures.

This presented several benefits to the design. Reducing the survivability requirement allowed for the removal of shock mounts, which significantly improved maintenance access and routing for piping and cabling. The signatures requirement was traded for a more standard, efficient propeller and changes to the hull form, whilst part of the weight margin, created by the removal of the AIP and torpedo tubes, was used to increase the stability of the platform.

The reduction in system complexity potentially offers increased availability, reliability and maintainability, lower design-and-build costs and lower overall costs of

ownership than the bespoke design of a naval vessel. As the design moves away from bespoke naval requirements then class society approval for design and in-service becomes increasingly inviting which could also reduce overall costs.

7 Conclusions

7.1 The Coastguard Submarine

The world's coastguards and border forces conduct a variety of challenging roles, often supported by naval submarines operating in a maritime security mode.

The coastguard variant of the WYVERN design investigates whether a small SSK can operate in a dedicated coastguard role, providing the required ISR capability without the high-end warfighting systems of a naval submarine.

A suitable baseline design allowed the impact of coastguard specific requirements to be evaluated and the overall feasibility determined. This was done by evolving the baseline into a submarine design specifically tailored for a coastguard, whilst maintaining a balanced design. The successful technical design can now be used to assess the capability benefits against programme constraints, such as cost and infrastructure.

7.2 Observations

Three key observations that are applicable outside of the coastguard context were identified during the development of the design. These are:

- Increasing a submarine's ability to counter low-level threats by adding a deck gun would be beneficial in certain scenarios;
- Modular systems offer flexibility but their integration have a large impact on the overall design;
- A non-naval submarine design can take advantage of less strenuous requirements by reducing complexity and seeing improvements in other areas including cost.

References

[1] A.C. Kimber, J. Booth, *Novel Technologies For Enhancing The Performance Of Constabulary And Security Orientated Ships*, RINA Warship (2010)

[2] United States Coast Guard, *Coast Guard Publication 1, Doctrine for the US Coastguard* (2014)

[3] European Commission, European Civil Protection and Humanitarian Aid Operations, *Emergency Support within the EU ECHO Factsheet* (2018)

[4] International Organization for Migration (IOM), 'IOMs Missing Migrants Project', *Mediterranean Update, Migration Flows Europe: Arrivals and Fatalities*, generated 27 March 2019 (2019)

[5] Ministero della Difesa, *Mare Nostrum Operation*, http://www.marina.difesa.it/EN/operations/Pagine/MareNostrum.aspx accessed February 2019

[6] S. Carrera, S. Blockmans, J.P. Cassarino, D. Gros, E. Guild, *The European Border and Coast Guard, Addressing Migration and Asylum Challenges in the Mediterranean?*, Centre for European Policy Studies, ISBN 978-94-6138--565-9 (2017)

[7] International Maritime Bureau Piracy Reporting Centre (IMB PRC), *Piracy & Armed Robbery News & Figures*, https://icc-ccs.org/index.php/piracy-reporting-centre/piracynewsafigures/275-piracynewsafigures accessed February 2019

[8] D.J. Agnew, J. Pearce, G. Pramod, T. Peatman, R. Watson, J.R. Beddington, T.J. Pitcher, PLoS ONE, *Estimating the Worldwide Extent of Illegal Fishing* (2009)

[9] UK MOD, *Joint Doctrine Publication 0-10 (Fifth Edition) UK Maritime Power* (2017)

[10] Ministerie van Defensie, Nederlands Instituut voor Militaire, *Historie, Maritieme antipiraterij operaties Somalië* (2010)

[11] P. Hennessy, J. Jinks, *The Silent Deep: The Royal Navy Submarine Service Since 1945*, 264 (2015)

[12] Royal Navy, *HMS Tireless has been tasked to assist in the search for flight MH370*, https://www.royalnavy.mod.uk/news-and-latest-activity/news/2014/april/02/140402-tireless-mh370-search February 2019 (2014)

[13] Ministero della Difesa, *Mare Nostrum: mother ship seized off Capo Passero*, https://www.difesa.it/EN/Primo_Piano/Pagine/MareNostrummother.aspx accessed: February 2019 (2013)

[14] *Speech by the Netherlands Minister of Defence, J.S.J. Hillen, on the occasion of the Medal Parade of the crew of HNLMS Dolfijn in Portsmouth on May 29 2012*.

[15] T. Gibbs, *Vidar®-7 – The Small SSK for the 21st Century*, BMT, RINA Warship 2014: Naval Submarines & UUVs (2014)

[16] S. Binns, *Meeting the Current Challenge of Designing High Capability SSKs*, BMT, RINA Warship 2008: Naval Submarines (2008)

[17] J.G. Castro, *Continuities and Displacements In The Biography Of 'Narco-Subs': From The Caribbean To The Pacific 1993-2013* (2014)

[18] United States Coast Guard, News. Release. *Coast Guard sees resurgence of low-profile smuggling vessels* (2017)

[19] United States Coast Guard, *Coast Guard Publication 3, Operations* (2014)

[20] Covert Shores, *Narco submarines, torpedoes and semi-submersibles*, http://covertshores.blogspot.com/2010/06/narco-submarines-torpedoes-and-semi.html accessed February 2019 (2010)

[21] Reuters, *Florida convicts leader of Colombian 'narco sub' gang*, https://uk.reuters.com/article/us-usa-florida-drugs/florida-convicts-leader-of-colombian-narco-sub-gang-idUKBRE87M0Y920120823 accessed February 2019 (2012)

[22] B. Ramirez, R. Bunker, Foreign Military Studies Office, *Narco-Submarines. Specially Fabricated Vessels Used For Drug Smuggling Purposes* (2015)

[23] BMT, *Wyvern Datasheet*, https://www.bmtdsl.co.uk/media/6740041/SBPD005-0517_WYVERN.pdf accessed: February 2019 (2017)
[24] MSI Defence Systems Ltd, *SEAHAWK LW25M A2* [brochure] (2017)
[25] United States Government Accountability Office, *Resources Provided for Drug Interdiction Operations in the Transit Zone, Puerto Rico, and the U.S. Virgin Islands*, GAO-14-527 (2014)
[26] Cdr D. Parry, *The History Of British Submarine Sonars*, http://rnsubs.co.uk/articles/development/sonar.html accessed: April 2019
[27] US Department of Defence, *Navy Report On New Attack Submarine (Senate - July 21, 1992)* (1992)
[28] Cmdre S. Saunders, *IHS Jane's Fighting Ships 2016-2017*, ISBN – 978 0 7106 3185 5 (2016)
[29] DAMEN, *STAN PATROL SERIES* [brochure] (2016)
[30] United States Coast Guard Acquisition Directorate, *HC-130J Long Range Surveillance Aircraft* (2018)
[31] RN Subs, *Andrew (P423)*, http://rnsubs.co.uk/boats/subs/amphion-class/andrew.html accessed: February 2019
[32] BBC, *2000: Suicide bombers attack USS Cole*, http://news.bbc.co.uk/onthisday/hi/dates/stories/october/12/newsid_4252000/4252400.stm accessed: April 2019
[33] BBC, *Yemen conflict: Rebels in deadly attack on Saudi warship*, https://www.bbc.co.uk/news/world-middle-east-38808345 accessed: April 2019
[34] W. Scharf, J. Reuter, R. Korver, *Submarine extendible turret system*, United States Patent No: US 7,278,347 B1 (2007)
[35] Submarine Industrial Base Council, *Virginia Payload Module (VPM) Preserves Critical Undersea Strike Capability* (2015)
[36] T. Whitten, *Achieving the Goal of a Submarine Modular Mission Payload System*, Undersea Defence Technologies, (2011)
[37] D. Morris, P. Buckton, *The Design Challenges of a Submarine Host AUV Hull-Plug*, Undersea Defence Technology (2018)

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