Analysis of Barrier and Netting Solutions for Subsurface Threat Mitigation: Efficacy, Challenges and Implications

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Abstract - Rapid development and enhanced capabilities of unmanned surface / subsurface systems and combat divers require the traditional marine security solution of surface based “static floating barriers” to evolve. There is a need for non-lethal countermeasures, such as subsurface netting, to provide security and access control below the water surface. A set of sensitivity studies were conducted to understand the dynamics, loads, and system responses to a variety of counter UUV net systems. These net systems were examined on floating platforms and dynamically deployed from unmanned aerial and surface vehicles. The results of the analysis identified system features necessary to protect waterside assets from underwater threats. This includes the importance of having an adaptable, configurable, and scalable floating barrier/platforms, optimizing the subsurface net mesh to minimize expected drift, and a better understanding of where/when each system should be utilized. Future areas of study are also identified to improve the effectiveness of these non-lethal countermeasures.

1. Introduction

In an era where the integrity of maritime security is intertwined with national defense mechanisms, there is a need for pioneering strategies to mitigate subsurface maritime vulnerabilities. Unmanned Underwater Vehicles (UUVs) have emerged as a formidable threat, bringing significant risks to maritime assets. Despite their (present) lack of sophistication compared to Unmanned Surface Vessels (USVs), UUVs navigate with stealth, making them notably challenging to detect and counteract. Their operational framework is also distinctly nuanced; UUVs often operate with pre-programmed navigation, move at slower paces, and carry limited payloads, but their subsurface operation and quiet demeanor enhance their threat potential by complicating defensive countermeasures.

In response to these multifaceted challenges, this research explores the efficacy of non-lethal countermeasures, focused on underwater netting technologies. In regions marked by intense maritime activity or in proximity to ecologically sensitive zones, the deployment of non-lethal countermeasures netting emerges as a balanced defensive strategy. Such a strategic inclination not only aligns with ethical considerations but also unfolds significant operational advantages, particularly when the identities and intentions of the underwater entities may remain ambiguous. These technologies can fortify maritime assets against unauthorized interventions, establishing a dynamic frontline defense that preserves the integrity of crucial infrastructures such as ports, naval bases, and offshore installations, whilst enabling timely mobilization of responsive actions.

The objective of the study was to explore and assess the use of netting technologies in non-lethal applications deterring unauthorized underwater vehicles, thereby safeguarding vital maritime infrastructures and assets. In doing so, important characteristics were identified, as well as important system features required for underwater netting to be effective.

2. Permanent vs On-Demand Nets

In this study, we analyzed two categories of net systems, each having unique operational and design complexities. The first category, called “Permanently Deployed” in this analysis, encompasses nets that are either permanently affixed to a floating barrier or platform and/or can be deployable from these structures. In this configuration, the net assumes a passive role, extending along the complete perimeter of the defensive architecture, ensuring a comprehensive protective barrier.

The second category explored the response of "on-demand" nets. These nets are delivered and deployed by drones or Unmanned Surface Vehicles (USVs), providing a versatile defense mechanism adaptable to evolving security exigencies. Characterized by predetermined dimensions, these nets would be strategically dispatched to specific locations, as directed by operational necessities, ensuring targeted and adaptable threat mitigation. These nets have been shown to have some benefits, however more understanding of these free-floating systems are needed to evaluate their effectiveness and potential environmental risks.

This dual-focused exploration was aimed to better understand the challenges and effectiveness of each net configuration. The results of this analysis will help end users in the selection of the proper equipment for their security footprint.

3. Approach

Both net categories employed the use of a finite element analysis software package (OrcaFlex®) to simulate the net in a marine environment. All net modeling followed well established analysis approaches utilized in the fishing and aquaculture industry [1,2,3] and all nets had similar solidity [4], however different materials and constructions were analyzed. First, the effect and response of a floating surface barriers' hydrodynamic performance with and without subsurface netting was analyzed. The barrier and netting were subjected to a variety of wind, wave, and current conditions and the system dynamics and critical loads were obtained.

In the second study, the behaviors of the "on demand" nets were analyzed. Two different aerial deployed nets sizes were dropped in an expanded state above the water surface. The vessel deployed net was set up to be statically deployed in the water column. Then, dynamic response of these nets was evaluated under a variety of environmental conditions. The resulting data was then used to understand how these nets responded, their limitations and areas of future work. The results of the study will help in the development of non-lethal countermeasures to this growing threat.

4. Surface Barriers and Subsurface Netting

Three types of surface barriers were analyzed in this effort, as seen in Figure 1: Heavy Duty Net Capture Systems, Light Duty Net Capture systems, and Vessel Destroy Barriers. All systems were constructed in the numerical model to be 93 m long and placed in 20 meters of water. Each end of the barrier was assumed to be fixed to a pile, to ensure similarities between the systems. Thus, the end points were restrained in the horizontal directions, but allowed to move vertically. All geometric and materials properties of the barriers were reconstructed in the model to ensure a proper system hydrodynamic response. It is important to note that this work effort was not intended to promote or demote a surface barrier system - rather to understand how nets affected the different barrier systems.

Three different material types of nets were analyzed, as seen in Table 1. The nets extended to the seafloor and the bottom of the nets were weighed with 5 kg weight distributed in 3.5 m intervals. The nets were suspended from the bottom center of the barrier systems.

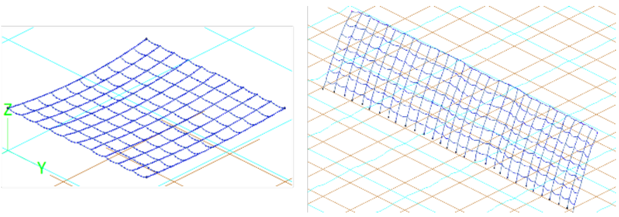


Fig. 2: Examples of on-demand analyzed on-demand nets; the aerial deployed (left) and vessel deployed (right).

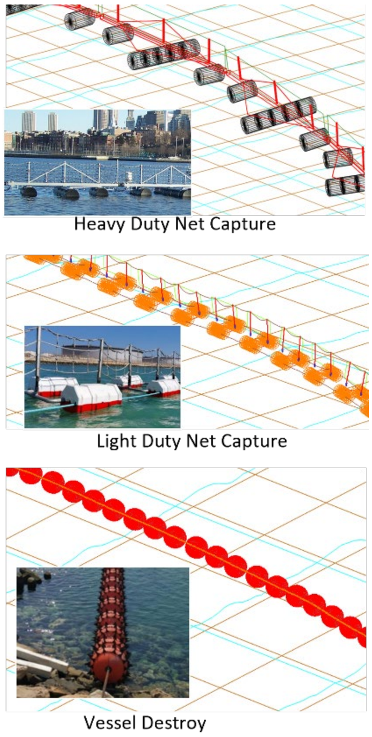


Fig. 1: Example of analyzed surface barriers. Images of the barriers shown can be found at: oceanetics.com (top); halodefense.com (middle), cochraneglobal.com (bottom).

5. On-Demand Netting

For the on-demand netting studies, two different deployment methodologies were examined: those being deployed by an aerial drone/vehicle and those by a surface vessel. The net materials and characteristics were similar to those used in the surface barrier study (Table 1) and can be seen in Figure 2. For the aerial net analysis, it was assumed that the net was deployed 5 meters above the surface, in 10m x 10 m and 20m x 20m sizes. Each net had 5 kg weights attached to the corners. Similar to the surface barriers, a 20-meter water depth was assumed.

The vessel deployed net analysis had a 93-meter length and extended to the seafloor at 20 meters below the surface. Five kg weights were distributed along the bottom of the net in 3.5 m increments. The top of the net was assumed to have buoyancy modules with a linear buoyancy of 4.5 kg/m.

Table 1: Net Properties

Material	Density (kg/m^3)	Solidity (%)	Strand Dia (mm)	Mesh Open (cm)
Monofilament	1150	4	2	10
Knotted Fiber	1150	4	2	10
Stainless Steel	7900	4	5	25

6. Load Cases

The full set of load cases for the permanently deployed study is presented in Table 2. The surface barriers were subjected to combinations of wind, waves, and currents. All waves were analyzed using a Joint North Sea Wave Project (JONSWAP) spectrum. The current velocity was assumed to linearly decrease as a function to depth to 50% of the surface value. Two sets of significant wave heights were selected to simulate a typical "operational" day and a storm event.

Table 2: Permanently Deployed Net Load Cases

Load Case	H_s (m)	T_d (s)	Current (ms^{-1})	Wind (ms^{-1})
1	0.5	3.0	0.05	7.7
2	0.5	3.0	0.255	7.7
3	0.5	3.0	0.51	7.7
4	1.5	7.5	0.05	20.6
5	1.5	7.5	0.255	20.6
6	1.5	7.5	0.51	20.6

The on-demand nets study did not subject the panels to wind and waves. Each on-demand net configuration was subjected to 3 water velocities: 0.05 m/s, 0.255 m/s, and 0.51 m/s. Similar to the permanently deployed load case, the net linearly decreased with depth.

7. Results and Discussion

Permanently deployed netting mean barrier tensions were found to vary significantly between the various systems. Whereas the heavy-duty net capture system saw the lowest relative change in tensions (ranging from 2% to 65% increases across the load cases), it was also subjected to the highest steady loads associated compared to the three systems (Figure 3). The Light Duty Net Capture and Vessel Destroy barriers had less overall barrier loads – however experienced a significant increase in mean barrier tensions when the net was added (ranging from 4% to 130% across the load cases). In addition, both systems had similar mean tensions in load cases 3 and 6, even though the wave heights were much larger in load case 6.

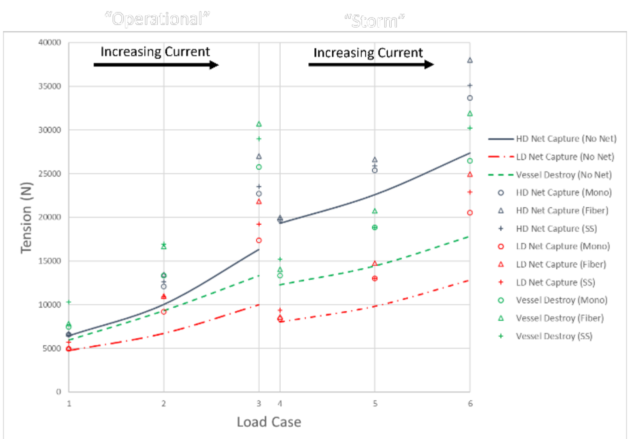


Fig. 3: Permanently Deployed Net Mean Barrier Tensions

Our findings found minimal impact on barrier/platform hydrodynamics in heave (vertical translation), with the net integration leading to a damping in heave response (Figure 4). Larger relative decreases were found in the shorter period waves, with average decreases of 12% in load cases 1 through 3 versus 3% in load cases 4 through 6.

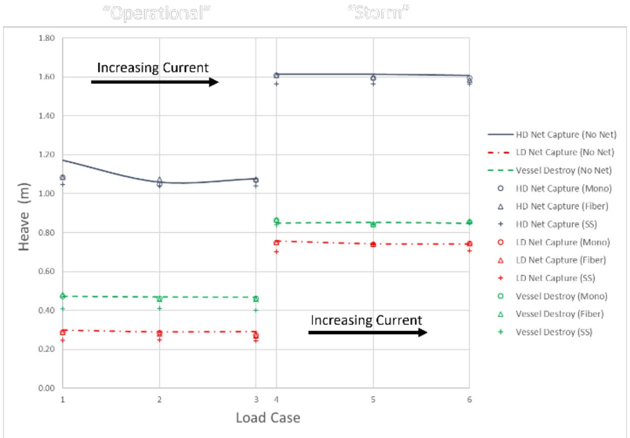
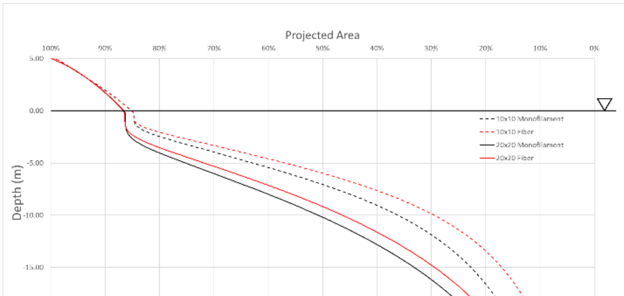


Fig. 4: Permanently Deployed Net Peak Barrier Heave

The on-demand net results for the aerial deployed and vessel deployed are presented in Figure 5 and Table 3, respectively. The aerial deployed nets projected area was found to reduce between 78 and 89%, depending upon size of the net and the net material. Interestingly, the current velocity did not change the decent rate nor projected area, thus only the 26 cm/s results are presented. The nets took approximately 42-48 seconds to reach the seafloor, depending upon the configuration.



Water Velocity (m/s)	Horizontal Displacement (until reaches seafloor)			
	10m x 10m		20m x 20m	
	Monofilament	Fiber	Monofilament	Fiber
0.05	N/A	N/A	N/A	N/A
0.26	7.9 m	9.1 m	11.2 m	17.8 m
0.51	15.7 m	18.2 m	13.9 m	22.4 m

Fig. 5: Aerial Deployed Net Area Loss as a function of Water Depth

The results of the vessel deployed nets are presented in Table 3. Due to the water velocity approaching normal to the net, the projected area did not reduce significantly as a function of time. The nets were found to reach 90% of incident water velocity within 22 seconds of deployment. This worst-case example translates into a drift of 11 meters in this timeframe.

Table 3: Vessel Deployed On-Demand Net Results

Water Vel (m/s)	Projected Area		Time to 90% Incident flow	
	Mono	Fiber	Mono	Fiber
0.05	97%	97%	N/A	N/A
0.26	97%	98%	6.4 s	6.8 s
0.51	94%	95%	16.7 s	22.1 s

8. Discussion and Future Work

This research underscores the promising potential of underwater netting as crucial assets in maritime defense strategies against subsurface threats, highlighting pathways for continued innovation and improvement in maritime security technologies. Permanently deployed netting can provide a heightened ability in access control effectiveness. However, selecting the best barrier system is highly dependent upon the local environmental conditions. The effect of the net was heavily dependent upon the barrier's reserve buoyancy and water plane area, with the heavy-duty net capture system seeing a reduced relative load increase, however also experienced a higher steady state load overall. For the systems with a smaller water plane area, the magnitude of the load fluctuation was much higher, at times increasing the mean load by 130%. In addition, the load response was similar in shorter and longer period waves. Managing the surface system to adequately support a net – in different environments - underscores a necessity for the integration of modularity within the barrier/platform, optimizing its adaptability in alignment with the distinctiveness of site-specific environmental conditions.

On-demand nets present security personnel with flexibility in their security posture. These nets, characterized by their strategic deploy-ability, may have environmental concerns if the nets collapse too much during their decent or cannot be managed after deployment. The aerial deployed on-demand nets were found to experience a significant projected area reduction in deep water, potentially limiting their usefulness. The decent rate between the net sizes and materials were similar. However, the monofilament nets both reached the seafloor faster with less drift.

The vessel deployed net results showed promise in the analyzed simulations. The nets only showed a slight decrease in their projected area. Although the nets reached the incident flow speed in a relative short amount of time, there is room to reduce this with different surface buoyancy and weight configurations – especially when on considers that vessel can handle much larger and more complex payloads compared to aerial drones. Therefore, balancing the surface buoyancy and counterweights will be important to limit this excursion.

However, more work is needed to better engineer these systems to meet future threats. Insights were gained into the operational nuances, technological adaptability, operational efficiency, and practical challenges associated with the deployment of barriers and netting. Thus, informing future strategies for enhancement and refinement. Efforts should include development of scalable & modular surface barriers that are designed to support a net and can be customized for a variety of unique environments. In addition, netting at or around the gates to facilitate vessel access needs to be investigated. For on-demand nets, it will be important to understand the dynamics and response of the net in various current/wave conditions (angles of attack), as well ensure the system can be tracked and recovered to minimize environmental impact.

9. References

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10. Author/Speaker Biographies

Dr. Judson DeCew is president of Ultrasea and has been a noteworthy leader in the ocean engineering space for over 25 years, working on projects that ranged from offshore aquaculture to marine renewable energy to maritime security systems. His thought-leading work has resulted in over 35 peer-reviewed journal publications and conference proceedings and 9 patents.

Michael Osienski, co-founder and driving force at Ultrasea, boasts an extensive background in ocean engineering and marine systems design. He has led pivotal projects, including the design and deployment of state-of-the-art marine gates and barrier systems, and ground-breaking research into the characteristic properties of chain-link copper alloy nets in marine conditions.