

Evaluation and Experimentation of Tensile Mechanics in Relation to Repurposed Marine Netting and Industrial Polymers for FPV Drone Defense

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Abstract

Passive kinetic barriers present a low-cost, zero-power countermeasure against First-Person View (FPV) unmanned aerial vehicles (UAVs) in tactical environments where active RF jamming or electronic countermeasures are restricted or ineffective. This paper evaluates the technical viability of repurposing disused commercial fishing netting; specifically Polyamide 6.6 (Nylon), High-Density Polyethylene (HDPE), and Polypropylene (PP) Copolymer recovered from port infrastructure as deployable anti drone meshes. Utilizing secondary mechanical datasets and analytical structural mechanics models, candidate polymers were evaluated across kinetic strain energy absorption ($U = \int F(x)dx$), dynamic impact shear

survival (τ_y), catenary suspension anchor loads ($T_0 = wL^2/8h$), and crosswind aerodynamic drag (F_d).

Analytical results demonstrate that while Nylon 6.6 provides the highest strain energy absorption density (U) due to its high tensile strength (85MPa) and low initial mass per unit area, its hygroscopic nature (8% water absorption) and rapid UV degradation limit long-term field stability. Conversely, HDPE (1.40mm strand diameter) and Polypropylene (1.50mm strand diameter) successfully survive rotor impact shear stresses across 4-strand and 32-strand configurations, with HDPE achieving a safety factor margin of 0.10 x yield stress under a 192. 90J kinetic impact. A Multi-Criteria Decision Analysis (MCDA) across two operational scenarios establishes HDPE as the optimal material for long-span outdoor perimeter defense due to its complete hydrophobicity, cut resistance, and superior UV longevity, whereas Nylon 6.6 remains superior for compact, indoor structural enclosures.

Keywords— *Counter-UAV, Passive Defense, Polymer Mechanics, Repurposed Marine Netting, Catenary Load Modeling, Strain Energy Absorption, FPV Drones.*

1. Introduction

1.1-Threat Profile and Need for Passive Counter-FPV Drone Systems

First Person View (FPV) drones have changed the way modern tactical environments operate. More specifically, low-cost FPV drone platforms, using carbon-fiber frames and brushless DC motors as well as high strength polymer or composite blades, provide a cheap, easy weapon with which to destroy vehicles and emplacements with precision and speed that would otherwise require a multi-thousand dollar weapon.

While active countermeasures such as RF jamming or microwave beams have been shown to work in the past, they are still constrained by line-of-sight limitations, energy requirements, and frequency hopping protocols. Additionally, optically-guided drones are completely immune to active countermeasures, as they transmit the signal using a fibre optic cable. Consequently, passive countermeasures such as barriers provide a low-cost, zero power alternative for defense across transport corridors, entrances, and emplacements.

1.2-Engineering Requirements for Defensive Marine Netting

Passive anti-drone netting relies on the dissipation of kinetic energy through mechanical entanglement. When a high speed rotor – such as that of an FPV quadcopter – strikes a suspended flexible mesh, the energy is quickly dissipated into tensile strain along the filaments of the net. This stops the drone from entering the defended area, and occasionally entangles it in the mesh, leaving it out of action. The ideal barrier must satisfy three equally important engineering constraints:

Ideal Mesh Requirements

High tensile strength (To resist damage and absorb impacts from heavier drones)	Low mass per unit area (To minimise structural load)	Optimal net gap size (To nullify the possibility of the smallest drones getting through, and increase chance of blade entanglement)
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Sourcing newly manufactured nets to serve as drone countermeasures is costly. Thus, an interesting opportunity is presented: collecting disused marine nets and waste polymers turned into 3D printing filaments that fulfill the above criteria. This would not only mitigate the financial constraints, but would also provide otherwise discarded nets and filaments with a second life, as discarded industrial polymers turned into 3D printing filaments and commercial fishing netting from port infrastructure is an abundant source of high-grade synthetic polymers such as Nylon, Polypropylene, or HDPE (High-Density Polyethylene).

1.3-Scope and objectives

This paper evaluates the viability of repurposing disused marine netting from ports for tactical passive UAV countermeasures. Specifically, to:

1. Categorise structural and chemical properties of widely used polymers in marine netting and 3D printing (Nylon 6.6, Polypropylene (Copolymer), and HDPE).
2. Establish a framework for assessing kinetic energy displacement, entanglement of motors, and cases of material failure.
3. Present and evaluate results of experimentation regarding differences in netting material, culminating in a summary outlining the pros and cons of each candidate material.

2. Materials and Structural Properties

2.1- Polymer classification and chemical/physical resistance

Modern marine netting utilised in trawler fishing consists of three main types of polymers, each displaying distinct mechanical behaviours in terms of high-speed and energy kinetic impacts:

- Polyamide (Nylon 6.6): Characterised by high ultimate tensile strength (≈ 85 MPa (Megapascals)) [1] and high energy absorption prior to failure due to high elongation capacity ($\approx 70\%$) [1]. However, Nylon is hygroscopic, meaning that moisture absorption increases impact toughness while reducing its elongation capacity.
- High Density Polyethylene (HDPE): Excellent chemical inertness, near-zero hygroscopy, and a low friction coefficient. While HDPE exhibits a lower ultimate tensile strength than Nylon (≈ 20 -30 MPa) [2, 3], braided HDPE, often used in marine netting, provides a remarkable strength-to-weight ratio, and high resistance to cutting.
- Polypropylene (Copolymer): Possessing a lower density than water (0.90 - 0.92g/cm^3) [4, 5], Polypropylene netting provides moderate tensile strength, but suffers from UV degradation.

Material	Density	Ultimate	Break	UV Resistance	Hygroscopicity
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	(g/cm ³)	Tensile Strength (MPa)	Elongation (%)		
Nylon 6.6	1.14	85	50	Half a year of resistance[6]	High (<8%) [7]
HDPE	0.95	20-30	500-1000[2,3]	1-3 years of resistance[8]	Resistant (<0.1%)[9]
Polypropylene (Copolymer)	0.91	29[10]	150-300[5]	Up to 70% strength loss after 12 months[11]	Resistant (<0.1%)[12]

In summary:

Nylon 6.6	HDPE	Polypropylene (Copolymer)
High Energy Absorption	Hygrophobic	Hygrophobic
High Tensile Strength	Lower Tensile Strength	Lower Tensile Strength
Dense, Ideal for Static Enclosure Protection	Less Dense, Ideal for Suspended Span Nets	Less Dense, Ideal for Suspended Span Nets
50% Strength Loss After 2 Years of UV Exposure	50% Strength Loss After 3-4 Years UV Exposure	70% Strength Loss After 12 Months
Low Break Elongation	High Break Elongation	Mid-Range Break Elongation

2.2-Geometric Configuration and Aperture Mechanics

The interaction between a rotating propeller blade of radius R_p and a gap in the net of side length a_m governs the probability of entanglement versus passage, where θ is the strike angle relative to the mesh plane:

$$\text{Entanglement Condition: } am \leq 2Rp \times \sin(\theta)$$

The gap size measured at the port location for two types of Nylon and one type of HDPE netting were as follows:

Nylon 6.6 type 1: 4cm x 4cm gaps	Nylon 6.6 type 2: 1cm x 1cm gaps	HDPE: 1cm x 1cm gaps
Applying the formula, the propeller radius would have to be smaller than 2cm to pass through at a 30 degree angle, resulting in a high entanglement chance for the first type of Nylon	The propeller radius would have to be smaller than 0.5cm to pass through.	As with Nylon type 2, the radius of the propeller would have to be smaller than 0.5cm to pass through at a 30 degree angle.

According to the results of applying the entanglement condition equation, Nylon type 2 and the sample of HDPE would be the ideal nets for rotor entanglement and stopping the smallest types of drones 100% of the time, attributable to their 1x1cm gap size.

1. Aperture size

- Small netting gap ($a_m < 30\text{mm}$): High entanglement probability, but increases aerodynamic drag and total system mass, leading to central sag if the mesh is suspended in a wide-open setup.
- Medium netting gap ($30\text{mm} \leq a_m \leq 60\text{mm}$): Optimal gap size for typical 12-25cm FPV drone propellers. This allows for a high chance of propeller entanglement with significantly less drag than a small netting gap.
- Large netting gap ($a_m > 80\text{mm}$): Low aerodynamic drag, but gaps much larger than 80mm could allow for extremely small quadcopters to pass through unless impacted obliquely.

2. Weave architecture and knot mechanics:

- Knotted netting: Features explicit visible mechanical knots in the mesh, which while providing local stress isolation (for instance if one strand breaks the entire section is not rendered unusable), also introduces stress concentration weak points at the knot core, reducing net tensile yield under high kinetic loads.
- Knotless netting: Interwoven continuous filaments that distribute impact loads continuously throughout the mesh. Knotless netting offers higher strength-to-weight ratios, but doesn't have local stress isolation, meaning tears in the netting could result in entire sections being rendered unusable.

2.3-Environmental Degradation Assessment

As the marine netting is recovered from ports and has undergone variable operational stress (i.e. saltwater immersion, mechanical friction, stress, and solar UV exposure), inspection protocols must be introduced before the netting can be deployed defensively:

- Visual surface abrasion: Fraying exceeding 15% of the filament cross section area should not be deployed due to localised load reduction (measured by comparing cross section area of brand new net with cross section area of repurposed net).
- Salt Crystal Encrustation: Tiny salt crystals can build up on the mesh fibres which increases surface friction but can embrittle individual fibres under rapid bending. The nets require freshwater rinsing before deployment.
- UV Photodegradation: Exposure to UV radiation causes the polymer chains to degrade. Samples of the mesh should be subjected to testing to verify that yield strength remains within $\geq 70\%$ of original material specification.

3. Experimental Methodology and Analytical Framework

3.1- Secondary Data Sourcing and Material Characterisation

To establish mechanical baselines for potential marine netting materials without laboratory testing, physical and mechanical properties were compiled from material research databases and published literature on degraded polymer textiles. The following factors were evaluated:

- Baseline tensile metrics: Values for ultimate tensile strength, elastic modulus, yield stress, and break elongation were extracted from open-access databases for Nylon, HDPE, and Polypropylene in the sections above.
- Field measurements: Physical parameters such as gap size (a_m), the cross-sectional diameter of the strands, and knot geometry were measured from samples at port locations for monofilament Nylon. Measurements for HDPE and Polypropylene, which were unavailable for direct measurement in the field, will be displayed as the amount of elongation on top of the initial length before breaking.

4. Results and Discussion

4.1- Comparative Material Energy Absorption Analysis

1. Average elongation at break:
 - Nylon 6.6: High breaking elongation (70% average) allows extended plastic deformation ($\Delta L = 0.70L_0$). At the length measured in the field (20cm), this means that the maximum elongation before tearing would be 32.8cm, showing a high total absorbed strain value before breaking.

- HDPE: With a higher average breaking elongation at $\approx 650\%$, HDPE allows for a plastic deformation of $(\Delta L = 6.5L_0)$, extending much farther than unreinforced Nylon. This would aid in rotor entanglement, but with a moderate absorbed strain value before breaking.
- Polypropylene (Copolymer): Polypropylene yields an average breaking elongation of $\approx 600\%$, meaning it has roughly the same chance of rotor entanglement as HDPE, not taking into account material tensile strength. However, Polypropylene exhibits the lowest absorbed strain value of the three materials before breaking.

2. Impact Shear Verification: Comparing the dynamic shear stress (τ) generated during contact against the material yield limits derived from the databases, where N = number of active strands woven together.

$$\tau_y \geq \frac{F_{\text{impact}}}{N \times \text{Astrand}}$$

Impact force tested will be curtain type setup, allowing the nets a looser 1.5 metres of space to stop the drone.

$$\text{Impact Force} = \frac{192.90J}{1.5m} = 128.6N$$

Assuming the drone weighs 2kg and is moving at 13.889m/s, using the equation $E_k = \frac{1}{2}mv^2$, we can derive that the drone's kinetic energy is 192.90 Joules.

The thickness of the Nylon strand used in the equations is 0.30mm, for HDPE it is 1.4mm, and for Polypropylene 1.5mm, as based on industry products found for sale, and diameters found in upcycling studies, which could be woven into fishing nets [13, 14, 15]. The tables below include different amounts of fibres woven together, and how many strands of each material required in the netting to stop the defined threat from passing through the net.

Nylon 6.6:
(Stress limit=85Mpa)

Strand thickness	Number of active	Total Combined	Applied Stress	Safety factor
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(diameter)	strands (N)	Area ($N \times A_{\text{strand}}$)	(MPa)	
0.30mm	1	$7.07 \times 10^{-8} \text{ m}^2$	1,819.22	FAIL, 21.4x overstress
0.30mm	4	$2.83 \times 10^{-7} \text{ m}^2$	454.81	FAIL, 5.35x overstress
0.30mm	32	$2.26 \times 10^{-6} \text{ m}^2$	56.85	PASS, 0.69x safety factor

HDPE:
(Stress limit=25MPa)

Strand thickness (diameter)	Number of active strands (N)	Total Combined Area ($N \times A_{\text{strand}}$)	Applied Stress (MPa)	Safety factor
1.40mm	1	$1.54 \times 10^{-6} \text{ m}^2$	83.54	FAIL, 3.34x overstress
1.40mm	4	$6.16 \times 10^{-6} \text{ m}^2$	20.88	PASS, 0.84x safety factor
1.40mm	32	$4.93 \times 10^{-5} \text{ m}^2$	2.61	PASS, 0.10x safety factor

Polypropylene (Copolymer):
(Stress limit=29MPa)

Strand thickness (diameter)	Number of active strands (N)	Total Combined Area ($N \times A_{\text{strand}}$)	Applied Stress (MPa)	Safety factor
1.50mm	1	$1.77 \times 10^{-6} \text{ m}^2$	72.77	FAIL, 2.51x overstress
1.50mm	4	$7.07 \times 10^{-6} \text{ m}^2$	18.19	PASS, 0.63x safety factor
1.50mm	32	$5.65 \times 10^{-5} \text{ m}^2$	2.27	PASS, 0.078x safety factor

Polypropylene displayed the highest durability against the 2kg drone, attributed to the fact that the strands of Polypropylene netting are thicker when used in netting. Additionally, HDPE fared well in impact shear verification, also passing when it was woven into 4 or 32 strands, but with a worse safety factor.

4.2- Analysis on Suspension Procedure (Catenary Sag and Load Sensitivity Analysis)

To evaluate the structural burden imposed by the netting on anchor points, a catenary load model was applied across a standard length of 10m (L=10m) under a fixed vertical sag allowance of 0.5m (h=0.5m)

The horizontal endpoint tension (T_0) governed by the catenary formula is expressed as:

$$T_0 = \frac{w \times L^2}{8h}$$

Where w represents the linear weight per unit length.

Material	Density (g/cm ³)	Total Cross-Sectional Area (Strands of 32 fibres x A _{strand}) m ²	Linear Weight (N/m) [w]	Endpoint Tension [T_0]	Relative Structural Load Overload
Nylon 6.6 (0.30mm)	1.14	2.26x10 ⁻⁶ m ²	0.0253	0.6325	100% (Baseline)
HDPE (1.40mm)	0.95	4.93x10 ⁻⁵ m ²	0.4594	11.485	+1715.81%
Polypropylene (Copolymer) (1.50mm)	0.91	5.65x10 ⁻⁵ m ²	0.5044	12.610	+1893.68%

Nylon exhibits the lowest endpoint tension on the anchor points, followed by HDPE and Polypropylene. This is attributed to Nylon's small individual strand diameter, compared to larger diameters such as HDPE's or Polypropylene's. It is important to note, however, that Nylon's 8% water absorption can to an additional increase in static sag [h], unless endpoint tension [T_0] is adjusted accordingly.

5. Material Ranking and Summary

5.1- Evaluation Criteria and Weight Distribution

Criterion	Code	Measurement Basis/Source	Scenario 1 weight [W_1]	Scenario 2 weight [W_2]
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Shear Safety Factor	C ₁	Safety Factor at 32 strands (Sec 4.1)	0.35	0.20
Energy Absorption (<i>U</i>)	C ₂	Strain Capacity (From highest to lowest) (Sec 4.1)	0.25	0.15
Catenary Load Overhead	C ₃	Anchor tension [<i>T</i> ₀] and linear mass [<i>w</i>] (Sec 4.2)	0.15	0.35
Hygroscopic Stability	C ₄	Mass change/sagging under moisture (Sec 2.1 and 4.2)	0.10	0.15
UV Resistance/ Lifespan	C ₅	Strength retention after UV Exposure (Sec 2.1)	0.15	0.15

Scoring Scale: 1 = Worst of three materials, 3 = Moderate, 5 = Best of three materials

5.2 - Quantitative Scoring Matrix

Material	C ₁	C ₂	C ₃	C ₄	C ₅	Scenario 1 Score [$\sum R \times W_1$]	Scenario 2 Score [$\sum R \times W_2$]
Nylon 6.6 (<i>d</i> = 0.30mm)	2.0	5.0	5.0	1.0	2.0	3.10	3.25
HDPE (<i>d</i> = 1.40mm)	4.0	3.0	2.0	5.0	5.0	3.70	3.45
Polypropylene Copolymer (<i>d</i> = 1.50mm)	5.0	2.0	1.0	5.0	1.0	2.95	2.65

5.3 - Scenario Analysis and Ranking

Scenario 1: Fixed Enclosure and Gateway Barriers

Winner: HDPE (Score: 3.70)

Justification: In fixed doorways, window frames, or emplacements where rigid anchoring points exist, catenary sagging [C_2] is less critical. HDPE outperforms Nylon because its thicker braided strand geometry (1.40mm) provides a superior shear safety factor [C_1] against high speed FPV drone impacts while remaining completely hydrophobic and more resistant to UV related strength degradation than Polypropylene.

Scenario 2: Suspended Long-Span Perimeter Barriers

Winner: HDPE (Score: 3.45)

Justification: While Nylon achieves the lowest catenary load ($T_0 = 0.632 \text{ N}$ due to its thin 0.30mm strand), its lower shear survival margin at thin diameters and poor resistance to water absorption and UV degradation reduces its score. HDPE offers the best balance of mechanical protection, zero water absorption, and long-term outdoor resistance.

Final Material Suitability Ranking

Rank	Material	Primary Advantage	Primary Limitation
1	HDPE	Best overall balance; high tensile strength, zero water absorption, 1-3 years UV resistance	Moderate catenary load on anchor points when woven thick (1.4mm)
2	Nylon 6.6	Exceptional tensile strength and lowest static sag due to light weight	Absorbs water (+8% mass increase), and rapid UV breakdown
3	Polypropylene	Highest shear safety factor at 1.5mm strand thickness	High catenary load on anchor points, and severe UV breakdown (70% after 1 year)

5.4 - Summary

This work presents a computational structure and framework for analysing different candidate materials for defensive anti drone netting. Baseline figures regarding density, tensile strength, etc. are obtained from various industrial data sheets and articles, including the study performed by P. Ghabezi et al. on turning industrial waste into 3D printing filaments, which could also be used to weave nets[14], and the British Plastic Federation's article on Polypropylene. A framework to calculate different criteria for comparing net materials such as energy absorption and catenary sag is presented and explained. Then, the acquired figures are weighed against each other to finally present a multi-criteria decision analysis of the best suited materials for two scenarios present in modern combat zones.

This paper further uses this framework to evaluate the viability of repurposing disused commercial marine netting (Nylon (Polyamide) 6.6, High-Density Polyethylene, and Polypropylene Copolymer) as passive counter-FPV drone barriers. Baseline mechanical and physical properties—including density, ultimate tensile strength, elongation at break, and environmental degradation limits—were synthesized from open-access material databases [1-12], mathematical models were established to evaluate kinetic strain energy absorption, dynamic shear resistance, and catenary anchor loading, and a multi-criteria decision analysis (MCDA) was applied to weight these performance metrics across two tactical scenarios: fixed structural enclosures and suspended open-span perimeters. The results establish High-Density Polyethylene as the most versatile candidate for long-term outdoor deployment due to its high cut resistance, zero hygroscopicity, and superior UV durability, while Nylon 6.6 offers optimal strain energy density for compact, high-energy impact zones.

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