A Comparison of the Hydrodynamic Resistance of Nylon and Spectra Trawls

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MITSG 92-18

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Abstract:

This report describes research on the resistance effects of using ultra-high-molecular-weight (UHMW) polyethylene netting instead of nylon netting of similar mechanical performance. The netting sizes compared were based on equivalent twine breaking strengths of the two materials. Resistance tests were done in the 52'-wide towing basin and the David Taylor Research Center (DTRC) in Bethesda, Maryland. Large, rigid test frames were used to support the netting in a realistic trawl shape in which mouth opening was held constant with speed. Nets of 1 7/8" stretch mesh were tested on a round-cornered frame 25' wide by 4' high using a trawl configuration based on Gulf of Mexico shrimping practices. Nets of 5 1/2" stretch mesh were tested on a round-cornered frame 21' wide by 8' high using a net configuration based on New England and West Coast groundfishing practices.

Test results showed a 28% drag reduction using #11 UHMW polyethylene compared to #21 nylon in a shrimp trawl configuration. Results for a groundfish trawl showed a 44% drag reduction using #18 UHMW polyethylene compared to #42 nylon. Subsequent mechanical tests indicated nearly equivalent knotted twine strengths for the compared materials while the abrasion resistance of the UHMW polyethylene was found to be 27% to 650% greater than the Nylon.

Introduction:

The resistance implications of netting size in trawl nets has been the subject of numerous studies and reports. Tests aimed at quantifying the effects of varying twine diameter and mesh size typically fall into one of three categories: laboratory scale-model tests (1), laboratory netting-panel tests (2 - 3), and full-scale sea trials (4 - 6). From these sources of empirical data, researchers have developed formulas to relate the drag of netting based on its specifications and its orientation and location in the trawl net.

Unfortunately the test methods listed above each pose limitations on the reliability of the results. Experiments using scale-model trawls tested in circulating water channels or tow tanks suffer from scale effects (Reynold's number mismatch) and improper flow characteristics (ambient turbulence), and lack of geometric control (the trawl shape varies with speed.) Similarly, laboratory tests on sections of netting, either flat panels or netting cones, seldom can fully account for the effect of the necessary support frame, the edge effects caused by a relatively small panel size, and test section blockage effects. While sea trials, to some, represent the ultimate experiment, the effects of environmental factors, the lack of control over trawl geometry, the complications associated with underwater instrumentation, and the inability to isolate the effects of specific changes makes reliable test data difficult to obtain and to interpret.

The recent introduction of high-strength, high-modulus fibers in netting twines has caused increased interest in the resistance effects of their adoption. Due to net makers' and fishermen's unfamiliarity with the materials and their higher cost per pound, reliable data on their performance is needed to determine their most appropriate applications.

UHMW polyethylene is produced domestically by Allied-Signal, Inc. under the trade name Spectra. Its unique mechanical properties have been shown to be of use in a variety of trawling applications including on-deck gilsons (7), trawl reinforcement lines (8, 9), and as netting in areas of high abrasion (10).

Table 1 compares the specifications of Spectra twine from Allied Signal and Nylon twine from other two suppliers. The data listed is from specification sheets provided by the manufacturers (11 - 13). The table reveals that, over the sizes listed, Spectra averages 117% stronger and 8% lighter.

	Spectra			Mfg. #1 nylon			Mfg. #2 nylon	
Size	Diameter (inches)	Strength (pounds)	Runnage (feet/lb)	Diameter (inches)	Strength (pounds)	Runnage (feet/lb)	Strength (pounds)	Runnage (feet/lb)
7	0.034	155	3,280	0.034	70	3,105	51	3,754
12	0.048	220	2,000	0.045	115	1,890	105	1,800
15	0.052	310	1,690	0.050	135	1,590	125	1,500
18	0.058	350	1,330	0.057	180	1,170	170	1,090
24	0.075	490	800	0.070	275	780	255	725

Table 1. Manufacturers specifications for nylon and Spectra twines.

For a given strength requirement, the crossectional area of a twine varies inversely with the strength per unit area of the fiber from which the twine is made. The use of Spectra fiber should, therefore, allow a twine only 68% of the diameter of the nylon it replaces. Since hydrodynamic drag varies roughly with the surface area of an object, it could be argued that the affects of using smaller-diameter twines in a trawl net could be predictable. Using this simple analysis, we could anticipate a drag reduction of 32%.

Unfortunately, three factors conspire to complicate such a straight-forward approach:

1. Reynold's number changes associated with the smaller diameter result in a slight increase in the drag coefficient.

2. When used with constant mesh size and for typical netting panel angles of attack, smaller diameter twine offers less blockage for its downstream neighbor, therefore a greater portion of the total twine is exposed to full flow velocities.

3. The reduced blockage associated with smaller twine reduces the average flow velocity through the netting.

In order for a net designer or fisherman to take full advantage of the drag reduction associated with smaller twine diameters, that reduction needs to accurately quantified. The experiments described in the next section of this report were conducted for that purpose.

Materials and Methods:

In order to eliminate the inaccuracies associated with the typical netting drag experiments described previously, a test regimen was used which provides the realistic flow conditions achieved in full-scale trials combined with the experimental control of a laboratory situation. Tests were done in the 52' wide towing basin at the David Taylor Research Center in Bethesda, Maryland (14). This facility has been used by the MIT Sea grant College Program in a variety of trawl related experiments (15). In one set of experiments, the resistance affects of nylon verses polyethylene twine was studied using full-scale commercial trawls (16).

In order to develop results applicable to a range of fisheries, two different trawl configurations were used. One, designed in a shrimp trawl configuration, was used to explore the twine diameter affects in a small-mesh, low opening net. Shown in Figure 1, it is 488 meshes around, 200 meshes deep, and constructed in 1 7/8" netting. The tapers and side-panel height is based on a typical 40' flat net design (17). As shown in the net plan, the wings and corner gussets found in a real shrimp net have been eliminated, allowing the fishing circle to be attached directly to a support frame.

To explore the effects of twine diameter on higher-opening trawls with larger mesh sizes than used in shrimping, a trawl design based on groundfish nets was developed. Shown in Figure 2, this design is 244 meshes around, 75.5 meshes deep, and fitted with a codend 60 meshes around by 36 meshes deep. It was constructed of 5 1/2" mesh and, as with the shrimp net, the panels usually found forward of the fishing circle have been eliminated to allow its attachment to the towing frame. The specifications of the four nets tested are shown in Table 2.

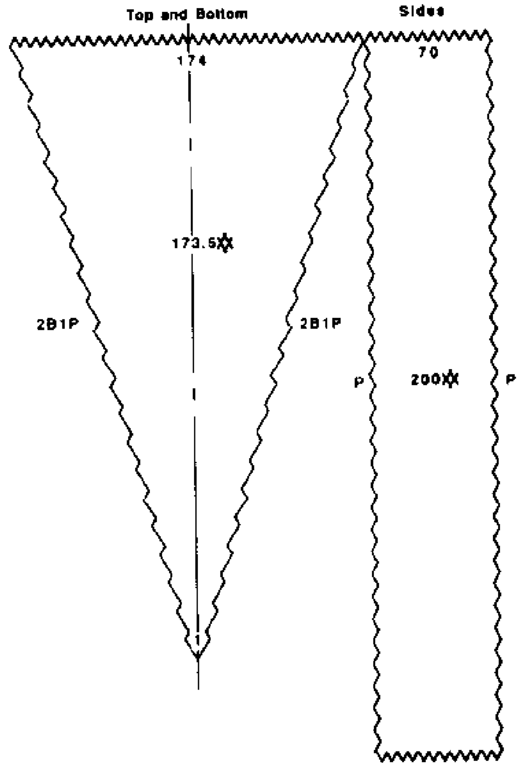


Figure 1. Shrimp trawl test net.

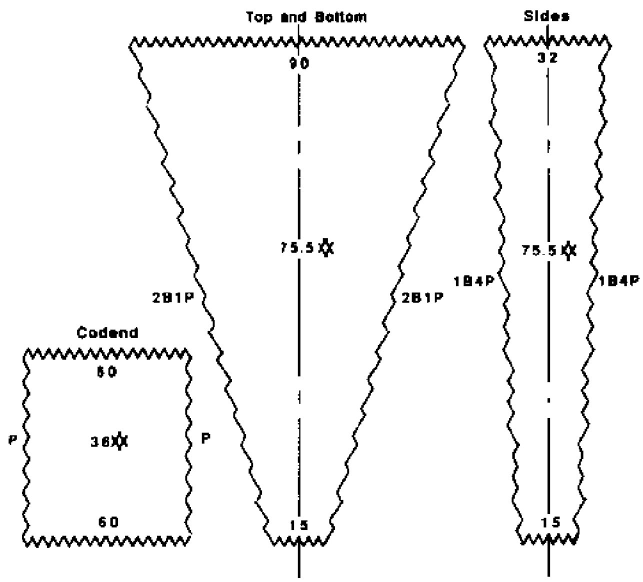


Figure 2. Groundfish trawl test net.

Trawl type Material		Shrimp nylon	Shrimp Spectra	Groundfish nylon	Groundfish Spectra
Mesh size	inches	1 7/8	1 7/8	5 1/2	5 1/2
Twine size		#21	#11	#42	#18
Twine diameter	inches	0.07	0.048	0.098	0.054
Circumference	meshes	488	488	244	244
Belly depth	meshes	173.5	173.5	75.5	75.5
Codend circ.	meshes	140	140	60	60
Codend depth	meshes	26	26	36	36
Twine area	square feet	106.1	72.7	92.8	56.3

Table 2. Summary of test net specifications.

As discussed earlier, conventional full-scale or small-scale resistance testing of trawl nets suffer from their variable geometry. The principal cause of this variability is that a trawl's vertical gape is dependent on flotation installed on the headline opposing weight fitted to the footrope. In a trawl net, these forces are constant while the drag forces increase with towing speed. The result is a shape which loses height with speed and, due to mechanical constraints, increases its width. A change in netting drag has the same effect; the trawl takes a new shape based on the relation between drag and weight effects. The altered geometry will bias the resistance effects of the twine-diameter change.

It is therefore necessary to freeze the shape of the trawl to isolate the parameter in question. For these experiments we developed a support frame to which the trawls could be attached. Efforts were made to minimize the drag and the weight of this frame and to make net changes convenient. A streamlined aluminum extrusion was used for the frame, providing sufficient strength and offering a trailing-edge extension to facilitate lashing the net in place. The aluminum extrusion is shown in Figure 3.

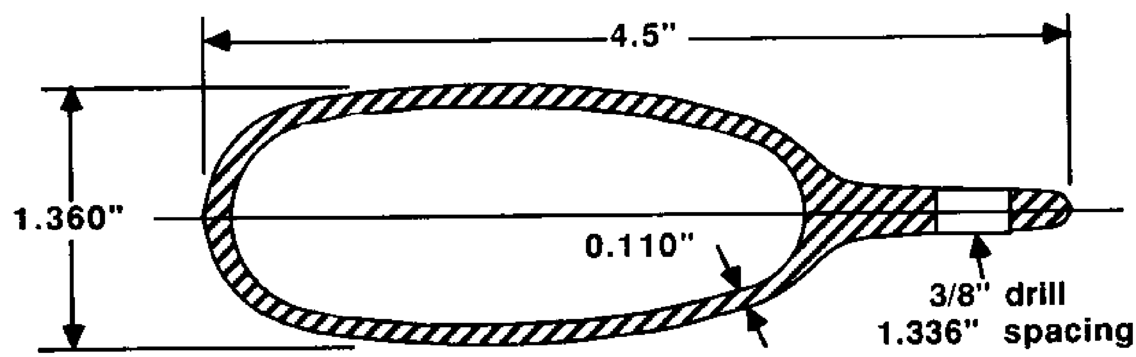
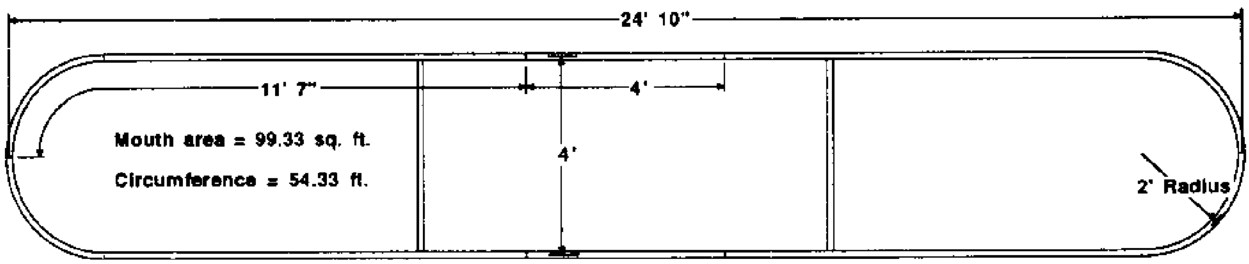


Figure 3. A crossection of the aluminum extrusion used in the test frames.

The round-cornered frame is shown in Figure 4. Its modular design allows its transformation from a low-opening shrimp trawl configuration to a high-opening groundfish shape. In the first case, the frame is 24' 10 inches wide by 4' high. To stabilize the height of this wide frame, two streamlined vertical struts were placed 8' apart in the center of the frame. To suit the groundfish trawl, the removable 4' sections from the top and bottom of the shrimp-trawl frame are transfered to the sides, yielding a frame that is 20' 10" wide and 8' high. One central strut was used to stabilize the mouth opening. The circumference of both configurations is the same while the mouth area is 99.3 sq.ft. and 166.7 sq.ft. respectively.

Shrimp trawl test frame



Groundfish trawl test frame

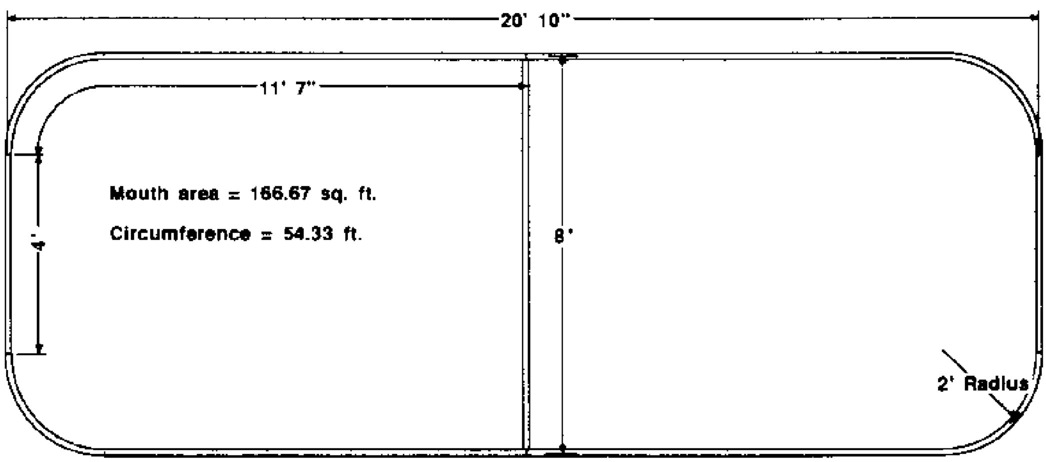


Figure 4. The test frames used in the resistance experiments.

Holes were drilled evenly along the trailing edge of the extrusion to match the fishing circle of the shrimp trawl, mesh for mesh. 488 holes were drilled, 3/8" in diameter and 1.336" apart, matching the 3 meshes every 4" used in shrimp trawl construction. This hole spacing also made a good match for the 5 1/2" netting. Lashing one of the 244 meshes to every other hole provided a 48.6% hanging ratio, close to the 50% used by many net makers.

The test frames were towed using a four-part bridle, approximately 30'-long, of 3/32" diameter stainless steel cable. The bridles converged to one tow point as shown in Figure 5. Also shown is the tow strut and the location of the frame with respect to the carriage while being towed. A 500-pound-capacity load cell built by AMTI (18) was used to measure the tension in the horizontal tow line. The load cell was excited using a 10 VDC power supply and its output was feed to a variable-gain Data Translation A/D board fitted in a portable computer. Resident data acquisition software read voltages over a specified time span and converted averages to pounds based on an initial calibration using weights.

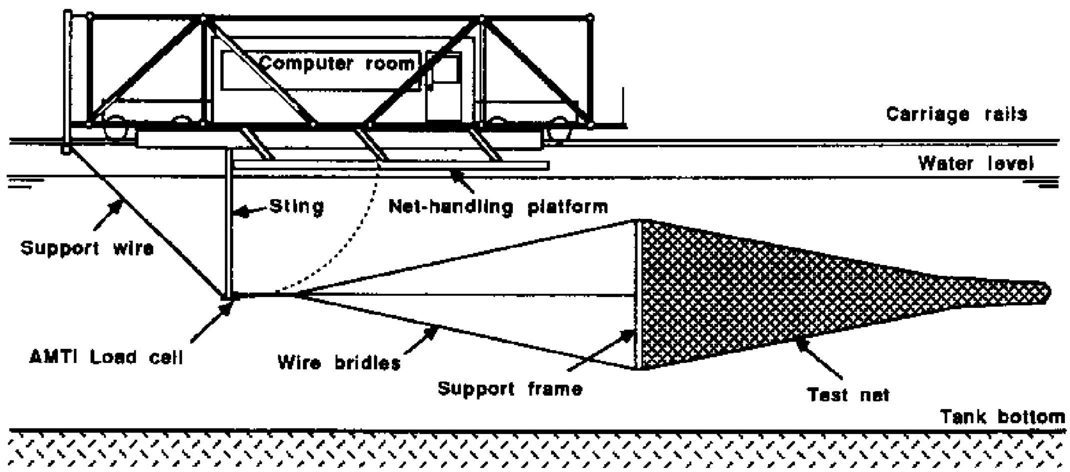


Figure 5. Carriage 1 at DTRC fitted with the towing sting and load cell.

Between runs, the test frames were supported in their approximate towing position with two light lines leading vertically up to the carriage structure. Overhead cranes at the DTRC facility eased the handling of the large frames during launch and recovery and during net changes.

Results:

To determine the drag of the nets alone, tare values for the bare frame drag were taken for both frame shapes. The tare data is presented in Table 3. Also shown is a simple velocity-squared relationship selected to match the actual data at the higher speeds. At the lower speeds the measured drag varied from this ideal relationship because the frames did not assume a properly-aligned orientation since the drag was much less than their underwater weight. These calculated values were used as the tare values in determining the trawl resistance results. The bare frame resistance accounted for between 4.5% and 10.7% of the total frame and net resistance measurements.

Tests on each net were run over a range of speeds within the limits of the load cell (500 pounds). This maximum speed varied from 2 knots for the nylon shrimp net to 3.4 knots for the Spectra groundfish net. A sufficient number of discrete speeds were used for each net to determine its resistance characteristics.

The results are presented in Tables 4 and 5, including the actual measured drag readings, corrected drag, and a least-squares second order curve fit. The drag difference between the two nets is then calculated from this regression and the percent reduction given.

In these tables a clear resistance advantage is shown using the Spectra netting. For the shrimp trawl configuration the average drag reduction is 28.4% while with the groundfish trawl configuration the average reduction is 44.0%. We can also note that for both designs, the advantage increases steadily with higher towing speeds. The drag reduction of each Spectra trawl verses speed is plotted in Figure 6.

	Shrimp Frame		Groundfish Frame	
Speed (knots)	**Measured** (pounds)	**Vel. squared** (pounds)	**Measured** (pounds)	**Vel. squared** (pounds)
0.00	0.00	0.00	0.00	0.00
1.00	14.56	5.71	13.88	4.55
1.50	21.80	12.85		10.24
1.75		17.49		13.93
2.00	23.14	22.85	23.33	18.20
2.25		28.92		23.03
2.50	35.72	35.70		28.44
3.00		51.41	40.96	40.95
3.40		66.03		52.60

Table 3. Tare values for test frame resistance.

Shrimp Trawl

Speed (knots)	Frame 1 (pounds)	Nylon (pounds)	Less frame (pounds)	Curve fit (pounds)
1.00	5.71	125.45	119.74	125.17
1.50	12.85	279.19	266.34	261.97
1.75	17.49	371.24	353.75	348.81
2.00	22.85	465.90	443.05	447.93
2.25	28.92			559.33
2.50	35.70			683.02

Speed (knots)	Frame 1 (pounds)	Spectra (pounds)	Less frame (pounds)	Curve fit (pounds)	Difference (pounds)	Reduction %
1.00	5.71	96.33	90.62	96.56	-28.61	22.858
1.50	12.85	196.73	183.88	190.78	-71.19	27.174
1.75	17.49	270.79	253.30	249.08	-99.73	28.592
2.00	22.85	344.07	321.22	314.82	-133.11	29.717
2.25	28.92	429.94	401.02	388.01	-171.32	30.629
2.50	35.70	491.08	455.38	468.66	-214.37	31.385
					Average =	**28.39**

Table 4. Shrimp trawl results.

Groundfish Trawl

Speed (knots)	Frame 2 (pounds)	Nylon (pounds)	Less frame (pounds)	Curve fit (pounds)
1.00	4.55	86.26	81.71	84.30
1.50	10.24	183.13	172.89	173.56
1.75	13.93			229.85
2.00	18.20	315.75	297.55	293.92
2.25	23.03	391.04	368.01	365.77
2.50	28.44	470.36	441.92	445.40
3.00	40.95			627.99
3.40	52.60			796.46

Speed (knots)	Frame 2 (pounds)	Spectra (pounds)	Less frame (pounds)	Curve fit (pounds)	Difference (pounds)	Reduction %
1.00	4.55	54.64	50.09	49.06	-35.25	41.810
1.50	10.24	106.99	96.75	98.45	-75.11	43.275
1.75	13.93			129.37	-100.48	43.715
2.00	18.20	183.11	164.91	164.44	-129.48	44.053
2.25	23.03			203.66	-162.12	44.321
2.50	28.44	274.80	246.36	247.02	-198.38	44.539
3.00	40.95	389.26	348.31	346.20	-281.79	44.872
3.40	52.60	488.88	436.28	437.49	-358.97	45.071
					Average =	**43.96**

Table 5. Groundfish trawl results.

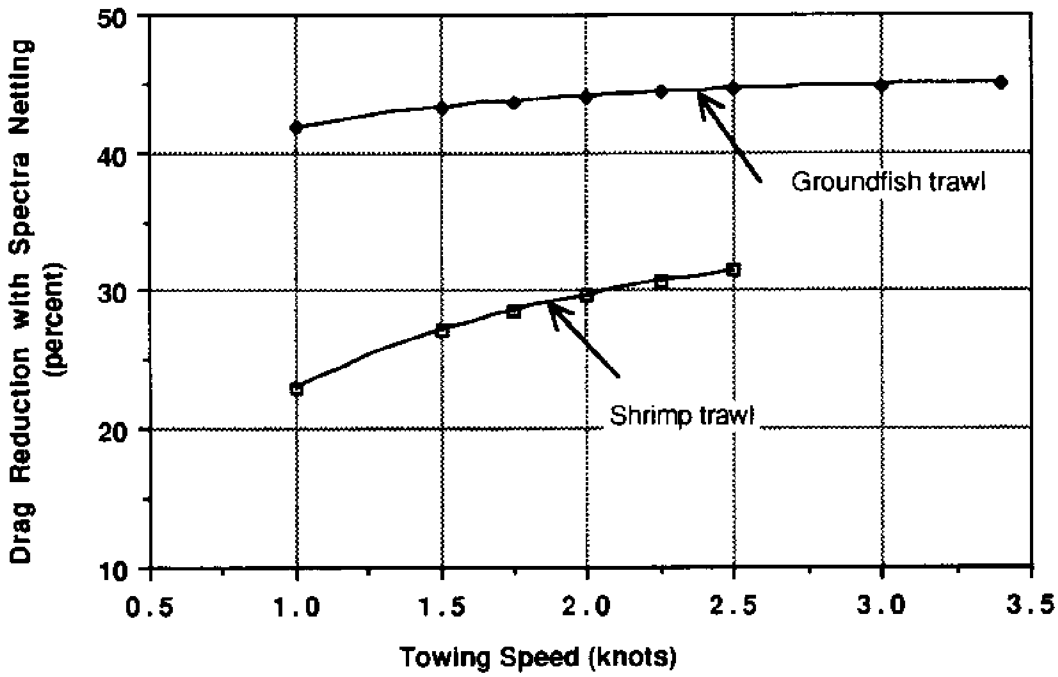


Figure 6. Drag reduction using Spectra netting verses towing speed.

Resistance data can be converted to non-dimensional coefficient form using the following relationship.

$$C_d = \frac{\text{Drag}}{1/2\ \rho\ V^2 A}.$$

Where C_d is the drag coefficient, ρ in the density of water, V is the speed in ft/sec, and A is the characteristic area in square feet. It is common for netting resistance to be expressed in drag coefficient form using the projected twine area or the net mouth area as the characteristic area. Table 6 and 7 present the test results in coefficient form using these areas.

As would be expected, the C_d based on twine area changes only slightly between the two netting materials. By contrast, but also as expected, the Cd based on the mouth area is considerably less for the Spectra trawls compared to the nylon trawls of heavier twine.

	Shrimp Trawl				Groundfish Trawl			
	Nylon		Spectra		Nylon		Spectra	
Speed (knots)	**Drag** (pounds)	**C_d**	**Drag** (pounds)	**C_d**	**Drag** (pounds)	**C_d**	**Drag** (pounds)	**C_d**
1.00	125.17	0.4161	96.56	0.4681	84.30	0.3203	49.06	0.3075
1.50	261.97	0.3871	190.78	0.4111	173.56	0.2931	98.45	0.2743
1.75	348.81	0.3787	249.08	0.3943	229.85	0.2852	129.37	0.2648
2.00	447.93	0.3723	314.82	0.3815	293.92	0.2792	164.44	0.2577
2.25	559.33	0.3673	388.01	0.3716	365.77	0.2745	203.66	0.2522
2.50	683.02	0.3633	468.66	0.3635	445.40	0.2708	247.02	0.2478
3.00					627.99	0.2651	346.20	0.2411
3.40					796.46	0.2618	437.49	0.2373
Average	**C_d =**	**0.381**		**0.398**		**0.281**		**0.260**

Table 6. Trawl drag and drag coefficient based on <u>twine area</u> verses speed.

	Shrimp Trawl				Groundfish Trawl			
	Nylon		Spectra		Nylon		Spectra	
Speed (knots)	**Drag** (pounds)	**C_d**	**Drag** (pounds)	**C_d**	**Drag** (pounds)	**C_d**	**Drag** (pounds)	**C_d**
1.00	125.17	0.4444	96.56	0.3428	84.30	0.1784	49.06	0.1038
1.50	261.97	0.4134	190.78	0.3010	173.56	0.1632	98.45	0.0926
1.75	348.81	0.4043	249.08	0.2887	229.85	0.1588	129.37	0.0894
2.00	447.93	0.3975	314.82	0.2794	293.92	0.1555	164.44	0.0870
2.25	559.33	0.3922	388.01	0.2721	365.77	0.1529	203.66	0.0851
2.50	683.02	0.3880	468.66	0.2662	445.40	0.1508	247.02	0.0836
					627.99	0.1476	346.20	0.0814
					796.46	0.1458	437.49	0.0801
Average	**C_d =**	**0.4066**		**0.2917**		**0.1566**		**0.0879**

Table 7. Trawl drag and drag coefficient based on <u>mouth area</u> verses speed.

Discussion:

The drag reduction related to the use of Spectra, or any other high-performance twine, can be attributed primarily to the geometric considerations associated with the smaller diameters allowed. Except for effects that might be caused by stretch, the results can apply to other materials. Indeed, from a resistance standpoint, reductions in twine diameter will always pay off in reductions in drag.

The significance of using Spectra is that the twine diameter reductions can be done without sacrificing the strength and durability of the trawl. Though the initial selection of comparable materials were based on manufacturers specifications (see Table 1) and anecdotes from industry, independent tests on the strength and abrasion resistance of these netting materials have also been done.

Table 8 is a summary of results extracted from a reports prepared by Nor'Eastern Trawl Systems (19, 20). In it, measured twine diameter, knotted breaking strength, and wet abrasion resistance are shown for the nylon and Spectra materials tested.

For the breaking strength tests, panels of netting were sewn into tubes and stretch between capstans on a test machine. Breaking strengths of the specimen were recorded. The dry knotted strength values in Table 8 represent the average of three tests divided by the number of twine bars sharing the test load.

The abrasion tests were done on a machine which rubs submerged specimens of netting with abrasive stones. The value given is the number of stone passes until the specimen failed at the load specified. Except where indicated the value given represents the average of five or six repetitions.

Material & Size	Measured diameter (inches)	Dry knotted strength (pounds)	Abrasion Cycles to Failure	
			10 lb. load	50 lb. load
Nylon #21	0.070	86.2	480	20*
Spectra #11	0.048	68.3	2963	38*
Nylon #42	0.098	139.4 (142.8)	5288	62.5 (986)*
Spectra #18	0.054	103.9 (150.2)	6706	410 (245)

Table 8. Results of strength and abrasion tests by NETS.
Data in parentheses is treated twine . * indicates one test only.

The disparity between these strength results and the specifications shown in Table 1 shows the typical degradation of strength when twine is formed into netting where knots cause premature rupture of the fibers (21). The knotted strength of nylon was found to be 59% to 63% less than the manufactures twine breaking strength. The knotted strength of Spectra was found to be 57% to 70% less than Allied's reported twine breaking strength.

In Table 8, data in parentheses is for netting samples that were treated with a bonding dip and depth stretched. With Spectra, this treatment increased the knotted strength. The treatment applied to the #42 nylon caused the abrasive stones on the NETS abrasion testing machine to gum up and reduce their abrasiveness. Although the machine was stopped periodically to clean the stones, the tests on that sample was suspect as abrasion in *situ is* not complicated by such phenomena. Neglecting the treated #42 nylon, Spectra showed an increase in abrasion resistance from 27% to 650% over nylon.

This combination of strength and abrasion resistance makes Spectra an attractive net building material. In the past, the net designer was faced with difficult trade-off between using small-diameter netting for drag reduction versus using heavier netting for durability. With Spectra, a low-drag, abrasion-resistant net seems achievable.

There are several reasons why the use of low-drag, high-strength netting can have special utility in net construction with important selectivity implications. In several fisheries, the addition of separator devices have been suggested as a way of reducing unwanted bycatch. These devices often take the form of an additional panels or added length towards the rear of the net, adding to the size, weight, and drag of the trawl. As a result, fishermen can experience an increase in drag and/or a loss in opening. Through the introduction of lower-drag materials in the separator device and the main parts of the net, the drag penalties of the separator device can be compensated for, returning the trawl system to its original performance. Gear designers specifying separator devices should consider the use of low-drag, high-performance materials as a way to improve the acceptability of their designs.

In most fisheries, the netting itself is the primary means of selectivity. Netting mesh size, particularly in the extension and codend, are generally thought to determine the size of fish that is retained. However, in many high-productivity fisheries, strength requirements have dictated the use of very heavy, multiple-layer codends. On the US west coast the use of two and three layer codends in double 6mm poly is common. Through the use of Spectra, a single-layer of lighter netting can be used, providing dramatic savings in weight and bulk and improved opportunities for size selectivity (22). The selectivity implications of using Spectra versus conventional codends can be visualized in Figure 7.

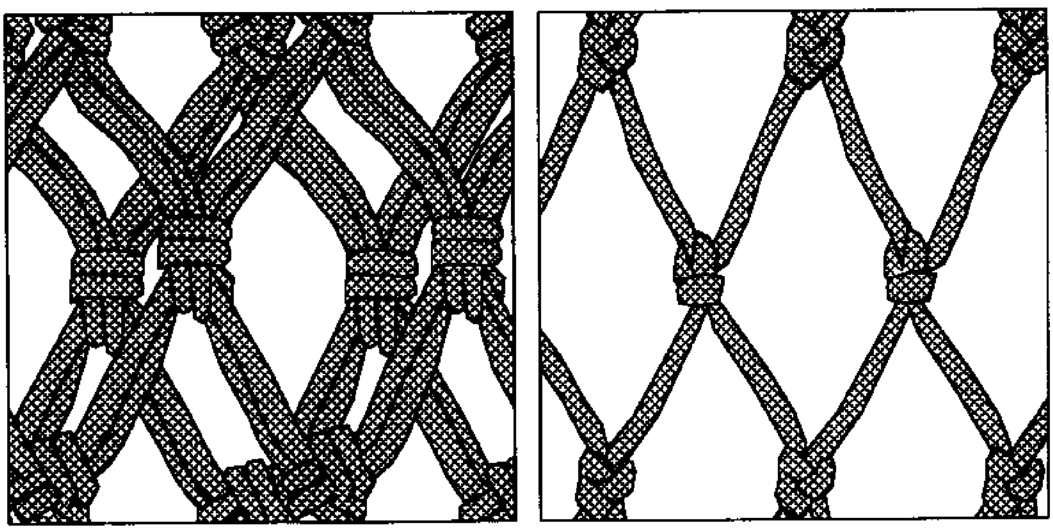


Figure 7. An approximate comparison of available escape opportunities of a two layers of double 6mm poly and 5mm Spectra codends.

Conclusions:

1. For shrimp net configurations, the use of #11 Spectra twine yields 23 to 31 percent less towing resistance compared to using #15 nylon twine.

2. For groundfish net configurations, the use of #18 Spectra twine yields 42 to 45 percent less towing resistance compared to using #42 nylon twine.

3. In either configuration the resistance advantage of Spectra over nylon increases with speed over the ranges tested.

4. Based on netting strength and abrasion tests, the substitution of Spectra twine as indicated above could yield trawls of equal or better durability than nylon.

5. The use of Spectra netting in a trawl can offer increased opportunities for size selectivity of the catch.

Acknowledgments:

This research was sponsored by Allied-Signal, Inc. The advice of Chris Griffin of Allied-Signal has been appreciated. The cooperation of DTRC is appreciated in providing the use of the test facilities. Ron Smolowitz assisted in conducting the tests. Hollis Forrester constructed the two shrimp test nets and Nor'Eastern Trawl Systems constructed the two groundfish test nets. The modular aluminum test frames were fabricated by Atomic Ltd., of Cambridge, MA.

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