PICKING THE RIGHT LINE FOR EACH JOB

When it comes to line, life truly was simpler a few decades ago. We used 3-strand nylon for dock and anchor lines, polyester (Dacron™of DuPoint) for running rigging and Dacron™ double braid or 7 x 19 wire with Dacron™ tails for halyards. However, the recent explosion of new fibers has been incorporated into a host of new lines with very specific properties: low stretch, high strength and high UV-resistance, for instance. This "embarrassment of riches" has made it much more difficult and confusing to determine the best line for a given application. To unravel this puzzle, we need to match up the basic demands of each line application with the basic properties of the various fibers.

Line Application Requirements

The most basic requirement for any line is that its working load limit meets or exceeds its expected load. Beyond this various applications demand varying degrees of two additional line qualities – low stretch and light weight. Table 1 summarizes the relative importance of these two demands for each application.

Table 1	**Stretch***	**Light Weight****	**Notes:**
Anchor Line	1	1	Elastic/not weight critical
Traveler Control Line	2	2	
Cruising Chute Pennant	2	2	
Vang	3	2	
Main Sheet	3	2	
Furling line	3	2	
Spinnaker Sheets	3	4	
Outhaul	3	3	
Jib Sheet	4	3	
Spinnaker Guy	5	3	
Toping Lift	2	4	
Spinnaker Halyards	3	5	
Reef Lines	3	4	
Checks/runners	5	5	
Jib Halyard	5	5	
Main Halyard	5	5	Weight/stretch critical

*5=need low stretch, 1=need elasticity (high stretch)

**5=need lowest possible weight, 1=low weight not critical

The demand for light weight is relatively straightforward, being increasingly useful for two purposes: to reduce weight aloft on lines used up the mast, and to prevent sheet weight from collapsing sails in very light air.

The demand for low stretch is somewhat subtler, depending on balancing five different factors:

(1) The amount of stretch needs to be matched to the sail material. A high-aspect, molded Vectran™ sail demands lower stretch lines than a low-aspect, crosscut Dacron™ sail.

(2) Longer lines demand less stretch. A 100-foot halyard which stretches 1% will create 1 foot of luff sag, while 1% stretch in a 25-foot outhaul is only 3 inches.

(3) Chafe prone applications require lower stretch. The stretchier a line, the more it will saw back and forth as the load on the line varies.

(4) Applications that are fast and easy to adjust can use lines with more stretch which can then be adjusted as they stretch in and out.

(5) Stretch is desirable in applications exposed to shock loading, and should not be reduced beyond that which can be handled by the hardware involved.

Friction is an additional property that is important in a few very specific applications – most notably lazy jacks and checkstays that rub on the mainsail. We originally used Dacron™ lazy jacks until we noticed that they were chafing the stitching on the mainsail. At our sailmaker's recommendation, we switched to uncovered Spectra™, the slipperiest line available as shown in Table 3. This has completely eliminated the chafe.

Line Properties

Table 2 outlines the basic physical properties of the most common line fibers. HMWPE (Branded as Spectra™ of Honeywell Performance fibers, Dyneema™ of DSM High Performance Fibers , Amsteel™ of The American Group), Kevlar™, Technora™ (trademark of Teijin) and Vectran™ (trademark of Hoechst Celanese) are high strength, low stretch and relatively expensive. Nylon is highly elastic (high stretch). PolyPro is relatively light and inexpensive, and Dacron™ is general purpose.

Table 2	**Nylon**	**Dacron™**	**Polypro**	**Spectra™***	**Technora™**	**Vectran™**
Strength (1)	1.0	1.0	.6	2.8	2.9	2.9
Stretch (2)	1.0	.6	.8	.1	.1	.06
Weight (3)	1.14	1.4	.91	.97	1.4	1.4
Friction (4)	.12	.15	.22	.08	.15	.15
Creep (5)	Neg	Neg	Yes	Yes	Neg	Neg

Cost (6)	$.13	$.28	$.10	$.69	$.46	$.60

*Also known as Dynama™, Amsteel™

(1) Breaking Strength per circumference squared, indexed to nylon
(2) Elastic Elongation at working load, indexed to nylon
(3) Specific Gravity, indexed to water
(4) Coefficient of friction
(5) Slight elongation when exposed to steady high loads
(6) $ per ton of breaking strength for 1/2" line

These fibers are combined in five basic types of line construction, each with its own strengths and weaknesses:

(1) Balanced double braid. A braided cover covering a braided core, both made of the same fiber and each carrying about half the line load.

(2) Parallel core. A braid covering surrounds a core of fibers bundled parallel to the axis of the line. This construction reduces stretch vs the balanced double braid construction with minimal increased cost.

(3) Core loaded double braid. A Dacron™ (usually) braid covers a braided core made from lower stretch fibers. Here the core carries virtually all the load, and the cover is there to protect the core from chafe and UV. This is the most common construction for the new 'high-tech' lines.

(4) Single braid. This consists of a single braid of fibers with no separate cover. This braid can be made of anywhere from 8 – 12 strands of fiber. This line can be the same strength and stretch at a much lower weight than the core loaded line, but of course without the protection from chafe and UV.

(5) Three strand. Three stands of fiber twisted into a line. This is a very traditional construction method. It allows the highest stretch and is very common for nylon anchor and dock line, and in Dacron™ for 'hemp looking' line on classic yachts.

Two of the latest developments include lines with 'heat resistant' covers (with Kevlar™, Nomex™ & Technora™), developed for runner tails on the America's Cup boats where the enormous loads were melting the line as it was eased around the winch drums, and lines with PBO™ (the latest high strength fiber) cores for halyards, runners and stays. PBO™ has limited UV resistance so it needs to be covered and it's not as durable as Spectra™ or Vectran™. Both of these developments are at the moment incredibly expensive and of relatively limited application on all but the most exotic boats.

Fitting the line to the application
Now that we have some understanding of both the application demands and the line properties we can fit the two together.

Halyards require light weight and low stretch. On cruising boats up to about 45 feet with crosscut Dacron™ sails, Dacron™ double braid line works just fine. On larger or higher performance boats, particularly those with laminate sails, where Dacron™ double braid would allow too much stretch, the traditional solution has been to use a wire to rope halyard. This is still a relatively inexpensive and very chafe resistant solution. The current BT Challenge boats are fitted with wire to rope halyards.

Shifting from wire halyards to parallel core Dacron™ braid for Dacron™ cross cut sails or core loaded double braid with one of the high-tech cores for laminated sails will reduce the weight aloft about 50% and make the halyards easier to handle. Vectran™ is generally judged to be the best core material for the main and jib halyards as it is the lowest stretch and does not creep, with Technora™ being slightly less expensive and slightly less durable. Spectra™ is generally judged the best core material for spinnaker halyards as it is the lightest of the high end fibers, and the slight creep under load is not critical to the spinnaker trim.

You can go one step further to reduce halyard weight by stripping off the Dacron™ covers for the part of the line that will be aloft when the sail is hoisted, or starting with a Vectran™ or Spectra™ single braid and slipping on a cover where the winch and clutch loads will be. This will reduce the weight of the line aloft by almost another 50%. You may also want to leave a short cover at the shackle end to protect the line where it goes over the sheave. To minimize the potential for UV damage to the line with a stripped cover halyard, tie the halyard tail to the shackle (or just use a light messenger line) and pull the exposed core portion into the mast when the boat is sitting at the dock so it is not exposed to UV. With Vectran™ or Technora™ cores it is best to get line that is pre-coated with a UV protectant or buy and apply a coating like Yale's Maxijacket™. Spectra™ is less susceptible to UV damage than Vectran™ so in applications where Spectra's™ creep and heat sensitivity is not too troublesome, some people use Spectra™ core line when the halyards will be exposed to a lot of UV .

You can then go a final step and switch to a 2:1 halyard system which reduces the loads on the line by about 50% and thus allows you to go to a smaller diameter line. 3/8" is about the minimum size you can reduce the halyard to and still have it easy to hoist and possible to hold with a rope clutch.

Whether this effort and expense will be worth it depends on the type of uses to which the boat is put. Hall Spars estimated that going to the maximum extreme (2:1 halyard/stripped covers/eliminating spare halyards/Kevlar™ runners & checks) would save about 30 pounds aloft on the average 35-foot sailboat. That would probably be noticeable on a well-run race boat – about the equivalent to adding a small (125-pound) crewmember sitting on the rail - but probably not noticeable on most cruising boats. The weight saving will obviously be much less if starting with rope rather than wire halyards or without the full conversion to stripped covers, etc.

Check stays and runners have also traditionally been wire, but the development of Spectra™ and Vectran™ single braid has created the opportunity to both save weight and chafe on the main sail and spreaders. At the very high performance end there are lines specially made for the check/runner application with parallel Vectran™, Kevlar™ or PBO™ fibers inside a plastic cover.

Reef lines tend to be shorter and lower than the halyards so are a little less sensitive to stretch and weight, but is prone to chafe from the many sharp turns and experiences a lot of flogging. They typically use line at one notch down in sophistication/cost from that used for the halyards.

Jib sheets and guys are usually relatively easy to adjust, need to be durable since they experience chafe and flogging and are low in the boat so don't need to be all that light weight, except for special light air sheets. Thus for regular sheets and guys a Dacron™ double braid is perfect until the boat gets so big that the Dacron™ sheets with the necessary working strength become too big to handle. 5/8 – ¾ inch sheets are generally viewed to be about as large as can be easily managed. From there, move up in line sophistication/expense to find a line with the required breaking strength in a manageable size. At the "cost no objective" performance segment, double braid Vectran™ is generally judged to be best for the jib. Spectra™ core with the cover stripped off is judged best for light air sheets.

The main sheet should similarly be Dacron™ double braid until it becomes too big to handle. The main sheet is the primary line exposed to two of the biggest shock loads on the boat – the accidental crash jibe and mast pumping while pounding to weather. Thus having some degree of stretch in the main sheet is valuable to cushion these shock loads and potentially save hardware from blowing up. Just to reinforce this point, you will note in table 3 that switching from a Dacron™ double braid to a Vectran™ sheet will increase the potential shock load by 480%.

Table 3	**% Stretch***	**% Shock Load****
3Strand Nylon	20.0%	15%
DoubleBraid Nylon	8.1%	37%
Parallel Core Nylon	5.5%	55%
Double Braid Dacron™	3.0%	100%
Parallel Core Dacron™	2.0%	150%
Spectra™	1.0%	300%
Technora™	1.0%	300%
Vectran	0.6%	480%

* at 15% of breaking strength

** compared to Dacron™ double braid, equal breaking strength for all lines

If you regularly fly your furling jib partially furled then the furling line should be relatively low stretch. For boats under about 40 feet a Dacron™ double braid is appropriate, for boats 40-50 feet a Dacron™ parallel core is appropriate, and for over 50 feet a Spectra™ or Vectran™ cored double braid is appropriate. In this final case, stripping the cover off the line up to the point it comes under load on a clutch or winch will save some weight, create extra room in the drum, and reduce the stretch just a bit more.

The vang, cruising spinnaker tack line and traveler control lines can again be Dacron™ double braid until the size gets too big. These three applications are exposed to shock loads and don't demand particularly low stretch so it makes sense to leave some stretch in them. Conventional wisdom suggests that nylon is too stretchy for any running rigging application. However, on *Hawk* we have actually added even more elasticity to these three specific applications by going to nylon parallel core line (e.g. climbing line) at the suggestion of friends of ours on a 50-foot high performance boat. This has worked very well, adding a big cushioning factor to protect the boat from hardware breakage during shock loads while not introducing too much stretch under normal working loads.

All of this can all be summarized with two vast generalizations. First, Dacron™ double braid is the appropriate economical solution for all running rigging applications, except halyards, on the vast majority of sailboats (all except the very large or very high performance boats). For halyards, Dacron™ double braid, Dacron™ parallel core or wire is appropriate for cruising boats up to 50 feet with Dacron™ crosscut sails, and Spectra™ or Vectran™ line for boats with radial laminated sails or bigger than 50 feet. Investing in more sophisticated/more expensive line beyond this becomes a very personal decision. On *Hawk*, we have done it in areas where we actually experienced chafe (lazy jacks and our second reef lines), in areas where we wanted to minimize shock loads (traveler and vang control lines), and in areas where stretch was obviously effecting sail shape (main and jib halyards and jib reefing line).

Second, if you are cutting your toothbrush handles in half to save fractions of an ounce of boat weight (as they do on the Whitbread and Open boats) and you want "cost-no objective" light weight and low stretch then stripped cover Vectran™ offers the best solution for almost all applications, with Spectra™ cored line useful when the lowest possible weight is desired and slight creep is not a big problem.

When it comes to line, life may be more complicated than a few decades ago. However, today's plethora of line options provides an amazing variety of potential combinations of line qualities - stretch, strength, size - which all translates into improved performance. That is, assuming you match the qualities to the application and find the right line for the job.