Old sailors used to spin yarns. Sailmakers used to use spun yarns - made from good, old-fashioned plants such as cotton and flax. Today's round-the-world yachtsmen need nerves or fibres of steel to meet their competitive challenges. Today's sailmakers use fibres of, well, almost anything other than natural, to meet the demands of modern sailing. Derryck Draper explores the world of aramids, polyethylene and polyester and glass and...

Sail Ho!

The homecoming to the cheers of tens of thousands of Frenchmen and women could not have been much more emotional. France had adopted the tiny sailor battling against almost insurmountable odds and cruel fate as one of theirs. It seemed as if they ignored the winner and were much more intrigued by the sailor he had beaten by a mere few hours after sailing single-handed around the world. For all the extraordinary and heart-warming activity surrounding the Vendée Globe achievements of Ellen MacArthur in coming second to Michel Desjoyeaux in February of this year, one abiding image must remain - that of the lone diminutive British girl dealing with the enormous area of sail on her yacht Kingfisher as she thrashed through the oceans at the bottom of the world.

To the non-sailor, possibly, a sail is perceived as several pieces of fabric sewn together, cut to an appropriate shape and hemmed on each edge. When it tears, just make or buy another. Quite logically questions of aerodynamics or tuning sail and hull for optimum performance are hardly likely to be considered. But sails provide motive power; when they are hoisted and trimmed the hull becomes alive and tries to fly as the wind provides lift along the curves of the canvas. Each has a character, which is imparted to the boat and provides either ecstasy or despondency depending on the ability of the sail maker to match sail to hull.

Technologically a sail has to provide the same performance as an aircraft's wing. The difference lies in the skill required of the yachtsman in continually adjusting the shape of the vertical foil to make the most of wind-speed and direction, a facility required of airmen only during take-off and landing. Sails must therefore be flexible, capable of accepting constant adjustment in air pressure and capable of deployment or stowing without an overriding care of substance or structure needing to be given. This has led to the development of high aspect ratio sails suitable for high wind applications, where the drag co-efficient should be as low as possible to maximise performance.

Methodical building

Researching this feature it quickly became obvious that sails are built, and not merely sewn together. Usage on mainly inland or coastal waters will allow the use of conventionally woven cloth, cut and sewn and usually easily repaired. But many of the larger, high performance sails - of the type that brought success to PRB and Kingfisher during the Vendée Globe race - are moulded to exact specifications from a variety of materials and hardly receive a stitch of any nature.

Photo: RTI/Kingfisher Challenge

Currently there are two methods of sailcloth manufacture, both using a lamination process, but producing widely differing finished products. The first might almost be termed conventional in that it produces flat sailcloth stored on the roll and ready for the cutting knife in the sail loft. Relatively low-cost technology, and the basis for later development, was achieved by bringing together a single layer of woven cloth and a single layer of film. By no means an advanced process by current standards, this form of laminate unites the dimensional stability of the film with the strength of the cloth. Because the panels in the sail construction need to be laid horizontally, the finished product is known as a cross-cut sail.

Radial sails, on the other hand, use a more advanced process which brings fibres, laminate film and an adhesive together under pressure at high temperature, in a process that will be familiar to many involved in the production of laminated cloth for outdoor clothing. Less familiar will be the requirement for precise control of the relative tension of the fibre and film to convey finished strength in the surface plane. Sail stresses tend to run along well-defined routes through the structure (hence radial), and it is logical to produce cloth that is stronger in one direction than any other. To do so cloth producers can align fibres in one direction only, leaving the finished product with exceptional properties on that line and, theoretically, almost none at all any other direction.

This, of course, is not a practicable solution since there are certain to be stress requirements, however minimal, crossing at angles to the main stress lines. Sailcloth manufacturers therefore place additional (off-axis) fibres running at an angle to the first lay (varying between 45 and 90 degrees) to accommodate these stresses. Such a system allows additional specification requirements to be factored into the finished cloth. By varying the type or characteristics of the off-axis fibres, the manufacturer can improve the flex fatigue or build in additional tear strength as required.

At the manufacturing stage, the off-axis materials also serve in a secondary function by holding in place the primary fibres in a form of woven scrim. Precision in layout at this stage is vital to the quality and performance of the finished product. Primary fibres must be parallel and aligned with the expected load. The secondary fibres may be woven as a locking mechanism - or be bonded to the primary fibres. There can be additional off-axis fibres laid in at varying angles to cater for loads that run neither directly across nor along the lines of the primary load carriers.

Designer labels

As with every other textile-based product where coping with mechanical stress is the primary function, it is the skills of the designers and manufacturers that create a fabric to match the intended use. In this particular instance, the type of boat being sailed and the racing conditions define the level of the stress and the qualities of the materials employed to match it.

For example, a sailcloth specified to offer strength and stretch characteristics along the primary fibres, and an appropriate level of flex fatigue and tear resistance across them to counter the tendency to disintegrate in a blow, might specify two polyester films sandwiching DuPont Kevlar or some other synthetic staple aramid for the primaries and polyethylene filament fibres - Honeywell Spectra perhaps - as the off-axis layer to provide tear protection. A further layer of Spectra might be incorporated at an angle calculated to improve the fabric's stability overall. A significant number of low denier, closely spaced fibres provides better performance than a lesser number of high denier at a wider spacing. Strict control over tension, pressure and temperature at the laminating stage is required to produce a high level of consistency in both finish and performance.

A considerable number of sails are still stitched together in the traditional manner, even though the cloth used might be held

together with adhesive and laminated polyester film. However, as required performance pushes harder and harder against the envelope, an increasing number of sails are now built individually to match the designed operating parameters of the hulls. Many are glued together using adhesive principles garnered from the space exploration programmes and modern structural procedures, but an improving percentage are the subject of moulding - a three-dimensional process akin to the production of laid-up glass fibre products but in this instance delivering a contoured, flexible sail that can be folded, stowed and redeployed as often as necessary.

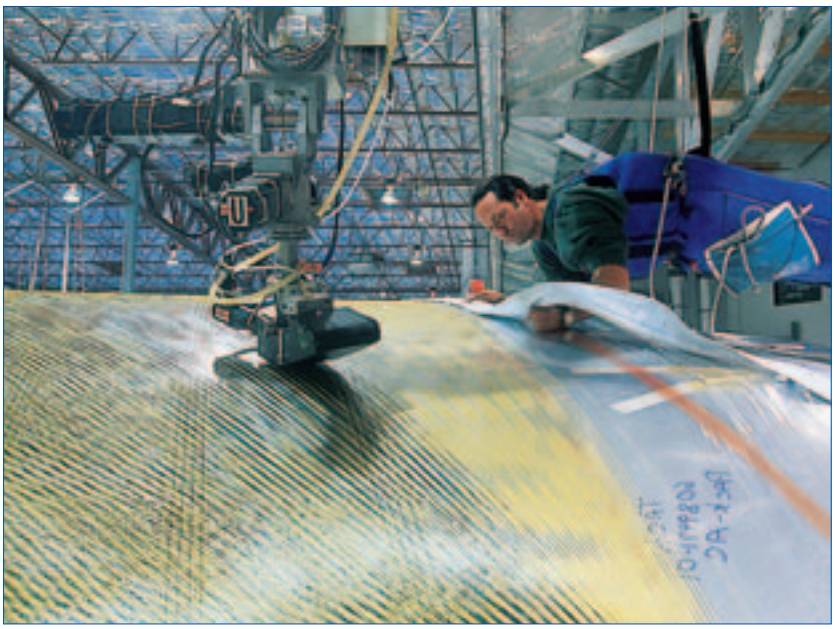
The developments' starting points are the requirement for a high performance three-dimensional shape, and the lamination procedures already discussed. The sail designers aim is to accurately align every fibre along the calculated stress lines in a three dimensional format to match the continuous dynamics of the finished sail in use.

The procedure uses a pre-curved mould for every sail. Over this is laid the film and the fibres, which are then laminated in situ. Whilst the film is applied manually, the fibres are laid to a predetermined programme by a computer-controlled multi-axis plotter. A further layer of adhesive and film is applied and the sail is heated by infrared lamp and subjected to precisely controlled pressure. The last may be by means of applied vacuum or a roller. Due to the limitations on the widths that can be obtained, the film has to be joined as necessary - and shaped to ensure that the primary fibres run in curves that match the anticipated stress paths in the finished sail. The understanding of the relationship between the unstressed moulded shape and the shape of the sail in use has been the main challenge for sail designers using this technique.

Chemical input

In common with virtually all other forms of sporting endeavour, 21st century sailing owes an enormous debt to the chemical industry and the development of synthetic fibres. If Desjoyeaux and MacArthur had to contend with the cotton canvas of yesteryear its unlikely that they would be competing in single-handed tests of sailing and stamina such as the Vendée Globe. Such has been the speed of textile development though, it is difficult to accept that it can only be a handful of years since nylon and polyester in cross-cut sails were the only fabrics of choice. Now there are a wide variety of fibres offering almost infinite selection of property and performance. The opportunity to mix and match is seemingly only governed by the imagination of the sail makers.

The brand names Kevlar, Twaron and Technora are almost household names in respect of aramid fibres. DuPont's Kevlar in particular is really a series, with a clearly defined set of attributes available to the specifier. Kevlar 29 and Kevlar 49 are the most likely versions to be found in high performance sail making. Weight for weight stronger than steel and with a high modulus, Kevlar fibres appear in almost every situation that demands lightweight strength and penetrative resistance.



A multi-axis plotter in action in a North Sails loft

Honeywell's Pentex fibres have developed a good reputation over the past five years or so. Their first proof of performance was in the 1996 Olympics and they have consistently added to the reputation in sport sailing during the intervening years. Pentex is a polyethylene napthalate originally developed for the automotive tyre market. With a 2.5 greater modulus over polyester, it is also said to exhibit a high level of dimensional stability. Look for the Honeywell product in medium weight sailcloth.

Spectra and Dyneema, from Honeywell and Toyobo respectively, are the best-known examples of high-density molecular polyethylene (HMDPE) fibre. Apparently the Holy Grail of sail making when introduced, its clay feet proved to be its susceptibility to creep - an inability to return to its original dimension after prolonged periods of elongation stress. In turn this led to partial, but permanent, stretching in small areas and the loss of the optimum aerofoil necessary to achieve the best performance.

However, HMDPE's other attributes - tensile strength, flex-fatigue and stretch resistance, an apparent ability to shrug off UVR, and high resistance to abrasion - made it almost the perfect fibre for high performance sails. When used in conjunction with other materials for the production of laminated sailcloth, HMDPE has proved to be the catalyst to bring out the best attributes in all of them. And advances in the understanding of sailing aerodynamics and improvements in sail manufacture have now allowed it to assume its rightful place as the textile leader in ocean cruising and a textile of choice for the performance sector.

It took a long time for carbon fibre to be accepted into the sailing market as a suitable medium for the production of sails. Architects and chandlery had made use of its properties for many years, but it was only in the context of the America's Cup 2000 that it appeared on the masts of the mighty.

On initial consideration carbon fibres are perfect sail material. Immensely strong. Stiff. Unaffected by UVR. Abrasion proof. High resistance to stretch. Only in one area are they suspect. As anyone who has viewed the results of a blade break-up on a gas-turbine fan can tell you, carbon fibres don't like to flex. Post-America's Cup experience, and designers are insisting that carbon's positive attributes are more than sufficient to justify the expense and the use of programme writing experience to build it into the sails of the future. Careful application of the various grades and some detailed attention being paid to the peculiar challenges involved in stowing the fabrics will surely take performance sail manufacturing into another era with fabrics produced from carbon fibres.

It is fitting to bring the discussion on fibres to almost full circle with a reflective look at polyester as a medium for sail manufacture. The original successor to cotton and flax yarns, polyester had, and still has, the commercial advantage of the low cost of raw materials. It is comparatively strong, resists stretch and wet degradation during storage, has an excellent flex-fatigue measurement and resists UVR.

But fashion and technical requirements move on in sailing as in other markets and polyester can no longer be regarded as high performance in this context. It has been overtaken technically by some of the fibres noted above, but is still widely specified for woven sailcloth and may be found as either primary or secondary layers in laminated fabrics. Recent developments in colouring have also given it a fresh lease of sea-life.

Polyester continues to play a major part in sail design and manufacture in its guise of laminate film. Originally the major element because of its strength and integrity under stress, developments in construction techniques have moved the stress from the film to the fibres and the lines of fibres working along the stress paths now undertake the major load carrying. Now sail manufacturers use the lightest films compatible with the intended function of the sail, and the film is ancillary, acting primarily to keep the fibres in place, add a UVR protective layer and provide an impermeable finish.

Polyvinylfluoride film makes an occasional appearance and is quoted for its marginally improved UVR performance over polyester - which is then countered by the fact that it absorbs water more readily than PET and lacks its dimensional stability.

Don't just sit there

This article is by no means exhaustive - not surprisingly books have been written on the subject of sail design, manufacture and performance. In common with almost all other aspects of active leisure there is only one effective way of researching the full facts - emulate Desjoyeaux and MacArthur and at least get your feet wet.

