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Materials

SP Systems Guide to Wooden Foil Construction

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Introduction

One of the easiest ways all owners can improve boatspeed is to acquire a new set of foils, the centreboard or daggerboard being the most important rather than the rudder. Although there are many excellent builders who can provide ready-finished foils with a high standard of construction and finish, a foil is one of the few pieces of high performance equipment which is not beyond the scope of most amateurs providing they have the correct information. This guide will cover the methods used to make wood based foils, concentrating on centreboards and daggerboards.

WHY USE WOOD FOR FOILS?

Although other materials such as PVC foam are being used now in some high performance classes, wood is still the most widely used material.

Why wood? Wood is relatively inexpensive and most people have some idea of how to work with it. Wood is easily shaped using both hand and electric tools and takes adhesives and finishes well. In addition wood has an excellent stiffness to weight ratio, exactly what good foils require, as well as outstanding fatigue resistance. However, wood is only effective if it is used dry and then kept well protected from moisture. There are many different woods to choose from and choice will be dictated primarily by both design and availability.

WOOD AS A STRUCTURAL MATERIAL

Microscopically, wood is like a closely packed bundle of parallel drinking straws. This is what gives wood its stiffness and high bending strength. Wood is nature's own unidirectional material. For foils it is most important to have straight grain with no knots and the wood should ideally be kiln dried for the best stiffness and dimensional stability. The stiffest wood foils have straight grain and certain woods are selected for fewest defects, Western Red Cedar and Spruce being obvious examples. However, most woods, particularly mahogany types, are not perfect which is why narrow strips should always be laminated and glued together for the wood to be most effective. Plywood is generally much less effective since up to half the plies usually have their grain orientated in a direction which is of little use in contributing to a stiff foil.

Foil Design

WAYS IN WHICH DIFFERENT WOODS ARE USED

There are four basic designs used today:

1. Relies on the wood to provide all the strength and stiffness required. Here a relatively strong, stiff and heavy timber such as a mahogany is usually selected. For some cases plywood may be adequate but will never be as stiff.
2. Uses the same wood as in (i) but the entire surface is sheathed with a lightweight woven glass fabric reinforcement (usually a single layer). This will give considerably enhanced resistance to surface damage and abrasion and a little extra stiffness though the improvement in stiffness will not be significant.
3. Uses a combination of a low density wood such as obeche, cedar or spruce together with mahogany to achieve an overall weight reduction without a significant loss of stiffness. These foils must be sheathed with woven glass to strengthen the lighter wood particularly.
4. Uses the wood predominantly as a 'core' material, which is sheathed with load-bearing fibre skins such as E-glass, or better still carbon, to provide the strength and stiffness required. The wood in this case can be a very light type such as obeche, yellow pine, spruce or even balsa but Western Red cedar is probably most widely used. More dinghy classes now permit this type of construction. Where mahogany has been traditionally used, changing from a tropical hardwood is preferable on both ecological grounds and for ease of shaping. It can also be kept reasonably inexpensive if glass and not carbon is used as the main reinforcement.

WHICH WOOD?

Table 1
A Comparison of the Stiffness (given by Youngs Modulus E, Parallel to the Grain) with Density, for a Range of Wood Species

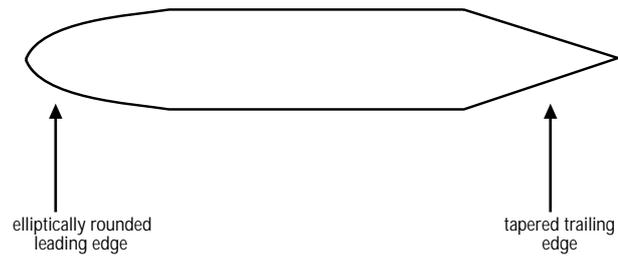
Wood Type	Youngs Modulus E, parallel to grain (N/mm ²)	Density (kg/m ³)	Specific Stiffness (stiffness per unit weight)
Balsa	4391	170	25.8
Western Red Cedar	8403	320	26.3
White Pine	9387	350	26.8
Spruce	11880	370	29.7
Kyaha Mahogany	11430	480	23.8

It can be seen that, in general, the heavier the wood, the greater the stiffness. Stiffness per unit weight (specific stiffness) becomes a 'constant' figure (approx.) and therefore this allows one to predict a wood's stiffness if its density is known.

SECTION SHAPE

Some classes have a rule restriction on streamlining which limits the amount of edge fairing and bevelling, keeping most of the section parallel-sided:

Fig 1 - A Parallel-sided Foil

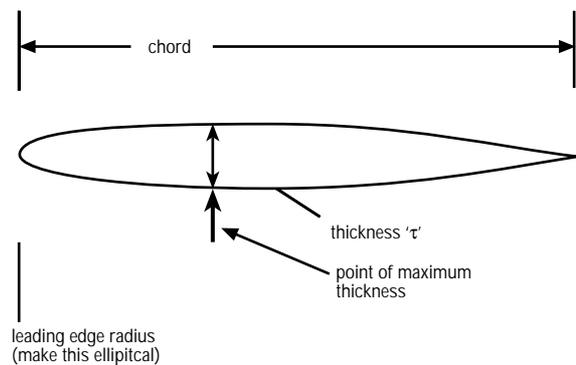


eg: Mirror, 420, 470, Enterprise, GP14

This type is by far the easiest to shape and most classes allow a fully laminated structure for maximum stiffness. However, a few classes still restrict the owner to using plywood which although not the most efficient, does help to obtain symmetrical shaping.

The fully streamlined section is the most efficient and satisfying to construct since there are many variations that can be tried within the class thickness restrictions. Generally it is best to use the thickest section which the rules permit. Other design considerations relating to section are: **leading edge radius, trailing edge dimensions, thickness taper and section characteristics:**

Fig 2 - A Streamlined Section Foil



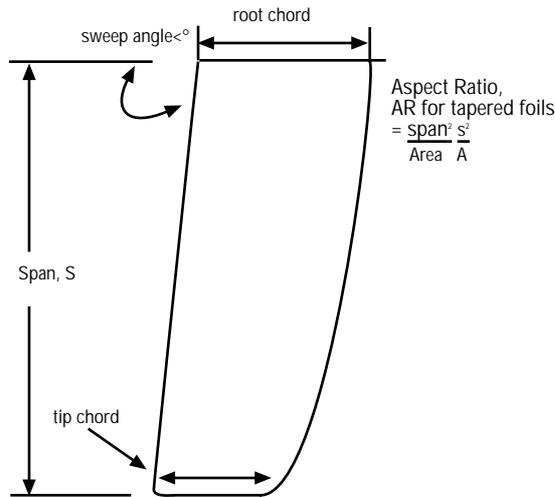
eg: 505, Merlin-Rocket, National 12, International Moth, Graduate

Use NACA-00 Series sections, a typical one being NACA-00-08 (8% thickness to chord ratio). Plot the shape for various stations down the span from the data given. Transfer on to graph paper and then to templates made from Formica or 4mm hardwood. You will require about 3 or 4 of templates per centreboard. These can be kept for future reference to either check the section periodically or to make a copy.

PLAN SHAPE

Plan shapes can sometimes vary within class measurement parameters but if it is unrestricted the best are generally elliptical. Other considerations which can affect performance are **aspect ratio, plan taper, area, tip shape and sweep:**

Fig 3 - Some Foil Parameters



Full information on foil design can be found in the books referred to at the end of this guide .

Materials

EPOXY ADHESIVES

All wood used, whether high or low density types, should be laminated in 38mm - 50mm strips glued with an epoxy adhesive. Appropriate SP Products are SP 106, SP 320, Ampreg 20 or Spabond 120 systems, using the appropriate Fast hardener and thickened with SP Microfibres. Epoxy has qualities which make it far superior to other glues such as urea-formaldehyde or resorcinol as it is non-shrinking, gap-filling, clear, tough, and does not require pressure to give a good bond. To ensure the best bond for all woods, especially softwoods, glueing faces should be either unplanned or roughened before applying adhesive.

EPOXY LAMINATING RESINS

Epoxy rather than polyester systems are essential for laminating as they have the necessary adhesion and toughness. Either Ampreg 20 for laminating or SP 320 is suitable, the latter being far preferable if a clear finish is required. Both systems give excellent fibre wet-out, adequate working time and the appropriate mechanical properties. Use standard hardener with Ampreg 20 and slow hardener with SP 320. Avoid using a fast hardener if possible unless you are skilled at using the products and appreciate the short pot life and working time available.

REINFORCEMENT FIBRES

The following types of fabrics and styles are appropriate:

(i) Plain sheathed foils

- woven E-glass, usually 165g - 200g/m²
 eg: RE165T (165 g/m²) or RE210 D (210 g/m²)

Either RE165T or RE210D is suitable for clear sheathing.

(ii) Foils requiring structural sheathing

- unidirectional carbon, 100g - 200 g/m²
 eg: UF-C125/400 (125g/m²), UC200/350B (200g/sm²)
- unidirectional E-glass
 eg: UT-E250 (250g/m²)

These foils also require a woven E-glass (one of the aforementioned) over the outer surface.

WHY UNIDIRECTIONAL FIBRES ARE NECESSARY

Although wood is a stiff material for its weight (high specific stiffness) and somewhat better in this respect than glass, even the most dense timber is not superior to carbon which has the highest specific stiffness of all available fibres in boatbuilding.

Table 2

Relative Stiffness Values of Wood vs. Synthetic Fibres

Material	Specific Stiffness (Youngs modulus, E)
Kyaha mahogany	23.8
Western Red Cedar	26.3
E-glass	18.7
R-glass	22.1
Carbon	71.5

Carbon is approximately three times stiffer than wood on a weight basis, so it is worth substituting carbon for wood where necessary. The necessary stiffness down the span can be built up by using an appropriate number of layers (laminations) of unidirectional glass or carbon. Those with an engineering background could work this out from first principles but to help everybody (including the author) an example has been prepared of what can be achieved using different woods and different reinforcements (see Appendix).

Stiffness across the chord can be achieved by using a woven glass reinforcement where 50% of the woven fibres (weft) will be orientated at 90° to the main axis of the span so these fibres run transversely across the chord towards the trailing edge.

Procedure for Making a Fully Reinforced Foil

PREPARATION OF THE BOARD

Cut the wood to 38 - 50mm wide strips and arrange to laminate together. Make sure each individual strip cut is turned 'end-to-end' and alternatively 'upside-down'. This arrangement will counter any tendency for an individual strip to warp. Glue the strips together with epoxy adhesive. When cured pass the laminated board through a thicknesser (after removing excess cured glue with a 'Surform' and hand grinder). At this stage refer to section covering "Leading and trailing edges".

Establish the plan shape and other design parameters. Scribe a centreline around the entire edge and work to a set of construction

lines pencilled or scribed identically on each face and edges (see Fig 4). These are set out to encompass the desired section shape (see Fig 5).

Shape using a plane (electric or hand plane or both) to remove the required amount of wood.

Shaping the Wood Blank

Figure 4 - Stage 1 - Marking Out

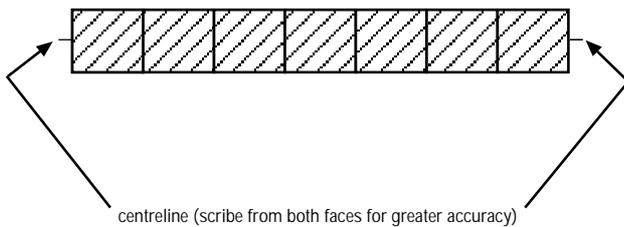


Figure 5 - Stage 2 - Basic Shaping

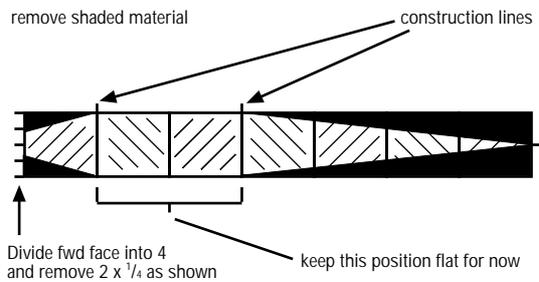
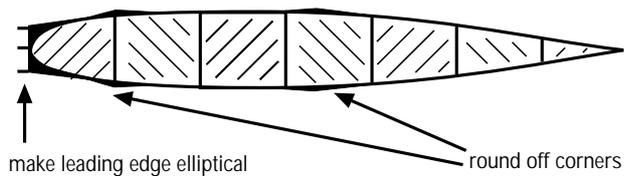


Figure 6 - Stage 3 - Rounding Off

Check section at each stage with template



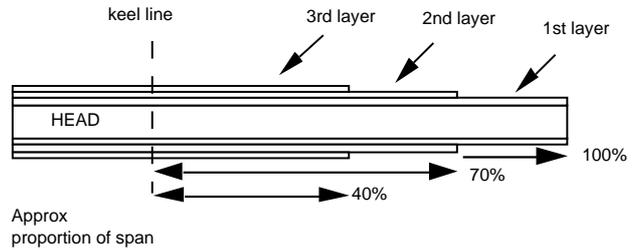
Leave 1mm width on the trailing edge of sheathed boards and up to 3-4mm on boards not sheathed.

Do the final shaping (see Fig 6) with spoke shave and 80 grit paper across the chord. Fair in any obvious 'flat' areas. Check regularly the profile of the stations along the length of the foil against the templates.

SHEATHING

Use the unidirectional fibres first, either in 100mm wide tapes confined to the area of maximum thickness or laid over the whole chord. Either two or three will be required over a low density wood core. If using narrow tapes it is best to remove some wood with a block plane to create a 'trough' in which the tapes can lie without creating any unfairness.

Fig. 7 - Plan for Laminating Unidirectional Glass or Carbon Fibres onto the Shaped Wood.



SHEATHING STAGE

Stage 1: 1st and 2nd (or 3rd) layers of unidirectional fibres (depending on stiffness required)

Stage 2: Overlaying with woven glass

STAGE 1 PROCEDURES

- Lay the shaped wood board flat and clean the surface with **SP Fast Epoxy Solvent**
- Using a brush or foam roller coat the entire surface with epoxy first using a Fast hardener mix, allow to cure then sand thoroughly with 80 grit paper. When laminating with glass (either UD types or woven) aim to:
 - Use the minimum amount of resin - do not float the fibres on the resin
 - Ensure a thorough wet-out of the fibres
 - Eliminate all trapped air with good consolidation technique using bristle or paddle rollers.
- Laminate the UD fibres one side at a time using nylon peel ply to finish. Before the resin has hardened fully turn the board over and repeat the process. Details of using Peel Ply can be found in SP Systems information guide on "Sheathing wood with glass fibre reinforcement."
- When cured, trim off round the edge with scissors and fair up with an epoxy filler mix (SP'S'Fill 400 is the easiest to use). Allow to cure and then sand with 60-80 grit paper. Recheck each station section with templates.

STAGE 2 PROCEDURES

The next stage is common to 'plain-sheathed' foils and involves laminating the woven glass reinforcement.

- Clamp the board by the head in a Black & Decker Workmate or vice so that the full length of the shaped section is accessible with the leading edge horizontal and uppermost. Forget about the head at this point, just work on the rest. The board is presented this way to enable you to wrap the glass easily around the leading edge in order to preserve the chord shape and give the required surface reinforcement. This method also helps to achieve a hard-wearing trailing edge (see later section on leading and trailing edges).

- (b) Drape the glass over the leading edge dry and trim roughly to size with scissors. Leave about 50 mm spare all round.
- (c) Roll on epoxy resin (using the appropriate speed hardener) to fully wet out the woven glass and snip off excess glass whilst wet.
- (d) Lay peel ply into the laminate. Leave at least 24 hours, remove board from the vice and then laminate the head area overlapping the cloth by 50 mm. Use peel ply again.
- (e) Leave to cure at least 12 hours then remove the peel ply, skim with epoxy filler and sand when cured. Check profile.
- (f) Apply one or two coats of resin (with fast hardener) to seal the filler and provide a smooth, hard glossy surface.

LEADING AND TRAILING EDGES

These techniques can be used singly or in combination:

- For a solid epoxy leading and trailing edge, cut a groove in the 'blank' once the plan shape has been cut out. Use a 3 - 6 mm diameter router and set it to cut a trough 5 - 8 mm deep around the periphery of the underwater portion of the foil. Fill the groove with epoxy thickened with colloidal silica and graphite powder but use an unthickened mix to prime the wood first. A hot air gun is useful here to achieve better epoxy penetration into the wood. When hard, fair off using a "Surform" tool first then 80 grit paper. When the board is fully shaped the epoxy leading and trailing edges will become apparent. This technique is useful whether the foil is sheathed or not.
- Another technique applies only to creating a trailing edge. When laying the woven fabric let the cloth extend 2 - 4 mm over the edge and allow the resin to gel slightly before trimming off. Fill the enclosed 'groove' with an epoxy mix thickened with colloidal silica when hard.
- The forward bottom edge can be very vulnerable - I recommend cutting off 10 - 15 mm at 45° after sheathing and recreating the shape from a filled epoxy, shaped and faired into the remainder.

Finishing Systems

Once the board is shaped and/or sheathed the following can apply:

If a clear finish is required 'flow coat' with SP 320 epoxy with **Fast** hardener working on one side at a time. In this case do not use epoxy filler over the glass as it will be visible. Build up to a good thickness of 2 - 3 coats before sanding and polishing (or use a 2 pack polyurethane varnish - SP Ultravar 2000 for the final coat).

If a painted or white pigmented finish is required use SP Hibuild 302 undercoat (white) first then a 2 pack polyurethane paint system for a hard finish. Alternatively flow coat using SP 320 epoxy resin system with SP white epoxy pigment incorporated. When hard wet sand with 180 grit down to 320 grade. Finally wet sand using 400 to 800 wet abrasive for a smooth finish. This latter method gives the most durable surface finish which can most easily be repaired.

Suggested Reading

Theory of Wing Sections - Abbott & von Doenhoff - Abbott 1959
The Design of Sailing Yachts - Pierre Gutelle - Nautical Books - 1984
Sheathing Wood with Glassfibre Reinforcement - an SP Systems Technical Information Guide

For further information contact SP Systems Technical Services

Appendix

Designing the Stiffest Foils

Exactly what and how much reinforcement material to use to build a stiff centreboard has always resulted in a bit of guesswork and using retrieved information based on experience of what works. However with the help of Finite Element Analysis it is possible to predict the effect on stiffness of using different materials. The objectives in this exercise were to examine the effect of changing the wood core and the amount, type and distribution of the reinforcement on stiffness, weight and cost.

Achieving a higher level of performance obviously has a cost since more expensive materials are used, so the stiffness criterion of tip deflection under a given realistic load, has been linked to the cost of the materials used (wood, resin and reinforcement) and actual weight for each example.

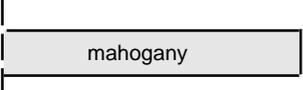
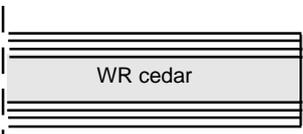
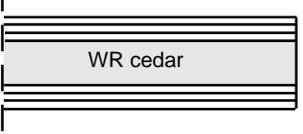
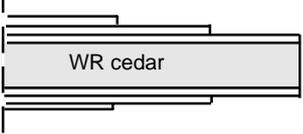
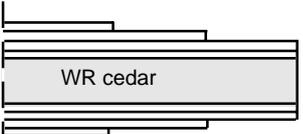
Calculations relate to a centreboard using the following materials and with the following parameters:

Wood core:	Brazilian mahogany or Western Red Cedar (WR Cedar)
Reinforcements:	Unidirectional fibres - carbon (200g/m ²) UC200/350B - glass (250g/m ²) UT-E250/500 Woven fibres - glass (210g/m ²) RE210D
Resin:	Ampreg 20 epoxy laminating system
Wood core thickness:	23mm (constant thickness down span)
Root chord width:	36.3 cm
Tip chord width:	18.8 cm
Span (from keel to tip):	100 cm
Plan shape:	roughly elliptical
Distribution of UD fibres effective in calculation:	100% of span (keel line to tip) 70% and 40% of span respectively
Applied load:	1000N (approx 100 kg) distributed along the span of the board in proportion to the chord. This is diagrammatically represented.

THE TEST EXAMPLES

The following compares the stiffness of an unsheathed solid mahogany board (Example 1) with ones using a core of lightweight cedar sheathed with three complete layers of unidirectional glass (Example 2) or three layers of carbon (Example 3). As an exercise we then compare the effect of reducing and redistributing the carbon more effectively (Example 4) and the effect of adding an additional complete layer (Example 5) on the stiffness (tip deflection

under load), weight and material cost. The material cost includes the cost of the stock wood, resin and reinforcement based on current retail prices and assumes zero wastage. An additional 15% would be realistic for waste. Reinforcement cost includes an overall covering of lightweight woven E-glass (RE210D) in all cases except the bare mahogany example where no coating cost has been included in the calculations. All costs and weights also cover materials used in the head portion of the board which was estimated at approximately 0.07 sqm area.

	Tip Defl. (cm)	Board Weight (kg)	Approx Material Cost (£)
Example 1 - Mahogany, no sheathing, no finishing resins 	9.1	3.44	18.50
Example 2 - WR Cedar + 3 layers UD glass to 100% of span 	6.6	3.45	23.84
Example 3 - WR Cedar + 3 layers UD carbon to 100% span 	2.8	3.45	59.50
Example 4 - WR Cedar + 3 layers UD carbon to 40%, 70%, 100% span respectively 	3.0	2.78	49.50
Example 5 - WR Cedar + 4 layers UD carbon to 40%, 70%, 2x 100% span respectively 	2.3	3.60	62.50

Conclusions

If high stiffness and light weight are required then selecting a low density wood core and sheathing it with unidirectional fibres is the best way to achieve this objective. The cost of glass sheathing can be largely offset by changing from an expensive wood (Brazilian mahogany which is widely available) to a relatively cheap wood (Western Red cedar). It gives a useful gain in stiffness (+ 27.5%) for no weight gain. If carbon is substituted for glass then stiffness increases dramatically (+ 69.2%) with a corresponding rise in cost (+ 178.4%). Weight does not change. Reducing the amount of carbon used and redistributing it away from the tip to areas where it will be more effective can reduce the cost rise to + 124.3% without a significant loss of stiffness (+67.0%). However this results in a significant weight reduction of 19.2% over the original mahogany unsheathed board. This is probably the optimum design. The effect of adding another full layer of carbon to each face gives the anticipated stiffness benefit over the last example of an **additional** 23.3% but with an **extra** 29.5% in weight and 26.3% extra cost of materials.

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SP Systems therefore strongly recommend that representative test panels and component sections are built and tested by the user in order to define the best process and materials to use for the desired component. This should be done under conditions as close as possible to those that will be used on the final component.

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