

(Junk Rig Association Newsletter, number 40, January 2003, and Journal of the Amateur Yacht Research Society, number 11, January 2003)

Background Thoughts.

The following notes were written in an effort to analyse available information as it applies to the windward performance of the westernised version of the Full Battened Chinese Lug Rig. They should be viewed as a personal interpretation as required for a particular set of problems. The diagrams below are either based on the diagrams of others or on best assumptions based on their results. The author is keen to receive criticism of these thoughts in an effort to open a debate and expand the pool of knowledge.

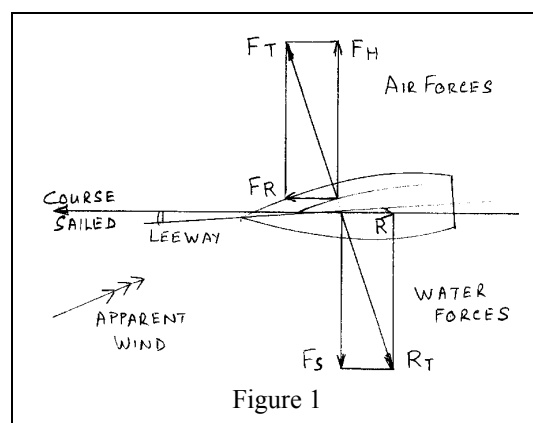
Basic Thoughts.

Since the first Single Handed Trans-Atlantic Race significant effort has been made to improve the performance of the Chinese Lug rig, yet it is still seen as being over complicated and to have poor windward ability. Unfortunately comparisons are usually made with highly tuned Bermudan rigs as used on America's Cup boats which have large well-trained crews and extensive sail wardrobes. No effort is taken of more realistic comparisons with family cruisers, where an elderly roller Genoa with a poorly set sheeting position will also produce poor windward performance, and which will be even less efficient as the wind frees. Until a boat with a fully battened lugsail produces a remarkable performance in some much-publicised popular event interest will stay low, leaving just a few enlightened enthusiasts to enjoy the many benefits.

The quest is to produce an easily handled rig for a lightly crewed cruising boat which will have equal or better performance than a cruising Bermudan sloop on all points of sailing. Inevitably this means concentrating on the windward performance.

Basic Hydrodynamic Theory.

Figure 1 is a simplified diagram of the forces involved in the close-hauled situation. F_T is the total aerodynamic force produced by the wind in the rig, and can be resolved into F_R along the track sailed, which drives the boat forward, and F_H perpendicular to the track sailed, which causes the boat to heel and make leeway. R_T is the total hydrodynamic force which is equal and opposite to F_T , which can be resolved into F_S which resists leeway, and is equal and opposite to F_H , and R which is along the track sailed and is equal and opposite to F_R .



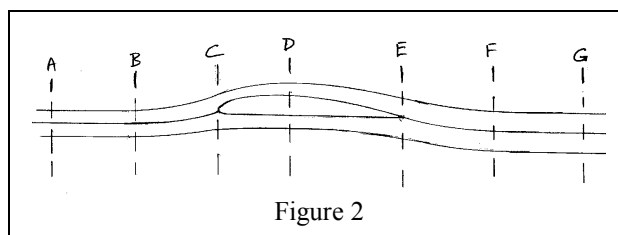
As the wind gets stronger it pays to reef to reduce the heeling force F_H to keep the boat moving at its best speed. As reefing reduces the total air force F_T it also reduces F_R , the driving force. This implies that simply increasing the total force F_T will not necessarily increase the boat speed, and as the wind gets stronger an increase in F_T will actually slow the boat below its best speed.

The simple answer to improving speed to windward must be to increase F_R without significantly increasing F_H , which is the same as swinging the vector F_T forward towards the bow of the boat. The question is how to find a simple solution to this simple problem.

Basic Aerodynamic Theory.

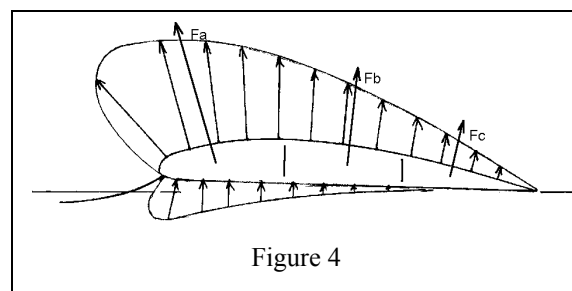
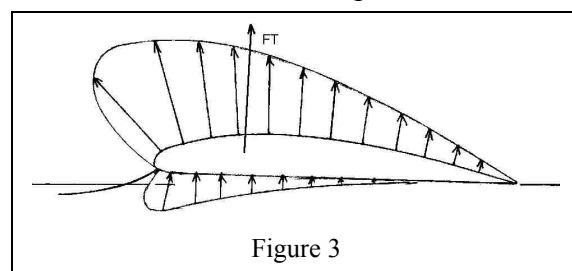
It may be helpful to look at the aerodynamic forces involved to find an answer to the 'simple' problem. Figure 2 shows the airflow around a simple flat-bottomed airfoil of the Clark Y type, and Figure 3 shows the forces involved.

Admittedly thick airfoils are somewhat different to sails, but this diagram should make the situation easier to grasp.



In Figure 2, between A and B, the air approaches the airfoil with the streamlines straight and parallel. From B to C the presence of the foil is first sensed by the air, which produces upwash (of which more later). At the stagnation point C the flow splits and the air going over the top accelerates over the curved leading edge and the pressure drops. The flow which goes below the foil slows and the pressure increases. After E the flow is deflected but by F will return to its original direction but with energy removed.

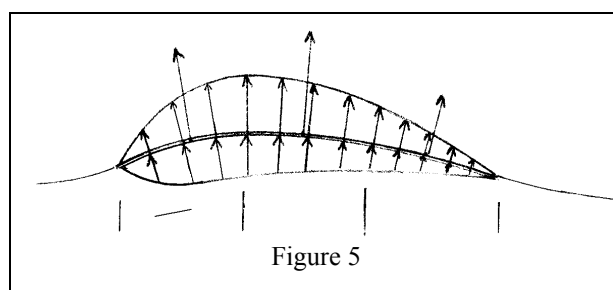
Figure 3 shows the pressure pattern affecting the foil. As pressure can only exert a force perpendicular to a surface, the force vectors will always act at right angles to the curved surface of the foil. The total force produced is the vector sum of all the vectors for each unit of area, and is the total force F_T referred to earlier. Rather than add all the force vectors it is interesting to divide the foil in thirds and add the vectors for each third separately. Although not accurately drawn, Figure 4 shows that it is the sum of the vectors from the first third of the foil, F_a , which produces the desirable forward directed force. This shows that it is the first third of the foil that is the most important for sailing to windward.



Figures 2, 3 and 4 show the impressive performance of a thick asymmetrical airfoil, and suggest that a wing sail should perform well. Unfortunately a single ply sail cannot have a thick leading edge, with the stagnation forced round to the lower side by the upwash and the air accelerating over the leading edge, which produces excellent windward drive. With a sharp edged sail the leading edge must exactly point into the airflow as it strikes the sail or a separation bubble will develop which will greatly impair the pressure development. Therefore the best a single ply sail can do is produce a force vector at right angles to the upwashed stream.

Figure 5 is an effort to show that the single ply sail can still produce useful 'forward' thrust provided that the first third of the foil is well cambered and that the sail starts to curve as early as possible to develop the suction at the front of the sail where the vectors will point furthest forward.

(In chapter 17 of his book *High Performance Sailing*, Frank Bethwaite gives very clear descriptions of the flow and pressure distribution around sails, and makes essential reading for students of sailing performance.)



The Effect of Upwash.

In Figure 2, between B and C the airflow starts to curve up as it approaches the foil. With a sharp edged sail it is important that the air meets the sail exactly in line or separation bubbles form. The more upwash the higher the sail can point to the relative airstream A to B, and as VMG to windward is the cosine of the angle between the true wind and the track multiplied by the boat speed then any increase in the upwash will improve VMG. The air approaching the sail cannot anticipate the sail, but can only react to the pressure pattern produced by the sail. The airflow can only be upwashed by the low pressure above and in front of the leading edge of the sail. Therefore achieving good suction at the leading edge is doubly important as it not only helps boat speed, but by promoting larger upwash also helps by reducing the tacking angle. If the first third of the sail is flat (as on many existing junk rigs) and the low pressure is not formed until a third of the chord from the leading edge the low pressure will have no significant effect on the approaching air and there will be no significant upwash, and therefore a large tacking angle.

All this infers that the solution to the 'simple' problem referred to earlier is to build a good camber into the first third of a sail, and encourage the airflow to follow the curve.

Practical Examples.

So how does this 'simple' answer fit existing practical Junk rig experience?

Despite achieving significant improvements in performance on his boat Felix, Bunny Smith pointed out that his Junk rig still under performed to windward. He illustrated this in Junk Rig Association (JRA) newsletter No.26, page 22, para. 8, with a sketched polar diagram. In para.18 he stated that when designing the Felix sail he decided on the basis of his airflow observations, sailing experience and aerodynamic knowledge that all sail area ahead of, in way of, and for one foot aft of the mast should be ignored in deciding the lead of the CE over the CLR. This infers that the forward area of the sail was having no significant effect. He actually moved the mast 3 feet forward (11.5% LOA), and raked it forward. Apparently this corrected all the handling problems and the boat then became perfectly balanced. This ties in with his diagram in JRA newsletter No.20, page 16, where he shows a large separation bubble covering the first third of the lee side of the sail. It's interesting that Joddy Chapman also found leading edge separation bubbles were predominant in his Junk rig experiments.

In stark contrast Frank Bethwaite, in his book High Performance Sailing, in Fig. 17.28 shows a modern wingmast with turbulent flow immediately reattaching, eliminating the separation bubble and establishing attached turbulent flow right from the front of the curved sail. At the end of para.17.10 he states that when they started to get the wing masts to work the boats all developed lee helm. They had to move the centreboard forward a foot or more (> 7% LOA) to balance the powerful suction close behind the mast (at the luff of the sail). This is the exact opposite to Bunny Smith's experience.

With the separation bubble over the flat first third of the sail the Junk rig under-performs to windward whereas the wingmast with attached turbulent flow over the first third of the cambered sail actually helps the dinghy plane to windward!

There are many other examples of the importance of the flow over the first third of the lee side of a properly cambered sail. Without a tight luff the jib of a Bermudan rig loses its designed cambered sail shape and flow, and its windward performance deteriorates. A partly reefed roller genoa also has very poor sail shape and performance to windward is much worse than if using a smaller hanked on sails. An old stretched genoa, with the camber blown aft will not point nor foot well to windward.

Without good suction near the luff of the Junk sail there is less upwash than with the Bermudan rig and therefore a wider tacking angle.

An Apparent Conclusion.

The above would suggest that until a method is found to build a properly cambered leading edge and achieve flow to the lee side over the first third of the sail then the Junk rig will not perform well enough to windward to sway the sceptics. Conversely, if this can be achieved then when combined with its other virtues, the Junk rig could embarrass quite a few people and achieve a large following.

An Examination of the Present State of Art.

All the above suggest that a flat, uncambered sail will not perform well to windward. The early Hasler/McLeod rig performance agrees with this, with poor drive and large tacking angle due to lack of upwash.

All the newer, better performing Junk sails employ camber, either from flexible battens, hinged battens or stiff battens with broad seam built into the sail. Unfortunately the achieved camber does not always extend forward to the luff. There is now some news of experiments with pre-bent battens with double skinned sails, which could prove to be very interesting.

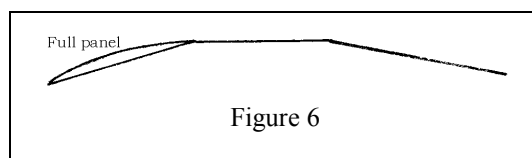
Flexible battens have the known disadvantage of bending more as the wind gets stronger, which is far from ideal. The forward section of the batten, in front of the mast, also tends to bend the wrong way and show no potential to easily produce the desirable camber and attached flow suggested above as required for good windward performance.

Hinged battens have the advantage that the camber is constant over the full wind speed range. Unfortunately the first 30% of the batten has to be stiff to prevent the batten hinging the wrong way which does not encourage the development of high suction forward to get the forward directed force and strong upwash desired.

Stiff battens with panels shaped by rounding or broad seam, as illustrated by Arne Kverneland in JRA newsletter 30, page 21, does seem to show some advantages, and some weaknesses. This set-up does not produce an ideal smooth airfoil surface but does have camber right to the leading edge at the middle of each panel when on starboard tack. The photographs on pages 21 and 24 show this, but the photo on page 23 shows the port tack case with the mast and the Hong Kong parrels distorting the airfoil shape. Arne claims that the rig tacks through 90 degrees and gives good balance. It would be interesting to fit instruments to see if the performance on starboard tack is significantly better than on port. It would appear probable that it is, and if this could be achieved on both tacks then the performance may be very interesting, particularly if the broad seam at the luff could be carefully tailored.

In JRA newsletter no. 31, page 14, Arne also stated that using hinged battens ‘gave some increased weather helm.’ This would suggest that the centre of pressure was positioned quite far aft in the sail, and not in the first third. Referring to his straight battens/ cambered sail in JRA newsletter no.30, page 24, he wrote that ‘he had to pull the sail a bit aft to avoid lee helm’ which would suggest that the first third of the sail was producing good drive. (This would tie in with the better performance achieved with Frank Bethwaite’s experience with the wing mast.)

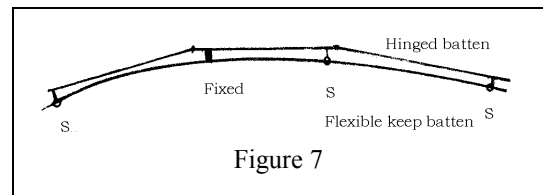
Of the 4 types mentioned above, stiff flat, flexible, hinged and stiff with shaped panels, the latter seems to be the only one able to produce camber in the forward third of the sail at the present state of the art. It may be that best performance will eventually be achieved by combining types, such as hinged battens with broad seam shaped panels over the first third of the sail, or between the straight sections of the battens, as in figure 6. Alternatively, fitting the sail to very flexible ‘keep’ battens attached by spacers



to structural hinged battens may achieve a desirable smooth camber in the sail, even into the first third of the sail. In figure 7 the battens are joined with a fixed spacer at F, and sliding spacers at S.

Considering the amount of shaping required with

Bermudan sails, and even with rigs like the Standing Lug it is asking a lot to expect a flat cut sail to perform well in a Junk rig, even on bent or hinged battens.



A Sideways Thought.

The above mention superior performance of wing masts would suggest that the thick forward section of the Swing Wing Rig, with the mast enclosed by the sail, has huge potential. It is a pity development did not continue as it would appear that a simple fundamental design error may have marred an otherwise very good rig.

Some Thoughts on a Different Vein.

At the moment there are a number of different outline sail-plans being used. Some are based on the early Hasler/ McLeod designs, others on the Felix form, and some on Vincent Reddish's observations. Rather than follow existing forms it may be worth considering some of the reasons behind the various features in an effort to obtain a better modern day solution. Features worth examining could include 1) batten angle, 2) yard angle, 3) sail outline, and 4) sail balance.

- 1) Batten angle. Although many think of the air flowing from luff to leech as being horizontal it must be remembered that in producing lift the high pressure air will blow up the windward side of a sail and the low pressure air on the leeward side will blow downward, and producing a vortex behind the sail. The lower the aspect ratio the more pronounced this 'span wise' flow will be. Bunny Smith was keen to promote turbulent flow on the lee side of the sail by 'tripping' the air over the battens. It may, however, be more important to accurately align the battens with the airflow on the windward side to provide a free uninterrupted journey across and up the sail, and not to 'trip' and lower the pressure of the high pressure air. Streamers or smoke may show the ideal batten slope on the windward side of a well cambered sail.
- 2) Yard angle. It seems to be generally accepted that the longer the luff the better the potential performance. This has produced long yards angled as near to the vertical as possible, like a Gunter rig. Modern airfoil design is paying more attention to efficiency by pushing the tip vortex as far out and aft as possible. A shorter less acutely angled spar may be more effective if fitted to a sail with a longer luff, by sweeping the actual tip further aft and encourage the vortex to flow from the extreme tip. A less acutely angled spar may even produce an efficient leading edge vortex as developed with the Crab Claw rig. As Tony Marchaj has pointed out, nature seems to like swept tip foils, so possibly evolution should be worth copying.
- 3) Sail outline. It would appear that all sail outlines are being drawn with a straight luff, with the sail needing adjustable luff parrels or Hong Kong parrels. Vincent Reddish reminded us that the original Chinese method of making the sail was to make the framework of boltropes and battens, and fastening the material to the tensioned framework. If this is done the tension in the angled leech boltropes will push the battens forward and will have to be balanced by the tension in angled luff boltropes pushing the battens back. This will produce a convex shaped luff, and if this shape is built into the sail then the requirements for luff and Hong Kong parrels may be reduced or eliminated. On the subject of Hong Kong parrels, which are required in current designs to keep the boltrope/ batten structure in shape when slack cambered sail panels are attached, the Chinese fitted the parrels at the luff. There does not seem to be any reason why they could not be fitted further aft or even towards the leech to cause less interference and allow better sail camber at the luff, or even eliminate them with better design.

- 4) Sail balance. Since Bunny Smith found it desirable to pull the sail as far back as possible with the flexible battens of the Felix rig it is notable that all rigs have been pulled back for windward work. If camber can be induced in the first third of the sail then it may be desirable to place as much of the sail as possible forward of the mast to achieve as much beneficial forward thrust as possible. Such increased balance in the rig could produce many desirable side effects, as mentioned later, as well as softer tacking and jibing. The mast could also be stepped further aft in the hull, which could have structural advantages.

Some resulting thoughts.

All these thoughts lead towards a different sail shape based the most promising features, which would appear to be –

1. Stiff battens, with broad seam to produce camber right to the luff.
2. Maximum clear cambered area in front of the mast to maximise the desired forward thrust.
3. A convex luff to balance the convex leech forces and simplify the rig.
4. A long luff with a moderately angled yard to push the vortex as high and as far aft as possible.

As the mast will spoil the sail camber on port tack, it would seem logical to split the sail around the mast and end up with a 'jib' and a 'mainsail' on the one set of battens, like a junk rigged Swing Wing or Aerorig. This would appear as in Figure 8 and may have the following advantages –

1. With the convexed luff balancing the convex leech, simple fixed batten parrels and downhaul tension aligned with the straight 'mainsail' luff there should be no need for either luff parrels or Hong Kong parrels.
2. The downhaul tension should control the twist as on a simple balanced lug so it should be possible to use a simple 2-part sheet on the boom.
3. With so much balance it should not be necessary to move the rig fore and aft to balance the boat on and off the wind.
4. The 'mainsail' may require less camber as the 'jib' shape and setting will be the most important to produce windward drive. Also the chord of the 'mainsail' would be reduced compared to a single sail case so there would be significantly less broad seam required achieving the sail camber.
5. The interaction between the two 'sails' may encourage faster flow over the lee side of the 'jib' and encourage enhanced upwash and better drive.

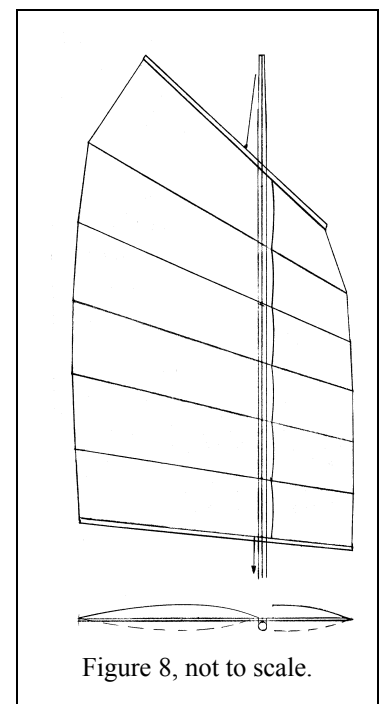


Figure 8, not to scale.

There could also be some disadvantages –

1. The shaping of the broad seam of the 'jib' panels would be critical to the windward performance.
2. Reefing may not be as easy as with a conventional junk as the bottom batten after each reef would have to be tensioned by a downhaul at both luff and leech, however modern single line reefing may help to achieve a good set.

The obvious name for this rig would be the Split Junk, or SJ for short.

Looking back through old copies of the JRA newsletter to No. 24, page 31, there is a very similar diagram in an article by Paul McKay, different only in that he had not placed the slot between the sails at the mast position. It's a pity he could not have been encouraged to follow his line of thinking over 10 years ago.

As mentioned in the first paragraph, the author is keen to receive criticism of these thoughts in an effort to open a debate and expand the pool of knowledge. *slieve@onetel.com*