St Ayles Skiff Rudder Design

and the Proposed Changes to the Construction & Measurement Rules

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1 Introduction

The following amendment to the measurement rules has been proposed by the SCRA, to be voted on at the next AGM:

> 15 (a) by specifying a standard rudder profile, in line with the design drawn by Mr Iain Oughtred *or in the alternative* (b) by specifying a minimum underwater wetted surface area of 850 cm squared, calculated against the expected waterline of a skiff with a normal weight crew rowing in salt water and that rudders must be attached to the sternpost at two points.

Several members of the North Berwick Coastal Rowing Club have already given their feedback with regard to the proposed change, and I thought I'd add my own penny's-worth. I've given the matter a great deal of consideration, and do not believe that either the (a) or (b) versions of the revision offer any improvement to the status quo.

As a sailor, rower and naval architect, I felt that I was in a good position to interpret the improvements – or lack thereof – that the new rule would offer. I think it would be a real shame if rules were implemented without considering all the facts, so I've written this document to provide details of the evidence that led me to this conclusion.

2 Enforcement

The (b) version of the new rule would be very difficult to enforce because the position of the waterline changes so much according to the loading condition. Trimming the skiff just 1° by the stern will cause the rudder to sink over 10cm deeper into the water; trimming 1° by the bow will lift the rudder 10cm out[1]. The increase or decrease in wetted area is 40% either way, based on the original rudder design.

The only way I can see that the rule could be realistically applied would be to require all clubs to assume that the waterline lies on the location shown in the drawings. Trust would have to be placed on self-certification, since this would be tricky to measure at an event. However, this still results in different clubs having different amounts of their rudders in the water depending on the weight distributions of the boat structure, hardware and – critically – the crew members themselves. I fail to see what purpose would be served by a rule that affects not just every club, but every individual crew combination so differently.

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[1] By my estimates, this would require the shift of something like 18.6kg between the bow and stern. I don't have the full drawing to hand at the moment, so my calculations are only approximate.

3 Revision Aims

I think the issue that has to be addressed is this: what is the intended purpose of the new rule? I've come up with three possibilities which, in decreasing order of importance, are:

1. **Safety**: Ensuring all rudders are sufficiently effective, so that clubs do not compromise safety in an effort to gain other advantages
2. **Fairness**: Ensuring that rudder design does not give some clubs significant advantages over others
3. **Tradition/Aesthetics**: Ensuring that the rudders are consistent with the traditional appearance of the skiff

I do not know which of the above points the new rule is aimed at, so I'm going to discuss whether it offers any improvements over the status quo for each separately.

4 Safety

An effective rudder gives the cox a high level of control over the skiff without having to call instructions to the rowers. This is desirable from a safety point-of-view, since it allows emergency manoeuvres to be carried out more quickly and effectively to prevent collision with other boats or navigational hazards. By specifying either (a) a standard rudder design or (b) a minimum rudder area, I am interpreting that the rules committee is aiming to ensure that clubs do not equip their boats with unsafe rudders.

It is outwith the scope of this document to explain exactly how rudders work, but a brief definition of two terms I'll be using is necessary. A rudder steers a boat by generating lift – a force that acts perpendicular to the boat's centreline. The size of the lift force is a measure of rudder effectiveness. Whenever lift is generated, induced drag is produced as a by-product. The primary function of a rudder is for turning, not braking – so a rudder has to produce large amounts of lift but a small amount of induced drag. The ratio of lift to induced drag represents rudder efficiency.

The problem with the (b) revision to the rule is that it seems to assume that rudder effectiveness and efficiency are dictated by the surface area. This is not the case. Whilst area does have an effect, so do all of the following:

- Planform – this is the shape of the rudder when viewed from the side
- Aspect Ratio – this is the ratio of the span (depth) to chord (longitudinal length) of the rudder
- Foil Section – this is the shape of the rudder viewed from above

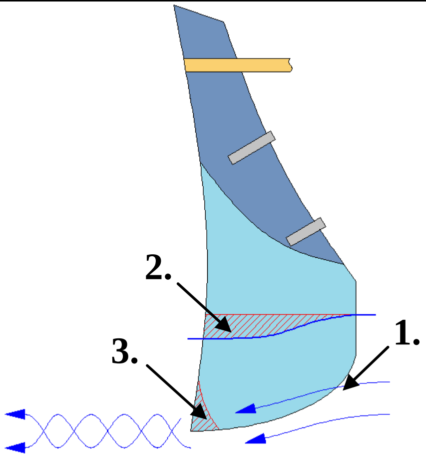
The rudder section – which needs to be foil-shaped to produce an effective, efficient rudder – is not directly affected by either version of the proposed change, so I'm not going to cover that here. I'm going to concentrate on planform and aspect ratio.

4.1 Planform

This shape of a rudder, viewed from the side, has a major impact on its effectiveness. The original planform, as shown on the Oughtred drawings, is not as effective or efficient as the rudder designs that have been developed by some clubs. Major improvements to safety are possible; I'm going to evaluate some of the features of the original rudder, along with some alternative designs.

The drawings below show the following features:

- the waterline, (blue line crossing the rudder)
- the flow direction of the water moving around the rudder (blue arrows)
- the vortices generated at the rudder tip (spiralling blue arrows)



Original Rudder (As Shown on Oughtred Drawings)

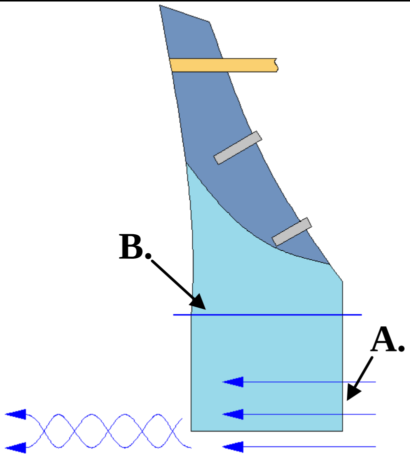
The original rudder planform suffers from a few issues, as follows:

1. This curvature at the leading edge is called 'sweepback', and it encourages the water to flow down under the rudder rather than around the sides. This reduces the lift and therefore the effectiveness.

2. The water being forced down by the 'sweepback' causes the water surface to be drawn down in the wake. This means that less of the rudder is wetted, and lift is reduced.

3. This surface area is being wasted, as the tip vortex at the bottom of the trailing edge will reduce its effectiveness.

Bizarrely, this planform would actually work better facing the other way!

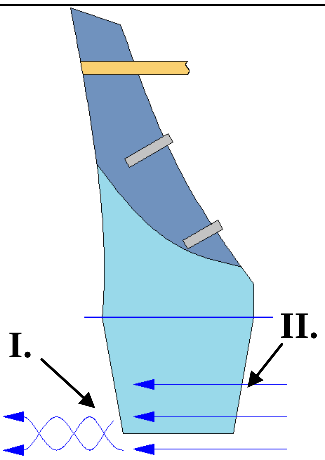


Rectangular Rudder

This far simpler shape actually offers vast improvements over the original design:

A. There is no sweepback, so water isn't diverted down below the rudder. The result is more lift, greater effectiveness and improved manoeuvrability.

B. Since the water isn't being pulled down, the waterline remains level. This means there is no reduction in wetted surface area, and more lift overall.

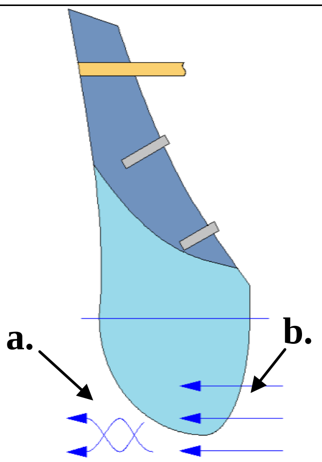


Tapered Rudder

This simple modification offers a further improvement:

I. The wetted area is greatest at the top of the rudder, and decreases with depth; this means that the rudder generates lift towards the top, away from the tip. The result: a major reduction in the size of the tip vortex, which improves the rudder efficiency.

II. The leading edge of the rudder is steeper than the trailing edge to minimise the sweepback and prevent water from being directed down under the rudder.



Elliptical Rudder

This is a further modification of the tapered rudder.

a. An elliptical shape makes a theoretically ideal hydrofoil or aerofoil, as the lift at the tip is effectively zero. This minimises the losses through the tip vortex. The elliptical shape was famously used in the wings of the Supermarine Spitfire, but is also common in both modern and traditional boat rudders.

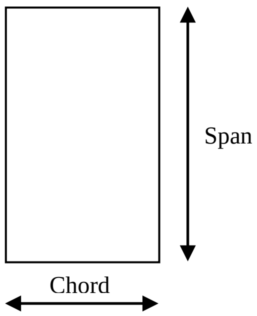
b. If the planform were to be a true ellipse (that is, symmetrical), the sweepback would cause the same problems discussed above. By making the leading edge steeper than the trailing edge, this issue is avoided.

My intention here is not to criticise the original rudder design or to claim that it does not work – clearly it does. The point I wish to make is that far more effective (and therefore safer) rudders can be made. I do not think implementing the (a) revision to the rules, and standardising a comparatively ineffective design, is a good idea. Adopting revision (b) fails to achieve anything, as a poorly-designed planform of greater than 850cm^2 will be less effective than a well-designed planform of smaller surface area.

4.2 Aspect Ratio

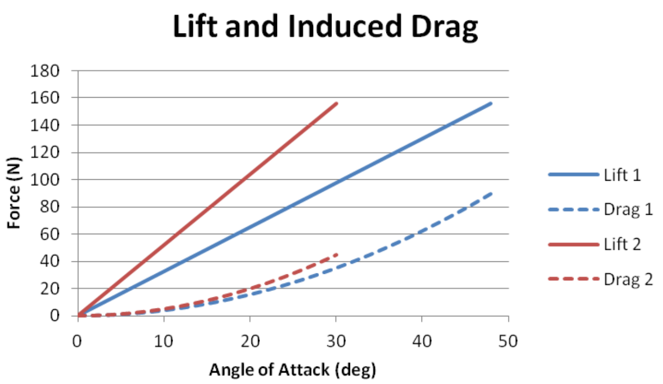
The meaning of this expression is clarified by the diagram below:

$$AR = \frac{Span}{Chord}$$

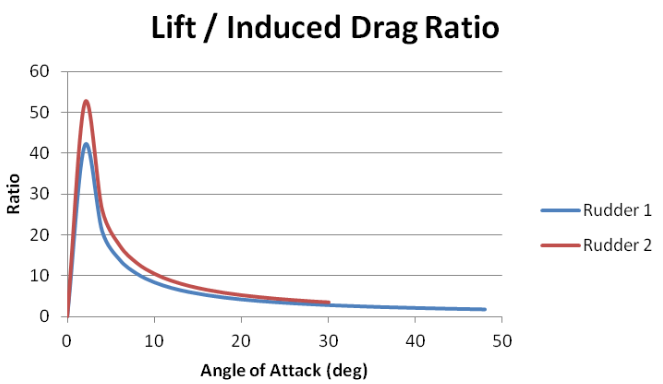


A long, narrow rudder is described as having a high aspect ratio, whereas a short broad rudder is described as having a low aspect ratio.

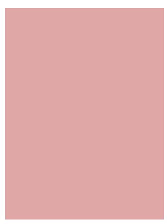
The effectiveness and efficiency of rudders with respect to aspect ratio can be calculated theoretically, but I'm not going to go into any detail explaining exactly how this is done. However, I've done the maths for two designs of rudder so that the effects of aspect ratio can be seen. Both rudders have the same wetted area. Sketches of the underwater profile are shown to the right of the graphs. Note that 'Angle of Attack' simply denotes the helm angle.



Rudder 1:



Rudder 2:



To summarise:

- High aspect ratio rudders are more efficient (greater lift to induced drag ratio) than low aspect ratio ones
- More lift is generated per degree of helm

High aspect ratio rudders also have more obvious stall characteristics. All rudders stall when too much helm is applied; when this happens, the lift generated suddenly decreases – in other words, the rudder stops working. It is much more obvious on a high aspect ratio rudder, making it easier for the cox to ensure it doesn't happen.

Setting the minimum area at 850cm^2 means that clubs wishing to exploit the benefits of high aspect ratio would be forced to extend the rudder below the level of the keel. This makes it:

- more susceptible to damage by grounding – a particular issue for clubs that don't store their boats afloat, and have to launch and recover from a slipway or beach
- more vulnerable to fouling – this would cause problems for clubs which, like ours, have to navigate waters where floating lobster pot lines are common

We increased the aspect ratio of our rudders by reducing the area – specifically, by removing the 'tail' that appears on the original design. This particular region of the rudder was largely ineffective anyway (as explained in section *4.1 Planform*); removing it both increased aspect ratio and produced a better planform (to something between a Rectangular Rudder and a Tapered Rudder).
Our rudders are both effective and efficient, not just *despite* the reduction in area, but *thanks to* the reduction in area!

5 Fairness

It is suggested that allowing rudders smaller than 850cm^2 will offer undue speed advantages by reducing the resistance. Allowing different rudder designs would also mean that some clubs would have more 'effective' rudders than others, which could also be interpreted as an unfair advantage. Finally, it could be argued that since some designs are more difficult to build than others, clubs with greater technical skills are at an advantage, too. I'm therefore going to deal with these three issues separately.

5.1 Resistance

A smaller rudder will indeed reduce the resistance – specifically, it will lower the skin friction which is directly proportional to wetted surface area. However, the effects are so small that they are almost negligible. Suppose an 850cm^2 rudder of square planform has its area reduced by chopping a third off the trailing edge (i.e. the back). At a speed of 4 knots, the total reduction in resistance will be 0.72 Newtons. That's the equivalent to the weight of 6 £2 coins.

I don't have the resources available to me to calculate the total resistance of a skiff at 4 knots, but it will be many hundreds of Newtons. The advantage gained is so small that it's virtually negligible. Think about the force that a crew member will be applying to move a skiff along at 4 knots. Multiply that by 4 to give the total force being applied by the whole crew. Now compare that to the weight those 6 £2 coins. The disadvantage of having that extra rudder area is comparable to the disadvantage of one of the crew members wearing a watch!

There are many immeasurably more effective ways of improving the performance of a skiff – for example, optimising oar design and seat spacing, minimising the resistance in the oarlock system, and even polishing the hull. By comparison, the wetted surface area of the rudder becomes a non-issue.

5.2 Manoeuvrability

I do not believe that improved manoeuvrability can be considered an unfair advantage, for the following three reasons:

Reason 1:
The rudder is not responsible for producing the forces that allow a boat to manoeuvre – it simply *initiates* the turn by rotating the hull such that the incoming flow hits the bow at an angle. The far greater forces on the hull itself then take over, causing the boat to turn. Think about the way that a canoe will try to spin perpendicular to the direction of travel as soon as it's no longer going in a perfectly straight line – the same effect happens here.
As such, a more effective rudder gives no major advantage in making a turn across a known course – it is simply applied closer to the buoy, since it is quicker to initiate the turn. Once the boat has started turning, the hull forces take over and the effectiveness of the rudder should have no further effect on the manoeuvre.

Reason 2:
Version (b) of the proposed rule change suggests a minimum rudder area, but not a maximum area. This implies that the rules committee does not consider highly effective rudders to give an unfair advantage.

Reason 3:
The turning effect that can be offered by the rudder is minimal when compared to the effect of checking with the oars on one side – and this is a common method used for turning around buoys during racing. The main function of the rudder is for minor course correction and manoeuvres to avoid navigational hazards and collision with other boats.

5.3 Manufacture

Common sense says that if a club is able to build a boat, it should be able to make an effective rudder. Optimising seating and developing effective oars both require a lot more technical skill than building a rudder (and both have a far greater effect on the final performance). Implementing version (a) of the rule based on this argument clearly isn't necessary.

6 Tradition & Aesthetics

Defining what constitutes acceptable aesthetics is very difficult (and it could be argued that since the business end of the rudder is below the water it doesn't matter anyway). Ensuring that the rudders are consistent with the traditional appearance of the skiff is a bit less open to interpretation.

The question that must be asked here is this: what does a traditional rudder look like? A Google search yields some examples of what typical rudder designs for traditional double-ended clinker-built boats look like:

Sailing Ship's Boat   Fair Isle Skiff (on which St Ayles is based)

Note that the ship's boat uses a variation of the elliptical rudder described above. The rudder of the Fair Isle Skiff is particularly interesting, as the St Ayles Skiff was actually based on this very design. It features a high aspect ratio rudder of a very similar design to the one adopted by NBRC, albeit canted further over so that it's closer to the keel.

Traditional boat builders may not have known so much about hydrodynamic theory as we do now, but they used rudder designs that they knew worked well based on experience, trial and error. As demonstrated by the two examples above, the solutions they reached are largely the same as those proven by modern calculations. The notion that the design shown on the drawings are in some way 'traditional' whilst other designs are not is simply untrue.

7 Summary

The main points I've made in relation to the three suggested aims of the new rule can be summarised as follows.

Safety: Ensuring all rudders are sufficiently effective, so that clubs do not compromise safety in an effort to gain other advantages

The original rudder may be acceptable, but there is plenty of room for improvement. Proposed revision (a) prevents clubs from using rudders that are more effective, more efficient and safer. It also prevents use of rudders that are better suited to local conditions or circumstances. Revision (b) is also restrictive, and critically fails to make any improvement over the status quo. Wetted surface area alone cannot be used as a measure of rudder effectiveness – planform, aspect ratio and section are all equally important. Rudders with less surface area can still be equally, or more, effective.

Fairness: Ensuring that rudder design does not give some clubs significant advantages over others

Reductions in wetted surface area give negligible reductions in drag. Improvements in effectiveness and efficiency are not considered to be unfair disadvantages, as they improve safety and have little effect on racing.

Tradition/Aesthetics: Ensuring that the rudders are consistent with the traditional appearance of the skiff

I'm not sure where the original rudder came from. The Fair Isle Skiff upon which the St Ayles Skiff is based, along with other similar classic boat designs, featured other, more effective rudder shapes.

8 Conclusions & Recommendations

The new rules will not make boats safer, fairer or more traditional in appearance. The benefits of allowing free reign over rudder design far outweigh the disadvantages. I have illustrated that implementing the proposed changes could have a negative impact.

My personal recommendations are as follows:

- Do not implement proposed rule (a), which standardises the original rudder design and prevents the development of more practical, effective and safer alternatives.
- Do not implement proposed rule (b) which is impossible to enforce in a manner fair to all crew combinations, and fails to make any improvement over the status quo thereby making it pointless.

The 850cm^2 wetted surface area already exists as a recommendation since it features in the original drawings, but it should not be used to restrict clubs from developing, implementing and sharing effective designs with smaller areas. It is in the best interests of every club to develop a rudder that is fit for purpose, so governance of this type really isn’t necessary. Every rudder would still be subject to overriding safety scrutiny by the SCRA; however, this should be done on a case-by-case basis rather than by implementing rules that are ineffective in serving this purpose.