A PERFORMANCE GUIDE FOR DF 95 RULE MAKERS

Assessing effects of some boat parameters on performance

Document control

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Background

When a class rule is changed, it is often driven by the intention of controlling or minimizing the effect on performance of some characteristic of the boat. This is particularly so for one-design classes. For example, constraints may be placed on the weight and position of batteries, or the surface finish on a hull. It is rare and quite difficult for rule makers to quantify the effects of these parameter on performance, resulting in rules often being made based on either anecdotal evidence or “gut-feel”.

This document helps the decision-making process by providing data on the impact of some changes on aspects of performance. For example, if a new type of masthead fitting is developed which reduces weight by 5 grams without any change in windage, the data will reveal the number of boat lengths gained on a typical race by adopting the new fitting. The rule makers can then decide if this difference is sufficient to warrant a change in the rules to prohibit the new fitting.

At present two topics are covered:

- Effect of adding, subtracting and moving weights vertically
- Effect of hull surface roughness

This document is a living document; it will be expanded and enhanced with time, as new topics are investigated (e.g. windage) and further analysis is conducted (e.g. effect of surface finish of fins).

Some overall findings and their implications

It is instructive to consider and compare the findings of some frequently debated rule changes:

- Adding or reducing weight in the hull.
- Adding or reducing weight in the rig.
- Sanding to different levels of hull surface roughness.

The metric used is the number of boat lengths gained or lost over a typical windward-leeward course of length 600m (duration about 10 minutes), averaged over a range of wind strengths. The results have been calculated for a DF95 class yacht.

- Adding 50g at the waterline will slow the yacht down by less than 1 boat length.
- Adding 5g at the masthead will slow the yacht down by less than 2 boat lengths.
- Sanding the hull with, say, 800 grade paper improves performance by less than 1 boat length in open (turbulated) waters, and about 5 boat lengths in still waters.

These findings suggest that it might be inconsistent to apply rigorous control of battery weights if there is little control on the weight of mast and sails, other things being equal (which they rarely are). This finding does not take account of other factors that might need to be considered e.g. cost, structural stiffness, windage. Also, it does not directly answer the question "How much difference is significant?", though it does help inform that judgement. Furthermore, it does not address a fundamental question: can a rule be enforced? Those considerations lie outside the scope of this document.

Effect of weight

Background science and assumptions

Adding a weight affects the drag of the yacht, and moving the weight up and down affects the stability or sail-carrying power of the yacht. The impact of these effects on performance was calculated with the aid of a Velocity Prediction Program (VPP) called WinDesign[1], adapted for model yachts. The inputs to the program are the shape and weight characteristics of the yachts, and the wind speed. The resistance, sideforce, boat speed, leeway angle and heel angle are then calculated by the VPP over a range of wind speeds and wind directions. The program output is the boat speed in seconds per mile for the range of conditions investigated. The difference in performance due to a change (e.g. adding a weight) is calculated in seconds per mile by comparing the changed and unchanged yacht performance.

These performance changes are then applied to a typical race course to yield the difference in boat lengths over the finish line that can be attributed to the change being investigated. The results have been calculated for wind speeds of 5, 12 and 19 knots, then averaged[2].

No VPP can cover every aspect of performance. Effects of longitudinal trim, wind waves, vertical wind gradient, longitudinal stability, acceleration etc. are rarely included with high accuracy, if at all. Nevertheless, VPPs have been used with great effect for more than 40 years to compare designs.

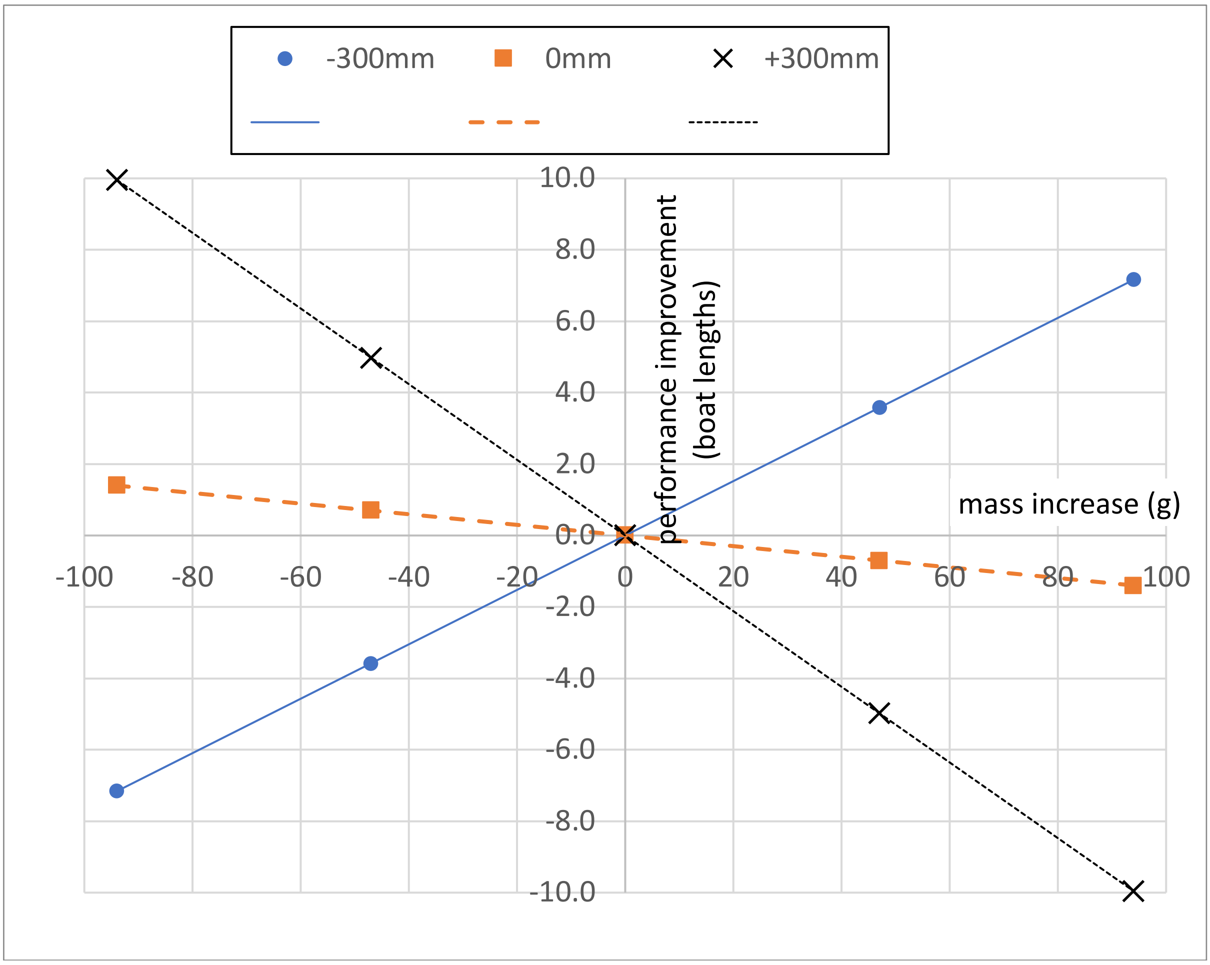
Results

These results are for a DF95 yacht on a 600m windward-leeward race course, comprising 3 laps of 100m per leg.

- Results are in boat lengths: negative is slower, positive is faster.
- Weight changes are in grams: negative is weight removed, positive is weight added.
- Height changes are the distance in mm from the waterline: negative is distance below the waterline, positive is distance above the waterline.

The results averaged over different wind speeds are shown in Figure 1. Table 1 shows the detailed results at each wind speed for the entire race, and also for one upwind leg and one downwind leg.

1 https://clayoliveryachtdesign.com/windesign-vpp
2 These are speeds measured at 10 m above sea level. Speeds at 2 m above sea level are about 20% less.



- *Figure 1 average effect of adding and moving weight*

Wind speed @ 10m height -->		5 knots			12 knots			19 knots			average
Mass added	Location	Upwind leg	Down wind leg	Race total	Upwind leg	Down wind leg	Race total	Upwind leg	Down wind leg	Race total	race
50g	@ WL	-0.1	-0.1	-0.8	0.1	-0.3	-0.8	0.1	-0.4	-0.5	-0.7
50g	300m above WL	-0.8	-0.1	-2.4	-1.6	-0.3	-5.6	-1.8	-0.4	-6.9	-5.0
50g	300m below WL	0.6	-0.1	0.8	1.7	-0.3	4.0	1.9	-0.3	5.9	3.6
5g	@WL	0	0	-0.1	0	0	-0.1	0	0	-0.1	-0.1
5g	@ m'head	-0.3	0	-0.7	-0.6	0	-1.8	-0.7	-0.1	-2.4	-1.6

Table 1 detailed effects of adding and moving weight

How to use the graph in Figure 1

Example 1: add a second battery

Adding a second battery is approximately equivalent to adding 60g at the waterline. Look at Figure 1 and identify which of the three lines to use: for a weight added at the waterline, this is 0mm change in height so use the orange dashed line. Go along the horizontal axis until you reach +60, then go down to the orange line and read across horizontally to the vertical axis. The answer is about -1. i.e. the boat will be one boat length slower over a typical race course if you add a second battery.

Example 2: halve the weight of the sails

A suit of Joysway A-rig sails weighs just over 35g, so halving the weight of the sails is approximately equivalent to removing about 20g from about 40% up the mast i.e. roughly a height of 300mm above the waterline. Identify which of the three lines to use: for a weight added 300mm above the waterline, use the black dotted line. Go along the horizontal axis until you reach -20, then go up to the black line and read across horizontally to the vertical axis. The answer is about +2. i.e. the boat will be 2 boat lengths faster over a typical race course if you can halve the weight of the sails.

Example 3: make the main boom heavier

Suppose we make the main boom 20g heavier. This will be at a height of about 100mm above the waterline. There is no line for a height of 100mm, but 100mm is about one third of the way between the 0mm line (orange dashed) and the 300mm line (black dotted). So imagine a line (or draw it in) one third of the way between the 0mm line and the 300mm line. Go along the horizontal axis to the +20g, then go up to the imaginary or drawn line and read across horizontally to the vertical axis. The answer is about -1. i.e. the boat will be just under 1 boat length slower over a typical race course if you have a heavier main boom.

Effect of hull surface finish

Background science and assumptions

Neither the material which the hull is made of, nor the type of paint system, has any effect on performance. What matters is the smoothness or roughness of the surface. Products such as wax or Teflon have no direct benefit on performance because they do not usually decrease the roughness. Indeed, wax can make the surface rougher by attracting dust and grit particles.

There are two types of flow over the hull – laminar low, which generates low amounts of friction drag, and turbulent flow, which generates high friction. The surface roughness of the hull affects the amount of friction drag generated by turbulent flow, but it does not increase the amount of friction drag within laminar flow. However, it does determine the amount of laminar flow present.

So a critical factor affecting the approach taken to estimating the effects of hull roughness is the amount or proportion of laminar (smooth) flow that is present over the hull, compared with the amount of turbulent flow. The effects of hull roughness for large yachts and ships has been well understood for 100 years because they operate almost entirely in turbulent flow. In contrast, very little research has been conducted on the effects of hull surface roughness on the performance of model yachts, because of the possibility of laminar flow being present[3].

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3 One of the few (only?) papers on this topic was published by the author in the Australian Naval Architect journal in May 2022, viewable at https://klakamarine.org/yacht-design/general-design-topics/

The effects of different surface roughness heights on friction drag have been calculated using fluid dynamics equations, then the resulting changes in friction were input to a Velocity Prediction Program (VPP) – the same one used for the weight variation analysis. This yielded seconds per mile variations for different roughness heights, which were then converted to boat length differences around a typical race course, for a hull sanded with different grades of sandpaper.

In generating the results, the following assumptions and approximations were made:

- Average wind speed 10 knots.
- Hull is slender and in line with the flow i.e. no leeway angle effects
- Surface finish of the fin, bulb and rudder are not considered (a work in progress).

The effect of hull surface roughness is strongly dependent on the natural turbulence within the water, because this determines the likelihood of laminar flow being present. For open water where there are breaking waves, or enclosed waters with pumped water circulating or powered vessels operating, there is significant turbulence in the water, which inhibits the development of laminar flow. However, in still ponds there is less turbulence, so the presence of laminar flow is likely, or at least possible.

Results

Results for open or disturbed waters (turbulent flow)

It is assumed that in open water the water is already turbulent as it reaches the hull, thus preventing the existence of laminar flow. The results are shown in Figure 2 for a typical windward-leeward course of length 600m (duration about 10 minutes), in a wind speed of 10 knots.

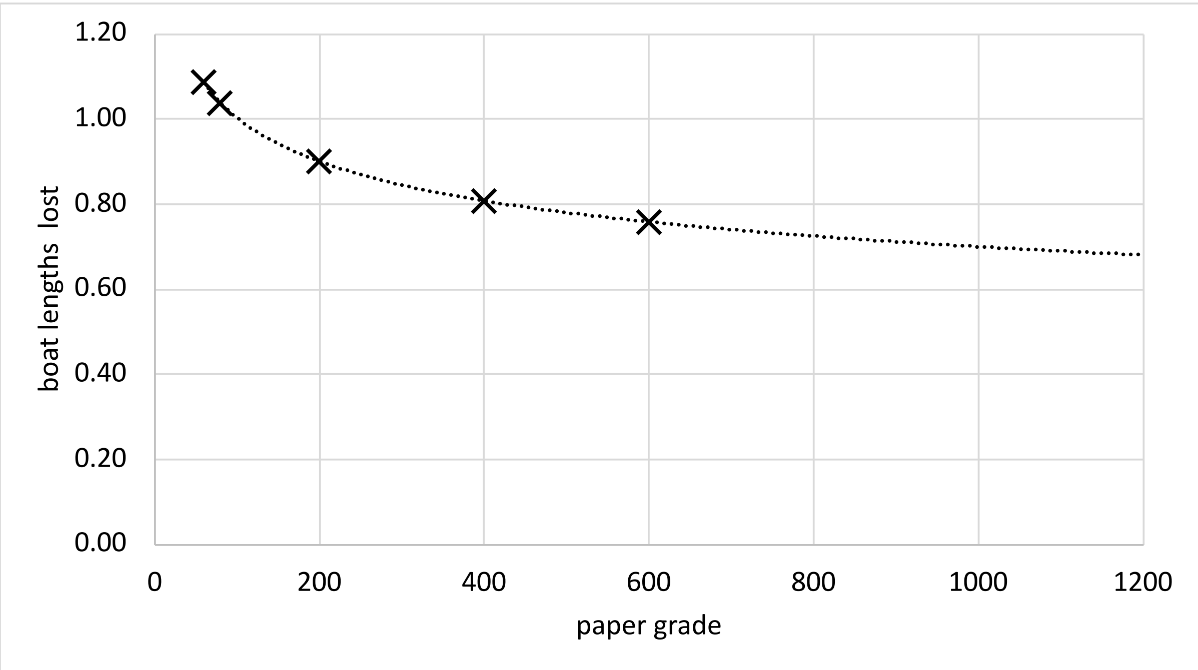

Figure 2 Effect of sandpaper grades on performance in open water

This shows the diminishing returns from working through the various sandpaper grades. For example, the performance gained by sanding from 80 grade to 400 grade is about 0.2 boat lengths (1.0-0.8); sanding down further to 1000 grade (a lot more work!) generates a further gain of only about 0.1 boat lengths.

Results for still waters

As noted earlier, if the water is still then there is the likelihood of laminar flow existing, and laminar flow generates much less friction than does turbulent flow. The assumptions and equations for laminar flow are quite different to and more complex than those for turbulent flow. As a consequence, the results cannot be presented in quite the same way. The surface roughness does not increase the amount of friction drag within laminar flow, but it does determine the amount of laminar flow present. The calculations have been conducted for only one condition so far (a work in progress).

Comparing **200** grade paper finish with **1200** grade paper finish, the calculations show that in still waters there is a gain in performance of **4.5** boat lengths on a typical windward-leeward course of length 600m (duration about 10 minutes), in a wind speed of about 10 knots. This compares with a gain of about 0.2 boat lengths for the same conditions in turbulent waters.

Therefore the effect of hull surface roughness on performance is critically dependent on where the yacht is sailed.

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