2016 Finn Swing Measurements
Fort Lauderdale 18-21 January 2016

Introduction

We would like to sincerely thank the Lauderdale Yacht Club for making their junior squadron facilities available to us for these measurements. The building, with a large garage door through which the boats could be brought, was ideal for the swing tests, with adequate space and no drafts. The LYC staff were very helpful and even lent us one of their 420s to swing. We were very fortunate to have the help and company of Tom Brandon, who had brought his son's Finn and the swing system from California for us.

Figure 1 *The Lamboley swing system at the LYC Junior Squadron facility*

The measurements were made on January 18th to 21st which gave us more than adequate time to measure the 19 US and 2 Canadian Finns. Hulls which had a valid certificate and all their correctors in place were only weighed, however the 9 boat which wished to remove weight were required to be swung.

The hulls were first inspected to ensure that they were dry and that the C/B was aft and up, and the mast fitting was aft. The positions of the correctors if present were then recorded. The hulls were weighed using the class scale which had been calibrated in Santa Cruz. One competitor complained about this as his hull was 1.5 kg lighter than he thought. Scale calibrations are latitude dependent and the latitude of Santa Cruz is 36.9719ºN while that of Fort Lauderdale is 25.7753ºN. The scale calibration was therefore off by 0.9991 or 100gm in a 116 kg Finn, which is in any case the resolution of the scale. The discrepancy was due to the fact that he had removed his flowerpot compass, a fact he forgot to mention!

Figure 2 *Tom Brandon and Bob Carlen*

For the swing tests the hulls were suspended with the top of the C/B case level, the axis 2 to transom distance λ measured, and then the class Pasco photogate timer was used to record the periods of typically five oscillation with bow amplitudes between 80 and 100 mm, and the average calculated. Daryl Peck checked some of our data by timing 5 oscillations with a cell phone and his data were in good agreement with ours, although with somewhat larger scatter.

The period on the second knife edge was then measured and the two periods entered into a spreadsheet to calculate the gyradius k_p and CG height a. The spreadsheet (available on request) had the facility to calculate the positioning of corrector weights so as to optimize k_p and λ, after which the correctors were adjusted, if necessary, and the hull was re swung.

Recording the individual oscillation periods has the advantage that one can see the variation, which was consistently a decrease with time as shown in figure 3. When the amplitude decreased below 80 mm the hull was given an impulse to increase it back to 100 mm. This consistently caused a larger period after which it again decreased. The anomalous decrease of the oscillation period with time, i.e. amplitude was previously observed as 0.0002 s/Osc in 1991 and is common to all Lamboley tests. However, the present rather larger variation, especially for T_2, and inconsistencies are attributed to changing inclination of the hooks, which increased as the hull swung.

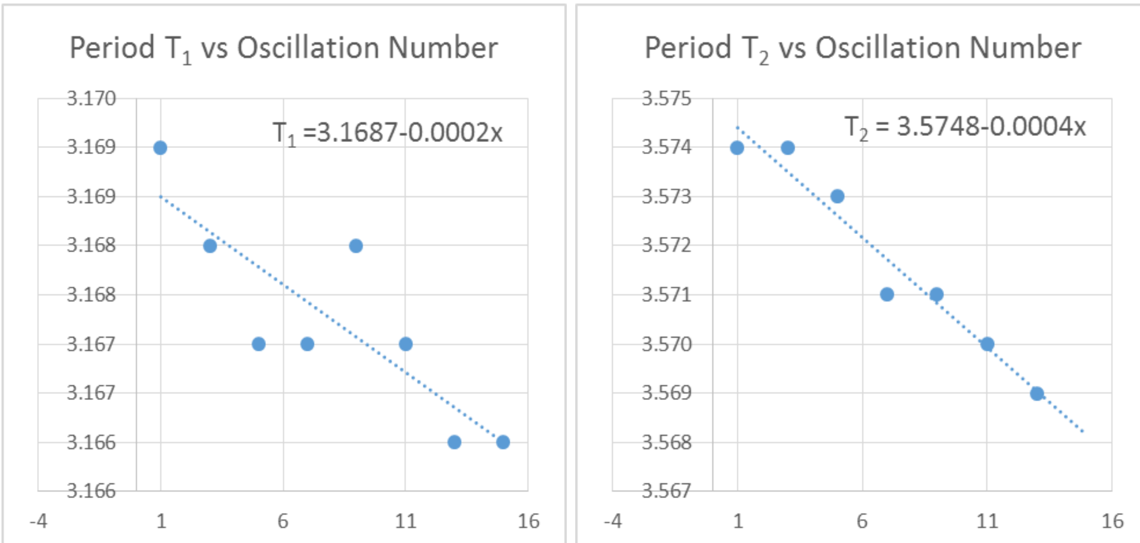


Figure 3 *Period 1 and 2 measurements showing the decrease with oscillation number.*

Lateral positioning of Corrector weights

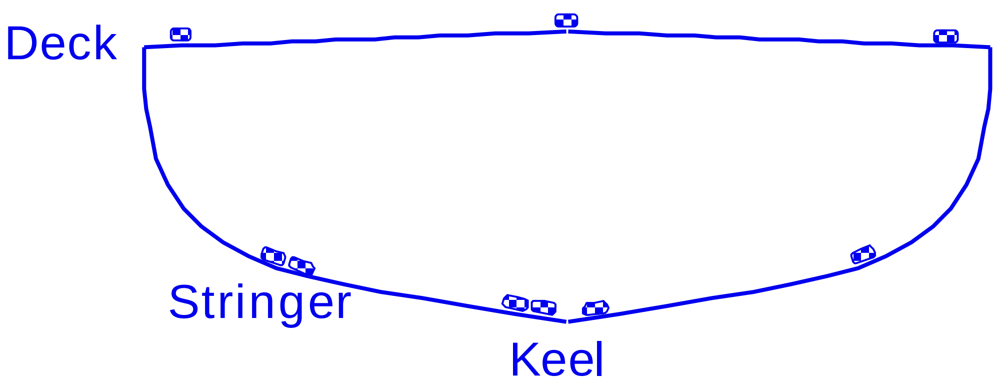


Figure 4 *Lateral positions of three 0.25 kg correctors at the transom a) on deck, b) on the stringers and c) at the keel.*

It was suggested that placing the corrector weights at the transom athwartships, i.e. on the stringers rather than at the keel line will change the pitch gyradius. Although this affects the gyradius about the roll axis, and to a minor effect the CG height *a*, a Lamboley test is only sensitive to the pitch gyradius k_p, which in turn is dependent only on the square of the distance of the mass from the pitch axis through the center of mass, and not its lateral displacement. If this is not correct then the theory of the Lamboley test is also not correct! However, as we had the time we measured the period T_2 for a hull with three 0.25 correctors placed at the transom as shown in figure 4, i.e. at the keel line, on the stringers and on the deck.

The results, see figure 5 and table 1 which includes the predictions assuming the keel data are correct, are a perfect example of how myths of this sort can originate and illustrate the limitations of swing testing precision, especially if everything is not precisely controlled.

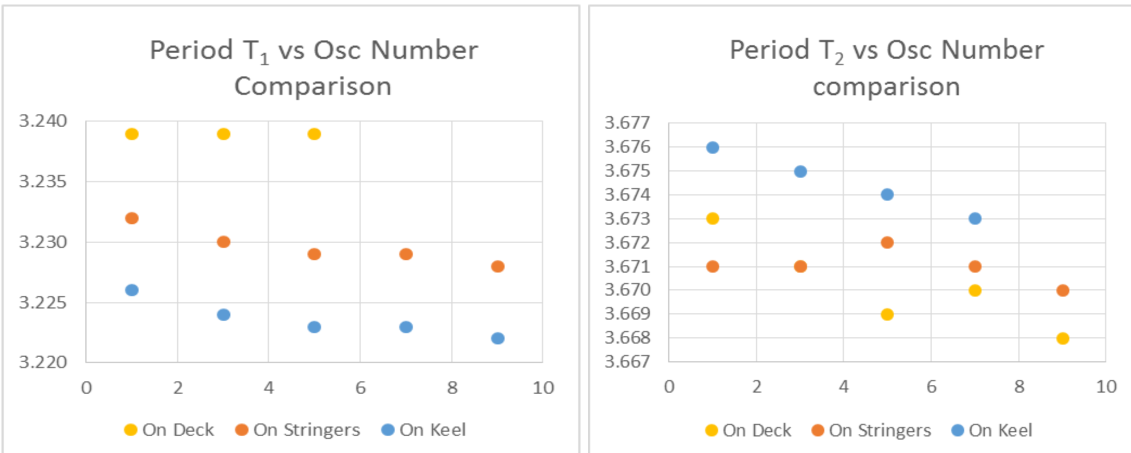


Figure 5 *The periods T1 and T2 for three 0.25 correctors at the transom a) at the keel, b) on the stringers and c) on deck.*

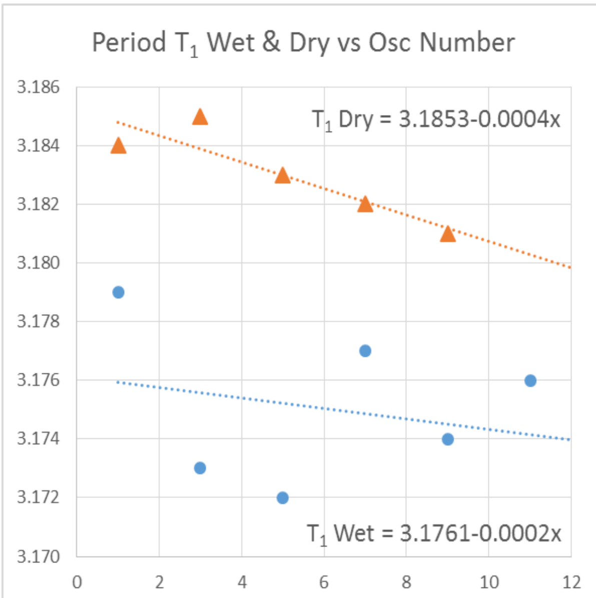
Table 1

Corrector position	Period T_1	Period T_2	Gyradius k_p or ρ	CG Hight **a**
On Keel	3.224	3.675	1094.9	606.3
On Stringers	3.230	3.671	1102.1	613.6
Predicted On Stringers	3.225	3.677	1094.9	605.7
On Deck	3.239	3.670	1111.7	622.2
Predicted On Deck	3.227	3.682	1095.1	604.4

The first thing to notice is that clearly moving the correctors from the keel to the deck must raise the CG, i.e. reduce A as predicted. These results however show a variation in the opposite sense and much too large thus bringing these results into serious question. These data were taken before it was realized that the inclination of the hooks has a major effect, see below, and this is probably the cause for these fallacious results. They do however demonstrate that if everything is not precisely controlled the results of swing testing can vary significantly.

Water in the hull

One hull, even after inspection that showed the buoyancy tanks were dry showed excessive damping of the oscillations, suggesting water in the hull. On standing this hull on its transom about 400 gm of water drained out. The swing periods when wet and dry are shown in figure 6 and demonstrate the effect of even a little water in the hull, the calculated gyradius increasing by 5 mm which is much larger than one would expect if 400 gm of lead were removed from the center of the hull.



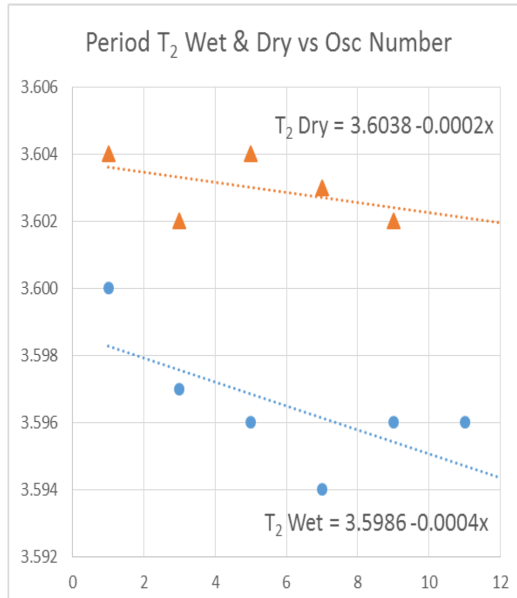


Figure 6 The *Period 1 and 2 measurements of a hull which was found with 400 ml of water in the central buoyancy compartment.*

New Lamboley Hooks

The measurements used the 2015 Lamboley hooks, see figure 7, made by Juri and adopted as the new standard for the Finn Class. These hooks differ somewhat from those shown in the Finn Class Rules, see figure 8, in that the vertical sections are only 15 mm wide, as compared with 25 mm wide, and the center bearing is 39 mm wide, as compared with 25 mm wide. The hull bearing points of the support lugs are 54 mm from the surface of the hooks, and are 197 mm below axis 2, as compared with the 200 mm specified in the rules diagram (easily adjusted by bending the lugs).

The mass of 2 of these 2015 hooks is 2.93 kg which is in the center of the 2.70 to 3.30 kg range the rules prescribe. A hook was swung and also balanced horizontally to determine the hook CG and gyradius. The hook CG is $a_h = 252$ mm below the axis 1 and the gyradius $k_h = 152.4$ mm, which are essentially the same as the 1976 class hooks.

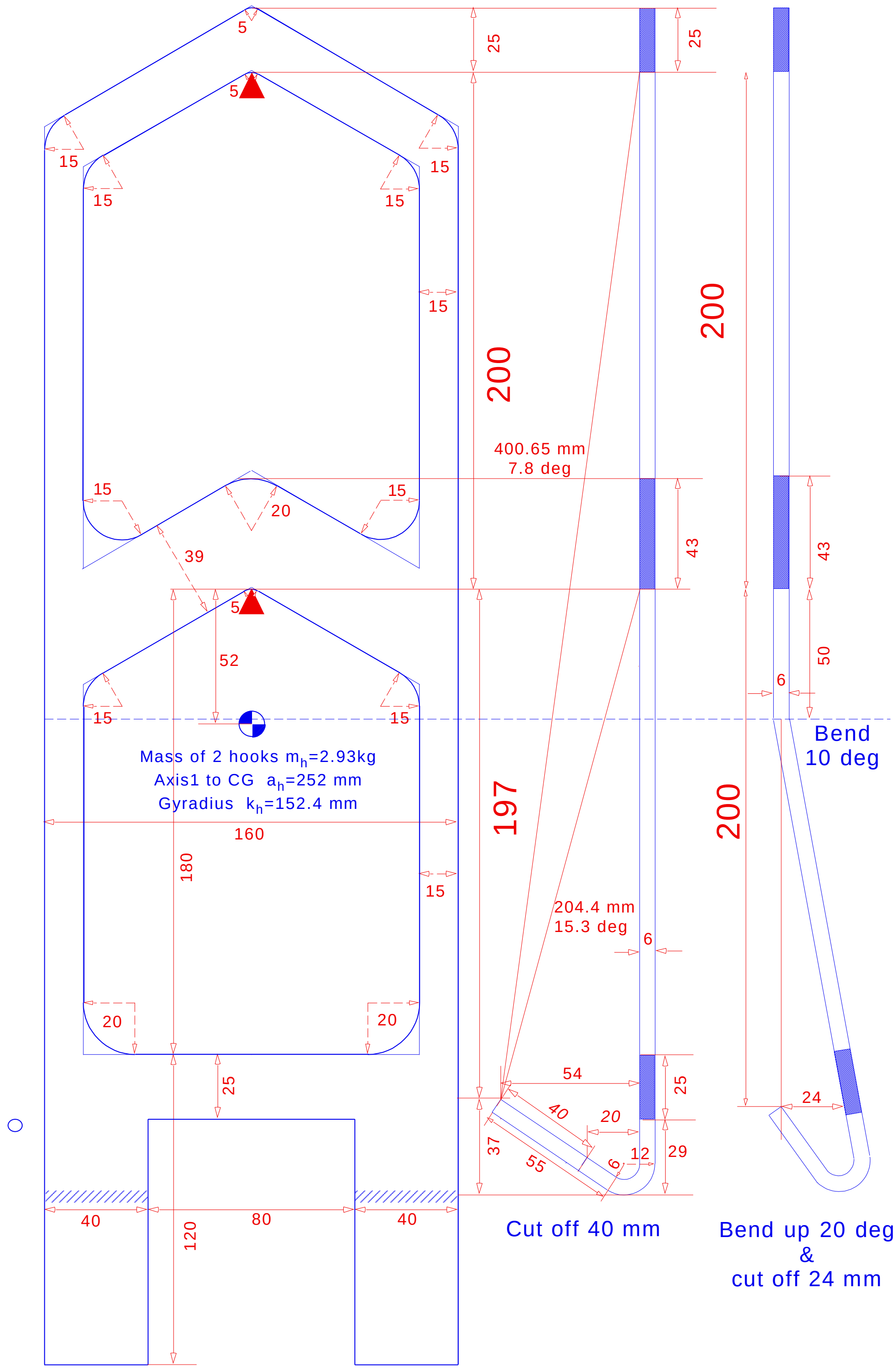


Figure 7 *The new 2015 Lamboley hooks, the mass of two is 2.93 kg as supplied. Two alternative modifications, which would avoid the hooks leaning in are shown.*

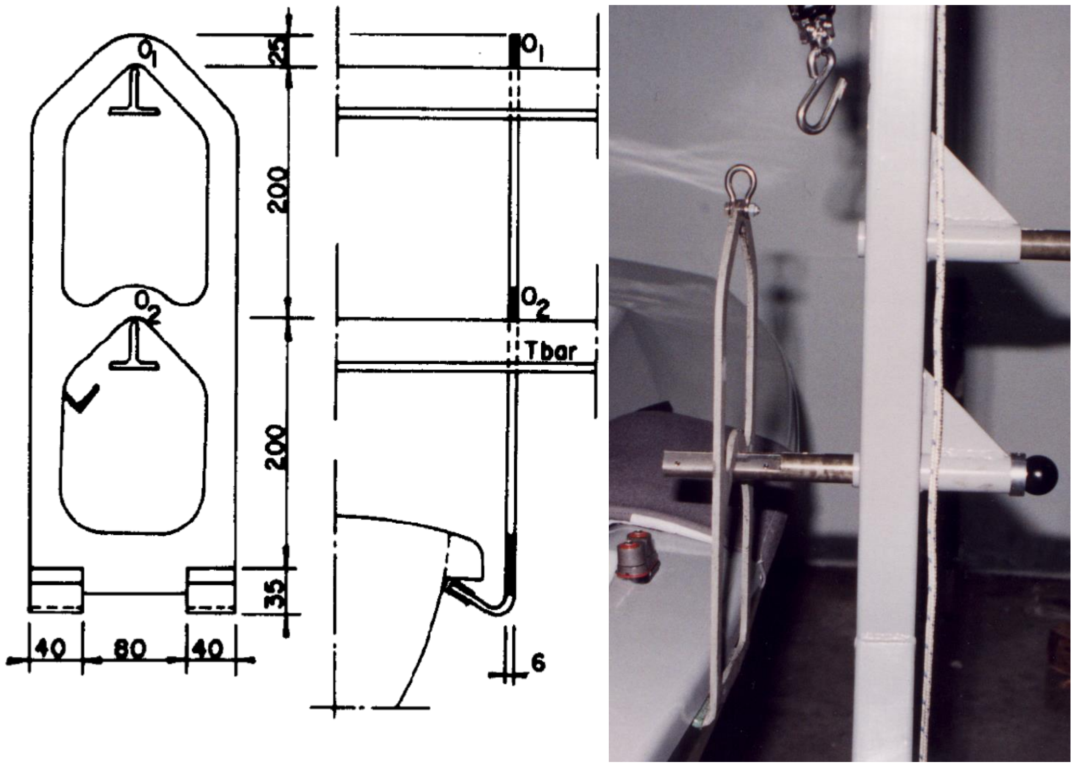


Figure 8 *The diagram, and a photo, of the mild steel hooks specified in the Finn Class Rules. The offset of the lug bearing point from the inner plane of the hooks is 42 mm, and the mass of two hooks* $m_h = 2.76$ *kg* ($2.70<m_h<3.3$ *kg).*

Inclining of the hooks

The support lugs of the 2015 hooks extend 54 mm from the plane of the hook, as compared with 42 mm for the class rules hooks (which also inclined) and this causes the hooks to incline, i.e. “lean in” especially when on axis 2. The theory assumes that the hooks remain vertical for both axis 1 and axis 2 so that the change in the vertical position of the axis relative to the hull is b = 200.0 mm.

The class Lamboley stand, and the Mark II version used for these measurements, have lifting tackle which lift the hooks, with the hull on them, off the knife edges and lowers them down vertically. However the hooks slide on the knife edges and do not remain vertical. The amount the hooks slide depends on the friction at the knife edge, i.e. its sharpness and the material of the hooks. In practice the hooks were adjusted to initially be as close to vertical as possible but this had the disadvantage that as the hull swings the friction is reduced and the hook inclination increases, which caused the period to decrease. Even with hooks that remain vertical the periods of oscillation decrease to an extent which is much larger than predicted for an ideal compound pendulum and this is presumed to be due to nonlinear damping and bearing effects. However, the unpredictable variation of the hook inclination significantly increased this effect as shown in figures 3, 5 and 6. When held vertical the 2015 hooks were observed to develop a small curvature.

Figure 9 *The significant incline i.e. "lean in" of the hooks, especially on axis 2, Even after having been vertically lowered onto the knife edges they slide. Note the large space between the hook and the gunwale as compared to that in figure 8.*

If there was no friction between the hook bearing surfaces and the knife edges the hooks would incline so that the support point on the knife edge is vertically above the hull support point on the hook lugs and the incline is therefore different on axis 1 and axis 2. The inward lean of the hooks, which we found unavoidable on axis 2, depends on how the hook is placed on the knife edge and often changes when the hull swings, leading to changes in the period. Figure 10 illustrates the difference in hook inclination on axis 1 and axis 2, thus changing "*b*" the vertical displacement of the axis, which is then no longer 200 mm, so the calculated gyradius k_p and CG position "*a*" are then not correct.

The zero friction inclination of the 2015 hooks, see figure 10, would be 7.8 degrees on axis 1 and 15.3 degrees on axis 2, which would lead to an effective value of "*b*" of 400.65 – 204.40 = 196.25 mm. This differs from 200 mm by 3.75 mm, i.e. much larger than the 1 mm allowed by the class rules. For a legal Finn with ρ = 1100 mm and a = 633 mm (T_1 = 3.200 s, T_2 = 3.604 s) inclined hooks lead to calculated ρ = 1095 mm and a = 624 mm (a reduction of 4.8 mm in the calculated gyradius and 8.2 mm in the CG height, and would require an extra 450 gm of lead at the transom to bring the calculated gyradius up to 1100 mm. Thus although this is the maximum effect to be expected it is significant.

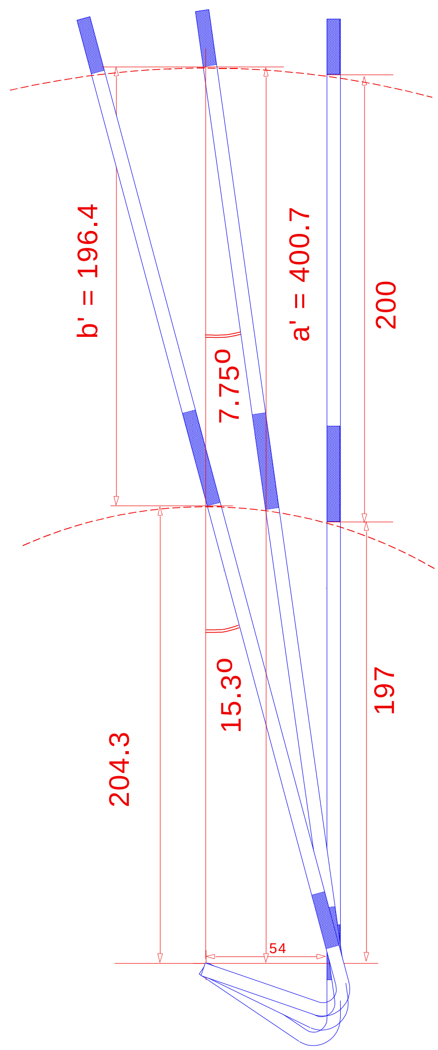


Figure 10 *The incline of the hooks on axis 1 and 2.*

Hook Bearing surface

There is another problem which is exacerbated by the incline of the hooks. When the hooks are vertical the knife edge contacts the whole 6 mm width of the hook, while when the hook is inclined inwards, as illustrated in figure 11, it contacts only the inside corner. Then as the hook slides on the knife edge it forms a prismatic groove, see figure 12. Laboratory experiments have shown that the indentation of point bearings in steel surfaces can have a significant effect on both the damping and period of pendulum oscillations. Even with vertical hooks there is anecdotal evidence that filing the bearing surfaces smooth affects the oscillation period. Furthermore due to the greater indentation on the lower bearing surface, see figure 12, the spacing "*b*" is no longer 200 mm. Subsequent measurements on the hooks showed that on the outside edges *b* = 199.88 and 199.80 mm while on the inner edges *b* = 199.44 and 199.30 mm.

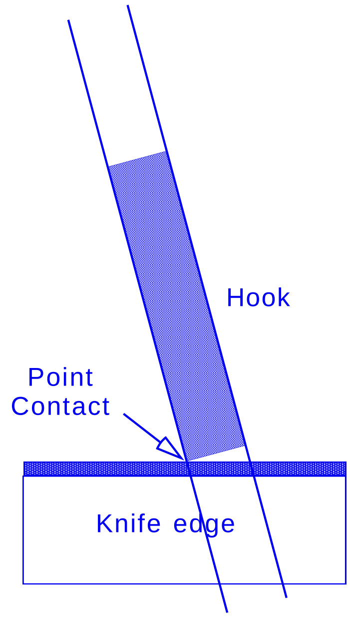


Figure 11 *The incline of the hooks causes the knife edge to make a point contact with the hook. In practice it causes a triangular groove in the hook bearing surface, see figure 12.*

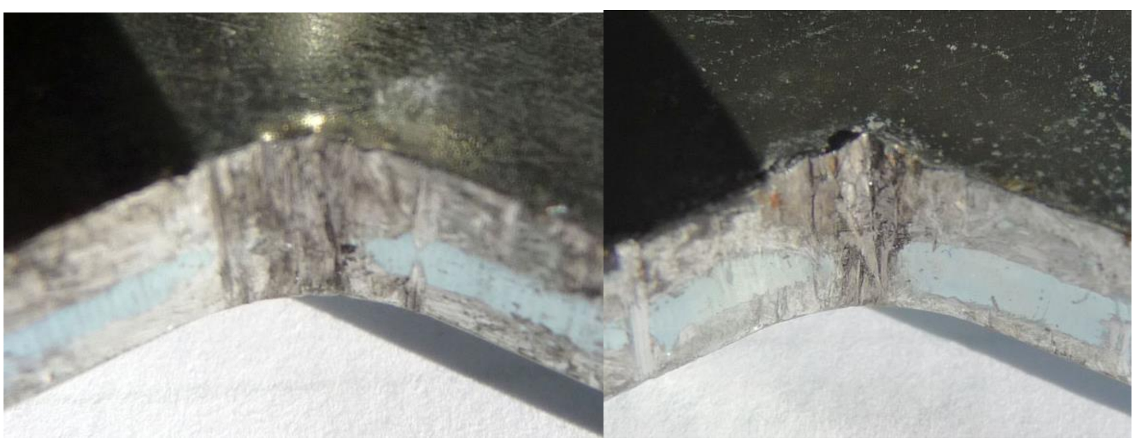


Figure 12 *The upper and lower bearing surfaces of the hook. Note the triangular groove in the inner edge of the lower hook bearing surface.*

Effect of b ≠ 200.0 mm

The Finn class rules specify that b has to be within 1.0 mm of 200 mm and the present hooks are well within this specification. However, it is of interest to calculate the effect of a value of b = 199 mm, which for a hull with k_p = 1100 mm and a = 633 mm would lead to k_p = 1101.3 and a = 635.2 mm, i.e. changes of Δk_p = +1.26 mm and Δa = +2.19 mm.

Hook Modification

The extension of 54 mm on the 2015 hooks is the cause of the inclining and should be reduced. The width of the Finn gunwale is limited to be less than 25 mm, see figure 13, so in principle the extension of the lugs could be as little as 13 mm, but a value of 20 mm is more reasonable. This can be achieved by modifying the new hooks, as shown in figure 7. A simple modification is to just cut 40 mm off the lugs. The hooks would then probably stay vertical, or at worst incline by 2.8° and 5.3°, which would have a minimal effect on the results, i.e. errors of Δk_p = 0.6 mm and Δa = 1.6 mm.

A better solution is to bend the hook by 10°, shorten the lugs by 24 mm and bend them up by 20°. As shown in figure 7 this brings the support point into the center plane of the hook and makes a_2 = 200 mm. These modifications would reduce the combined mass of the two hooks to 2.78 kg or 2.84 kg respectively, so still within the class rules *(2.70<m_h<3.3 kg).*

Filled Gunwales

D.6 - Gunwale rubbing strakes

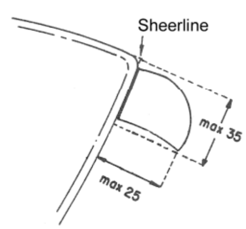


Figure 13 *The Finn Class gunwale rule diagram*

The Finn gunwales are limited to be less than 25 mm wide and 35 mm high but there is no rule about the gunwale being hollow or filled. Most Finns have hollow gunwales into which the hook lugs fit for firm support. The hook centerline is then perpendicular to the gunwale and for most Finns is close to vertical when the top of the centerboard case is horizontal. The new Devoti “Fantastica” Finns have hollow gunwales which are however filled in the region of the pussy pads which is fortunately just aft of where the hooks support the hull. If however other sailors decide to fill their gunwales it is possible that they will extend the filling to the region where the aft lug supports the hull but not to where the forward lug sits. If the filling is not concave this may cause the lug to slip off the gunwale. If the aft lug supports a filled section while the forward lug supports a hollow section the hook centerline will be tilted aft leading to similar problems to those with inclining hooks. Fortunately so far this is not a problem, but it could become on. If for example the difference in gunwale height is Δs then the change Δb in effective b due to the hook tilt is $\Delta b/b \approx \Delta s^2/2x160^2$. So for Δs = 20 mm $\Delta b \approx$ 1.6 mm.

Gravitational acceleration

The local gravitational acceleration g comes into the calculation of the gyradius from the oscillation periods T_1 and T_2. Thus for an accurate calculation of the gyradius the local value of *g*, the acceleration due to gravity, should be used rather than the values quoted in the Finn Class rules. It could, however, be argued that the rules require that the gyradius be less than 1100 mm when calculated as per the chart or the example in the rules, i.e. using the value of *g* assumed in the rules, and not the local value. This would mean that a hull which was legal at the North Pole could be illegal at the Equator!

The gravitational acceleration *g* assumed in the Finn Class rules can be derived from the example data given on the Chart and in the example, see table 2. Due to round off the values g_1 and g_2 derived from *a*, k_p, and T_1 and from *a*, k_p, and T_2 are not identical and are averaged as g_{ave}. This would suggest that Gilbert Lamboley used $g = 9.80$ m/s^2 to draw the chart, and the calculator example uses $g = 9.81$ m/s^2. Thus if a Finn legal value is to be adopted for programs to calculate the gyradius and CG height the value $g = 9.810$ m/s^2 is to be preferred.

Table 2

Finn Class	T_1	T_2	a	k_p	g_1	g_2	g_{ave}
	s	s	m	m	m/s^2	m/s^2	m/s^2
Chart	3.590	4.340	0.520	1.180	9.801	9.791	9.796
Text	3.310	3.810	0.593	1.124	9.817	9.812	9.814

Table 3 presents the swing periods for a modern Finn hull with $k_p = 1100$ mm and $a = 633$ mm swung at various Olympic venues. The values of k_p and *a,* calculated using $g = 9.810$ m/s^2, and there deviations are presented in columns 5 to 9. Note that the calculated gyradii in Fort Lauderdale were about 1.7 mm larger than would have been measured at the Devoti factory, but are almost the same as future measurements in Rio.

Table 3

City	Latitude	Gravitation	T_1	T_2	a	k_p	Δa	Δk_p
	degrees	m/s^2	*s*	*s*	*mm*	*mm*	*mm*	*mm*
Pole	90.00	9.8322	3.196	3.600	632.6	1098.1	-0.4	-1.9
Helsinki	60.1708N	9.8193	3.198	3.602	632.8	1099.2	-0.2	-0.8
Weymouth	50.6130N	9.8112	3.200	3.604	633.0	1099.9	0.0	-0.1
Brno	49.2000N	9.8100	3.200	3.604	633.0	1100.0	0.0	0.0
Sydney	33.8650S	9.7964	3.202	3.606	633.3	1101.2	0.3	1.2
Ft Lauderdale	26.1333N	9.7904	3.203	3.608	633.4	1101.7	0.4	1.7
Rio	22.9068S	9.7882	3.204	3.608	633.4	1101.9	0.4	1.9
Acapulco	16.8636N	9.7847	3.204	3.609	633.5	1102.2	0.5	2.2
Equator	0.00	9.7803	3.205	3.609	633.6	1102.6	0.6	2.6

Older Finns!

Most hulls as they grow older tend to increase weight in the middle, much as their owners might! The unfortunate result is that although already overweight they have to add even more weight at the transom to increase the gyradius. The boat shown in figure 14 had an ingenious solution, namely to cut out a triangular opening in the centerplate. This not only reduces the weight but it does so in the middle of the boat and thus increases the gyradius.

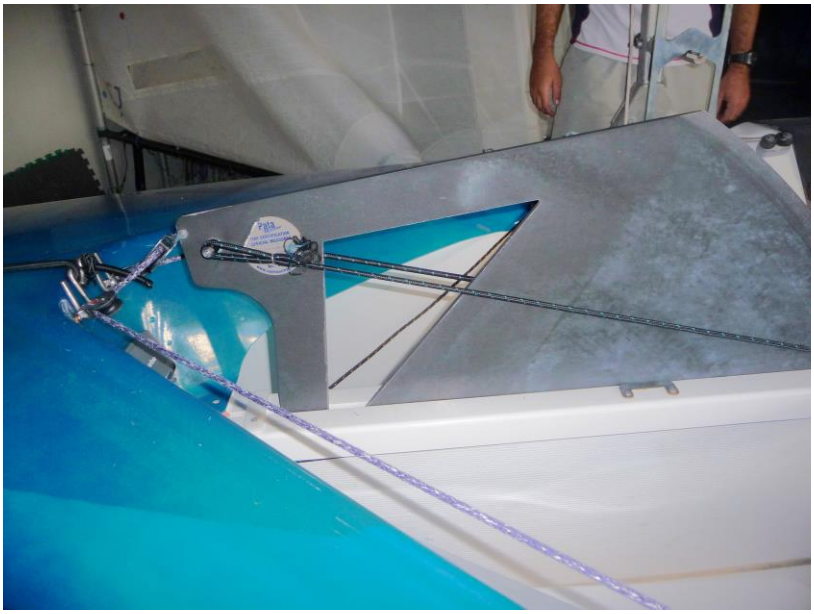


Figure 14 *The cut out of the centerplate increases the gyradius while reducing the hull weight.*

Conclusion

It was a great pleasure to meet with friends in the Finn Class and to conduct weighing and swinging in perfect conditions with plenty of time. Fortunately we had great weather, not too hot and no rain (the day after we finished it absolutely poured down). Apart from the inclining hooks we had no problems and we recommend that the class modify the hooks in one of the ways suggested in order to overcome this problem. We would again like to thank LYC and Tom Brandon for his help and for transporting the swing system.

Peter Hinrichsen and Bob Carlen 8 February 2016