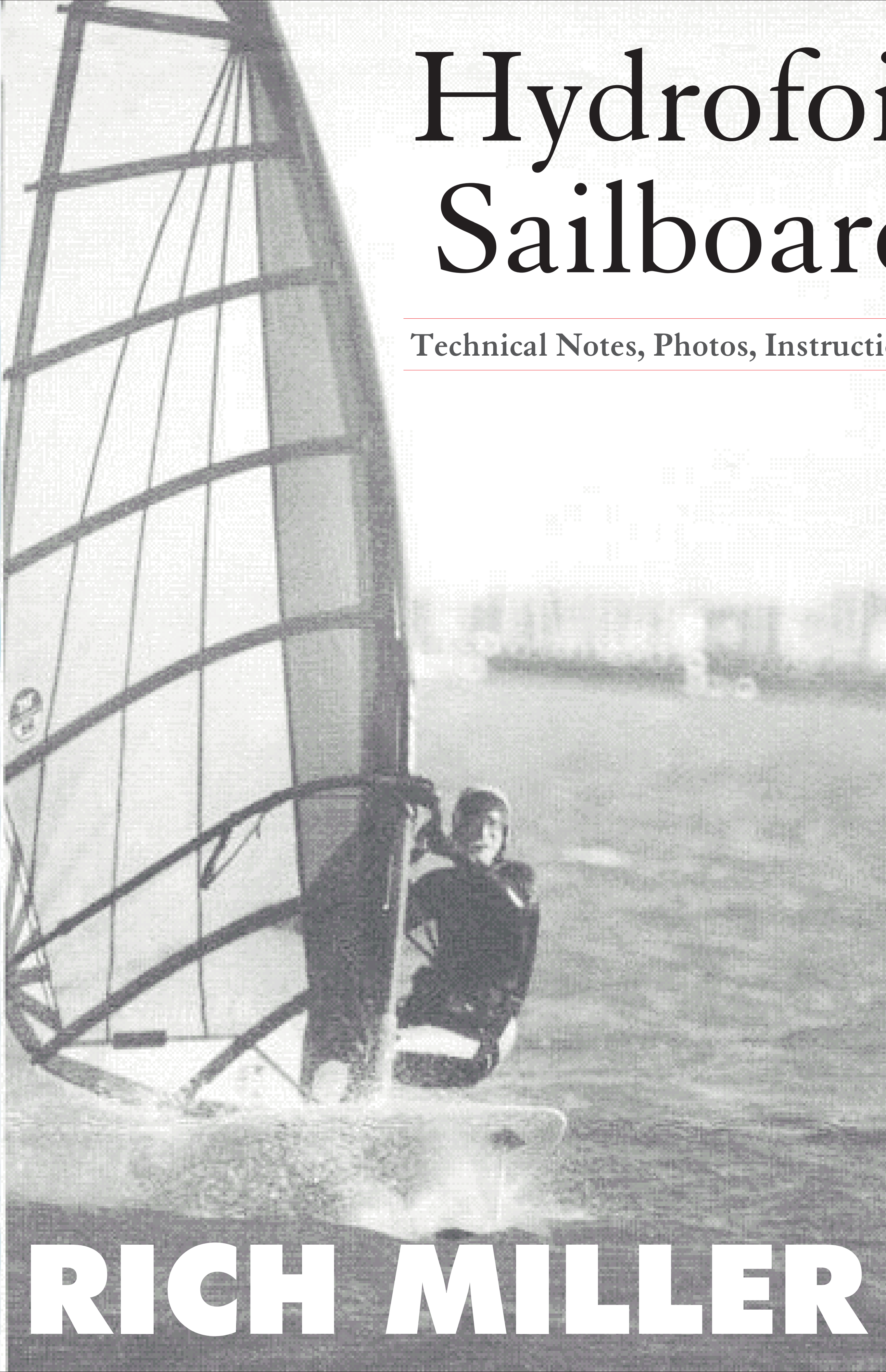
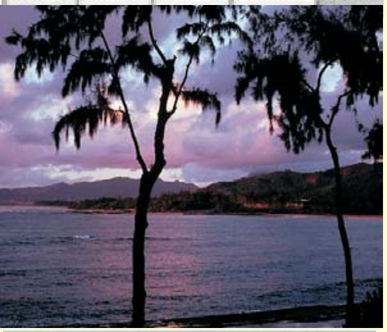
Hydrofoil Sailboard

Technical Notes, Photos, Instructions



RICH MILLER



Contents

He has added exactly what was lacking in the canard surface tracking pitch sensor... very simply and elegantly... I think it's terrific!

Sam Bradfield

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The Miller Hydrofoil Sailboard

For racers of the future, this design provides fast acceleration and a smoother ride on choppy seas

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Since the beginning, board sailors have been talking about putting hydrofoils on a sailboard, flying up out of the water, getting rid of lots of drag, and going really fast. A few people have taken the idea beyond discussion, writing patents and building prototypes. During the mid-eighties, a hydrofoil designed by Sam Bradfield was sold by the Harken Company. That design consisted of an entire small airplane that was mounted on a fin that attached in the centerboard slot of the original Windsurfer. Although some of the prototypes and the Bradfield-Harken hydrofoil were able to lift the board and rider clear of the water, none delivered performance that even equaled that of the conventional sailboards available at the time.

Now there is a hydrofoil sail-board system that may turn the fantasy of great hydrofoil performance into reality. Developed over the last six years by Rich Miller and friends, the Miller Hydrofoil delivers a smooth and very stable high-speed ride. Steering is extremely precise. In short board conditions, it planes up very quickly, then undergoes terrific acceleration, to speeds often exceeding those attainable on conventional boards. It points extraordinarily high when working to windward, and the ride on bearing off to a beam reach is breathtaking.

The Miller Hydrofoil was designed to handle just like a conventional sailboard. It works with standard sails and harness systems, and all the controlling movements are what you'd expect. It is steered by rolling, and trimmed by raking the mast in the usual way. Jibing, too, is conventional, except that the jibing maneuver must be preceded by a simple manipulation that is described further below. The board remains flying throughout the jibe.

The Miller Hydrofoil system consists of a main foil assembly, mounted in the fin box, and a canard foil assembly mounted in a special frame that is glued into a hole cut in the board near the tip. The canard is a controlling, rather than a weight bearing, foil. The main foil, mounted almost directly under the sailor, supports almost all the weight of the board and rider. It is designed to remain submerged at all times, and it is guided in doing so by the canard foil, which pops to the surface before board take-off, and generally remains there during subsequent operation. The key to the high performance of the Miller Hydrofoil is the reliability with which the canard foil tracks the surface. Secure surface tracking in the Miller design leads to pitch stability, which is important for keeping the board flying in puffy wind and when overtaking waves on broad reaches, and is also crucial to automatic height control, which is essential to high-performance hydrofoiling. Without automatic height control, foilborne operation inevitably degenerates into porpoising, where the foils alternately fly into the air and dive too deeply, leading to very inefficient motion and poor control.

Testing early in the development of the Miller Hydrofoil showed that a special type of foil is needed if the canard is to remain reliably on the surface. The type is called supercavitating, and doesn't look at all like a standard wing. Rather than having the usual tear-drop shaped section, it has one more like a narrow wedge, with its point facing forward. The result is a foil reminiscent of a meat cleaver with its business end in front.

The earliest version of the Miller Hydrofoil consisted of just a conventionally shaped submerged main foil and a surface-tracking supercavitating canard, both mounted symmetrically with respect to the keel plane of the board. The board took off easily and was sailed flat. However, when sailors tried to lean out to power up the rig, they found that the rear fin, which was necessarily exposed to the air at its top, ventilated, and the board spun out. To get more power, and at the same time avoid spinning out, they had to roll the board to windward.

The more the roll, the more they could power up, and the faster they could go. Unfortunately, it also happened that as the roll increased, so did the tendency of the board to round up into the wind. To keep the board going straight, it was necessary to hold the sail far forward of the usual place, which couldn't be done from a comfortable resting position in the harness.

Of many ideas to overcome this sail-balance problem, hinging the canard and "unrolling" it relative to the board was the first to work. To date, it is the only good solution that has been found. As long as you sail on one tack, unrolling is a perfect solution, leading to a fully-powered and, at the same time, balanced ride. However, since the canard needs to be unrolled in opposite directions on opposite tacks, the canard assembly requires a hinge, together with mechanisms for shifting and locking it, which add notable mechanical complication. And, the manipulation of these mechanisms adds to the sailor's task while jibing. Before the jibe, the canard needs to be moved to its centered position, and afterward unrolled for sailing on the new tack.

To try to avoid the complication of a hinged canard, various fixed canard arrangements have been tried, but none has been very satisfactory: they typically behave very badly in the jibe and in waves. Thus, because of the terrific performance it allows, the extra complication of the hinged canard is amply justified.

A final note: Many people who first see the hydrofoil in flat water ask if it can handle waves. The answer is emphatically yes! An important rationale for the use of hydrofoils in general (not just on sailboards) is that they don't "see" waves smaller than the foils themselves, and thus effectively smooth out the water, allowing higher speed operation than is possible on surface craft that constantly slam into seas. This general fact holds true for the Miller Hydrofoil as well, which handles chop much better than conventional boards. If you can sail a short board, you'll find it easy to learn to fly the Miller Hydrofoil. You can arrange a free lesson and demo ride by calling (510) 525-8006 or by approaching Rich Miller when you see him at one of the local sailing sites. He's easy to find; he's the one sailing just a little above the water.

Update from Rich Miller:

Since this article appeared in 1997, I have made a number of changes in the design, most notably the replacement of the inverted T main foil by one in the shape of an inverted Y with anhedral angle of 35 degrees on each side. This rather improbable change led to startling improvement in performance. In addition, I have gone to very high aspect, constant chord wings, again with significant gain in performance. I am not personally a very good sailboarder, but the hydrofoil advantage is so great that typically no conventional sailboard can stay with me on any point of sailing. And, the worse the chop, the greater my advantage. Unfortunately there is no real production of my hydrofoil kit, although I have made foil sets available to the few people who have shown interest. Now that the design is working so well and in fact is quite easy to learn to sail, I would like to make it more generally available.

The Miller Hydrofoil Specifications

YOU ARE ENCOURAGED TO WORK WITH THESE DESIGNS

To encourage further development, I allowed my hydrofoil patents to lapse; the designs described here now lie in the public domain, and may be freely copied. I would be most interested to hear of other's experiences or improvements.

Top front view of the Miller Hydrofoil in its current design

VISUALS

There are photos on the International Hydrofoil Society's website (www.foils.org/gallery/sail.htm). These include action shots as well as a view showing a Y-foil and canard assemblies. I have an old VHS format video (circa 1995) which shows the system, as it then was, in operation. The performance shown was quite exciting. The current setup works much better — it's faster and more stable.

ASSEMBLY SPECS

Here are the specs of my current foils. There is also some motivating description. Feel free to write, e-mail, or call if you have questions; I am happy to talk or correspond. This compilation includes other chapters about construction, adjustment, sailing technique, theory, etc.

The two most important features of this particular hydrofoil design are the use of a lightly-loaded surface tracking canard foil to stabilize pitch and height, and the maintenance of significant windward roll (up to 40 degrees) which lets fully submerged main wings carry both the bulk of the vertical weight-induced load and the sail side force, leaving a partially submerged fin unloaded.

Automatic pitch and height control is essential to satisfactory performance. Sailors just don't have the reflexes to do this themselves at high speed in messy water. Designs lacking automatic control are always seen to porpoise — alternately fly out of the water and plunge back in, which is slow, as well as frustrating to the rider.

Sailing the board rolled to the degree that the fin carries little or no steady hydrodynamic side load is critical to high-powered operation. Because the top of the fin is necessarily out of the water when the board is flying, any significant side load on it will suck air down to the wings, causing spin out or tail drop. The fitting of anti-ventilation fences on the fin, which seems necessary to protect against unavoidable momentary side-load fluctuations, is not enough to do the whole job.

In addition, and from a practical point of view, as important as its effect in mitigating ventilation, board roll

Bottom front view of the Miller Hydrofoil

acts to keep the foil-induced torques on the sailor's ankles at bearable levels. Indeed, with proper foot strap placement, and optimally banked main foil, ankle stress is negligible.

MAIN FOIL ASSEMBLY

The main foil assembly consists of a fin and two wings. The wings are permanently attached at the bottom end of the fin, each at an anhedral angle of 35 degrees (measured down from the horizontal), so that when viewed from the rear, the assembly has the form of an inverted "Y." The wings are mounted on the fin without sweep — the leading edges of the fin and the wings lie in a plane transverse to the board axis.

As a consequence of the "Y" arrangement, in operation, when the board is rolled to windward, the two wings become differently oriented relative to the surface. At full roll, the leeward wing span direction points horizontally, while the windward wing points nearly vertically (actually 20 degrees off vertical given the specified anhedral).

There are two advantages of the rolled "Y"-foil over the rolled "T." The first results from the difference in the distribution of directions of lift forces among the two wings and the fin, and affect the behavior of the foils when sailing under conditions of non-optimal roll, that is, when sailing so that resultant weight and sail force vector acting on the main assembly does not lie in the midplane of the fin. In that case, the foil assembly must generate a force component perpendicular to the fin midplane. By the geometry of the "T"-foil, this force component cannot come from the wings, so must come from the fin itself. But, the wetted area of the fin is small relative to that of the wings, and worse, the fin is surface piercing, so the attempt to generate the necessary lift is likely to actually result in ventilation, both of the fin and one wing.

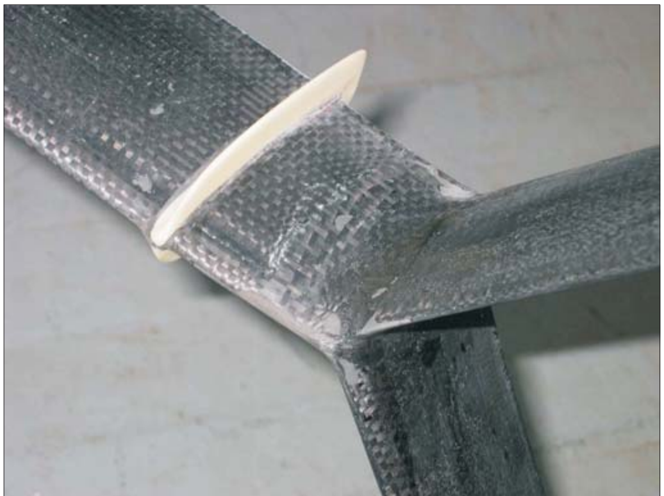
On the other hand, with the "Y"-foil, the wings are oriented to that they can generate the required extra force component largely by themselves, minimizing the load on the fin. In effect, the secure, deeply submerged, relatively large, windward wing takes over the task from the vulnerable fin.

In practice, the rolled "Y"-foil makes the board feel more like a conventional sailboard in that extra side force (due, for example, to a gust) leads up to a slight increase in leeway, but nothing else; with a "T"-foil, the board tail tends to slide up and spin out unless extra roll is quickly applied.

The second advantage is that the "Y"-foils allow (in principle) arbitrarily high span wings without a concomitant increase in fin length (and wetted surface); this under that constraint that you need to keep the board's weather rail clear of the water while keeping the leeward wing tip submerged. The benefit of high span is twofold: high-aspect, efficient foils become possible, with improved pointing and downwind performance; and, high roll-rate damping can be achieved, especially if non-tapered wings are used.

Greatly to my surprise, board roll against the ankles (in foot straps) has been the factor that limits (especially, high-speed) performance. The problem is that when the board is sailed in balanced roll, cross and vertical flow perturbations due to wave action cause rolling torques which can go either way, and so are hard to prepare for. In regular waves, these perturbations are themselves regular and the sailor can get into the swing of things. However, in messy water, it is very hard to see what's coming up. The inherent roll-rate damping of constant chord, large-span wings, provides a practical mitigation — not only because the sailor has more time to react, but also because the board has time to reach new water with its chance of opposite cross flow. In smooth water, and especially in the artificial conditions under which speed trials are held, these roll

The main foil assembly consists of a fin and two wings -- a small fence located on the fin above the "Y" junction is visible in the photo



One small ventilation fence located 2″ up from the "Y" junction at a small positive attack. Helps prevent flow of air down the suction side of the fin to the wings.

Tuttle box shown from bottom and Styrofoam plug used in adapting the box to carry the fin head --The opening in the box is 5/8″ x 6″ and the outside dimensions are 2″ x 7.75″ x 5.75″

considerations become moot, and low span, tapered foils work fine.

Finally, I note that the roll problems described above are much more severe with "Y"-foils than with "T"-foils, so the design question is whether the other benefits of the Y's are worth the added problems. In my experience, overall performance has improved since I went to the "Y"-foils.

The fin must have a symmetric section, since, by design, it will suffer loads from both sides with equal probability. I currently use the Selig 1014 section (see the end of this chapter for coordinates of this and other sections mentioned) and a slightly tapered planform having chord 3.5" at the board and 3" at the junction with the wings. The length of the fin between these points is 17". The Selig foil is very low drag at low lift, and therefore appealing. However, the most important attribute of the fin is its resistance to ventilation under perturbing side loads, and I'm not confident that the hollow aft parts of the Selig section are helpful here. Possibly a more conventional symmetric NACA foil, maybe even one with its thickness relatively forward would be better. In any case, the fin wants to be very stiff! Otherwise the ride gets squirrelly. It's more acceptable for the wings to flex, but (unlike the conventional sailboarders) I've never found that flexibility in foils is helpful.

What's a "Tuttle Box?"

There are a number of "standard" fin boxes used by sailboarders. A fin box is built into the board near the tail and serves as a receptacle for a matching fin head. Usually the fin box / head combination is designed to fix the fin rigidly in one position. In the Miller hydrofoil, the fin needs to be adjustable in pitch. One of the standard boxes, designed by Larry Tuttle and available from Waterat Sailing Equipment in Santa Cruz CA, is particularly strong, and has parallel planar sides, which make it easy to modify to allow the required adjustment.

Two ventilation fences should be mounted near the bottom of the fin to help prevent flow of air down the suction side of the fin to the wings. I put one fence 2" up from the "Y" junction, the other 4" up, both at a small positive attack. I cut the fences from 1/16" circuit-board material, and they extend about ½" out from the fin. Recently I experimented with omitting the upper fence, and that seems to work.

Fin head showing retaining screw and washers and the adjusting screw with jam nut

The wings should have an asymmetric section since they always lift toward their top surface. I have had good results with the Eppler 407. For all-around performance with moderate (6 sq. meter) sails, I use wings having constant chord of 3" and half-span of 17" (tip to root, each side). Increase the span if you want (especially if you plan to compete with the new, high-pointing, huge-sailed course boards), but certainly don't decrease it. These dimensions and foil section produce a hydrofoil that is easy to control, has really good pointing and downwind ability, and has plenty of speed on the reaches.

More recently, in a search for greater speed on the reaches (at the cost of reduced up and down wind performance), I have been sailing on constant-chord wings having a chord of 2.5" and half-span of 14", incorporating the thinner NACA 2411 section. My attempts to go to still smaller chord have failed because I have been unable to make layups that are strong enough. My 2411 foils are solid unidirectional carbon, with a woven cloth carbon skin applied on the bias. Performance is surprisingly good, even in quite large ocean waves, but the ride is very quick and delicate compared to the 17" Epplers. These foils will fly with a 6 meter sail, but really come into their own at 5 meters.

If you want a foil for speed trials in smooth water, try cutting down the NACA foil to 10", or a bit less, half span. But, you ought to practice on bigger, more stable foils before attempting this.

One of the important side benefits of this hydrofoil design is that you don't need to go to smaller boards or foils when the wind comes up. Largely because of the windward roll, the board doesn't bounce up and blow away like a conventional board. Indeed, you get the feeling that the nose wants to drive down, to keep the canard glued to the surface. Consequently, you can choose a board volume that makes a comfortable floater, adequate to uphaul large sails, and possible to sail home if the wind drops, and use it with any foil assembly.

Wind velocity, and so, sail size, does affect the choice of foils. In lighter wind, you need larger (or better, more efficient) foils for takeoff and upwind performance. However, you can always sail on a foil that is too large, and the only downside is lower top speed on the reaches. Upwind, a large, efficient foil converts to somewhat less speed, but better pointing, so you may end up better off even when it's howling.

The fin must be fitted at its top end with a head suitable for mounting in a heavy duty fin box and must be capable of being adjusted in pitch. This adjustment is generally a one-time affair, done when first setting the foil assembly in the board, and it has the effect of fixing the depth at which the wings ride when the board is going at maximum speed. (I use a Tuttle box since it has parallel sides (makes adjustment easy), and goes all the way through the board (strong against side torque).

A construction concern: The major point of vulnerability of the main foil assembly is the junction. It needs to be very strong, and at the same time, streamlined. The next most vulnerable point is where the fin leaves the box, but this is much less a problem than the junction — the addition of some extra shear support in the head layup is adequate.

Prototype foils of the larger sections can be easily made by planing a wooden core and covering with carbon fiber or glass, and epoxy.

FRONT FOIL (CANARD)

The front foil (canard) assembly consists of a supercavitating-type foil (section looks like a meat cleaver, with a sharp leading edge and a blunt trailing edge, the bottom is slightly concave down, and the top, since it travels in an air bubble and doesn't touch the water at speed, is irrelevant). I use the bottom section from the BuShips (Bureau of Ships) "Parent" hydrofoil, coordinates given later, and I don't worry much about the top. The chord of this foil is 4.5", its span is 12", and the thickness of the square trailing edge is ½".

This foil is fixed to a (very stiff) somewhat tapered strut that can have a round or bullet shaped section (rounded front, square aft). A round carbon fiber tube, 5/8" at bottom and 3/4" or so at top works well. The length of the strut is 12". Since the strut is meant to provide an air path to the top surface of the supercavitating foil (actually used in ventilated mode), it definitely should *not* have a streamlined

What's a "Canard?"

In a Canard Foil Arrangement, the main foil assembly is located aft of the vehicle's center of gravity, and its foil area (lifting surface) represents the major portion (65% or more) of the total foil lifting area. The remaining area is given to a smaller foil located well forward of the center of gravity. The smaller foil is called the "canard."

The front foil (canard) assembly consists of a supercavitating-type foil (section looks like a meat cleaver, with a sharp leading edge and a blunt trailing edge), and a stiff strut

The canard assembly must be hinged at its top end (where it attaches to the nose of the board) so that it can be deflected in roll and locked in deflected position

shape. The lack of streamlining is not a problem, since the strut is only submerged at very low speed before takeoff, and occasionally when the board encounters a steep bit of wave, and in that case, a round section is good, since it causes minimal steering force.

The canard is supercavitating because conventional, subcavitating foils work very badly in surface-skimming mode. Conventional foils tend, at random times, to drop, carrying a top-surface air bubble with them. As this bubble slowly (often a matter of seconds!) sheds, lift increases and the foil comes back up. Such a foil provides a terrible surface reference. A ventilated supercavitator, on the other hand, gets all its lift from its bottom (pressure) surface, giving up entirely on suction lift. This makes its lift and surface tracking much more reliable.

The hard thing about the canard assembly is that it must be hinged at its top end (where it attaches to the nose of the board) so that it can be deflected in roll and locked in deflected position. The deflection is required to preserve the balance against turning of the standard sailboard rig. The idea is that when the board is rolled, the canard is unrolled so that its foil remains essentially flat on the water surface, thereby producing no steering torque. This allows the rig to interact with the main foil assembly in just the same way it does with the fin on a standard sailboard.

The locking is critical for roll stability. With a deflected and locked canard, small additional roll to windward causes the windward canard tip to dig in like a ski tip and steer the board to weather, which causes the sailor's inertia (and to a lesser extent, that of the board) to carry over the foils and undo the roll increment. If the initial roll change is to leeward, all signs reverse, and again the perturbation is canceled out.

The direction of the hinge axis turns out to be important as it controls the relative rigging angle between the canard and main wings as a function of canard deflection. I find I get good behavior when this axis points straight along the board centerline from the nose toward the tail of the board, without inclining either up or down. Then the canard strut itself should angle down and forward about 7 degrees from perpendicular to the hinge axis, and the canard foil itself should be mounted on the strut in such a way that when the canard is undeflected and you sight along the top (ventilated) face of the canard foil you see the main fin at a point somewhere between the two ventilation fences.

Canard deflection and locking must be done at speed by the sailor in standard sailing position. The more you power up, the more you must roll, and the more you must deflect the canard. On jibing, the canard needs to be brought to its central (neutral) position, and then deflected the other way on the new tack. I have worked out a mechanism involving a couple of continuous loop strings and a special mast base that allows the strings to be carried up to and along the booms and not twist on the mast when during the jibe. For a sailor in a conventional sailboard harness, it is easy to free up one hand to motivate the string on the near boom.

There are probably other ways of effecting the deflection. It would be particularly nice to have a mechanism that lived entirely in the board itself and didn't climb the mast, but I haven't been able to make that work, primarily since it is nearly impossible to reach down to the deck with a hand when sailing fast. Moving the feet is also much more difficult than you might imagine, but a foot activated, perhaps hydraulic, control does seem possible.

A more philosophical note: it is very attractive to imagine some sort of self-setting canard mechanism, and I have thought about this for years. There are two basic difficulties. The first is that the locked canard is critical to board roll stability — even a small amount of play in the mechanism degrades performance — and it doesn't take much more to make the board uncontrollable.

The second difficulty seems more daunting — the information you send in setting the canard deflection is really, and immediately, the desired average (over seconds or minutes) board roll. At a greater remove, you're setting the desired effective average sail force coupled with the sailor's desired bodily attitude, both dependent on wind and wave, as well as on the sailor's current psychological state. It is hard to envision an automaton that could get these things right.

FOIL SECTION TABLES

- **First column is x-coordinate (chord direction)**
- **Second column is y-coordinate (thickness direction).**
- **The points run from the trailing edge (x=1), over the top of the wing to the leading edge (x=0), and back along the bottom of the wing to the trailing edge.**

NACA 2411				BUSHIPS Parent	
0.99730	0.00059	0.00375	-0.00794	1.0	.0888
0.98918	0.00235	0.01290	-0.01483	.9	.0801
0.97578	0.00520	0.02723	-0.02061	.8	.0723
0.95720	0.00906	0.04662	-0.02531	.7	.0644
0.93365	0.01380	0.07080	-0.02893	.6	.0565
0.90535	0.01927	0.09948	-0.03151	.5	.0486
0.87260	0.02532	0.13238	-0.03310	.4	.0408
0.83577	0.03175	0.16912	-0.03379	.3	.0329
0.79520	0.03839	0.20932	-0.03368	.25	.029
0.75138	0.04506	0.25255	-0.03291	.2	.024
0.70475	0.05158	0.29842	-0.03165	.15	.0194
0.65583	0.05777	0.34642	-0.03005	.1	.0142
0.60513	0.06347	0.39612	-0.02830	.075	.0134
0.55322	0.06852	0.44740	-0.02637	.05	.0084
0.50067	0.07276	0.49933	-0.02415	.025	.0052
0.44807	0.07606	0.55132	-0.02174	0.0	.0
0.39597	0.07830	0.60280	-0.01925	.025	-.0002
0.34455	0.07912	0.65320	-0.01677	.05	-.0004
0.29485	0.07831	0.70198	-0.01436	.075	-.0006
0.24745	0.07588	0.74862	-0.01208	.1	-.0008
0.20292	0.07193	0.79257	-0.00994	.15	-.0012
0.16175	0.06659	0.83337	-0.00798	.2	-.0016
0.12448	0.06006	0.87053	-0.00621	.25	-.0022
0.09148	0.05253	0.90368	-0.00463	.3	-.0028
0.06317	0.04427	0.93238	-0.00326	.4	-.0044
0.03985	0.03553	0.95633	-0.00211	.5	-.0072
0.02170	0.02654	0.97528	-0.00120	.6	-.0110
0.00897	0.01752	0.98895	-0.00054	.7	-.0160
0.00172	0.00862	0.99723	-0.00013	.8	-.0228
0.00000	0.00000	1.00000	0.00000	.9	-.0314
				1.0	-.0420

SELIG 1014				EPPLER 407			
1.000000	.000000	.000340	-.003235	1.000000	.000000	.001772	-.003852
.991986	.000518	.000937	-.005468	.986683	.004621	.003459	-.005605
.978634	.001844	.001845	-.007797	.966835	.012229	.005393	-.007249
.963659	.003761	.003084	-.010230	.946849	.019680	.007526	-.008822
.947323	.006176	.004672	-.012736	.926613	.026619	.009852	-.010329
.930053	.009008	.006631	-.015293	.906135	.033124	.012376	-.011777
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.857105	.023460	.018485	-.025913	.822935	.056230	.024478	-.017223
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.819544	.032152	.027815	-.031750	.780761	.065634	.031857	-.019888
.800605	.036754	.033749	-.034849	.759530	.069774	.035955	-.021222
.781547	.041499	.040702	-.038053	.738216	.073562	.040367	-.022565
.762381	.046333	.048835	-.041363	.716824	.077007	.045129	-.023919
.743374	.051124	.058349	-.044765	.695363	.080119	.050286	-.025287
.724908	.055663	.069389	-.048227	.673838	.082909	.055887	-.026673
.707075	.059779	.081987	-.051683	.652253	.085388	.061988	-.028084
.689689	.063415	.096030	-.055049	.630614	.087571	.068658	-.029524
.672497	.066589	.111354	-.058269	.608927	.089475	.075976	-.030993
.655238	.069316	.127728	-.061300	.587202	.091111	.084029	-.032492
.637662	.071647	.144893	-.064115	.565443	.092488	.092914	-.034022
.619637	.073667	.162625	-.066697	.543654	.093617	.102737	-.035577
.601207	.075439	.180774	-.069049	.521845	.094514	.113597	-.037150
.582510	.076980	.199233	-.071179	.500025	.095182	.125580	-.038728
.563647	.078309	.217925	-.073098	.478203	.095617	.138752	-.040295
.544660	.079443	.236793	-.074818	.456384	.095814	.153129	-.041827
.525572	.080389	.255794	-.076349	.434573	.095776	.168676	-.043301
.506404	.081157	.274895	-.077700	.412781	.095506	.185303	-.044684
.487174	.081751	.294065	-.078876	.391021	.095001	.202875	-.045950
.467899	.082177	.313282	-.079882	.369310	.094254	.221235	-.047076
.448592	.082440	.332540	-.080720	.347668	.093256	.240219	-.048049
.429262	.082542	.351843	-.081394	.326122	.092000	.259678	-.048859
.409914	.082487	.371186	-.081911	.304707	.090481	.279485	-.049496
.390551	.082275	.390551	-.082275	.283476	.088697	.299540	-.049957
.371186	.081911	.409915	-.082487	.262500	.086648	.319761	-.050233
.351843	.081394	.429263	-.082542	.241876	.084334	.340085	-.050316
.332540	.080720	.448592	-.082440	.221728	.081761	.360467	-.050178
.313282	.079882	.467899	-.082177	.202210	.078944	.380878	-.049788
.294064	.078876	.487174	-.081751	.183493	.075915	.401304	-.049131
.274894	.077700	.506404	-.081157	.165763	.072724	.421731	-.048197
.255794	.076349	.525573	-.080389	.149183	.069426	.442146	-.046975
.236793	.074818	.544661	-.079443	.133882	.066073	.462541	-.045447
.217925	.073098	.563647	-.078309	.119916	.062716	.482919	-.043600
.199233	.071179	.582511	-.076980	.107277	.059403	.503284	-.041441
.180773	.069049	.601208	-.075439	.095906	.056172	.523639	-.038979
.162625	.066697	.619638	-.073667	.085704	.053043	.543990	-.036234
.144893	.064115	.637663	-.071647	.076558	.050022	.564340	-.033228
.127728	.061300	.655238	-.069316	.068347	.047112	.584696	-.029988
.111354	.058269	.672497	-.066589	.060958	.044309	.605066	-.026555
.096030	.055049	.689689	-.063415	.054290	.041606	.625451	-.022978
.081987	.051683	.707075	-.059779	.048251	.039000	.645847	-.019319
.069389	.048227	.724908	-.055663	.042763	.036478	.666249	-.015660
.058348	.044765	.743374	-.051124	.037764	.034028	.686645	-.012076
.048835	.041363	.762381	-.046333	.033197	.031640	.707021	-.008619
.040702	.038053	.781547	-.041499	.029013	.029308	.727376	-.005336
.033748	.034849	.800605	-.036754	.025173	.027022	.747711	-.002262
.027815	.031750	.819544	-.032152	.021648	.024773	.768027	.000577
.022771	.028769	.838389	-.027709	.018408	.022556	.788315	.003153
.018484	.025913	.857106	-.023460	.015427	.020366	.808568	.005428
.014829	.023165	.875654	-.019441	.012693	.018192	.828779	.007364
.011688	.020496	.894033	-.015679	.010198	.016022	.848940	.008922
.008970	.017879	.912208	-.012191	.007934	.013848	.869035	.010068
.006631	.015293	.930053	-.009007	.005890	.011663	.889046	.010748
.004672	.012736	.947323	-.006176	.004083	.009457	.908949	.010894
.003084	.010230	.963659	-.003761	.002547	.007217	.928718	.010390
.001845	.007797	.978634	-.001844	.001310	.004934	.948335	.009058
.000937	.005468	.991986	-.000518	.000424	.002610	.967797	.006685
.000340	.003235	1.000000	.000000	.000141	.001447	.987132	.003076
.000039	.001070			.000010	.000260	1.000000	.000000
.000039	-.001070			.000479	-.001958		

The Miller Hydrofoil Board Modifications

BOARD COMPATIBILITY

The rear ("main") foil assembly is designed to mount in a Tuttle Fin Box, but in order to achieve extra stiffness against side loads, the main fin fits more deeply into the box than the standard Tuttle Fin does. If the available depth at the rear of the fin box is at least 2" and at the front of the box at least 3.5", the box can be modified in a standard way to allow the needed main foil pitch adjustment and, at the same time, adequately support the fin. (For comparison, the standard Tuttle Fin inserts to a depth of 1.25" at the rear and 2" forward.) On most boards having Tuttle Boxes, the extra depth will be available since with the installation recommended by the manufacturer, the box extends from the bottom all the way to the deck skin. In all but the slimmest-tailed boards, this provides adequate depth for the hydrofoil.

EXCEPTION: Some boards which take Tuttle Fins have integrally molded fin boxes that are not of the Tuttle design, and which do not provide interior space that goes all the way through the board. Some options to consider in case you have such a board are listed in the last section of this note.

NOTE: Sometimes a fully through-mounted Tuttle Box is partially filled (usually with foam) which can be safely removed to provide the full 3.5" depth. On the other hand, if you have a through-mounted Tuttle Box, but if the tail of your board is too slim, you again might check the suggestions in the last section of this note.

The front ("canard") foil mounts in a special frame (provided in my kit) which must be glued into a hole cut into the nose of the board. Installing the frame is like installing a fin box, but somewhat less elaborate, so quicker. Once the frame is in place, the canard foil assembly screws into it, making the assembly easily removable. NOTE: the need to glue the frame into the board means that the board must be constructed of bondable materials. Epoxy or polyester-filled glass or carbon skins, and any of the standard core foams used with them will be fine.

Although boards of any shape and volume can be used, experience has shown that a no-nose comfortable floater with modest nose rocker gives the most enjoyable all-round performance. Low nose weight is highly desirable. It leads to better pitch stability, better behavior in waves, and better sail balance, all adding up to a quicker, more lively ride.

For similar reasons, a longer board is to be preferred. This may seem counterintuitive, but the longer the lever arm between the canard and the main, the better. Long boards track better. Short boards end up being twitchy.

And, if you have a choice, a narrow board is better than a wide one. Narrow boards can be rolled further without running the weather rail into the water. Nothing very dramatic happens if the rail hits, but it does slow you down. Even spray resistance on an airborne hull has a noticeable effect on speed.

A board having enough volume to float you and the rig is highly recommended. Since one hydrofoil board works in all winds and sea conditions, you don't need to go to a short board when the wind comes up. With a floater, you will be able to uphaul and sail home in displacement mode if the wind drops. Boards with still more volume (and weight) will work with the hydrofoil system, but have the same drawbacks that they do in conventional sailing, giving a less lively feel, and being harder to carry around and launch.

Finally, since the canard hydrofoil, and not the nose, is responsible for keeping the front of the board up, the amount of nose rocker is immaterial to performance, and less rocker makes mounting the frame a bit easier and lets the board ride a bit higher. Less rocker also mean less windage, which is an advantage when it blows.

FIN BOX MOD (CONCEPTUAL)

Assuming you have a through-mounted Tuttle Box with adequate depth, the only thing you will have to do to the box is to build, in place, a glass-filled epoxy box adaptor. The adaptor does two things. It reshapes the top, inside of the box so that it mates properly with the fin head, and at the same time, strengthens the box against upward loading.

This resizing and strengthening is necessary because of the requirement that the hydrofoil fin be adjustable in pitch. Such adjustment is not necessary for conventional fins, and fin boxes are designed to defeat movement in pitch. Because of its flat, parallel, sides and its recommended through-board mounting, the Tuttle Box is particularly easily modified to allow pitch adjustment without loss of side-to-side stiffness.

Fin pitch adjustment determines the rigging angle of the main wing, which in turn sets the range of main foil immersion depths during flight. Note that although this adjustment is indispensable, it is typically used only when a foil is being set in a board for the first time. It allows compensation for variations in the way the fin box itself is mounted in the board and for design variation in fin-wing assemblies. It may also serve to fine tune for the weight of the operator, and possibly even the state of the seas. Since the adjustment screw is attached to the foil and not the board, once a foil has been adjusted for a given board, it can be swapped in and out without readjustment.

A conventional Tuttle Fin fits into its box by jamming between the fore and aft inside faces of the box. This jamming fixes the fin position uniquely. It also prevents any upward load from going to the deck skin, which needs only withstand the downward force (usually minimal) that is transmitted through the fin mounting screw(s). In order to allow pitch adjustment, the head of the hydrofoil fin bears directly upon the top inside face of the box, and does not touch the fore and aft faces of the box. This means that the entire upward force from the main wing is supported by the box top and is distributed from there to the board itself. The thin deck skin of the standard Tuttle Box installation will not stand the strain, and thus needs to be beefed up.

FIN BOX MOD (PRACTICAL)

The box adaptor is built in place using the supplied Styrofoam plug. The plug defines the shape of the volume available for the fin head, which is designed to allow the head to rotate against the adaptor along a surface of constant radius near the top front, while remaining clear elsewhere. The rotation of the fin toward the back of the board is limited by a 1/4-20 adjusting screw, fixed with a jam nut, threaded into the top rear of the fin head. Finally, the fin is held in the board and locked against the rotation surface and the adjusting screw by a long, centrally located, 1/4-20 retaining screw inserted from the top through the board deck and box adaptor.

The plug comes with a 1/4" hole drilled through it and covered on the upper side with a piece of masking tape. When fully inserted, the bottom of the plug should be level with the board bottom. With the board upside down, and with any existing holes through the deck covered with masking tape, build the adaptor by pouring milled-fiber (not microballoon) filled epoxy, mixed to a toothpaste-like consistency, into the box. Cover the poured mixture with several layers of thin-epoxy wet glass. Push the plug into the box to the extent indicated above. Mix enough epoxy to so that when you insert the plug, excess glue will squeeze out in front of and behind the plug. Clean excess glue from the board bottom, and make sure that the 1/4" hole in the plug remains clear. Let the glue mixture harden.

Using a long 1/4" drill, guided by the hole in the plug, being very careful, drill through the adaptor and the deck. This provides an opening for the fin retaining screw. Since the screw is fixed relative to the fin head, it rocks with the head when pitch is adjusted, which means that the hole will need to be a bit ovaled. This does not cause problems since the screw does not need to be sealed against airflow as it does on a conventional board.

Use a ½" chisel to break up the Styrofoam plug and clear it from the box. Again with the chisel, carefully remove any residual glue from the side walls of the box.

Finally, set the pitch adjusting screw in the fin head so that when the foil assembly is inserted into the box and secured in place with the 1/4-20 retaining screw, the fin leading edge is perpendicular to the board bottom. This reference position should be somewhere in the middle of the adjustment range.

CANARD FRAME INSTALLATION (CONCEPTUAL)

First look at the canard hydrofoil. Notice that it has the shape of a cleaver, with a sharp edge and a square edge. The foil is meant to be operated with the sharp edge forward! Foils of this type are called "supercavitating" and behave quite differently from conventional "subcavitating" foils. In contrast to the canard, the main foil is a subcavitator and operates as you would expect, with its rounded edge forward and its sharp edge aft.

The canard frame should be installed as near the front of the board as possible, subject to the requirement that the final construction be strong and waterproof. The need for a strong installation should not be underestimated: during normal operation, the canard foil generally rides on the water surface and takes a very considerable pounding from the tiny wavelets.

The reason for locating the canard so far forward is that it extends the “wheel base” of the system, which gives the canard greater mechanical advantage over the board and leads to lower canard loading (more speed) and more secure surface tracking by the canard (better pitch stability).

In order to preserve a greater amount of board rail, allowing a more forward frame location without sacrificing strength, you can knock off the forward outside corners of the frame, and to cut an appropriately shaped (non-rectangular) hole in the board. If you leave a minimum of 1” of rail intact outside the hole (this will be at the forward corners of the frame), and if you tie the board skin to the frame skin with glass cloth, the nose strength will be adequate.

After cutting the hole in the board (see below for some hints), the canard frame must be glued into the board in a particular attitude relative to the main foil. This is critical since it is the interaction between the canard and main foil that generates pitch stability and automatic height control for the board during flight. In addition to setting the frame into the board in the correct attitude, it must also be mounted in the correct position in relation to the board nose. This means that when the frame has been glued into the board, and the excess frame material has been ground away, the shelf in the frame against which the canard mounting plate rests is still intact and is appropriately recessed into the board. Getting all this right is not really very hard and the procedure is described next.

Mount the main foil assembly in the board as described above. When this is done, the main foil (wing) will be located 17” away from the board at the bottom, and the ventilation fence closest to the wing will be 15” away, and the other fence will be 13” away. Turn the board upside down so that it is lying on its deck.

Center the canard support side-to-side relative to the aluminum mounting plate, and screw the mounting plate flat against the bottom shelf of the frame. (This is the way the canard assembly was shipped to you.)

First set the frame recess. Insert the frame in the hole and adjust its position so that the front inside part of the frame shelf is recessed as much as possible without having the head of the forward 3/8” hinge bolt (the hinge bolts are the ones that go though the fiberglass gudgeons on the aluminum base plate) start to disappear below the level of the board bottom.

Next set the frame pitch. Look aft, sighting along the suction face of the canard hydrofoil (that is, the face closest to the board; this is also the relatively flat face). Rock the frame in pitch (without changing the recess at the front of the shelf) until your line of sight points precisely halfway between the two ventilation fences on the main fin (as a check, note that the other, pressure, face of the canard hydrofoil is oriented about 5-deg. higher in pitch than the suction face, and if you sight along it, you should be looking out into space, not seeing the main foil at all, or possibly just seeing the tips of the wing). You will probably glue the frame into the board with the recess and attitude as now set, but before gluing, check the next two paragraphs.

For normal boards, the recess at the forward edge of the frame shelf will result in a somewhat greater recess at the after edge, but the after edge will still be somewhere in the board, and there will be a structurally adequate amount of frame left above the shelf after you grind away the excess material. If, after setting the frame recess and pitch as above, this is not the case, you will have to change the front recess and redo the pitch adjustment.

By maximizing the recess of the shelf into the bottom, you allow the curved lead screw on the top of the base plate to stick further up above the deck, which means that when the pinwheel is fully deflected to one side, the cord loop going back to the mast foot deflects less as it passes over the rear part of the frame. Less deflection means more trouble-free operation. In the completed installation, the ideal thickness measured from the aft part of the shelf through the board to the deck is 1.125”. Thickness greater than 1.25” may cause problems, and a thickness of 1.5” will definitely be too much.

Now you can glue. After the glue has set, remove the screws holding the canard mounting plate to the frame and remove the canard assembly. Grind away the part of the frame projecting beyond the bottom and deck surfaces of the board. Turn the board so that the deck side is up. With a file, round the aft deck side of the frame so that the canard control cord will slip as freely as possible along it. Finally, cover the ground portions of the frame (the places where the foam itself is exposed) with pieces of glass tape that overlap both the skin of the board and the glass skin of the frame. By binding the skins, this glass adds significantly to the strength of the final installation. In addition, the glass on the section of the frame that you rounded provides a wear-proof, slippery surface for the control cord. When installing the glass, don’t bother to feather it into the skins, since skin smoothness at this part of the board is completely unimportant. Simple lap joints are perfectly adequate functionally and are structurally stronger.

CANARD INSTALLATION (PRACTICAL)

Although the canard frame can be installed using glass and epoxy in the same way you conventionally install a fin box, there is a much simpler and faster method in which the frame is glued into the board with 8-10 lb. two-part closed-cell(!) polyurethane foam. This is the method described here. Use a knife or fine backsaw (or one end of a hacksaw) to cut through the bottom skin, making an incision 1/8" larger than the frame. Remove the skin, and continue the cut through the foam to, but not through, the deck skin. Delineate the deck cut by carefully pushing the point of an awl through the deck skin while supporting the skin on the deck side so that it doesn't delaminate from the foam. Once the cut in the deck is thus defined, make the actual cut from the deck side, again to avoid delamination. Remove the material cut free, creating the hole for the frame. The frame should insert freely in the hole, and be able to wobble a bit in pitch.

Remove the frame from the hole, and do something to remove another 1/4" of foam from around the hole so that the skins will overhang somewhat. (If your board has foam-core skins, leave the skins, including the hard foam between the cloth layers, intact. Create the overhang inside the composite skin.) One method of removing the inner foam that works very well with the usual board filling Styrofoam is to take a butane torch set to a very low flame and very briefly paint at the foam with the flame. The foam will melt back (and may even seal itself).

Next, with the board lying bottom side up, use a round file to make a pair of half-moon-shaped notches in the bottom skin at the edge of the frame hole. These notches should be about ½" in diameter, one on either side, and located about half way between the front and back of the hole. When pouring the foam, you will pour it into these notches, which are a lot easier to hit than the narrow gap between the bottom skin and the frame.

Prepare the canard frame by roughing up the gluing surfaces with a light sanding using coarse sandpaper. This will improve bonding. Tape the area of the board nose around the hole with masking tape to make cleanup easier.

Now, position the frame (with the canard assembly screwed to it) as described in the previous section. Using a few small wedges of stiff foam pushed between the frame and the board, fix the frame in place. Then lock the frame against motion through the board by pressing some medium sized finishing nails against the outside skins of the nose and into the frame material. You can do this in such a way that the nail holes are in material that will eventually be ground off. Next, in order to seal the bottom of the volume into which you will pour the foam, and also to more securely fix the frame position, span the gap between the deck (currently facing downward) and the frame with masking tape.

Once again check that the frame is correctly positioned. All that remains is mix and pour the foam. Work quickly. Stir and pour. If the mixed liquid starts to foam before you have got it poured into the gap, you're in trouble. One way to get a little extra working time is to start with the two parts of the foam chilled (you can put the cans in the refrigerator for a while). You might find it worthwhile to practice a bit with the foam before going to the real pour.

After you pour, and while the foam is working, keep checking the attitude and position alignments to make sure that they are not changing. If you detect any motion, you can hold the frame manually for the few minutes it takes for the foam to stop moving.

In 5 or 10 minutes the foam will have finished working and will be pretty stiff. Wait a little longer until it is really hard, then remove the tape, unscrew the canard assembly from the frame, and grind away the excess frame and foam. Significantly round the rear deck side of the frame as described above, slightly round all other sharp corners (to allow the glass to turn them more easily), and apply glass tape to bind the board skins to the frame skin. Instead of tape, in which the glass fibers are parallel with the strip, it often works better to cut cloth rectangles on the bias. With the fibers at 45 degrees to the edge, bias-cut cloth tends to follow contours more easily, and stay flat without lifting when wet out. When the glass layer is hard, sand it a bit to remove any burrs and sharp edges, and you're done!

FOOT STRAPS

Correct foot strap location turns out to be very important for optimal operation of the hydrofoil. Compared to conventional boards, your weight needs to be further aft and more inboard. Ideally, you want to have the aft foot balanced right on the board centerline, and directly over the fin head. The front foot should be a comfortable distance forward and about 4" to windward of the aft foot.

Thus, you will probably need to reposition your foot straps. Mount a single aft foot strap on the board centerline, centered fore and aft over the main retaining screw. Mount the usual pair of forward straps, each angled slightly out and forward. Be sure to make a strong installation, for

Mount a single aft foot strap on the board centerline, centered fore and aft over the main retaining screw. The picture shows an alternate installation with aft end sliding on a transverse track. This arrangement lets the heel of the foot come more over the board centerline.

although there will be very little ankle torque when the board is sailed properly, a relatively small error in roll, coupled with the long lever arm of the main foil can really load up the straps.

NON-STANDARD FIN BOXES

If you have a through-mounted Tuttle Box but the tail of your board is too thin, you still have a number of options. First, if you have 3.5" depth anywhere in the box, just cut off some of the fin head so that it fits into the space available. If, as is almost certain, the 3.5" is at the front of the box, and things are really tight, you will have use the front corner of the fin head as the pivot and reinstall a 10-24 adjustment screw in the rear. Such an installation is functionally as good as the ideal one, and you should make it without further ado.

If you have an integrally molded box that happens to meet the requirements of the previous paragraph, use the same fix.

If, one way or another, the available depth in the box is significantly less than 3.5" at the deepest point, you probably need to do something more radical. In such boards you have the choice of letting a portion of the main foil fin head extend below the bottom skin, which causes a bit more drag when the board is hull down, but doesn't cause problems when flying, or you can cut off some of the fin head. Neither of these options is recommended since they reduce the stiffness of the main foil against side loads, which can compromise handling and stability.

The conservative thing to do is simply to replace the fin box with a through-mounted Tuttle. If the board tail is not thick enough, build it up by adding a small mound of foam and glass on the board deck. Do this before installing the new box.

Another, seemingly bizarre, but actually quite attractive possibility if you don't have enough depth, is the addition of a pair of fillets on the bottom skin of the board that effectively extend the box downward to achieve the desired 3.5 inches. This yields full sideward stiffness and is very easy to do.

HYDROFOIL KIT DESCRIPTION

I am sometimes able to supply a kit that contains all the parts needed to convert a conventional board for hydrofoiling. It consists of a (rear) main foil assembly that fits in a standard Tuttle fin box (5/8" width, straight sides, necessary to allow pitch adjustment), and a (forward) canard foil assembly that mounts in a frame I provide which you glue into a rectangular hole you cut in the nose of your board (the board must be made of some kind of material you can glue to — polyester or epoxy laminates are fine). The canard assembly includes the mechanism for rotating the canard foil in roll, which is a central feature of my design. In addition, there is a special mast base which mounts in the (unmodified) mast track, and some small blocks that attach to the mast and booms. These things lead the strings that rotate the canard to within easy reach on the booms.

Presently, the kit is not a market product, but consists of parts I have made for testing. Typically, some of the parts are used (i.e., have been tested). I can provide the kit *only* on the understanding that it is an experimental device which may well be unsafe, and that the buyer assumes total responsibility for its use.

I sell a kit for $500 U.S. (but price is adjustable downward, depending on how up-to-date or used the parts are) which covers the cost of materials and a bit for my labor.

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The Miller Hydrofoil - Initial Setup

SETUP, ADJUSTMENT, AND TESTING TO GET THE HYDROFOIL ON THE WATER AND FLYING

The material in this chapter assumes that you have already modified your board by adapting the fin box and by installing the canard mounting frame. If you haven't, see the previous chapter "Board Modification"

ABOUT SETUP AND ADJUSTMENT

Setup, adjustment, and testing described here are sufficient to get the hydrofoil on the water and flying. Once you have some flights under your belt, and have gained some experience in using the canard shifting mechanism, you will want to refine the initial adjustments.

Sailing fast and comfortably on a conventional board requires careful tuning and balancing of the various parts; on the hydrofoil, which is generally tighter in handling and more delicate in balance, the importance of precise adjustment is even greater.

CANARD SETUP AND TENTATIVE ADJUSTMENT

If it is not already in place, fit the main foil in the rear box, and fasten it lightly with the retaining screw. Turn the board so it is bottom up.

Set the canard in its frame (from the bottom, with the sharp edge of the canard forward, feeding the control loop cord (the "canard loop") through the frame so that it comes out on the deck side). You want the canard mounting plate to be flat on the shelf in the frame, but don't yet insert the mounting screws. Now sight aft along the flat, suction face of the canard foil. Your line of sight should hit the main fin half way between the two ventilation fences. If that is not the case, insert some 10-24 washers (or better, flat 2-holed, full-width shims) between the plate and the shelf, either at the front or the rear of the plate, to get the line of sight in the right place. Once you have done that, secure the mounting plate to the frame with the 10-24 mounting screws (passed through the shimming washers, of course). You now have a good initial setting of the canard.

Feed the control loop cord (the "canard loop") through the frame so that it comes out on the deck side

CHECK OF THE CANARD MECHANISM

It's worthwhile at this point to take a moment to check the canard deflector in action. Stand the board right side up with its rear resting on the tips of the main wing. Support the board nose so that the canard is clear of the ground.

Holding one part of the canard loop in each hand, and maintaining a small amount of tension to the canard pin wheel, pull alternately with one hand or the other to spin the pin wheel on the curved lead screw, and watch the pin wheel drive the canard head along the arc of the screw. (As the wheel moves to the side, keep the strings aligned with the groove in the wheel.) You should be able to run the canard head easily all the way from one side to the other without any sense of binding.

Notice that there is not much clearance between the cheek plates on the canard head and the curved screw, but there should be enough. Any contact at all will cause binding, and must be eliminated.

If the canard does not run to the stops without binding, you need adjust the relative position of the hinge bolts if the binding is against the front or back of the lead screw, and reposition the lead screw in its mounting flanges if the binding against the top or bottom.)

MAST BASE PLATE & CANARD LOOP TENSIONER

Now mount the mast base and canard loop tensioner in the mast track, with the tensioner aft of the base. A good initial position for the base universal is 46" forward of the main foil retaining screw.

Lead the canard loop back from the top(!) of the canard pin wheel sheave, through the canard fairlead, around the port tensioner block from the outside, forward around the front of the mast base pin wheel lower sheave, aft around the starboard tensioner block from the inside, and finally forward through the fairlead to the bottom of the canard sheave. Adjust the tensioner to provide the least tension that will keep the loop in place. (When the line gets wet, it will stretch a bit, so you can allow for this, or just re-tension later.) Notice that when the loop is led correctly, the two parts running forward will screw 1/4 turn to the right.

If, in your installation, the tension adjustment is inadequate, you will need to splice and install a new canard loop. I usually find it easier to just cut off the old loop and splice the new one in place. If you carefully plan the loop length, the adjustment range of the canard tensioner is usually adequate to accommodate all mast base positions (for different sails and conditions) that you might use on the board .

At this time you should make another test of the canard mechanism. Check that the canard is still hanging in the air, and pinching the canard loop between two fingers at a point well back from the nose, move the loop along itself to drive the pin wheel and the canard. Again the canard should move freely and easily.

When the canard is near its centered "neutral" position, the canard loop may hang entirely free of the board, or perhaps just the bottom part will rub on the deck near the canard frame. In any case, displacing the loop along itself should move the canard very easily, with the loop cord tracking perfectly over the various sheaves. As you deflect the canard, the pin wheel, moving along the lead screw, goes more deeply into the frame, bringing the loop cord into greater contact with the aft portion of the canard mounting frame at the place where you rounded the frame during installation. The loop should slide freely on the rounding. (At sea, the loop will water lubricated, which will help.)

MAIN SETUP & TENTATIVE ADJUSTMENT

Now return to the main foil and adjust it. This adjustment will be considerably more tentative than the one just made on the canard because different main foils have dynamic properties that hard to guess by looking at the foil. Once you get out on the water, you will be able to refine the tentative pitch adjustment to an optimal one. However the following procedure will get you started.

Deflect the canard 35 degrees in roll to one side (it doesn't matter which) by spinning the pinwheel screw via the control string. Turn the board upside down.

When you have deflected the canard the right amount, and sight from the rear of the board, one main wing will look parallel to the canard foil. Call that the "reference" wing.

Mount the mast base and canard loop tensioner in the mast track, with the tensioner aft of the base

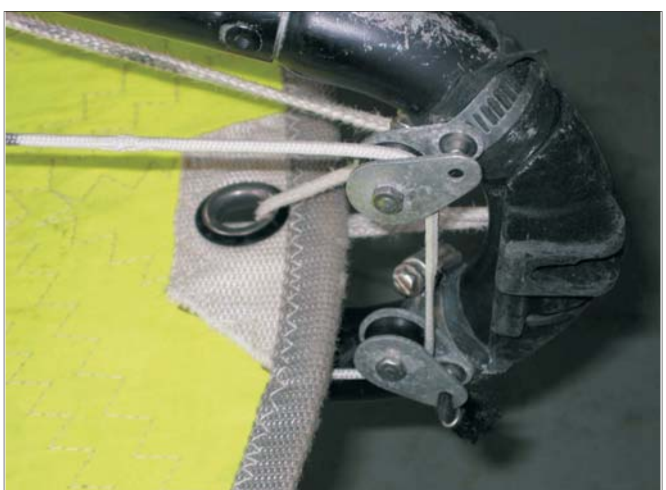
A good initial position for the base universal is 46" forward of the main foil retaining screw

Now you need to establish the line of zero lift of the reference wing. If the water flows past the wing in this direction, the upward and downward forces will just cancel, and the wing will produce no lift. A decent approximation to the angle of zero lift of a foil is given by looking from the wing's sharp trailing edge and moving your eye so that if you only look at the part of the wing immediately adjacent to the trailing edge, you will see equal amounts of upper and lower surface. Your line of sight, if extended forward, will come out of the wing through the top surface, somewhere behind the leading edge. The more the trailing edge of the foil is deflected downward (like built-in flaps), the further behind the leading edge this line will emerge, the more upward it will point.

Adjust the pitch of the main foil so that the line of zero lift passes 2"-3" inches below the canard foil. Since the canard is supposed to be on the surface during flight, this setting of the main foil should insure that the main foil never gets closer to the surface than the 2"-3", no matter how fast you go! The main foil will pull downward if it somehow momentarily gets closer than this.

In setting the main foil pitch you need to remove the foil from the box, set the adjusting screw, and reinsert the foil, pulling it against the box top with the retaining screw. Once you have got the adjustment where you want it, tighten the jam nut to hold the adjustment. Tighten the main retaining screw firmly.

Re-center the canard in roll, and stand the board on its foils.



The tail blocks are attached below(!) and at the rear corners of the boom by means of the integral stainless hose clamps

Note: The elaborate description relative to the line of zero lift is useful for making a preliminary setting, and is instructive for understanding the dynamics that keep the foils in the water when you're going fast. However, as a practical matter, after you've been sailing, and want to vary the pitch of the main foil to make the board fly a bit higher or lower, it is much easier to keep the canard centered and sight along one of the ventilation fences (remember which one you used) to note the original pitch, and then re-sight along it after making the adjustment. A change of 1" in where the line of sight passes the canard makes a significant change in the limiting height of the board.

ATTACHING BOOM TAIL BLOCKS

The tail blocks are attached below(!) and at the rear corners of the boom by means of the integral stainless hose clamps. Pad them and tighten them enough so they won't slip and rotate on the boom. They should be positioned so that they lead diagonally in and forward. When the boom loop passes behind the blocks, it must clear the sail clew. You may have to set your booms to be a bit longer than usual, and leave a bit more outhaul showing, to accomplish this. You can leave the blocks permanently attached to the booms.

These blocks (as well as the mast blocks, below) are designed to be "snatchable". This is done not only so that the boom loop can be easily fitted, but more importantly, so it can be quickly disconnected without the aid of tools if it becomes necessary to separate the rig from the board while at sea.

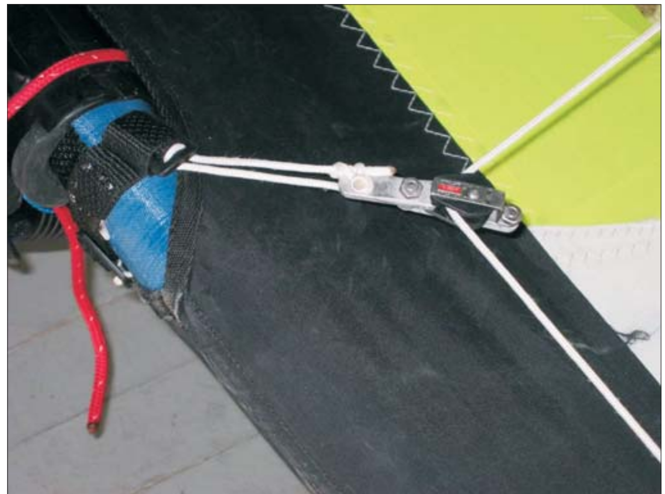
BOOM LOOP TO MAST BASE

Between sailing sessions, if you don't need to transport the board by car, you can leave the board as setup as it is now, with the mast base, loop tensioner, and canard loop in place.

(If you do need car transport, the easiest way is to remove the mast base and tensioner, wrap the canard loop around the front of the board and tie it to itself. Then, flip the board upside down, nose forward, and strap it to the racks. It will ride easily, with the foils in place, at highway speeds.)

Returning the situation with the mast base, tensioner, and canard loop in place. You must next install the boom loop. This is quickly and easily done. Rotate the upper part of the mast base so that the fairlead above the pin wheel points forward.

You must next install the boom loop -- This is quickly and easily done



Port mast block and webbing, with boom loop in place -- make a final test of the canard mechanism by pulling on the boom loop

Since there is only modest adjustment available (through positioning of the mast blocks), the boom loop must have a length dependent on boom length and boom height, and so indirectly on sail size. I find it easiest to maintain a number of boom loops, one for each of my sails, which I leave attached to the sail bag when not in use.

The easiest way to fit the boom loop is to form a small bight and feed it down through the fairlead on the base above the base pin wheel, then fold it out and up over the top of the mast base and all the rest of the boom loop, finally landing behind the base. If you then pull on the opposite (long bight) the short one can be pulled into place behind the base and into the upper pin sheave. Then take the long bight and pass each of its parts back along its own side of the mast base, and drop the remaining line on the deck, also behind the base. Now if you install the rig on the base in the usual way, the long bight of the boom loop will be correctly positioned to drop in place over the mast block sheaves and then over the boom tail sheaves.

Final-test the canard mechanism, this time by pulling on the boom loop. Leave the main foil on the ground. Use one hand on the upper part of the mast base to lift the canard into the air, and at the same time prevent the mast base from rotating. Now, use the other hand to pull on one part of the boom loop. The canard head should move to the opposite side of the board. If it goes the wrong way, the canard loop twists in the wrong sense along the deck.

ATTACH MAST BLOCKS

Rig the sail on the mast and booms in the usual way. The mast blocks are attached via a pair of adjustable strings to plastic rings sewn onto the bottom, horizontal, strap of an inverted T-shaped arrangement of 1” Dacron webbing. Wrap the horizontal part of the “T” around the mast, in the mast sleeve cutout just below the booms, and secure it with the plastic buckle. Lead the vertical strap of the “T” up along the front of the mast and under the loosened boom clamp. Leave as much slack as possible in this bit of webbing, and temporarily re-tighten the clamp.

ATTACH RIG TO BOARD

With the boom loops positioned as described above, attach the rig to the board in the usual way. Leave the rig lying on the ground and the board on its side.

LEAD & TENSION BOOM LOOP

This is the last step. Take the long bight of the boom loop where it emerges from the mast base fairlead, and stretch it aft to the tail of the boom. Snatch it onto the tail blocks. Take the part of the boom loop on the ground side of the rig between the tail blocks and the fairlead and snatch it onto the ground side mast block. Snatch the other, upward facing, part of the boom loop onto the upward facing mast block. Remove slack in the boom loop system by sliding the mast encircling webbing upward toward the booms. Secure the blocks by removing the slack from the vertical bit of webbing, and, with the booms in the desired position, tightening the boom clamp.

Ideally you want no real slack in the boom loop, but also no tension. With too much slack the boom loop catches on your foot straps when you water start. With too little, movement of the canard becomes more difficult. When you have a happy medium, you’re done rigging, and can go sailing.

Getting Started -- Your First Flights

The material in this chapter is meant to help you prepare for your first hydrofoil flights. It describes some mundane things like how to carry the board, and how best to stow the board on the beach. It describes the use of the boom loop to set the canard deflection. It leads you through slogging, takeoff, straight and level flight, and steering (without changing tack). It warns of "The Crash" and tells you how to avoid it. It touches on tacking and jibing. The hydrofoil jibes readily, and can, in fact, be kept flying all the way through the jibe. High-speed tacks from a planing start also work just fine - tack just as you would on a very short board. You'll find you can cruise a long way straight upwind.

After reading these sections, you ought to go out on the water and try it all out. Sailing the hydrofoil is not really any harder than sailing a regular board. All the basic moves are the same. Mostly what you'll notice is a difference in feel. The hydrofoil is quicker and more delicate in movement than a conventional board — especially, acceleration onto a plane is very fast, and steering is much more precise.

For you first time on the hydrofoil, choose a day, time, and place where conditions are moderate. The main thing is that the wind and water shouldn't be scary to you. With equivalent rigs, the hydrofoil generally planes up before a conventional board does, so you don't need to be overpowered to fly. Also, if you have a too much power, you can find yourself accelerating to very high speed before you're ready to deal with it. As for the water conditions, although the hydrofoil does really well in chop and even very large swell, you will find it better to make your first flights on reasonably smooth water. That way the foils will stabilize at lower speed, and the interaction of the foils with the water will be clearer to you. It's like learning to ski on a smooth gentle slope rather than on a steep one with lots of moguls.

Most intermediate sailors are able takeoff and get flying with only a few minutes of trying. Within a half-hour they have mastered straight and level flight, and along the way, have taken a few major crashes.

The there is another note that contains suggestions for making adjustments to the foils, the mechanism, and the rig based on how the board behaved on the water. If something doesn't go according to plan during your sail, try to remember as particularly as you can what happened, and see if something in the adjustments note might be helpful.

The thing to keep in mind as you tweak the adjustments and hone your sailing skills is that, just like a conventional board, the hydrofoil has a "sweet spot" in tuning — a combination of canard and main foil pitch adjustments, mast foot position, rig and harness adjustment, mast rake, canard roll angle, and sailor position — which, if hit just right, allows the board to essentially sail itself. It goes straight and fast with finger-tip control on the booms and only very gentle pressure on the ankles. It turns with just a hint of board roll from the ankles or rake of the mast.

CARRYING THE BOARD

Use the usual low carry with one modification. With the board lying on its side on the ground, foils upwind, and nose pointing the way you want to go, flip the sail so that its clew is forward. Stand between the board and the mast. Pick up the upper boom with one hand and the UPPER forward foot strap with the other. Rest the mast on your hip, and go. The reason for grabbing the upper foot strap, rather than the more usual lower one, is that since the foils are so long, you want to keep the foils pointing sidewards rather than downward.

When you lower the board into the water using a low carry, lay it down upside down, so the foils don't hit the bottom. Once you are in waist deep water, flip the board right-side up.

If you are strong, you can also lift the sail onto your head and flip the board upside down onto the sail in the usual high carry. Since the foils and mechanism add about 4 lbs. to the weight of the board, this carry is definitely harder than usual.

THE BOARD ON THE BEACH

If the rig is not attached to the board, the best way to leave the board is standing on its foils, with the canard centered (in "neutral") and with the nose pointed directly into the wind. Since the canard support is so much shorter than the main foil and fin combined, the nose stands very low compared to tail, and the wind tends to keep the board pressed downward. This position is also actually quite protective of the foils since the main wing rests on the hydrodynamically unimportant tips and the canard rests on its trailing corner.

If the rig is attached, lay the board on its side with the foils pointing directly into the wind. Lay the mast so that it points downwind. This position is not only stable in very high winds (since the board keeps the sail out of the wind), but both the foils are in the air and unlikely to be scratched. Also, if the board is on a beach, the moving parts of the canard mechanism are kept away from the sand.

WASH OFF THE SAND

Both the canard pin wheel and the mast base pin sheaves are vulnerable to jamming by tiny amounts of sand or even salt crystals. It is good practice generally, and absolutely essential if you are sailing from a beach, to turn the board upside down as soon as you get into the water, and jiggle the boom loop (to jiggle the mast base pin sheaves and the canard pin wheel) to wash out any sand that may have lodged on them. Do this before you do anything else. Certainly do it before you try to actually flip the booms or set the canard roll angle.

YOUR FIRST DAY

You will want moderate wind and water, and a location with a safe retreat. Choose a situation in which you would be COMPLETELY AT EASE on your conventional equipment. Winds of 15-17 mph and a 6 meter sail will be plenty to get you flying if you weigh 170 pounds or so. Big sails and light wind are desirable since the water is generally smoother and the new things you will experience will happen more slowly.

Start with the canard in neutral. If the canard needs to be repositioned while you and the rig are in the water, grab the boom loop where it runs parallel to the mast, with your two hands holding parts of the line on opposite sides of the mast, and move your hands in opposite directions. (If you try to move the canard using the deck loop, you may get a tangle at the mast base.) Once you get the hang of things, you will generally find it easier to ignore the canard until you are on the board and in the harness. At that point, you will have a free hand to pull the canard string, and the canard will respond effortlessly.

Get standing on the board (water start or uphaul) in chest deep water (so you don't mash the foils into the sea floor). Sail the board very slowly on a close reach for a bit to get the feel of the board and the somewhat different hull-down sail balance. You'll find that because there is so much foil in the water, you can point very high when slogging. However, returning downwind may pose more of a problem.

This might be a good time to try a tack or jibe. Low-speed tacks on high-volume (or if you're skilled, low-volume) boards work just as they do on conventional boards. Ditto low-speed, hull-down jibes, if the wind is light enough. A pivot jibe in place will also work if you know how to do one.

THE CANARD AND STEERING

In normal operation, the canard foil skips along the water surface, providing a reference that stabilizes pitch and depth of submersion of the main foil.

In addition, if the canard is inclined in roll, it produces a force toward the side more deeply submerged, which causes the board to steer in that direction. This effect, of converting roll into steering, is present on a conventional board, but the great distance between the canard and the main foil magnify the steering effect in the hydrofoil hugely over that of an ordinary board. Actually this is a FEATURE, since it effects the major roll stability of the hydrofoil, but so much steering for so little roll does take getting used to.

Of course, the rig, especially its rake angle fore and aft, also affects steering, and the hydrofoil, as any sailing craft, can only proceed on a steady course if the center of lateral effort of the rig passes over the center of lateral resistance of the foils, that is, when the rig and foils are in balance. A rig too far forward causes a turn to leeward, and one too far aft, a turn to weather.

BASIC TAKEOFF

For your first takeoffs (and even later ones when the wind is very light), keep the canard in neutral.

Get the board moving on slowly on a beam reach, or thereabouts, with the hull flat on the water. Before you do anything else, get into the harness. This would be premature on a conventional board, but with the hydrofoil it helps keep you positioned correctly relative to the rig. Your feet should be forward of the forward foot strap, with the forward foot near the weather rail and the other on the board centerline, and you should be standing relatively upright (remember, you're going slowly!).

Now, keeping your forward foot fixed, power up a bit to get a little more speed and slide the rear foot back until you can put it in the rear foot strap. Do that! Again, this is unconventional but turns out to be better for the hydrofoil.

You can get into the rear foot strap at quite low speed because the extra lift from the main foil keeps the tail of the board from dragging as it would on an ordinary board. The benefit of having the rear foot in its strap is that it gives you precise control of the board in roll, which you need since roll couples so strongly into steering. And, steering, in particular, over-steering due to wobble in roll, is going to be your main problem for a while.

Your legs are now spread rather widely. With the rear foot tightly in place in its strap, take a bit more power and speed and begin to slide your front foot aft along the weather rail. Before you expect it, the canard will pop up onto the water surface and stay there. Try to hold this situation steady for several moments, keeping your course and speed constant, to get a feel for how the board behaves in this state.

Continue powering up (still modestly) and sliding your foot. When your foot reaches the front strap (about 15-inches forward of the rear foot) the main foil will start to come up. As it does, take care to keep the board level in roll while at the same time adjusting the fore-and-aft rake of the rig to keep the board on a steady course. That is, STEER WITH THE RIG, WHILE KEEPING THE BOARD AS LEVEL AND STEADY AS POSSIBLE IN ROLL.

These things will take some attention, since the hydrodynamic forces change rather quickly as the board comes clear of the water. The board will accelerate due to the loss of hull drag. The main foil will continue to rise all by itself. As it does, the board starts to level out in pitch (since the canard previously rose to the surface and has stayed there). This all happens much faster than you would like.

As the main foil moves into its very efficient, cruising attitude, the drag drops rapidly, and you will experience a terrific momentary acceleration. Hang on for a few seconds while the board picks up speed. Pay particular attention to keeping the board level and on a constant course during this acceleration.

Finally, once the acceleration ends, and the board stabilizes, you can put your forward foot, which has up until now been just resting on the weather rail, in the strap.

As speed increases, the board actually becomes more stable on its foils. But it won't seem that way to you at first, because errors in board roll or fore-and-aft sail imbalance will be magnified by the speed. Eventually, you will learn to respond in time with the board's quickness, and you will see the stability - the board really will do what you tell it to, and will stay where you put it.

Well, now you're flying. If you have managed to keep your course steady and were judicious in the amount of power you applied, you won't really be going that fast, but you will be amazed at how light and smooth the sailing feels. You will be standing rather upright on the board, hardly leaning out at all.

However, more likely, on your first few tries you will be steering all over the lot, spinning up to windward and plopping into the water, or much more unpleasantly, turning out of control downwind. The downwind turn is worse since the board speed increases as you go, and unless you take the right corrective action, you are liable to be launched heels over head.

THE BIG CRASH

If you are turning downwind because your sail is out of balance and the board is yawing to leeward (rig center of effort forward of the lateral center of resistance of the foils), then a large and abrupt roll to windward causes a sudden flow of water onto the TOP of the canard, which drives it down and to leeward, taking the board nose with it. You, on the other hand, keep going forward, up and over the rig. SPLAT! OUCH!

The ERROR here is to attempt recovery by rolling the board to windward. This would work on a conventional board, but is risky on the hydrofoil. The CORRECT ACTION is to pull the rig HARD AFT. If you do that, the board nose will likely come back to windward and you will be fine.

To emphasize: ALWAYS USE RIG STEERING (not board steering) TO CORRECT (serious) YAW.

The big crash seems to occur far less frequently with the "Y"-foils than it does with the "T"-foils. I believe this is because yaw couples more strongly to roll, which, in turn, couples to corrective steering. That is, yaw to leeward creates a lift imbalance on the wings which generates an axial torque that rolls the board to windward, automatically undoing the yaw. All this means that you need to work harder to get into a situation where you're carrying a dangerous amount of yaw.

However, despite precautions, you might sometime find yourself crashing. In that case there is still something you should do: HOLD ON TO THE BOOMS TIGHTLY. Since the board nose is driving to leeward, the rig almost always ends up hitting the water upwind of the board. You want to be with it. If for no other reason, if you are still holding onto the booms, you are definitely on the other side of the board from the foils.

THE JIBE

Actually, if you find yourself turning downwind, there is another POSSIBILITY, but you're probably not ready for it yet. You could just continue the downwind turn, indeed, roll into it, over-sheet the rig, and ACTUALLY DO THE JIBE!

BOARD AND CANARD ROLL

The ultimate purpose of rolling the board is to allow you to power up the rig in a stable and manageable way. The rule is: THE MORE YOU WANT TO (AND CAN, WIND PERMITTING) POWER UP, THE MORE YOU ROLL THE BOARD AND THE MORE YOU COUNTER-ROLL THE CANARD. And wonderfully, there is a test for whether you are correctly rolled: You are in the foot straps and there should be absolutely no strain on your ankles! And the canard should be flat on the water. Look and see! Finally, the board should be maintaining a constant course. This constrains the rig's center of effort correctly.

Up until now, you have been flying in neutral, with the canard centered, and have been cheating on one or another of the above tests. You have gotten flying, but will not have been completely comfortable. Now it is time to start adjusting the canard roll angle - putting the canard "in gear", rolling the board appropriately, and begin reaping the full benefits of the hydrofoil design.

If the control loops are set up properly, pulling aft on the boom loop that passes near you hands will cause the canard head to move to leeward. This is the only way you ever deflect the canard! On heading into a tack or jibe, you restore the canard to "neutral" by pull forward on the string. You should never need to move it further than centered. On the new tack or jibe, you again follow the rule, string aft to get in gear, forward to return to neutral.

When moving the canard control while flying, do so only SLOWLY(!), to allow the board time to settle into the new configuration. At first, while you are getting used to the effect of canard angle, just use small deflections, say up to a quarter of the full available throw. These will be enough to show you what's going on without leaving you terrifically powered up. You will discover that even a little canard will feel much better than the neutral you have been sailing with up to now.

What you will find in practice is that, as you move the boom loop aft (dialing in more canard), the board will seemingly automatically roll to windward (keeping the canard flat on the water), the rig will rake aft, and your weight will settle out, down, and aft, putting you in increasingly powerful and stable sailing positions.

However, you will also be going faster and faster. At maximum canard, you will be practically hanging over the transom and dragging your tail in the water, and the speed will be impressive. It is best to try out more canard angle while pointing upwind rather than on the reaches, since upwind you need more power and get less speed in return for it.

This is enough to think about for the moment. Go out and try it! There is more discussion of canard and board roll below, but you can leave it for later.

GETTING HOME — GOING DOWNWIND

After your first few flights, it will be apparent to you that the hydrofoil really wants to work its way upwind. Except in the very lightest planing winds, that is the direction of least fear and most control. Upwind you can always luff a bit and slow down. You can pick a course on the very edge of planing and just toy with the idea.

The reaches don't work that way, especially with high-end racing sails. The sad fact is that it is very hard to de-power these sails and slow down. In some conditions, sheeting out actually seems to make you go faster. The thing to do on the reaches is to LOVE THE SPEED. The foils will handle it if you can. Just do what you have been doing upwind - get way back and down and go for it. Hint: Low booms and long harness lines seem to help.

However, you may need to be able to get home before you're ready to commit to passion. Sailing at a site with an upwind landing is one way to go. Sailing with big sails in light winds is another. In that case, the top speed on the reaches will never be all that great, and you will be able to deal with it.

Another thing that is quite helpful is to use an unbattoned wave sail. These really flatten when sheeted out and you can just sit lightly powered on a beam reach in really screaming winds, taking just enough power to keep flying, but not so much that it's scary.

But, the thing you really need to do is learn to FLY WAY DOWNWIND, SLOWLY, on the broadest possible reach.

You can do this on the hydrofoil just as you do on a conventional board, standing rather upright on the board, sheeted in tightly, and sailing on very low velocity apparent wind! Because you will not be using much power, you want very little canard angle, and you will be standing upright and relatively forward. However, you also want to keep the canard lightly loaded, so don't stand that far forward! Long harness lines, or even no harness lines help. If you want to slow down, BEAR OFF to further reduce the apparent wind. As long as you're flying, you will be going faster than the seas. Give the canard some help as it approaches the back of the next wave by pointing up a bit, leaning your weight out and back.

Once you get used to this downwind flying, you will find it glorious! You stand so high and pass through a field of waves seemingly in slow motion. Plus, you get downwind easily and safely.

The catch, when it's windy, is that you need to turn from slow upwind to slow downwind through a terrifying couple of moments of acceleration when the board is passing through the reaches! The trick is the same as for removing a band-aid — do it really fast! Commit to a radical turn downwind right away.

ADVANCED TAKEOFF

Except in the lightest winds, you can compress the takeoff steps somewhat. Pull on some canard as soon as you get in the harness, and do the whole takeoff with a little roll. Conversely, in very marginal winds, leave the canard in neutral, and pump the board onto its foils just as you would on a conventional board. Sometimes in these light conditions it helps to put the front foot in its strap first, which keeps your weight more forward and lets the canard help the main foil lift. Or, you can forget the straps entirely if conditions are modest enough.

Generally, after taking off with little or none, pull on some canard as you want to power up and consolidate the takeoff. Then more and more until you are settled into your cruising attitude. Sometimes more canard and roll actually seem to generate wind, probably because the foils are getting into a more efficient state, so pulling on a bit of canard in the midst of a delicate takeoff can actually help.

IMMODERATE WIND

In high wind, the takeoff steps described above compress radically in time. In very high wind, once you get it worked out, you can just lean out against the wind and the board pops up onto its foils essentially instantly. In these conditions, it is possible to take off with nearly maximum canard already installed, but this is very tricky. Better, start with canard at about ½ deflection until you've stabilized on the foils.

In low wind, the opposite happens. You have to go through all the steps very carefully, and draw things out in time, babying the whole process along.

Of course, as your skill increases you will find short cuts to the takeoff procedure, and distinct steps will start to merge.

SAILING IN WAVES

Like a conventional board, the hydrofoil is easiest to use (and learn on) in flat water. Of course, the water is never completely flat; whenever there is enough wind for foilborne operation, there are always some ripples. The canard, riding on the surface, hits every one of these, and chatters constantly. This is normal. However, since the main foil remains fully submerged, and since almost all the sailor's weight is on the main, the ride ends up being, on balance, smooth. You soon learn to ignore the disquieting chatter.

In waves, the hydrofoil really comes into its element. It never even sees the small ones. The foilborne hull clears them, and the canard cuts through their crests and comes flying out the far side. Paradoxically, since the canard spends more time completely submerged or completely airborne, a lot of the canard chatter disappears. There is absolutely no body slamming like that experienced on a conventional board in short chop.

In medium sized waves, the hydrofoil can be made to motor up and down, giving the smoothest possible ride. By timely weighting and un-weighting of the front foot, the hydrofoil can be held to the surface as though glued there, with no launching and no slamming, just efficient traveling. On the other hand, the sailor can, optionally do the weighting in reverse and gain air time. With the present foils, this is not recommended since they are not stressed for the impact of landing.

MORE ABOUT ROLL

The design of modern conventional sailboards is such that when planing, the combined center of mass of the board, rig, and rider is significantly forward of the center of lateral resistance of the board and fin combination. To be in balance, and so capable of sailing a steady course, the net vertical lift (mostly from the hull) needs to go through the combined center of mass, and the horizontal force from the sail needs to apply on a line passing over the center of lateral resistance. The raked rig, with its conventional harness attachment on the boom accomplishes this balance.

In order to mimic the conventional force distribution, and thus allow the use of an ordinary rig and harness combination, the hydrofoil was designed so that, in steady operation, the canard can be kept horizontal, and thus contribute to vertical lift, but not to lateral resistance. With all the lateral resistance coming from the main foil assembly, but with some weight on the canard, the center of vertical lift from the foils is forward of the center of lateral resistance, just like it is on the conventional board.

At the same time, it was found advantageous to sail the hydrofoil in very significant windward roll. (This is just the opposite of what is done with conventional boards, which are sailed flat, or slightly rolled to leeward when pointing.) There are a number of reasons why roll is a good idea in the hydrofoil:

The earliest designs had (inverted) “T”-shaped main foil assemblies and were sailed flat. Thus, lateral resistance came entirely from the fin (vertical part of the “T”). But since the top of the fin was always exposed to the air when flying, there was a great tendency for air to draw down along its upwind (suction) side, causing loss of (horizontal) lift and spin-out, and sometimes even ventilation of the main foil itself with resulting tail drop. Anti-ventilation fences on the fin were only useful for preventing spin-out if the side load was small, and so, the board could never be powered up very much.

By sailing in roll, however, with the wing (bottom part of the inverted “T”) banked to windward, all necessary side force could come from it, leaving the fin completely unloaded. This minimized the tendency to ventilate, and allowed much more powerful flights.

Sailing in roll had another immediate and obvious advantage: it reduced the ankle torque that the sailor needed to apply to the board. In fact, when the board is optimally rolled, so that the fin is not supplying any net hydrodynamic side force, the total force vector from the main foil assembly lies in the fin’s symmetry plane, and so generates no rolling torque on the board. This is most comfortable on the ankles. Conversely, when the board was sailed flat, the tension on the ankles could become overwhelming.

But even when sailed rolled, T-shaped main foil assembly had problems. It was critically important to roll the board just the right amount to balance the horizontal force from the sail against the vertical force needed to lift board and rider. Errors in roll could be compensated only by side flow on the fin, which frequently led to ventilation and board spin-out.

The current (inverted) “Y”-shaped main assembly was developed to overcome this difficulty. With the “Y”-foils, the wings themselves are able to resist roll error, and the problem of spin-out is almost entirely eliminated.

There are other reasons to sail rolled. One is that the foils are most efficient when optimally rolled.

Another is that rolling moves the effective center of effort of the main foil to leeward, which, like moving the fin aft on a conventional board, allows, indeed requires, the rig to be raked more aft to maintain sail balance. This lets you close the slot and get your body lower and into a more stable position, reducing the probability of getting launched in high winds and heavy seas.

Finally, rolling gives the rider more leverage over the rig, and so transmit more power to the board.

All these things argue that you should sail rolled. However, since you also want to keep the canard flat on the water, we are led to the rule that THE MORE YOU ROLL THE BOARD, THE MORE YOU MUST COUNTER-ROLL THE CANARD.

You may find it helpful to think of the canard adjustment on the hydrofoil as analogous to centerboard adjustment on a sailboat. It is used to set sailing trim. The canard roll adjustment is not meant to function like a rudder -- it is not used for moment-to-moment steering. Steering is done by rolling the entire board, or by changing the mast rake.

Finally, as a sort of test on all of the above, note that if the wind drops off a bit, so that the sail won’t hold up your full weight, you must unroll the board somewhat (that is, roll it back toward, but never as far as, level), and to get the sail balance to be right, you need to adjust the canard angle toward neutral.

TELL ME WHAT YOU LEARN

Continued development requires feed back. I would be delighted to hear of your experiences, ways of doing things, and ideas for improvements.

Sailing Tips for the Miller Hydrofoil

A USEFUL COLLECTION OF LESSONS LEARNED TO DATE

… When you first put the board in the water, turn it upside down and jiggle the mast base and canard strings to wash the sand out of the base and canard mechanism before you try to pull the strings for real. It doesn't take much sand to jam the moving parts.

… When the strings are set up correctly, pulling BACKWARD on the string on YOUR SIDE of the sail moves the canard head to the OTHER SIDE and moves the canard itself to YOUR SIDE. That means that the canard will be FLAT on the water when the board is rolled to WINDWARD. This is the way the board is meant to be sailed.

… The more you want to POWER UP, which means the more side force from the sail you want to support, the MORE you should roll the board to WINDWARD, and the MORE AFT you should move the string to UNROLL the canard. UNROLLING the canard means rolling in the opposite direction to the board roll so that it flattens out relative to the water. Think of moving the string AFT as putting the hydrofoil in GEAR.

… As you pull in MORE CANARD, and so go to MORE WINDWARD ROLL of the board, you will be able to settle your BODY OUT and BACK, thereby UNLOADING the CANARD. This allows the board to go faster, and also, very importantly, lets the nose ride over waves rather than crashing into them. In addition, when your body is out (so, low and back), you are more secure against launching over the rig. This is especially important in overpowering conditions. The other great benefit of ADEQUATE ROLL is that it UNLOADS YOUR ANKLES, making sailing very comfortable.

… When you're ready to jibe, push FORWARD on the string to center the canard relative to the board. Think of this as putting the hydrofoil in NEUTRAL. Once you're in NEUTRAL, you can just plane through the jibe as you would on a conventional board. The main difference is that you need to keep your weight BACK over the main foil to prevent the canard from diving. There is so much lift coming from the main foil that you can stay well back without sinking the tail. However, even though your body is back, make sure to push the sail WELL FORWARD when over-sheeting to initiate the jibe. Having the sail forward turns out to let you keep your weight on the inside board rail, just as you do on a conventional board. During the sail flip, bring the sail decidedly AFT onto the new side. This again lets you keep weight on the inside rail during the transition. Generally, making moves that would lead to a PIVOT jibe on a conventional board make a PLANING jibe on the hydrofoil.

… The hydrofoil sails best when the CANARD is as LIGHTLY LOADED as possible. Stay well aft, and keep MOST of your WEIGHT ON the MAIN FOIL. When properly loaded, the canard will skip along the surface of the water, bouncing into the air on each wavelet. If you load the canard too heavily, the board will slow down a lot. If your take too much weight off, you will lose steering control. If you take ALL the weight off the canard, the board will fly out of the water, foils and all, and you will have JUMPED. However, LAND VERY GENTLY since the foils are not built strongly enough to take hard landings.

… When the hydrofoil is sailed properly with the canard flat on the water surface, the canard generates vertical force but no side force. Thus, all the board forces that can resist the sail side force come from the main foil (there being no hull in the water as there is with a conventional board). This means that you must POSITION the RIG (mostly in rake) VERY ACCURATELY to balance the sail and foil forces. If you miss by even a little, the board will turn without rolling, that is, it will YAW. Since UNCORRECTED YAW can lead to the BIG CRASH (see below), you will want to avoid it.

… When the hydrofoil is flying, there is a strong coupling of roll into steering. That is, as the board ROLLS TO WINDWARD, the windward tip of the canard digs into the water and STEERS THE BOARD TO WINDWARD. This effect is very powerful since the canard is so far in front of the main foil. (This strong coupling is what leads to over-steering when you're first learning, but as you become more proficient, you will find it good to have such quick, accurate steering control.)

… The roll-steering coupling is responsible for almost all the ROLL STABILITY of the hydrofoil. Roll stability means that if the board happens to roll a bit, say to windward, an AUTOMATIC CORRECTION comes into play which rolls the board in the opposite direction, in this case to leeward, and so undoes the original roll. This automatic correction is ABSOLUTELY CRUCIAL for high speed operation of the hydrofoil. If it is defeated in some way, the board becomes completely uncontrollable!

… The way that roll-steering coupling effects roll stability in the hydrofoil is just the same as on a bicycle or a surfboard and works as follows: If the board rolls to windward, it also steers to windward, which brings the board somewhat across your previous path. The inertia of your body and the board tends to bring both up and over, in effect, tripping over the foils. This tripping of the board is actually a roll to leeward, which undoes the original roll (and steering) to windward.

… When sailing the hydrofoil, you will generally want to MAXIMIZE ROLL STABILITY, and the way you do this is to keep your ANKLES FIRM so that if your body lifts up or drops down, the board is forced to go in the same direction. The rule is TAKE THE BOARD WITH YOU! You will be amazed how much disturbance the board will take care of by itself if you follow this rule. As noted before, when the board is adequately rolled, the pressure on your ankles is minimal, and you can maintain them firmly in position with little effort.

… The above rule, said another way, is that WOBBLY ANKLES on a FAST REACH spell DISASTER!

… THE CRASH. The hydrofoil is generally very stable and easy to sail once you get the hang of it, but it is susceptible to a SPECTACULAR crash. This crash occurs in a very particular situation, and by making the right move, you can AVOID IT. Here is how it happens. You're sailing steadily along with the canard flat on the water (good) or with its windward tip somewhat dug into the water, and its leeward tip somewhat elevated (bad). In either case, some imbalance of the rig occurs (say due to a puff of wind) and the center of effort of the sail shifts forward, causing the board to YAW more and more to LEEWARD. If this happens, what YOU SHOULD do is RAKE THE RIG AFT to correct the yaw. If you do this soon enough, the board will immediately return to its original path, and there will be NO PROBLEM!

… However, if instead of raking the mast aft, you try to bring the nose back around by using your ankles to roll the board to windward (this is a natural thing to try), if the yaw has gone too far, water will hit the top of the canard, driving it down and to leeward, and the entire board, and you along with it, will be launched. This will happen so fast that the only thing you can do is hold onto the booms and take your beating. Actually, if you can hang onto the booms, you will get a lot of braking from the sail and you won't be going all that fast when you hit the water. Also, since the board nose always drives to leeward as well as downward, you tend to come down in the water and not on the board itself. Think of this crash as akin to "catching an edge" in skiing. It is never any fun. So, the rule here is CORRECT YAW WITH MAST RAKE, NOT BOARD ROLL!

… More tips to come as more experience is gained.

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