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(Truly) something else – Part II

Rig designer Randy Smyth, engineer Steven Robert and builder Wolfgang Chamberlain pick up the story of the Eagle 53 'aggressively remarkable' flying cat from Paul Bieker, Andrés Suar and friends

CONCEPTION TO BIRTH

– Randy Smyth

How did the Eagle 53 begin? I can only convey that part of the story based upon (reliable) hearsay. The story I was told goes like this…

One man's inspiration while watching the 2013 America's Cup in San Francisco transformed his excitement into a powerful challenge to Tommy Gonzales, the captain of his Gunboat 90 *Sunshine*. Immediately following the Cup Donald Sussman approached Gonzales with this aggressive request: 'Can you build a 75ft fully foiling catamaran, sporting a "practical wing sailplan" that can be sailed without a crew of professionals?'

Tommy dug deep into his decades of experience as a professional multihull captain and even more years of racing pedigree and answered simply, 'No! That is not possible with today's technology. But…' he went on, 'it is currently possible to build those advanced features into a 45ft catamaran and the lessons we learn can later be incorporated into a 75-footer.'

That began this dream project. Sitting quietly in Tommy's home overlooking the blue waters of the Caribbean he hit me with the Eagle challenge. He already had some design ideas that he had been formulating for decades. His initial sketch focused on the 'Eagle Ray' as a natural flowing shape to guide the new catamaran's design flavour. Tommy had also previously visited our loft in California when he shared his single wing element concept with me. At the time he had no boatbuilding facility, no designers, no engineers and certainly no boatbuilders.

I took the 'practical wing' portion of the design as a personal challenge and our collaboration was born. Donald had it right. What good is an America's Cup wing if it has to be laboriously taken down and stored in a warehouse each night?

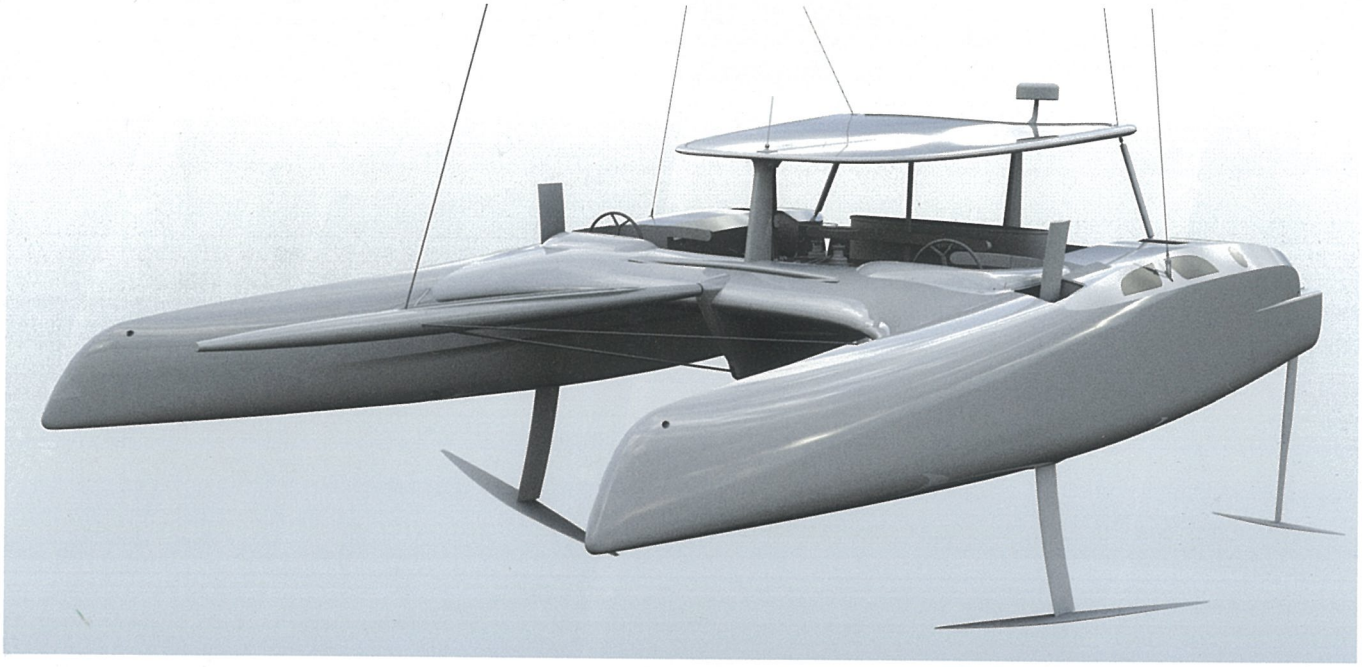
My own wing experiences were varied:

- Skippered a Sam Bradfield fully foiling 18ft trimaran at the 18-Square Meter North Americans in the 1980s. The design sported a two-element solid wing without stays that pivoted 360°.
- Raced a C-Class cat extensively with a solid wing plus trailing edge flap.
- Crewed the 60ft Orma trimaran *Apricot* during the Around Europe Race, again in the late 80s. The second of the two *Apricot* tris carried a large rotating wing mast-plus-mainsail combination.
- Wing trimmer on the 1988 America's Cup-winning catamaran *Stars and Stripes* with Dennis Conner. Despite being 30 years ago that two-element wing was very similar to the America's Cup wings in Bermuda.

None of those wings fitted the 'practical wing' criteria for the Eagle. With the exception of the 18 Meter wing, they were all prone to danger when left upright and unattended in any wind. Unique to the 18 Square Meter wing was its ability to pivot 360° thanks to the unstayed configuration. However, the substantial bearings, wing structure and support structure meant that the weight penalty was severe (I called it the 'hold the pencil by the eraser' engineering nightmare).

After much head-scratching the lightbulb went off. What if the wing of our new 45-footer could be left up 24/7 and was able to free-pivot 360° but now employing shrouds and a forestay to avoid the weight penalty of an unstayed configuration? After returning from Tommy's home in St John (which was subsequently blown off the island by the hurricanes), I started a preliminary design.

The Hybrid Wing concept was simple. Just design the wing to fit within the cone of the masthead forestay and shrouds. Incorporating a top bearing for the shrouds and forestay and a trailer ball at the bottom, the wing can pivot 360° for full feathering capability.



***Left*: there is cool and contemporary accommodation below (Part I) but the exposed steering position reminds you that the Eagle 53 is primarily a daysailer. But that gives those driving this project the room to experiment more aggressively than would be possible on a bluewater design... for now. Using the initial C-foils performance is already proving exciting and manageable, but by the time the first phase of development is complete – probably next winter – these unusual but logical curved T-foils (*above*) should be built, and once installed development can begin on a fully automated flight-control system. At that stage expect some of the Ultim teams to pay an interest – at least one of which are already working on a similar system but tailored for an even smaller crew than on the Eagle...**

Voilà, the wing can now be left up without worry. With a square-top mainsail hoisted on the trailing edge the combined hybrid wing and mainsail cross-sectional shape form an efficient asymmetric airfoil. With adjustments to the wing rotation a wide range of cambers can be quickly achieved to add power or to depower. Reefing the mainsail adds further to the Hybrid Wing's versatility.

A carefully designed package of headsails add to the wide range of sail area combinations that are possible. A fully battened self-tacking jib is flown from the forestay; forward of the forestay is a roller furling screacher that flies from a masthead halyard and tacks to the end of the bowsprit. This dramatically increases sail area for VMG downwind sailing and light-air reaching.

Our next step was to test the hybrid concept in the real world. The first prototype was built by Vinnew Pard in a garage-style environment for my 21ft *Sizzor* trimaran. *Sizzor* had a few years of fine-tuning under the belt with its conventional carbon rotating mast sailplan so made for a useful benchmark. We put the new hybrid sailplan through its trials at my home in Fort Walton Beach, Florida.

Our initial conclusions were 'green light' positive. Compared to the proven control rig, the hybrid configuration pointed higher upwind or could hit the same angles but at higher speeds. Off the wind the ability to add camber with additional mast rotation produced amazing power which translated to more speed and lower angles sailing VMG downwind.

Then one morning during the programme, at 0400h, a Florida thunderstorm marched through my backyard. I heard the whistling wind and in a panic jumped out of bed and ran outside in my undies to see if the Hybrid Wing was OK. To my surprise, right behind me was Tommy wearing the same attire. We could have stayed in bed... the test wing was feathering in the gyrating winds without a problem.

Despite our initial excitement we were now forced to hide our prototype proof of concept in a warehouse until a patent was approved. Once the critical papers were received and securely filed away we decided it was appropriate to raise the stakes, trialling the Hybrid Wing in the Everglades Challenge in March of 2014.

This is a 300-mile adventure race from St Petersburg through the Everglades Park finishing in Key Largo. *Sizzor* is a single-handed high-speed home-built trimaran that produces enough adrenalin to often allow me to finish the course without sleeping.

The 2014 race was no exception. After a long and fast first night I was hit the next morning by some vicious thunderheads that caused me to lower all sails except the Hybrid Wing. When the huge downdraft puffs hit I just released the wing rotator and the foil instantly feathered directly into the wind. As the puff steadied in direction I pulled the rotator back on a little and blasted along until the next severe downdraft arrived. Not only did I finish first out of about 100 starters but I set a solo course record of 1d 11h 18m.

In hindsight I'm not sure I could have survived the thunderheads even with my conventional rig double-reefed.

Getting serious

Fast Forward Composites went from dream to reality under Tommy Gonzalez's leadership and the guidance from master boatbuilders Wolfgang Chamberlain and Vinnie Pard. While the first Hybrid Wing was still being tested Tommy had also purchased a building for Eagle's construction in Bristol, Rhode Island.

He then assembled his build team, their first task being to convert the building into a clean-room manufacturing facility complete with ovens, autoclaves and the associated equipment required to build a composite boat as advanced as the Eagle was going to be. Meanwhile, the Eagle design team assembled by Paul Bieker were close to having the final CAD files ready to start mould building.

This certainly remained an evolving process... As the Eagle took shape it grew steadily from 45 to 53ft. Different foiling packages were considered. Testing began to develop an early experimental computer-assisted foiling system that was installed on an existing Stiletto 23 catamaran. Fast Forward Composites were already living up to their name.

That said, some on the design team were still far from convinced that the Hybrid Wing was ready to jump from the 21ft, 200lb solo *Sizzor* to the 53ft foiling Eagle. Yes, we had learnt a lot, resulting in plenty of evolutionary ideas and refinements following the Sizzor test programme... but we still had some convincing to do.

So, in the summer of 2015, Fast Forward Composites in collaboration with Gunnar Salkind and myself designed and built the tooling for a larger trial rig, this time for *Caliente*, a 40ft ProSail cat. Construction was meticulously undertaken by Hall Spars.

Some of the next refinements included:

- A square-top wing profile with associated 'top-hat' bearing assembly to project the shrouds and forestay outward to a wider top stance.

This shot nicely illustrates the composition of the Hybrid Wing: a modest chord wing spar is made up in the now traditional way with the forward D-section carrying the primary loads, but with light, solid carbon top-hat pre-formed ribs to shape and support the wing covering in place of the more usual honeycomb-core webs. The super-high aspect mainsail attaches on cars while the trailing edge of the wing is convex which allows the leech twist of the sail to be controlled with less mainsheet tension than using a straight luff

- Halyard locks for the screacher, jib and mainsail.
- The wing ribs were redesigned and the engineering of the composite structure of the spar was optimised.

Testing the Hybrid Wing on the *Caliente* delivered some eye-opening moments. One occurred motoring back to the dock with the sails down, when my 15-year-old son pushed on the 'clew' of the freely rotating Hybrid Wing. Instantly, within one boat length, we came to a dead stop despite the motor still churning forward! The wing has its pivot point close to the centre of effort so a small clew deflection engages a lot of aerodynamic power. We also learned not only that the new wing could be used for reverse power, but it also made for an effective side-thruster when docking.

Meanwhile, our claims of the free-feathering capabilities of the Hybrid Wing would also soon be put to the test. While moored off Bristol, Rhode Island in 2017 with its Hybrid Wing aloft, *Caliente* rode out a succession of hurricane feeder bands bringing winds of 50-70kt. When the weather improved a close inspection revealed that boat and rig had no issues (there was some relief at this point).

Sailing performance was also full of learning. We found that when over-powered we could effectively reef the hybrid 'mainsail' by easing the sheet, twisting off and depowering the top of the square-top rig in a very reassuring fashion. The mainsail design on the Hybrid is very flat, since it is essentially just the trailing edge of the wing so very little drag results when it is twisted off in this way. Off the wind this feature was also effective to not only depower, but to lower the centre of effort and reduce heeling moment... and with it the bow-down forces that ultimately limit all multihull performance.

Compared to *Caliente*'s conventional rotating mast sailplan the Hybrid Wing made it easier to fly a hull smoothly. Small amounts of mainsheet adjustment were all that was required to find the sweet spot for hull flying. *Caliente*'s wing rotation was also highly effective in adding power when reaching and downwind VMG sailing. Even with lots of rotation we were impressed with how the tell-tales on both sides of the wing and sail were flowing smoothly. This confirmed our expectations that we could have both high lift coefficients and low drag with the Hybrid Wing.

Another factor that is important in larger multihulls is the high structural loadings produced by mainsheet tension. As multihulls sail faster the apparent wind moves further forward. In power-up conditions reducing twist in the leech of a conventional multihull mainsail is crucial. However, reducing twist requires lots of mainsheet load and a corresponding high count of carbon in the mainsail leech itself (as well as increasing the structure required at the take-off point).

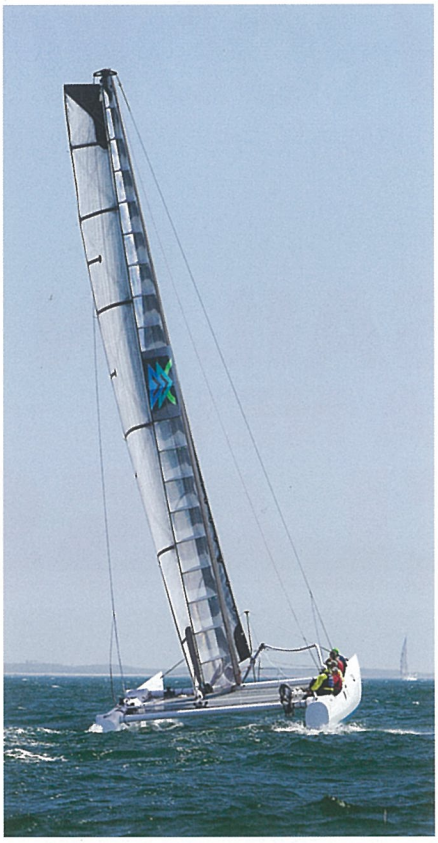
The Hybrid Wing reduces mainsheet loads dramatically in two ways. The first is the simple one: since the wing accounts for a high proportion of the sailplan area the mainsail itself is much smaller than on a conventional rig.

The second factor is a little more subtle. With a convex curve on the trailing edge of the Hybrid Wing, rotating the wing causes the middle of the luff to sag to leeward. So if the leech twists the same amount as the luff sags, the wind sees zero effective twist. Thus there is no reason to try to grind (or hydraulically pump) the leech into a straight line as with a conventional mainsail... Mainsheet loads are reduced further.

Windage is another performance killer for fast multihulls. Since the Hybrid Wing is thick in chord it has immense inherent structural strength. No spreaders, diamonds, intermediates, lowers, running backstays or jumpers are needed. Standing rigging is reduced to only two shrouds and the forestay for a major reduction in parasitic drag. Weight savings from the minimal standing rigging are an added benefit.

The Eagle 53 will travel to far horizons, often aboard ships as deck freight. Eagle's Hybrid Wing is built in two sections which allows safe transport with the wing halves secured between the hulls.

So far the Eagle has been sailing primarily ▷



The first Hybrid Wing prototype was fitted to Randy Smyth's Everglades special *Sizzor* trimaran (*left*) – Smyth used the rig to win the 2014 edition of the 300-mile Everglades Challenge and set a new course record. An interim step-up trial rig was decided upon as the safer option before going ahead with the full-size rig for the Eagle 53, Hall Spars building this spar (*right*) for the ProSail 40 *Caliente*

in St John, USVI after her launch in December 2018. The work-up has been meticulous. This first phase of Eagle testing has the Hybrid Wing sailplan combined with a C-foil and winglet-rudder package. Phase two will be with the T-foils installed, plus differential elevators, all managed electronically.

Finally, how does the Eagle 53 perform? As with *Caliente*, hull flying has been smooth and controlled. At 14kt the C-foils provide initial skimming-lift which progressively reduces hull immersion with speed. Short-term bursts of full flight have been achieved at speeds in the low 20s. Plus we have been hitting upwind speeds of 16kt with ease and the mid-20s when reaching. During my short time sailing in February we sailed with only the mainsail, Hybrid Wing and jib. Next we will test the Hybrid Wing with the screacher to open the door for VMG performance downwind.

Thanks to the electric winches, a central control station, the self-tacking jib, the furling screacher and boomless self-tacking mainsail (with those low clew loads) and the 360° feathering Hybrid Wing, Eagle can be sailed efficiently with only the owner Mr Sussman onboard, plus Tommy and his first mate Amber. So the design requirement of the Eagle being able to be sailed without a boatload of professional sailors has been met.

I personally look forward to continued sailing adventures on the Eagle while pushing the envelope of performance, ease of handling and electronically controlled foiling. I have particular admiration for the build team that Tommy assembled at Fast Forward Composites to make Paul Bieker's design vision become reality. The Eagle story has only just begun.

STANDING IT UP

– Steven Robert, ST2 Design

We became involved in this project thanks to Paul Bieker, after having worked together on a number of America's Cup campaigns and other projects. The design team assembled was made of familiar faces, and discussions were immediately fruitful. We were talking the same language, from designer to structural engineer to builders. The Hybrid Wing structural design group consisted of myself and Xavier Douin.

The challenge proposed by Tommy and the team at Fast Forward Composites was a refreshing concept, but at the same time it uses designs and techniques that have been developed and proven over the last few America's Cup cycles.

The Hybrid Wing is similar to the wings that were stepped on the multihulls for the AC33/34/35, in a sense that we have a main front element carrying most of the load. This element is like a long chord mast and has several familiar features: to facilitate transport the wing is split into two parts, the design of the splice tailored to maintain the desired aero shape while keeping the weight in control. The aft part of the Hybrid Wing is made of frames and covered with film in the normal way.

The structural part of the Hybrid Wing is a D-section, built with two sides and the lateral shear web.

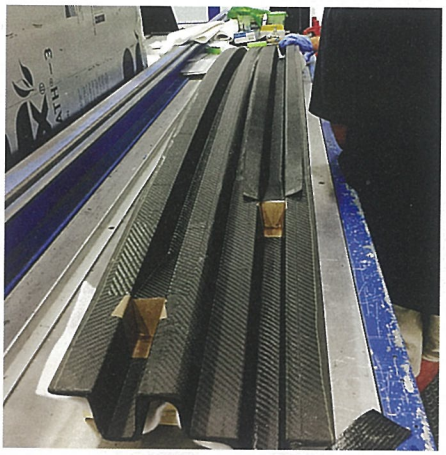
The design brief was to have a reliable and robust rig, so some of the features have been adapted to be less fragile than for a pure inshore racing spar. For example, the ribs that define the wing shape are made of single skin top-hat sections rather than honeycomb cored flat stock. The design process of these parts involved a collaborative discussion to achieve robust parts that could be efficiently built.

The distinctive characteristic of the Hybrid Wing is its ability to feather in the wind and rotate freely 360° when at the dock. The preliminary small-scale hybrid wings proved to be a valuable foundation for our work; however, the scaling is always a challenge and some further detailing and refinements were developed.

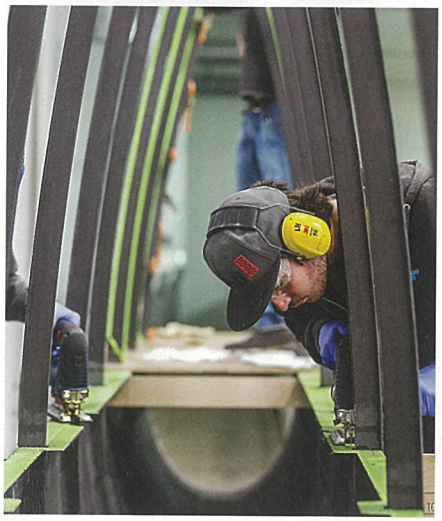
The planform shape of the wing was drawn by the design team to reach the maximum performance while achieving the free-rotation feature. Thus the chord of the wing at the top is a compromise between aerodynamic efficiency and the transfer of the load from the rigging. The two shrouds and the forestay are attached on a three-legged crane that we called the 'top hat'.

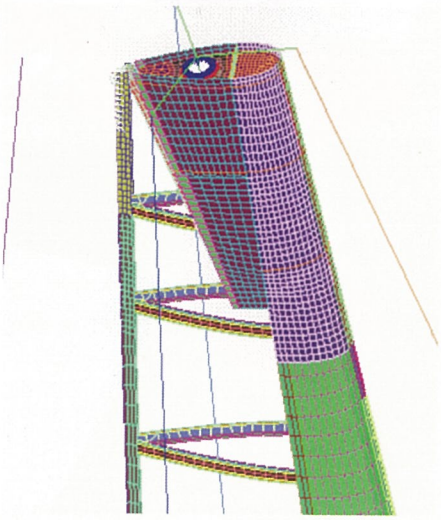
To keep the wing rotating freely the chainplates on the top hat have to be offset from the rotation axis and this offset corresponds to the half chord of the wing at the top. This induces cantilevered loads which need to be transferred to the Hybrid Wing through the top hat, on which all legs are bending members. On the wing itself the load is transferred to the spar through a set of bearings and a composite structure that we called the 'backpack'. This structure sits in the middle of the chord at the top of the wing, while the structural spar is the front part of the section.

The Hybrid Wing is secured at only two



An America's Cup programme would be proud of the build quality of the first Eagle 53 with machined carbon tooling used for all the main components and painstaking attention to detail minimising weight in the areas where material can creep into a build unnoticed – such as edge fillets and (limited) secondary bonds. Eight sections of female tooling were used to make the total 58 monolithic carbon wing ribs (*left*) with aluminium plants being used to fine tune between the ribs in each grouping. The 'backpack' seen in this FEA shot (*below*) is used to transfer the load from the legs of the shroud attachment 'top hat' to the geometric centre of the wing chord





locations: the top hat on the top of the wing, and the mast ball under the foot. When the boat is sailing the aerodynamic forces are applied on the wing, with the structural spar D-section resisting bending and resolving the compression of the stays.

The goal of the design is to minimise the sag of the wing by defining the appropriate stiffness; the challenge for the design team is to come up with the optimum thickness of the wing along the span to achieve a satisfactory structural stability. In the construction process the appropriate stiffness was achieved thanks to extensive use of high-modulus carbon unidirectional stacks in the corners of the D-section.

When the boat is back from sailing the sails are lowered. Unlike a conventional sailboat, the sail is not stored on a boom. The sail must be taken off the rig so that the wing can then rotate freely.

On *Caliente* the size of the mainsail made it manageable to use bolt ropes, but the much larger Hybrid Wing on the Eagle 53 features track and cars. However, during our brainstorming we came up with the principle of a removable lower trailing edge on the wing; now when the sail is lowered the sail and cars are stacked on a section of the trailing edge that can be disassembled from the wing completely making the de-rigging process a lot neater.

The design of the Hybrid Wing was an interesting and unique challenge. It was a fruitful collaborative process that ended up in a beautiful result thanks to all of the talented people involved.

INTO PRACTICE

– Wolfgang Chamberlain, Fast Forward Composites

The Hybrid Wing D-section is split into a top and bottom section, each section being approximately 40ft long. Considering the chord length of the sections, particularly the wider lower section, we decided to split the tooling at centreline to allow for easier access to the forward extents of the 'D'. We modelled the sections into 10ft tooling blocks and cut direct female tools on our Ares CMS five-axis mill.

We then joined our existing laminating tables together to create a beautiful single carbon surface measuring 10ft wide and 60ft long. The upper section tooling blocks were assembled on our tables and we were then able to process the D-sections and the shear web in the same cure cycle sequence.

Pre-release of the cured outside skins was a concern for us, so we modelled some features into our tooling to help distribute the vacuum across the surface of the cured outside skin. We then roll-formed honeycomb core over an alloy tool to complete the inside skin laminate.

To give ourselves more time to assemble the top hat bearing structure we built the upper D-section first. Once the upper section components were completed we moved them to the assembly jig where we joined the right and left halves and installed the ribs and shear web. With the tables cleared, the lower D-section could be started while the top hat/upper D-section connections were manufactured and assembled.

Ribs

A defining criterion for the Hybrid Wing was the necessity for extended periods of use without the need to be un-stepped and serviced; our prototype wing had stayed on the platform at a mooring in Bristol Harbor for an entire summer, exposed to the weather and rain for months on end.

In a move away from the conventional carbon/honeycomb rib panels, Paul Bieker floated the concept of thin-skinned monolithic top-hat sections. It was agreed that the hat section rib would certainly be more durable, but with 29 ribs to deliver we needed to find a solution to minimise the tooling required for each one.

So the 29 ribs were divided into eight sections of female tooling. Using carefully machined aluminium plants, we were then able to modify the trailing edge details for each rib. For the shorter ribs we changed the angle of the plant and moved it closer to the interface with the D-section. Thus each rib tool could be used to fabricate three or four sections.

Once laminated, the ribs would be loaded into the autoclave and cycled overnight en masse. The fabrication of the ribs, 58 in total, happened in parallel to the lamination and assembly of the D-sections to which they would attach.

Assembly

The upper and lower D-sections were assembled on a CNC-cut jig. To minimise the hinging moment at the interface of each rib and the shear web, the ribs extended approximately 200mm into the D-section. After the ribs were bonded on, the shear web was notched and carefully slid up from the bottom of the D and rotated into place on pre-formed D-section flanges. Trailing-edge sections and the top-hat bearing structure were installed and the finished sections were prepared to ship to the Caribbean.

Splice

The upper and lower sections of the wing were spliced together in the same fashion as the Cup wings using titanium side and forward splice plates. All of our titanium work for the wing was supplied by Alpine Machine in Arlington, WA, while WinMar Racing supplied the precision radial and thrust bearings that are critical to carrying the loads generated by the top hat without compromising wing rotation. ❑