KAi

KITEBOAT PROJECT & KITE ASSIST INSTITUTE

UPDATE 2011 (Quarter 2)

KAI Kite Assist Institute

Quarter 2 Report, 2011

Kiteboat Projects

Kite Assist Projects

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1 KITEFOILER DEVELOPMENT, TESTING, & DATA

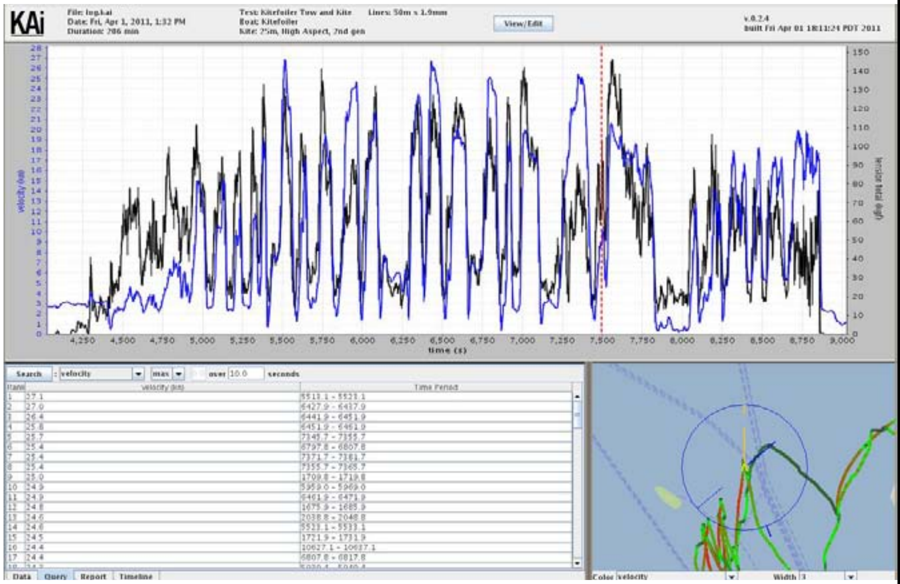
SUMMARY

This quarter we continued with a vigorous testing schedule, verifying the efficacy of the side T-foils, testing the new side J-foils for the first time, and experimenting with different rudder foils. We also returned to the original Hobie Trifoiler J-foils for several tests, in pursuit of more data comparing the J shape to the T shape. We used our most reliable arc kite, the 25m^2 M-B-6-25-v10-9s, for ease of testing during April tests, but in May began using the Kitefoiler platform to try various new kites designed in conjunction with Armand Torre. The most successful of these kites was a 25m^2 flat kite, which we used for Kitefoiler tests in June.

PROGRESS DETAIL

1.1 Kitefoiler Testing with Side T-foils

April 1, 4, 5, 9 Tests: T-foils Plus Kite



KAIView data from the April 1st test

On April 1, we performed our first test using the side T-foils with a kite, the 25m^2 M-B-6-25-v10-9s. The foil performance during this test was very good, and we achieved 27 kts boat speed in wind speeds ranging from 10 to 16 kts. Both because of this great result and because we'd like to practice sailing longer distances, we entered the 70-mile Border Run race from Newport Beach to San Diego later that month. In preparation for the race, we practiced launching the kite and sailing the boat with only two people, Don and Joe. We put a four-horsepower motor on the back of the boat so they could motor out without the Protector's assistance. Kite launching went very well and the boat achieved 25 kts in 13 kts of wind, on April 4.

The following day, Don and Joe again successfully executed kite launch and retrieval alone. They were able to launch on the first attempt and to recover the kite by flipping it upside down to winch it in and then righting it on the mast to deflate. Additionally, the boat was able to foil with three crewmembers, Don, Joe, and Richard, in relatively light wind, which was a lifting improvement over the smaller trifoiler foils.

Prior to the race, we painted the boat with our signature red-to-yellow fade, to give it a team look. On the 9th, race day, the wind was so low that we, and many of the other small boats, needed to be towed to the

(above from left): lowering the boat into the water with all three T-foils visible; Don and Joe prep to launch the kite using the launching mast; foiling as dusk falls start and eventually had back out of the race, but the experience still proved valuable for exploring folding and trailering options and for honing kite launch and retrieval procedures with a reduced crew size.


(top row from left): Joe preps the boat on the beach in Newport Beach; the tow boat pulls Don and Joe out to the start of the race

April 12 Test: New J-Foils

We completed the new J-foils during the first week of April and tested them on the Kitefoiler for the first time on April 12. While towing the boat out, the Protector needed to be going about 20 kts in order for the Kitefoiler to start foiling, which was a much higher number than either the old J-foils (15-16 kts), or the T-foils (12-13 kts). While sailing with the kite up, it was hard to keep the boat on the foils. Part of that phenomenon was likely due to very choppy conditions and swells knocking the boat off course, but overall the J-foil performance was inferior to that of either the T-foils or the original Trifoiler J-foils.



(above from left): the J-foils mounted on the boat prior to the test; Joe and Don try to get up speed; the Kitefoiler fights chop on the 12th

April 13, 14 Tests: Compressed Air Kite Inflation

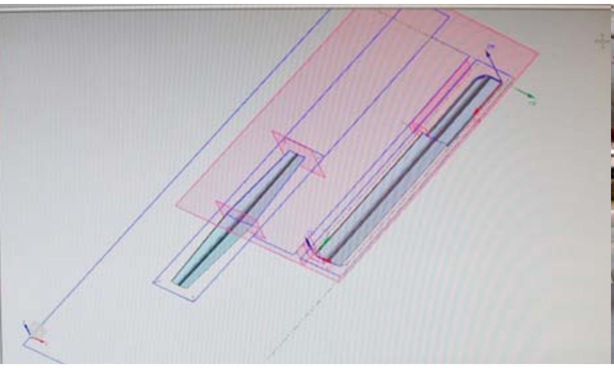
On the 13th we resumed using the side T-foils. We continued to use the M-B-6-25-v10-9s kite for both this test and a test the following day. During both tests we were able to foil stably with three peo-


above left, Richard and Don inflate the kite using the compressed air tank while Pete Lynn watches; Don, Pete, and Richard foiling with the kite up ple, although when the wind dropped we had to remove a person to resume foiling. An additional goal for both of these tests was to use a compressed air tank to inflate the kite on deck. The process proved relatively seamless and a real time-saver. We also modified the boat hull to make a special waterproof container for the tank.

1.2 New T-Foil Rudder

Design

Mid-April, we began building a larger stern T-foil for the Kitefoiler, because the original foil had trouble providing lift with heavier crewmembers. The new foil is designed to support more weight—it has a larger surface area, mostly due to a larger vertical section–the vertical part on the older foils tapered as it reached the rudder stock, but this one retains the same width. Additionally, the new foil is filled with a close-celled foam that provides positive buoyancy, unlike the other foils.




(above from left): a CAD drawing of the new T-foil; Richard checks the mold fit; the mold prepped for carbon; the completed T-foil on the boat

May 9, 10 Tests

On May 9th we used the new rudder T-foil for the first time. We towed the boat back and forth several times with four crew members and adjusted it until it could lift their full weight comfortably. The following day, we kited with the new T-foil, using Armand's 25m^2 flat kite. The boat foiled well with three crewmembers. We reached a maximum speed of 27 kts, in 10-15 kt winds.



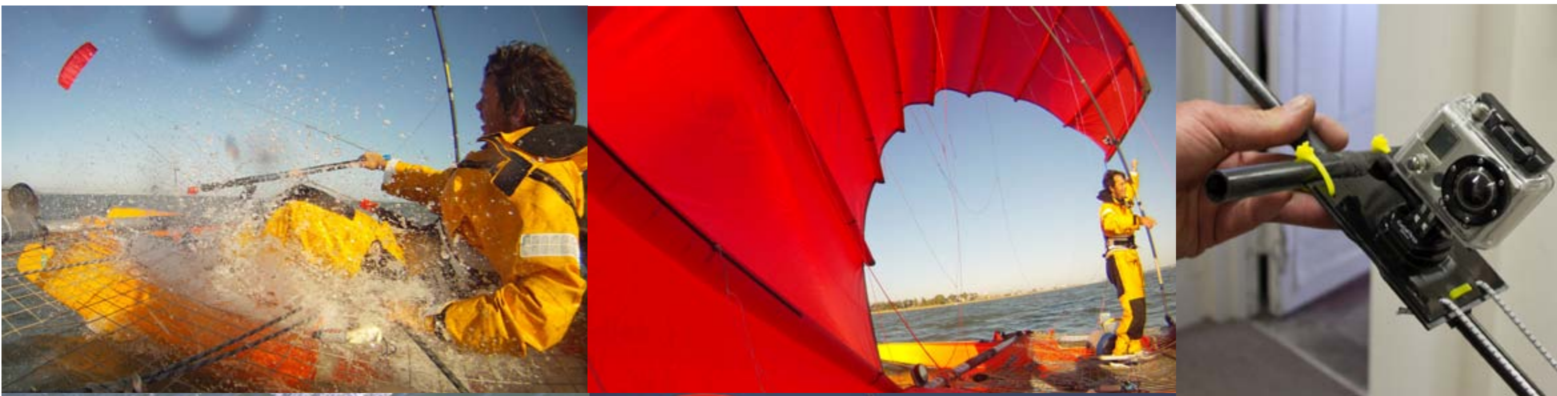
(above from left): Damon inspects the new T-foil post-test; Richard, Armand, and Don foil on May 10; a screenshot of the KAIView map from the May 10 test

1.3 Testing With Original J-Foils

June 14, 15, 16, 17, 21, 22, 23 Tests

Because our new J-foils proved so disappointing in April, we used the original Trifoiler J-foils for June tests, to compare their performance with that of the T-foils. We also dedicated much of this time to vetting Armand's 25m^2 kite. Kite solutions are discussed further in the next section.

During one test, on June 16, we broke the rudder after accumulating seaweed, but were able to fix it overnight for testing the next day. On June 17, we were able to use Dudu's helicopter to capture photos and video of the boat from the air. On June 21, we added a stabilizer to the winch, to aid in speedy kite recovery, and on June 23, we debuted an improved line camera mount that is easier to position on the lines and more versatile for use with different kites.



(top row from left): sailing with the 25m^2 flat kite; handling the flat kite on deck; the new line-cam mount; (bottom row from left): handling the 30m^2 Naish kite on deck; a view from the 25m^2 flat kite

1.4 Conclusions

As we progress on the build for KV2, we are debating the foil shape and size that is best for that platform, and we are using Kitefoiler tests to help us eliminate contenders. The reason that we have so many different foils for each boat is that there are five major variables that affect the size and shape of the foil—radius of the curve from vertical to horizontal surfaces, dihedral of that curve, section of the foil, vertical area of the foil, and horizontal area of the foil—and each different combination provides a potentially very different result.

The main performance difference between the T- and J-foils on our boats is that the T-foils provide lift at lower boat speeds, while the J-foils provide better turning to windward and are more forgiving in waves. We are trying to determine which foil shape is best to optimize for our boat and ideally strike a good balance of both lift and upwind performance.

The original J-foils are not optimized for our Kitefoiler, but they are currently the J-foils that we like the best. The larger J-foils that we fabricated from carbon and tested in April required too much speed to lift the boat, and they were unstable in choppy conditions. The original J-foils have a larger radius and more dihedral than the April J-foils, and more radius and more dihedral seem to translate to a foil that is more forgiving in chop—i.e. it cuts through the waves instead of crashing down from them. Additionally, our April foils had a thicker section than the originals—this was to provide strength, but likely created more drag than necessary and raised the foiling speed. Finally, the original J-foils are tapered, providing more area at the top, which means more lateral resistance and better upwind performance. The April J-foils are straight, which was easier to build, but did not prove as effective in turning to windward.

At present, we are leaning toward J-foils for the new boat—indeed, we've already begun construction on a J-foil mold for the new boat, but the excellent lifting characteristics of the T-foils mean that we'll likely revisit them in the future.

2 KV2 DEVELOPMENT

SUMMARY

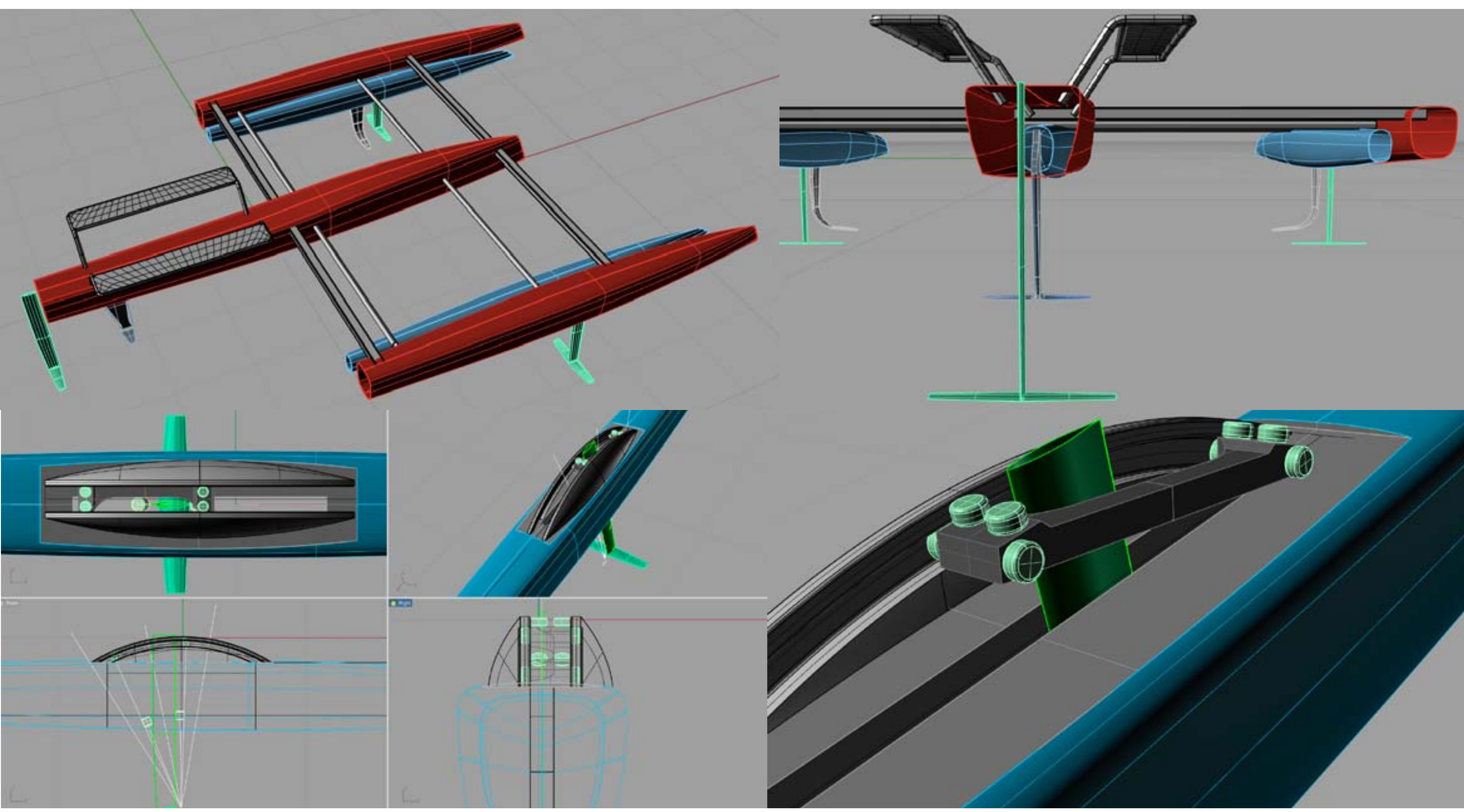
Thanks to the extensive Kitefoiler testing early in the year, we gathered enough data to begin building the next generation Kitefoiler in May. The original Kitefoiler was a quick-build platform to test the virtual pivot point foil concept, but the new boat, the Kitefoiler Version Two, or KV2, will be built from scratch as a kite-specific platform, like K1. The KV2 design is similar to the original Kitefoiler in that it has three large hulls, two virtual pivot point side foils, and one rear T-foil. It will be larger than the original Kitefoiler, however, and will fold, like K1, to fit in a container.

In June, we hired a new junior boatbuilder, Vincent Felice, to help with the boat, and we made significant progress on the build, finishing the float molds, the center hull shells, and the float shells. We finished building the beams and began installing the bulkheads on the main hull. We also began fabricating the first J-foil mold and designing the new winch.

SUMMARY

2.1 Design Requirements

The total length of the completed KV2 will be about 35 ft; folded for shipping in a container or trailering, the boat should be 25 ft. When folded, the boat's width should be less than 8 ft, and when assembled, we want it to be as wide as possible. The boat is designed to be able to be assembled by one person and sailed by two, with up to three guests on board. Everyone should stay dry while the boat is foiling. The boat should begin foiling at 12 kts, and should be able to reach a maximum speed of 30



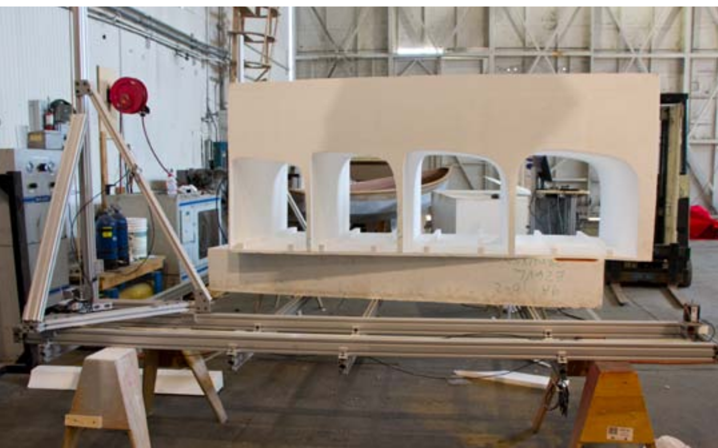
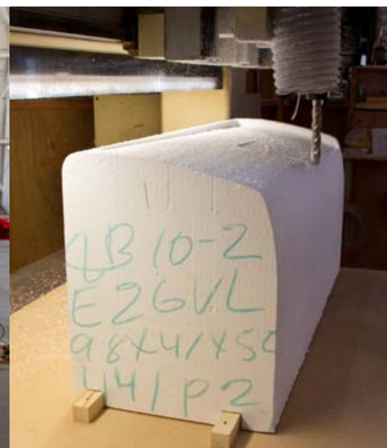
(top row): two views comparing the KV2 (red) to the original Kitefoiler (blue); (bottom row): several views of the new cassette-and-foil system for the new boat kts, with a cruising speed of 25-27 kts.

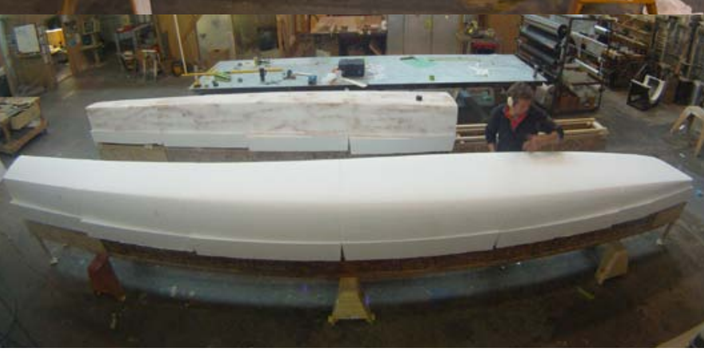
Additionally, the KV2 will have the advantage of cassettes that are integrated into the floats–the Kitefoiler cassettes are affixed to the outside of the hulls, which provided easy access for the many adjustments that were necessary early-on, but which also creates an excess of drag.

2.2 Mold Build

We began work on the male molds for the KV2 in mid-May. To speed the build process, we used a new mold construction technique. Previously, we fabricated male molds by building a wooden frame, attaching wooden battens, and covering those battens with bendy plywood. This time, we used our new hotwire CNC to cut blanks from a large block of Insulfoam, a type of recycled EPS (expanded polystyrene) that is designed for insulation. We then milled the blanks to the correct shape on the 5-axis router and glued the blanks to a strongback frame.

There are four different molds: two halves of the center hull and two halves of the side floats. (The side floats will be identical, so we can use the same molds for both.) By the end of May, we had cut, milled, and sanded all of the blanks for the molds, and we had sheathed the center hull mold in fiberglass, painted, faired, and waxed it to completion. The center hull mold was a direct male plug, meaning that we built a plug of the correct boat shape, and then laminated on top of that. We constructed the float molds by making a female mold off of an original male plug. In June, we glassed and completed the float molds.

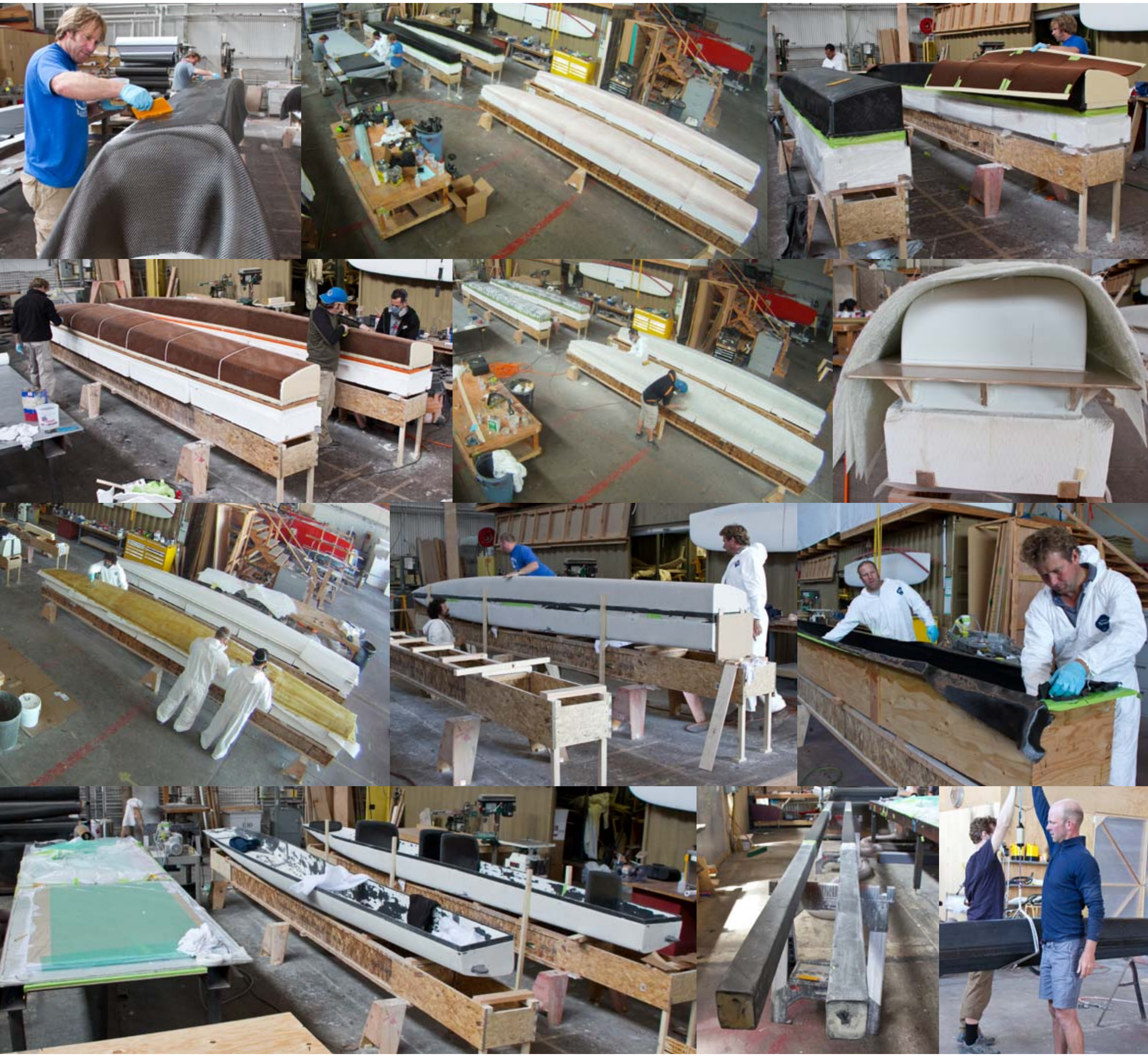






(top row from left): a Styrofoam block on the hotwire CNC; milling a blank on the 5-axis CNC; Dudu prepares a strongback frame for the blanks; (bottom row from left): Richard sands Styrofoam blanks that have been glued to the strongback; fiberglass dries on the mold

2.3 Hull & Float Build

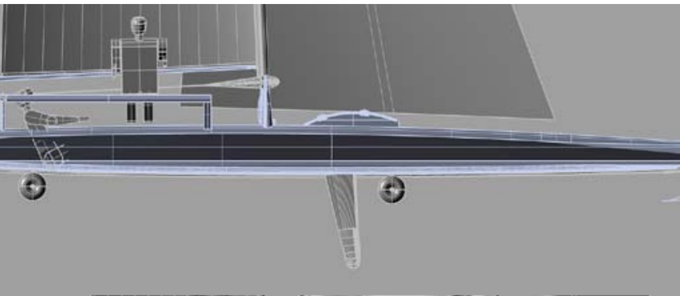
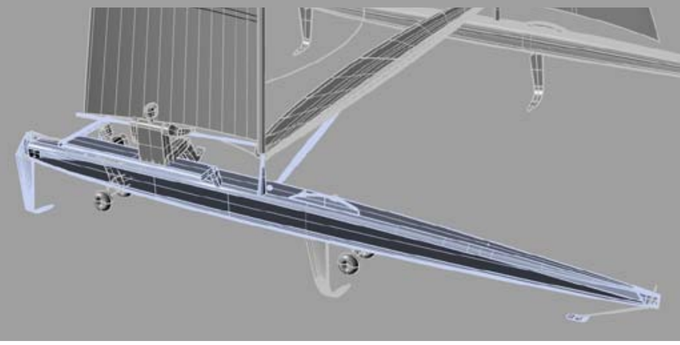
On the last day of May, we began work on the center hull itself; we laid two layers of carbon and a layer of Nomex and put them under vacuum. By the end of June, we had finished building the panels for the floats and center hull and had also completed the beams. We weighed each piece to check final weight against projected weight and improve our estimate for the overall weight of the vessel. The floats measured 27 kg each, which is excellent, as it perfectly fits the projected model. The center hull weighed 42 kg, which is also nearly identical to our projection. The beams weighed about 25 kg each, which is about 5 kg more than we'd estimated, but still acceptable. We expect that the bulkheads will add about 4 kg to the center hull and about 2.5 kg to each float. The filler and paint will add some additional weight, and the foils, foil cassettes, rudder mechanism, kite chair, tramps, winch, launching mast, and additional gear and finishing details will all add significant weight. Our current projection for the completed boat is around 400 kgs without crew.



(top row from left): Damon and Richard laminate the first layer of carbon for the boat hull; the hull molds with the first layer of carbon and the sanded float molds awaiting fiberglassing; Dudu trims the two carbon layers, while Damon adds a pre-fit layer of over-expanded Nomex; (second row from left): adding Nomex core to the center hull; sanding the float plug; fiberglassing float plug; (third row from left): fiberglassing float plug; fitting the center hull halves together; putting carbon in the female float mold; (bottom row from left): adding bulkheads to the center hull; finishing the beams; weighing a finished float shell

2.4 J-Foil Mold

This month we began work on a mold for the first J-foils for KV2. The mold follows exactly a design from Greg Ketterman of J-foils intended for use on a sailing quadfoiler of similar weight and size to our boat.

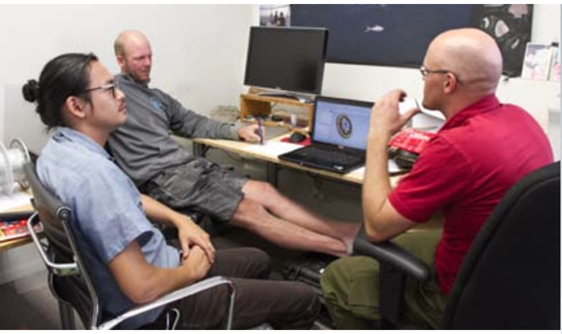
(top row from left): a drawing from Greg Ketterman of his quadfoiler with the J-foil design that we are using for KV2; the J-foil mold under construction; (bottom row from left): another view of Greg's design

2.5 Winch Design

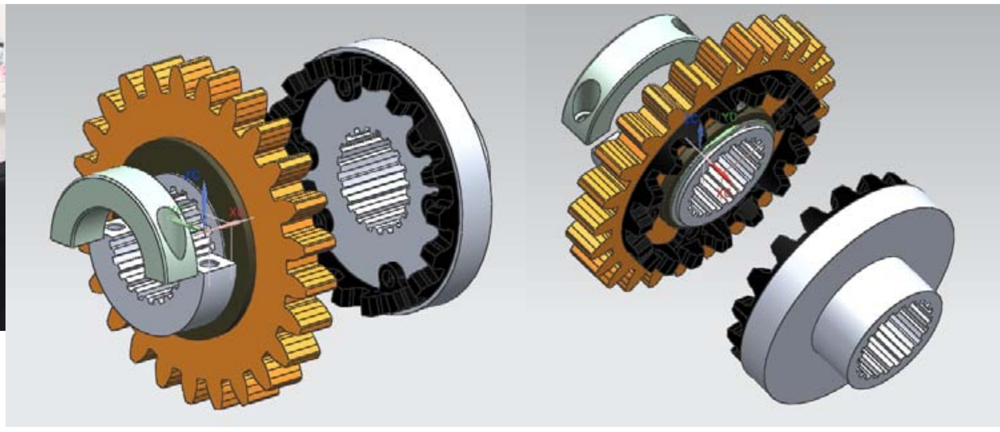
The completed KV2 will also feature a new multispool winch, based on our winch prototype, which we are currently using and have used for the last year. We contracted Mose O'Griffin and Jay Jean-Hank Ho help with design and fabrication.

The multispool concept means that each of the five kite lines has its own spool and that each spool can turn independently of the others. There are many situations in which this is desirable. For example, when loading or replacing the lines, one can handle them individually. This is much easier to deal with than a monospool winch, which requires that all of the lines unspool at once. Additionally, when drift launching the kite (the type of launch in which the kite is swum/carried out and launched from the water) or 5th line launching (when the kite is upside down and reeled out on the 5th line as if it were a single line kite), the multispool winch prevents tangles due to over-wraps, which occur when one or more flying lines are pulled taut and the other lines are slack. In general, any time that there is a chance of differential line pulls, the multispool winch will allow it without issue, while the monospool winch will often tangle.

Currently, the prototype winch has three modes: coupled, decoupled, and only 5th line decoupled. "Coupled" mode means that all of the spools are connected, and they spin together. This is useful for executing a flying recovery (kite is right-side-up and still flying as it is winched in). "Decoupled" mode means that all of the spools are free to move independently, the advantages of which are described above. "Only 5th line decoupled" means that the four flying lines are connected, but the 5th is free to move independently. This allows a flying launch from the mast, since the kite can pull out as much of the 5th line as it needs to as it deploys.



above, Joe discusses winch design with Jay and Mose; at right, Mose's CAD drawings of the dog faces



There are also situations where the kite-flier needs to switch between modes of operation. For example, if the kite falls out of the sky and lands on the water, the 5th line must be pulled in immediately for safety and to keep the kite under control. This requires the 5th line to be decoupled. After the kite has flipped upside down and is under control with the flying lines slack, the winch needs to be shifted into coupled mode, and all of the lines need to be winched in together (with the initial 5th line bias remaining throughout in order to keep the kite safely inverted until it reaches the boat). With the existing winch this shift is possible, but awkward, and making that shift easier is the primary modification that we want to incorporate into the new design.

We hope to create a simple and positive shift mechanism by using a custom-machined clutch dog on a splined shaft. The dog faces will mate together with a toothed face, and the sliding half of the assembly will be actuated by a shift lever (not shown in the diagrams). This should allow the spools to be coupled and decoupled from the drive shaft easily and quickly, even under moderate load.

Eventually, all of the spools will be actuated independently. This would allow a fine adjustment of the flying lines to account for any small discrepancies in steering bias or angle of attack. We will begin by having just the 5th line shiftable, allowing us to test the performance of the mechanism before we finalize the design.

Also in the new winch design will be a strengthened and lightened spool, which will be able to take a larger line tension. This will be combined with an electric servo-powered drivetrain that is sized to the same larger loads. The strengthened drive system will become important as we move toward flying launches and landings on all points of sail, rather than just downwind. Also in some applications, the ability to have continuously variable line lengths (with the winch taking the full kite load) may be desirable.

The last element in the new winch design is a powerful braking system, which has fine modulation for flying launches in light winds and can be completely locked off when needed. ■

3 KITEBOAT KITE TESTING & DEVELOPMENT

SUMMARY

This quarter we explored Cuben Fiber kiteboat kite solutions, including modifying the all-Cuben kite into a Cuben-Dacron hybrid and testing seam-joining techniques that would eliminate the need for a bladder. We also brought in Pete Lynn and Armand Torre as consultants on designing flatter kiteboat kites to withstand higher loads.

Pete is a regular kite consultant for the project, but Armand is a new addition. A French kite designer who has worked with Anne Quéméré, he visited our workshop for two weeks in May to fly two distinct designs of kiteboat kites. The first design is a flat shape with a special bridle meant to withstand higher loads; Pete also designed a flat kite for us with a unique bridle, which we tested in April, and he returned in May to confer with Armand. Armand's other design is a variation on the design he made for Quéméré: a folding "bird kite" meant to improve on-deck launching—we tested two variations of the bird kite, one 12m^2 and one 25m^2, with other small differences.

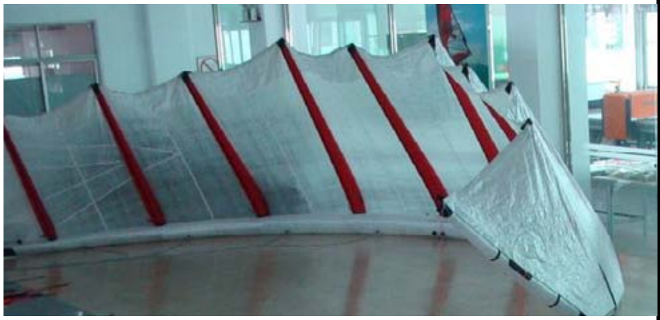
PROGRESS DETAIL

3.1 Cuben Fiber Kite Update

This winter, we designed a 25m^2 all-Cuben Fiber kite, which failed along the seam lines. Over the course of Quarter 2, we learned that even for our much smaller lifting kites, Cuben Fiber is not well-suited to stitched seams, and that the material tends to rip where it has been sewn, particularly when loaded.

As short-term solution for that kite, we removed all of the Cuben Fiber struts and replaced them with Dacron struts. We also replaced the leading edge and added Dacron reinforcements every place that the Cuben material was vulnerable. The canopy is still made of Cuben Fiber, so it is lighter than our traditional kites. We plan to test it on the boats early next quarter.

We have also been exploring long-term solutions that can eventually allow us to have successful all-Cuben Fiber kites. This quarter, we explored tape-joining solutions and also experimented with using glue on the seams for the lifting kites.



the Cuben-Dacron hybrid kite at the factory in China

Joe inflates the Cuben Fiber tube

Another goal for the Cuben Fiber kites is eventually to make them bladderless, which is contingent on finding an excellent, stitch-free sealing method for the seams. In April, we made an inflatable test section of a small strut out of Cuben Fiber, using VHB tape adhesive to seal the seam and urethane glue to attach the valve. We then inflated the tube until it exploded, at 4.5 psi. The Cuben material we used was a 13 g/m^2 high bias, which is an extremely lightweight laminate that has spectra fibers in both 0/90 degrees and also at +/- 45 degrees. The results of this test (4.5 psi) were promising, but we will need to perfect the sealing method so that it can be repeated reliably for an entire kite.

3.2 Flat Kites

We have been pursing flat kites as a possible solution to our large kite problem because, as long as we load every strut, the flat shape has more projected area, which means that a flat kite can provide more power than an arc kite of the same area can. Additionally, the load-spreading characteristics of a flat design allow flat kites to take higher loads, so flat kites are a better choice for scaling up.

In April, we began testing a 12m^2 flat kite that Pete Lynn designed as an alternative to our arc kites. Pete's design uses a "bridge" bridle, which includes two bridle arcs that match the kite arc and short supports that connect to the kite. This winter, we collaborated with Armand Torre via email to design another flat kite. This kite is similar to Pete's kite, but Armand's bridle solution is similar to a parachute bridle, featuring many lines that branch off from the four flying lines. In May, Armand visited to fly his design with us.

far left, Pete's 12m^2 flat kite with "bridge" bridle design; near left, Armand's 25m^2 flat kite with parachute bridle design

Testing Pete Lynn's 12m^2 Flat Kite

Mid-April, we brought back from China the 12m^2 flat kite. We tested it with Pete in Alameda over several days, both on land, and using a courseboard. The goal of these tests was to gather enough information to improve the design and scale it up for use on the boats. Pete is currently designing a 25m^2

kite for us of similar design.



(from left): Pete flies the kite on the beach; Pete returns from surfing the kite as Don heads out to try it; the bridge bridle shape in flight

Testing Armand Torre's 25m² Flat Kite

We conducted beach tests of Armand's 25m² flat kite during the first week of May. Each day we flew the kite on land to calibrate the bridle, and then we surfed the kite to observe its performance under load. On May 4, Pete Lynn joined us as well.

On May 10, we tested the 25m² flat kite with the Kitefoiler, using the launching mast and the compressed air tanks. The kite proved as easy to launch as our arc kites, and we were able to reach a maximum speed of 27 kts. However, the flat kite offered less steering than the arc kites, which meant that, although the kite provided more power once the boat was up to speed, it was harder to get the boat on its foils. When using an arc kite, we can grab more wind by turning aggressively to generate initial foiling power. We use the vertical wingtips to turn the arc kites, which allows us to swoop the kite to scoop up wind; with the flat kite, we turn by breaking the back of the kite, and that twisting movement decreases power. The benefits of the flat kites appear to outweigh this difficulty, however, so we'll continue to work with the bridling to improve steering. Both Armand's and Pete's bridle solutions seem promising, so we are pursuing both for the time being.



(from left): a closeup of the bridling on the 25m2 flat kite; Dudu, Pete, and Armand discuss bridling; Pete and Armand fly the flat kite on the beach

During June, we used Armand's 25m² flat kite for the majority of our Kitefoiler tests. We have been corresponding with Armand via email, and hope to have a new kite prototype to test next month. We had some trouble flying the flat kite, as the wind was consistently low, and the shape of the kite is not optimal for low-wind sailing. A round kite has more projected area in the middle to provide horizontal lift and keep the kite aloft at the edge of the window, whereas the flat kite was very difficult to keep aloft at the edge of the window in low wind. We'll continue to test with this kite in July, when we hope to have better testing conditions. We also experimented with a 30m^2 Naish kite from 2003, which had no bridle, to compare the deck handling of the two. It was comparatively very simple to launch and recover, so simpler bridling is certainly a future goal.




(above from left): Don, Armand, and Richard launch the 25m^2 flat kite; the kite picks up speed; the Kitefoiler foiling; a closeup of the kite while the boat is foiling

3.3 Bird Kites

Armand's bird kites also have a flat shape, but they feature an additional carbon-rod cell, which enables folding during launching. These kites can fly in a positive dihedral mode on only one line, which means that they can be released from the deck in a folded, stable position, like a bird with its wings up. Once the kite is at altitude, the control lines are engaged, which snaps the wings out into flying position and engages steering.

During the first week of May, we flew the 18m^2 bird kite on land at the beach to refine the bridling, and on May 9 we launched it from the Kitefoiler. We had some trouble initially, due to our unfamiliarity with the design and Armand's unfamiliarity with our launching mast, but we did successfully raise the kite in the air and snap it into position. A carbon batten broke during launch, however, so we did not try to pull the boat with it, and we began using the 25m^2 kite instead.



above left, the folded 18m^2 bird kite; above center, the deployed 18m^2 bird kite; right, the 18m^2 bird kite flying from the Kitefoiler

During the second week in May, we took the larger kite to the beach each day. We checked the shape, adjusted the bridle, and practiced releasing the kite and transitioning from a folded position to an open position. On May 13, we finally tried the 25m2 bird kite with the Kitefoiler. We were able to get the kite up on the mast, but had trouble launching successfully.

Conclusions

(top row from left): Dudu works with the bridle on the $25m^2$ bird kite in the shop; Dudu and Armand fly the kite at the beach; (bottom row from left): the $25m^2$ kite ascends in folded dihedral mode; the kite flies in deployed mode; Don, Dudu, and Armand launch the $25m^2$ bird kite on the Kitefoiler

Much of the difficulty with on-deck launching of the 25m2 kite stemmed from the complicated nature of the kite's rigging. There were so many bridle attachment points that the bridle tangled easily on deck. Additionally, rigging the cell calls for even more lines, which can get messy. We are now brainstorming to reduce line tangling. An additional problem is that, once in the air, the kite pulls very hard in dihedral mode, which is hard for the kite-flyer to handle. It may be possible to control this pull, however, by adjusting the angle of attack. ■

4 KITEBOAT ELECTRONICS & SOFTWARE

SUMMARY

This quarter, we continued to expand the capabilities of the KAIView application, enabling direct conversion of boat test data into the KAIVIew format, and updating the software to a new version (0.3.0). We also upgraded our electronic sensors and improved our logger software to make it more user-friendly. The Kite Assist Electronics section includes crossover improvements, including our Android phone control work.

PROGRESS DETAIL

4.1 Hardware

InduComm Radios

Paul Larkin from InduComm visited in early April and accompanied us on our April 5 Kitefoiler test. He brought the newest prototype of the hands-free radio system we commissioned.

The system fit inside one ear of a crew-member and picked up voice through his or her jawbone, which was meant to reduce wind noise. The radio had both push-to-talk and open-mic options. There were one captain's headset and several crew headsets. For our test, Paul wore the captain's headset on the Protector, and Don, Joe, and Richard wore the crew headsets on the Kitefoiler. Paul attached a directional antenna to a pole on the Protector. We followed behind the Kitefoiler at various distances to test the range of the system. The system worked well at first, but was inconsistent. We could still hear wind noise, and one mic was permanently muffled. Paul took our input and will return next quarter with the next prototype.


above left, Paul sets up the radios while wearing the captain's headset; above right, Richard models one of the crew radios

GPS Goggles

We purchased a pair of goggles with built-in head mounted display (HMD) and GPS/gyro/altimeter in order to see if they would be useful for kiting, if the electronics could be hacked to display other information, and to learn about the design of the display and optics. The goggles, called "Transcend GPS," are produced by Recon Instruments and Zeal Optics, primarily for the snowboarding market.

In kiteboat tests on June 15 and 16, we found that the display was not very convenient for viewing while flying a kite, since the user must look down to see it. The display optics are large enough to be obtrusive even when removed from the goggles, and would not fit well on a helmet or glasses. The display hardware is a Kopin 230K micro LCD designed for applications such as video camera viewfinders. It is controlled by a Kopin A220 display driver IC. A mirror and lens make it possible to read the display from a few inches away without refocusing one's eyes.

While the electrical interface makes it relatively simple to control the display with our own hardware, the physical design of the device makes it less than ideal for our application.

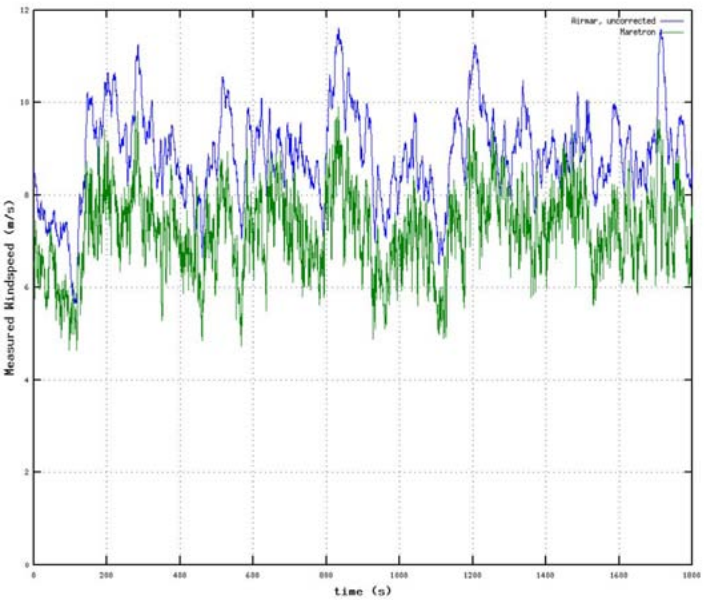


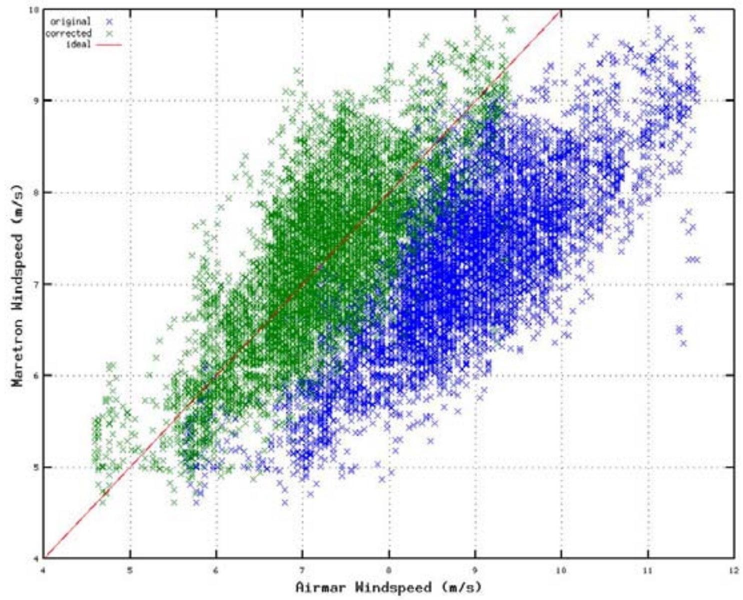
(above from left): Don models the goggles on a Kitefoiler test; the disassembled electronic hardware

4.2 Wind Sensors

We have been concerned about the accuracy of the wind sensor that we have been using on the Kitefoiler, an Airmar PB200 ultrasonic anemometer. In May, we took the sensor to Crown Beach, along with our old standby, a Maretron WS100 (also ultrasonic), and a handheld mechanical anemometer, to compare their performances. We found that the Airmar sensor reported wind speeds that were 23% higher than the other two sensors, which tended to be in good agreement with each other.

Some of the divergence shown in the graph is expected, due to varying filter parameters, sensor positions, and local air turbulence, but the systematic rightward-shift in the plot is a concern. In order to perform this test, we also updated the logger software to handle multiple NMEA 2000 wind sensors; this will also make it easier to handle multiple instances of other N2K sensors in the future.





(top row from left): the measured Airmar speeds (blue) shown with the measured Maretron speeds (green); the blue cloud shows the measured correspondence between the two sensors, the red line shows the ideal correspondence, and the green cloud shows the result of scaling the Airmar output for best fit with the Maretron; (bottom row from left): Jamie reads the output from the wind sensors on a laptop; the Airmar sensor (left) and the Maretron sensor (right) at the beach

4.3 Kiteboat Logger

We can now start and stop the kiteboat logger and verify that it is powered on without opening its protective waterproof case or connecting from a remote device. This has involved running the power switch and LED from the internal PC to a waterproof switch on the outside of the case, a job that was made trickier by the miniaturization of the PC. This operation also opens the way to making an external supervisory circuit that can control the PC power and monitor the battery state on longer excursions.

Other improvements to the logger include auto-detection of removable media, software to assist with calibration of the wind sensor while we are on the water, and an independent charging port. When a

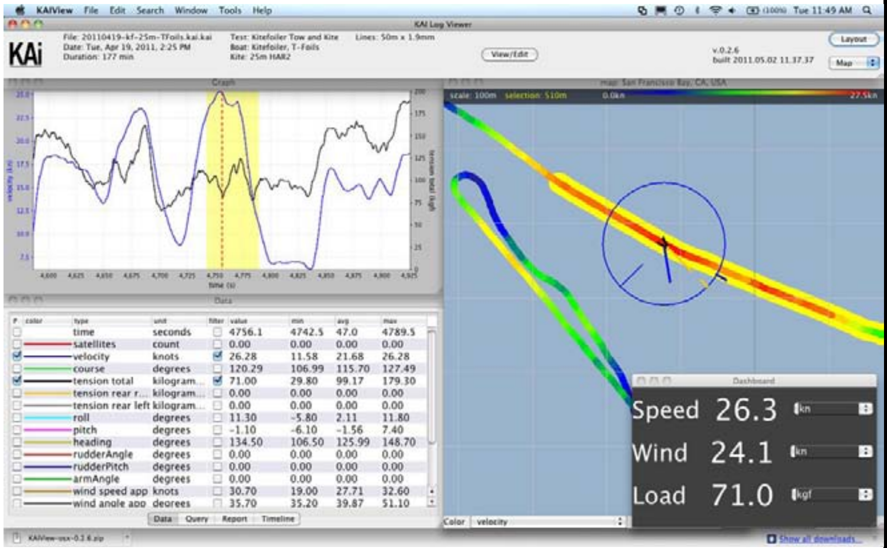
above left, the external logger switch; above right, removable media ports miniSD or USB drive is attached, the logger automatically writes log data to the external device, and we also made it possible to directly import the data into the KAIView software, which is discussed below.

4.4 KAIView Updates

We made multiple improvements to the KAIView software this quarter, progressing to version 0.3.0.

Early in the quarter, we focused on the mapping component and its integration with the other data displays. We wanted to make the mapping window more useful as a primary interface to the data, instead of just a supplement to the graph display. We increased the default size of the map window, and added a legend to show the geographic scale and the meaning of the color-coded data.

In addition to these visual changes, we improved the correspondence between the selections made in the graph window and those made in the map. Right-clicking and dragging in either view will create a selection that is shown in both views. (Note that the center button was previously used for selecting regions in the graph, but since the button is non-existent or mapped to system functions in OSX, we will avoid it from now on.)



the selection made in the graph window corresponds to the selection shown on the map–the KAIView dashboard option displays the boat speed, wind speed, and line tension

Under the Tools menu, we added a “Dashboard” option, which brings up a simple, large numeric display of the boat speed, wind speed, and line tension to make it easier to watch just these three values while stepping through a dataset. The dashboard text can be resized with the +/- keys.

In the graph window, we matched the y-axis ranges of certain quantities that we frequently compare to each other. This means, for example, that boat speed and wind speed will always be plotted such that they can be directly compared in the graph without having to carefully watch the vertical scale

We also partially resolved the problem of windows getting “lost” if minimized on OSX by adding a “Layout” button on the top-right corner of the display. This button (along with the selection box below it) resets all windows to either a map-centric or graph-centric arrangement.

By the end of June, we had added the ability to adjust the range of values for which colors are displayed when boat data is plotted on the map. This makes it possible, for example, to restrict the color range to areas where the boat is on foils (above about 15 kts).

We also made the display of wind and boat heading/course more readable and intuitive. In the circle around the boat, the blue radial lines indicate the wind direction. The line outside the circle is the true wind direction and the line inside is the apparent wind direction. The yellow radial lines indicate the boat heading and course. The outer yellow line shows the course, and the inner yellow line shows the heading. The yellow-highlighted angle between them is the leeway.

Additionally, we roughed in tidal current data. While the tide data can be displayed on the map, we are still trying to find the best way to use the tidal information in coordination with other sensor data and how to package the data with the boat data. For now, this feature is not accessible from the graphical user interface.

Finally, .kai format files can now be generated within KAIVIew.

(above from left): the color displays indicate boat speed; the line inside the circle indicates apparent wind direction, while the line outside indicates true wind direction–yellow radial lines indicate boat heading and course; red numbers show tidal current data

4.5 Boat Log to KAIView Conversion

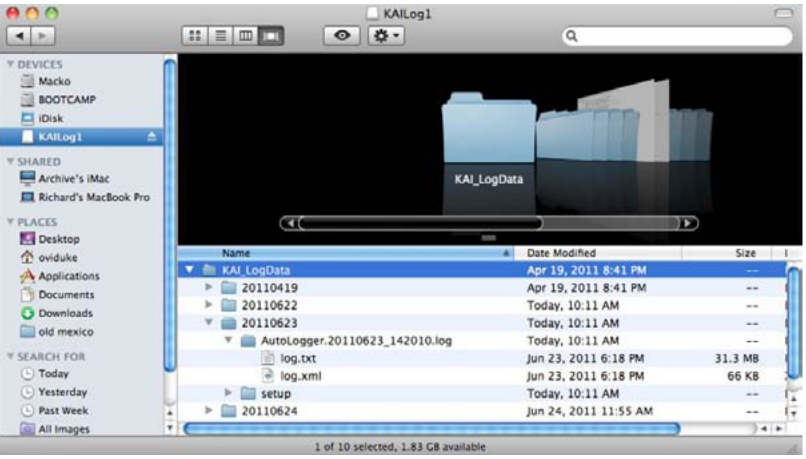
It is now possible to record boat test data and convert it to KAIView format without the need for any special software or hardware tools. Data can be recorded directly to a mini SD card, and the data on the card is converted from raw log to .kai format within the KAIView application. Although it takes a few words to describe, the process is itself quite simple.

Outlined below is the procedure for recording data to mini SD card and converting the data in KAIView. Note that there are numerous places where the process can be improved, and several changes will be made soon.

1) Insert Card & Start Logger

Before testing, and before the logger is powered on, insert a mini SD card into the card slot in the logger PC. In the first picture, the card is shown sticking out of the card slot and not fully inserted. If the card is detected when the logger starts, then it will store the log file there.

step 1: insert the SD card in the logger



step 2: copy data to computer

2) Shut Down Logger & Copy Data to Computer

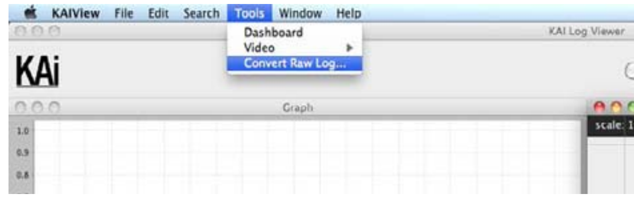
After testing, and after powering off the PC, remove the SD card from the logging computer and connect it your own computer. Due to the way in which data is written to SD cards, it is more important to shut off the computer “nicely” using the pushbutton.

On the SD card should be a top-level directory called “KAI_LogData.” Within this directory, there is a sub-directory for each day of tests. For example, 20110623 refers to June 23, 2011. Within each test day directory, there is a sub-directory for each log. A new log is started each time the computer is powered on. Usually, this log directory will have a name that includes the date and the time that the log started. In the second image, the date and time are shown as 20110623 (June 23, 2011) and 142010 (2:20:10 pm). Usually we are looking for the last log on the last testing day.

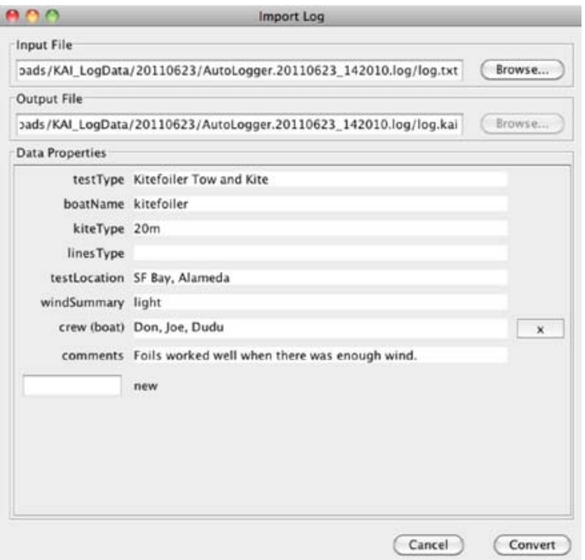
Copy the log directories of interest to your computer. Note that you must copy the directory that the logfile is in (and not just the log.txt file) because applications will look for several files that must be stored together.

3) Start KAIView Converter

Start KAIView, and select Tools --> Convert Raw Log... from the dropdown menu.



step 3: select "convert raw log..." from the dropdown menu



step 4 & 5: select file in the "import log" window. and enter metadata

4) Select File to Convert and Output File Name

In the “Import Log” window that pops up, click “Browse...” in the “Input File” section, and find the directory that hold the test data just copied from the SD card. In this directory is a file called “log.txt”. Select this file. It’s full path should appear in the input file text field, and the output file text field will show the name of the file to be created (by default it is “log.kai” in the same directory).

5) Enter Metadata

Now enter the test metadata in the provided fields. For example, the name of the boat, type of kite, and overall comments. To add a new metadata field, enter the new field name in the lower-left box and type the enter key. To remove a field, click the “X” button to the right of it.

6) Start Conversion

Click the “Convert” button. The process is slow and there is not yet a progress bar. It takes about 2 minutes for each hour of test data recorded, but it will eventually finish and you can open the new KAIView data file. If you have doubts that it is working, you can open the OS X “Console” application, and some progress may be shown there.

Planned Improvements

- prevent a crash when the logfile has inconsistencies due to forced shutdown of logger
- provide helpful error messages when the import fails due to a user mistake
- add a progress bar while converting the file
- have KAIView find the SD card and available data files when it is plugged in
- more conversion options (channel data processing configuration)
- “templates” for test metadata, and/or default to last values entered
- make the import window modal
- make the importer more lenient about which input file or directory gets selected

KITE ASSIST PROJECTS

1 LIFTING KITE DEVELOPMENT & TESTING

SUMMARY

This quarter most of our kite work was focussed on developing new generations of inflatable rokkaku kites. Dudu made two trips to China, one in April, and one in June, to work with the factory team there.

PROGRESS DETAIL

1.1 Fled Testing

In addition to collaborating with Armand on kiteboat kites design, we asked for his recommendations regarding our inflatable lifting kites. On May 5 and 9, we flew our standby inflatable Fled kite with various bridle configurations. This kite is very powerful, so it can potentially lift a large payload, but the bridling is crucial in order to maintain control and stability and has proved a sticking point in the past.

Dudu and Armand fly the inflatable Fled at Crown Beach on May 9

1.2 Inflatable Rokkaku Design & Testing

This quarter, we developed several different generations of rokkaku kite, progressing from generation 1 (G1) to generation 13 (G13).

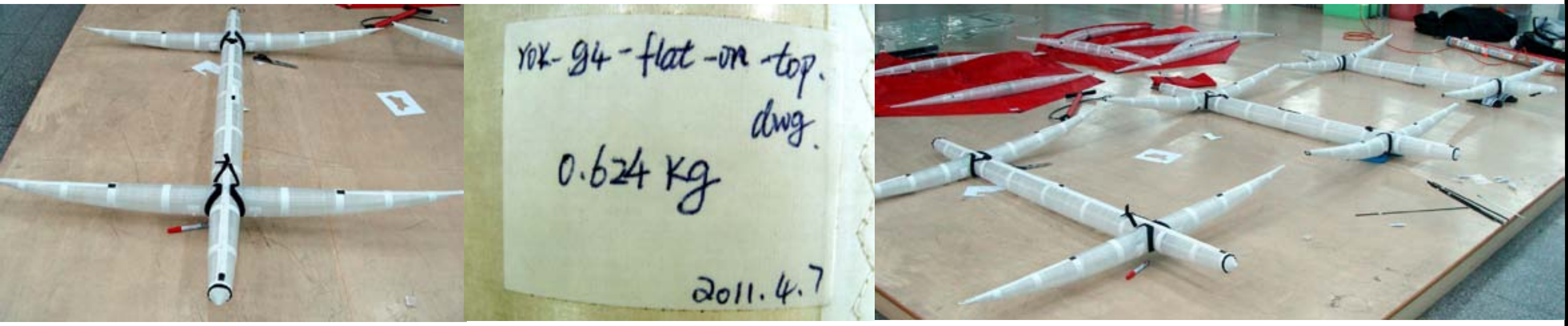
G1, G2, G3

Prior to Dudu's arrival in China, the team assembled three Cuben Fiber kite skeletons, G1, G2, and G3. G2 proved confusing to assemble, so before G3 we improved the software mapping between the 2D and 3D views and added more precise alignment markings to make intersections easier to put to-

(top row from left): the 3D view of G2; a detail of the strut-spar intersection on G2; the inflation valve on G2; the G2 Cuben Fiber skeleton; (bottom row from left): the G3 skeleton; the G3 inflation valve; a detail of the strut-spar intersection on G3; the G3 specs gether. However, all three kites had trouble flying stably, displaying a tendency to steer to one side due to small twists created by their difficult assembly. We continued to search for more precise techniques to assemble the panels to avoid twisting and unstable flying. We also analyzed and discussed finish details, valve placements, and ideas to save weight.

G4

The final weight of the inflatable skeleton for G3, not including the skin, was over 600g, which was unsatisfactorily high. To reduce the overall weight of the kite, we began attempting to reduce weight on every possible detail. G4 featured flatter struts and better canopy attachment, but no real improvements in flight or weight.

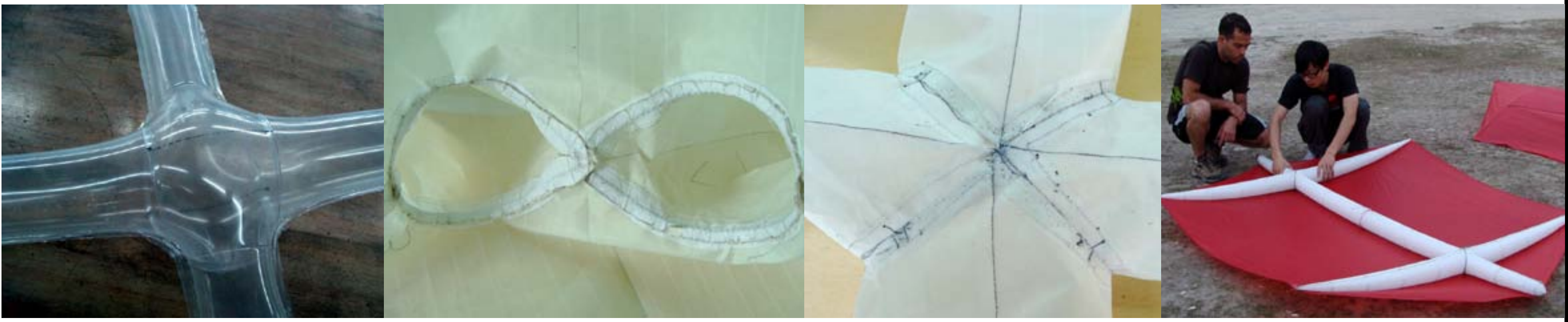


(above from left): the G4 skeleton; the G4 specs; the G4, G3, and G2 skeletons together

G5

Our next kite, G5, had no zippers, no octopus valves, no battens, and only one small Boston valve at the tail in order to reduce weight. We eliminated the octopus valves, one-way valves between struts and spar that equalize pressure, by making a single bladder with a center body and four legs. We made special openings on the nose and tail in order to insert the bladder. Additionally, we developed a new method for joining the spar to the struts, eliminating the heavy webbing and reinforcements—the result could be inflated to full pressure and could withstand twisting without a problem.

We made the first G5 prototype out of Dacron in order to check the geometry without using the more expensive Cuben Fiber. Even using Dacron, however, the weight result was impressive, at 540g for the total kite. The flight results, however, were still a problem. We tracked the problem to the frame stiffness—the canopy was stretched too tightly and did not allow the strut tips to bend toward each other to create the optimal flying curve.



(above from left): the G5 bladder; G5 joint detail; G5 strut-spar intersection; Dudu and Cheuin attach the G5 skeleton to the canopy

G6

In order to address the stiffness problem, we separated the struts and main spar again for G6. We reduced the diameter at the joints to half the diameter, keeping the central thickness the same but using a bottleneck reduction where the tubes crossed. The geometry of this kite was easier to assemble than the other versions, but the structure did not work in flight—it broke easily with any small increase in loads. We did learn, however, that the kite tended to bend upwards at the center of the strut between the bridles, and that compression happened at the boom, so strength is necessary at those points, but perhaps not as crucial elsewhere. We also confirmed, by yanking hard on the flying lines to induce deformation, that most of the loads were on the front strut, which meant that we needed to add more strength there.



(above from left): the G6 skeleton plus canopy; a closeup of the bottleneck reduction at the spar-strut cross point on G6; the G6 kite in flight

G7

In version G7, we sought to unite the best design features of G5 and G6. To generate G7 we made several software improvements—we improved intersection lines, fixed tessellation functions (to tessellate flat panels and copy triangles to shaped panels), mapped tick marks along intersections, enhanced object mark definitions, and enabled intersections between two tubes to have multiple lines on the layout map, so different sorts of tube intersection were possible.

Our solution to the strut-spar problem was to join the front strut and center spar as a cross piece and to leave the back strut separate. The linked front strut then gained stiffness from its alliance with the center spar, whereas the independent back strut was free to accommodate airflow and prevent undesirable steering. The integrated front strut and center spar shared one bladder, eliminating the need for an octopus valve. The main spar crossed over the back strut without joining it, resuming its normal curve on the other side. The strut was connected to the spar only through a loop connector, which loosely held them in place. This point was the point about which the strut could rotate around the main spar.

We flew the first G7 prototype with very good results and, later, a second one with improved geometry, thanks to some more software upgrades. We cleaned up the intersections by rotating the strut coordinate system to the same angle as the location it was placed on the main spar. We also rotated each strut toward the other at the tips to allow for enough slack in the canopy between the front and back spars to improve flight stability. Using G7, we finally achieved good steering with a fully-inflatable rokkaku. It worked much better than the previous versions, which had a tendency to steer and even loop to one side because of twisted struts or too-stiff canopies.

In addition to steering improvements, however, we were also striving for weight reduction by testing the limits of strut and spar diameter. The G7 had quite small diameters, which proved a limitation for the structure, because, although the kite flew well, the main spar would break when we tugged the line too hard. The narrow struts were also more difficult to assemble correctly, and it was more difficult


far right, the crossover between the central spar and the back strut on G7; near right, Dudu tests the G7 kite to achieve a straight main spar at that diameter, so the ideal strut diameter would need to be slightly larger.

G8

Enter G8. G8 featured larger spar and strut diameters, at 91mm for the center spar and 85mm for the cross struts. We expanded the software capabilities to include rotation of the strut coordinate system—this enabled us to rotate the strut tips toward each other, allowing outboard canopy curve. Additionally, we gave the spar and each strut individual curvatures and maximized canopy loading by developing nice pocket solutions and reinforcements at the strut and spar ends. For this kite, we used more sections to allow for more precise geometry, and we felt secure enough in our design to make the struts, center spar, and canopy all of Cuben Fiber, for the lightest-weight result.

G8 flew steadily like G7, but was able to withstand strong pulls without breaking, unlike G7. Due to the larger, stronger spar diameters near the struts, however, the overall weight was slightly more, despite the materials difference.

G9

The G9 kite was a more refined version of G8. It had slightly smaller diameter tubes than the G8 kite, slightly more rocker in the main spar, and better finish solutions. G9 served as the baseline for kites 10-12, which we defined in terms of their deviation from G9's specs.

During a payload test in about 15-knot winds, we loaded G9 with sand bags until it began to deform, and then observed the flight pattern with that weight suspended from the line, just below the bridle connection point. The kite's payload limit was 225g. Flight without the payload was very stable and with the payload much less so.

(above from left): the G9 kite flying with a small payload; Dudu flies the G9 kite as Armand adds more sand to the payload; the kite begins to deform as the wind picks up and the payload increases

G10

The G10 kite was an attempt to recreate the G9 design without a bladder, using only Cuben Fiber struts, but those proved prone to leaking. We temporarily abandoned the bladderless idea while we

(above from left): the G10 spar-strut intersection; Don sprays the inflated G10 with soapy water to find leaks; a closeup of the bubbles that indicate leaks in the cuben fiber seams perfect joining techniques.

G11

The G11 had the same strut-spar connection design as G7-G10, but it was 25% smaller overall (both in tube diameter and in canopy size) than the G9, and its tubes were made of Dacron, not Cuben Fiber. Although Dacron is heavier than Cuben Fiber, it is also much tougher, and so does not require the kind of reinforcement that Cuben Fiber does. For this reason, we used Dacron for the spars and strut on G11 to see if the weight saved by Cuben Fiber tubes was really significant. Dacron proved much heavier, despite the reinforcement, so the next kite will use Cuben Fiber again.

In June, we debuted the G11 kite. The kite flew stably but had a tenancy to steer in one direction, which was also a problem with many of the earlier inflatable rokkaku versions. After some bridle adjustments, we flew the G11 kite again alongside the G12 kite with AoA adjuster attached. Despite the added weight of the adjuster, the G12 still performed much better than the G11, which continued to steer to one side.

During the second China trip (June 27-July 1), we tried to stretch and twist the kite a few times to see if that would improve flying. It actually did, but it was still not as stable as the best kites (G9 and G12). After some investigation, we tracked the problem to a mistake in the file where one of the intersection lines was offset to the wrong side. The program had a bug which surfaced when generating intersection lines and offsetting them. We fixed the bug by inserting new functions to intersect surfaces and mapping them to the panels.


(top row from left): Don prepares the G11 kite for a test; the front intersection; the back intersection; (bottom row from left): the G11 kite in flight; the valve and reinforcement around the valve; the strut-canopy attachment point

G12

The G12 kite used the same size canopy and same materials as the G9 kite, but it had struts and spars that are 10% larger in diameter. At the point where it crossed the back spar, the center strut gains a slight additional diameter, because the triangle-shaped cross-point had proved a weak point on earlier kites.

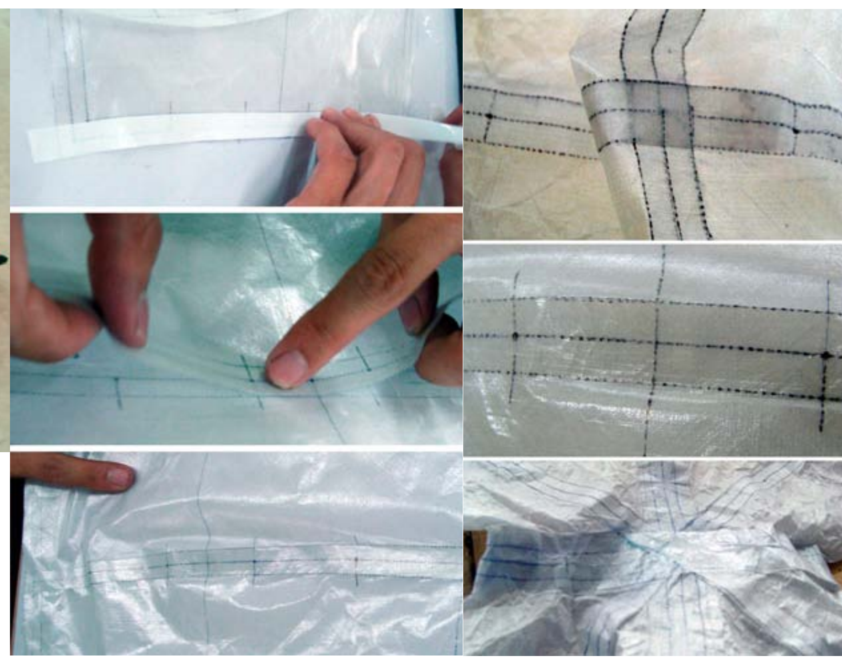
We used the G12 kite during most of the June AoA adjuster tests. During the test on the 23rd, during which we also attached a wind sensor to the line (in addition to the adjuster on the kite), we observed some deformation that suggested that stiffer struts might be necessary for lifting larger payloads, but the problem was fixed with bridle adjustments. During a kite test in Maui on the 28th, we flew the G12 kite in winds up to 25 knots, which did not noticeably affect the kite's stability or shape. It did, however, make it impossible for one person to reel the kite in, a problem that we hope to solve with the AoA adjuster.

G13

The G12 kite has become our new baseline for geometry and size. The G13 kite is 25% larger overall (in canopy and tubes) than the G12 kite. G14 will be 25% smaller overall than G12. Additionally, these kites will feature general improvements to the design, which are discussed below.

One such improvement is taping the kite seams instead of sewing them. For G13, we used the double-sided tape to align the seam overlap and then a wide Cuben cloth tape over the outside of the closed tube. After adding the skin and fittings, we inflated the kite to less than 2 psi, just to conform the final geometry. The kite looked nice and clean and straight, and the whole thing weighed less than 500 grams, even though it was 25% bigger than G12, which was itself larger than G8 and G9.

After photographing the kite, we inflated it to standard flying pressure, around 4 psi, and the kite failed exactly at the widest diameter, at the meeting point of the closing and intersegment seams, because the closing seam gave out from the hoop stress being larger than the longitudinal stress. This failure suggested that the tape was not strong enough to hold the closing seam. Our next solution was to use tape to close the panels nicely and to leave some space to finalize the closing with Super Glue. We made a quick prototype using this solution and noted that the Super Glue's strength allowed us to inflate to and maintain flying pressure. We'll inflate this prototype to its failure point early next quarter, in order to judge the likely long-term success of the solution.



above, the lightly inflated G13 kite; at right, detail shots of gluing seams

1.3 Overall Design Improvements

Our goals for the rokkaku kites during the second China trip included using two new kinds of tape, one double-sided, and one cloth, that we'd brought from the US. Our hope was that this tape could eliminate stitching on the kite tubes. We would still use a bladder, but it would be lighter. Additionally, we wanted to reinforce the ends of the Cuben Fiber strut and spar tubes with Kevlar, and to make the finish on those areas neater, both more aerodynamically-shaped and more lightweight. Also, the small Boston valves on the previous kites had not included sufficient space to include the cap tether, which had made it easy to misplace the cap, so we wanted to restructure this. Finally, we wanted to eliminate text marks and reduce the size of tick marks on the kite, for a nicer finish, and to add proper bridle loops for ease of rigging.

The rokkaku design has two main pieces—the inflatable body, which has open ends without the traditional folding-inside finish, and the skin, which has the all the fittings to lock the inflatable body ends and to load the body from the bridle loops with a small panel that goes around the tube. After making the CAD drawings of these details, we cut them and built the skin with all the fittings. We assembled the G13 kite in the manner described above, using the double-sided and Cuben tape for closure. After those seams failed, we added Super Glue to finalize the seam, which initially looked promising but which is also difficult to execute in a uniform manner. Another issue that we need to check is whether we used the tape incorrectly. Our previous cloth tapes required heat to seal properly, but it is possible that we should not have used the same heat for Cuben Fiber tape. It does seem that the closing seam will need more strength to hold the hoop stress, so our next step will be to use the glue between the double-sided tape and the Cuben Fiber tape, instead of after the Cuben tape.

above left, Cuben Fiber bridle loops; above right, small Boston valve and canopy attachment details

We also observed that the tape-closing solution does not add as much material as the stitching solution, so the tubes do not bend the same way as they did on previous designs. As we test in July, we will be looking to see if this bending poses a problem for flight stability and efficiency—if it does, we can add more curvature to the design to compensate. Other items to be changed in the next iteration include removing webbing at the end covers and instead using a straight line for easy panel finishing, reducing the width of Kevlar reinforcements around the strut and spars, and removing the top closing seam on the Kevlar reinforcements for a nice finish and clean airflow.

2 KITE ASSIST ELECTRONICS

SUMMARY

This quarter, we neared goal of completely wireless sensor control by developing WiFi access for our logger and remote access hacks for the GoPro cameras. We also made significant advancements toward ground control of airborne electronics using Android phones and tablets.

PROGRESS DETAIL

2.1 GoPro Update

Lens Modification

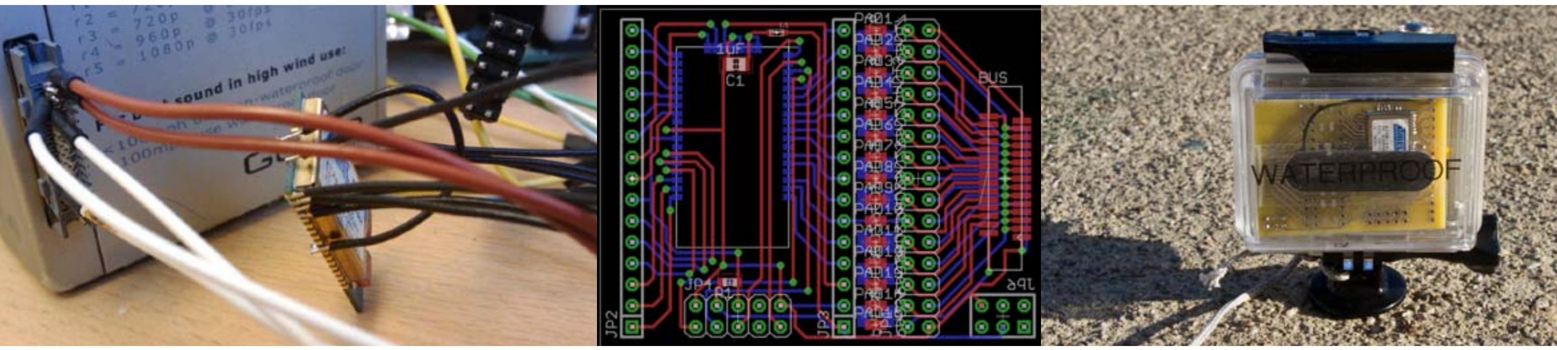
Following the example of several online GoPro enthusiasts, we fitted an HD Hero camera with a standard, non-fisheye lens. This will be helpful for kite views where we'd like a narrower field of view and also for certain boat applications where we'd like to be able to use a photograph to measure angles with as little distor-

Jamie puzzles through focusing the standard lens on the GoPro; a photo taken with the new lens; a photo with the old lens tion as possible.

Wireless Remote Control

We have been incrementally working on making our GoPro cameras remote-controllable via the ZigBee wireless protocol. The objective is to make a minimally-invasive modification to the camera that allows us to detect which cameras are present, to turn the cameras on and off, and to initiate synchronized recording by multiple cameras. Any addition to the camera should also be able to fit in a protective case for actual testing in the water or on a kite.

We also made a circuit board that gives us wireless, networked control over GoPro HD Hero cameras and requires no camera modification. To minimize overall complexity, we connected to the cameras entirely via the exposed bus connector. We can start and stop all cameras at the same time, and keep a record of those times in our logfiles. This makes it possible to record video and images that are synchronized to the other test data, and it will also conserve camera battery life and minimize the amount of excess footage.



(above from left): a bench test of the zigbee hardware connected via the bus interface; the PCB layout to allow a more compact and robust packaging of the bus connector and ZigBee hardware; the wireless modifications to the GoPro cameras fit nicely inside the extended "Bac-Pac" cases, so they can be sealed for use in all weather conditions

2.2 Logger as WiFi Access Point

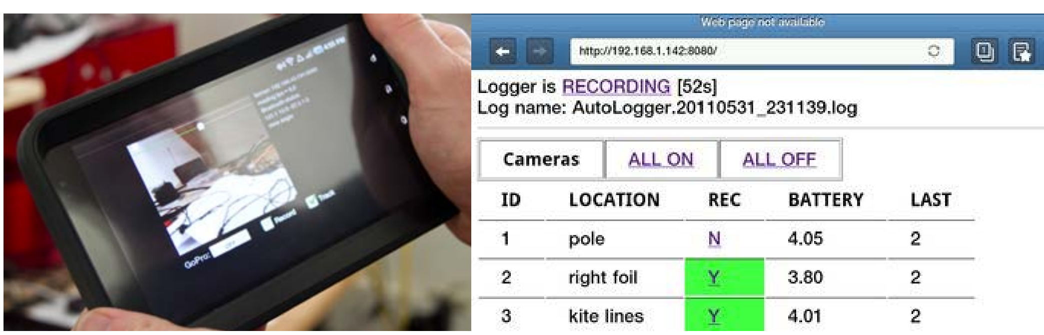
The box that we use for logging tests contains a very small Linux PC that connects to sensors, records data, and manages data displays. We wish to be able to connect to it remotely from our phones and laptops to verify that it is operating correctly, to control its operation, and to have a rich real time display of all recorded data. To this end, we have set it up to function as a wireless access point, which was not possible on the hardware using standard Linux builds. Now that this is working, we can connect via any wireless device and be directed to a Web page hosted on the logger.

the logger box with new wireless capabilities

2.3 Hardware

Samsung Tablet

We purchased a Samsung tablet to aid Android camera control development tests, which involve multiple mobile devices. The initial approach uses plain static HTML, but once working we hope to move it to a more dynamic server-push framework. Its larger size than the



near right, the Samsung tablet; far right, logger control on the tablet phones has also been useful in developing remote control for the logger and in angle of attack (AoA) adjuster tests.

2.4 Angle of Attack Adjuster Tests

Mid-quarter, we began working in earnest on developing an AoA adjuster for the lifting kites, a mechanical attachment that allows the kite flier to adjust the AoA on a single line kite, using a ground-based remote control device. First, we used a worm gearbox to adjust the bridle lines and a toy airplane radio controller to direct it. By the end of the quarter, we had graduated to using an actuator to adjust the AoA and an Android phone to control it. After verifying the concept with these prototypes, our final goal is a more compact and waterproof version of the setup.

The adjusters operate by changing the length of the back lines. While flying, the front lines on a kite take most of the load—the back lines take only about 25%. Shortening the back lines changes the AoA so as to reduce the load on the flying lines, which is helpful for reducing the force on a winch when reeling in the kite. Lengthening the back lines changes the AoA to project more kite area and increase the kite's power, which is beneficial when lifting a camera or other object.

Gear Box Tests

On June 2, we tested the first iteration of the AoA adjuster, made from a worm gearbox and a receiver manufactured for use in a toy car or airplane. We attached the adjuster to the bridle of the G9 rokkaku kite, our most reliable rokkaku kite at that time, and used a model airplane radio antenna to control it. The adjuster worked on the ground, but had trouble under load and at much distance from the controller. On June 5, we repeated the test using a similar setup, but we substituted the G12 rokkaku, a similar but wider-tubed kite, for the G9 rokkaku, and we used a different model radio controller, in the hope that its range would be stronger. The larger G12 kite was well suited to the lifting task, but the range of the alternate radio controller was not significantly better. In both tests, we noted that the scope of movement available to the gearbox was not great enough to make the magnitude of adjustment that we required.

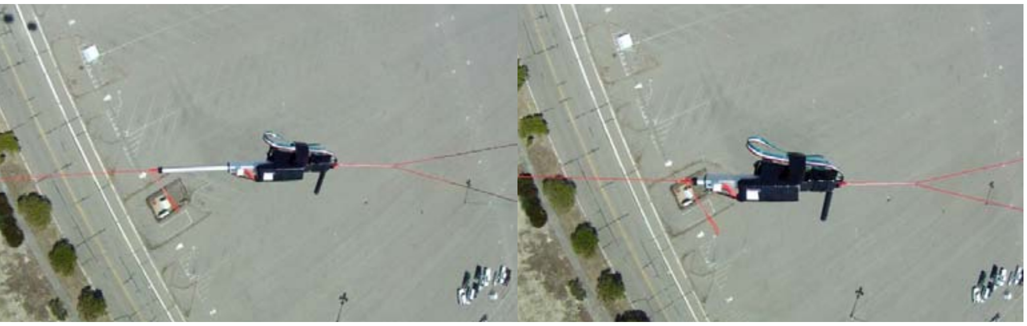
(top row from left): in the foreground, the worm gear box–in the background, the receiver and battery; Jamie and Don practice using a radio controller with the gear box and receiver in the office; Don tests the gear box aoa adjuster with the G9 rokkaku kite; (bottom row): three different radio controllers used with the gear box aoa adjuster

Actuator Tests

On June 8, we tested our next generation adjuster, a linear actuator, also mounted on the kite bridle. We used the G12 kite and controlled the actuator from the ground via Bluetooth using an Android phone and tablet. After some bridle adjustments to accommodate the actuator, the kite flew with stability and lift comparable to a standard-issue carbon-sparred rokkaku that we used as a control.

We found that the 10 cm extension of the actuator was enough to make a noticeable difference in the kite's elevation and line tension but not enough of an adjustment to explore the full useful range of AoA. We were pleasantly surprised to find that the Bluetooth range easily reached from the ground to the kite, however. Our expectation was that our mobile Android devices would not have sufficient range, and that we would need to put an additional one on the kite to relay WiFi control signals from the ground.

We weighed the adjuster components—actuator (56g), radio link and servo controller (26g), battery (18g)—and again tested this configuration on June 12, with similar results.

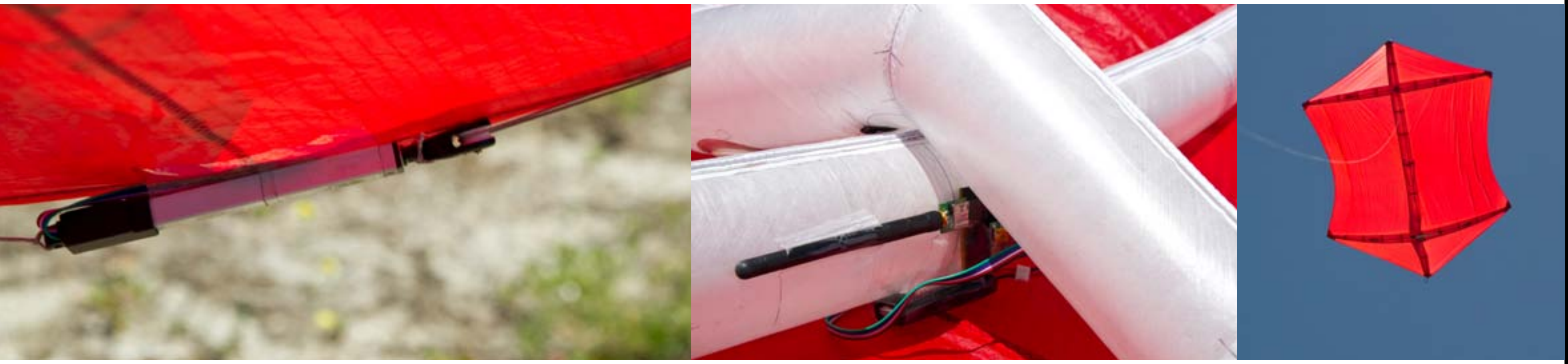


far left, the actuator situated in the bridle line, as seen from a GoPro camera attached to another line–the actuator is fully extended here, having the effect of "sheeting out" the rear bridle lines and decreasing the AoA–in this state the kite generates less lift, reducing the line tension and situating the kite lower in the sky; near left, the actuator is fully retracted, sheeting in the rear bridle by 10 cm and increasing the AoA

Actuator Tests With Pulley System

To double the effective range of the actuator, we added a pulley system. During our next test, on June 23, we again used the G12 kite and, this time, fixed the actuator to the back of the rear spar of the kite, to make it more stable than the previous versions, which dangled off the bridle. As in the earlier incarnations, we placed a radio link and servo controller at the back spar-strut intersection, in order to receive commands from the ground. We again used an Android phone to talk to the adjuster.

The adjuster worked well after some tweaks to the bridle and kite pressure to accommodate the setup. The wind was gusting between 7 and 12 knots of wind, which provided some variation, but we will still need to test this setup in various conditions to judge its versatility. We did test the configuration again in Maui, , in slightly higher winds, with good results. The next step is to attach the kite to a winch with a load cell, in order to quantitatively gauge the effect that the AoA adjustments have on the line load.



(above from left): the actuator with pulley attached; the radio link and servo controller; the G12 kite flying with the actuator attached to the outside of the back strut