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BOATS

BY **NORM DEWITT**

It started with a sailing loophole. For the 1998 America's Cup races held in San Diego, a challenge under the original Deed of Gift had few stipulations, other than that single-mast racers were limited to 90 feet in length. As a direct result of this open rule-book, the New Zealanders challenged with the enormous—at least compared with the previous twelve-meter racing boats–90-foot monohull *KZ-1*. But their advantage in having been designing and developing the boat in advance met its match when the defending American *Stars & Stripes* team countered with a smaller hard-wing catamaran design that simply disappeared over the horizon against *KZ-1*.

As a direct result of this embarrassing mismatch, the IACC monohull class of AC boats emerged. Used from 1992 to 2007, this rule restored sanity to the regatta, and the improvements in design were incremental, evolution versus revolution.

That all changed in 2011 when the shoe was on the other foot: Swiss defender *Alinghi* was challenged by Golden Gate Yacht Club, and the courts again decided that the loosely defined Deed Of Gift would govern the technical rules of the regatta. The 90-foot carbon-and-titanium trimaran *BMW Oracle* squared up against the similarly gigantic *Alinghi V*, a 90-foot catamaran, both taking costs and technology to previously unheard-of levels and crossing many inappropriate lines, such as using engine-powered hydraulic systems (see "Spar Wars," *Roundel* Feb 2010) instead of man-power alone. Millionaires no longer need apply; the America's Cup was now the province of billionaires, if not JPL or NASA.

This latest interpretation of the open-rule Deed Of Gift—a document written in the 1850s—again resulted in sheer domination by an American team, as *BMW Oracle* brought the Cup back to America.

But the excitement of watching blazingly fast gigantic boats with their insane closing rates was undeniable, so for the next America's Cup regatta in San Francisco Bay, the AC72 class was adopted. These huge catamarans took

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THE **CUTTING EDGE** OF TECHNOLOGY TOOK **BMW** BACK TO THE **AMERICA'S CUP.**

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another quantum technological leap; the hulls were completely out of the water much of the time, and the term "foiling" entered the America's Cup vocabulary. Eleven-member crews struggled to achieve maneuvers while up on their blades at top speeds approaching 40 knots. Suddenly there was an X-Games extreme-sport factor at play; the spectacle was jaw-dropping, something heretofore unseen in America's Cup regattas. However, tragedy soon followed this quantum leap in speeds, with *Oracle* pitch-poling (an end-over-end crash) into oblivion, and the loss of British Olympian Andrew James "Bart" Simpson in a crash of the Swedish entry *Artemis* reminded the world of the dangers of cutting-edge racing, by land, sea, or air.

Early domination of the 2011 finals by Emirates Team New Zealand made them the favorites going into the finals and through the first few races. However, that gave way to a late surge of boat performance and seamanship by Team Oracle, and despite an 8-1 deficit, they rallied—and in possibly the greatest comeback in sporting history, took it to the final race tied 8-8, a winner-take-all scenario unseen since *Australia* won the Cup in 1983. In the end, Team Oracle sealed their comeback with victory in the final race, a regatta for the ages.

Oracle Team USA / Sam Greenfield

Today's America's Cup boats fly with just their hydrofoils in the water.

For the 2017 America's Cup regatta, BMW returned to sponsor the efforts of Team Oracle USA in an attempt to retain the Cup. This defense took place in Bermuda in a new smaller boat; the AC50 (fifteen-meter) catamaran rulebook has tightly-written specifications in the hope of both reducing costs and avoiding costly technologies that can do little more than separate the massively-well-funded from the less so. Although *Oracle* was soundly trounced by Emirates Team New Zealand's *Aotearoa*, the boat's technical wonders deserve our attention nevertheless; as our cars evolve into autonomous robots, it seems that racing yachts are turning into airplanes.

The vertical foils below the hull are known as dagger boards, and balancing the boat on these

Norm Peterson

Oracle Team USA/ Sam Greenfield

foils is a critical part of the sailing act. You can see how you'd want lift on the leeward (off-wind) hull to keep it flying on the supporting tripod of the two rudders, but when you're on the opposite tack—when it would be fully retracted and now on the windward side—you would want aero downforce to keep the boat flat: downforce when retracted on the windward hull and hydrodynamic lift when it's deployed on the leeward hull. The rulebook says that there are no design restrictions upon the dagger board when it's fully retracted—which appears to be a rulebook loophole asking to be exploited.

A horizontal foil at the bottom of the rudder can be adjusted for angle of attack, providing either lift or downforce, much as you would trim the wings on a race car to achieve the necessary balance. "The idea," says Design-team member Bryan Baker, "is that the elevators at the bottom of the rudder are providing vertical force, and they keep the boat level, basically giving pitch to the boat. The rudder is a long shaft with an elevator at the bottom, which is basically an upside-down T-section."

The boats have gone from hydrodynamic experiments, dragging scale-model hulls around in test tanks, to all-out flying machines. Says Baker, "Unfortunately, given the speeds and scale that we are working with, we are pretty much relying mostly upon computational fluid dynamics for our solutions. One thing we kind of toyed around with is making scale models to wind-tunnel test the windage, which is one thing we did with BMW. They made the little model of it and stuck it in the wind tunnel with one of our aerodynamicists there for that. Another thing that BMW has helped us out with is that they've been writing aero drag calculations, as one of the places that is pretty draggy is the platform; think of it kind of like a bobsled-type problem, where you have an open cockpit and the breeze is coming over the deck at 40 or 50 knots. So you are trying to seal up as much as you can and make it as aero-streamlined as you can."

It wasn't many America's Cups ago that the crew moved to sitting on the floor to keep them out of the airstream on the windward side of the hull. Now, with the current generation of water-based aircraft, crew-positioning is a high-tech art in itself. Says Baker, "Ideally, if you had everybody hiking together, the front guy would take the brunt of the aero load, and the rest of it would be almost for free [aerodynamically], but that is where you'd get the righting moment. But there is a pretty big safety concern with hanging most of the crew off the side of the boat—not to mention that they also need to be generating oil, energy in the hydraulics, so they need to be grinding all the time."

Hydraulic systems are extensive throughout the modern AC boat. "All of our surfaces are pretty much actuated in part by hydraulics. Starting with the aero wing [the mainsail], the amount of twist that is in the actual shape is hydraulically driven. Some teams have gone to hydraulic main sheets, so there is no longer a winch or any real rope used to pull in the wing. The jib is on a hydraulic ram, so that is sheeted by hydraulics. As you go down into the hydro packages, the dagger board is changing its angle by hydraulic actuators, as are the rake of the rudders and the tiller-driven system for the steering."

Interestingly, the New Zealanders famously took the Cup this year through the use of pedaling grinders; in fact, Simon van Velthooven, an Olympic cycling

medalist, was new to the yachting game; the America's Cup qualifiers were his introduction to sailboat racing!

Pedal grinders had their hands free for other tasks aboard *Aotearoa*. The maximum crew size is now six versus eleven previously, but not everybody is multitasking all the time on *Oracle*. "You've got four guys who are essentially in the bow of the boat just grinding the entire time," says Baker. Still, with only six crew members, most are multitasking. Peter Rusch [*Oracle*'s media rep] says, "The three front positions on the boat are grinders, with each responsible as well for things like moving boards up and down or in and out. The fourth spot back is the tactician, who faces forward and grinds a lot. Then there's the wing-trimmer, and finally at the back, the helmsman."

With all this furious grinding going on, there is obviously the need for a hydraulic energy-storage system, devices called *accumulators*. This system frees the grinders from being tied to a station during maneuvers, as the accumulators power the needed trim. "You can think of it as a big spring," says Baker. "They are constantly filling the accumulators with pressurized hydraulic oil. When the skipper commands for one of those control surfaces to move, that comes either from the grinding station or these accumulators."

Oracle Team USA / Sam Greenfield

Despite the name Team Oracle USA, the crew consisted of Aussies and Kiwis.

Current top speeds are around 46 knots. "The speeds are definitely wild," agrees Baker, "and we've been achieving things that are definitely amazing. We haven't gotten much past that [46] in terms of the top speed, but what is really impressive is that Bermuda is a lighter venue, but we are actually able to foil around the course in these lighter conditions. If you were to take the 72-foot boat [the San Francisco AC winner] and stick it in the water with the same conditions, we would end up lapping that thing."

Small wonder a technical partner is Airbus, because the Oracle AC50 is perhaps best equated to modern-day fighter planes, where the aerodynamics are so unstable that it requires a computer program to operate on that knife edge. "The more unstable you are, the more power you need, so the more energy you need to produce," says Baker.

So far, the America's Cup boats have not become an expensive exercise in artificial intelligence with a software program automatically operating the dagger boards, foils, elevators, and sail trim. "It has to be an open loop," says Baker. "The only way to close that loop is with a human by the rules. You are not allowed to sense ride height, you are not allowed to actuate the [dagger] boards off that."

Oracle's mainsail is a twin-masted affair. The front foil would be disturbed on exit by the proximity of that second mast—however, the trim is perpetually in a high-lift configuration similar to an aircraft on the runway. "It's a multi-element foil, where there is a gap that opens up between the flap and the main part of the wing," says Baker. "Downwind, we are really pushing on that as

Oracle Team USA / Sam Greenfield

Our Kiwis Can Beat Your Aussies!

Team New Zealand seemed to have an advantage throughout the trials, with heads-up match-racing by their helmsman—Olympic champion Peter Burling—flawless crew work, and the likely advantage of using cyclists on bicycle stations to pump up the hydraulics which operate virtually everything on a modern America's Cup racer. In the Challenger semis, Emirates Team New Zealand eliminated England's Ben Ainslie Racing/Land Rover BAR's *Rita*, 5–2, despite having pitch-poled *Aotearoa* in the pre-start of Race Four. Then they dispatched the Swedish boat *Artemis* in the Challenger Final, 5–2.

Oracle—crewed mainly by Australians—won the Qualifiers before the Challenger matches, which meant that *Aotearoa* started with a minus-1 score. It made zero difference: *Aotearoa* won five races before *Oracle* finally broke through with a win. Race Eight was telling, as a slow *Oracle* in the pre-start was attacked from leeward and luffed by Burling until *Oracle* was effectively parked. *Aotearoa* cracked off and accelerated toward the start line, and it was effectively game, set, match. In Race Nine, *Oracle* helmsman Jimmy Spithill did everything he could to win the start and hold off New Zealand to the first mark, but a quick tack and superior boat speed on the part of *Aotearoa* sealed the regatta.

It was the second time that the USA had lost the America's Cup to New Zealand; Peter Blake, Russell Coutts, and Team New Zealand sailed *Black Magic* to a dominant sweep of the '95 Cup finals in San Diego. In a final sad twist of irony to the 2017 regatta, the brilliant designer of *Black Magic*, San Diego's Doug Peterson, died on the day that New Zealand once again won the Cup from the USA.—*Norm DeWitt*

hard as we can, and when we are going upwind, we are twisting our flap off so that the top part of the wing is actually pushing the other way, and you get some inversion in the load. Unlike a conventional sail that would luff, ours actually can take the force, as it's a hard element, so there is no luffing, and you actually get a slight amount of restoring moment at the top of the rig."

That the new AC50 boats can now foil through all maneuvers is somewhat mind-numbing. "We are fully foiling upwind, and we are never really touching down anymore, which is pretty wild," says Baker. The only time a boat is allowed to have all four foils down in the water is for a few seconds prior to a maneuver, such as a jibe or a tack. "It's still an evolution we are going through trying to understand exactly how to do it quickly and better. The energy and work when you are doing that maneuver—it requires moving things quite a bit, and requires a lot of oil."

Surface finishes have a very tight specification, and the days of getting a finish with 600-grit sandpaper and calling it good are long gone. Again, as with aircraft, boundary-layer manipulation of the surface is a science in itself, first outlawed on the AC72 boats in San Francisco. "There are a lot of different ways you can interact with the boundary layer on a surface," says Baker. "There are polymers you can inject into the flow that will speed you up, there are rivulets you can add that will interact with that boundary layer to reduce the drag. The goal with the rule has been to eliminate cost from all those avenues you can explore on reducing shear drag, experimenting with all kinds of things."

As with racing cars, the relationship between the center of pressure aerodynamically and the center of gravity have a big effect upon how "snappy" the response is to the helm. "Those are actually pretty close to each other," says Baker, "so I can tell you for a fact that the amount of yaw or how fast they can turn the boat through a turn is very fast. The center of mass is pretty close to that as well; that mass is not distributed across the boat, and the heavier items are all close to the middle."

And what of Sir Ben Ainslie, the former *Oracle* tactician from the AC72 win in San Francisco? He had his own challenge boat, *Rita*, sponsored by Land Rover, trying to bring the America's Cup to England for the first time—with Andy Claughton leading the design team and some of the best minds from the ranks of England's Formula 1 industry, including Martin Whitmarsh (formerly with McLaren) and Adrian Newey, the design wizard responsible for countless victories. "I did lots of work early on," says Newey, "but I kind of got involved in Formula 1. I was doing lots of early simulator work and some ideas, but it sort of petered out."

That was good news for fans of *Oracle* or BMW—but it wasn't enough to beat the Kiwis in Bermuda.

Grinders are a vital element of yacht-racing, cranking with both hands.