Gomboc: A design high-flier for ETNZ

By Ivor Wilkins

Among the many talents and skills brought to bear on the design and development of Emirates Team New Zealand's winning boat for the 35th America's Cup was an extremely valuable but highly secret contributor called Gomboc.

Wikipedia devotes considerable space to guiding us through the arcane world of physics and mathematics to define a notion first imagined in 1995 by Russian mathematician Vladimir Arnold.

However, Dan Bernasconi, who presided over ETNZ's design brains trust, obliges with a simplified definition: "Gomboc is the name of a mathematical shape which has exactly two positions of equilibrium, one of which is stable and the other is unstable."

In the world of foiling, the search is for equilibrium against an array of forces constantly threatening instability. Appropriately then, Gomboc was the name given to a highly sophisticated in-house software program aimed at overcoming those hostile forces and achieving the high-speed equilibrium that enabled the team to soar to victory.

In the post-match euphoria of the triumph in Bermuda, skipper Glenn Ashby said, "We knew we had to be extremely innovative and aggressive with our design philosophy. We knew we would have to risk big to win the America's Cup."

That aggression applied across the board to create the features that distinguished the Kiwi campaign, including the cycling system, appendages and foil and wing control systems.

Reinforcing that aggression concept, team managing director Grant Dalton added: "We knew we couldn't outspend them, so we had to out-think them. We had a saying that we wanted to throw the design ball out as far as we could and see if we could get to it."

Crucially, stretching the performance frontier had the full endorsement of Ashby, Peter Burling, Blair Tuke, Ray Davies and the rest of the sailing team. It came to rule every decision across the boat. Once adopted, decisions were pursued with total commitment.

With hydraulic demand at a premium, for example, the cycling decision was adopted early and Ashby refused to employ grinders to prevent any threat of reverting to traditional thinking. As an aside, Bernasconi revealed that the cycle system, which proved so beneficial not just in delivering more power but in freeing more hands to help control the boat, might have gone even more radical.

The team looked hard at having the cyclist lie prone to further reduce windage, but just could not find the space to make that work. There was also concern that in Bermuda's tropical conditions, the cycle-grinders could overheat if they were completely out of the airflow.

In identifying where the biggest design opportunities lay it was clear that foiling would occupy the most attention. "The trade-off with foiling," says Bernasconi,
is between a boat that is easy to sail but slower, versus a boat that is hard to sail, but can deliver more performance. We took a decision right at the beginning that we would ignore the easy-to-sail options and would go all-out for performance.”

Traditional reliance on VPP gave way to a much more complex analysis of performance – taking account of the wide range of dynamics that come into play when yachts engage in close combat.

“VPP tends to push you down an optimal path of straightline speed. We used VPP remarkably little in this campaign and put much more emphasis on measuring how fast you could get the boat around the track, taking account of acceleration, manoeuvres and so on.”

Perhaps reflecting Bernasconi’s background in Formula One, lap times trumped straightline speed. The lap time approach forced a global consideration of everything on the boat – the appendages, appendage control system, wing control, crew functions, hydraulic demand.

“Gomboc was the key to predicting lap times. It is a combination of a VPP, real-time simulation and an appendage design package,” Bernasconi explains. “From a hydrodynamics design point of view, 90% of the America’s Cup is about developing the best analytical tools. In the end, whoever has the tools that most accurately predict lap times is going to be able to produce the best boat.

“A huge effort on the performance side of the design team is devoted to developing those tools. The actual shape of a foil comes very late in the process. Months of investigation and analysis take place before the final foil shape is produced just days before the build deadline.

“Making sure the tools are telling the truth is where the big effort is required.”

Operating in a largely virtual realm, how is accuracy assured? “A lot comes back to the first principles of the physics. That is our job as engineers, to make sure we are modelling the important aspects well. That is something which is always developing.

“When we started this years ago we would model a foil shape with simple lift and drag characteristics at various sections along a rigid structure. Then later, we were able to model how the foil would bend and twist under load, how it would be affected by stall at low speeds and by cavitation at high speeds, how the flow of the wake from the foil would affect the rudder.”

Bernasconi started developing the early version of Gomboc in the aftermath of the Deed of Gift Match in 2010. He was part of Ernesto Bertarelli’s design team and, with time on his hands following the match defeat, thought he would turn his attention to developing software that would hopefully be useful in the future.

Since then, with inputs from design team members and others, it has undergone considerable refinement with full-scale validation and experimental testing. “You can look at the real loads on the foil through fibre optics and compare them with the prediction. The same with take-off speeds versus prediction, and angles of attack; for example, when you are sailing at 32 knots, is the rake angle the same as the simulator predicted?

“There are lots of avenues to explore. When you see something that doesn’t match, you hunt it down and figure it out and improve the simulation.”

For the 2017 campaign, the tools were pretty well advanced and improved further.
through the process. “We developed a pretty full tool set for analysing and modelling foils. The appendage group of Bobby Kleinschmidt, Guillaume Verdier and Nick Hutchins collaborated closely with other designers and sailors to feed shapes and structures into those tools and simulations.

“We also used commercial RANS and FEA programs for more detailed evaluation of fluid flow and structure, but the primary design tool was the in-house simulation software.”

The first test of the process came when, at last, the sailors could move off the simulators and onto sailing the test platform. Their verdict? “Pretty good,” says Bernasconi modestly. “The comments from the sailors after we launched Boat One was it was just like sailing the simulator.”

That was only the beginning, however. “If you looked at the foils on our test boat, you can see continuing development. The foils which with which we won the America’s Cup – we called them seven and eight – were considerably different from the test foils.

“That showed confidence in our tools, because those would become one of only two pairs of race foils. To commit to them, even though they were quite different from anything we had actually sailed with, did require great confidence in our simulation that they would be sailable and fast.

“How we got there was a process of multiple iterations. For the five test foils and four race foils we had on the water, we must have done laps on the simulator of at least 500 test foils and 400 race foils.

“That is the beauty of simulation. It takes only five minutes to try a new shape.”

With the sailors driving the simulators, they could also contribute ideas about foils which could be quickly run through the program.

“As designers we were lucky to have the sailors we did have. They were fully supportive about pushing the process as hard as possible. We did run tests on some shapes that were completely uncontrollable, but in the end we arrived at foils that had very little compromise in performance and were controllable.”

The end result was the sharply angular foil shape quite different from the rest of the fleet and reckoned to have about 20% less surface area than Oracle’s. This area reduction was achieved by using higher aspect-ratio foils with shorter chord lengths – something Oracle tried to move towards by modifying their foils in the five-day break between the first and second Match weekends.

Having opted for very high performance foils, the next challenge was getting the most out of them on the water. Here the design team came up with a fully automated test system where computers flew the boat on an autopilot named Polo.

“This was useful to prove where we could get to with control of the foils, to set the bar if you like. The sailors could see what the computer could achieve and challenge themselves to match it.”

And to a large extent they did. “Through the manoeuvres, the sailors could actually do a better job, but in a straight line the computers had a slight advantage. They have a higher control bandwidth than humans, which gives them more instantaneous reactions.”

For racing, of course, automated systems were outlawed, so the team had to develop manual controls and techniques to replicate as closely as possible the automated performance.

Important as the foils and their control systems were, they were only one brick in the wall and the task for the team was to integrate all the elements into a coherent package. The hydraulic wing control system and the method of trimming for twist played a significant role as did rudders and elevators, which represented a late part of the ETNZ development.

A lot of development went into maximising the 3° rudder rake differential which enabled the windward rudder to exert considerable downforce, adding to the righting moment of the boat. On arriving in Bermuda, ETNZ spotted that Oracle were sailing with slack lower shrouds and soon realised that this would allow the hull platform to twist more under load, dropping the windward bow and consequently increasing the rudder rake by as much as 0.5° – enough for a significant increase in righting moment.

Reconnaissance photos of the Oracle boat confirmed this increased ‘racking’, and a war of words ensued between the teams and the Measurement Committee: a Class Rule interpretation initially stated that sailing with slack lowers was not permitted, but this decision was later reversed, meaning ETNZ would have to match Oracle to remain competitive.

“We needed to strengthen our wing-spar to allow us to sail without the support of the lowers, and had planned to start work reinforcing the spare wing,” explained Bernasconi. “Then we capsized, and suddenly we needed that spare wing on the water, delaying the modification programme. In the end, we first sailed with the reinforced wing and slack lowers
Between arriving in Bermuda and racing in the match, the team’s performance improved by a massive 5-10% – close to two minutes faster round the track ...

only the day before the Match – and were learning about the limits from then on.”

The race rudders, like the foils, were quite extreme, very low drag with elevators that could twist under load. “The elevators are highly loaded areas. If you can design appendages to deform under load in the direction you want them to move, there is performance potential to be gained.

“We came quite late into our rudder and elevator development. Most of the development of the test boat was around foils rather than rudders, which meant we did not have a lot of opportunity to get our rudder and elevator combinations right. In fact, if our race rudders had not worked out, we would not have had a second chance to get them right. In the event, however, they made a big difference.” Another feather in Gomboc’s cap.

In any design narrative one hopes for a eureka moment when the gods offer a surprise gift out of the blue. Bernasconi shakes his head sadly. “It was more a case of believing in the tools and being prepared to spend significant R&D looking at options.”

If the gods did offer some assistance, it was in the weather. The ETNZ package worked well across the wind range, but seemed most potent in the light-medium wind range, about 7 to 12 knots. For once, the reality matched the statistics and Bermuda lived up to June expectations. “This time round, the wind gods paid back what they took from us in San Francisco.”

More importantly, from lessons learned in San Francisco an early commitment was made to pursuing improvement all the way to the end and they achieved that. Bernasconi believes the team, as it was when it arrived in Bermuda – long after most of the others and having spent the New Zealand summer training alone – would not have had much chance of winning the Cup.

“The performance gain in Bermuda in terms of competitiveness was a big number, somewhere between 5-10%. A 10% performance gain in a 20-minute race is two minutes faster. That is massive.

“The boat developed during that time in Bermuda, but more significantly, the sailors got extremely good at working out how to get the best out of the boat.”

For Bernasconi, who admits to being a jittery spectator during racing, the sweetest moment came in the first downwind leg of the final race of the Match. Trailing off the startline, ETNZ rounded Mark One behind Oracle and then surprised the Americans with what the team called a “no-look gybe”. This involved gybing the boat with nobody signalling the intent by moving across the boat.

“To be able to control the wing, the foil drop and the rake without anybody crossing to the other side – and then to soak lower and faster on the foils to overtake – embodied everything our unique set-up allowed us to do. It was a very sweet moment.”