That final millimetre

After 30 years' developing bespoke CFD tools and applying them to the design of an impressive range of craft from IACC America's Cup yachts to commercial hydrofoils, yacht designer and ACT Technologies co-founder Akihiro Kanai took particular pleasure in watching the successful results of his handiwork at a smaller scale, first at the Tokyo 2020 Regatta in Enoshima and then in Marseille at Paris 2024

In 1990 my first serious encounter with Computational Fluid Dynamics (CFD) was a free-surface flow simulation around the stern of a high-speed hydrofoil catamaran, which I undertook as a postgraduate student.

At that time a typical workstation had only 100MB of memory and 32-bit CPUs. Even so, and running at what would today be described as a snail's pace, it was a big step forward to have this new tool to evaluate the performance of a vessel; even 35 years ago it was clear that, moving forwards, researching and developing CFD codes was going to become essential for designers to be able to design marine craft to the level of optimisation that would soon be expected. But not just yet… because back then the reality was that there were very few commercial codes available.

Two years later, in 1992, I continued my CFD research at Stanford University, but CFD remained a rather esoteric and experimental genre. The CFD 'journey' as we look at it today had still barely started.

That situation would change suddenly in 1993 when I was called back to Japan for a new America's Cup project, which would be using CFD to the fullest extent possible from the outset to investigate hull and appendage solutions.

As far as I am aware this Japanese Cup programme was one of the first serious applications of CFD to real-world marine vessel design. Since then, of course, countless CFD codes have been developed around the world and CFD tools have become an unremarkable component of such work. Here I will review some of my own work and experiences in the CFD field.

ACC America's Cup monohulls

In the 1990s CFD capable of handling free surface calculations began to be used for the development of International America's Cup Class (IACC) hulls, with such CFD codes also being developed with accelerating intensity at research institutions and universities around the world. The Nippon Challenge, of which I was a member, was no exception with development conducted at universities being quickly applied to our own design tasks.

The CFD we used at that time calculated sail forces based on given wind speeds and directions through sail models, with the hull's attitude changed to balance the forces acting on the hull calculated by the free surface analysis around the hull.

This CFD model was quite challenging for its time. During the project hull designs and simulated tank-testing were repeatedly evaluated using CFD, which as far as possible was then physically validated in the actual tank to test for accuracy. Ten years later, in 2003, this same basic CFD code was still being used in updated form by the GBR Challenge in New Zealand.

In parallel with our new CFD tools, dedicated software was developed to automatically generate candidate ACC hull shapes which were then evaluated in the CFD tool. To the best of my knowledge this early combination of CFD and design software allowed us to progress design development much faster than had been seen in previous Cup programmes.

Opposite: Silver medallists Keiju Okada and Miho Yoshioka went to the Paris 2024 Olympic regatta as reigning world champions in the Mixed 470 class, their latest Pearson hull and foils benefiting from detailed CFD and tank studies by the author's ACT Technologies. The now married Japanese pair had competed separately at several previous Olympic regattas in the 470, in the Women's and Men's categories. Like the Finn and Flying Dutchman classes, the 470 one-design class rules incorporate just enough by way of tolerances in design and build to ensure development never ceases to be a hot topic. Funky new Snipe bow treatment (_above_), again from ACT

Commercial vessels

CFD for commercial ships began to be applied around the same time as for racing yachts. Since there are no significant changes in the hull's attitude as seen in yachts, calculations are typically performed more quickly and with the ship in an upright position. However, self-propulsion calculations must now be introduced to account for the resistance increase due to propeller rotation, as well as the propeller efficiency itself as affected by the ship's stern wake. Even if hull resistance is low, poor self-propulsion characteristics can lead to higher power requirements, so a design balancing resistance and self-propulsion elements is necessary.

According to the IMO regulations that came into effect on 1 January 2013, vessels that entered new construction contracts on or after this date or those delivered on or after 1 July 2015 must meet the Energy Efficiency Design Index (EEDI) requirements which specify the maximum allowed CO_2 emissions per ton-mile of cargo for different types of ships.

Post-2018 EEDI Phase 2 required a 20% reduction from the previous reference line, and a 30% reduction is required from 2025. Consequently, the importance of CFD is increasing as ship design optimisation and fuel efficiency technologies are actively developed. Previously CFD development focused primarily on model-scale tank testing but, as with some well-known scaling issues in yacht design, critical discrepancies between estimated and actual power requirements for full-scale ships have also arisen. However, with the latest advancements in computing power, CFD development modelled at full-scale is now also beginning to be within reach.

Wind-assisted commercial vessels

In response to EEDI regulations, projects utilising traditional sailing technologies have become increasingly common over the past decade. One such project I am involved in is called Wind Challenger, which involves equipping commercial ships with rigid sails approximately 50m in height, reducing fuel consumption by measurable worthwhile amounts.

The 'sails' are equipped with a telescoping mechanism that allows them to extend and retract vertically for reefing and storage. Additionally, we succeeded in developing a crescent-shaped cross-section profile which enhances lift by allowing a larger camber. This enables the single wing to generate lift comparable to a wing with flaps.

Using multiple rigid sails, the interference between the sails in the fore and aft axis is significant. Therefore, it is crucial to find the optimal sail angle for each wind direction (AWA) to achieve best performance, which again we determine using CFD. The forces estimated from the sails and the forces on the hull and rudder below the waterline must of course balance out, which in turn determines the hull's drift (leeway) angle, rudder angle, speed and fuel consumption.

A program similar to a yacht VPP is now required, which we named the Energy Prediction Program (EEP). This calculates performance for various wind directions and speeds, allowing accurate estimations of fuel savings using a routeing program tailored to common commercial routes.

We are currently also working with another project, Wind Hunter, which further extends applications of rigid sails. This involves a ship powered solely by wind, with a turbine installed underwater to generate electricity and produce hydrogen. The generated hydrogen is stored by combining it with toluene. When the storage is full the ship returns to port to unload the tank and then heads to another location with wind ▷

power to continue hydrogen production.

This ship is essentially a sailing yacht but tasked with hydrogen production. As with racing yachts, minimising resistance and maximising driving force and sail propulsion are crucial, making the successful optimisation of the hull design, sail size and configuration crucial. Without modern CFD tools it is unlikely that such a novel solution would even be worth pursuing.

Hydrofoil catamarans

Foiling technology, such as that used in the AC75, has garnered significant attention in sailing, with new foiling designs sprouting up in every direction. Using 100% foiling – where all the weight of the vessel is supported by lift – requires very precise control of the foils, but offers the advantage of substantial resistance reduction. For large, high-speed passenger ferries, however, increased weight leads to higher loads on the foils and cavitation issues, making it challenging to achieve 100% foiling.

The hydrofoil catamaran we are currently working on is a hybrid high-speed passenger ferry that relies on lift for about half of its support and buoyancy for the other half. This approach allows for much simpler foil control compared to 100% foiling and also reduces the risk of major accidents, enhancing safety. Inevitably, due to the wave-making of the hull, the resistance is greater than with 100% foiling, making hull and foil shape optimisation crucial, with CFD once again being indispensable.

Additionally, stability in waves can now be verified through CFD which marks an important step forward in the technology.

Racing yachts and dinghies

As late as 2004 my involvement in sailing craft was still essentially limited to my work in the America's Cup. Since then, however, I have been able to focus on a broader range of racing keelboats and dinghies. Given that racing yachts always attract attention for their performance, I find it very rewarding to enhance their potential using the latest tools available, CFD always delivering a compelling case for good design decisions.

The original CFD code used for IACC boat development holds many memories. Whether it was those times when it failed to deliver good results, despite numerous attempts, or moments when it produced a hull design that made a significant leap forward, it was always there underpinning everything we worked on.

More recently, as that original code became inadequate functionally, I have switched to using the commercial code FineMarine. This is used to model hulls with appendages, and to simulate planing plus more complicated shapes and conditions. It also supports VPP model calculations, enabling more accurate VPP analysis.

Our own original VPP uses a unique sail trim model, which deforms the shape of the jib and mainsail using parameters including depth, twist and traveller positions, with sail forces modelled by CFD for the VPP. This model can now reliably reproduce optimal trim conditions for each wind speed and direction on the VPP. This enables estimation of values closer to actual sailing conditions than general VPPs.

Racing yachts are created using each designer's best logical and scientific methods. Each designer pours their own thoughts and passion into their respective vessels. Hence my own most recent design – the 36ft *Samurai 2* – represented the culmination of some 30 years of work. Similarly, however, I have been applying the same dedication to dinghy and small craft development, with a particular fondness for the Snipe and 470 classes.

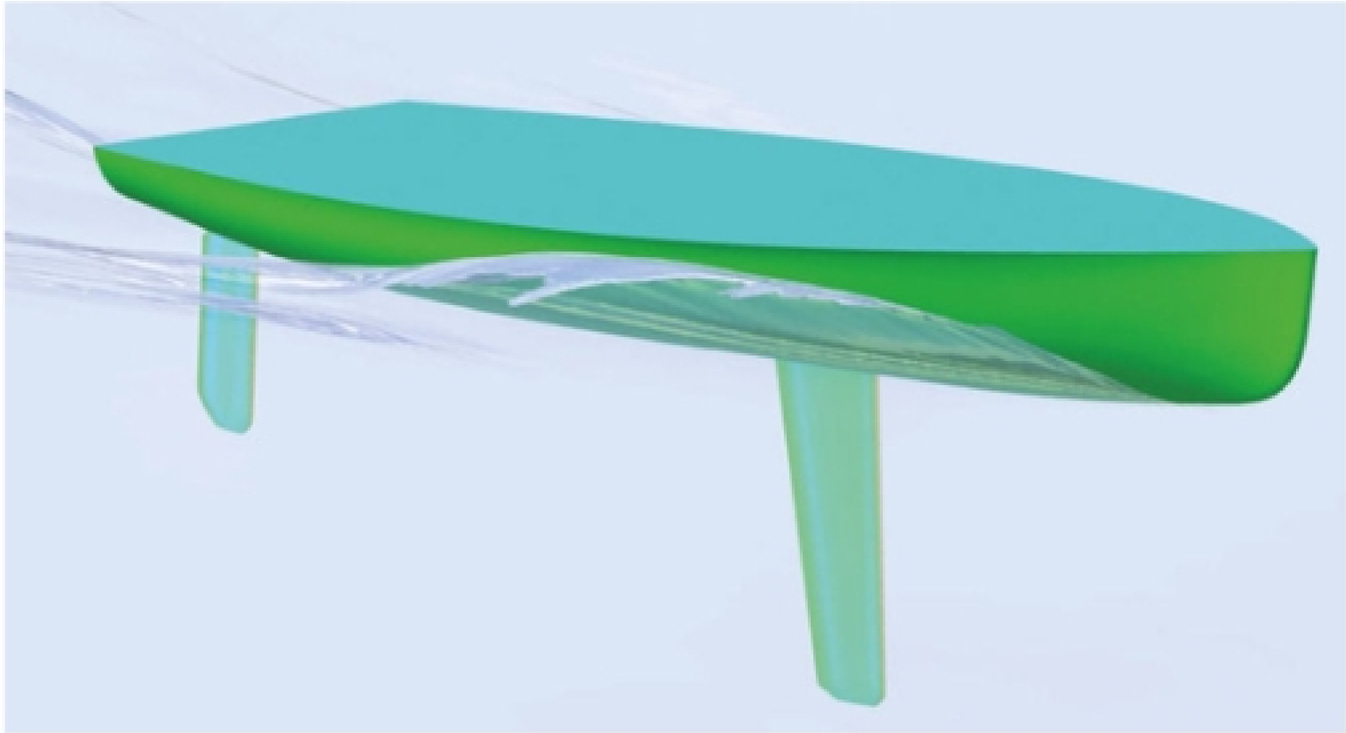
For both the primary goal of my projects was to develop new hull shapes with minimal resistance within the constraints of the class rules. For the 470, by conducting numerous CFD simulations under various conditions, we achieved what we measured to be a drag reduction of up to 3% in some conditions compared to previous 'designs'. We also improved performance in waves and manoeuvrability, allowing the boat to handle more efficiently.

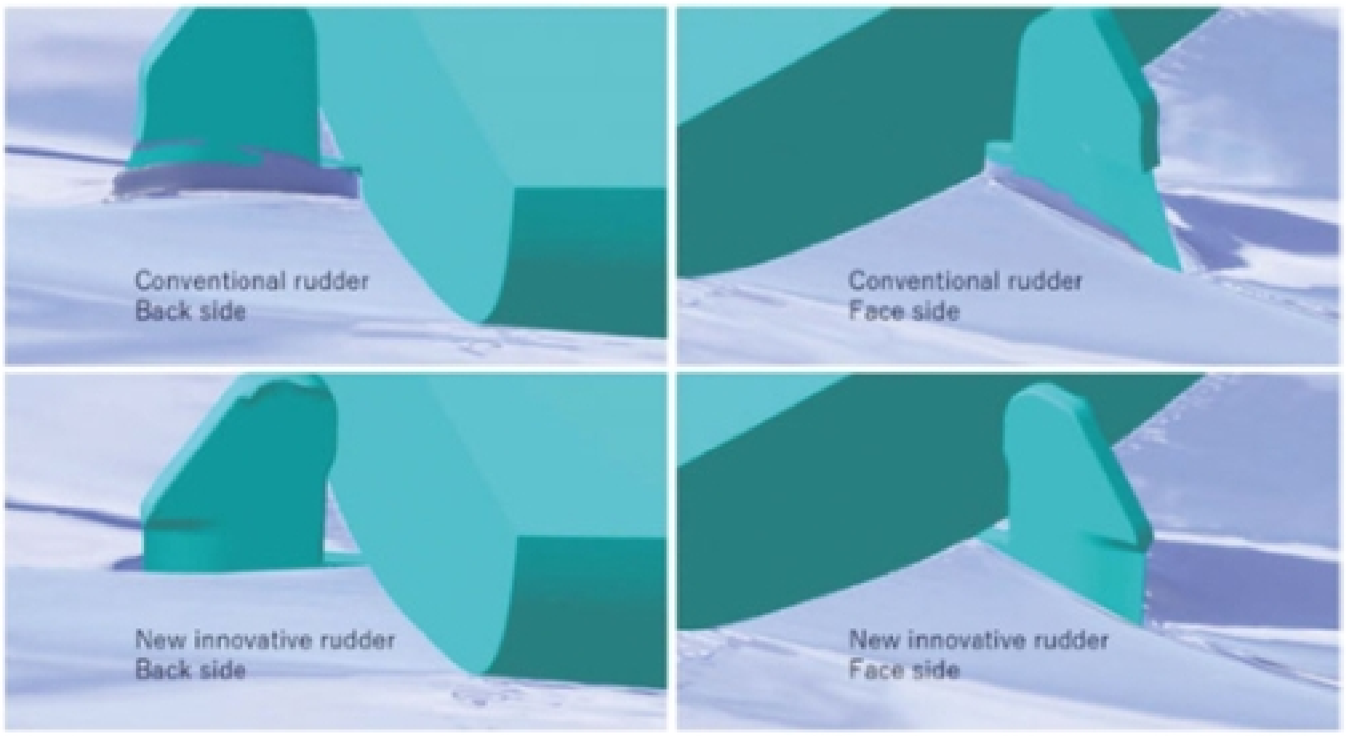
For the Snipe, using CFD we also studied aerodynamic performance, resulting in a new cut-away shape for the foredeck gunwale that does not contravene the rules.

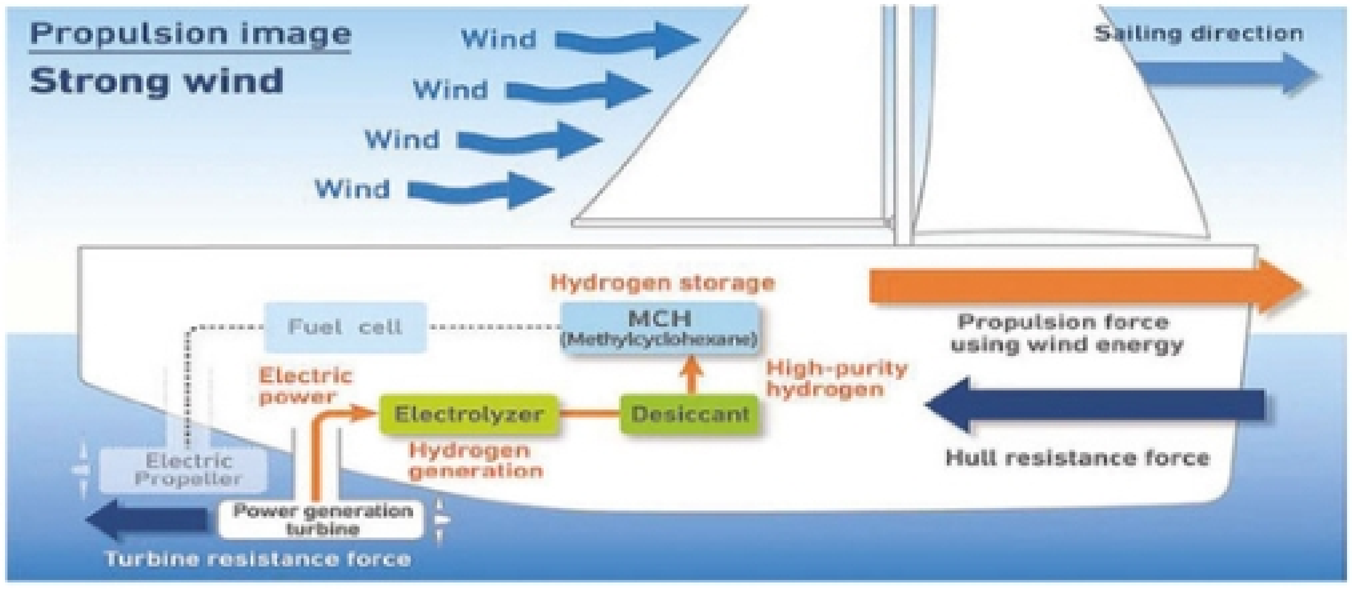
For our latest improved 470, we also developed a radically different rudder shape, where the leading edge is slightly tucked in beneath the hull (Europe class sailors will quickly recognise the configuration). This modification proved able to smooth out waves coming off the transom, resulting in a significantly cleaner flow compared to the waves generated by conventional rudder designs, resulting in a further reduction in drag.

Of course we always need to prove our ideas in 'real life' at full scale, and in the case of the two dinghy classes discussed

Opposite: two more happy customers. Australians Mat Belcher and Will Ryan have just secured their long-overdue gold medal in the Men's 470 at Enoshima in 2021 using a new 470 rudder (*left/below*) from Akihiro Kanai's ACT Technologies. Wind Challenger (*above*) is one of the two current wind-assist commercial shipping projects in which ACT is involved; the crescent aero-profile of the telescoping 'wings' in this system diverging from the majority of rival wind-assist with their quasi-traditional solid sails or spinning Flettner rotors – the crescent shape being explored for the better driving force it has demonstrated at narrower true wind angles. And the Wind Hunter system (*below*) – an ambitious and imaginative solution for turning wind into hydrogen for use in fuel cells and other applications







here the results to date have been extremely gratifying.

Our innovative rudder concept for the 470 first went public when it was used by Australia's 2020 Tokyo Olympic gold medallists Matthew Belcher and Will Ryan; significantly, much of their technical preparation for Tokyo was overseen by former skiff champion, America's Cup skipper and yacht designer Iain Murray, who has a formidable grasp of all things performance related. More recently our 470 rudder and our modified 470 hull were employed by the Japanese team of Okada and Yoshioka who took a silver medal at the 2024 Paris Olympics.

As we have touched on in this brief article, CFD now makes a positive contribution in the design of almost every type of marine vessel. CFD will be increasingly used in the development of future new technologies and it already offers solutions for commercial ships to save fuel.

In the realm of racing yachts and large cruising and superyachts, CFD can increasingly simulate complete vessels, rigs, sails and underwater appendages, and I believe that in due course it will almost entirely replace the 'traditional VPP'.

Then again could there come a time when AI controls everything, making designers themselves obsolete? ❑