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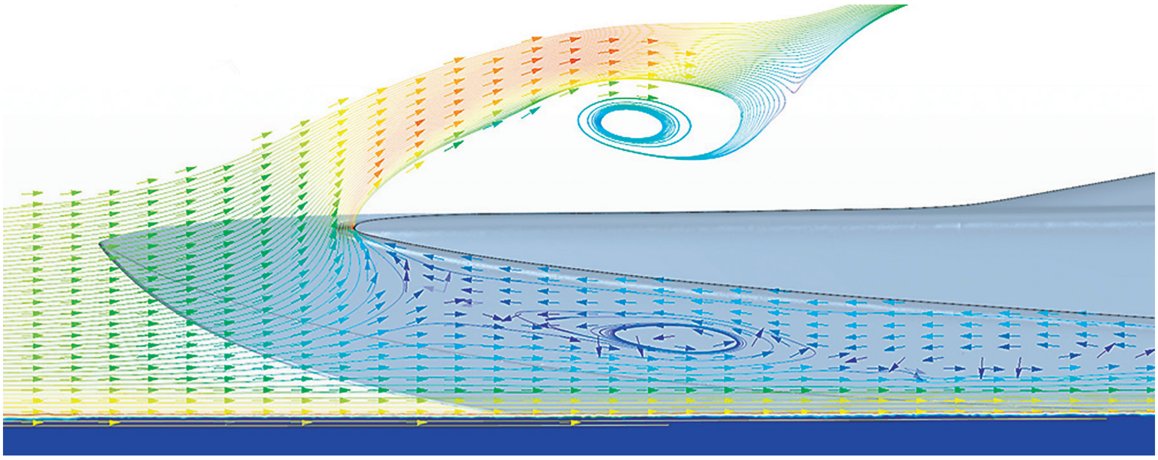
REFINING A HIGH-SPEED CAT, PART 2
CREATING THE LONGTAIL 30
A FOIL SHOP IN FRANCE
SHORE POWER, PART 1

Accommodating Higher Power

Part 2: Aerodynamics



COURTESY TOTALSIM

CFD analysis of hull aerodynamics holds the potential to answer many performance questions, including the cause of an infamous side-by-side blow-over of identical high-performance catamarans during competition in Key West in 2019.

by Clay Ratcliffe

> *In Part 1 of our series "Accommodating Higher Power" (Professional BoatBuilder No. 191) we explored a case study of hull refinement and the practical application of recent advances in computer modeling to the art and science of hydrodynamics. Looking back at the traditions of modern boat manufacturing, we delved into bottom design, old-school versus new-school tooling methods, and learned how builders can update trusted hulls with improved running surfaces.*
>
> *Here in Part 2 we'll look at aerodynamics—making improvements above the waterline.* —*Ed.*

Eighty percent of the surface of a standard high-performance monohull or catamaran is out of the water, running through air. I remember as a kid putting my arm out the rear window of our car, twisting my hand right and left, and feeling lift and downforce for the first time. We all have experienced that exercise, and the aerodynamic laws we learned as kids hold true with any object surrounded by air. As boat designers and builders, how much attention do we give to that 80% of the hull surface, and how important is it?

Our Part 1 hydrodynamics case study vessel was a 32′ (9.75m) Doug Wright Designs open-cockpit catamaran. We performed what CAD designers call reverse engineering. We started with an object in completed form, but we didn't have modern triangulated point-to-point computerized coordinates to form a CAD file. Thus, with the aid of FARO Technologies (Lake Mary, Florida) we scanned the entire vessel to an accuracy of 0.004″ (0.1mm). Then, with the help of Dimensional Engineering (Houston, Texas), we transformed the raw data into a full-mesh watertight stereolithography (STL) file suitable for the next step: computational fluid dynamics (CFD) modeling of the hull's hydrodynamics and aerodynamics.

Above—*Computational fluid dynamics (CFD) modeling of the aerodynamics of a Doug Wright Designs 32' (9.75m) high-speed catamaran revealed that while it ran at 100 mph, air compressed between the hulls, deck, and water was creating a backflow high in the tunnel and leaking out the front to mix with the airflow over the deck.*

COURTESY PORTA PERFORMANCE

When these boats are flying, as they frequently do during competition, tunnel pressure is released but must be quickly and smoothly reestablished when the boat recontacts the water. The risks are that while airborne the boats will either catch too much air and flip over backward or bury the bow when they land right-side up.

See the Air

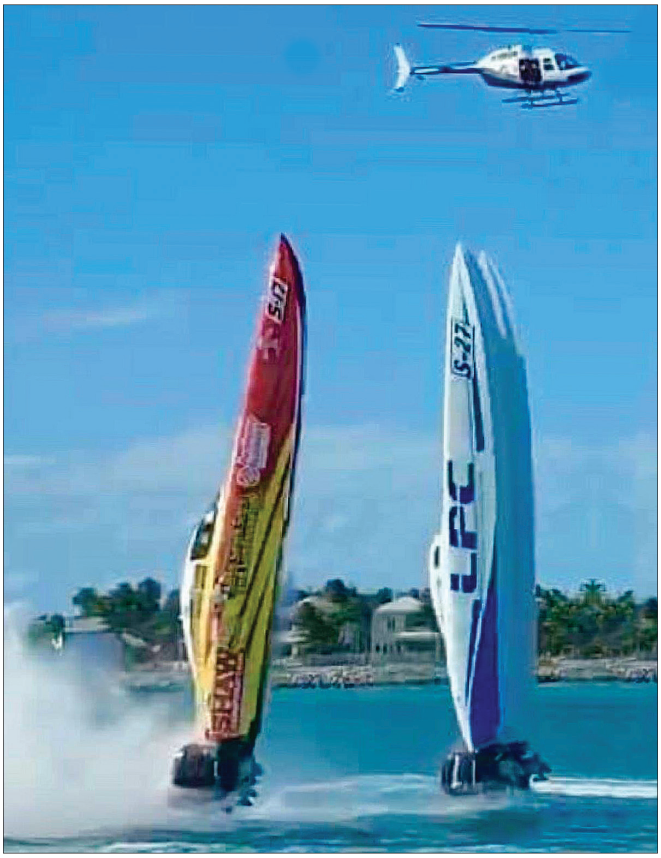
Before working in performance boats, I was in auto racing and a fan of Dale Earnhardt. He often said he could "see the air" as he entered the corner. I remember watching him come in from the first 100 miles (161 km) of a Super Speedway at Talladega slouched down in the seat, five-point harness loosened, his hands loosely grasping two rungs of the steering wheel. He asked for 1.5 lbs (1.5 psi/0.1 bar) in the right-side tires and half a turn on the left rear suspension. He was conducting seat-of-the-pants "tuning," because he could see (and feel) the air and the dynamics it had on an object slicing through it at 200 mph (322 kmh) on the back straight. Granted, in a boat we are aware not only of primary forces coming from the right and the left like a race car on a twisty high-speed road course but also oncoming waves, quartering seas, winds from all directions, and shifting loads that can move the center of gravity. But with 80% of the boat's surface area in the air, let's look at how we can "see" the air and modify it to enhance boat performance, efficiency, and safety.

From a camera's point of view at the water's surface it is easy to see that when traveling at speed, a high-performance catamaran is barely in the water. The weight supported by the water is close to zero, meaning the boat is actually "flying" on a cushion of air.

Headwinds and turbulent wave structures launch the high-speed catamaran and make it airborne often more than 50% of its operational duty cycle. Once the vessel launches, all the hydrodynamic hull design we refined in Part 1 is of little consequence until the next impact with the water. With engines mounted at the aft extremity of the boat momentarily unsupported by water, the stern drops, the bow rises, and the boat becomes an airplane in stall mode without the benefit of wings, ailerons, flaps, or other controls. If it doesn't flip over backward, it then crashes back into the water transom first, tripping, and then risking stuffing the bow torpedo fashion in the wave ahead of it.

Key West World Championships

During the last Race World Offshore World Championships in Key West (November 6, 2019), an unexpected and unfortunate incident occurred in the Super Stock class race. Boat owners Bill Allen (Allen Lawn Care Race Team) and Loren Peters (Loren Peters Racing) were running side by



COURTESY PORTA PERFORMANCE

This simultaneous side-by-side blow-over during competition in 2019 got the attention of the crowd and led driver Scott Porta, who was racing just ahead of the accident, to pursue CFD analysis of the dynamics between the two boats running at speed.

side in two equally designed Doug Wright 32′ race-prepared catamarans when they simultaneously flipped 180°, bow over stern. The accidental “blow-over” appeared to be choreographed. Fortunately, no one was injured, but many on the race course that day wondered how two boats running side by side could instantly go from running on a horizontal plane to vertical and then back to horizontal in a split second.

For the drivers, the experience was unbelievably fast and nearly indecipherable as far as aerodynamic analysis goes. Bill Allen (owner/throttleman, Allen Lawn Care Racing) recalled it like this: “I was a little short on room, and I don’t know if they didn’t know I was there or what…. I think, you know, that we got together, and it blew over. So, at the time that we made initial contact, we were at 106 mph. But I can say this, I guess in a boat race when you bump, stuff goes crazy.”

Loren Peters (owner/throttleman, LPC Racing): “Billy Allen was coming up on the starboard side.… I scooted over a little and Billy did the same thing. All of a sudden, we’re right up next to each other. We were deck to deck. I see Billy going up, and right after that, I felt lift. My life flashed before my eyes. We went completely over in a split second.”

Scott Porta (owner/throttleman, Porta Performance) was throttling the catamaran just ahead. He describes the incident: “We were probably running 113 mph. The two boats just behind us were side by side trying to conduct a straightaway pass and positioning for the turn. These two [boats] naturally gathered up next to each other. The compressed tunnel air that normally escapes from under the sides of the boats was stopped when these guys got next to each other. The increased tunnel pressure easily pushed the bows up. Then the wind-drag and momentum took over. Think of it like when you try to slam a refrigerator door as hard as you can and the gasket traps the escaping air and prevents a hard closing of the door. The idea of boats gathering up next to each other and having a blow-over actually isn’t new and is common in single-engine tunnel boat racing. However, this may be a first for an offshore race.”

Porta’s ongoing efforts to refine the running surfaces of these Wright-designed catamarans for competition and recreational use were informed by this dramatic episode as well as by his own accumulated time behind the wheel on that model.

Porta: “Catamarans run on a cushion of air. There are physics issues we felt the need to address. With race and recreational cats running well over 100 mph, our mission has been to improve design: first, to create the largest possible margins for safety in turns and rough water; second, to design for softer landings to reduce driver fatigue and equipment failure; third, to reduce running surface drag for improved performance at lower trim angles. The resulting reduction in frontal area increases speed and stability while creating a larger window of safety. Aerodynamics is the next frontier to explore for the biggest possible untapped gains.”

To simulate the blow-over, we had two options: the conventional wind tunnel and model construction, or computational fluid dynamics (CFD). As in Part 1, CFD was the easy choice for obtaining results quickly and the ability to model subsequent design remedies. Again, we chose TotalSim US (Dublin, Ohio) as our technology partner.

Let’s review the particulars of the case study boat and the theoretical running conditions:

- Doug Wright 32′ wide-tunnel catamaran
- 5,000 lbs (2,268 kg) fully fueled, ready for passengers
- Twin Mercury 300XS engines (300 hp, approximately 600 lbs/272 kg each)
- Flat water
- Wind speed 0 mph
- Design speed 100+ mph (161+ kmh)

As speeds approach 100 mph, two primary dynamics contribute to lift and resultant speed on this model:

Engine lift—With a bullet-shaped gearcase and the X-dimension raised to a high level, a hydrodynamic phenomenon occurs. The half-submerged gearcase alone generates enough lift to carry the entire weight of the 600-lb outboard.

Hull lift—The shape of the catamaran tunnel captures and traps air between the sponsons, thus providing lift that supports most of the weight of the boat.

The CFD Assessment and Conclusion

Nathan Eagles, principal at TotalSim, and Scott Porta set out to see how the air currents at 100+ mph influence handling, speed, and efficiency of the catamaran. When Eagles saw the footage and spoke with Porta about the tandem liftoff at Key West, his immediate thought was to apply the tools and experience from other motorsports work to help explain why this happened and potentially develop some countermeasures that could reduce the risk of it reoccurring.

At the beginning of the project, Eagles offered a corollary: “Assessing safety and developing countermeasures to reduce the risks posed by aerodynamic forces when vehicles get outside their normal operating envelope is something the motorsports community has worked hard to address for many years. My initial foray was as head of CFD at the Williams F1 Formula One team, where I worked with the F.I.A. *[Fédération Internationale de l’Automobile, the sport’s governing body—Ed.]* to understand the forces acting on an F1 car as [it] pitched nose up, and at which angle the aero forces overpowered the weight and inertia forces.”

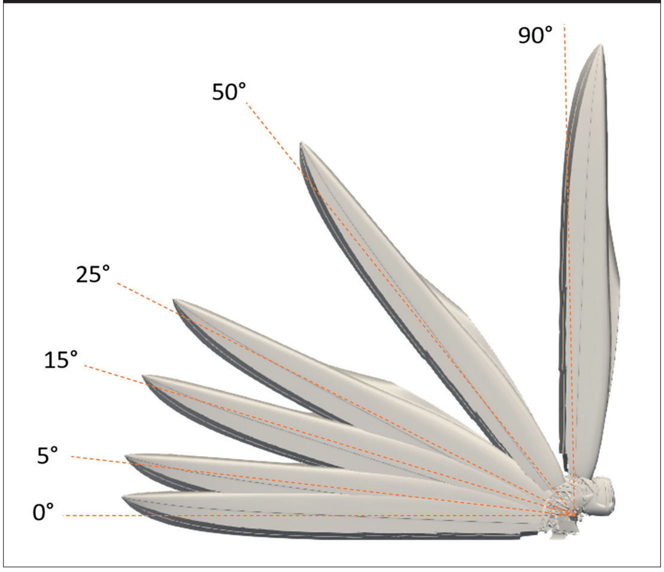
Later, during the development of the aero kits, TotalSim responded to one of the requirements imposed by Indycar. When the nose pitches up, the new bodywork was to be more stable than its predecessor while traveling sideways and/or backward. This meant that as the shape and the form of the car developed for efficient downforce and drag production around the track, TotalSim had to make sure the forces and moments acted to ground the car if it got airborne (its aero kit won the 100th running of the Indy 500 with no serious accidents).

The first step in analyzing the Key West event was to understand the typical forces and moments acting on the Doug Wright 32 when running where Porta was out in front and on his own. To do this, Eagles took the same geometry file Dimensional Engineering had created from the FARO scan and built a CFD model that focused only on the surface in contact with the air.

Eagles: "We set the angle of the hull relative to a flat sea state at several positions (**Figure 1**) and then assessed the forces and moments at each of those positions (**Figure 2**). The key forces under consideration are the drag (force acting against the forward motion) and lift (vertical force pushing up away from the water). The result of the combination of the lift and drag forces was a pitching moment (nose-up) about the center of gravity created by these forces."

We can see from Figure 2 that as the angle of the isolated boat increases from 0° to 50°, the drag and lift forces (and resultant) increase as well, as does the pitching moment. We also see that the resultant is nonlinear, meaning that as the angle changes, the curves get steeper, indicating that doubling or tripling the angle more than doubles or triples the forces and moments. This characteristic implies gross instability, because once the aerodynamic forces exceed the weight of the boat and the bow starts to lift, the forces continue to increase at a rate that makes correction exceedingly difficult.

Figure 1. Angles Assessed in Blow-Over Model



COURTESY TOTALSIM

Having established the characteristics of the isolated boat, the next step was to place the boats side by side to see if anything changed. From the footage and the comments from the pilots, Eagles positioned the virtual boats 3′ (0.91m) apart, set the angle of attack (AOA) at 5°, and ran the simulation. **Figure 3** shows the same isolated boat forces and moments with the two-boat simulation data superimposed on top. The results are quite dramatic.

We see both drag and lift increasing compared to the isolated boat, with the drag on each of the side-by-side boats being equivalent to the drag on an isolated boat at around a 7° AOA (suggesting they may be slowing each other down), while the lift of the side-by-side boats is equivalent to an isolated boat at around 16°. The huge changes in lift and associated pitching moment change are greater than the restoring moment of the weight, so the boats are no longer trimmed out, and the bows begin to rise.

Figure 2. Attack Angle Influence on Lift, Drag, and Pitching Moment of Single Boat

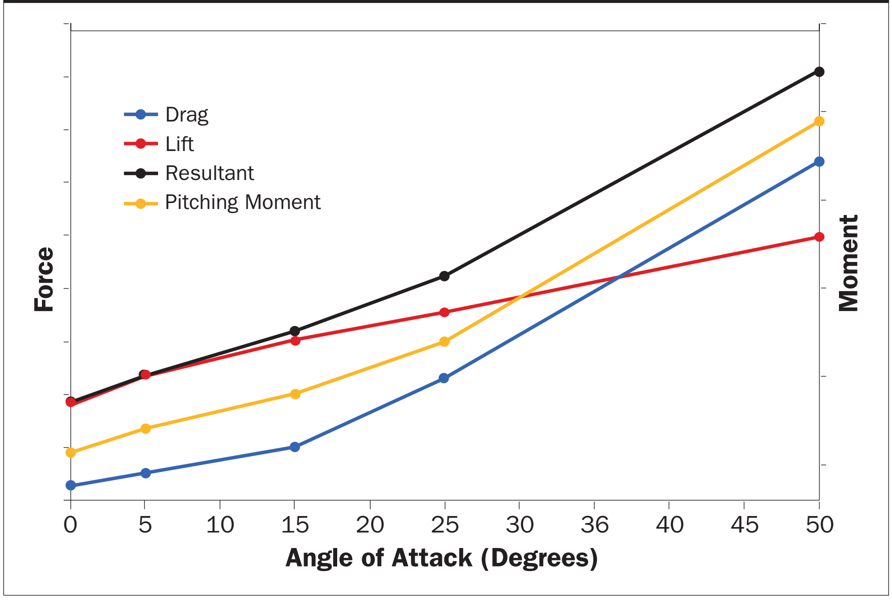


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Figure 3. Dynamics of a Single Boat vs Boats Running Side by Side

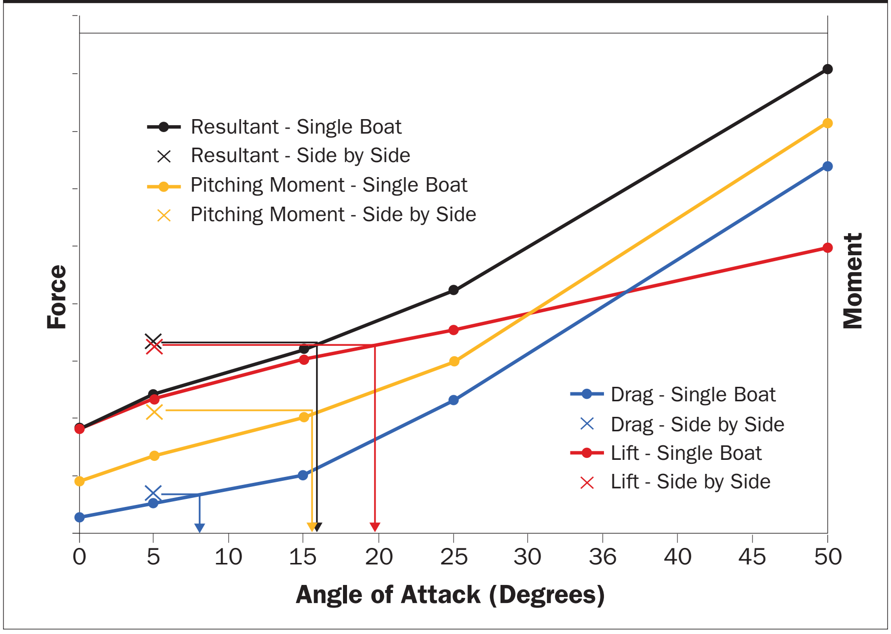


Figure 4a. CFD of Lift and Downward Force on Single Boat

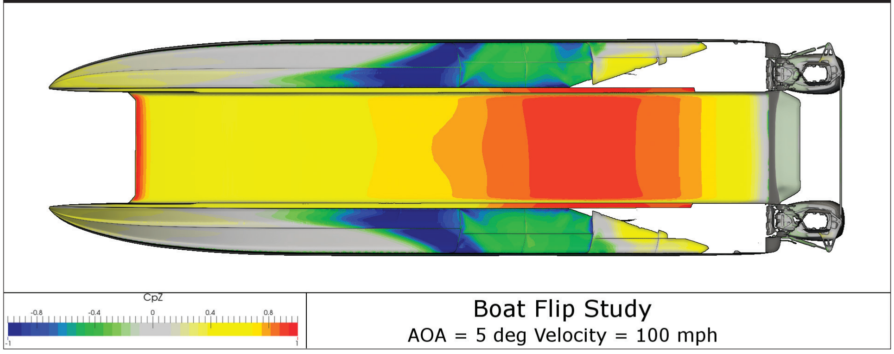
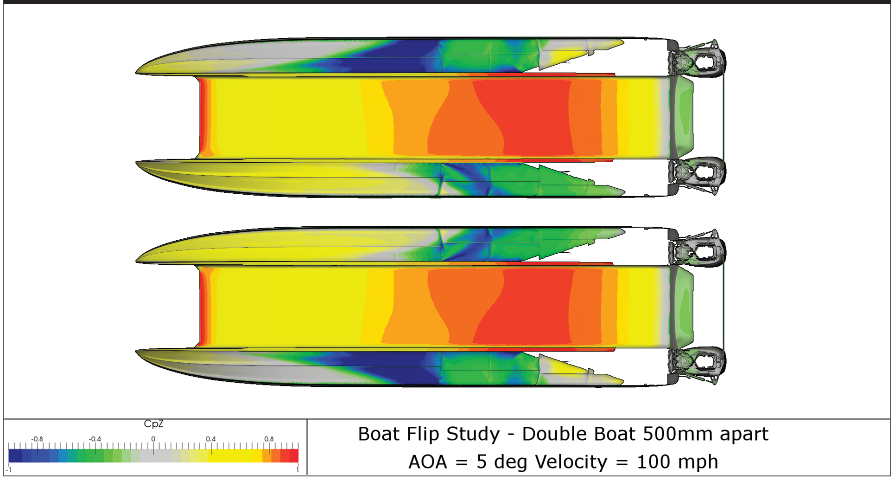


Figure 4b. CFD of Lift and Downward Force on Boats Running Side by Side



COURTESY TOTALSIM (ALL)

As we saw in Figure 2, as the angle increases, so do the forces; and as the bows come up, the forces go up, the bows rise some more, and this continues until the boat flips over. The CFD force data illustrate a dynamic that would lead to the event we saw in Key West. But why did it happen?

This is where CFD really starts to show its strengths. The forces we have looked at are a result of pressure changes on the surface of the hull. These changes are created by local accelerations and decelerations of the air as it washes over the hull and deck, and CFD can show us how and why these occur. In **Figures 4a** and **4b** the underside of the hull colored by the component of pressure is creating lift for the two different configurations. Yellow depicts low amounts of lift; red is high lift; green is low levels of downforce (the aerodynamic force pulling the boat toward the water); and blue is high downforce.

The plots show that the entire tunnel surface is creating lift whether the boat is alone or side by side, and there is not much change between the two scenarios. However, the sponsons tell a different story. The isolated boat is showing strong downforce coming from both sponsons at the section just ahead of where the hull meets the water (blue patch midway down the sponson). This downforce is generated by the air accelerating in the narrowing gap between the hull and the water surface. This is illustrated in **Figure 5a** as velocity vectors colored by speed, with blue showing low speed and red showing high speed.

Eagles: "As air enters the tunnel, it starts to slow down as it packs up under the boat, and as it progresses it gets squeezed into a tighter volume and starts to push out at the sides, accelerating (red arrows) as it washes outboard over the hull surface. As the air accelerates, its pressure drops, creating suction, and this in turn generates a force pulling the hull towards the water. There are some effects also happening

Figure 5a. CFD of Air Velocity on Single Boat

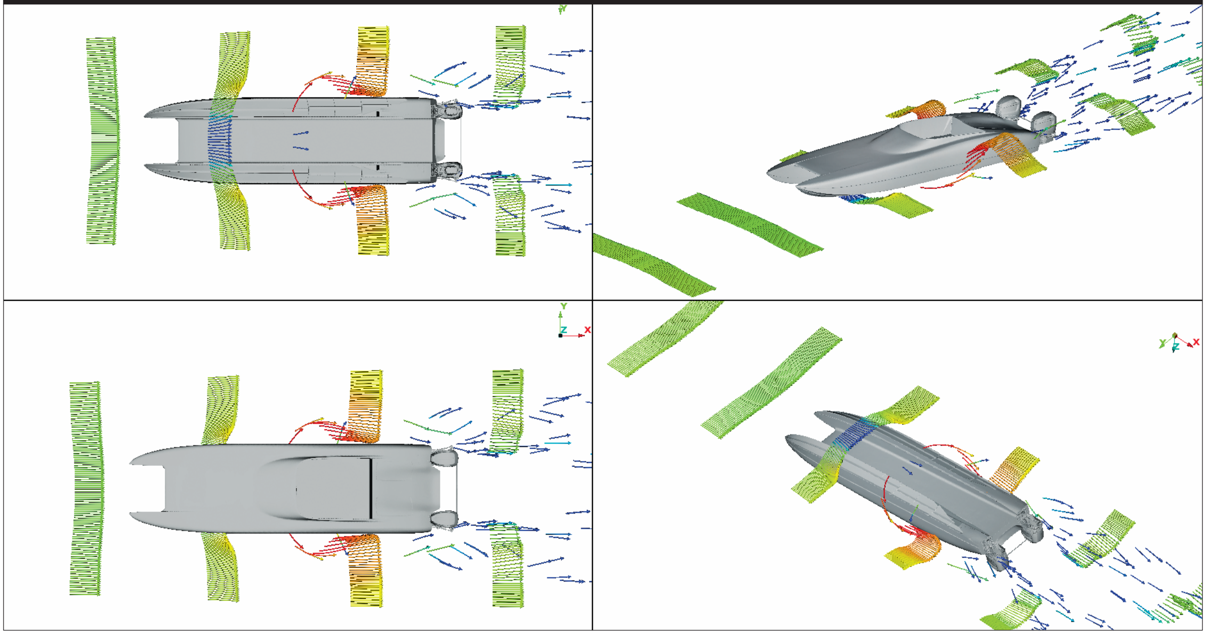
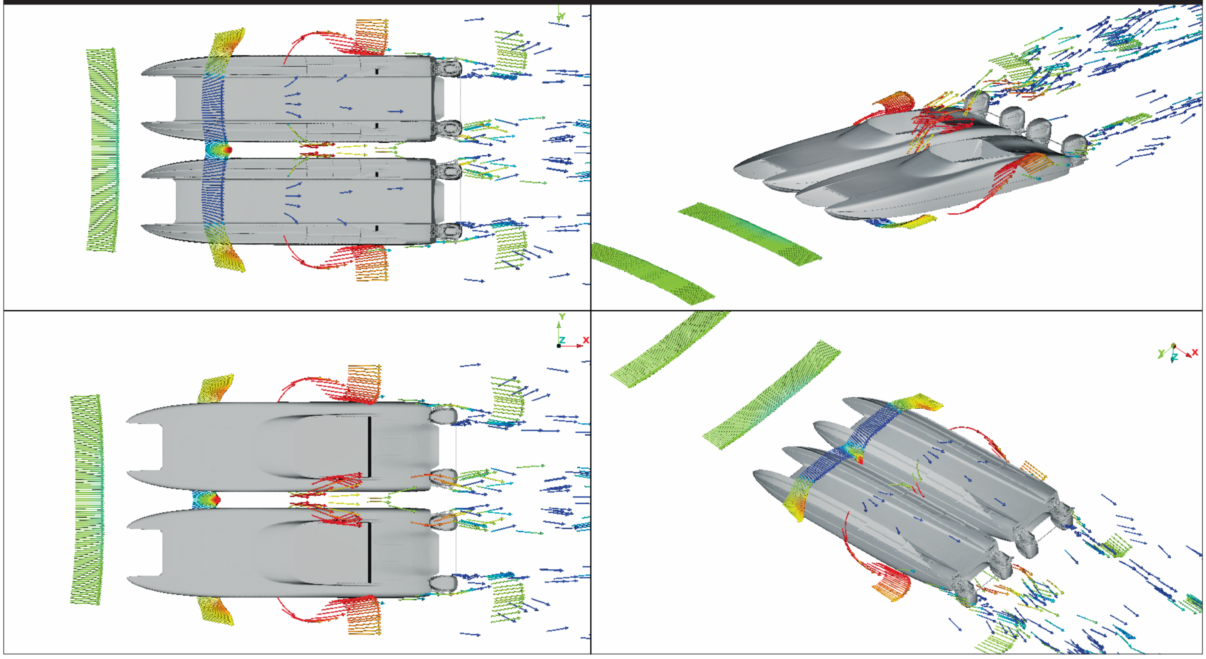


Figure 5b. CFD of Air Velocity on Boats Running Side by Side



COURTESY TOTALSIM (BOTH)

on the deck side, but these are secondary compared to the hull and have not been covered here."

Looking at the side-by-side configuration in Figure 4b, we see an effect on the outer sponson similar to what is seen on the isolated boat. However, on the inside sponson we see most of that downforce has been eliminated and replaced by lift across the majority of the surface. This is the source of the liftoff mechanism that caused the blow-over. The velocity vectors of the side-by-side configuration show that air is unable to get out as effectively, as it's blocked by the sponson of the adjacent boat, as illustrated by the slow-moving blue arrows in **Figure 5b**. This slow-moving air has higher pressure and therefore does not create the suction we saw in the isolated boat, with the net result that the inside sponsons on both boats now create significantly more lift, disrupting their stable trim and causing the bows of the nearly identical hulls traveling at the same speed to flip quickly and almost simultaneously.

"The simplest way to reduce the risk of this happening in the future is to make sure there is sufficient gap between boats that the air can get out," Eagles said. "However, racing being racing, when you are fighting for the patch of water leading around the buoy, I suspect that this probably will not be what is at the forefront of your thinking."

He concluded: "A more practical solution would be to adopt something like Indycar or NASCAR and add a device to the boat that when deployed creates a counteracting force that cancels out the lift and stabilizes the pitching moment. This could be a passive device [auto-deploying] or active [driver initiated] and will require discussion with the governing bodies to make sure it does not adversely impact the racing or create issues of its own. I sense there might be a new project on the horizon."

Real-World Aerodynamics

Most relevant to designers and builders of recreational powerboats, our case studies show that aerodynamic design really starts affecting a boat above 60 mph (97 kmh). With multiple higher horsepower outboards being bolted on the transom, almost every boat manufacturer has a model capable of that speed, but aerodynamics are relevant on more sedate vessels as well. Builders use phrases like dry ride, acoustically tuned cockpit, comfortable, and wind free to describe the virtues of even a 20-knot boat. That's no surprise when social media is full of posts about how "car-like" their recent boating experience had been. The current automotive comfort expectations have raised the bar for everyone. Gone are the days of the passengers in a top-down convertible being exhilarated by the wind in their hair on a gusty open highway. Modern convertibles are acoustically and aerodynamically refined. The open sky is still overhead, but engineering has all but eliminated the noise and wind of the convertible.

Let's say that a boat owner drives to the marina in a quiet and aerodynamically refined convertible before boarding a newly acquired sport boat, a product that may cost twice or three times as much as the car. Shouldn't expectations for comfort and noise be the same on the boat as in the car?

Jake Fraleigh, president of Eliminator Boats (Mira Loma, California), on the importance of aerodynamics to his recreational models: "In the past we used a higher deck, and we noticed that people in the back of our cockpits were getting lots of wind buffeting. Our newest models have flattened decks. We pulled the 'bubble' out of our top deck, and that allowed our new windshield design to positively affect our aerodynamics for cockpit comfort."

Because Eliminator is installing more outboards, which means the boats go faster, Fraleigh said, "on both our 31 and 33, we are widening our tunnels now and changing the slope of the deck and tunnel entry, therefore creating more tunnel pressure. We have even added 45° angles to the sponson area upper-deck plane entering the tunnel for better entrapment of air under the boat. We have focused on more lift and therefore a faster, more agile boat."

Nigel Hook, owner of SilverHook Powerboats (Sanford, Florida), confirmed the importance of CFD modeling during design and model refinement. "The SilverHook was designed as perfectly aerodynamic [with the help of CFD] by Ocke Mannerfeldt of the Swedish firm Mannerfelt Design Team. It has wings, although not movable; it has automatic stabilization. The consumer design has the same CFD advantage. It is fast, efficient, and safe. Only through aerodynamics are we able to manifest the true race-proven features."

Conclusion

For now, the new minimum expectation for North American powerboat buyers is twin outboards, and the new normal is triples or quads on higher end vessels. More power adds speed, and with speed, airflow becomes very important to boat designers and builders. Boats can and do fly, if only for brief intervals, but managing their seakeeping, safety, handling, and comfort at those speeds requires as much attention to aerodynamic design and analysis as to hydrodynamics. To that end, more manufacturers are using CFD modeling to create and simulate the performance of any given design, especially as they pile on more power to meet market expectations. The results can range from understanding and correcting sources of dangerous instabilities and performance flaws, to quieting the ride in the cockpit and keeping the hair out of your eyes. PBB

***About the Author**: Clay Ratcliffe is a 45-plus-year veteran of high-performance industry technical design and marketing. After converting from auto to offshore powerboat racing, he has been a catalyst for boatbuilders to bring well-established design methods into performance-boat manufacturing.*

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