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The Breakthrough QE IV Ferry

By Roger Hatfield, Sep 20, 2022

Courtesy Gold Coast Yachts

The 104′ (31.7m) tandem catamaran QE IV ferry, built in 2016 by Gold Coast Yachts (GCY) in St. Croix, U.S. Virgin Islands, is an innovative four-hulled vessel that pushed the design and engineering team, the builders, and the U.S. Coast Guard's certification process to the limits. But the boat has proven a reliable and efficient commercial people carrier in the six years since her launching.

After a decades-long career in the field, I've come to define multihull naval architecture as: the use of predominantly lightweight composite materials whose properties can be accurately determined only through exhaustive tests; the placement of those materials in very irregular shapes that are difficult to analyze; and the plunging of these creations into the oceans of the world to be subjected to the occasional rogue wave. It's a particular moment of glory for a multihull designer who receives approval by some conservative regulatory agency that bestows upon them the permission to operate the vessel commercially.

This is the story of one such project, the creation of a four-hull 104′ (31.7m) interisland ferry we built and launched at Gold Coast Yachts (GCY) in St. Croix, U.S. Virgin Islands, in early 2016 for our client, St. Croix resident Warren Mosler. With five full years of operation now behind us, we can review the history of this unusual vessel, which has run approximately 100,000 miles carrying thousands of passengers over some exceptionally bumpy Caribbean waters, and declare it a success. But during design development and the build project, that positive outcome was often far from clear.

The quirks of inspiration and fate that created the *QE IV* started with a sharp businessman's brainstorm, made real by a successful, innovative boatbuilding company. Wikipedia describes Mosler as an American economist, hedge fund manager, politician, and entrepreneur, who ran for U.S. President, U.S. Virgin Islands congressman, and VI Governor. However, it was his experience as the man behind high-end Mosler Automotive sports cars (1985–2013), and his affection for the island of St. Croix that brought him to this novel vessel design. Gold Coast Yachts had designed and built more than 138 custom multihulls, from racers to cruisers, its bread and butter being commercial Coast Guard–certified day-charter motorsailers, excursion boats, and ferries.

Courtesy Gold Coast Yachts

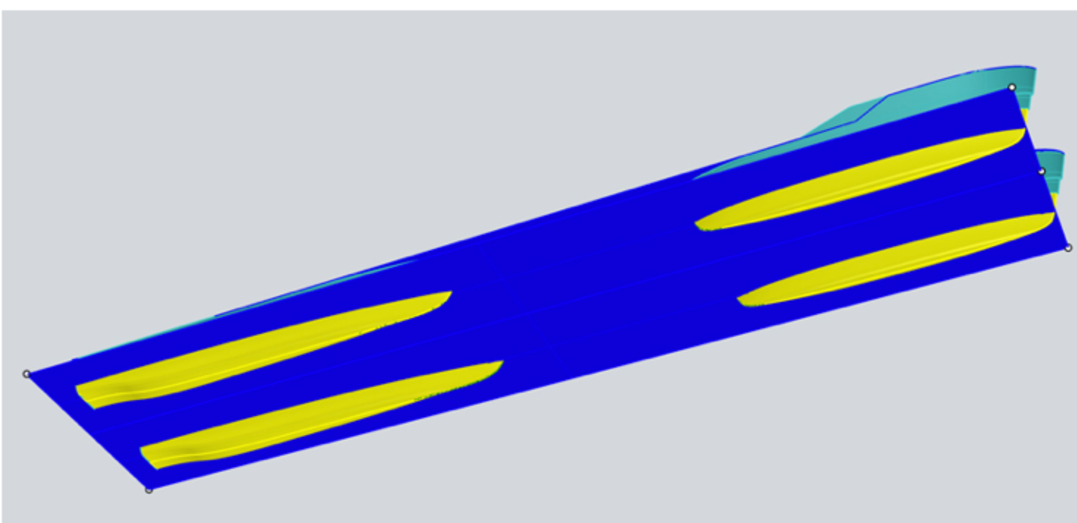
Client Warren Mosler's first big project with GCY was the 47' (14.33m) cruising catamaran Knot My Problem, inspired by the commercial fleet of eight wave-piercing cats on the island in 2008.

The genesis of the project began when the fleet of eight GCY wave-piercing power catamarans buzzing around the islands caught Mosler's eye. In 2008 he contracted the build of Gold Coast's 82nd vessel, a 47′ (14.33m) wave-piercing, cruising power catamaran, and named her *Knot My Problem*. We had reluctantly agreed to give the 3D design files of the hulls to Mosler's car designer so he and Mosler could create the cabin.

The result is an unconventional, voluminous euro-style cabin perched on our slender, wave-piercing hulls. Mosler had employed carbon fiber in his racecars and insisted we save weight in the boat's superstructure with the same material. Those first components from GCY were simply wet-bagged carbon cloth over foam, but they certainly were stiff, saved weight, and supported the large cabin without adversely affecting *Knot My Problem*'s performance. Her name is a tender tease on the island attitude of carefree living as much as a challenge to other boats for rough water speed, seakeeping comfort, and moderate fuel consumption.

Despite that success, we were skeptical seven years later when Mosler approached us with his four-hull project idea. Having built a solid working relationship with him during the 47′ build, we knew we were taking little financial risk and had only to decide if it exposed us to undue ridicule for breaking yachting conventions, insurmountable regulatory challenges, or some long-term liability.

Mosler had set his mind on starting a new ferry system to run between St. Croix and St. Thomas, knowing there was a great need for it. All earlier attempts for ferries had failed for several reasons, primarily structural and economic—the typically rough conditions cracked boats and kept the ridership down. Since most of the ferries were designed to carry 150 passengers (or more), they could not meet their break-even costs. Mosler knew the boat had to be fuel-efficient and comfortable. He was sure he had a solution that he trusted us to realize, and he was not concerned with what others might think about how many hulls it had or its aesthetics. Furthermore, he could afford to turn the boat into his next cruiser if it failed as a ferry.



Courtesy Gold Coast Yachts

The view from below convinced designer Roger Hatfield that there could be efficiency in the aft hulls drafting in the wakes of the forward hulls and that the four short hulls might perform better in choppy seas than two long hulls.

Behind the scenes he had started tinkering with two 8′ (2.44m) dinghies structurally joined in an unusual tandem arrangement (one in front of the other). When he started to test-drive it, the boat looked awkward at best, and it rolled a bit, but it was usable. He swore it was awesome and then decided to cut each hull in half longitudinally, closing off the open sides of the four half-hulls to make two sets of mirror-image hulls, still in the tandem combination. He then placed a sturdy deck over the whole thing. We all had another chance to drive this new thing around, and it performed better. It seemed to deal with the oncoming waves more easily, and clearly rolled far less. Thus, the first tandem catamaran was born.

That experimental vessel didn't prepare me to think in terms of the 100′ boat Mosler was visualizing. I tried to explain the difficulty of taking this crude ¼-scale model and deducing accurate assumptions about a full-scale vessel. The laws of similitude state that any vessel four times as long would likely be four times as wide and four times as high and therefore, for any shape, 64 times heavier.

I was using these physical scaling laws to identify the required power, the likely speed, and the vessel's motion, but honestly, I struggled with how ungainly this craft would appear. In a moment of self-reflection, I found myself unexpectedly in my father's shoes. An MIT-trained naval architect, 50 years earlier he had struggled with my fascination with the first modern multihulls. Having grown up near Marblehead, Massachusetts, surrounded by "proper yachts," he had a distaste for multihulls that was purely aesthetic conditioning. The conventional monohull shape with graceful, long overhangs had started largely as a racing rule-beater and, in my opinion, has set naval architecture back significantly, even until today. Fortunately, my father was able to set aside his prejudice and provide a smart analysis of the multihull's remarkable potential performance. Faced with another unconventional hullform, I promised myself to do the same.

There were other practical considerations of creating a vessel with no preceding model to draw from. If GCY were to accept this project, we would need up-front money to create a "ballpark" study. We had to sketch it out, create a suitable structure, analyze the weight, and estimate the cost of materials, the potential performance, etcetera, in the head-spinning design spiral of an entirely new hull configuration.

I had always been curious about the infinite variety of hull shapes and combinations skinny multihulls could use. I had spent years pondering and riding on catamarans, trimarans, outriggers, and proas. I image everyone loves to rotate images in 3D, studying things from all angles. The eureka moment for this project came when I drew the 3D concept of the four hulls in tandem and rotated the structure to see it from a fish's perspective. It was obvious that in this arrangement the aft hulls might be able to gain efficiency by drafting on the forward ones. We've all stared up at migrating geese flying in a close V formation.

I have drafted hundreds of other cyclists and swimmers, and though it is best to follow very close, almost any distance reduces your effort. Indeed, triathlon rules suggest that trailing bikes will benefit within as much as five bike-length spaces behind a leader.

Considering Mosler's passion for automotive design, I began picturing analogous land vehicles. I saw that a boat might operate better in our rough conditions if it were shaped like a four-wheeled jeep rather than like a tank, with its flat tracks forced over the top of every ridge. He separated the hull into forward and aft components. This tandem configuration with its lack of displacement amidships would theoretically ease vessel motion by reducing the tendency for the whole craft to teeter on a crest and then fall into a trough. That, with an attendant increase in overall length, *could* reduce undesirable pitching motions.

Also, the early hydrostatic studies showed that the proposed boat could be relatively narrow by conventional catamaran standards and minimize the effect of rolling motions. She would benefit by having less of the sometimes-jerky response of a wide cat and yet avoid the slow roll of monohulls, which are frequently not in rhythm with the waves. Finally, the tandem offered a new seakeeping benefit: an unusual escape route between the hulls for big side-slamming waves.

Despite the desire to call this new thing a quadmaran, Mosler insisted from early on in calling it a tandem-cat to better suggest the hull configuration, not just the total number. The boat's name is simply *QE IV.* For Mosler, the reference may be to his favorite monetary policy, Quantitative Easing. For me, QE stands for "Question Everything," something our world could do a bit more of. I can assure you it does not refer to any monarch.

Courtesy Gold Coast Yachts

Building the Paul Bieker–designed 53′ (16.15m) all-carbon foiling catamaran Fujin was the project that pushed GCY's crew, with help from consultant Phil Steggall of Bravolab, to perfect their infusions of carbon fiber laminates.

GCY was fortunate to have this large project following on the heels of our first all-carbon-fiber 53′(16.15m) racer/cruiser *Fūjin*, named after the Japanese Wind God. She was designed by Paul Bieker and Eric Jolley of Bieker Boats. Bieker's and the owners' acceptance of our shop was, in part, based on our ability to infuse carbon fiber to a high standard. To help, we hired Phil Steggall of Bravolab, who is well known in the world of singlehanded ocean multihull racing. He came to teach us the specifics of carbon fiber infusion and how to meet Bieker's requirements. We had already infused more than 60 large hulls with E-glass and Corecell foam using epoxies. Thanks to Steggall, our next small step guaranteed quality wetout for carbon and was confirmed through numerous lab tests. (For more on building *Fūjin*, see *Professional BoatBuilder* No. 155, Rovings, page 14, and the story behind foiling cruising catamaran Eagle.)

Courtesy Gold Coast Yachts

Fujin's lightweight and functional interior

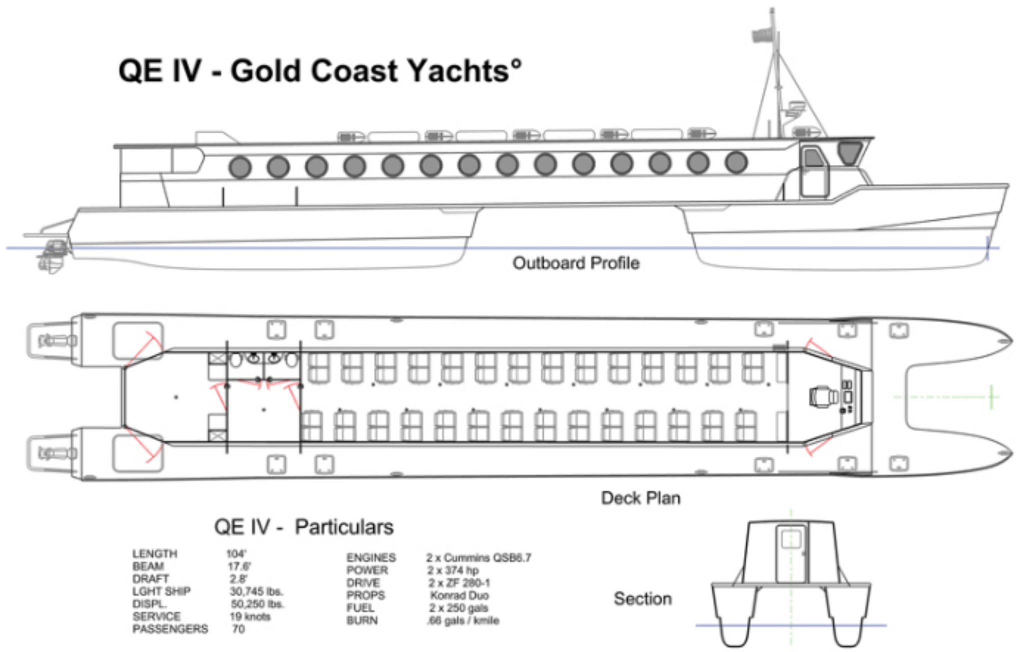
Learning how to infuse carbon fiber offers several advantages over wet-bagging or carbon prepregs. Wet-bagging tends to yield heavier laminates. It doesn't remove excess resin, leaving the cloth resin-rich and increasing the potential for thousands of microscopic air bubbles that weaken the structure. As the name implies, prepregs come already pre-wet-out with the correct resin ratios. A potential problem is that they have a finite open time when the material is brought out of cold storage and begins its thermally driven cure. It was always a concern that our shop was located in the tropics and might be vulnerable to the cure happening before the various laminates were ready to be bagged down.

Also, any gaps in prepregs that were not perfectly prefilled in the core remain as voids. With infusion, the time pressure is eliminated. The various laminates are simply laid in place, and once the bag is down and the vacuum pulled, you can pick when to infuse, introducing the freshly mixed resin and catalyst. The actual infusion of liquid resin under vacuum fills every microscopic void before it cures. Careful weighing and testing of panels showed that infusion, which greatly reduced voids, increased the compression strengths. By building with flat-panel methods (or in the curved panels by separating the infusion into steps of outer skin, core, and inner skin) we were able to keep the near perfectly filled panels down to about a 5% weight increase over other processes. That was a fair price to pay, especially in a commercial structure.

Courtesy Gold Coast Yachts

The profile of QE IV illustrates how narrow this unique vessel is.

Because carbon fiber has a thinner thread than E-glass, it is harder to wet out. We used carbon cloth developed over several years by Bravolab. It included a 6-gram nylon micro-web as the transfer medium between every 200 to 300 grams of carbon. When we created and maintained a powerful vacuum of 24+ Hg, we created the lowest resin-to-cloth weights and were not restricted by the number of laminates we could infuse in one operation. This vacuum demands a tight mold, a near-perfect seal between the mold and the bag film, and then a myriad of piping that ultimately leads to an industrial vacuum pump, always with a backup pump and generator standing by. To achieve the best epoxy properties, the final step is to thermally post-cure each skin of the panels. Every panel we made for *Fūjin* was then carefully weighed to confirm estimates and to keep the as-built weight spreadsheet accurate.



Courtesy Gold Coast Yachts

The plan views shows how the long passenger cabin serves as the structural box beam at the core of the boat.

Mosler watched the construction of *Fūjin* closely, especially the state-of-the-art carbon fiber infusion. He saw that he could invest a bit more into his planned ferry to make it lighter and more fuel-efficient. So, his new focus was on a minimum break-even cost, rather than expansive seating for some unrealistic payout.

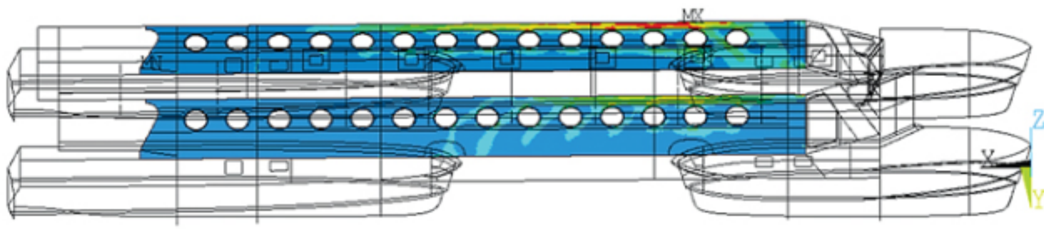
The primary structure holding the tandem catamaran together would be a long, hollow box (beam) running fore-and-aft, which would also serve as the passenger cabin space. The two forward hulls and the two aft hulls were to be connected to this long box, each with the conservative, proven pair of crossbeam bulkheads typical of catamaran construction.

With our conceptual analysis completed, we agreed to build the *QE IV* under one condition: we would have a thorough structural review done by an outside firm. First, we needed a computational fluid dynamics (CFD) study to assess the hydrodynamic pressure loads and the resistances so we could finalize structure and powering requirements. Then, applying finite element analysis (FEA), we could confirm the structures we had estimated by applying the loads from the CFD study.

Courtesy Gold Coast Yachts

An exaggerated representation of bending stresses on the cabin structure.

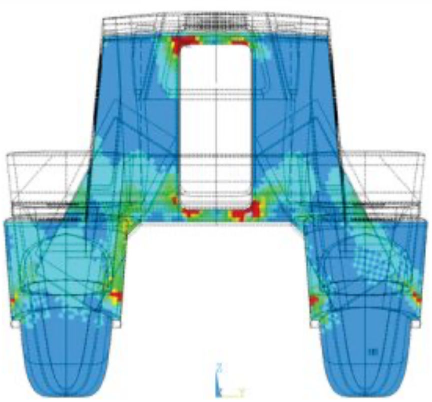
The initial CFD study concluded that *QE IV* would have relatively low overall running resistance, allowing for smaller and lighter engines and therefore less fuel burn. Later, the FEA analysis would review roughly five million individual elements, each for its fiber direction, its potential failure modes including tensile fiber rupture, the epoxy matrix failure, interlaminar shear, skin wrinkling, core shear failure, and panel buckling. We knew the four hulls had an unusual connective structure; predictably, it needed some effort to assess the suitability of this concept. The FEA revealed global and local stresses, helpfully locating potential hot spots. The entire FEA review took an air-conditioned, room-size, high-power computer more than two weeks to calculate.



Courtesy Gold Coast Yachts

This rendering indicates stresses in the cabin sides when slammed by a quartering sea at the port bow.

Every computer geek knows the mantra "garbage in, garbage out" as a reminder that, even run through the best computer programs, nonsense input yields nonsense output. We ran that risk, because our hydrodynamic pressure assumptions that the CFD created drove the entire analysis of the FEA. While our past successful experiences led us to question some of those higher CFD outputs and to be cautious with such an unusual project, we accepted them.



Courtesy Gold Coast Yachts

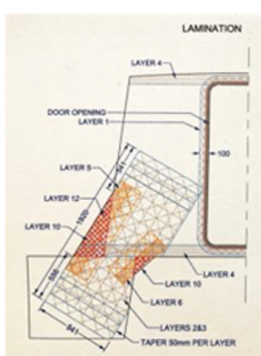
Here the FEA reveals stresses in the crossbeam in the same scenario.

This first run of the FEA indicated that the stress level of most components would pass at the speed and wave heights we thought we would be operating in, though there were many highly stressed localized hot spots. Each set of FEA outputs produced renders and computations. The renders easily located the stresses—red spots showing the highest stress concentrations, yellow and green the medium stresses, and blue indicating very low stresses with the materials we had chosen. We adjusted the laminates accordingly by adding layers in those hot spots and in some instances removing layers.

The three renders above illustrate the vessel being hit by a port bow wave; the render above left is highly exaggerated for emphasis. Note that the boat could never bend like that; carbon fiber is very stiff and brittle. Before launching, when the boat was jacked up under the starboard stern, we were amazed to see the port hull's stern lifting when the starboard rose a mere ½″ (13mm). The cabin-side and the beam render are from later FEA evaluations and show few hot spots due to the added reinforcing laminates.

The safety factor rating placed on materials (determined and required by regulatory bodies) is determined by how they respond to long-term cyclical loading, which affects not only the longevity of the structure but its initial cost and final overall weight. The working rule for this design was that all areas needed a safety factor of *three*. The output data with each render included that numerical assessment. A safety factor of one is defined as a slow loading of some structure until it fails. To protect against long-term cyclical loads (usually taken as 10 million cycles) each material has an approximated required value. For steels, because they have been exhaustively tested, the required safety factor value for long-term use is only 2.4. For aluminum it is 3, but for fiberglass layups it is typically greater. Industry researchers suggest that for quality wood and carbon fiber construction, the number could be as low as 2, but there are insufficient test data to confirm this.

As a prejudiced believer in multihulls, I had been naïve enough to think the U.S. Coast Guard would appreciate the relative safety of this boat. Since the *Titanic*, everyone has laughed at the idea of an unsinkable vessel. But I saw how some easy calculations could indicate that *QE IV* would be impossible to sink. In addition, my experience with multihull catastrophes was that they rarely ended up being catastrophic, in part because they typically remained afloat. Because the vessel was so unusual, we got the feeling from the local office and the USCG headquarters that they all hoped the project would just vanish. After our initial structural submission, we received one letter suggesting that we consider applying regulation 46 CFR 177.340, intended for "consideration of alternate design analysis for vessels of novel design, unusual form or special materials." *QE IV* unfortunately fit into all of those groups, but that didn't mean we could use a novel, unusual, or special method of analysis for our project.



Details of the ample laminations connecting crossbeams to the hulls and cabin structure show how the FEA results drove GCY to apply very conservative specifications.

BEAM 6500

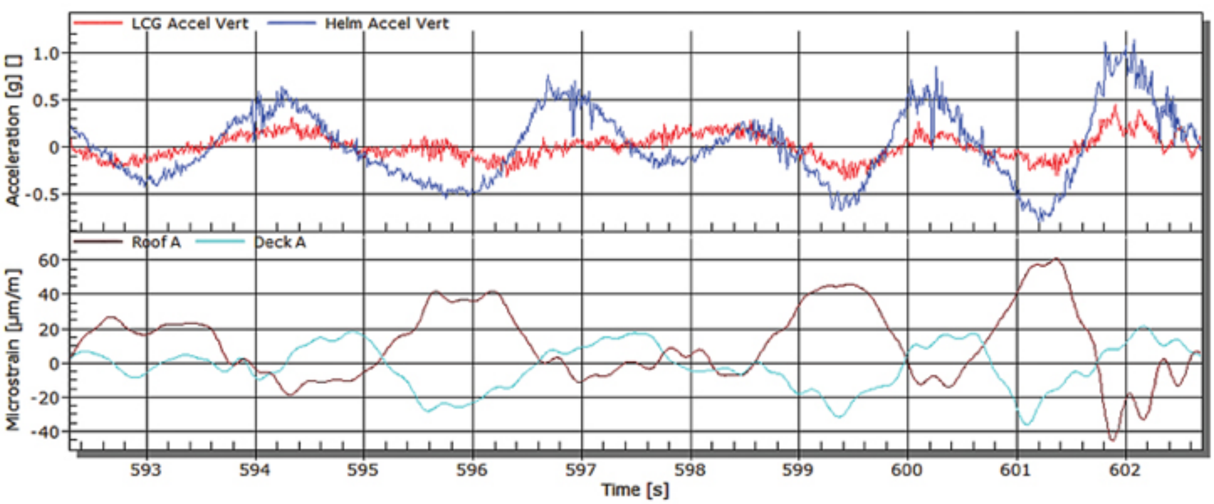
LAYER	MATERIAL	WARP ANGLE	COMMENTS
1	C400 +/-45	0	PARTIAL
2	(2) C400 0/90	30	PARTIAL, ALTERNATE W/ LAYER 3
3	(2) C400 +/-45	30	PARTIAL, ALTERNATE W/ LAYER 2
4	(5) C300 UNI	0	PARTIAL
5	BUTTRESS LAM	SHOWN	PARTIAL, SEE DETAIL
6	GUSSET LAM	SHOWN	PARTIAL, SEE DETAIL
7	(3) C400 +/-45	0	FULL, ALTERNATE W/ LAYER 8
8	(3)C400 0/90	0	FULL, ALTERNATE W/ LAYER 7
9	1" M80 FOAM	-	FULL, EXC. AT SKIN TIE & LAYER 10
10	1" M100 FOAM	-	PARTIAL
LAMINATE SYMETRICAL ABOUT ABOUT CORE. LAYER 9			
PROSET 145 OR 114 RESIN SYSTEM			
CORECELL FOAM AND FORMAX CARBON FIBER			

Courtesy Gold Coast Yachts

GCY shares a laminate schedule.

The certification process with the USCG did not go smoothly. After my retirement in mid-2016, most of the final technical work to get this boat approved had fallen to Karl Peterson, who had become the head of the GCY design team. He reached out to others, including David Walworth of Walworth Yachts, to help coordinate the final approvals. Where we had believed the CFD pressures were a bit high, the USCG thought they were too low and would not trust our database of experience. As the process dragged on, the elephant in the room was the elephant in the shop—*QE IV* by now was nearly completed.

We finally got a clear directive from the USCG on what it would accept. In essence, the directive was to strain-gauge the completed boat to confirm the FEA, which meant entirely disregarding the CFD study. It was a risky exercise. The proposal was to measure strains in eight predetermined locations, including some that had shown to be hot, while gathering acceleration data at the LCG and at the helm station forward. The vessel would be allowed to operate only within a matrix of calculated speed to wave heights, which depended on the strains versus accelerations. This would be a massive amount of data to collect and correlate. It had to be done with *QE IV* loaded with drums of water to simulate a full load of passengers and traveling to the nearest NOAA buoy, 35 miles away, that was transmitting real-time wave heights and their periods. The graph above illustrates this collected information combined with real-time wave heights that were measured near the buoy. The top blue curve represents the accelerations at the helm; the red line shows them at the LCG. The graph also shows that the vertical accelerations experienced forward are constantly greater than those experienced at the LCG.



Courtesy Gold Coast Yachts

Data from a series of tests of QE IV loaded with drums of water and fitted with strain gauges and accelerometers yielded results confirming that the strains on the roof and deck of the passenger cabin and vertical accelerations at the helm and LCG were within acceptable working norms. The U.S. Coast Guard approved the boat for commercial operation.

Most important is the direct relationship between vertical accelerations from the waves and the vessel stresses recorded below them. As the vertical acceleration increases from bigger waves and faster speeds, the loading on the longitudinal box structure increases, and is seen as increasing strain in the roof and deck. Also note that the roof went into tension as the deck went into compression.

The data allowed Peterson and his GCY team to prove to the USCG that the vessel was satisfactory for service. Mosler had invested a large sum in this FEA analysis and the final strain-gauge proof in order to get regulatory approval. In retrospect, the value of the FEA was that it highlighted hot spots and helped create a better distribution of materials than what could have been identified from the first principles. But it was obvious after on-water testing that our original first-principles predictions had been accurate and that the CFD, contrary to the USCG belief, had simply overestimated the loads. This CFD overprediction had forced the FEA to be more conservative, which in turn pushed us to add as much as 1,000 lbs (453.59 kg) of structural materials that will affect fuel burn for the working life of the boat. Perhaps that additional structure will extend *QE IV*'s useful life carrying passengers on this rough route, as she has already done successfully for the past five years. Few boats get this much scrutiny.

Having met the structural challenges of the build, we assessed the performance goals of operation. Most importantly, we achieved our fuel efficiency objectives. She typically travels at 19 knots with an average fuel burn of about two-thirds of a nautical mile per gallon. Few vessels are as efficient as *QE IV*, in part due to her very low weight. She has the incredibly low displacement-to-length ratio of 13.4. She is the same weight and length as the French 30m (100′) Ultime maxi-trimarans and half the weight of *Comanche*, the 100′ ocean racing maxi monohull (see “0 to 60,” in PBB No. 153, page 20).

Do I dare look into the future? Mosler is evaluating a backup ferry that would run in the reciprocal direction to *QE IV*. Bieker, the foil expert, has observed that this unique catamaran configuration is a near-perfect structure for foils. With a foil on each hull, the tandem catamaran form would be, in the event of a foil failure, an incredible structure to land on. Mosler is wary of the costs to add and maintain foils, even in the open waters of the Caribbean. There is a lot of Sargasso weed, some fish trap lines, and the occasional innocent cetacean. Multihull designer Jim Brown believes that there are many potential ferry routes around the world where using foils might be risky, but for the sake of maximizing fuel and motion comfort it may be worth pursuing this concept. As I suffer from seasickness, I became fascinated early on with the wave-piercing hull concepts. Due to the typically rough Caribbean conditions, 10% of the vessels that GCY has designed and built are wave-piercers simply to improve passenger comfort. Mosler is contemplating a three-hull boat for similar reasons. He is currently investing in a design with a large forward hull with two smaller trailing after hulls. Therefore, my suggestion for this next craft was two smaller torpedo-shaped wave-piercing hulls held way forward, with a large single hull on the centerline aft carrying the majority of the weight.

My takeaway lessons from *QE IV* are to try not to get trapped in time by prevailing ideas and perspectives, to always be appreciative of time spent on the water simply messing around with boats, and to Question Everything.

About the Author: *Roger Hatfield grew up with sailboats. He built a Jim Brown 31' Searunner and with his wife, Cynthia, sailed into the sunrise in 1977; designed and built a 34' racing trimaran in 1978; and sold plans for two 34' trimarans before starting Gold Coast Yachts with Rich Difede in 1983. The company has built more than 130 custom boats ranging from 11' to 104', starting with best wood-epoxy building practices for 50-some vessels, then fiberglass and foam infusion for another 70 vessels, plus the two all-infused carbon fiber boats described above.*