Team New Zealand (A)

Doug Peterson leaned back in his chair and twisted the cap off another Steinlager. The Wharf Cafe had grown crowded and smoky since the meeting had started. "We really have to get ourselves a proper conference room next time," he thought, as he stared out over a misty, gray Auckland harbor.

It was late May 1994. Peterson had been working on the design of New Zealand's 1995 America's Cup yacht for over a year. As lead designer, he had conceived the original concept and recruited the design team who, for the first time, was making extensive use of sophisticated computer-aided design and simulation tools. Now, as the team assembled for its weekly review after the day's sailing, the time had come to commit to the construction of the new yacht.

Peterson pondered the decision they faced. The budget allowed for two yachts to be built; however, there were several strategies they could take with regard to their design. Should they build two yachts with *similar* hull and keel designs, so they could vary the details of the keel design and race them against each other to assess potential improvements? Should they build two yachts with hulls optimized for *different* sailing conditions? Or should they build one yacht now, but delay building the second, waiting till after another round of prototype tests, while they experimented with the first one on the water? The decision they made in the next hour would profoundly affect their chances of winning in San Diego and becoming only the second team in 145 years to win the Cup from the Americans.

The America's Cup

In 1851, the Royal Yacht Squadron of England offered a silver trophy, called the "Hundred Guinea Mug," to the winner of a sailing race run around the Isle of Wight, a small island off the south coast. Open to all nations, the race attracted 15 English entries and only one foreign challenger—the eventual winner, America. The Hundred Guinea Mug thereafter became known as the America's Cup, in honor of its first winner, and when the last surviving owner of the victorious team donated it to the New York Yacht club, it was decided that challengers from other countries should be allowed to compete for the trophy in a "friendly competition between foreign nations." The rules for these races were defined in a document called "The Deed of the Gift."

The first America's Cup challenge was held in 1870. Over the next 30 years, the American defenders successfully defended against teams from England, Scotland, Canada, and Ireland. At this

Doctoral candidate Alan MacCormack prepared this case under the direction of Associate Professor Marco Iansiti as the basis for class discussion rather than to illustrate either effective or ineffective handling of an administrative situation.

time, participants were not limited in design, hence boats varied greatly in both size and power. However, since the European challengers were required by the rules to cross the stormy North Atlantic under their own sail power, their boats were often heavily built and slower than the Americans'. Races were often one-sided affairs, of little interest to spectators.

In 1920, the rules were changed to specify the use of J-class designs, enormous single-masted boats over 100 feet long, with masts 120 feet high and a crew of 40. While races became closer, ultimately, the results were the same. Between 1920 and 1937, the Americans made another four successful defenses. After a long break due to World War II, J-Class boats were ruled too expensive, and a new 12-meter class was created, with 65-foot long hulls, 90-foot masts, and a crew of 11. The rules were changed so that challengers' boats could be transported to the race site by ship rather than having to sail. As designs converged, racing became even tighter. Even so, between 1958 and 1980, the Americans defended successfully another eight times.

In 1983, the longest winning streak in sports history—132 years—ended when the revolutionary Australia II, with a radical and controversial "winged keel," defeated Liberty, under the helmsmanship of Dennis Conner. In 1987, however, Conner regained the cup in Perth with Stars & Stripes, racing for the San Diego Yacht Club. The next year, a team from New Zealand, exploiting a clause in "The Deed of Gift," challenged Conner with a huge boat nicknamed "The Big One." Without time to redesign, Conner defended successfully with a 60-foot ultralight catamaran, the first use of a double-hull in the America's Cup.

In 1992, a new yacht class was defined for the lighter winds of San Diego. The International America's Cup Class (IACC) required boats of 75 feet in length, with 110-foot masts and a crew of 16. By using advanced materials, boats became lighter for their size, and hence faster in the light winds. While America 3 eventually defeated the Italian challenger in the final, the 1992 races were enormously expensive. The American defender built five boats, the Italian challenger four. Both spent over $60 million. It was decided in the future to reduce expenses; each team would be limited to only two boats, with further limits on the use of sails and other equipment.

The 1995 cup races would follow a "round-robin" format. First, the boats would be divided into two groups: the defenders, from the country of the current cup holders, and the challengers, from all other nations. The racing would then be divided into three parts. In the first, which will start in January, the challengers will race against each other for the right to enter the final (this will be called the Louis Vuitton Cup). In the second, which will run simultaneously with the first, yachts from the host country will race for the right to defend. Finally, in May, the winning challenger team will race against the winning defender team for the America's Cup. Boat designs will be allowed to evolve between each race, until the start of the final.

Exhibit 1 shows a picture from a recent America's Cup race. Typical time differences between first- and second-placed boats would usually be less than one minute.

The Design of a Racing Yacht

The design of a modern day racing yacht comprises four essential elements—the hull, the keel, the mast, and the sails (see **Exhibit 2**). The objective of the design team is to produce a light boat with as low a drag factor as possible. The structure, however, must also have the strength and stability to cope with highly variable wind and sea conditions. To achieve this balance, teams rely heavily on the skills and experience of the lead designer to make many critical trade-offs during the design process.

The bulk of the initial design work focuses on the hull and keel, as these are on the critical path for the construction of the yacht. To develop these, designers have traditionally relied on what is referred to as the "tank and tunnel" process for getting feedback on performance. This process entails construction of a series of scaled-down physical prototypes which are tested in a wind tunnel and a towing tank (a large swimming pool equipped with a winch at one end, which tows the prototype down the middle) providing data on the amount of drag generated by a particular design.

During the initial stages of a typical yacht development, around 5 to 6 physical prototypes are built at one-quarter scale (20 feet) and subject to testing in the wind tunnel and towing tank. Fabrication and testing of these prototypes takes several months and costs about $50,000 per prototype. Data on the performance of each of these designs are analyzed to assess their relative performance characteristics and used to project potential design enhancements. A further set of prototypes is then built, and the whole process repeated. This series of prototype iterations typically occurs 3 or 4 times prior to freezing the design for construction. As Peterson explained:

> The tank and tunnel method is a design process where experimentation occurs in bursts. Every couple of months, you get back the results of your experiments. As a result, there is a limit to the number of design iterations you can perform. A typical project can rarely afford more than 20 prototypes, due to time and money constraints. In each design cycle, you have to rely on big gains in performance.

The Use of Simulation in Design

The design of the critical surfaces on a modern day racing yacht is a complex activity. The presence of many interactions means it is not easy to predict the effect of even small changes in the structure. The system is "chaotic," and predicting its behavior is much like trying to predict the weather. While traditional "tank and tunnel" design methods rely on experienced designers and informed trial and error to overcome such complexity, the advent of cheap computer hardware and automated design tools have led to rapid advances in the possibility of simulating designs.

Modern day yacht design makes use of several tools to help automate the process. Among the most important are Finite Element Analysis (FEA), a tool which analyzes the structural characteristics of a design; Computational Fluid Dynamics programs (CFD), which help simulate the flow of water over the yacht's critical surfaces; and Velocity Prediction Programs (VPP), which predict how fast a particular design will be in a given set of wind and sea conditions.

CFD programs were originally developed for the aerospace industry, traditionally being used to model the flow of air over an aircraft's control surfaces. The software is "panel-based," the structure first being "broken up" into many small panels, each of which is represented by a set of mathematical equations. The program links these panels together to form a model of the complete design, then solves a set of equations governed by fluid mechanics theory to calculate the pressures and flows at the surface. While CFD had been around since the sixties, its application to yacht design was a recent phenomenon as the teams began design work for the 1995 America's Cup. In its initial applications, it had met with only limited success, and opinions were mixed as to its usefulness.

Advantages of Simulation

The major advantages of simulation over traditional design methods fall into three main areas. It is cheaper and faster than constructing physical prototypes, generates more insight into why particular designs are better or worse than others, and avoids problems associated with "scaling-up" the design from a physical prototype to the real world.

The primary advantage of simulation is in its speed and cost. While programs often require a significant amount of computing memory and processing power, once a basic design has been configured, design iterations can be run in a matter of hours, at little cost. The only limitation on how many iterations can be conducted relates to the amount of computer power available and, more important, the capacity of the design team to interpret results. In general, the bottleneck becomes a team's ability to generate and evaluate new configurations, not its ability to test them.

Another important advantage of simulation is that it establishes an understanding of the trade-offs involved with alternative design choices. Although tank and tunnel methods give a good indication of the overall performance of a design, they do not help the designer interpret why one design is performing better than another. CFD, by comparison, can show the pressure distributions and flows around a hull or keel which generate the drag produced by a given design.

A final advantage of simulation is that it avoids the problems of "scale-up." This occurs when the use of scaled-down models introduces distortions which affect the accuracy of test results. For example, certain types of drag, generated by the chaotic nature of a fluid flowing over a surface, are very sensitive to scale; hence, results from reduced-scale physical models are likely to be inaccurate. The use of simulation avoids such a bias.

Drawbacks of Simulation

While simulation has many advantages over tank and tunnel tests, these tools are, however, complementary. As Peterson emphasized, "Even with all the simulation in the world, no one is going to commit $3 million to a yacht without towing it down a tank first!" Physical prototypes are used extensively early in the design process to set the basic parameters of the hull and keel. Once these have been defined, simulation is used to help optimize their shape.

The importance of simulation is greatly increased once the hull and keel have been built. CFD can be used to substantially improve the performance of the yacht through the design of aerodynamic wings which attach to the bulb at the bottom of the keel (the lead weight which gives a yacht its stability). In the run up to a major race program, extensive testing and refinement of these appendages occurs, driven by the results of simulating different designs. These changes can lead to substantial improvements in performance.

Ultimately, however, all of these tools are only as good as the designer in whose hands they are placed. The lead designer is responsible for putting together the initial concept, without which no amount of simulation will yield a good design. Also in charge of directing the experimentation strategy, the designer is the person who says "what to try next." The concept design and experimentation strategy together provide critical "stakes-in-the-ground" and a sense of direction—activities for which automated design tools provide little help. As Peterson noted:

> The CFD program can't design a yacht from scratch without conceptual input. It doesn't know what parameters it should be optimizing. Consider designing a golf ball to fly as far as possible off the tee. The computer won't tell you the ball should have dimples, but if you specify this as a design parameter, it will find the optimal dimple pattern and density for you.

Team New Zealand

During May 1993, general manager Peter Blake began putting together the team of people that would work together for over two years in an effort to win the America's Cup. The Team New

Zealand syndicate comprised about 50 people, with activities split between team management, design and construction, and the crew, skippered by Olympic Gold medalist Russell Coutts (see **Exhibit 3**).

The budget for the syndicate, raised from corporate sponsors in New Zealand, was $20 million. While comparable to the budgets of other teams, Team New Zealand had decided to build two boats, rather than one, due to the experimental benefits this would give them during the testing period. Given the full cost of a boat, mast, keel and sail program was around $3 million to $4 million, it was clear from the start that the money for other resources would be severely limited. The team would need to be small, focused, and highly motivated, with everyone adopting multiple roles.

Blake's philosophy in running the team was to have all the critical people on board from the beginning. On 24th May 1993, the team assembled for the first time. Rather than dive straight into the detail of design and crew training, they spent the first three weeks working together with an external consultant to outline the mission for the team and a vision of how they would work together. Peterson described the process:

> We spent a lot of time going over why certain teams had won or lost in the past. What we found was that unsuccessful efforts were often driven by one or two personalities, be they designer-driven, skipper-driven, or owner-driven. Successful teams were truly "managed," not dominated by one voice. Hence we wanted to run the syndicate in a democratic fashion. When we had differences of opinion on which direction to go, we'd put it to a vote. One of the most important outputs of the three weeks was the mission statement which described the way that things would run. Above all, we stressed open communication and dissemination of knowledge, even to the extreme of running classes on yacht design and weather forecasting for anyone who was interested.

With the three-week "vision thing" behind them, the staff at last assumed their more traditional roles. The crew began training, using the yachts which had been built for the last America's Cup, and the design team began work on the concepts for the new design.

The Design Process

Doug Peterson was appointed to lead the design team. An American by birth, Peterson had extensive experience with designing boats and racing yachts. Peterson had no formal design or engineering training, but had been designing boats for as long as he could remember: "This is what I have always done. I can remember when I was in high school, I would spend all my time designing boats on pieces of scrap paper instead of paying attention in class." About 30 years and thousands of designs later, he was considered to be one of the world's leading yacht designers. His latest achievement was the design of the America 3 boat, the America's Cup winner in 1992. Peterson was given responsibility for developing the overall design concept for the Team New Zealand boat, specifying test models, analyzing results, and developing construction plans.

As the design team planned to make extensive use of automated design and simulation tools, Peterson assembled a mix of experienced yacht designers and simulation experts. Among them, Dave Egan was recruited to run the design simulations. Egan's appointment brought to the team prior experience in simulating yacht designs and a working knowledge of the required computer hardware, having previously been a sales agent for Silicon Graphics.

The design was initially driven by Peterson, who defined the initial boat concept and specified an implementation plan. Peterson drew upon the knowledge he had accumulated with the America 3 team to put his first thoughts to paper. Given America 3 had built five boats, each of which was significantly different in design, he had a lot of experience to help him. During the design process, the America 3 team had conducted over 65 prototype tests in the wind tunnel alone.

Egan's first job was to code this concept design into a geometry model for the simulation program, providing a baseline for performance. With this accomplished, design iterations and performance simulations began in November 1993. The initial simulations focused primarily on the design of the hull, with relatively simple keel variations (see **Exhibit 4**). The team would have to commit to the hull design in May 1994, in order for construction to begin.

The Simulation Effort

Running CFD required substantial amounts of computer power. For example, to simulate the keel required coding 13,000 individual panels as part of the modeling program, creating data files of 6 to 8 Gigabytes in size. While several syndicates were using similar analytical programs, the resources available to them and strategies they followed differed considerably.

Most syndicates had lined up large corporations to help with the task, allowing processing to be performed on the largest and latest supercomputers. Young America, for example, had over a million dollars of computer time available to them, through a partnership that included both Cray and Boeing. Boeing ran the design simulations on Cray supercomputers based in their headquarters in Seattle, using advanced CFD software developed for their aerospace needs. These machines were among the world's fastest computers, each costing several million dollars. Every few weeks, the Boeing engineers would run large batches of simulations and feed back their results to the Young America designers in San Diego. This allowed them to test a massive number of experimental designs.

The strategy adopted by Team New Zealand reflected the resource constraints presented by the budget. The team decided to use a small network of workstations which could be operated locally. Given the poor history CFD simulation had in yacht design, Egan was given less than $100K to cover personnel, hardware, and software. As he recalls:

> The early days of the project were a constant challenge to find resources. We were running around companies looking for computer time. At one, we managed to grab a 16 processor Challenge computer for a month prior to it being commissioned. The MIS guy never knew what happened! Then we gained access to a SunSparc2™ workstation. Soon, however, the rising number of design iterations we needed to explore began to exceed its capacity.

As luck would have it, during Christmas 1993, Jim Clark, the CEO of Silicon Graphics, was in New Zealand having his yacht refitted. A keen sailor, Clark had invited several members of the team aboard his yacht. Over dinner, as he learned of their predicament, he immediately offered the INDY™ workstation installed in his yacht for the team to use. As Egan explains:

> Making contact with Jim was extremely timely. Although we declined the offer of his waterproof INDY, he did put us in touch with the local SGI office. They gave us access to the spare cycles on their demonstration machines, a 4 processor Challenge™ server, and a couple of workstations.

The involvement of Silicon Graphics in the project grew with time. The company eventually became a sponsor of the team and lent a lot of computing equipment to the effort. This effectively increased the syndicate's simulation budget significantly. With a combination of workstations, the team could now simulate a new design every 2 or 3 hours. It gave the team immediate access to experimentation as the equipment was located a few feet from the dock. Egan emphasized the benefits of this approach compared with the tank and tunnel tests:

> Instead of relying on a few big leaps, we had the ability to continually design, test, and refine our ideas. The team would often hold informal discussions on design issues, sketch some schematics on the back of a beer mat, and ask me to run the numbers. Using traditional design methods would have meant waiting months for results, and by that time, our thinking would have evolved so much that the reason for the experiment would long since have been forgotten.
>
> We considered the crew our customers, in charge of what went into the design. They needed to drive the process. By having a computing strategy based upon local workstations, we had the ability to display results of simulations to them using flow-fill graphics. How we demonstrated the difference between two designs turned out to be a powerful marketing tool to help convince the crew of the benefits.

Team New Zealand's approach to simulation was extremely practical, heavily influenced by Peterson's experience. As he explained:

> Dave [Egan] was very realistic on the uses and limitations of CFD. In practice, if you start with a bad design, simulation won't get you anywhere near a good one. Some of the other syndicates let CFD drive their process. The Australians, for example, had some really deep simulation experts, and see where that got them.[1] At the end of the day, the real performance advantage is in the initial design. Everything else from there on in is just incremental improvement.
>
> Take the Velocity Prediction Program. Trying to work out how the sails will perform is an extremely unreliable science. There's so much variability in the air flow. I told them to tweak it until they got the answer I expected; then we looked at the coefficients to see if they looked reasonable. In the end, it doesn't matter. All you're looking at is the differences between alternative designs. No one really believes we can accurately predict the time we'll put up over the course in San Diego.

During the six months between November 1993 and May 1994, the team cycled through building physical prototypes for tank and tunnel testing three times, building 14 scaled-down models. The first set of prototypes provided a performance baseline for the initial concept, allowing the team to parameterize the Velocity Prediction Program and establish an estimate of the time around the course in San Diego. For the second and third set of prototypes, Peterson attempted to improve upon the initial design using a combination of experience and the flow-fill pictures generated by the CFD program. The improvements were significant, with the best prototype from the third set of tests bettering the time of the initial concept design by over two minutes. Egan described the situation as of early May:

> We were emerging with a robust design for the hull and keel. We had reduced the drag considerably over the concept design, but now, each new prototype was giving us less and less improvement. The third set of prototype tests, which we'd just got back, produced less than half the improvement of the second. There was a strong argument that the most improvement potential was now in the keel appendages, where a lot of enhancements can be made through the design and placement of the wings. To run those experiments, however, you have to put a real yacht in the water.

1 The Australian boat sank in one of the early trials, while racing against Team New Zealand

Testing of the actual boat in the water would be combined with CFD simulation of the keel. The two would have to be used together, since historically only about a third of the changes suggested by CFD resulted in "real" improvements to the design.

"Two boats, or not two boats, that is the question."

In late May 1994, the syndicate was faced with a major decision. Construction of the first yacht was planned to begin next month for an August delivery (boat construction took about two months). This would leave about four months for travel to San Diego, testing, and improvements before racing was to begin in January. However, the initial budget had provided money for two boats, and there were several theories on how to get the best value from the second one.

One option was to commit to building two yachts now for delivery in August. This way, the yachts could be used in combination to conduct test iterations on the keel wings. Another option was to build only one yacht now, use this to begin testing different keel wings, and meanwhile conduct another round of prototype testing on the basic hull and keel design. The second boat could then be built just prior to the start of the qualifying competition in January.

Building two boats now would allow Team New Zealand to put two boats in the water at the same time. Egan articulated the perceived logic behind a two-boat testing program:

> The two-boat testing philosophy is driven by the fact that the sea is a noisy environment in which to run experiments. If we build two yachts of similar design, we gain the ability to run better experiments. We can put two keels with different wing designs on each boat, race them, and see how much difference there is. Then we can swap the keels and make sure the results hold for the other boat and crew. This way, there is no argument over whether the wind or sea conditions affected the results. The problem is especially relevant, given the improvements that come from changes to the keel wings are relatively small, in the order of two or three seconds over the whole course. Detecting these differences in noisy conditions is extremely difficult. Just a minor change in wind speed between two trials can easily swamp the effect of a design change.

In the past, teams using a two-boat testing program had shown that it was possible to run and verify the performance of a different keel wing design practically every 24 hours, particularly if the two boats were identical. During the day, while the crew were on the water, the simulation team would analyze hundreds of potential improvements to the keel appendages and select one or two which appeared most promising (**Exhibit 5** shows the results of a simulation run for a specific keel design). Overnight, the construction team would work on the new designs and have them ready to sail the next morning. When the crew arrived, they would take the boats racing to verify whether the design changes produced "real" improvements.

With only one boat, alternative keel designs had to be removed and fitted during the sailing day. If conditions changed, the crew would often have to sail each design a number of times to identify which was better. As a result, verifying the results of design changes was slower than with two boats. Therefore, some argued that the differences in improvement speed between one- and two- boat testing would soon add up.

Building only one boat now traded the benefits of rapid feedback inherent in a two-boat testing process in favor of another cycle of testing prior to committing to the second yacht. Proponents of this approach argued that although the improvement potential in the basic design of the hull and keel had diminished, another cycle of tank and tunnel tests was still attractive. At the same time, running experiments with different keel appendages, even with only one boat, would still produce significant design enhancements. In combination, these two activities would yield greater overall improvement to the design and in addition would give the team the flexibility of building the second boat later in the development cycle. Building two boats now, they argued, was a waste of money and opportunity, particularly if these were identical.

Team New Zealand were not alone in having a budget big enough for two boats. As they tapped the sailing grapevine, however, other syndicates were taking diverse approaches.

The Japanese syndicate had decided to stagger the construction of their boats, opting to conduct another round of prototype tests before committing to the second one.

The leading Australian syndicate was building two boats simultaneously, but each was of very different design.

None of the three American defenders had decided to build two boats, despite having budgets of similar size to that of the New Zealand team. They had spent the money on other items, including more prototypes and iterations for tank and tunnel testing.

Team New Zealand's decision boiled down to three basic options: building two identical boats now; building two different boats now, perhaps one following one of Peterson's more aggressive concepts that hadn't made it to the wind tunnel yet; and building one boat now and one boat after some additional testing.

Exhibit 1 America's Cup Competition

Exhibit 2 Schematic of a Recent Racing Yacht

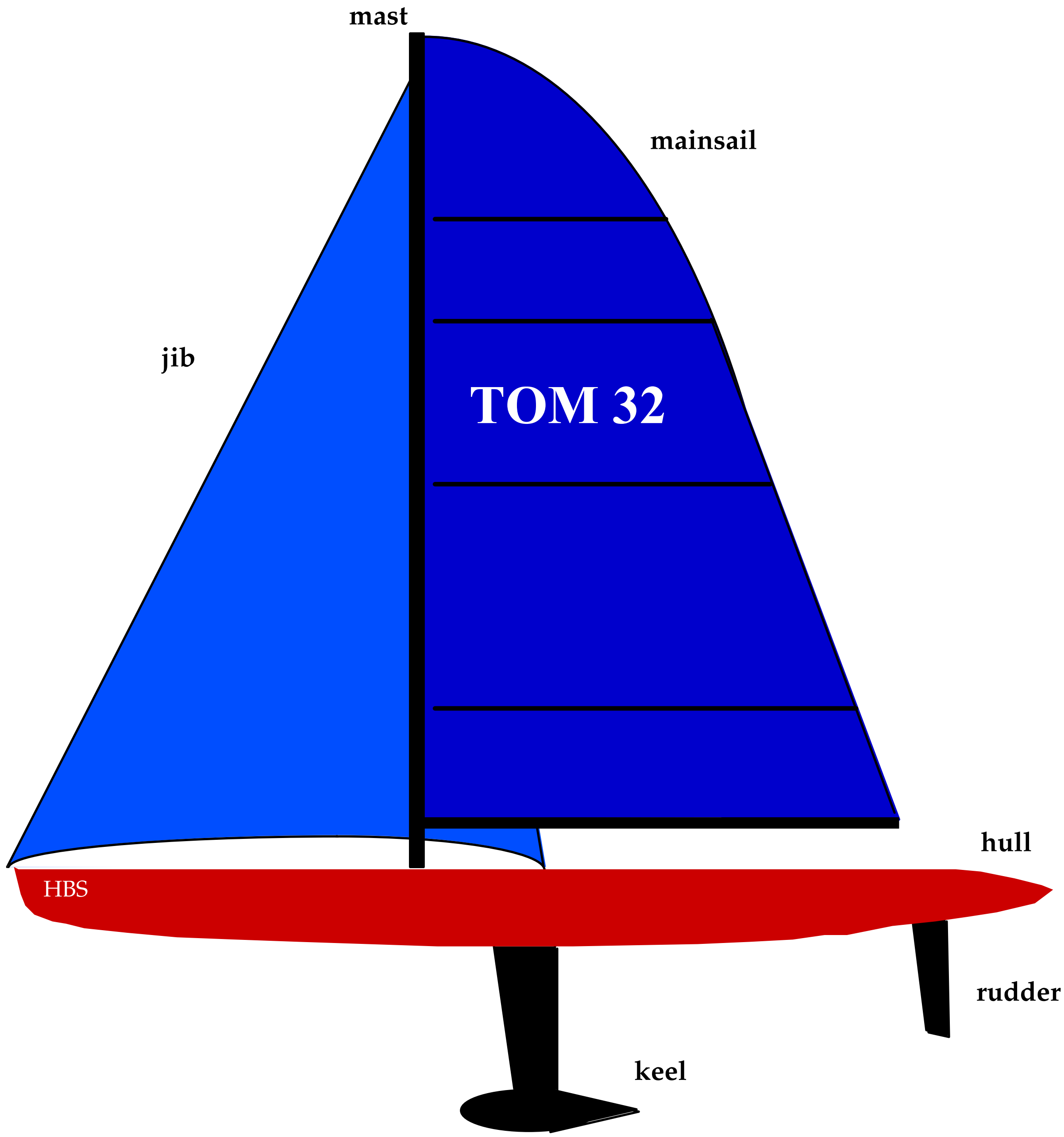

Exhibit 3 Team New Zealand Syndicate: Key Staff Members

Syndicate Head:	Peter Blake
Yacht Club:	Royal New Zealand Yacht Squadron
Syndicate Budget:	Estimated $20 million
Team Sponsors:	ENZA (New Zealand Apple and Pear Board) Lion Nathan (Steinlager) Lotteries Commission Television New Zealand Toyota New Zealand
Management	
Campaign Public Relations:	Alan Sefton
Campaign Business Manager:	Ross Blackman
Lead Crew	
Skipper:	Russell Coutts
Navigator:	Tom Schnackenberg
Afterguard:	Brad Butterworth Rick Dodson Murray Jones
Design Team	
Chief Designers	Doug Peterson Laurie Davidson
Computational Dynamicist	David Egan
Aero/hydro Dynamicist	Richard Karn
Performance Analyst	Peter Jackson
Structures/weather	David Alan-Williams
Construction	
Construction Chief	Tim Gurr
Structural Experts	Wayne Smith Mike Drummond Chris Mitchell Neil Wilkinson

Exhibit 4 Computer-Generated "Flow-Fill" Picture of an Early Design

Note: Red indicates the highest turbulence, followed by yellow, green, blue, and indigo.Minimizing turbulence reduces overall drag.

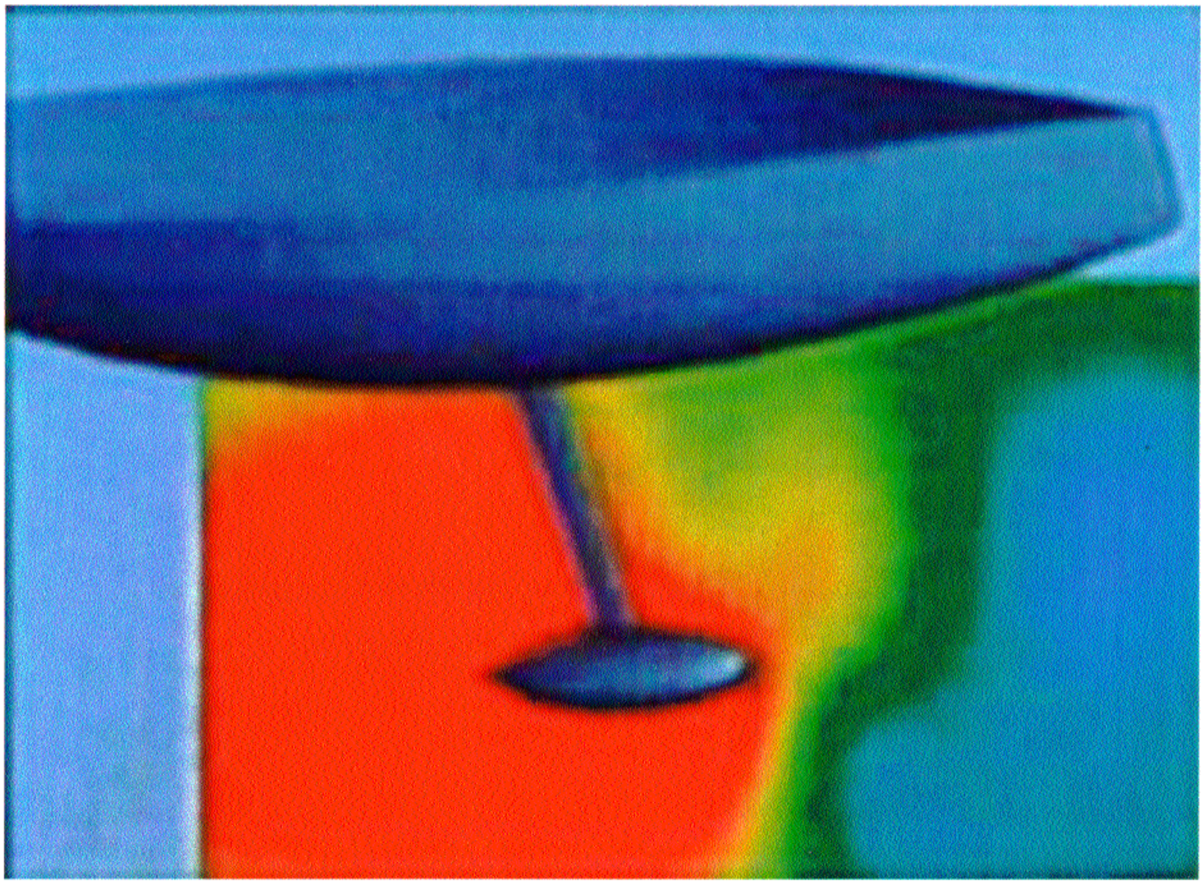

Exhibit 5 Computer-Generated Results of Keel Simulation

Note: Red indicates the points of highest drag on the keel, followed by yellow, green, blue, and indigo.