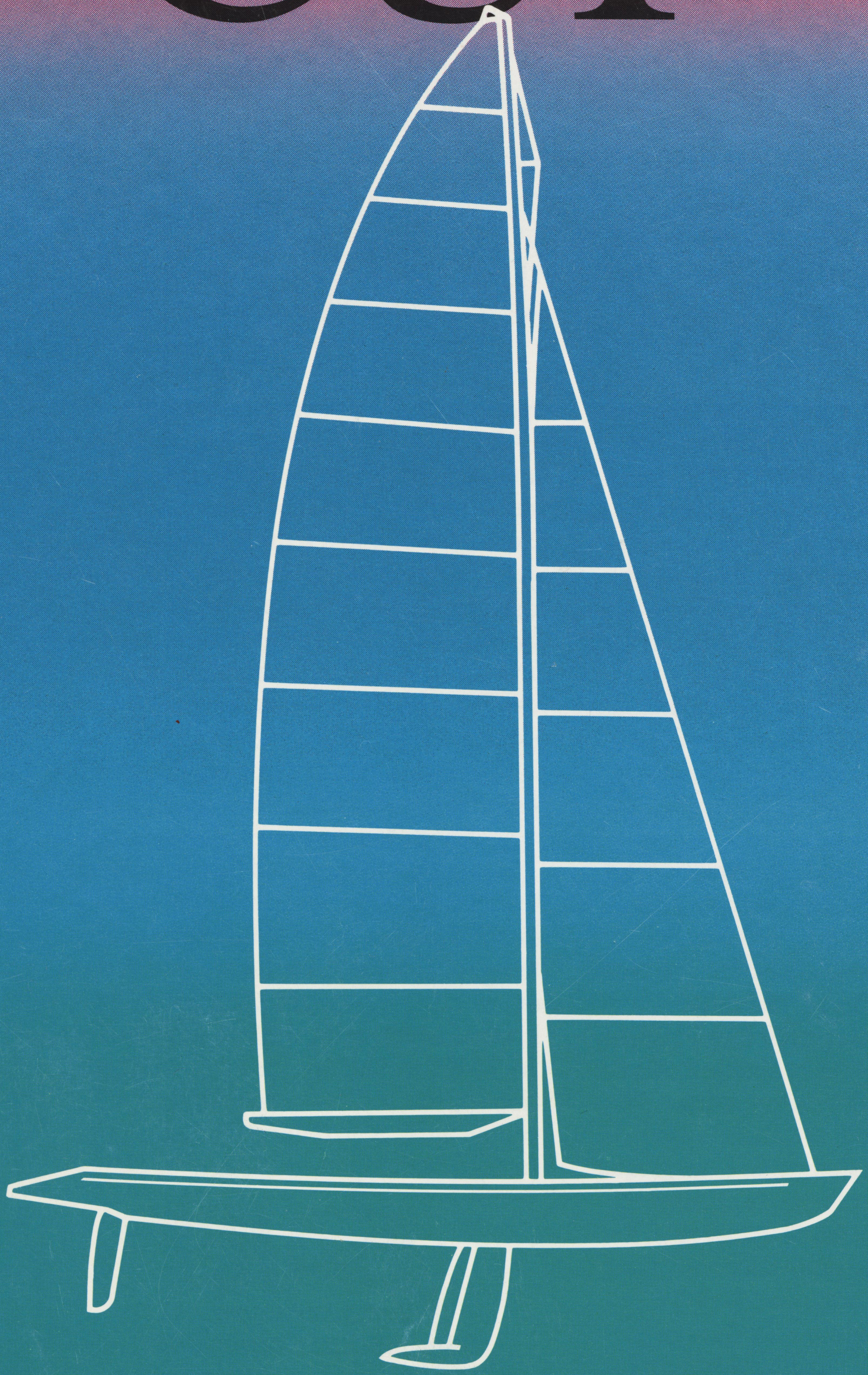
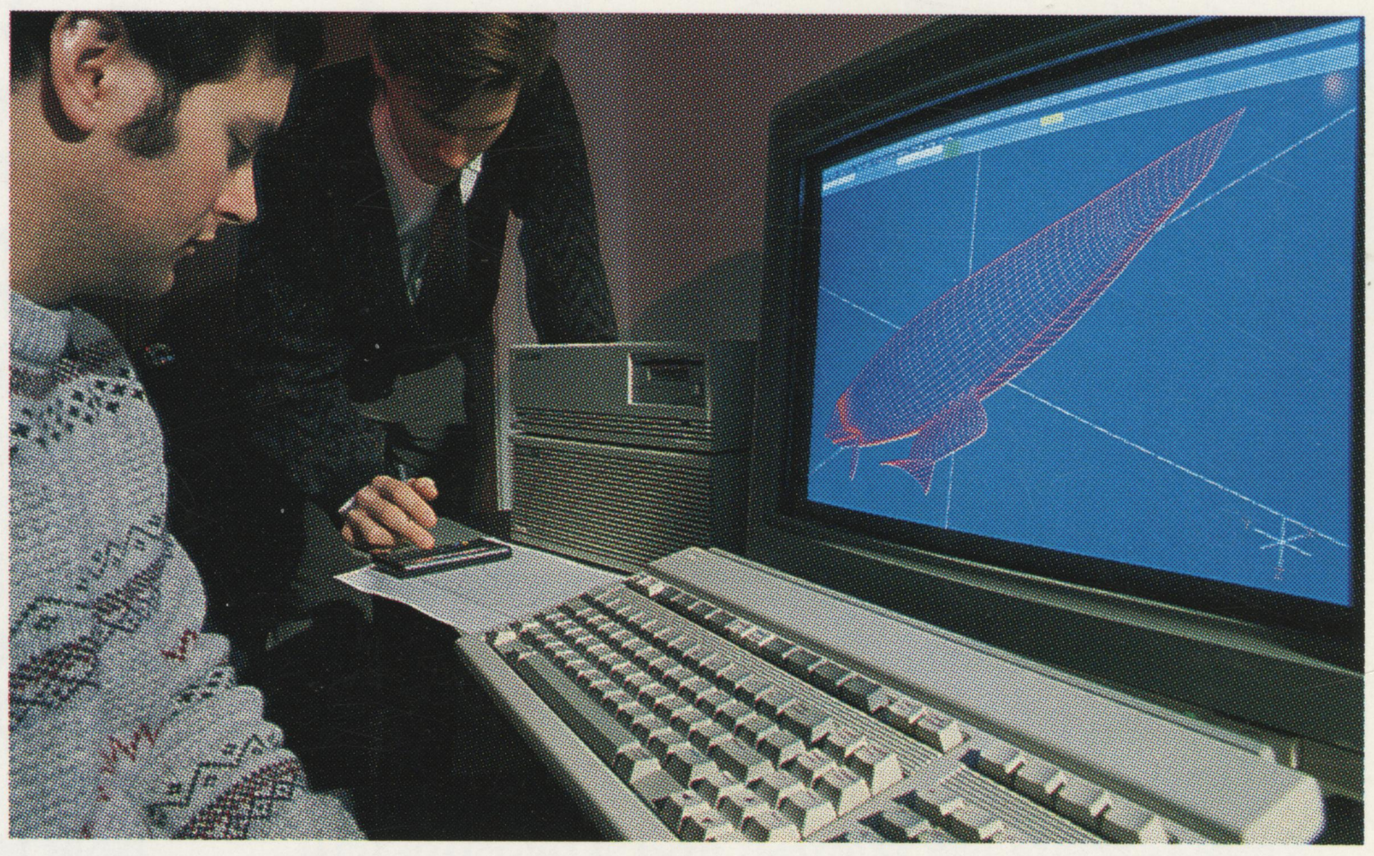
# TECHNOLOGY *AND* THE AMERICA'S CUP

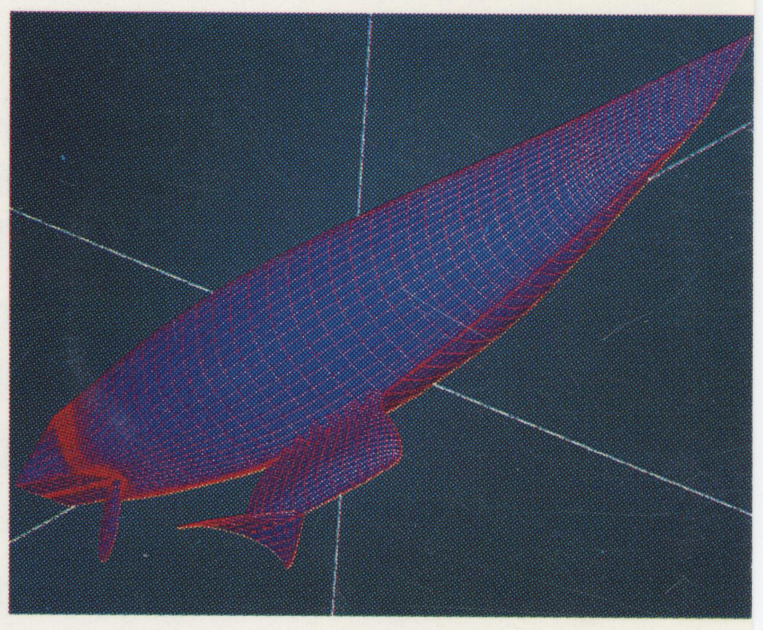


The 1983 loss of the America's Cup—the most prestigious yachting trophy in the world—left one critical question on many people's minds. Had skipper Dennis Conner and his crew been beaten by skillful sailing or by the Australia II's mysterious new design?

After extensive computer analyses of the Australia II, scientists at Science Applications International Corporation (SAIC) provided the answer: Conner had not lost the Cup - his boat had.

The Australia II's victory showed what a technically superior boat could do and launched a scramble to incorporate high technology into 12-meter racing. When the U.S. and other countries sought the Cup in 1987, one thing became clear: to an unprecedented degree, the outcome would depend as much on a contest among the scientists and engineers of the competing countries as on the competition among the sailors.





Recent America's Cup races have challenged U.S. leadership in technology. In 1984, Dennis Conner assembled a design team for the Sail America Foundation and the San Diego Yacht Club to win back the America's Cup in 1987. He recruited three top U.S. yacht designers—Britton Chance, Bruce Nelson and David Pedrick—as well as leading high-technology firms. Science Applications International Corporation (SAIC) served as a key technical support contractor for the team. To manage the high-powered combination of design and technical talent, Conner selected John Marshall, a world-class sailor with vast experience aboard 12-meter yachts. SAIC's Nils Salvesen was asked to lead the technology team.

Computer analysis played an unprecedented role in the design process for the 1987 challenge. In designing *Stars & Stripes*, the team used a computer simulation of sailing vessel dynamics known as the Velocity Prediction Program (VPP). The team entered physical information about the boat into the VPP to predict the optimum sailing angle and speed for any combination of wind speed and heading. SAIC and one of America's leading authorities on sailing, John Letcher, developed a specialized VPP program for 12-meter design.

The VPP allowed designers to predict what each design change meant to overall performance. The most promising designs were tested using one-third scale models in the ARCTEC wave tank facility.

Scientists from Grumman Aerospace took the lead computationally in applying potential flow panel methods (similar to those used for studying lift in aircraft) to identify promising keel shapes. To analyze keel designs, the design team harnessed the power of the world's biggest number-cruncher, a Cray XMP/48 supercomputer.

Data collected during the *Stars & Stripes* trials off Hawaii and Australia validated the VPP predictions. Peter Lissaman of AeroVironment (builder of the *Gossamer Condor* and *Albatross* aircraft) used modified aircraft dynamics equations to evaluate the tacking performance of *Stars & Stripes*.

More than anything, the hull form of *Stars & Stripes* '87 made her a winner, according to *Yachting World*. The hull design resulted from wave resistance computations made by another SAIC team, led by Carl Scragg in San Diego. They discovered that this hull form was optimum for the high wind speeds anticipated in Fremantle.

Finally, SAIC consultant John Letcher applied probability and game-theory methods to develop another code, the America's Cup Simulator (ACUPS). The ACUPS will race two boats around a computer course, showing the interaction under actual weather conditions. To achieve this realism, the ACUPS model relied on a ten year historical data base of wind and wave conditions off Fremantle, Australia. This was collected and analyzed by R. Lee Davis and Chris Bedford of Galson Technical.

In the end, the culmination of thousands of VPP runs, hundreds of computer flow codes, 33 model tests and four full-size boat trials, was the return of the America's Cup to the U.S.

However, Conner and Sail America did not have long to enjoy their victory. Just as they began to plan for the 1990 Cup regatta, a challenger upset tradition. The New Zealand challenge forced them into a match race three years earlier than planned.

The compressed time schedule made the 1988 design effort very different from the earlier effort. Time did not allow scale model testing, necessitating an even greater reliance on computer methods. Unlike the complex formula for the 12-meter rule, the 1988 design had only one major constraint, a 90-foot maximum waterline length.

SAIC, in conjunction with George Hazen, developed an integrated system for computer-aided hull design and geometry modeling based on the 3-dimensional code FAST YACHT. Based on these computer analyses, the design team produced two sleek, ultralight 60-foot catamarans. One catamaran employed the traditional soft sail. The other incorporated a radical new rigid winged-sail built by the creators of *Voyager*, the experimental plane that flew around the world without refueling. The winged-sail catamaran proved to be a powerful defender for the U.S. in 1988.

Today's America's Cup competition requires involvement in advanced technology designed to give our sailors an edge. The emphasis has shifted from a relatively few designers working in a more traditional, intuitive mode to multidisciplined teams of scientists, engineers, and designers working in a systematic, closely integrated fashion using the latest technology. At SAIC, we call this the system integration approach. This same approach will enable the U.S. to defend the Cup against foreign challengers in 1992.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To jump-start U.S. efforts to win the next America's Cup, Science Applications International Corporation (SAIC) organized a high-level research program called the Partnership for America's Cup Technology (PACT). PACT initiated an intensive effort to develop basic technology and sophisticated computer tools to help U.S. syndicates design their Cup boats.

"The next America's Cup races are set for May of 1992, barely two years away" said J.R. Beyster, Chairman and CEO of SAIC. "Foreign challengers are moving ahead with the critical technology and boat design process while we in the U.S. have been twiddling our thumbs waiting for the outcome of the court decision. The new International America's Cup Class rules are set. We've got to get on with the design job!"

To serve as general manager for PACT, SAIC retained John Marshall, an avid supporter of technology application in America's Cup efforts. For PACT's first project, Bruce Nelson, designer for Peter Isler's Syndicate, produced lines for a parent America's Cup yacht design, and tank tested it at the ARCTEC facility in Escondido, CA. Under the direction of SAIC senior researcher Carl Scragg and naval architect Eric Schlageter, researchers will feed the results into the SAIC Velocity Prediction Program (VPP). The VPP analysis will assess the speed potential of different boat designs and modifications. PACT will make the lines, experimental data, and the VPP available to viable American syndicates.

The San Diego America's Cup Defense Subcommittee endorses PACT as an important defense step. "We are extremely grateful to SAIC for their initiative," said Chairman Gene Trepte. "We believe this shared research will play an important role in helping America compete with strong foreign syndicates."

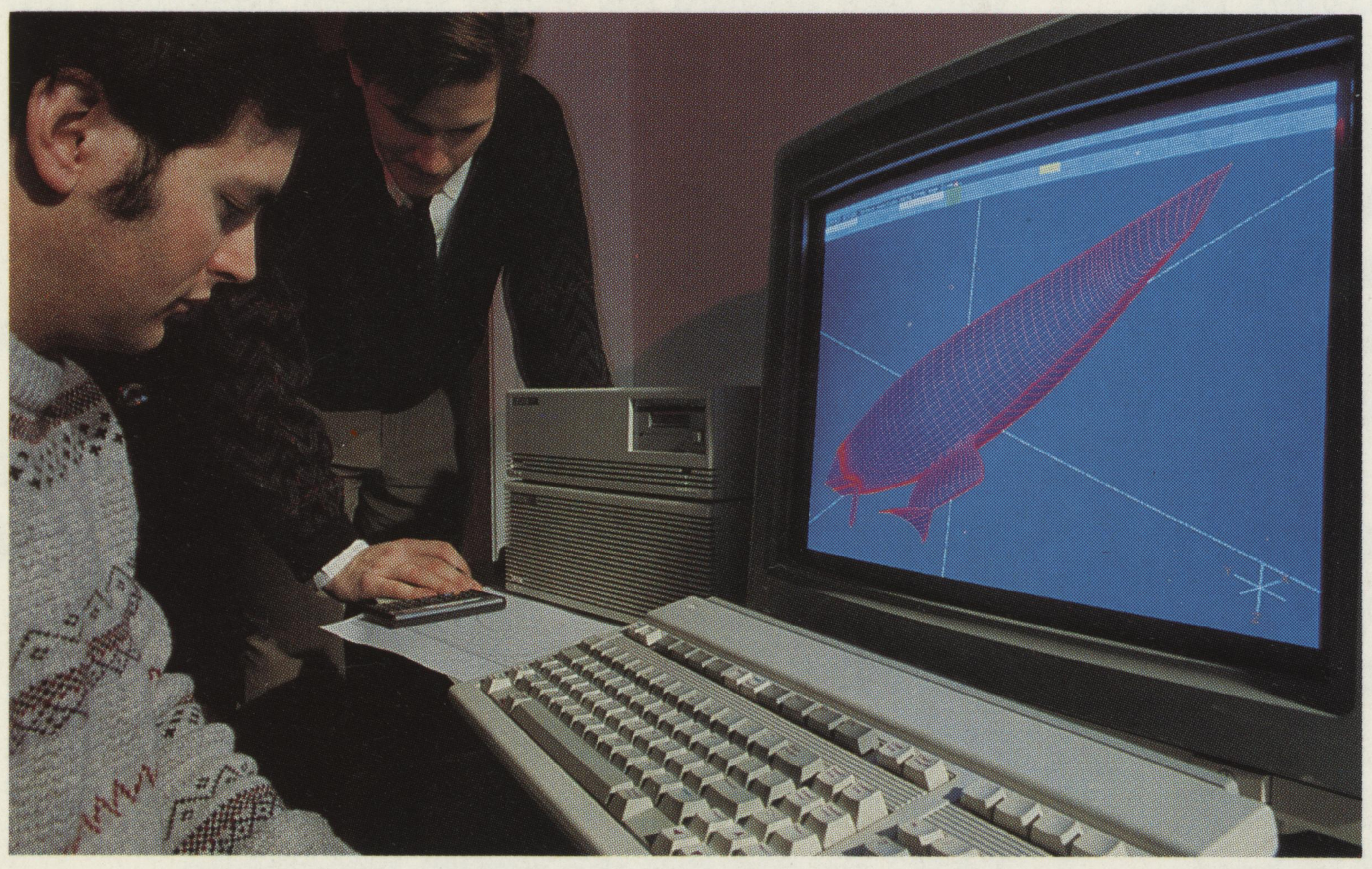
**PACT**
PARTNERSHIP FOR AMERICA'S CUP TECHNOLOGY
Technology to Retain America's Cup

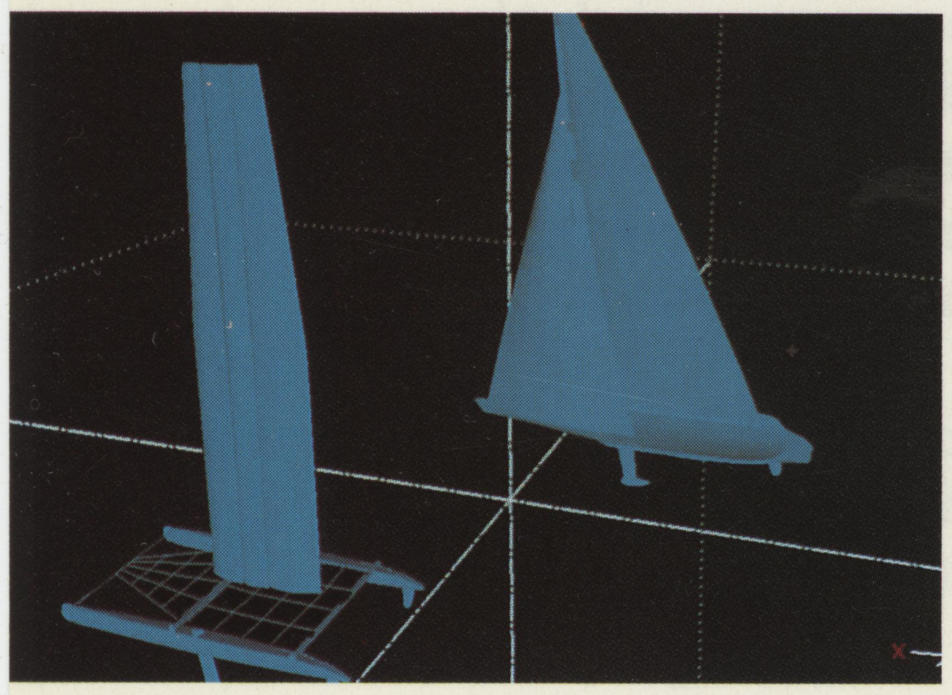
# TECHNOLOGY AND THE AMERICA'S CUP®

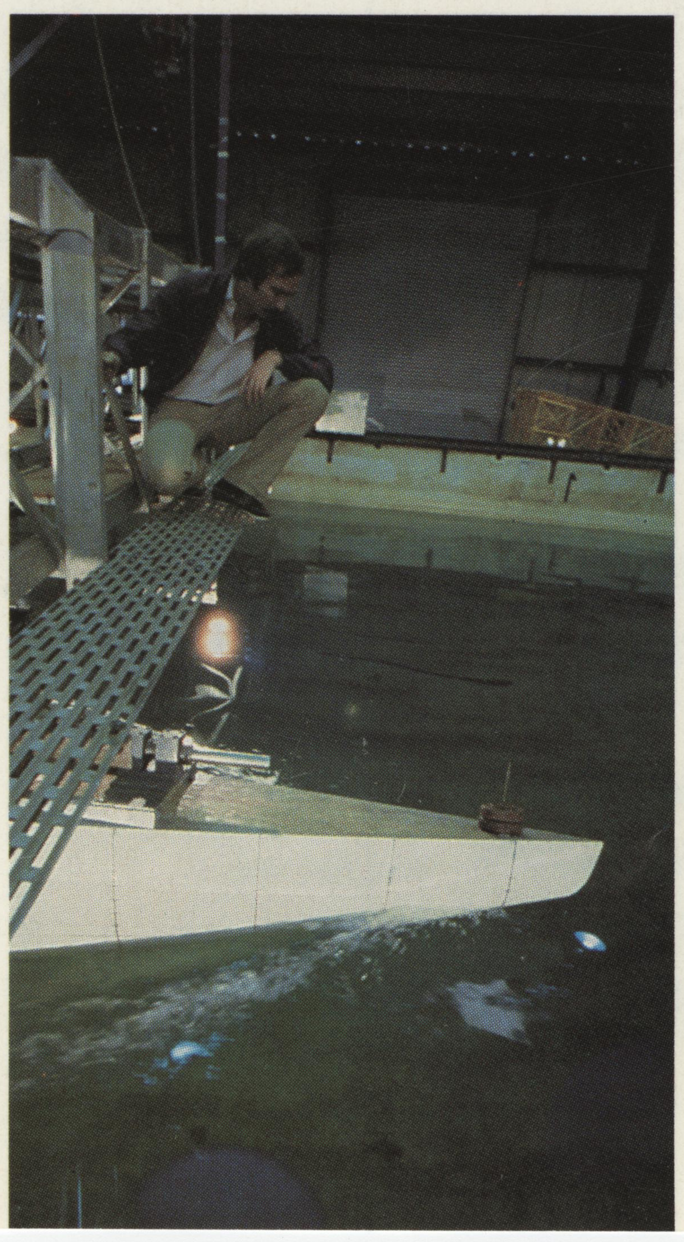
**F**ollowing the 1983 loss of the America's Cup — the most prestigious yachting trophy in the world — one critical question was on many people's minds. Had skipper Dennis Conner and his crew been beaten by skillful sailing or by the *Australia II's* mysterious new design?

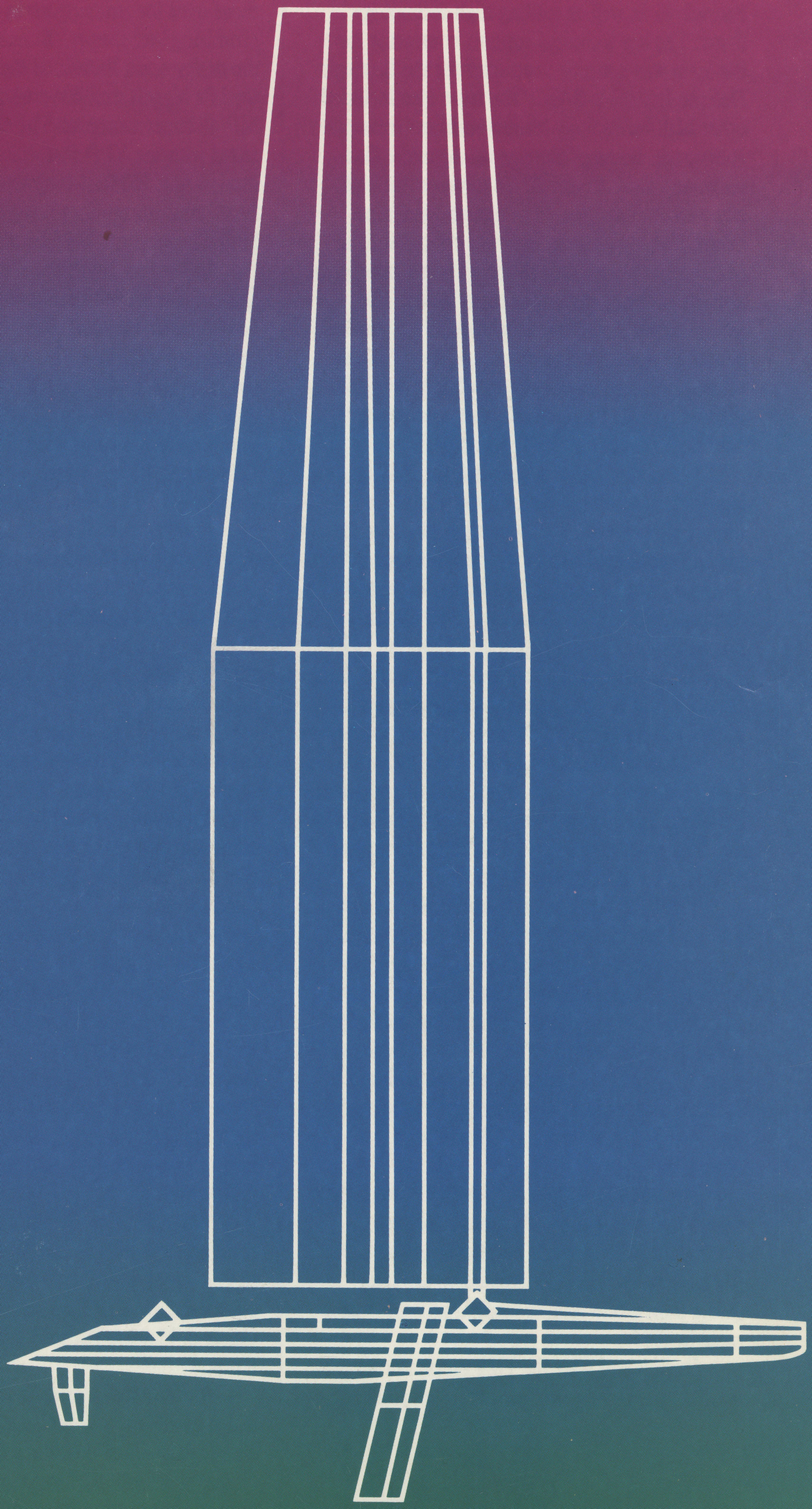
**A**fter extensive computer analyses of the *Australia II*, scientists at Science Applications International Corp. (SAIC) provided the answer: Conner had not lost the Cup — his boat had.

**T**he *Australia II's* victory showed what a technically superior boat could do and launched a scramble to incorporate high technology into 12-meter racing. When the U.S. and other countries sought the Cup in 1987, it was clear that to an unprecedented degree, the contest would be as much between the scientists and engineers of the various countries as between the sailors.









For the U.S., it became a race to prove that America was still the technology leader. When Conner assembled a design team for the Sail America Foundation and the San Diego Yacht Club, he recruited the top three U.S. yacht designers — Britton Chance, Bruce Nelson, and David Pedrick — as well as leading high-technology firms. The key technical support contractor for the team was a major contractor for the Strategic Defense Initiative, SAIC. The team also included other high-technology leaders such as Grumman Aerospace, Boeing Commercial Airplane Company, and Cray Research. To manage this high-powered combination of design and technical talent, Conner selected Harvard-educated John Marshall, a world-class sailor with vast experience aboard 12-meter yachts, as team leader. The technology effort, eventually involving a panel of nearly 30 scientists and engineers, from full-time participants to occasional consultants, was coordinated by Nils Salvesen, the manager of the Marine Hydrodynamics Division at SAIC.

When the design process for the 1987 challengers began, computer analysis played an unprecedented role. This was especially true for the Sail America Foundation design team. In designing the *Stars & Stripes* boats, they used a computer simulation of sailing vessel dynamics known as the Velocity Prediction Program (VPP). Physical information about the boat is input into the VPP and the program predicts the optimum sailing angle and speed for any combination of wind speed and heading. SAIC naval architect Clay Oliver in Annapolis, Md., and one of America's leading theoreticians in fluid dynamics, John Letcher, developed a special VPP program that was tailored to 12-meter design.

The VPP was crucial because, for the first time, it allowed designers to truly understand what every design change meant to overall performance. It also allowed scientists to weed out bad designs very quickly on the computer before going to model testing. The VPP's predictions were validated by data collected and analyzed by Richard McCurdy of Ockam Instruments during the *Stars & Stripes* trials off Hawaii and Australia.

For *Stars & Stripes '87*, the VPP predictions were borne out; the boat's speed advantage combined with Conner's hard-won sailing expertise gave *Stars & Stripes* impressive victories (more than a one-minute lead) in all four final races in 1987.

During and after the 1983 races, the *Australia II's* "secret weapon," its exotic winged keel, was a magnet for media attention. Scientists on the design team used computer analyses to unlock its secrets. When they began designing a keel for *Stars & Stripes*, a Grumman team, directed by Charles Boppe, took the lead computationally in applying potential flow panel methods (similar to those used for studying lift in aircraft) to identify promising keel shapes. To analyze keel designs, the design team harnessed the power of the world's biggest number-cruncher, a Cray X-MP/48 supercomputer. The designs were also tested with the VPP and with one-third scale models in a 300-foot-long wave tank. Another SAIC consultant, Tom Lang of Semi-Submerged Ship Corporation, oversaw all the model testing.

More than anything, it was the hull form of *Stars & Stripes '87* that made her a winner, according to *Yachting World*. The boat's design (unusually wide in the bow and even more so in the stern just under the water) was unfashionable after the *Australia II* win, but according to computations made by another SAIC team, led by Carl Scragg in San Diego, this was one of the hull designs with the least drag and wave resistance.

Another consultant, Peter Lissaman of AeroVironment (builder of the *Gossamer Condor* and *Albatross* aircraft) also contributed to the hull design. Lissaman used modified aircraft dynamics equations to evaluate how different hull shapes would affect *Stars & Stripes* tacking performance.

Finally, Clay Oliver of SAIC and John Letcher applied probability and game-theory methods to develop another code, the America's Cup Simulator (ACUPS). While the VPP can calculate the gain or loss in boat speed as a function of wind speed, the ACUPS will actually race two boats around a computer course, showing the interaction between the boats under actual weather conditions. To achieve this realism, the ACUPS model relied on a historical data base of wind and wave conditions off Fremantle, Australia, for the past ten years. R. Lee Davis and Chris Bedford of Galson Technical collected and analyzed this data, and helped develop forecasts for monthly (keel changes), daily (race/no race), hourly (sail selection), and minute (racing tactics) time scales.

When *Stars & Stripes* arrived in Australia, she came armed with one final piece of technology — an on-board computer system based on equipment from Ockam Instruments Inc., Data General, Hewlett-Packard, and Digital Equipment Corp.

And the fruit borne by the study of thousands of velocity prediction programs, the analysis of hundreds of computer flow codes, the testing of 33 one-third scale models in the wave tank, and the use of four, full-size hulls was, of course, the return of the Cup to America last year.

The Sail America Foundation and Conner did not have long to enjoy their victory, however. Just as they were beginning to plan for the 1990 Cup regatta, a challenger once again upset tradition, this time by forcing Sail America into an unexpected match race three years earlier than planned.

Because of the compressed time schedule, the 1988 design effort was very different from the earlier effort. There was not enough time for scale model testing necessitating an even greater reliance on computer methods. Second, in contrast with the traditional 12-meter design, the 1988 design was essentially only constrained to a 90-foot maximum waterline length. Because of this, Clay Oliver and John Letcher developed revised VPP codes for evaluating both design trade-offs for the new *Stars & Stripes* boats and the capabilities of their New Zealand opponent. In addition, SAIC naval architect Chris Cressy and consultant George Hazen developed an integrated system for computer-aided hull design and geometry modeling that is based on the 3-dimensional code FAST YACHT.

Based on these computer analyses, the design team produced two sleek, ultralight, 60-foot catamarans. To help design them, four new designers joined the *Stars & Stripes* team. Gino Morrelli and Bernard Nivelt, two internationally-known, "Formula 40" catamaran designers, concentrated on a more traditional, soft sail design while Dave Hubbard and Duncan MacLane were the key designers for a more exotic winged-mast or "hard-sail" catamaran. Both boats were built from an extremely strong, yet lightweight composite material — carbon fiber epoxy — that the design team choose with help from Mike Zuteck.

The radical new rigid wing sail was built by the creators of Voyager, the experimental plane that flew around the world without refueling. Burt Rutan and his company, Scaled Composites, constructed and helped design the winged mast with support from Sikorsky Aircraft and from John Roncz of Gemini Technical.

The effort to win back the Cup brought with it a new involvement in advanced technology designed to give our sailors an edge. The emphasis has shifted from a relatively few designers working in a more traditional, intuitive mode to multi-disciplined teams of scientists, engineers, and designers using the latest technologies and working in a systematic, closely integrated fashion. At SAIC, we call this the system integration approach. It is the same approach that has allowed us to build a company — forged over nearly two decades of solving complex technical problems — that understands how to produce total, integrated solutions that work.

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# SAIC technology helps win back America's Cup

SAIC
Science Applications International Corporation

April 29, 1987

Science Applications International Corporation became involved in the 1986-1987 America's Cup campaign because we felt that our national honor in technology had been challenged. The Cup's loss was symbolic of world-wide threats to American technological leadership. Immediately after the races, it was clear that the Australians had an innovative technical design ... the winged keel. But more importantly, as we later learned, they demonstrated a systematic approach to the *process* of design. That process included a balance between innovation, engineering analysis, and rigorous testing which was lacking in the U.S. program. Essentially, they beat us in a technology race, an area believed to be a U.S. strength. To win in 1987 we needed to overtake them technically in less than three years.

Dennis Conner realized all of this from the start and chose a team approach to developing and applying technology to help design a faster boat. It was a team effort in every sense of the word. There was a group of three gifted naval architects, several technology and test facility contractors, SAIC scientists, and numerous consultants, advisors, and technicians ... all of whom had major contributions to make.

*Stars & Stripes'* victory is a tribute to the genius of Dennis Conner, both for his helmsmanship and his leadership, and to John Marshall, the design coordinator, who pulled us together to produce a faster boat. We are very proud to have been a major part of this cooperative effort. The victory is something all Americans can be proud of. It also has taught us an important lesson by showing that American science and ingenuity, if applied cooperatively, can produce winning results.

SCIENCE APPLICATIONS INTERNATIONAL CORPORATION

J. R. Beyster
President and Chairman of The Board

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*Other SAIC Offices: Albuquerque, Atlanta, Boston, Chicago, Colorado Springs, Dayton, Denver, Huntsville, La Jolla, Los Angeles, Oak Ridge, Orlando, Palo Alto, San Diego, Seattle, Tucson, and Washington, D.C.*

# SAIC scientists and engineers help *Stars & Stripes* win America's Cup

When the Sail America Foundation yacht, *Stars & Stripes '87*, battled to win back the America's Cup last month, it was more than a race between sailors, it was a race between scientists and engineers as well. Three years of computer design work by SAIC was on the line.

Prior to losing the America's Cup in 1983, American 12-meter yacht designers did not use state-of-the-art hydrodynamic codes. For the 1987 America's Cup, all the syndicates used these codes to build their boats. SAIC had been using similar codes for years in its work for the U.S. Navy's Office of Naval Research, but the America's Cup races would test whether our technology could be applied successfully to 12-meter yacht design.

"Public demonstrations of superior technology are hard to come by," observed John Marshall who headed the *Stars & Stripes* design team. "It's difficult to demonstrate the superiority of a new jet fighter costing hundreds of millions of dollars." But the America's Cup, he said, provided "a technological showplace."

SAIC staff first became interested in 12-meter yacht design during the 1983 America's Cup races when they saw how much better *Australia II* was than the U.S. boat, *Liberty*. "It was more than just a problem in hydrodynamics," said SAIC president J. Robert Beyster. "It was symbolic of the threats being mounted against America's technical leadership in so many key technology areas."

*Public demonstrations of superior technology are hard to come by, but the America's Cup provided a technological showplace.*


Nils Salvesen, manager of SAIC's Marine Hydrodynamics Division in Annapolis, compared the loss of the America's Cup to the launching of Sputnik by the Soviets, noting that "America should have been stronger because of our technological advantage." Both events galvanized action.

A short while after the 1983 races, the Office of Naval Research asked the Annapolis division to find out why the winged keel made the *Australia II* faster than *Liberty*. According to calculations performed by Doug Loeser and John Talcott of the Naval Hydrodynamics Division in La Jolla, *Australia II's* winged keel design resulted in approximately 15 percent greater keel efficiency. After discussing these results with the Sail America Foundation, the company was subsequently contracted by the Foundation to perform hull and keel analyses of challenge boats being designed to win back the Cup.

**On the cover:** *In the waters off Fremantle, skipper Dennis Conner and the Stars & Stripes crew won back the America's Cup in a boat that SAIC helped design. Photo by Daniel C. Wilson/Creative Services.*

**Left:** *To prepare for America's Cup, the Stars & Stripes boats sailed in trial races off Hawaii.*

In joining Sail America's design team, SAIC scientists from the Annapolis division and from the Naval Hydrodynamics Division in La Jolla began working with scientists from Boeing Aerospace, Grumman Aerospace, and Cray Computer; with yacht designers Britton Chance, Dave Pedrick and Bruce Nelson; and with Marshall and *Stars & Stripes* skipper Dennis Conner.

Using a velocity prediction program (VPP-12) developed by SAIC/Annapolis, the scientists evaluated the performance of more than 100 hull and keel design innovations.

Then SAIC scientists began "computer sailing" in specific conditions. "That gave us input for a larger computer program (the America's Cup Simulator or ACUPS) which determined how the final boat design would perform in different wave and wind conditions," said project director Clay Oliver.

"When the designers made a change in the keel or hull, we would race their boat against another boat on the computer and tell them whether the new boat would be faster or slower in given wind conditions," Oliver said.

To ensure accurate wind conditions on the computer, the design team had access to weather data from Fremantle for the past ten years.

Once computer simulations had eliminated less workable designs, 22-foot yacht models were built and tested at Offshore Technology Corporation's wave tank in Escondido, Calif.

Finally, four full-scale 12-meter yachts were built. The first, *Stars & Stripes '85*, proved a real breakthrough. Not only was it fast, but its performance was almost exactly as predicted by SAIC's Velocity Prediction Program. "It was so much faster than *Liberty* that we couldn't even use *Liberty* for testing," remembers Carl Scragg, who headed the SAIC/La Jolla team from the Naval Hydrodynamics Division.

The second boat, *Stars & Stripes '83*, was built with the same hull and keel as *Stars & Stripes '85*, but in a different size. That boat helped the design team study how size influenced performance. A third boat, *Stars & Stripes '86*, was an experiment involving a more radical design with a full bow shape. Although it was extremely fast when sailing downwind, *Stars & Stripes '86* tended to be slower and less stable when sailing upwind and the sailors preferred *Stars & Stripes '85*.

Then the design team proposed a final boat that would consolidate all their experience. But skipper Dennis Conner liked *Stars & Stripes '85* so much that when the design team sought permission to build *Stars & Stripes '87*, he balked. The designers argued that although *Stars & Stripes '85* was fast in heavy weather, it was vulnerable in light weather and at the low speeds used during tacking.

According to Marshall, one argument finally convinced Conner: SAIC's Velocity Prediction Program had been 100 percent accurate until then: "trust the scientists."

*One argument finally convinced Conner: SAIC's Velocity Prediction Program had been 100 percent accurate until then: "trust the scientists."*

*Stars & Stripes '87* was built and shipped to Hawaii for five days of testing against *Stars & Stripes '85*. Conner made his decision in one day.

"What I got was a boat that was more competitive in the 12 to 18-knot wind ranges and still a little faster in the higher ranges," he said.

By the time the final design change came, SAIC had won over the Sail America Foundation. Right before the start of the America's Cup semifinals, *Stars & Stripes '87* installed a new pair of wings on its keel to give the boat better performance in sailing upwind.

"We don't have to test the new wings," Sail America chairman Malin Burnham told reporters at that time. "We are not experimenting. We have spent hundreds of hours on computer designs and we are 75 percent certain the wings will give us a substantial increase in speed. There's a five percent chance of no change in speed and no chance that we will be slower."

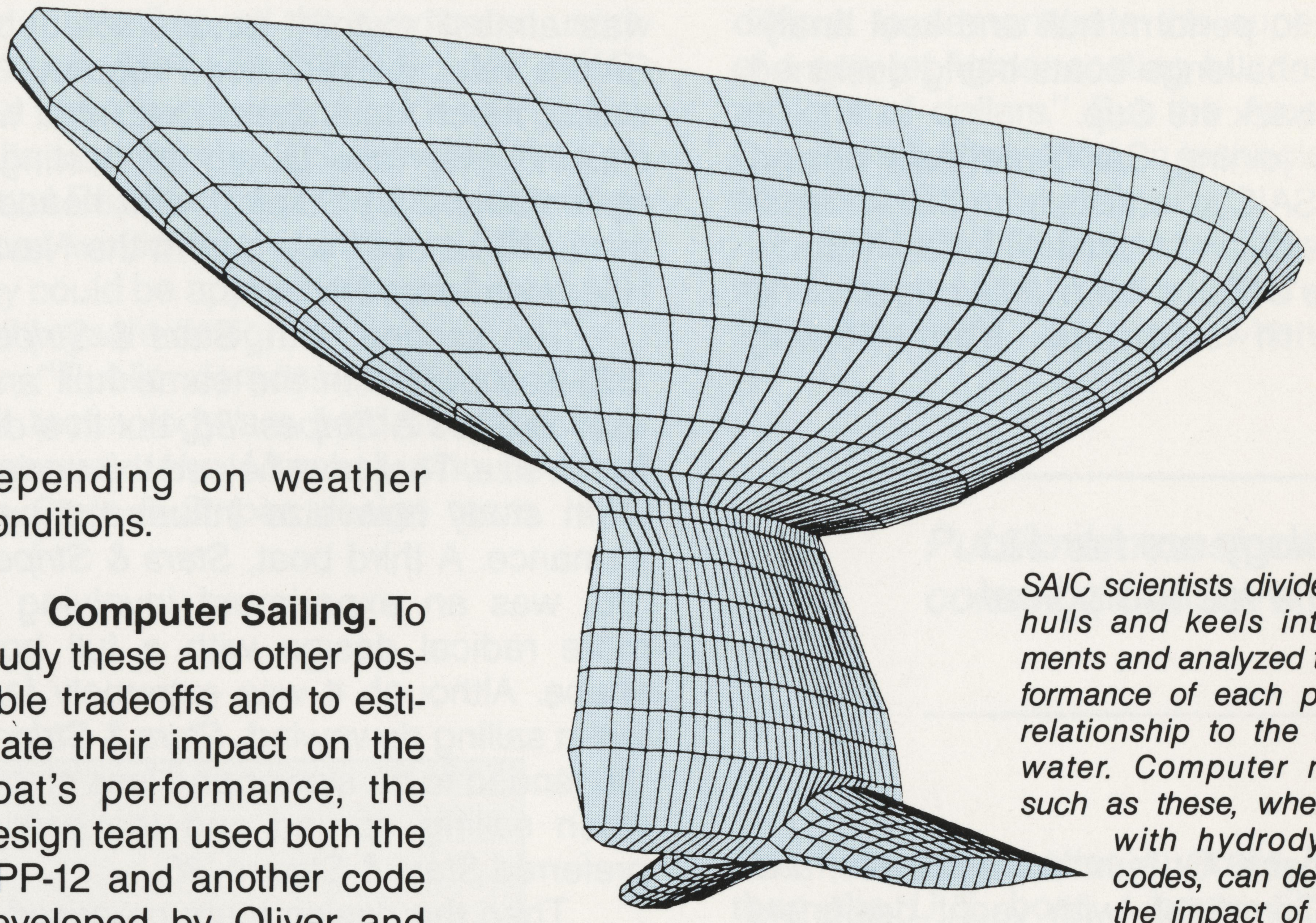
SAIC's Velocity Prediction Program had to be right one more time and it was; when it predicted that *Stars & Stripes* would win more than 90 percent of its races against Australia's *Kookabura III*.

What was the final outcome of three years of computer design work and boat building? Conner's first answer was that we maintained our "pride, heritage and tradition."

Then he added that "the design tools are applicable for years to come — perhaps even in national defense. Why do people pour so much money and effort into cars for the Indianapolis 500? The technology filters down to the cars you and I own."

Winged keel advantage

# SAIC hydrodynamic codes help design *Stars & Stripes*



*SAIC scientists divided boat hulls and keels into segments and analyzed the performance of each panel in relationship to the flow of water. Computer models such as these, when used with hydrodynamic codes, can determine the impact of even a slight design change.*

When yacht designers and SAIC scientists first proposed building *Stars & Stripes '87* — the boat that won the America's Cup — their design contradicted yacht design theory and experience. Longer 12-meter boats were almost always faster in heavy winds, but the design team was proposing a shorter 12-meter boat they claimed would pass the longer boats in heavy winds. When the Sail America Foundation approved construction of *Stars & Stripes '87*, one factor, more than any other, influenced their decision: the proven reliability and accuracy of an SAIC computer code called the Velocity Prediction Program-12 Meter (VPP-12).

The code was specifically developed for 12-meter yacht design by Clay Oliver and John Letcher of SAIC's Marine Hydrodynamics Division in Annapolis. In using the VPP-12, the SAIC scientists were not anticipating a major breakthrough. "We knew if we did a lot of little things right, we could give *Stars & Stripes* a slight edge," said Annapolis division manager Nils Salvesen.

"If drag is reduced by one-half percent in a Navy ship, a slight economy in fuel might be realized. Reducing drag by one-half percent in a 12-meter could make the difference in winning the America's Cup," he explained.

**Design Tradeoffs.** Designing 12-meter yachts involves a seemingly endless series of tradeoffs, because unlike normal yachts, these boats must be designed according to a complicated and rigid formula whose answer must equal 12 meters (the boats are not actually 12 meters in length). The formula involves four parameters: length (measured a couple of inches above the water), mid-ship girth, freeboard, and sail area.

The most important tradeoffs are between boat length and sail area. Normally, larger boats have larger sails, but for 12-meter boats, yacht designers must choose between a longer boat with smaller sails or a shorter boat with larger sails. Both offer advantages depending on weather conditions.

**Computer Sailing.** To study these and other possible tradeoffs and to estimate their impact on the boat's performance, the design team used both the VPP-12 and another code developed by Oliver and Letcher, the America's Cup Simulator (ACUPS). Both models will race two boats around a computer course and tell researchers whether the proposed design change will result in a gain or loss in speed (in seconds/mile).

The VPP-12, which was a primary model used by the design team, calculates the gain or loss in boat speed as a function of wind speed. The ACUPS, used for special cases, produces an actual simulation of the race, showing the interaction between the boats under actual weather conditions the *Stars & Stripes* might encounter. To achieve this realism, the ACUPS model incorporated a historical data base of weather conditions off Fremantle, Australia, for the past ten years.

In addition, to center in on the optimum keel design, the design team also used three-dimensional potential flow codes — the VSAERO code (developed by NASA) and the Exodus code developed by SAIC's Naval Hydrodynamics Division in La Jolla.

The various codes allowed scientists to weed out bad designs very quickly on the computer before going to model testing, "an important consideration for a large design team that was generating ideas too fast to test all of them in the model tank," according to naval architect Carl Scragg (SAIC/La Jolla). Even after computer modeling, the design team still tested forty, 22-foot scale models in a tank.

**12-Meter Design.** In designing 12-meters, there are two key design objectives according to Scragg: carry as much sail as you can (by maximizing righting moment) and minimize the hydrodynamic resistance. To maximize the righting moment, designers position the lead low in the keel. To minimize resistance, designers basically reduce the hull's surface area and improve the keel's efficiency. Although there are many types of hydrodynamic resistance, three are especially important: wave resistance (caused by the hull); frictional resistance (caused by the hull and keel); and lift-induced drag (keel and rudder).

**The Winged Keel Advantage.** When scientists at SAIC/Annapolis and SAIC/La Jolla used their hydrodynamic codes to analyze the two 1983 America's Cup finalists, they found that the hull of *Australia II* had higher wave resistance compared to the U.S. boat, *Liberty*. But *Australia II* more than compensated for that with better righting moment, lower frictional resistance, and most important, significantly lower lift-induced drag as a result of the boat's winged keel. All of these factors combined to give *Australia II* a 2-second/mile speed advantage in heavy winds and an 8-second/mile advantage in light winds.

# SAIC hydrodynamic codes

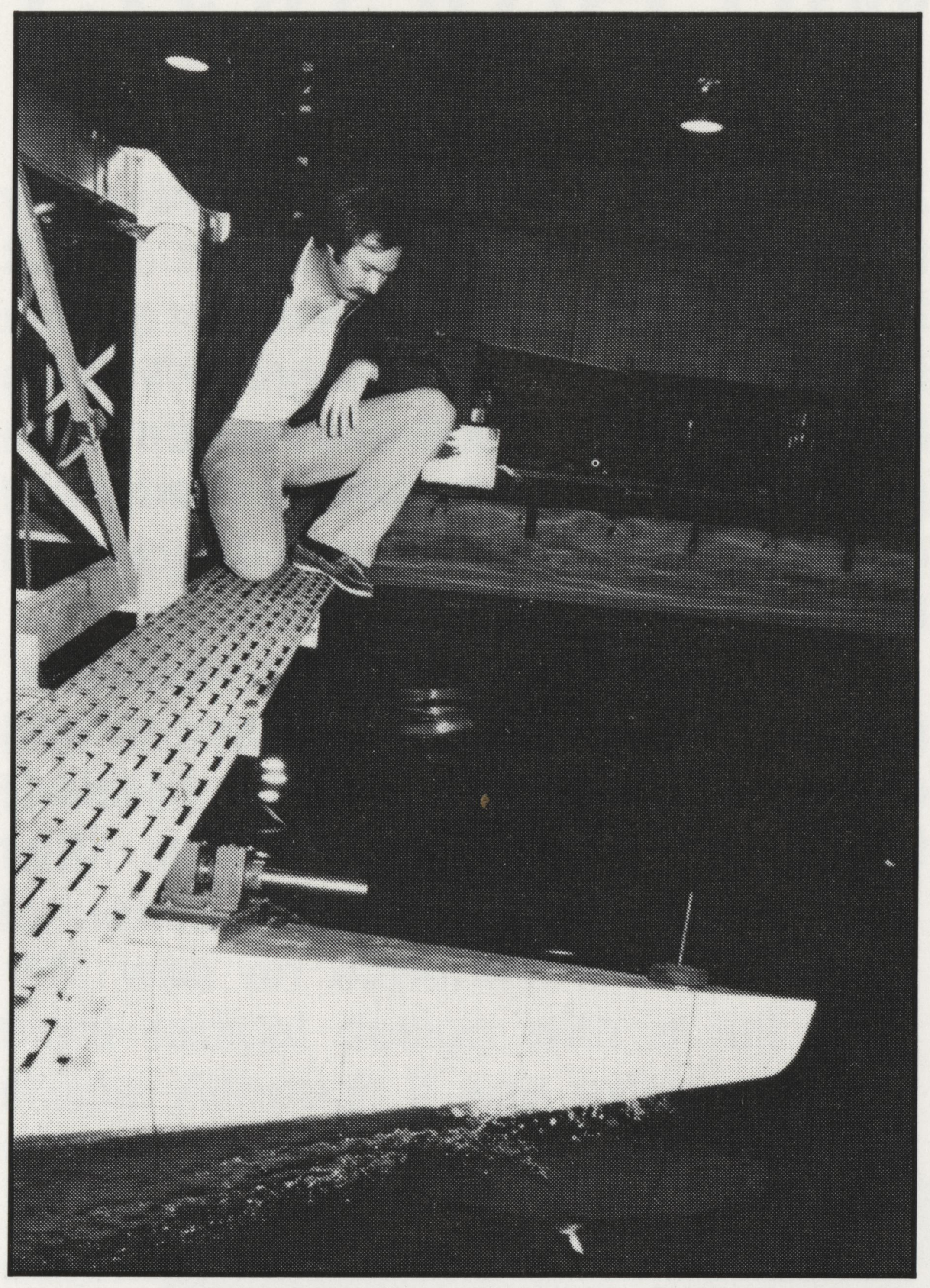
To understand why the winged keel gave *Australia II* such an advantage, Scragg explained that in sailing, the wind forces pushing a boat sideways can be many times larger than the wind forces pushing a boat forward. Heavy, lead keels (the *Stars & Stripes '87* keel weighed roughly 50,000 lbs.) keep the boat from slipping sideways as well as from tipping over. Like a wing or an airfoil dipped in the water, the keel produces both lift and drag.

Because the lift is basically fixed — a certain minimum lift is required to oppose the sideways forces pushing against the boat's sails — the key to improving keel efficiency is to reduce the drag; exactly what winglets on a keel do. As the keel moves through the water, creating a vortex that causes lift-induced drag, the winglets smooth and reduce the vortex and minimize drag.

Winglets improve a keel's efficiency so dramatically, that a winged keel has the same efficiency as a conventional keel that is approximately one-and-a-half times longer. Recognizing the importance of this advantage, all but one of the 1987 America's Cup design teams put winged keels on their boats.

**Hull Design.** While keel design focused on reducing lift-induced drag, hull design focused on minimizing another type of resistance, wave resistance. Wave resistance is very different from other types of resistance, because it increases rapidly with speed, until at fast enough speeds, the boat gets "stuck." There are wave crests at the bow and stern and a big trough under the middle of the boat. This situation is called "hitting the wall" — increases in wave resistance are so rapid that a tremendous increase in sail force is necessary to achieve a tiny increase in speed; it is next to impossible to sail faster.

To overcome problem areas such as these, "we used an iterative approach," explained Salvesen. The SAIC-developed VPP-12 and ACUPS programs were used to calculate the appropriate hull length, then the OPTIMIZE program was used to generate optimum hull designs. These were sent to yacht designers who created hull lines, which were then fed into the Wave Drag program to check theoretical wave resistance. Then models were tested and the test results were fed back into the VPP-12 and ACUPS programs to repeat the cycle.



*SAIC naval architect Carl Scragg observes wave-tank testing of a scale hull and keel model.*

**High Versus Low Speed.** Generally the best high-speed boat is the worst low-speed boat, and vice versa, according to Scragg. A high-speed boat may have the advantage while sailing downwind at 10 to 12 knots, but in a tacking duel, where boat speeds can drop to 7-1/2 knots, the lower-speed boat would take the advantage.

Because *Stars & Stripes '85* was a large, heavy, high-speed boat, the design team felt it was vulnerable in light wind and tacking. Based on VPP-12 predictions, they recommended building *Stars & Stripes '87* with an optimized hull shape that had a waterline length which was 2 feet shorter (a significant amount because 12-meter yachts only vary from a minimum of 44 feet to a maximum of roughly 48 feet). The computer model predicted that the shorter boat would be faster in light and medium winds — a result that was expected — as well as in the heavy winds for which she was optimized — a prediction that contradicted yacht theory and experience.

***Stars & Stripes* Versus *Kookabura.*** When *Stars & Stripes '87* faced the Australian defender *Kookabura III* in the finals, the two boats were within 2 inches of each other in length. However, the *Stars & Stripes* designers had opted for a higher-speed optimized hull which held down wave resistance. Although *Kookabura's* maximum sized winglets (an 11-foot span from winglet tip to tip) minimized lift-induced drag, they also gave the boat more frictional resistance than *Stars & Stripes'* small winglets; a factor that put *Kookabura* at a disadvantage when sailing downwind.

According to the VPP-12, at 12-1/2 knots wind speed, the boats were equal in speed. Above that, *Stars & Stripes '87* had the speed advantage (as much as 7 second/mile in 20 knot winds). Based on the data base of Fremantle weather, wind and wave conditions that favored *Stars & Stripes* should prevail. Once again, the VPP was correct; only once during the final races did the wind drop below 8 knots and the advantage went to *Kookabura*.

"Our work has lifted naval architecture from an art form with a little science to an art form with a lot of science," he noted. "But we are still a long way from boats designed exclusively by computers."

"We did a lot of little things right and that gave us a small advantage. But there are whole areas that we didn't touch," said Scragg. For example, it was beyond the state of the art to study the resistance caused when a boat's hull plows through heavy seas (added resistance), although this visibly slows the boat down. Noted Scragg, "We're hoping the 1990 America's Cup will give us a chance to solve some of these other problems."

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