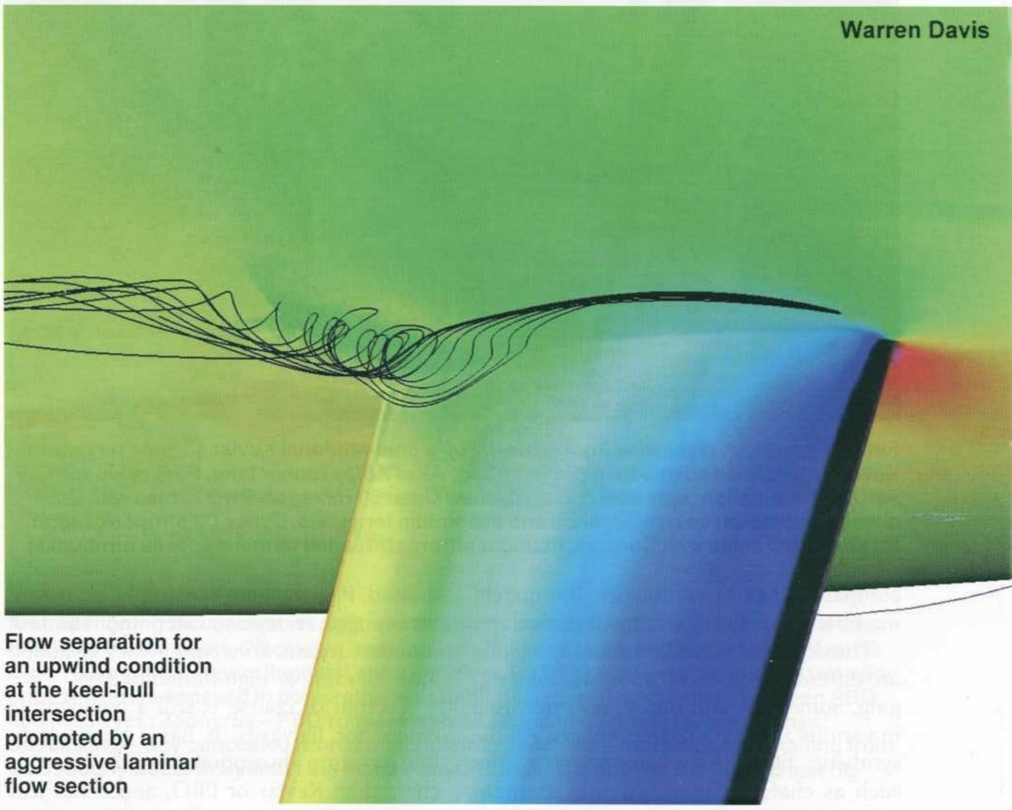
Expanding influence

DESIGN America's Cup design simulation tools are now being applied across a wide range of naval architecture, both by those with existing in-house access and also through the contracting of external consultants. Claudio Fassardi describes a project undertaken in conjunction with Javier Soto Acebal



Warren Davis

Flow separation for an upwind condition at the keel-hull intersection promoted by an aggressive laminar flow section

Since the beginning of sailboat racing designers have relied mainly on perceived 'on-the-water' performance as an indication of the success or failure of their new design features. Feedback from the sailors and the sailboat's track record allowed designers to implement improvements in their future designs with some degree of certainty of success. However, the multitude of factors that affect sailboat performance make such trial-and-error development based on on-the-water experience a poor method for quickly achieving better designs.

Some knowledge base of hydrodynamics and aerodynamics has been available to the yacht design community since the very beginning. However, feasible and economical ways to test ideas and analyse results by means other than perceived on-the-water performance have not been available until quite recently.

Recent scientific developments in the areas of hydro and aerodynamics coupled with significant advances in computing power and computational methods have allowed designers to take advantage of new ways to test their ideas and improve their designs, before sending drawings to the boatbuilder. Originally very expensive and sophisticated, for a while these optimisation technologies were only truly accessible to highly funded America's Cup syndicates.

Then, as technology continued to develop and analysis tools and methods became more economical, a few designers launched in-house R&D programmes, or hired consultants on a project by project basis, to gain a technological edge over the competition and to offer their clients a better product.

Historically, the initiative of implementing these design optimisation technologies has rested heavily on designers, who are often limited by factors such as the need to maintain a specialised and multi-disciplinary staff. However, designers and owners can now take advantage of these technologies externally, by funding optimisation programmes tailored to specific project requirements when the designer's own in-house capabilities are insufficient.

This article describes how such a tailored optimisation program was set up to assist one small European design office, bringing together a team of naval architects, aero and hydrodynamicists and structural engineers, to optimise a baseline racer-cruiser design by applying current America's Cup technology.

In this case, BMT Scientific Marine Services was contracted in December 2001 by Javier Soto Acebal Naval Architects of Spain to assist in their design optimisation of a new 100ft fast sloop. BMT proposed and implemented an optimisation programme that used exactly the same technology that is currently offered to its America's Cup clients, although tailored to the client's budget and time schedule.

The boat

Javier Soto Acebal: 'This sloop must have all the usual cruising amenities but at the same time be fast enough to race successfully on the growing Mediterranean Maxi circuit. Many alternatives were analysed to produce a fast boat, including keel alternatives such as canting vs lifting keel, and fixed keel with and without water ballast.

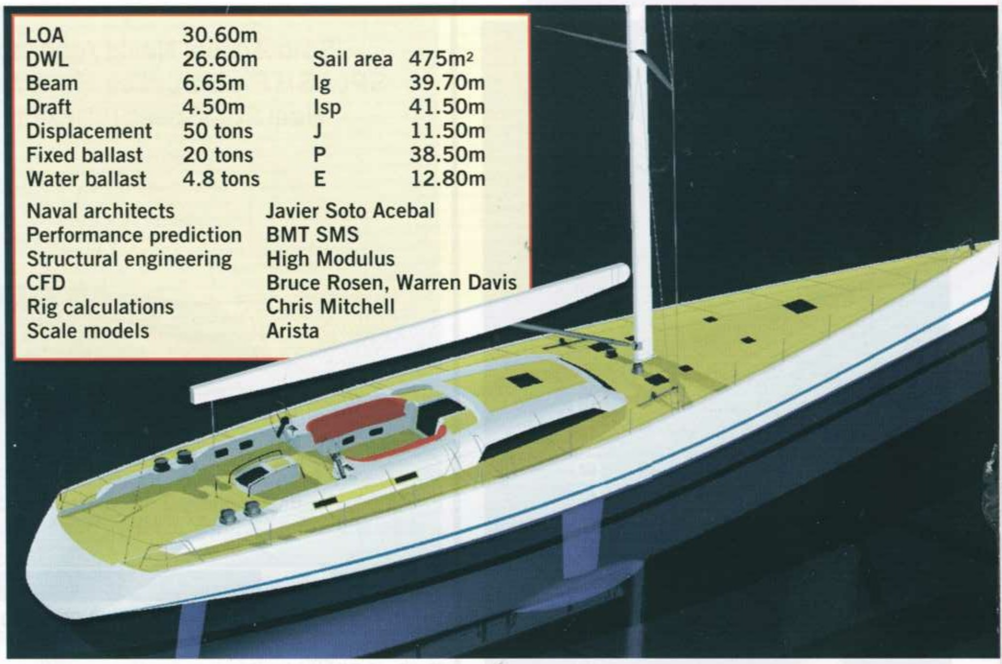
Simplicity ultimately directed us to the fixed keel with water ballast. The principal disadvantage was that a draft limitation (due to berthing requirements) pushed for a relative high keel area. So to achieve a better hydrodynamic performance a trim tab was included. The high-tensile steel keel strut and bulb for this boat features a typical modern 'T' configuration. The rudder is also of modern very high aspect ratio.

Simplicity again directed us to select an aft-swept spreader rig layout. Runners are not necessary on the boat but auxiliary runners will be installed for ocean voyaging to reduce mast fatigue. The boat will not carry traditional poles, since the only downwind sails will be gennakers and Code Zeros tacked to the stem. The helm was sited as far forward as possible, locating the helmsman in an area with relatively low motions and better visibility. The concealed mainsheet is operated via a Magic Trim system located under the cabin sole.

The hull has fine 'V' entry sections, flared topsides aft and a powerful low profile stern. There are few concessions in the hull geometry with its high prismatic and hollow forward sections.

Before the optimisation programme was begun two 1/40 scale models (with different transoms) were milled to achieve a nice, aesthetically balanced baseline hull.

The boat itself will be built with unidirectional and biaxial carbon prepeg consolidated to a Nomex core, all heat cured under vacuum. Structural engineering services were provided by High Modulus and directed by Daryl Senn. He explains: 'The focus of the structural design was to optimise the performance of the structure while maintaining the minimum weights and properties necessary to satisfy the ABS Rule for Offshore Yachts, with consideration of High Modulus's own in-house requirements over and above that rule where appropriate.



LOA	30.60m		
DWL	26.60m	Sail area	475m^2
Beam	6.65m	Ig	39.70m
Draft	4.50m	Isp	41.50m
Displacement	50 tons	J	11.50m
Fixed ballast	20 tons	P	38.50m
Water ballast	4.8 tons	E	12.80m

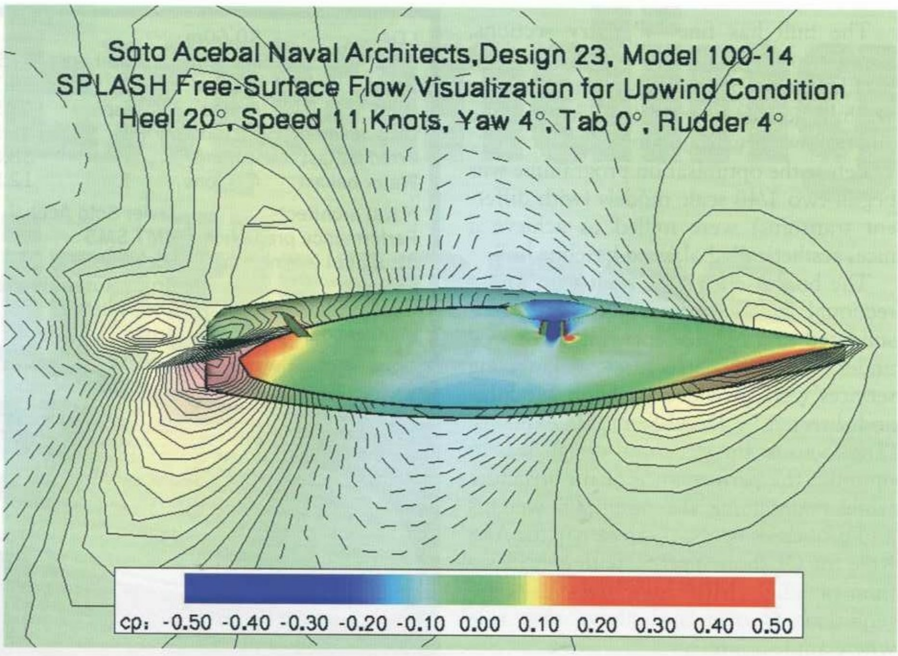
Naval architects	Javier Soto Acebal
Performance prediction	BMT SMS
Structural engineering	High Modulus
CFD	Bruce Rosen, Warren Davis
Rig calculations	Chris Mitchell
Scale models	Arista

'One area identified as having potential for improved performance was the fore and aft stiffness. The hull laminate was optimised to achieve maximum fore and aft stiffness, reducing hull bending from rig loads. To obtain a stiff hull without weight increase and at reasonable materials cost, the hull skins were designed as a hybrid laminate of intermediate modulus (IM) and standard modulus (SM) carbon fibre. The IM fibre has similar density to SM fibre but has a stiffness some 25% greater, allowing a significant increase in stiffness for the same laminate weight. The IM fibre is laid longitudinally, contributing to both local panel properties and overall hull stiffness, while the SM fibre is used in the less critical off-axis and transverse directions.

'Kevlar fabric is applied to the outside skin of the hull shell and to exposed areas of the deck to provide improved durability and impact toughness. The core materials throughout the hull and deck shell are aramid paper honeycomb, except in the forward bottom shell, where P-grade Corecell foam was used to improve the impact toughness and damage tolerance of the shell laminate.'

Optimisation program

Given the time and budget constraints of the project, BMT proposed an optimisation program based on CFD modelling and VPP ▷



Typical SPLASH-generated pressure contours for an upwind condition

performance prediction. The objective of the CFD work was the development of the hull design and appendages. The baseline hull and the three variations evaluated featured baseline appendages: keel with no trim tab, bulb and rudder. The hydrodynamic data produced for each of these configurations was then used to develop the hydrodynamic models that characterised each hull.

In conjunction with BMT's aerodynamic model, the hydrodynamic models were used as input for the VPP to predict optimum sailing parameters for a range of true wind speeds and angles. For the hull configuration selected, the optimum upwind sailing parameters (velocity, heel, leeway, rudder angle etc) were used to determine, from the corresponding CFD results, the relative lift sharing between rudder and keel for yaw balance evaluation, and the individual flow and loading conditions for appendage development. Further CFD work was then performed to optimise the rudder and keel planforms and sections and also bulb shape.

To support the hull optimisation CFD work was performed using SPLASH free-surface panel code by Bruce Rosen. For each hull configuration a 200 sailing point test matrix covering a wide range of velocities, heel, leeway and rudder angles was executed. All configurations had the same displacement, while hull variations featured differing combinations of waterline beam to hull draft ratios and prismatic coefficients. The hydrodynamic characteristics of a given configuration were represented by drag and lift areas, and yaw and roll moment volumes produced by the CFD code for each point of the test matrix. These were used to derive spline-fitted surfaces for use as the hydrodynamic models in the VPP.

BMT's proprietary VPP allows for the use of hydrodynamic data produced by CFD or tank tests. It is user-friendly and runs successfully in Excel; dedicated versions are distributed to our clients to allow them to further explore the effects on performance due to changes in sailplan or appendages. The VPP also features, for selected sailplans, an aerodynamic model previously calibrated against 'on-the-water' measurements.

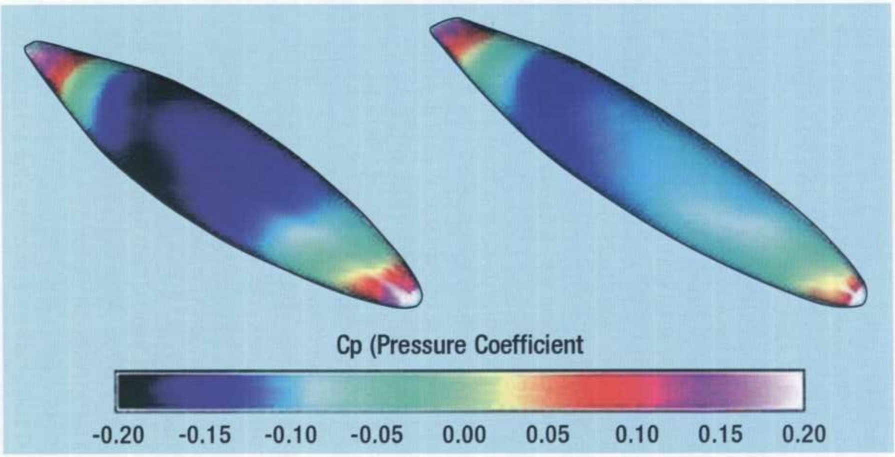
Based on the owner's objectives a candidate hull design was chosen on the basis of sec/mile performance for all-round sailing. A true wind velocity range of 12-14kt was selected as the operational upwind condition for appendage optimisation, and corresponding loads and flow conditions were obtained from the hull's CFD results.

Warren Davis, using Overflow and XFOIL, conducted the final appendage optimisation. Overflow is a 3D Navier-Stokes analysis code that can predict hull-appendage interaction effects, including any flow separation and/or vortical flows. Overflow cannot predict flow transition, and was thus run as fully turbulent flow.

Overflow was initially used to evaluate the viscous flows in the bulb-keel and keel-hull intersection regions and later to optimise the baseline bulb. The keel-bulb intersection and the keel-hull regions can be sensitive to the keel section flows, particularly when the keel section is an aggressive laminar flow type, like the one evaluated, with a strong adverse recovery pressure gradient in its aft region.

If it is not carefully 'managed', this adverse pressure gradient can interact with the accelerating flow on either the bulb or the hull and result in unwanted flow separation, or create additional vortices, both of which increase drag.

To investigate this possibility an Overflow simulation for an upwind sailing condition was performed, fully turbulent, on the baseline configuration. Warren Davis comments on the results: 'The keel-bulb intersection showed the expected necklace vortex forming at the leading edge of the keel, but no additional flow separations



Pressures are more evenly distributed and of lower maximum magnitude for the new bulb (*right*). The pressure gradients on the aft section of the Baseline Bulb are more adverse, resulting in a thicker aft boundary layer so more form drag than the new bulb

were seen. The removal of this necklace vortex would require a detailed local shaping of the local bulb surface to counteract the keel section accelerations and decelerations.

'The keel-hull intersection showed that the flow in this region was separating on the hull surface near the trailing edge of the keel. This flow separation arises because the airfoil chosen for the baseline keel was an aggressive natural laminar flow shape. These airfoils have highly scalloped aft closures, required to attain a large forward length of laminar flow and then close the airfoil with an adverse pressure gradient, that recovers just on the edge of flow separation to minimise the skin friction in this turbulent aft keel region. The problem is that the hull region adjacent to the keel has this aggressive adverse pressure gradient imposed on it, while the hull has not been similarly shaped to minimise flow separation. Thus the hull flow separates inducing drag.' A fuller aft section keel was developed to resolve this problem.

Keel development continued by analysing with XFOIL the new keel section with trim tab, with an operational upwind deflection angle of five degrees. XFOIL is a 2D airfoil analysis code, which can accurately predict lift, drag and moments in the presence of natural transition. Since the inclusion of a trim tab in the upwind condition would produce an excess of lift, and lift is directly proportional to the keel area, the operational lift can be achieved by reducing the keel area. Further, this reduction of area would represent a decrease in keel drag in all conditions. The analysis indicated that total upwind and downwind drag reduction of 2% and 0.5% respectively could be achieved by introducing a trim tab and decreasing the keel chords by approximately 15%.

Finally, the baseline bulb was analysed using Overflow again to look at the full 3D surface pressures, drag and surface streamlines. The analysis revealed that an improvement could be obtained by increasing the length-to-depth ratio (L/D) and widening the beaver tail. To maintain the same righting moment the overall volume was preserved in the new bulb design, but the increase in L/D led to an increase in surface area of 6%.

Warren Davis explains: 'This surface area increase would generally result in a higher drag (friction drag), but other factors in the design came into play that counteract this increase. In particular, bulb form drag is the product of the surface area, a form factor and the local skin friction coefficient. While the new bulb surface area was increased 6% over the baseline bulb, its L/D also increased 10%, which led to a 4% reduction of its form factor. Thus the surface area increase and the form factor decrease just about cancel out, leaving the baseline and new bulbs at the same drag. However, the surface pressures for the new bulb were more conducive to a longer run of laminar flow, thus reducing the local skin friction coefficients and reducing its total drag.'

The new bulb then gained its advantage in the expected longer and more stable regions of laminar flow. And the bulb's beaver tail was made wider to reduce keel/bulb induced drag at the upwind lifting condition.

The analysis of the rudder was confined to balancing the planform by reducing the induced drag with a forward-swept trailing edge at the tip, while keeping the load away from the root where the thick boundary layer of the hull builds up and ventilation could develop in upwind conditions.

Building of this design is underway in Europe and we will find this boat racing in the Mediterranean by 2003. ☐

Claudio Fassardi is a naval architect at BMT SMS Inc. He has worked for America's Cup syndicates since 1990, starting with model tests for PACT, Beach Boys (which later merged with A^3*) and Team Dennis Conner. In 1995 he worked for TDC and in 2000 for AmericaOne. He now works once again with Team DC*

Javier Soto Acebal is a naval architect running his own yacht and powerboat design practice and is also Professor of Yacht Design at Universidad de Quilmes