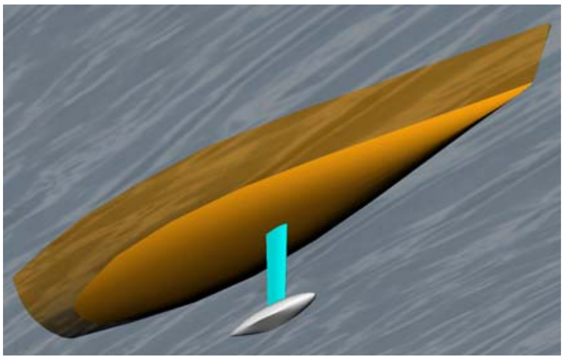
# Keel Optimisation using CFD Methods

*Among the 8 yachts currently competing in the Volvo Ocean Race six are developed by the same yacht designer. To increase competitiveness against their rivals most teams started individual research and development programs to achieve some advantage in terms of boat design and performance. The Illbruck Challenge found that one of the fields promising to be a candidate for successful optimisation would be the keel of the Volvo Ocean Racer (VOR), in particular the ballast bulb. Thus a research program has been invented with the intention to develop a new keel bulb design.*

Recent Seahorse articles reported about CFD as methods for flow analysis used in the design and development of racing yachts like Volvo Ocean Racers and Americas Cup Yachts. CFD (Computational Fluid Mechanics), a term combining methods that simulate flow phenomena with the help of computers, rapidly became the primary tool for flow scientists working in the preliminary design stage of yacht development. At our institute various CFD methods have been used to study flow around hull, appendages and sails of yacht of different types, among them 8mR- and IMS-yachts. CFD methods not only promise better cost efficiency than experimental flow investigations, they also allow deep insight in the local characteristics of the flow and thus provide helpful design information. This review describes a practical application where these methods have been used to develop an enhanced bulb design for VOR *Illbruck*.

## Keel and Bulb Design of VOR yachts

While still moderate in design VORs are true offshore dinghies. The length to displacement ratio (Length³/Volume) of a ballasted fully loaded VOR is comparable to a manned Laser dinghy. For downwind courses the high aspect keel blade and ballast bulb have to be optimised for low drag at low leeway angles, giving the design target to minimize viscous drag. However on deep upwind and beam wind courses hydrostatic stability and induced resistance have increasing impact on keel design, a fact of rising importance since the appearance of the Code 0s. These three parameters – viscous drag, hydrostatic stability and effective span, the latter one being a measure for induced drag – are the corners of the playground for any optimisation effort for the bulb/blade.



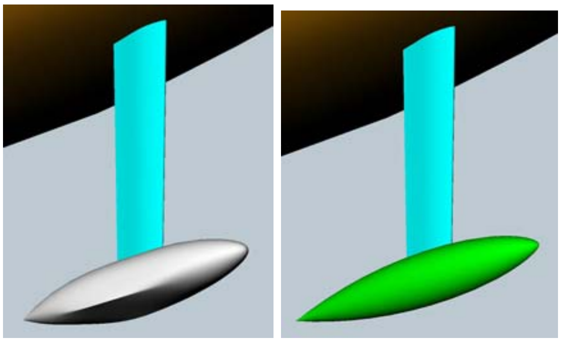


Fig. 1: Ballast bulb of VORs try to find best compromise between low viscous drag, deep centre of gravity and large effective span.

The latest bulbs of the *Illbruck V1* and *V2*, training boats of the *illbruck Challenge*, known as *EF Language and EF Education* from the last Whitbread Round The World Race had a chined section shape giving deep centre of gravity however on the costs of some resistance penalty. The idea behind the chines is that they not only allow low placement of the centre of gravity but also might contribute to the effective span. Compared to that a rotational symmetric bulb of same length, beam and volume would have lower wetted surface and thus viscous drag however the centre of gravity is located significantly higher.

To fully enlighten the correlation between viscous resistance, effective span and centre of gravity a series of more than 20 different bulbs have been designed with some input from FYD's Steve Morris and i*llbruck Challenge*'s R&D-manager Michael Richelsen. Bulbs differed in length and section shape. Some had beavertails, some not. All bulbs had same volume and maximum beam allowed by the VOR-rules

## RANSE CFD investigation

Analysis of the flow around the bulb has been carried out using the *Comet* © RANSE code. RANSE methods allow the simulation of viscous flow by solving the so called *Reynolds Averaged Navier Stokes Equation*. The basis of these equations are the physical principal that mass neither can be generated nor vanish and that momentum only changes due to external forces. Formulated for a flow volume around the geometry investigated so called partial differential equations arise that are solved numerically. RANSE methods are computational intensive tools however with the availability of compute clusters based on cheap standard PCs they are getting affordable for many.

A general problem of the RANSE methods is that accuracy of results strongly depend on proper discretisation of the flow domain – the division of the flow volume around the bulb/blade into small so called Finite Volumes. This is a time and knowledge intensive job done by specialists using so called grid generators, dedicated CAD-like programs.

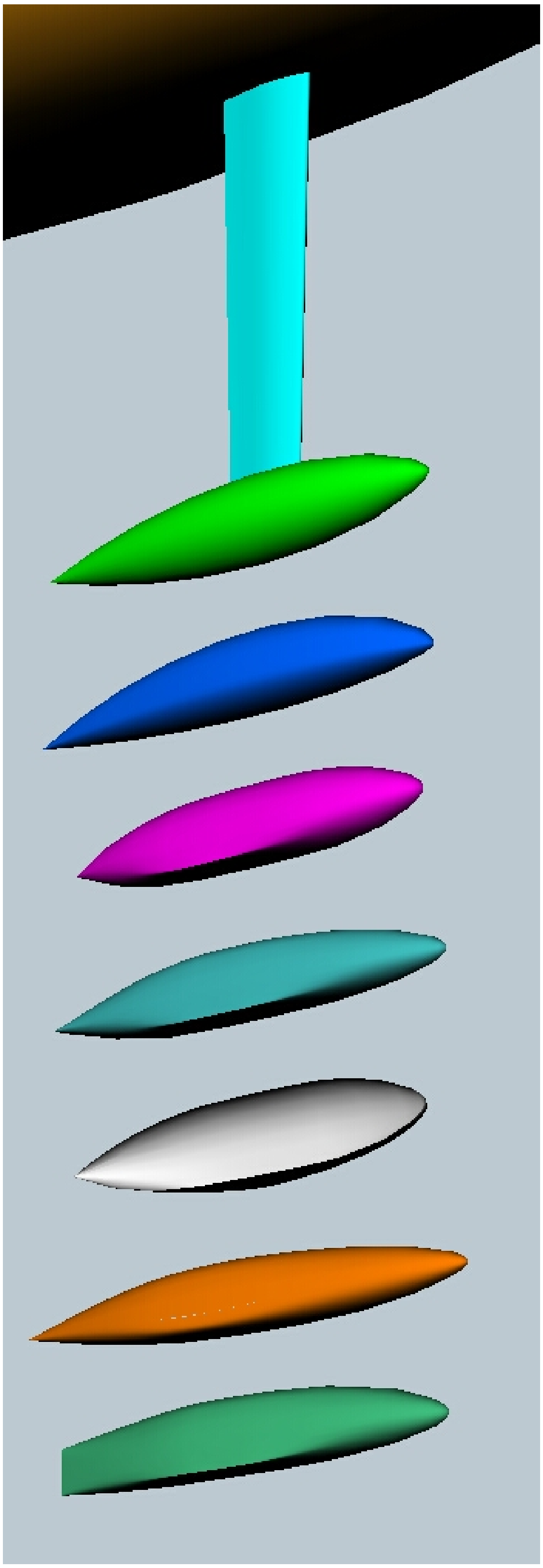


Fig. 2: More than 20 bulb designs have been developed differing in length, section shape, some with beavertail, some without.

For the bulb investigation grids of about 750000 grid cells have been used. Special attention has been devoted to produce grids of identical topology and smoothness.

We used unstructured grids with hexahedral grid cells because they allow resolution of the boundary layer with much less grid cells than the alternative tetrahedral/prism grids also widely used.

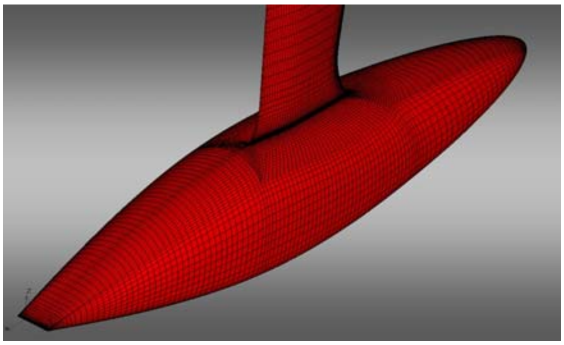


Fig. 3: Surface grid on a beavertailed bulb of VOR yacht. The corresponding volume grid consists of approx. 750000 grid cells resulting in a nonlinear system of equations with 4.5 million unknowns.

## Results

Each bulb of the series has been tested numerically for a couple of operational flow conditions from upright non lifting condition to various heel and leeway angles. Since the focus of the investigation was the bulb, neglecting the free surface has been an acceptable simplification of the flow problem. The upright non lifting simulations then gave bare viscous resistance.

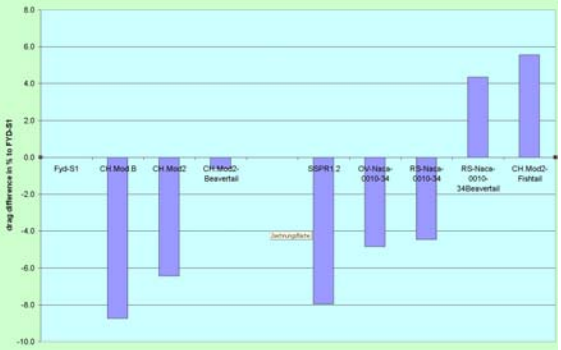


Fig. 4: Difference of viscous resistance for some bulb designs

Fig. 4 shows the results of the non lifting upright resistance of some bulbs compared to a reference design. It has been shown that viscous drag of bulbs can be reduced by up to 8% compared to the latest bulb of the *Illbruck* training boats.

For the simulations of the heeled boat producing side forces due to some leeway angle a typical result is Fig. 5, showing a polar diagram, where drag is drawn above lift. Results show that chined bulbs produce more drag at zero side force however their effective span is larger resulting in lower induced drag.

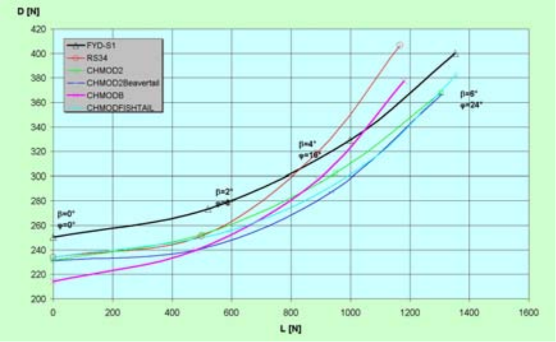


Fig. 5: Polar diagram of some bulb designs

A view on pressure distribution allows insight in local flow phenomena. Fig. 6 shows contour plots, lines of constant pressure on the surface of the bulbs, for the reference bulb and the final bulb. Pressure contours are used to optimise the geometry of the bulb, in particular the bulb-blade junction and the laminar to turbulent transition point.

## VPP Integration

While bulbs with squeezed section shapes provide deeper centre of gravity and thus more hydrostatic stability a result of the CFD studies has been that this occurs on the costs of some additional upright resistance. To find proper balance of these two counterparts CFD test results have to be integrated into Velocity Prediction Programs (VPPs). Since the CFD calculations have been carried out neglecting the free surface (the generation of waves) direct integration of CFD results was not possible. We thus decided to use resistance changes with respect to a reference design to be thrown into VPP analysis. The idea behind this is that any change in resistance found in the CFD runs will also be found in towing tank testing with a large model scale. Of course then at least some results from the towing tank tests with a reference design have to be available. This is an approach with many drawbacks and hurdles but for this investigation it worked with reasonable accuracy.

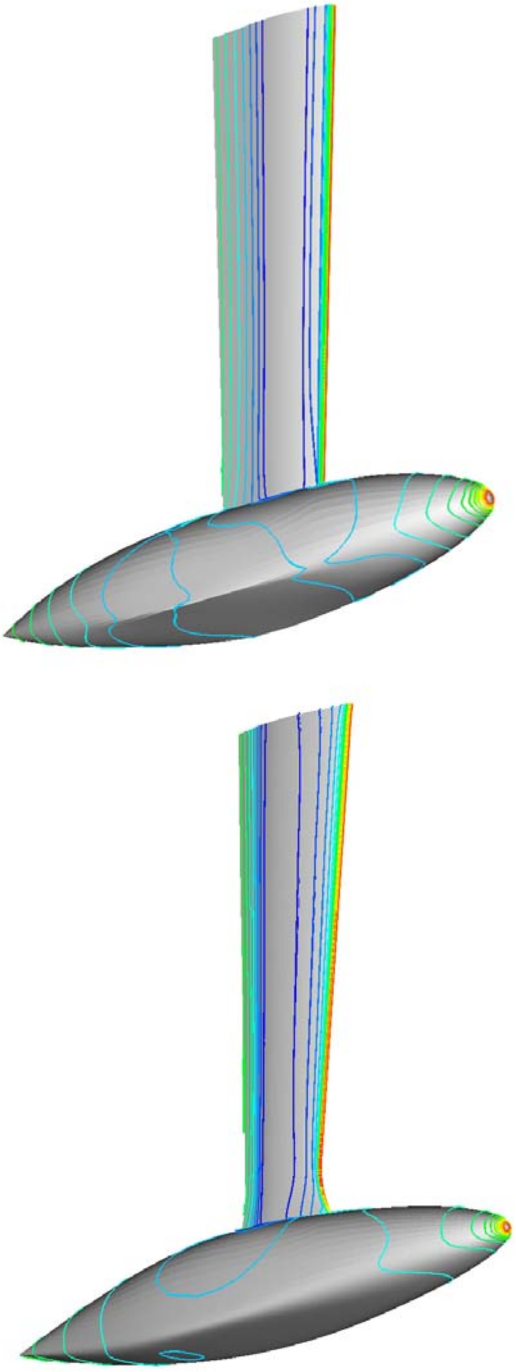


Fig. 6: Pressure contours on reference and final bulb

In this way VPP runs with a reference design and a target design convert deltas of resistance and centre of gravity into deltas of boat speed on various courses. For a bulb with larger resistance the reference however deeper centre of gravity the VPP results look as shown in Fig. 7. At low wind speed additional resistance reduces upwind and downwind velocity, at higher wind speeds the additional stability pays off resulting in higher velocity in particular for the upwind case.

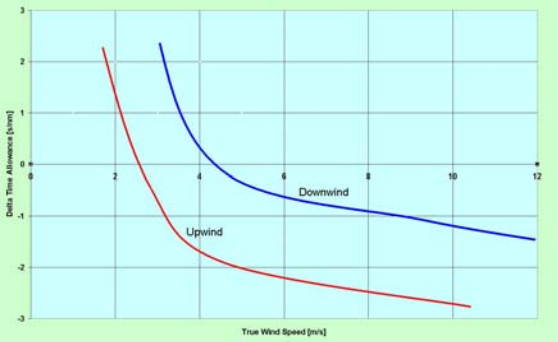


Fig. 7: Seconds per nautical mile speed gain or loss of a target design compared to a reference design

The final decision which bulb design to prefer then is a matter of the routing / weather specialists with their knowledge of probabilistic weather conditions to be expected on the race course.

## Restrictions of current CFD codes

RANSE methods still do have some restrictions which can lead to wrong design decisions. One example is turbulence modelling. Common RANSE flow codes are using turbulence models that assume fully turbulent flow in the entire flow region. This does not match reality. On keels of typical dimensions large regions of laminar flow can be expected and it is common practise to optimise the design of blade profiles to enhance the laminar region.

A simplified study of the bulb profile did show that lengthening the bulb (of constant buoyancy and beam) results in smaller resistance using RANSE methods. However doing the same calculation with a boundary layer method capable to predict laminar-turbulent transition quite the opposite result evolved, see Fig. 8

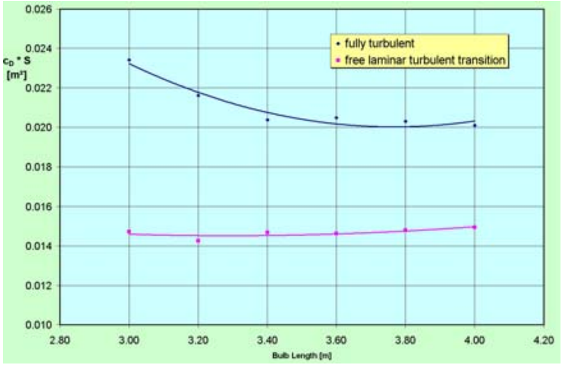


Fig. 8: Drag area over bulb length, fully turbulent and free laminar turbulent transitions

It is of only minor importance that the drag calculated with RANSE methods is pretty much overestimated. This can be calibrated using artificial wall smoothness. However RANSE –calculated resistances decreases with length while boundary-layer-method calculated resistance increases, just slightly though but the trend is reversed.

For the future we can hope that better turbulence models will be available that will be capable to predict laminar turbulent transition with reasonable means. And still the problem will remain to a certain degree. As long as information of the natural turbulence intensity of the seaways is not available or insufficient, results from even the best turbulence models remain to be inaccurate and the use of RANSE methods will depend on assumptions to be derived from experience and intuition.

## The full scale test

At the end of our study we got an optimised bulb with only subtle differences to the reference bulb from the training boats: The bulb is longer and flatter, its nose radius is smaller and the chines have a small radius. The most obvious change might be the beavertail. This bulb is in use on the *illbruck V3* boat, currently sailing the Volvo Ocean Race.

At the time this is written the participants of the Volvo Ocean Race started for their third leg. While *illbruck's* win of the first two legs of the race is primary due to the tremendous good job of the crew on board and the very thorough preparation including advanced sail design and boat construction, the modified bulb will have made its contribution to the overall performance of the boat..

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