A RESEARCH PROGRAM ON PERFORMANCE OF PLANING SAILING YACHTS

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SUMMARY
The aim of this paper is to expose the results gathered at the end of the first year of a three years research program concerning the planing of sailing ships. The practical objective of this program is to characterize planing hull’s behaviour with a method as simple as possible like Savitsky did for motor boats with V-shaped hull. The general methodology of the project is to combine the use of experimentation techniques (towing tank tests or sea-trials) and CFD calculations. The paper shows first comparisons between CFD codes (REVA and ISIS) and towing tank tests data. Fixed model test method has been chosen to compare with CFD results and to be used in the six degrees of freedom simulator which is a new kind of VPP. Sea trials for further exploitation are also described.

NOMENCLATURE

\[ V \] Length of the model \((m.)\)
\[ g \] Gravitational constant \(\left( m.s^{-2} \right) \)
\[ V \] Displacement of the model \(\left( m.^3 \right)\)
\[ H \] Depth of the towing tank \((m.)\)
\[ H_0 \] Mean water level \((m.)\)
\[ S_w \] Wetted surface area \(\left( m.^2 \right)\)
\[ F_{L} = \frac{V}{\sqrt{gL}} \] Length Froude number (adim.)
\[ F_{V} = \frac{V}{\sqrt{gV^2}} \] Displacement Froude number (adim.)
\[ F_{H} = \frac{V}{\sqrt{gH}} \] Depth Froude number (adim.)

1. INTRODUCTION

The usual definition of planing is when hydrodynamic lifting force is sufficient to make the wetted length and the wetted surface decrease. This usually happens for length Froude number superior to 1 \((F_{L} > 1)\) or Froude displacement number around 2 \((F_{V} \approx 2)\). When planing appears, the resistance increases more slowly with speed than for displacement and semi-planing regime.

A lot of work has been done about the planing phenomenon of motor boats. In 1964, Daniel Savitsky[1] submitted an original method to evaluate the drag and the equilibrium trim angle of V-shaped hull at a given speed. Since then, complementary works have been done but without extending the theory to large round hull shapes with wind propulsion. There are two problems: firstly, hull shapes are more various and complicated than V shapes, and secondly, a sailing yacht can’t be optimized for a single speed. That means it sails in displacement mode, in semi planing mode and in planing mode and should be optimized for those three.

For the Groupe Finot-Conq, this research program has two main goals:

- A better understanding of the phenomenon, the tendencies, the key factors and limitations to design the hulls
- A way to take into account the planing phenomenon in velocity prediction programs and to choose the best design according to the end-user objectives.

To answer those questions, we choose to combine different available tools and techniques: sea-trials, towing tank tests, CFD codes and 6DOF simulators.

Towing tank tests, semi-captive or fixed, are a reliable way to know the hydrodynamic loads acting on the ship for a given configuration. However, to make a thorough analysis of flows and loads, it is more difficult to know the local quantities that are pressure, velocity, vorticity, loads by sections, etc. CFD codes are an easy way to know both global and local variables but they must be validated for those kinds of fast boats. Validation (precision and validity limits) is therefore a key step. Tank tests are used as reference for global loads (forces). The first hypothesis is that if numerical calculations are able to compute forces correctly then local quantities should be correctly computed. The second one is that if calculations and tests in confined conditions (in towing tank) are in good agreement, then calculations can be used with confidence for the study.

Calculations and experimentations will then be used to model all the hydrodynamics loads acting on the hull. Those models will then be implemented in velocity prediction programs or in the 6DOF dynamic simulator to quantify boat performance.

2. ON THE CHOICE OF CAPTIVE MODEL METHOD FOR TOWING TANK TESTS

When testing sailing yacht hulls in a towing tank, the semi captive method is the more commonly used. The
hull has a fixed heel and drift angle but is free to trim and sink. This is an efficient method to compare two hulls during the design process. As far as the centre of thrust and the centre of gravity are well positioned, it has the advantage of letting the boat go to an equilibrium position which is realistic for classic hulls at moderate speed.

However the pitching moment is corrected by moving a mass along the longitudinal axis of the boat. The displacement of this mass is calculated to take into account the estimated position of the application point of aerodynamic loads. To do that precisely, it would be necessary to carry out several tests to determine the good position of the mass according to the hydrodynamic drag obtained at the given speed. Notice that the influence of the vertical component of aerodynamic loads is always neglected.

For sailing boats designed to reach the planing regime, hydrodynamic efforts are very sensitive to trim and heel. In this case the semi captive method loses its interest because it is necessary to carry out many tests to obtain all the possible attitudes corresponding to the aerodynamic loads under the various conditions of navigation and sails settings. Supposing that numerous tests were done, there remains the disadvantage that the method gives the trim angle and the vertical force (Fz). Making a model and simulating the boat behaviour in six degrees of freedom is therefore more complicated.

However, the main disadvantage of the semi captive method is that the equilibrium position of the planing boat obtained during the towing tank tests is not fairly representative of the equilibrium obtained with sail propulsion. The pitching moment of aerodynamic forces greatly influences the trim (which is free) and the influence of transverse component is not taken into account since the heel is fixed.

In the final analysis, the captive model technique was chosen. The first reason is that we have to compare experimental results with CFD for given attitudes, displacements and speeds. The second reason is that we aim to calculate equilibrium and performance with any aerodynamic loads and to do that, we have to build a model of the hydrodynamic forces acting on the hull according to working parameters. The third reason is that we need to know lifting forces and pitching moments to understand planing phenomenon and compare to CFD results.

2.1 CAPTIVE MODEL TEST TECHNIQUE

The dynamometer used is an isostatic 6 components dynamometer. It was designed at Ecole Centrale de Nantes in 2005 for testing submarine boats. It was then adapted to surface ships. The dynamometer is equipped with 6 transducers, that have a precision of 0.008% FS. There is one transducer of 1kN FS for X component, two of 1kN FS for Y components and three 2kN for Z components.

A specific device had been built for calibrating the dynamometer. Calibration consists in calculating the 36 coefficients of the linear transfer matrix by loading dynamometer with a lot of known forces in the range of applied loads during tests.

The sensible part of the dynamometer is rigidly fixed on the boat, so the forces are measured in the boats axis.

The frame of the dynamometer is attached to the movement generator, called “Hexapode”, which is used here as a static orientation device to fix models’ attitude and vertical position during the run.

Reference loads (“zeros”) are acquired model in running position but out of the water.

Displacement is fixed by measuring the hydrostatic forces acting on the model when in the water. The Hexapode let us set that displacement with a theoretical precision of 0.01 mm which corresponds to 0.3 N (in our case, 0.03%). The measurement of moments can be used to check the centre of hydrostatic efforts position and therefore model position: zero heel and trim angles corresponding to architect’s plan. During the first campaign, high precision optical tracking system (Qualisys) was used to check model attitudes and deformations of the whole system.

As the boat is fixed, captive model test technique is extremely sensitive to perturbations in the towing tank.

- Variation of the level of water in the tank (1mm corresponds to 30N of displacement) thus nominal displacement should be carefully checked every day.
- Oscillation of the stationary wave in the tank (which induces an oscillation on the starting displacement). A procedure was used in the third campaign to try to compensate the effects of this very deterministic wave.
- Planarity of the rails of the towing tank. Earth curvature correction was implemented according to the carriage position.
- Correction for model and dynamometer windage has also been implemented.

The principal disadvantage of the method is that the hydrodynamic efforts depend on five parameters (three for attitude, one for vertical position and one for speed). To obtain a satisfactory and coherent model, even by applying a rigorous experimental planning, it is necessary to carry out a significant number of tests. Some combinations of parameters do not correspond to realistic points of operation.

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2.2 MODELS AND TEST CAMPAIGNS

Three different hulls were tested during three different campaigns taking place in March 2007, June 2007 and March 2008 for a total of about 900 runs. Tested hulls are two Open 60’ models and a real size dinghy.

The Open 60’ models were at scale 1/4.5 with a length of 4m and a beam of about 1m. Dinghy was 2.80m long and about 1.3m wide.

One Open60’ hull was tested with a canting keel and asymmetrical boards; others models were only tested as ‘naked’ hull.

![Fig 1: Open 60’ Model plan](image)

The towing tank of Ecole Centrale de Nantes is 140m long, 5m wide and 3m deep. Speeds were from 1 to 7 m/s corresponding to length Froude numbers up to 1.3.

The length of the Open 60’ model is too important for the towing tank, according to ITTC recommendation. The model was designed for tests in a large towing tank (BEC DGA Val de Reuil). For cost saving reasons, we had to reuse them. This point will be discussed further.

The main objectives of those campaigns were:

- Effect of trim and heel on vertical force and drag (March 2007)
- Effect of hull shape on vertical force and drag (June 2007)
- Effect of appendages on vertical force and drag (March 2008)

2.3 UNCERTAINTY AND REPEATABILITY

As three campaigns were made with the same technique and same hull, repeatability of the technique

The uncertainty of the measurement device is estimated to be inferior to 0.5%. The most difficult part of the tests due to the captive model technique is the repeatability. In other words, if we can be sure that the model is exactly in the same conditions (attitude, displacement, phase of the tank wave oscillation, carriage speed) then we will have an uncertainty of 0.5% from the measurement system.

As explained before, it is possible to try to correct the uncertainties due to exterior conditions but it seems very time consuming to try to control them. Attitudes given by the Hexapode are 0.1° precise and that has been verified by optical tracking measurement system. Z position giving displacement is 0.01mm precise. Carriage speed is repeatable.

The main source of uncertainty between two identical tests is the stationary wave oscillation in the tank.

The displacement is measured just before the run when the carriage is ready to start on its wheels. To avoid the deformation of wheels, waiting time before the run must be minimized. To measure a correct initial displacement or to know the phase of the oscillation we’re starting with, waiting time should be greater than the period of the first mode of the stationary wave which is 52.7s. This is a too long waiting time and cannot be done. A wave gauge was therefore installed near the carriage starting area together with an inductive transducer to synchronize the measured water level height and forces with the effective start of the carriage. Initial displacement can be controlled and the phase of the oscillation at starting time can be known.

Concerning measurements during the run, we know that the stationary wave has one node in the middle of the tank.

For low speeds runs, measurement can generally be done around this position. This minimizes water level oscillations effects. For high speeds runs, the stable phase occurs generally after the middle of the tank. Therefore, the water level during the stable phase depends on the phase of the stationary wave. The system implemented gives the possibility to calculate the water level difference during the stable phase and to correct the vertical force in consequence.

The difference with the mean water level at a position \( x \) and at a time \( t \) due to the stationary wave is given by the following formula:

\[
H(x,t) = H_0 \cos(2\pi \frac{t}{T} + \phi) \cos(2\pi \frac{x}{\lambda})
\]

With

\[
\phi = \arccos(H(x_0,0)/H_0 \cos(2\pi x_0 / \lambda))
\]

which is the phase at the starting time for the starting position \( x_0 \).

The vertical force measured during the run is corrected using the following approximation:

\[
\Delta F_z = Sw.H(x,t)
\]

Short time repeatability is good as two identical tests of a same campaign have a difference of less than 1% on every forces component.
Long time repeatability is also acceptable as the differences between two tests made during two different campaigns (water temperature correction included if between June and March) is generally bigger than between two tests of a same campaign but always inferior to 5% and generally around 3%.

In conclusion, uncertainty of captive model tests can be optimized using different techniques to correct the influence of exteriors parameters. Relative uncertainty of measurements made during the last campaigns used to validate CFD codes is estimated to 3%. Others campaigns have a slightly higher uncertainty estimated to 5%.

2.4 FLOW VIZUALISATIONS AND DYNAMIC WETTED SURFACE

To be able to extrapolate with higher precision, the dynamic wetted surface must be known. A good evaluation can be made using submarine video cameras. This was experimented during each of the three campaigns. A classic video camera was fixed under the water. Acquisition was triggered from tank shore. Waterlines had been drowned on the model so that the wetted surface area can be approximated with fairly good precision. This has also been useful to compare with CFD dynamic wetted surface (see section 3.2).

To see flow direction, tell tales had also been stuck on the hull. About 50 runs were done with those tales and flow directions are visible especially for runs with a non zero drift angle or heeled runs. This was also used to compare with CFD stream lines.

3. CFD CALCULATIONS

One of the goals of this work is to compare results of available CFD codes with experimental results.

At this stage of the work, we had the opportunity to compare two of the three codes developed at the Fluid Mechanics Laboratory of the Ecole Centrale de Nantes: REVA, which is the oldest one and ISIS-CFD, the newest one.

One of the tank tested Open 60’ hull designed by the Groupe Finot was used for comparisons. The boat is in fixed position with 0° of heel and 1° of trim (positive when bow is up – This definition of trim is the one used in the following sections). Speeds are from 8 to 25 knots (real scale).

3.1 REVA CALCULATIONS

REVA was developed by G. Delhommeau since 1985 and solve the potential flow with a linearized free surface around then hull. It is possible to compute resistance (and other forces) including to the deformation of the free surface and the induced resistance due to appendages. Calculation is surface type which facilitates meshing and reduces CPU time.

Main restrictions of REVA are:
- No viscous resistance or viscous effects.
- A linearized free surface condition which limits the influence of dynamic length and wetted surface on the wave resistance

Therefore the following effects are not taken into account in REVA:
- Vorticity, separation, viscous wake
- Viscous resistance of the appendages and of the link hull-appendages
- No turbulent flow around appendages (only laminar)

REVA seems to calculate correctly drag and vertical forces up to length Froude numbers of 0.5 but after that, vertical forces are not computed correctly. The following figure shows an example of comparison between calculations and experiments. The hull is in fixed position. Computations are done in exact same conditions with tank walls and bottom.

![Figure 2: Drag and vertical force comparison between REVA and tank tests as functions of length Froude number](image)

The relative precision of REVA for length Froude numbers under 0.5 is about 5% for drag and vertical force. This is fairly reasonable given the very low computation time.
After $F_{r_L} = 0.5$, REVA seems to be unable to see the planing phenomenon. A comparative study has been made on pressure repartitions between REVA and ISIS-CFD. This will be discussed in section 3.3.

### 3.2 ISIS-CFD CALCULATIONS

The other code used, ISIS-CFD, was developed by EMN (Equipe Modélisation Numérique) of LMF. Turbulent flow is simulated by solving the incompressible unsteady Reynolds-averaged Navier-Stokes equations (RANSE). The solver is based on the finite volume method to build the spatial discretization of the transport equations. The face-based method is generalized to two-dimensional, rotationally symmetric, or three-dimensional unstructured meshes for which non-overlapping control volumes are bounded by an arbitrary number of constitutive faces. The velocity field is obtained from the momentum conservation equations and the pressure field is extracted from the mass conservation constraint, or continuity equation, transformed into a pressure-equation. In the case of turbulent flows, additional transport equations for modelled variables are discretized and solved using the same principles. Free-surface flow is simulated with a multi-phase flow approach. Incompressible and non-miscible flow phases are modeled through the use of conservation equations for each volume fraction of phase/liquid discretized with specific compressive discretization schemes detailed in [2]. Several turbulence models ranging from one-equation model to Reynolds stress transport model are implemented in ISIS-CFD. Most of the classical linear eddy-viscosity based closures like the Spalart-Allmaras [3] one-equation model, the two-equation $\omega$ SST model by Menter [4], for instance are implemented. Two more sophisticated turbulence closures are also implemented in the ISIS-CFD solver, an explicit algebraic stress model (EASM) and a Reynolds stress transport model [5]. Recently, a module coupling the flow and the equations of motion for 6 degrees of freedom has been incorporated in ISIS-CFD, together with several mesh deformation algorithms developed for fully unstructured grids.

Computation were made on 4 processors BiOpteron of 2.4 GHz with 4Go of RAM.

Mesh was generated using ICEM-CFD by Yann ROUX (K-Epsilon). It is a half mesh with 800 000 cells which is a low density mesh.

Computation time is about 48h per configuration. This should be compared to REVA computation time which is about 5 minutes on a desktop computer. Computations are done with bottom but without walls. This is due to a small limitation of the code at the moment and should be fixed soon.

ISIS-CFD was unable to compute correctly a test case with walls. Therefore, all the following conclusions are only suppositions given the preceding results.

It seems that ISIS-CFD is able to compute correctly drag and vertical forces for high Froude numbers. The overall relative differences are 6% in drag and less than 4% for vertical force.

The drag differences are probably due to walls effects at high speeds. When sailing in restricted waters, there is two major effects affecting ship’s resistance which are:

- An hydraulic effect resulting from the obstruction of the water cross section leads to a higher relative velocity and therefore a higher resistance. This effect is weak because cross section ratio with the section of the tank is less than 1%.

- Propagation of waves is highly affected by water depth.

In 2007, Friedhoff [6] made an extensive study on planing craft in shallow water. Conclusions are that between depth Froude number of 0.8 and 1.2, there’s a hump in the resistance curve as well as an augmentation of the vertical force. For displacement Froude numbers above 3, depth has no more influence.

Comparisons made between ISIS-CFD and tank tests are for depth Froude number up to 1.2 and displacement Froude numbers up to 2.82. That means that tank effects on drag and vertical force are non negligible. On the other side, differences showed between ISIS-CFD and tank tests are somehow small and could be explained by
the lack of tank walls in computations and a rather small mesh density.

Other computations done without tank bottom show that ISIS-CFD was sensitive to it and computed a smaller resistance and vertical force without bottom which confirms Friedhoff’s experiments.

Free surface deformation as well as dynamic wetted surface is also correctly computed. Comparisons have been made with submarine images for dynamic wetted surface and carriage fixed cameras for free surface deformation and correlations are fairly good.

Appendages have not been tested with ISIS-CFD. That will be done in the next couple of months.

In conclusion, results given by ISIS-CFD seem to be representative of the reality. The code is able to compute correctly drag and vertical force for round planing hulls. Main advantage of this code is that it is very simple to use with no need to change computations parameters (time step and accelerations excluded) when changing hull forms or speeds. That makes it a very robust and somehow simple CFD tool for naval architects and designers in the pre design phase as in the optimization phase. The main limitation in using ISIS-CFD extensively is CPU time.

It remains to compare results with those of ICARE, the third available code in LMF which is computing faster. ICARE, developed by Bertrand Alessandrini, is combining a RANS solver with a non linear free surface condition. This allowed filling two major lacks of REVA: viscous wake of the hull and taking into account apparent length and wetted surface.

The main limitation of ICARE for high speed boat is the breaking wave on bow which can not be formally taken into account by the resolution method but only corrected. Schematically said, spray is “absorbed” to not perturb the resolution algorithm. ICARE has not been used successfully yet on those hulls at high Froude numbers. First comparison will be done soon.

3.3 COMPARISON REVA AND ISIS-CFD

To try to understand the differences between REVA and ISIS-CFD in the calculation of the vertical force, pressure map comparison was done. This revealed that REVA seems able to locate correctly the centres of pressure but is unable to integrate them correctly.

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4. SEA TRIALS

Sea trials are the best way to observe the real behaviour of the whole system (boats, sails and crew) in action. Therefore, three days of sea trials were conducted in Quiberon Bay (France) during January 2008. This work had been prepared and realized in the frame of the cooperative research program CAPVoile (Ecole Nationale de Voile et des Sports Nautiques of Quiberon and LMF/ECN).
The boat chosen was an Open6.50 designed by the Groupe Finot-Conq, a 6.5m long sport boat having high capability for planing. A professional crew was sailing it.

The main objective of those trials was to correlate the sailors feeling of planing with measured data. However, the results will be used for validating simulation when hydrodynamic characteristics of the Open6.50 will be known with further towing tank tests or CFD calculations.

4.1 EQUIPMENT AND PROCEDURES

The wind was measured with three light catamarans equipped with 2D sonic anemometers at 4.5m height, one catamaran with 3D sonic anemometer at 5.5m height and two 2D anemometers on shore. The catamarans (anemometers) were moored at each corners of the navigation zone. Those measurements give a precise knowledge of the wind speed and direction on the zone.

The Open650 was equipped with:

- An inertial measurement unit (IMU Xsens) logging at 50Hz to measure roll, pitch, yaw, accelerations and rates of rotation.
- A GPS, logging at 10Hz (fixed on the transom). When they are post treated with data from the on shore GPS base, GPS raw data give a centimetre precision of the trajectory and a reliable boat speed.
- A synchronizing and data logging system (Cadden).
- A video camera fixed on the top of the mast and two HF micro sets for the crew to comment what they were feeling. The Video camera and micros, as they were time synchronized, revealed great utility to analyse the data with a fair knowledge of what had happened on board: crew position, puff, technical problem, etc.

Repetitive sequences of downwind sailing were made. Crew position, apparent wind angle, crew weight and length of the spinnaker pole were changed to observe their effects.

4.2 FIRST RESULTS

Test conditions were nearly perfect as they were three different types of wind conditions: light to medium winds (8-12 knots), medium winds (12-16 knots) and heavy wind (20-25 knots). Favourable wind direction makes wave height always small (estimated maximum 0.3m). This allowed us to obtain following sequences:

- Beginning of planing and non-sustainable planing
- Sustainable planing in medium conditions
- Planing in heavy conditions.

4.2(a) Beginning of planing

The figure 6 is the comparison between three runs where the crew feels the beginning of planing. Wind is between 11 and 14 kts at 120°. We noticed that a trim peak appears at the instant where the crew feels the boat accelerating and going to planing. This is common to every runs acquired during trials. After this peak, trim angle decreases quickly and stabilizes at a lower value. Boat speed is then more or less stable.

![Figure 6: Beginning of planing phenomenon](image)

Boat speed and trim angle for 3 different wind speeds.

This peak of trim seems to be characteristic of the beginning of planing. It is difficult to measure the dynamic altitude variation due to planing because it is few centimetres and small compared to heaving due to waves.

4.2(b) Effects of planing on speed and trim

![Figure 7: Boat speed and trim angle for a downwind leg in 20kts of wind – sustainable planing](image)

Figure 7 shows a complete downwind leg with 20 knots of wind at 145°. The trim peak discussed previously is clearly visible. Effects of planing on boat speed and trim angle are also very clear. Trim stabilizes at 2.7° and boat speed remains stable around 16 knots. At the end of the sequence the behaviour is modified because of a puff coming at 25kts. The first puff effect is a quick increase in trim angle probably due to many factors: lift effect of
the spinnaker, the quick increase in apparent wind speed and then of the aerodynamic load and other transitory effects. Speed increases too and stabilizes when the trim angle goes back to a value near 3°.

This means that planing stabilizes boat speed and trim angle and characterized by quite steady values of those quantities.

4.2(c) Effects of crew weight and position on sustainable planing

Figure 8: Boat speed and trim angle for different crew positions (upper figure) and different crew weights in 14 knots of wind.

Figure 8 shows comparisons of different crew positions and crew weights and their effect on boat speed and trim.

Upper figure compares a very aft crew position and a more central one. Obviously, the mean trim angle is lower when crew is centred. The boat speed is also lower.

The lower part of the figure compares three different crew weights with 3, 4 or 5 persons aboard which corresponds to weight variations of 20% (displacement variation of 1%). Inertia effects of crew mass are clearly visible. The difference between 3 and 5 people is the stability of trim angle and boat speed. With 5 persons aboard, there’s a lower top speed but a higher average speed. Data with 4 peoples aboard are with wind a little bit lighter but speed variations can be compared with the other sequences.

As a conclusion, there's a high correlation between trim angle and boat speed when planing. A trim peak is visible at the moment when the boat begins to plane. Planing stabilises boat speed and trim angle. Trim angle is a key factor to go planing and high trim angle can be achieved with a crew more aft or even heavier or with sails thrust oriented a little bit upward to lift the nose as it is the case with the Open650.

It remains to verify if simulation will confirm those observations.

5. SIMULATION & VPP

The database of hydrodynamic efforts on bare hull allows us to build a model which can be used in a 6DOF simulator.

Because planing boats sail in various regimes we try to develop a model on a base of spline functions of speed like Teeters [7] does. When boat has a large transom like Open 60’, the wetted hull characteristics greatly change with attitude and we chose to express polynomial factors of splines as function not only of attitude but also of corresponding wetted surface, length and beam. The response surfaces obtained for each effort and moment are satisfactory only between 12 and 25 knots. We currently work to understand why and to improve or change this model.

5.1 6-DEGREES OF FREEDOM SIMULATOR

To evaluate yacht performance, hydrodynamic model has to be associated with models for the propulsion forces and appendages. As a first approach, the goal is to investigate attitude, appendages and ballast configuration which gives the best boat speed for a given propulsive load.

Aerodynamic propulsion efforts due to the sails are a very complex function of boat attitudes and movements and of sail shapes, trimmings and settings. Therefore, the main idea is to separate drastically the hull problem and the propulsion problem. Aerodynamic loads are imposed or evaluated with simple models like those used commonly in VPPs. After finding the optimum attitudes of the boat for different propulsion efforts, another problem will be to find the sails shapes, trimmings and settings which effectively give the propulsion efforts needed.

Classic VPPs generally solve only three static equations for drag, lift and heel. The principle which we adopted to find the equilibrium is solves the 6 equations of motion
in time domain. The simulation runs until the steady motion is obtained. This method is much more adapted to planing boats as it takes into account trim and sinkage effects.

The equilibrium will be realistic if models and coefficients concerning the steady motion are accurate. Others hydrodynamic characteristics (inertial, damping, hydrodynamic derivatives) can be approximated or fitted to improve the convergence.

Let us note that more we will know precisely hydrodynamic and aerodynamic derivatives, more the transitional stages will be representative of the real dynamic behaviour.

Main advantage of this kind of simulator is to allow acting on parameters to see their influence on the whole system performance.

Currently, this simulator has been used for the following studies:

- Boat with fixed trim:
  - Study of the sinkage and drag for a given speed
  - Study of the sinkage and speed for a given drag
- Boat free to sink and trim: influence of the height of aerodynamic loads centre on speed
- Influence of appendages on trim at high speeds
- Influence of ballast, keel angle and centre of aerodynamic effort on boat performance for a given sail thrust: User guide of the boat.

Only tank tested hulls are modelled in the simulator. The objective is to be able to model every type of modern large hull using only a reasonable number of numerical computations. This should be done before the end of the program.

5.2 FOLLOWING STEPS

Nowadays, more and more boats are equipped with high level navigation unit that includes an IMU to improve real wind estimation and to help the autopilot.

Full datasets have been retrieved from the Open 60' GENERALI designed by the Groupe Finot-Conq (skipper: Yann ELIES).

Those datasets, covering the whole 2007 season including two transatlantic crossings, are currently studied to compare the real performance to the Wolson Unit VPP predictions. The data were logged with HR system (NKE) at a frequency of 25Hz. Attitudes of the boat as well as accelerations and other data are available. This constitutes a very rich database about the real behaviour of sailing ships.

Data can be used to correct velocity prediction programs and to analyse the effect of boards and canting keels, rudder angle, wing mast angle.

This will also be used as validation data for the simulator.

6. CONCLUSION

In order to conclude, different tools and methods have been tested for studying the planing phenomenon: tank tests, numerical computations and sea trials. No tool is completely satisfying and can be used separately. It remains many problems to solve before defining the best use of the tools to answer the initial question: how to design boats that planes earlier and closer to the wind.

However tank tests have allowed validation of CFD codes and the construction of a first model of the hydrodynamic forces acting on the hull that is used in simulators. This will be extended to different type of hulls using ISIS-CFD computations to correct the model and will constitute a velocity prediction program in six degrees of freedom. REVA will be used as a quick tool to look at the displacement of pressure centres due to change in hull geometry before a final validation with ISIS-CFD.

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9. AUTHORS’ BIOGRAPHIES

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