THE 24TH CHESAPEAKE SAILING YACHT SYMPOSIUM

ANNAPOLIS, MARYLAND, MARCH 2022

ABSTRACTS

Hydrodynamic Studies of a Foil-Assisted IMOCA-60 using FloSim and RANS CFD Codes

Brian Maskew, Computational Flow Simulations LLC – maskew@methownet.com
Hannes Renzsch, FluidEngineeringSolutions – hannes@fluidengineeringsolutions.com
Britton Ward, Farr Yacht Design – britton@farrdesign.com

The latest generation of IMOCA-60's have incorporated the use of hydrofoils to generate vertical lift and righting moment. The addition of the foils has resulted in substantial performance gains but has introduced a host of additional challenges. Unlike the fully flying AC-75's, the IMOCA-60's operate in both a fully displacement "Archimedean" mode and in a skimming foil supported configuration. The IMOCA class rules prohibit the use of rudder elevators and so we develop a foiling attitude where the boat is supported on the foil, keel and the aft most portion of the hull. The foils may be retracted and some angle change is allowed to provide some level of manual lift regulation. Simulation of this flight arrangement is complex in calm water, let alone in the waves of the Southern Ocean. From a design perspective we need to accurately predict the performance of candidate designs across a wide range of conditions, including an understanding of the boats dynamic "flight stability" and performance in waves. The paper examines a number of motion and stability issues of a foil-assisted racing yacht sailing in both in calm water and in waves.

Of particular interest to these dynamic simulations is the body motion solver. As discussed by various authors the semi-implicit coupling of flow simulation and body motion can introduce convergence problems, particularly for light, fast boats where the dynamic added mass and inertia are often larger than the actual static mass and inertia leading to a diverging body motion solution within the time step. Artificial increases in pitch inertia – numerically equivalent to severe under-relaxation - may be considered to achieve consistent convergence but risk masking real stability phenomena.

Analyses have been carried out with both the boundary element method (BEM) code FloSim, and with a highly modified version of OpenFOAM in an effort to cross-validate the solutions and explore the influence of solution methodologies on numerical and physical sources of flight instabilities. Solutions for a few key-point cases are obtained looking for close agreement in predictions of force and moment, and in pitch, heave, yaw etc. This BEM/RANS strategy is a cost- and time-effective ploy for pursuing such investigations or indeed any activity where a large matrix of operating conditions needs to be populated, such as in VPP analyses for candidate designs for a new yacht, or in a race handicapping process; the time needed for upwards of 1000 cases using RANS alone would be prohibitive, whereas

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the mixed BEM/RANS approach provides a very reasonable turn-around, yet with the credence of verification at targeted independent solutions at focused sailing points.

The paper includes a description of the FloSim computer model and treatment for the foil-assisted IMOCA-60 yacht comprising the hull, foils, rudders and canting fin/bulb; details are included of how the appendage models are handled in terms of root junctions and free surface intersections, and also how their settings and deflections are applied.

The RANS simulations are based on a highly modified version of OpenFOAM (see previous papers by Renzsch, Graf, Mayer et al). In this version numerics and solvers suitable for simulating large-scale high-Reynolds free surface flows have been implemented. Specific developments in the rigid body motion solver have been undertaken to improve the stability and accuracy of the simulations of high speed, dynamic craft. In the present approach the added mass and inertia are calculated during runtime based on previous results of the body motion solver. Besides giving a numerically stable solution – even for unsteady motion – this allows for a reliable estimate of added masses to be used e.g. to refine the potential flow solution. In this paper the body motion solver is described, and its behavior analyzed. This will be concluded by the application to the IMOCA dynamic stability problem with direct comparisons to the FloSIM BEM method solutions.

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ANNAPOLIS, MARYLAND, MARCH 2022

ABSTRACTS

Development of a Six Degree of Freedom Velocity Prediction Program for the foiling America's Cup Vessels

Neil Patterson, University of Tasmania, Australian Maritime College, Australia
Jonathan Binns, University of Tasmania, Australian Maritime College, Australia

Since the introduction of hydrofoils to the Moth sailing class in the early 2000's foiling has become increasingly popular in sailing from windsurfers to large 75' foiling monohulls. The last 3 America's Cups have been competed on hydro foiling vessels. Design programs such as Velocity Prediction Programs (VPP) have become a key asset to America's Cup teams to allow for the optimisation and testing of designs before manufacture. Presented is the development of a Six Degree-of-Freedom (6DoF) Quasi-Static Velocity Prediction Program (SVPP) and Dynamic Velocity Prediction Program (DVPP) for the 35th and 36th America's Cup foiling AC50 Catamaran and AC75 Monohull. The models have been validated against race data from the 35th and 36th America's Cup showing good correlation for a wide wind range of 8 to 22 kn. The paper presents how the AC50 SVPP was used for analysis on the impact of Rudder Rake Differential (RRD) on overall performance, and predicting the optimal wind range for use of the light and heavy weather dagger boards on the AC50 Catamaran. The AC75 SVPP and DVPP was used to analyse the effect of hull shape and the main foils' fixed angle-of-attack (AOA) on time-to-flight and peak velocity to determine optimal foil setup and pitch angle when foiling. The SVPP and DVPP use XFLR5 software suite to model the foils. Experimental data for a T-foil tested in the Australian Maritime College towing tank facility has been used to predict viscous and free surface effect adjustments to the predictions from XFLR5.

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THE 24TH CHESAPEAKE SAILING YACHT SYMPOSIUM
ANNAPOLIS, MARYLAND, MARCH 2022

ABSTRACTS

Practical Performance Prediction of Foil-Configured Monohull Yachts

Clay Oliver, Yacht Research International, Ltd.
Etienne Gauvain, Wolfson Unit MTIA, Southampton, UK

Interest in foil-assisted monohulls continues to increase. Indicative of this trend is the success of the current IMOCA60 class, the proliferation of new or modified foil-assisted dinghies, performance luxury yachts, as well as race boats, including the novel America's Cup Class (AC75).

What tools and methods are currently used to develop and investigate the performance of a foil-assisted yacht?

Approaches range from VPP hacks, adjusting displacement and stability input, to the resource-intensive CFD and response-surface methods typical of modern America's Cup projects. Between these extremes sit various approaches, many of which might be characterized as kluges of a potential-flow foil runs fitting with force balance spreadsheet routines.

Is there a practical, design-oriented, sufficiently accurate approach that is generally available to the design community to evaluate the total performance of the foil-configured yacht and its appendages? This paper describes methods recently developed and incorporated in a newly available VPP program for yacht designers and analysts.

New methods to calculate the foil forces within the VPP solution loop for fully- or partly-immersed foils are discussed. A variety of non-trivial hydrodynamic issues are addressed, including dynamic hull forces and moments when wetted. A practical approach to surface-piercing foil hydrodynamics with the potential for ventilation and stalling is presented.

Calculations for quickly varying forces and moments must be incorporated in a multi-degree of freedom and multi-state solution, for all the state variables (velocities, position, orientation, etc.) as well as control variables, such as rake, dihedral, and elevator.

The methods and design-oriented computer program described in this paper have been used for various successful projects. The procedures are illustrated for various non-planar foils, including DSS, so-called "Dali", L, C-Foils, as well as planar configurations such as a T-Foil rudder.

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ANNAPOLIS, MARYLAND, MARCH 2022

ABSTRACTS

Velocity Prediction Program for an Hydrofoiling Lake Racer

Michele Francesco Melis, Hamburg University of Technology, Hamburg, Germany
Dr. Heikki Hansen, DNV, Hamburg, Germany
Dr. Martin Fischer, NC Raceboats, Noumea, New Caledonia
Prof. Dr. -Ing. Moustafa Abdel-Maksoud, Institute for Fluid Dynamics and Ship Theory at the Hamburg University of Technology, Hamburg, Germany

The aim of this paper is to develop an accurate and robust six degrees of freedom quasi-static VPP model applied to a high-performance sailing yacht. The model is set up to assist NC Raceboats with the VPP based hydrofoil design, considering the sailing performance in three modes: archimedean, transition and hydrofoil. The yacht is a lightweight monohull designed for light wind conditions with a variable number of crew members. The design includes a self-stabilizing hydrofoil configuration and an elevator rudder. The software tool, which is used for the velocity prediction program, is FS-Equilibrium, developed by DNV. The software offers a modular workbench in which each force can be modelled with semi-empirical force modules, which are based on validated methods and theories. The performance prediction are interpreted and discussed: as foreseen, the performance of the high-performance lake racer in hydrofoiling condition is significantly greater compared to its assessment in archimedean sailing mode. In medium breeze conditions, the yacht is able to lift up on its hydrofoils and attain flight mode. The minimum hydrofoiling speed investigation demonstrates that the VPP is able to consistently iterate trough the transition mode. This paper shows that it is possible to develop a VPP model for a hydrofoiling sailing yacht on the basis of relatively simple assumptions and theories.

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ABSTRACTS

Sailing in waves: A numerical method for analysis of seakeeping performance and dynamic behavior of a wind powered ship

Martin Kjellberg, SSPA Sweden AB, Gothenburg, Sweden
Frederik Gerhardt, SSPA Sweden AB, Gothenburg, Sweden
Sofia Werner, SSPA Sweden AB, Gothenburg, Sweden

Due to the many advantages of diesel propulsion and the availability of cheap oil, interest in commercial sailing vessels has been minimal for most of the 20th century. Now, at the beginning of the 21st century the climate crisis has changed this. In alignment with the UN's emission reduction goals, IMO agreed to cut greenhouse gas emissions by at least 50% by 2050 compared to the 2008 level. Before this background the largest sailing ship in the world is currently being developed in Sweden. This wind powered car carrier concept, called Oceanbird will have five 80-metre-high wing sails targeting emission reductions in the order of 90%.

The prediction and analysis of the seakeeping performance of such a ship is of importance not only in terms of sailing dynamics but also when it comes to the structural design of the rig.

To this end, a numerical method for predicting a ship's motions and loads on its rigid wing sails is described and a demonstration of how the method can be used to obtain such loads is presented.

The numerical method is based on an unsteady 3D fully nonlinear potential flow hydrodynamic model coupled with a hybrid 2D RANS/3D lifting-line aerodynamic model. Simulations in various sea states with short-crested irregular waves and corresponding wind conditions are conducted, resulting in time histories of the aerodynamic and inertial forces acting on the rig.

Possible applications of the method include fatigue analysis of the wing structure, where the accumulated fatigue damage over the lifespan of the rig structure depends on the sum of aerodynamic forces and wave induced inertial forces. Other potential applications include sail dynamics, parametric roll and sheeting strategies.

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ABSTRACTS

Multi-wing Sails Interaction Effects

L. Marimon Giovannetti, SSPA, Gothenburg, Sweden
U. Dhom´e, KTH, Stockholm, Sweden
K. Malmek, Chalmers University, Gothenburg, Sweden
A. Persson, Chalmers University, Gothenburg, Sweden
C. Wielgosz, KTH, Stockholm, Sweden

The interaction effects of multiple wings interacting and the change in efficiency due to those effects as well as optimal sheeting angles are becoming an important area of study with the advent of windpropelled ships for goods transport. This research presents a first analysis of wind tunnel tests carried out at the University of Southampton R.J. Mitchell wind tunnel where three wings are subject to turbulent flow with Reynolds number in excess of 1 million. A range of possible variations of ship heading, and apparent wind angles are tested taking into consideration the blockage effects and the geometrical characteristics of the working section. The forces and moments are captured on each individual wing as well as in the overall wind tunnel balance with 6-components balances. Furthermore, pressure sensors and PIV data are recorded during the tests to provide the experimental campaign with results that can validate both qualitatively and quantitatively the numerical tools developed to aid the design stage of wind propelled vessels.

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ANNAPOLIS, MARYLAND, MARCH 2022

ABSTRACTS

Concurrent Multi-component Optimization of Stiffened Plate Yacht

Tobias Lorimer, University of Auckland, Auckland, New Zealand
Tom Allen, University of Auckland, Auckland, New Zealand

Optimisation has established itself as a necessary tool when designing competitive high-performance yachts. The inherently complex material characteristics of composite materials mean there must be careful consideration of the effects of laminate design to meet loading and efficiency demands. Implementing an optimisation approach to the development of composite structures and their laminates will enable designers to design more effectively. This paper aims to investigate a more holistic approach to designing large multi-part composite structures using concurrent GA optimisation tools, investigating the effect of optimisation on the decision-making and design processes. Specifically, how can better design decisions be influenced by incorporating tools that augment an experientially based complex composite structural design process? A tool has been developed that concurrently optimizes laminate architecture and the arrangement and number of internal structural members to maximize structural efficiency. The purpose of the tool presented here is to allow designers to assess the effects of any 'design branching' decisions. These are decisions that significantly affect the final structural arrangement of a racing yacht. The tool uses GAs to assess in-plane and pressure loading effects on hull plating supported at multiple locations. GAs are used as they offer a much quicker process time than more traditional brute force approaches and can be adapted to run a series of different objective functions.

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ABSTRACTS

Wingsail Profile Optimisation Using Computationally Efficient Methods

William Birch-Tomlinson, University of Southampton, Southampton, UK
Prof Stephen Turnock, University of Southampton, Southampton, UK
Dr Martyn Prince, Wolfson Unit, Southampton, UK

On any race yacht, having the ability to maximise boat speed is key to obtain winning race performances. To achieve this the sail or wing must be set at its optimum profile. To find the best wingsail profile the trend recently has been towards more computationally expense approaches, but can we use less intensive methods to contribute to the design and race optimisation process when time and resource may be limited and mindful of the environmental costs? With an extensive number of different flying shapes, a computationally efficient approach at accurately finding optimum wingsail profiles for any given wind speed and direction is required. Using a two-dimensional section of the wingsail, lift and drag characteristics were found using Reynolds Averaged Navier-Stokes (RANS) simulations within Star-CCM+. A modified lifting line (LL) model was programmed in Python which used the two-dimensional characteristics to give fast and accurate predictions of drive force and heeling moment in a twisted inflow. The LL code was verified using experimental data, and showed that with analytical corrections, accurate predictions of lift and induced drag could be obtained. 3D RANS simulations confirmed that the LL model with correct tuning of the root vortices could predict driving forces and heeling moments within 1% and 5% respectively for a typical range of angle of attacks (AoA) and wing shapes. LL predictions took ~8 seconds on a laptop compared to ~2 hours for 3D RANS simulations running on a High-Performance Computing cluster. A machine learning algorithm using Kernel ridge regression was trained and can then interpolate and give accurate predictions within 1% of the LL. Results could be obtained in ~0.001 seconds showcasing the large computational savings. This method permitted an exhaustive search of different wingsail profiles, giving information on parameter trends such as AoA, camber, and twist. This provides a tool that could be adopted by sailors and teams to aid in setup and trimming of wings for maximum performance.

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ANNAPOLIS, MARYLAND, MARCH 2022

ABSTRACTS

Towards Dynamic Velocity Prediction of NACRA 17

Stig Staghoj Knudsen, Technical University of Denmark, Kgs. Lyngby, Denmark
Jens Honor´e Walther, Technical University of Denmark, Kgs. Lyngby, Denmark
Brian Nyvang Legarth, Technical University of Denmark, Kgs. Lyngby, Denmark
Yanlin Shao, Technical University of Denmark, Kgs. Lyngby, Denmark

NACRA 17 is a small foiling catamaran used in Olympic sailing. Sailing in the NACRA 17 is truly unsteady, especially in the foiling conditions. Dynamic velocity prediction has gained a lot of attention in recent years do to the unsteady nature of foiling sailboats.

Different approaches have been applied to predict the motions of foiling or skimming boats in unsteady conditions. Typically the aerodynamic forces are computed by the quasi-steady theory assumption. Static coefficients are used and the applied velocities are corrected with boat motions. The hydrodynamic forces of a fully foiling boat can be computed in a similar fashion, but this method fails to include the effect of changes in the free surface as well as added mass.

This paper proposes an approach where dynamic coefficients of the NACRA 17 hydrofoil are determined based on unsteady CFD simulations. In the simulations the foil is moved in prescribed motions in one DOF at a time and dynamic coefficients are extracted for different frequencies of motion. All coefficient are combined in a coupled system of equations and the equations can be solved in 6 DOFs in the time domain. A number of test scenarios with time varying conditions are simulated and compared with full dynamic 6 DOF CFD simulations. The initial investigation of the approach show promising results, but more investigation are needed to validate the approach and corresponding limitations.

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ANNAPOLIS, MARYLAND, MARCH 2022

ABSTRACTS

Progress in Development and Design of DynaRigs for Commercial Ships

Manuel Fluck, North Sails, Lorient, FR
Alexander Wright, Wolfson Unit MTIA, University of Southampton, UK
Dale Morris, Southern Spars, Copenhagen, DK
Martyn Prince, Wolfson Unit MTIA, University of Southampton, UK
Jeremy Elliott, North Sails, Lymington, UK

For most of the past century sailing was (besides very few exceptions) associated with pleasure and racing only. Recently, however, this is changing as the commercial sector becomes increasingly interested in direct wind propulsion systems. The reasons are obvious: increasing fuel cost (direct or though emission penalties) and environmental awareness (intrinsic or driven by customer demands). In this paper differences between the design requirements in the commercial market and the pleasure or racing yacht industry are discussed and enhancements to the existing design tools relevant for commercial studies are presented. Sailing yacht studies have repeatedly shown how important it is to design and optimize the aero and the hydro aspects of the vessel in synchrony. This is equally or even more important for commercial ships, where part of the thrust might still come from the engine. Thus, the engine together with economic objectives of the shipping operations enter into the design space. With the example of DynaRigs a few select results are first presented when analyzing the aerodynamic design space alone. Detailed results from several performance analyses via our Performance Prediction Program (PPP) are then discussed as well as some outcomes from the structural analysis to show the importance of combined aero, structure, hydro, and potentially engine as well as economic design decisions. The paper concludes with an outlook on future work.

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ANNAPOLIS, MARYLAND, MARCH 2022

ABSTRACTS

Agent Based Match Racing Simulations: Starting Practice

D. Lidstr¨om, Chalmers University of Technology, Sweden
T. Lundh, Chalmers University of Technology, Sweden
L. Marimon Giovannetti, SSPA, Sweden

Match racing starts in sailing are strategically complex and of great importance for the outcome of a race. With the return of the America's Cup to upwind starts and the World Match Racing Tour attracting young and development sailors, the tactical skills necessary to master the starts could be trained and learned by means of computer simulations to assess a large range of approaches to the starting box. This project used game theory to model the start of a match race, intending to develop and study strategies using Monte-Carlo tree search to estimate the utility of a player's potential moves throughout a race. Strategies that utilised the utility estimated in different ways were defined and tested against each other through means of simulation and with an expert advice on match racing start strategy from a sailor's perspective. The results show that the strategies that put greater emphasis on what the opponent might do, perform better than those that did not. It is concluded that Monte-Carlo tree search can provide a basis for decision making in match races and that it has potential for further use.

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ANNAPOLIS, MARYLAND, MARCH 2022

ABSTRACTS

The Use of GPS Data to Predict Racing Yacht Collision Conditions

Alex Melia, The University of Auckland, Auckland, New Zealand
Mark Battley, The University of Auckland, Auckland, New Zealand
Tom Allen, The University of Auckland, Auckland, New Zealand

To make SailGP races safer for the sailors taking part in them, the crashworthiness of the yacht used in SailGP, the F50, is under evaluation using physical and numerical testing. To determine load cases for this testing, GPS data from a past SailGP race was analysed using a purpose made extensible tool. Three plug-in extensions were written to identify potentially dangerous sailing events using three different methods; the starting and ending times of these events were used to filter similar statistics generated at every timestep of the GPS log by a fourth plug-in. Analysis of these statistics revealed two unique potential impact scenarios, the first an oblique side-on-side event and the second resembling a “T-bone” style event. The closing speeds of the competitors in these events, the angles between the competitors in these events, and the height difference between the competitors in these events were used to produce load cases for each of these two scenarios. Considerations toward potential crashworthiness improvements of the existing F50 design, as well as an outline of a method to design structures with improved crashworthiness for future iterations of the F50 using the derived loadcases, are given.

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ANNAPOLIS, MARYLAND, MARCH 2022

ABSTRACTS

Real Time Heading Sensors Fusion and Fault Detection

Pia MATHIAS, Universit´e Bretagne Sud, Lorient, France
Johann LAURENT, Universit´e Bretagne Sud, Lorient, France
Pierre BOMEL, Universit´e Bretagne Sud, Lorient, France
Hugo KERHASCOE¨ T, Madintec, Lorient, France

In modern offshore racing, performance often depends on two main factors: a good autopilot and the right strategy decisions taken by the skipper. Some sensors are crucial to ensure the quality of those two keys of success, among which we can mention the heading sensors. Unfortunately, those sensors, whether magnetometers or GNSS based, are subject to disturbances and faults of various origins: magnetic disturbances from other devices, GPS fix or reception issues, sensor drift, etc. The aforementioned fault on sensors can cause autopilot's solution to diverge which can result in serious damages for the boat or the crew. Assurance of a valid measure is therefore a key point to ensure reliability of autopilot system and skipper's decisions. This paper presents a method to produce consistent values of true heading and yaw rate while detecting fault on sensors.

The proposed solution relies on the hypothesis that sensors using different technologies and placed in different spots inside the boat will not be subject to identical and synchronised disturbances. Thus, by fusing intelligently the information coming from several sources, a continuous and consistent true heading measure can be maintained. A simple dynamic model for the heading and yaw rate is implemented and asynchronous filter update is done depending on available measures. The difference between the estimated state and the measure is used to determine whether a sensor is faulty or valid and the update is done consequently; then the information on sensors status and quality of the estimation can be propagated. Here, we detail the method able to detect faults on the heading sensors and to provide a substitution value if necessary. The proposed model is validated by test campaigns that were conducted using both data logs and on-board tests. Results show that we can improve and maintain true heading measure quality and detect and isolate faulty sensors.

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ABSTRACTS

A High Blockage Correction for Downwind Sails

Jean-Baptiste R. G. Souppez, College of Engineering and Physical Science, Aston University, Birmingham, UK (j.souppez@aston.ac.uk).
Ignazio Maria Viola, School of Engineering, Institute for Energy Systems, University of Edinburgh, Edinburgh, UK (i.m.viola@ed.ac.uk).

Model-scale testing of yacht sails and wings often suffers from blockage due to the physical constraints of experimental facilities. With blockage, a greater increase in flow speed occurs in the vicinity of the geometry compared to an unblocked flow as a direct consequence of the restricted cross-sectional area. This leads to higher forces than in unconstrained flow, making comparison and validation between tests conducted in different facilities difficult, while also flawing performance prediction if the forces are not suitably corrected. Blockage correction for streamlined bodies and bluff bodies such as flat plates normal to the flow, are well-established. However, it is not the case for lift-generating bluff bodies experiencing high trailing edge separation, such as highly cambered plates and downwind yacht sails. This study focusses on the development of a blockage correction for highly cambered plates, specifically circular arcs, comparable to horizontal sections of downwind yacht sails. Measurements are undertaken at positive incidences below deep-stall for Reynolds numbers ranging from 53,530 to 218,000 in a towing tank and a water tunnel to devise a blockage correction. The critical impact of the free surface deformation on wake blockage is evidenced. This allows to set a maximum limit to the amount of blockage a cambered plate can experience before blockage correction is no longer accurate. Hence the importance of closed measurement sections to prevent free surface deformation. Furthermore, the experiments revealed that flow behaviours such as the laminar-to-turbulent transition are preserved even with high blockage. These findings provide experimental insights into the effect of blockage on highly cambered plates, and it is anticipated they will support future force experiments conducted on downwind sails in high blockage conditions.

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ABSTRACTS

CNC Enabled Wood/Metal Composite Construction of (Relatively) High Performance Sailing Yachts

Christopher D. Barry, P.E. (CA, WA, MD); Small Craft T&R Committee SNAME

One problem for high performance yachts is to produce a light enough, strong enough structure. This is possible with modern fiberglass “composite” construction, but at substantial cost to produce the molds. Thus composites are expensive for limited construction. However, the term “composite” means a combination of any two different materials. Prior to advent of fiberglass, “composite construction” meant a combination of wood and metal, generally wood planks and perhaps primary framing over steel, bronze or aluminum secondary framing and other heavy structure. Prince Edward’s, (later King Edward VII) famous yacht Britannia was yellow pine over steel frames and was certainly a high performance yacht in her time. This system is now being used by a few builders of large, mainly traditional “revival” design yachts, (Barry, 2017) but it is applicable to much wider range of boats and could help reduce the cost and increase the availability of limited run yacht construction (and possibly opportunities for yacht design commissions).

The most important development is the ready availability of CAD/CAM/CNC design and cutting (for both metal and wood), but engineered wood, and modern coatings and adhesives, and even composite fastenings are also important enablers. The major framing structure is cut out of metal by plasma arc, water jet or laser cutters using standard metal industry techniques and equipment. The wood shell is made by strip planking, cold molding, or a combination, carvel or lap strake planking, or plywood. Planks or shell “plating” can be CNC cut as well, providing substantial reductions in labor for a one-off or limited production boat compared to either making a mold for a fiberglass boat or for traditional wood construction. Finally, large heavy timbers are not required which not only reduces labor, but allows use of sustainable timber resources and sequesters the carbon that the tree took from the atmosphere while growing in a form that hopefully will last for some decades at least.

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ABSTRACTS

Free-Surface Effects on Two-Dimensional Hydrofoils by RANS-VOF Simulations

Laetitia Pernod, IRENav, Ecole Navale, 29240 Brest, France
Matthieu Sacher, ENSTA Bretagne, CNRS UMR 6027, F29200 Brest, France
Jeroen Wackers, LHEEA, Ecole Centrale de Nantes, CNRS UMR 6598, 44300 Nantes, France
Benoît Augier, IFREMER, 29200 Brest, France
Patrick Bot, IRENav, Ecole Navale, 29240 Brest, France

Foiling yachts and crafts are both very sensitive to the flying height in terms of stability and performance, raising the scientific issue of the influence of the free-surface when the foil is at low submergence. This work presents numerical simulations of a 2D hydrofoil section NACA0012 at 5° angle of attack in the vicinity of the free surface, for different values of the submergence depth, for a chord-based Froude number of 0.571 and a Reynolds number of 159,000. URANS equations are solved with a mixture model to capture the free surface, and using an automatic grid refinement. Verification of the numerical model and validation with data from the literature are presented. Deformation of the free surface and alteration of the hydrodynamic forces compared to the deep immersion case are observed for a submergence depth-to-chord ratio h/c lower than 2. The foil drag increases up to more than three times the infinite-depth value at $h/c \approx 0.5$. The lift force slightly increases until h/c around 1, and then decreases sharply. For $h/c < 0.5$, the pressure field around the foil is totally modified and the lift is swapped to downward. The study highlights the importance of considering the effect of finite submergence to compute foils' hydrodynamic forces, for example to be used in Velocity Prediction Programs (VPP) of foiling crafts.

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ABSTRACTS

Numerical Water Impacts of 2D Hull Forms using Dynamic Overset Meshing

Connor Pearson*, University of Auckland, Auckland, New Zealand
Tom Allen, University of Auckland, Auckland, New Zealand
Mark Battley, University of Auckland, Auckland, New Zealand

The phenomenon of 'slamming' is often the critical design load for high-performance marine craft. Slamming involves the solid-fluid impact of a hull structure which results in large forces acting on the structure due to the volume of water displaced in a very short time. Due to its importance in the design and operation of marine craft, the impact of ship forms into water has been the focus of a significant body of literature. These studies have primarily focused on rigid shapes, so the effects of hydroelasticity have not been examined in detail.

In this paper, a robust and practical methodology for water impacts involving overset meshing and the VOF method using the FLUENT solver is presented. The framework involves a high resolution dynamic overset mesh attached to the body in a coarse Cartesian background mesh. Results for a simple 2D wedge impact are compared to experimental, analytical, and numerical results and a good agreement to the validation material is observed. Finally, a 2D transverse section based on the ORMA60 racing yacht Banque Populaire VIII was studied. This methodology to obtain impact force and pressures is intended to be applicable for designers of high-performance sailing craft to improve the prediction of hydrodynamic loading on their hull-form designs.

The work carried out in this study is part of an ongoing PhD investigating existing and proposed structural design configurations for high-speed marine craft and analysing failure mechanisms under dynamic ocean loads. Various structural configurations will be analysed using the framework outlined in this paper.