ABSTRACTS

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HPYD1 ABSTRACTS

NUMERICAL AND EXPERIMENTAL AEROELASTIC ANALYSIS OF SAILS

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Abstract. The main goal of this work has been the investigation of non linear behaviour of sail rig under aerodynamic load. To this aim, a first computer code has been developed to perform the viscous aerodynamic analysis of a multi-sail system including mast effect. The code is based on 3D vortex lattice method coupled to 2D boundary layer solution along streamlines [1]. Then the structural analysis has been performed using a finite element code. The final ***ISTIA*** code couples the aerodynamic and structural solutions performing successive iterations [2]. The aerodynamic problem has been faced using quadrangular vortex rings. Two-dimensional integral boundary layer equations, including the separation bubble model, have been used to evaluate viscous effects (including mast effect) on the inviscid pressure distribution and on the final sail shape. The structural behaviour of the sails has been assumed to be similar to a membrane under pressure loads. Three nodes iso-parametric triangular elements have been chosen for the finite element method. To validate the structural computer code an experimental test has been set up and a simple machinery has been built allowing shape measurements of a rectangular membrane under constant pressure load. The ***ISTIA*** code estimates the final shape of the multisail system set at a prescribed angle of attack, aerodynamic loads, all stresses, and the final aerodynamic and performances coefficients (like C_L, C_D, $C_{Propulsion}$, etc.). It is also capable to analyse non-isotropic material like those commonly used in sail fabric. Finally a sail rig model has been built and set in the wind tunnel belonging to the Department and sail deformation under different load conditions has been measured and compared with numerical results.

COMPARISON OF WIND TUNNEL AND FULL-SCALE AERODYNAMIC SAIL FORCE MEASUREMENTS

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Abstract. In this paper the comparison of aerodynamic sail force measurements from model scale wind tunnel and full-scale tests is presented. Wind tunnel testing of yacht sails is an effective design tool, but is at present mainly used for comparative testing. Comparing wind tunnel to full-scale data is important to better understand the associated scaling effects and make wind tunnel testing more accurate for quantitative sail force prediction. The full-scale data is taken from the sailing yacht DYNA developed at the Technical University of Berlin in Germany and is based on a 10-meter International Measurement System (IMS) cruiser/racer. For this project a 15% scale model was developed and upwind and downwind sail configurations comprising mainsail, genoa III and spinnaker were tested in the Twisted Flow Wind Tunnel (TFWT) of the University of Auckland. The parasitic drag was measured in the wind tunnel and compared to approximations used in velocity prediction programs (VPPs). The influence of the sails on the flow above the mast where the anemometer is located was investigated in the wind tunnel and the full-scale results are corrected to take this effect into account. The curves of lift and drag coefficient against the effective wind angle are compared to the coefficients obtained from the full-scale measurements. For the upwind configuration a significant force component up the mast was observed and its influence as the yacht heels was assessed. Comparing the results highlights the difficulties associated with modelling sail forces but also shows that wind tunnel and full-scale measurements relate to each other.

TANK TESTING AND DATA ANALYSIS TECHNIQUES FOR THE ASSESSMENT OF SAILBOAT HYDRODYNAMIC CHARACTERISTICS

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Abstract. This paper describes current tank testing and data analysis techniques with an emphasis on aspects critical to International America's Cup Class (IACC) sailboats. Pre-test planning is discussed from the perspective of long testing programs typical of well funded IACC campaigns. Initial considerations such as scale selection, model construction techniques/materials and the definition of the test matrix are discussed. Dynamometer design is reviewed and procedures to overcome its limitations are presented. Tankery issues such as waiting time, velocity measurement and residual turbulence are examined and recommendations for resolving these are given. Finally, typical data extrapolation techniques are discussed including the development of hydrodynamic models for Velocity Prediction Program (VPP) use.

CFD INVESTIGATIONS AND DESIGN INTEGRATION FOR IACC YACHTS

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Abstract. The paper reports about CFD investigations of mast and appendages of IACC Yachts, carried out for the illbruck Challenge (iC). Appendage development and optimisation is based on a mixture of potential flow and RANSE simulations taking into account bulb, blade, wings, rudder and canoe body, neglecting the free surface. A large amount of different appendages configurations are compared.. Different grid topologies and operational conditions are investigated.. Special attention is paid to proper integration of results into VPPs. Additional RANSE calculations did take into account the free surface using two-phase-flow method. While restricted in number of test cases, these simulations provide information about inflow conditions to be assumed to the test cases where the free surface has been neglected. A second field of intensive RANSE investigations has been mast profile optimisation. While initially restricted to mast-mainsail-profiles reliable results could only be achieved if jib and even head foil are taken into account. Full three dimensional RANSE calculations have been used to prove validity of optima for mast profile geometry derived from 2DRANSE simulation results. A family of profiles is compared under various operational parameters.

THE EFFECT OF PITCH RADIUS OF GYRATION ON SAILING YACHT PERFORMANCE

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Abstract. Traditionally a racing yacht is designed with as low radii of gyration as possible, especially regarding the pitch radius. A small radius normally provides less relative velocities between hull and water and thus less added resistance. Recent model tests at SSPA with a sailing yacht in head seas have indicated that a minimum of the added resistance can be found for a certain radius of gyration. The relation between the radius of gyration and the added resistance is of course best investigated by extensive model tests. However this is expensive and time consuming. A cost effective procedure is to combine model tests with computer based velocity predictions.

There are a number of different Velocity Prediction Programs (VPP's) available around the world today. Most of them are based on equations of equilibrium, one for each degree of freedom, that are explicitly solved. These programs work well as a basis for the judgment of the calm water characteristics for a sailing yacht. Many of them also have algorithms for estimating the added resistance in waves, which is normally based on regression formulas, derived from frequency based strip theory calculations.

At SSPA a time domain dynamic prediction program has been developed , a DVPP (Dynamic VPP), that provides possibilities to study also the dynamic characteristics of a sailing yacht. The input data are the same as for a conventional VPP, however, also the hull form is entered in the form of sectional coordinates. The principles for the program is that all the horizontal hydrodynamic forces are expressed in the same way as in the conventional program, however the velocities in the different degrees of freedom are corrected for the wave particle velocities. Additional wave induced forces are also obtained from wave particle accelerations and by pressure integration over the whole momentary wetted surface.

VPP VS PPP:
CHALLENGES IN THE TIME-DOMAIN PREDICTION OF SAILING YACHT PERFORMANCE

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Abstract. In this paper we describe some preliminary work in the development of a tool for time-domain simulation of yacht performance in waves. This tool (termed Performance Prediction Program, or PPP) was created to properly consider all aspects of yacht dynamics at design stage, rather than restricting design optimisation to the maximisation of boat speed in idealised conditions. This PPP has been developed in parallel with a six-degree of-freedom Velocity Prediction Program (VPP) in order to perform comparative studies.

The approach used to predict yacht motion in the time-domain is described in this paper, along with the challenges posed by the incorporation of conventional aero- and hydrodynamics models commonly associated with VPPs in a new and unconventional design tool. Some of the solutions adopted to meet these challenges are outlined, whilst the difficulties peculiar to this type of analysis and not normally faced in the development of conventional VPPs are highlighted.

Some of the results obtained using the developed PPP are briefly presented and compared with those of the complementary sixdegree-of-freedom VPP and other obtained using a commercial VPP. Some details of a more comprehensive validation exercise are also included. Finally, some considerations on the practical use of PPPs in racing yacht design conclude the paper.

ACCURACY IN SAIL SIMULATION: WRINKLING AND GROWING FAST SAILS.

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Abstract. This paper describes some techniques for improving accuracy in the computation of structural membranes. Of importance in membrane computations is the modelling of the wrinkling of the surface that occurs to relieve compression. The paper describes an improvement to current theory by consideration of optimum-shift in the stiffness matrix derivation. The paper also describes the way that wrinkling interacts with the kinematics of the element grid. Results are presented demonstrating the effects of varying grids, with and without the modelling of wrinkling. The paper discusses error propagation in linked procedures that include membrane structural analysis and describes an automatic membrane design scheme using optimisation techniques.

THE RIG OF THE RESEARCH SAILING YACHT "DYNA" MEASUREMENTS OF FORCES AND FEA

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Abstract. The "DYNA" is a research sailing yacht of the TU-Berlin, also called the "Sail-Force-Dynamometer". She is an entire measuring device for aerodynamic and hydrodynamic forces. The focus in the paper is on measured and computed forces in the standing rigging and in the mastfoot. The aim of the work is to better predict loads and deformations of rigs from high performance yachts for design purposes. The forces in the rig are measured with 20 separate force transducers for mast compression, all shrouds, stays and sheets. A global FEA model of the rig is built up. Geometrical non linear computations for the load cases dock pretensions and sailing upwind with 30° heel are performed. Results are internal forces and deformations of the rig. The loads from the sails are calculated by a load model based on the righting moment of the "DYNA" and the sag angles of the sails. The results of the measurements and the computations are compared with each other.

ANALYSIS OF RUDDER SPAN EFFECTS ON IMS HYDRODYNAMIC INDUCED DRAG

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Abstract. The physical draft of keels has long been known to be critical for the upwind performance of sailboats and has long been an element of handicap rules. The IMS rule uses a relatively sophisticated algorithm for assessing keel draft yet, as is the case with other rules, has never included any influence of rudder span. However, there is considerable empirical evidence that rudders can make a significant contribution to performance by increasing the total effective draft. Tank test research was conducted to explore rudder span and quantify performance differences. The results have been incorporated into the IMS 2002 rule in a way that is intended to give some rating relief to boats with shallow rudders yet not drive optimised design in that direction

IMPLEMENTATION, APPLICATION AND VALIDATION OF THE ZARNICK STRIP THEORY ANALYSIS TECHNIQUE FOR PLANING BOATS

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Abstract. Zarnick developed an approach to calculate the resistance, motions in waves, and resultant pressures of planing craft by stripwise integration of the forces on transverse sections modelled as wedges entering the free surface vertically. A practical software implementation of this technique was developed and compared to model test results for a variety of military, recreational and working craft. Numerous modifications and improvements to the technique were made in the course of this study, most notably to a series of coefficients to represent buoyancy and three-dimensional lift and drag factors, to improve the correlation of the method. The final results of this study show that this method produces better evaluations of resistance for relatively high-speed vessels than previous methods and compares reasonably well with model test results for motions. This method explicitly models variable beam and deadrise, which previous methods cannot address. The basic background of the technique, its implementation and the development and modifications of coefficients is discussed with a history of validation efforts to improve the correlation.

ACHIEVING HIGH PERFORMANCE WITHIN THE RESTRICTIONS OF EU RECREATIONAL CRAFT DIRECTIVE

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Abstract. The majority of designers and builders are now very familiar with the European Recreational Craft Directive (RCD). This paper is not intended, therefore, to be a review of the requirements of the Directive, (although a little background is required). This paper is intended to show that, contrary to popular belief within the industry, the RCD allows for some considerable flexibility that can be harnessed to achieve a compliant high performance craft. It is a common view that to satisfy the requirements of the European Recreational Craft Directive, a boat must comply with all the applicable harmonised standards. These standards are generic and were written in broad-brush to suit all types of craft. A task they achieve, generally with aplomb. Designers of high performance and radical craft that push boundaries, however, will find that their design ambitions are frequently thwarted by the standards' broad-brush approach. This paper introduces an array of methodologies, alternative to applying the harmonised standards, which exploit the significant flexibility permitted by the RCD.

THE ACCURACY AND REPEATABILITY OF TANK TESTING, FROM EXPERIENCE OF ACC YACHT DEVELOPMENT

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Abstract. Extensive tank test programmes continue to be employed in the development of ACC yacht hulls and appendages. Tank testing is a physical modelling technique, as distinct from the numerical modelling that is also employed in design for lines generation, hydrostatic and seakeeping calculations and in computational fluid dynamics. All modelling methods have their limitations and sources of inaccuracy and no doubt workers in all these fields seek to refine their methods as the demand for accuracy and reliability increases. This happens in particular during ACC yacht development because of the pressure of competition for the Louis Vuitton and America's Cups and due to the resources that are brought to bear on the problems.

This paper addresses issues that affect the accuracy and repeatability of tank testing and the efforts that have been made to help designers discriminate differences of less than 1% in the drag of their boats. The challenge in this task involves engineers and facilities around the world and it should be to the benefit of all to share an insight of the issues involved so as to provide designers with the best information to enable them to engage in the competitive aspect of the problem. Uniquely, in the recent history of tank testing for the America's Cup, the Wolfson Unit has been involved with tests for the defender and three challengers using two different facilities. In addition the Wolfson Unit has supplied yacht dynamometer designs and data acquisition equipment for use by two further challengers in two other tank facilities.

ADVANCED PARAMETRIC YACHT DESIGN

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Abstract. For high performance yacht design systematic investigations of the design space play an increasing role. Normally, numerical tank testing and race simulation programs are applied to find a set of near optimum designs which then are tested at model scale. Systematic shape variations, utilizing the gradient of the performance with respect to the selected design variables, can significantly accelerate the search for an optimum design, due to the reduction of designs to be evaluated. However, the gradual change of a hull shape is not a trivial task, especially if the design is governed by measurement rules. Performing the task of systematic shape variation with respect to a set of design variables manually is quite impossible. Taking into account the unique formulations of different measurement rules, no general tool can be applied. Instead a special design scenario has to be set up, where knowledge from designers, software engineers, sailors and the owner has to be merged to a single-objective formulation. This paper presents the course of an implementation, negotiations and the results of a parametric CAD-Program for a 30m^2 inshore yacht measurement rule (*German L-Boot*). Measurement restrictions, integrated knowledge from the designers experience and the definition of design variables are subject of an extensive discussion. The resulting modeller is fully based on parametric design principles and can be applied in an automated optimisation process without user interaction [1]. It is based on variational principles applying fairness measures, resulting in numerical battens. A tailor made set-up for the specific measurement rule and important parameters – identified in close co-operation with the designer – are made accessible and directly applicable for straightforward search of the optimum design.

YACHT PERFORMANCE PREDICTION : TOWARDS A NUMERICAL VPP

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Abstract. The coupling of aerodynamic computations of the flow around the sail and hydrodynamic computations for the flow around the hull of a sailing boat is achieved in order to predict its performance in calm water. The aerodynamic code is based on a lifting surface model for the sails and a vortex method for its wake. The hydrodynamic one is a Boundary Element Method using the steady wave resistance Green's function with a particular attention to the accuracy of the computations of the various boundary integrals involved. The motion of the sailing boat upward is studied by computing the horizontal acceleration at each time step and then deducing the velocity and position of the boat. The heel balance is performed in a very simplified model: the aerodynamic rolling moment on the sails is balanced by static moments, due to the keel mass and the crew one, assumed to be located at a certain distance off the symmetry plane of the boat. Different options of these calculations are available: the heel angle is fixed and the weight of the crew located on one side of the boat can vary; it is also possible to give a maximum value to this crew mass and let a free heel angle; the last option is to let a fixed crew weight and free heel angle. Results are presented only in steady flow.

FINITE ELEMENT ANALYSIS OF COMPOSITE BOATS

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Abstract. Advances in computer technology plus the potential for materials saving and boat performance improvement has meant hat Finite Element Analysis (FEA) has increasingly become a standard tool for boating designers. However, recent spectacular boat ailures from designers employing this methodology have highlighted the need for a systematic and rigorous approach to analysis ork. This paper addresses the main issues involved in incorporating FEA into the boat design and production process. Issues include geometry cleanup, element selection, meshing, material and layup definition, load and support specification, analysis, optimisation and results interpretation and presentation. Examples ranging from luxury motor yachts through to high performance racing yachts are discussed.

FINITE ELEMENT ANALYSIS OF COMPOSITE BOATS

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Abstract. Advances in computer technology plus the potential for materials saving and boat performance improvement has meant hat Finite Element Analysis (FEA) has increasingly become a standard tool for boating designers. However, recent spectacular boat ailures from designers employing this methodology have highlighted the need for a systematic and rigorous approach to analysis ork. This paper addresses the main issues involved in incorporating FEA into the boat design and production process. Issues nclude geometry cleanup, element selection, meshing, material and layup definition, load and support specification, analysis, ptimisation and results interpretation and presentation. Examples ranging from luxury motor yachts through to high performance acing yachts are discussed.

VALIDATION OF CFD METHODS FOR DOWNWIND SAIL DESIGN

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Abstract. The suitability of CFD codes based on the Reynolds Averaged Navier Stokes equations is investigated for use in downwind sail design. Simulations are performed using CFX5 and are validated using wind tunnel experiments carried out at the Auckland Yacht Research Unit. Due to the complexity of the downwind flow situation the simulations are limited to two-dimensional analysis. The complex separated flow around downwind sails is heavily dependent on the choice of turbulence model. Accurate prediction of eparation points is difficult and turbulence models typically delay separation and thus underestimate the size of the wake which has a arge influence on lift and drag calculations. The SST *k*-omega model was found to be the most suitable model available in CFX for eparated flows. In the wind tunnel experiments, the spinnaker geometry is approximated by a circular arc with 24.7% camber. Force easurements were taken through a range in angle of attack from 5 to 30 degrees. At all angles of attack the flow is unsteady and eriodic vortex shedding is evident. Through flow visualisation it is apparent that three-dimensionalities exist in the

separated wake. dditional validation work has also been carried out using a 10% camber section which has a flow that is nominally two dimensional nd is steady and predominantly attached at low angles of attack.

UTILITY OF FLYING SHAPES IN THE DEVELOPMENT OF OFFWIND SAIL DESIGN DATABASES

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Abstract. Large differences commonly exist between a computer based original design shape and the resulting flying shapes of offwind sails. This gap increases the level of requisite artistry in the sail design process. Replacing an original design shape in an offwind sail design program with a single representative flying shape (reflective of a realistic sailing and trim condition for that class of sail) could partly close this gap. Validity of this notion requires, at a minimum, that the underlying geometries of the two candidate sails, resulting from the design shape and flying shape approaches, are identical. The objective of this study was to investigate the potential of this notion by first designing/constructing a model sail, measuring plausible flying shapes in the wind tunnel environment, creating new sail designs whose shape mimics the measured flying shapes, and then comparing the mathematical properties of the underlying geometry (as defined by the resulting curvature of the external edges and internal seams) of the candidate designs (the original design shape and the flying shape mimics) to each other. Potential improvements to the offwind sail design process by developing an offwind sail design database (a collection of baseline designs appropriate for different applications) based upon representative flying shapes rather than present style based upon design shapes is discussed.

ENHANCED DEPOWERING MODEL FOR OFFWIND SAILS

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Abstract. Methods to represent the depowering of sails exist in the aerodynamic models of contemporary Velocity Prediction Programs (VPP) and work with varying degrees of success. Although these depowering models were originally developed with upwind configurations in mind, they are also commonly applied to sailing conditions where offwind sails are used. Recent efforts on the part of several groups using experimental and computational means have reported progress in improving depowering models for upwind sails. Unlike those efforts, this investigation studies appropriate depowering models for asymmetrical offwind sails designed to operate at close reaching angles. The resulting enhanced depowering model for offwind sails is based upon experimental studies performed in the Glenn L. Martin Wind Tunnel. VPP results for a generic 72' turbosled are reported to demonstrate the impact of enhanced depowering aerodynamic modeling on speed prediction and sail inventory selection. The approach has been found to substantially improve the velocity prediction in conditions where boat stability tends to limit boatspeed potential and has been used on a number of occasions to improve the prediction of sail crossovers and to optimize sail inventory selection.

IMPROVING THE DESIGN OF SAILS USING CFD AND OPTIMIZATION ALGORITHMS

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Abstract. Two current Stanford Yacht Research projects are presented, both related to the analysis and design of upwind sails, and part of a larger research effort to develop efficient and robust sail and hull shape optimisation methods.

First, we discuss the in-house development of a methodology to predict and improve the flying shape and forces on America's Cup sails. We adapted and parallelized a 3D unstructured incompressible Euler solver developed by Jameson and colleagues. The computed pressure loading is transferred to the structural package NASTRAN, which computes the deflected shape of the sail. The mesh is displaced accordingly, and a new pressure loading is computed. This process is repeated until convergence. The computed lift and induced drag for a main sail with elliptic planform compares well with results from lifting surface theories. The flow solver is more efficient than commercial solvers and highly suitable for the computationally intense viscous sail flow calculations.

Second, we present a sail shape optimisation method, which combines the commercial CFD package FLUENT with gradient-based cost function minimisation. Results are presented for the optimisation of sheeting angles for the rig of a three masted clipper yacht. We investigate two cost functions, both characteristic of a sail's aerodynamic performance: the reciprocals of the driving force coefficient and the ratio of driving to heeling force coefficients. Comparing results for upwind and close reaching apparent wind angles shows that the latter leads to well trimmed sails, whereas the former causes the sails to be over trimmed, which is as expected.

WIND TUNNEL TESTING OF DOWNWIND SAILS

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Abstract. This paper describes research which is aimed at providing a better understanding of the performance of downwind sails, specifically gennakers and asymmetric sails. Wind tunnel tests have been carried out at the University of Auckland in the Twisted Flow Wind Tunnel to examine the effects of heel angle and foot gap on sail performance.

SHEAR IN SOLID COMPOSITE STIFFENER WEBS

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Abstract. This paper analyses the shear distribution of composite stiffener webs in high performance yachts with the intention of being able to predict shear buckling of composite stiffener webs under point and uniform distributed load. The aerospace and civil engineering fields have done most of the theoretical work concerning composite stiffeners. To date, marine stiffener design methodologies are based on requirements set out by maritime scantling authorities. These requirements are often based on either isotropic materials or "low-tech" composite construction. Efficient design of composite structures requires that full advantage of the orthotropic properties of marine composite materials be taken. In order for this to occur, information specific to marine applications must be developed and made available to designers. It is the intent of this paper to begin to fill that gap.

MEASUREMENT OF WAKE CROSSING MOTIONS AND LOADS

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Abstract. As the use of sophisticated engineering analysis techniques become more widespread during the vessel design process, it is important that there is a thorough understanding of the applied loads. Despite the acknowledged importance of using realistic loading conditions to ensure accurate predictions, there is very little data available for small high performance vessels.
A research programme to measure and predict the seakeeping performance and structural response of small high performance vessels has been established by Industrial Research Limited to foster continued innovation by the New Zealand boatbuilding industry. This paper presents results from a series of 'wake-crossing' measurements undertaken on 12m RIBs used by the Auckland Maritime Police Unit for policing duties during America's Cup activities in New Zealand.

REGULATORY CONSTRAINTS ON THE STRUCTURAL DESIGN OF HIGH PERFORMANCE YACHTS

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Abstract. Weight is often critical to the performance of modern sailing and power yachts. Advanced composite materials and design technologies, combined with improvements in processing techniques, have enabled engineers to produce significant savings in the structural weight. These savings can be translated into lower overall displacement, and hence better performance, particularly in highspeed motor yachts. In high performance sailing craft reduced structural weight can lead to higher ballast ratios and greater righting moments.
There are numerous constraints imposed on the engineer, including the obvious issues of costs, and capability of the yard to adopt the higher technology materials and extract the maximum benefit. We know from the aerospace experience that a fully auto-claved carbon prepreg structure is possible, but not necessarily cost effective or practical in the marine environment.
One of the constraints not often appreciated by owners, designers, and builders is the imposition of regulations and rules regarding the construction. These range from the requirements of scantling authorities such as Lloyds Register of Shipping, ABS etc. through to "consensus" restrictions such as imposed by various class associations (i.e.: Volvo 60's, IACC etc). Often the optimum solution, designed to meet the structural, cost, and other practical constraints, is not able to achieved because of these regulatory constraints.

NON-DESTRUCTIVE INSPECTION OF MARINE COMPOSITE STRUCTURES

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Abstract. This paper describes a research programme aimed at developing improved non-destructive inspection techniques for marine composite structures. The design and manufacturing of panel specimens with simulated void and delamination defects is described. Results are presented of comparative trials of alternative inspection techniques on these samples and actual damaged specimens from real structures. Defect types include void and delaminations in glass/epoxy, glass/polyester and carbon/epoxy skin laminates and at the skin/core interface, shear cracks in foam, Nomex honeycomb and balsa-wood cores, unfilled joins between core blocks, voids in glue joints in bonded carbon/epoxy mast tubes, and impact fractures in solid and cored laminates. Non-destructive inspection techniques used include mechanical impedance based methods (such as quantified tap testing, with acoustic spectral analysis and instrumented impact hammer), pulse-echo ultrasonics, and what is believed to be the first application of Synthetic Aperture Radar microwave sensing to these types of materials. The results of the comparative trials show that no single technique is likely to be able to find all of the defects that occur in marine composite materials. However the quantified tap-testing and Synthetic Aperture Radar sensing techniques offer significant potential as practical in-field inspection methods. Ongoing experimental and theoretical developments of these two methods are described.

AN ADVANCED FINITE ELEMENT METHOD FOR FLUID DYNAMIC ANALYSIS OF AMERICAS CUP BOATS

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Abstract. This paper shows a step forward in the development of a stabilized method for solving the Reynolds equations (RANSE) including free surface effects. The starting point of this method is the modified governing differential equations for an incompressible turbulent viscous flow and the free surface condition, incorporating necessary stabilization terms via a Finite Increment Calculus (FIC) procedure. Time integration scheme of the method is based on an implicit monolithic second order method. Implementation of the algorithm, based on the Finite Element Method (FEM) using unstructured grids of linear tetrahedra, allows us to take into account dynamic sinkage and trim, being especially adequate for hydrodynamic analysis of racing boats. This paper also presents a validation study of numerical results obtained for America's Cup boats.

THE EFFECT OF WATER DEPTH ON THE PERFORMANCE OF HIGH SPEED CRAFT

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Abstract. With the design speeds of some powered leisure craft increasing, the paper explores the relationship between speed, water depth and performance. Particular attention is paid to residuary resistance and the generation of wave wash and the size of the waves in the wash is shown to be greatest in the trans-critical regime. Not unexpectedly, this is in concert with the behaviour of the residuary resistance coefficient which is shown to peak in the same Froude Depth Number range. The relationship between hull design and wash height is then explored to see what hull parameters have the greatest effect. Using model measurements, wash height is shown to depend largely on three global hull geometry parameters, and the reduction of these to as low values as possible, consistent with practical considerations, should help in the quest for low wash hull forms.

DEVELOPMENT OF A MORE REALISTIC SAILING SIMULATOR

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Abstract. New software has been developed for an existing simulator. The physical model of the simulator has been rewritten and now includes a lot of extra features which have increased the realism of the simulation considerably. The new physical model has been explained in this paper and compared with the old model.

ADVANCES IN OPTIMIZATION IN YACHT PERFORMANCE ANALYSIS

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Abstract. We describe some applications of mathematical optimization techniques to yacht performance analysis. Applications
include sail trim optimization in wind tunnels, match race modelling under uncertainty, and America's Cup design optimization
under uncertain weather conditions.

YACHT OPTIMISATION BASED ON GENETIC ALGORITHM USING RANSE SOLVER

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Abstract. The design process of a sailing yacht comprises three steps which are performed sequentially: hull design, hull evaluation, and performance analysis. Generally, this process is repeated iteratively while modifying the design until the designer either runs out of time or money: the design is then "optimised". As numerical tools and computers progress, the numerical approach has accelerated to about less than a day per form and hence outpaced considerably the classical experimental approach. Further more, a large number of parameters are necessary to describe a hull and its appendages in sufficient details (at least fifty). Hence, it is humanly impossible to understand intuitively how the design variables influence the performances of the yacht in various wind and sea condition. It is therefore impossible to efficiently optimise a hull without a methodology. This paper presents a numerical performance evaluation tool which integrates four essential elements: a hull modelling software, a mesh generator, a free-surface RANSE solver and a Velocity Prediction Program. This tool automatically performs faster and more efficiently the same steps as in the classical open loop design process. In a further development, this numerical performance evaluation tool is managed by appropriate optimization algorithms in a closed loop to reach the objectives that have been defined while respecting such constraints as the ACC rules. The numerical tools specifically developed or integrated in the optimisation loop are first described. Finally, an example of multiobjective optimisation is presented on an America's Cup Class hull.

WORKING LOAD TO BREAK LOAD: SAFETY FACTORS IN COMPOSITE YACHT STRUCTURES

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Abstract. The loads imposed on yacht structures fall broadly into two categories: the distributed forces imposed by the action of the wind and waves on the shell of the yacht, and the concentrated loads imposed by the rig and keel to their attachment points on the structure. This paper examines the nature of the latter set of loads and offers a methodology for the structural design based on those loadings. The loads imposed on a rig attachment point vary continuously while the yacht is sailing. Designers frequently quote "working load", "safe working load", "maximum load" or "break load" for a rigging attachment, but the relationship of this value to the varying load is not always clear. A set of nomenclature is presented to describe clearly the different load states from the "steadystate" value, through the "peak, dynamic" value to the eventual break load of the fitting and of the composite structure. Having defined the loads, the structure must be designed to carry them with sufficient stiffness, strength and stability. Inherent in structural engineering is the need for safety factors to account for variations in load, material strength, geometry tolerances and other uncertainties. A rational approach to the inclusion of safety factors to account for these effects is presented. This approach allows the partial safety factors to be modified to suit the choice of material, the nature of the load and the structure and the method of analysis.
Where more than one load acts on an area of the structure, combined load cases must be developed that model realistically the worst case scenario. In particular if the loading is quasi-static, the total loads on the structure must be in equilibrium. This is particularly important for Finite Element Analysis since an unbalanced load case can lead to excessive reactions at the points of restraint of the Finite Element Model. A method is presented for the development of a balanced load case for upwind sailing which allows significant insight into the behaviour of a yacht structure under "real" sailing conditions. The keystone of this approach is a method for constraining the model in a statically-determinate manner, to avoid adding unrealistic stiffness to the model. Finally, once the structure has been built, it is sound practice to proof test it to give confidence in its reliability. The value of load for proof testing is a difficult choice but is made more straightforward by the rational approach to load definition presented in the paper.