face to face with Ignazio Maria Viola and Ubaldo Cella

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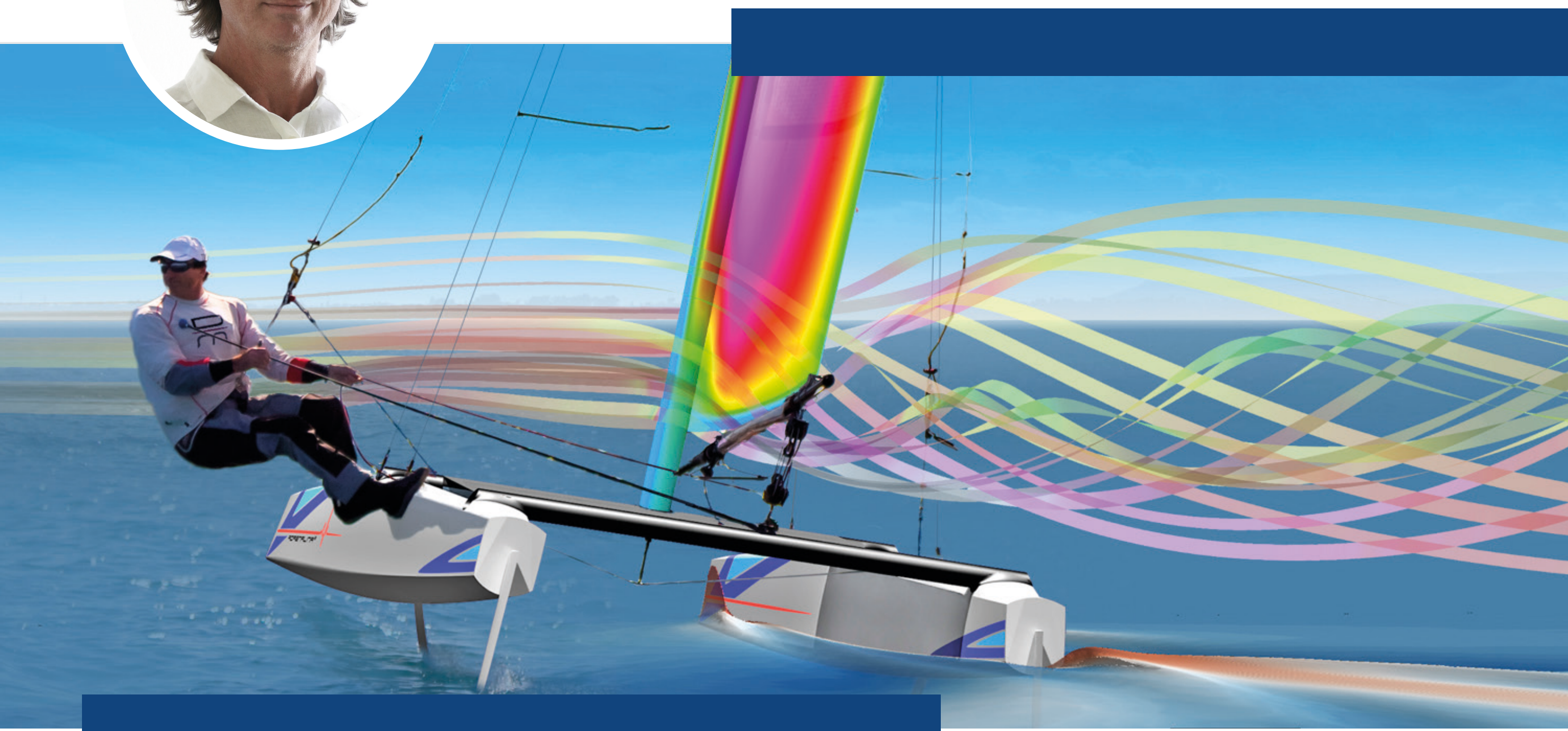

The growing importance of numerical simulation in the nautical sector

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The *Journal of Sailing Technology* (JST) is the definitive source for keeping abreast of the latest trends and technologies that are propelling the nautical sector. JST is a free, open access, and peer-reviewed journal that has become a global reference for the future of sailing thanks to its compelling content and unquestionable authority, which is why we decided to interview Ignazio Maria Viola, Editor-in-Chief, and Ubaldo Cella, member of the editorial board.

It is widely recognized that computer-aided engineering (CAE) has been playing an increasingly significant role in the marine industry in recent years. On the other hand, not many know that mesh morphing is an essential technology that can greatly improve computer simulation.

It offers numerous advantages in the geometric parameterization of design problems, drastically reducing development time and cost. RBF Morph is a pioneer and leader in RBF (radial basis functions) tools, and a long-standing Ansys partner.

Ignazio Maria Viola, Professor at the University of Edinburgh's School of Engineering's Institute for Energy Systems, and Ubaldo Cella, a researcher in the "Mario Lucertini" Department of Enterprise Engineering at the University of Rome Tor Vergata and a Senior Engineer at RBF Morph, offer an in-depth look at the rapid innovation that is disrupting this sector. Cella, an experienced recreational and competitive sailor, also won an award in the 2016 Ansys "Hall of Fame" competition for a study on a high-performance catamaran.

The "Mario Lucertini" Department of Engineering at the University of Rome Tor Vergata includes rbfLAB, a research laboratory focused on the advanced use of RBF in the most diverse fields and applications of engineering, from shape optimization for automotive or aerospace to the study of fluid-structure interaction in the biomedical field. DemoFly - a rbfLAB-led research project focused on the design of sport catamarans - aims to develop a wide-ranging design methodology that combines the search for the best overall boat configuration with the application of high-fidelity tools to optimize sails and appendages. DemoFly entails the development of overall performance analysis methodologies, the optimization of the various components, and the validation of the tools through the construction of prototypes and experimental tests [1]. The University of Edinburgh hosts VOILAb, a team of researchers focused on fluid mechanics, operating within the Institute for Energy Systems. This group is under the leadership of Prof. Ignazio Maria Viola (voilab.eng.ed.ac.uk).

How is JST positioned in the sailing industry?

Ignazio Maria Viola: JST strives to be a repository of the best papers and an archive of the advances in the science and technologies of sailing, including sailboats as well as any other application related to sails and wind propulsion. The journal also aims to support the research community in rigorously conducting and reporting their studies, contributing to improving the quality of research in the field.

What role does CAE play in the nautical sector today?

Ubaldo Cella: The sailing industry has evolved enormously in recent years, and the role of CAE has become increasingly significant. CAE incorporates leading design tools used for major sailing competitions, in particular the application of aeronautical skills for the America's Cup (AC). This process began several decades ago. One notable example was in the 1992 AC, when Raffaele Marazzi, an aeronautical engineer coming from the Italian aircraft manufacturer Aermacchi, used CFD (computational fluid dynamics) to design the keel and winglets of the Moro di Venezia. Today, the use of numerical analysis technologies is standard practice and confidence in their accuracy has drastically reduced the need for experiments during the design process. CAE methods are now commonly used in both cruising and racing boat design, making them an indispensable tool for the industry.

We are seeing a growing interest in open source software for design. What is the status of commercial versus open source tools and which ones are most used in the nautical sector?

Ignazio Maria Viola: The most demanding computational simulations are those related to fluid dynamics. They can calculate the aerodynamic forces exerted by air on the sails, and by water on the hull and appendages. Commercial software is often preferred for more complex simulations, for example, to calculate the hydrodynamic forces on a vessel free to heel, trim and sink, due to its robustness and ease of use. In contrast, an open source code such as OpenFOAM is often used when the modelled physics is simpler, such as for the air around a sail that is considered rigid. Open source codes are also preferred to commercial software when the accuracy of the simulation is critical and high spatial and temporal resolutions are required, involving several thousands of parallel processors. This is often the case in fundamental research, where OpenFOAM is increasingly being used in the scientific community.

How is RBF Morph positioned in this field and what is its role in the yacht design process?

Ubaldo Cella: Mesh morphing techniques offer several advantages for geometric parameterization of design problems, including: the ability to work directly on numerical domains; consistency of numerical analysis solutions (eliminating the need for remeshing of discretized domains); and robustness of procedures. Software based on radial basis functions, like the RBF Morph solver, offers additional advantages, such as highly efficient parallelization and high-quality morphing actions. RBF Morph's user interface offers great flexibility in configuring complex parameterizations, making it a key component in developing design methodologies, especially where numerical optimizations and automated analysis workflows are involved. These advantages have been amply demonstrated in a wide range of scientific literature addressing design problems in various engineering fields. Therefore, RBF Morph's efficiency, robustness, and speed of configuration make it a highly effective tool for engineers striving to optimize design parameters and achieve high-quality results [2, 4].

Could you describe the integration of reduced order models (ROM) and digital twins in the design of a sailboat and during racing?

Ignazio Maria Viola: Reduced order models such as potential flow theory implemented in panel codes are very common in both sail aerodynamics and hull hydrodynamics. They have been widely used in yacht design since the 1970s and have proven successful in high performance sailing. Digital twins, used to perform time progressing numerical simulations of boat dynamics, are commonly used in America's Cup design and are crucial for designing boats that manoeuvre quickly, for example.

What observations do you have regarding multi-objective and multi-physics shape optimization?

Ubaldo Cella: A numerical optimization approach to design is key to exploring the boundaries of a design problem. When combined with multi-disciplinary analysis tools, optimization procedures can significantly expand the possibilities of exploration. However, a common mistake is to view such methods simply as tools that automatically provide the best solution at the touch of a button. When used with competence and awareness, numerical optimizations are

powerful tools that can produce outstanding results. However, their application requires appropriate skill and experience; otherwise, they become an expensive way to generate a solution that is not necessarily the best. Developing numerical optimization environments also requires specialized knowledge in several fields, such as parametric solid modelling, CFD, FEM (finite element method), programming, and mesh morphing. The theory of numerical optimization is a vast discipline, and a thorough understanding of the advantages and limitations of the numerous algorithms available is crucial. In combination these factors make it particularly difficult to develop efficient optimization strategies and the results are always highly user-dependent. Therefore, engineers must have diverse skills and a deep understanding of the design problem they are addressing [3].

What are the main trends regarding the design methodologies we talked about earlier?

Ignazio Maria Viola: The rapid increase in available computing resources makes it possible to perform more complex simulations with greater ease and accuracy.

A good example of simulations that are becoming more accessible and affordable in terms of computation are fluid-structure interaction simulations. These simulations necessitate mesh modification or the remaking of a new mesh at each iteration to reflect the changed solid body geometry. We expect to see a substantial increase in the number of journal articles on these types of simulations for both sail aerodynamics and foil hydrodynamics in the coming years. On the other hand, there are already a number of papers showing advances in machine learning for yacht design, which is likely to become another major trend in the coming years. Finally, across the ship building industry, there is an increased use of model reduction methods in which high-fidelity simulations are used to inform lower fidelity models that provide the solution for a larger set of parameters.

What can you say about the adoption of response surfaces and what is the level of integration between simulations and velocity prediction programs (VPPs)?

Ubaldo Cella: VPPs provide a crucial framework for the development of sailboat design. They are algorithms that solve the balance of forces and moments acting on a vessel in order to predict yacht performance by modelling the physics of its various components, such as aerodynamic forces on sails, hull hydrodynamics, lift/drag of appendages, and inertial properties. The accuracy of VPP modules is essential to estimate yacht response in various sailing conditions and to determine design quality. However, to integrate VPPs into effective optimization procedures, it is essential to strike the right balance between the accuracy and the computing costs of the analysis techniques used. Implementing analytical formulations and metamodels based on high-fidelity analyses are therefore key areas of study for improving the productivity of design methodologies.

This is because identifying the optimal design parameters requires a significant number of simulations to be performed, and the computing costs can quickly become a bottleneck if not managed effectively. It is therefore crucial to identify the optimal level of accuracy required for each VPP component and to adopt analyses capable of balancing computing cost and accuracy. Achieving this balance is a continuous challenge, and there is ongoing research to improve the accuracy of VPPs while keeping the computing cost within manageable limits [5].

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