VIRTUE – The Virtual Tank Utility in Europe
Extending the scope and capabilities of maritime CFD

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Abstract:

Launched in January 2005, VIRTUE initially concentrates on the development of new, and the improvement of existing, Computational Fluid Dynamics tools which will allow an integrated and complete numerical analysis of marine hydrodynamic behaviour in a virtual environment – the Virtual Tank Utility. Hence it will complement traditional experimental analysis. By improving the accuracy, flexibility and reliability of CFD predictions, and by integrating presently disparate tools into an integrated platform, VIRTUE will deliver important advantages to the shipbuilding industry, including reduced manufacturing costs through shorter lead times and more focussed designs; improved design and product quality and an increased range and quality of services offered by European hydrodynamics service providers.

1. The hydrodynamic challenges of Maritime design

Hydrodynamic performance of ships is one of the most decisive factors for quality, economy and safety in waterborne transportation. Analysis and optimisation (in so far as it is currently being performed) of the hydrodynamic performance or behaviour of ships at sea is often a lengthy, time consuming process, sparsely supported by modern computational techniques. This element which is prominent in the design process for ships and maritime structures is a limiting factor for the overall performance of the Maritime Industry.

Improving this situation will clearly improve the situation and performance of Shipbuilding and overall Maritime Industry. Being able to fix design constraints for a typical one-of-a-kind product early in the design process allows for a substantially improved accuracy in the production planning and cost evaluation processes. Improving global design and optimisation processes will thus have direct as well as indirect – via a shortened production lead time – influences on the products and production costs.

This challenge has been clearly recognised by the European Commission in the present R&D Framework programme, FP 6. The VIRTUE project was launched as an Integrated Project (IP) under the FP 6 umbrella in the “Sustainable Development, Global Change and Ecosystems” work programme. The project is expected to help the European Maritime Manufacturing industry to maintain its edge in the worldwide competition.

1.1 Maritime CFD today

Due to the very special environmental conditions associated with the operation of ships and most other maritime products, i.e. sailing at a “free surface”, the requirements for the numerical treatment of fluid flow are significantly more complex than those of other vehicles. Academia and research institutions in the Maritime field have since long worked on numerical simulations, accompanying traditional model testing. CFD methods have been developed mostly with a
dedicated field of application in mind. Examples are (potential theory) strip methods, wave resistance or propeller codes. Concentration on particular applications has caused a large variety of methods, based on different methods and technologies to be developed in the past. Today’s developments are without any doubt helpful tools to analyse hydrodynamic behaviour, but it must be clearly noted that they hardly allow for an integrated analysis of a variety of different objectives. This will still call for a sequential process applying a variety of different methods and suffer from often complex data exchange and conversion processes.

Experimental or model tank testing enjoys a long tradition and, due to its history and experience gained with calibration of results, a wide acceptance in terms of accuracy of predicted results. Today experimental results are still the measure with which to compare all numerical results. Although there have been significant improvements of the quality / accuracy of CFD predictions over time, e.g. the European EFFORT project /KC/, it must be noted that there is still a lack of accuracy associated with many numerical flow predictions. This forms another prime objective for the present research, together with the fact that CFD will allow to circumvent problems inherently included in today’s model to full scale scaling procedures.

1.2 VIRTUE’s Approach

The work performed in the VIRTUE project addresses both of the present shortcomings of CFD applications identified above, and it provides significant improvements to the hydrodynamic analysis during the design and optimisation stage in that it will improve the quality (and accuracy) of numerical flow prediction, hence deliver better CFD results and, it will provide these improved results in shorter time. The latter being achieved through thorough integration of presently widely disparate methods into a common platform. The project’s developments will thus influence production costs mainly by providing reliable data for the evaluation of new designs in shorter time.

The need for improvements of quality of numerical predictions exists in various areas of CFD applications, ranging from pure propulsive performance analysis, ship motion analysis in a seaway or during a manoeuvre to the analysis of cavitation and its adverse effects on propeller and hull vibrations. Consequently, the VIRTUE project has adopted a rather classical subdivision of ship hydrodynamic analysis: the project integrates “services” from four different virtual tanks dealt with in different work packages:

- The Virtual Towing Tank;
- The Virtual Seakeeping Tank;
- The Virtual Manoeuvring Tank
- The Virtual Cavitation Tank/Tunnel.

The 5th work package, the Integration Platform, will provide the prerequisites for an integrated optimisation based on common standards for data provision and the presentation of results.

This huge program is associated with a massive effort which can only be spent by a large community of experts. Through large-scale international collaboration, bringing together 22 European partners such as the leading model basins in Europe, academia, software providers and marine consultants, VIRTUE will not only greatly improve quality and accuracy of general purpose and specific CFD methods and tools but also integrate a wide range of today’s disparate numerical analysis methods in a virtual environment simulating complete ship behaviour at sea and providing an important complement to real test basins in the provision of marine hydrodynamic services.
1.3 Taking technology beyond the state-of-the-art

While the current and potential role of CFD techniques differs between the various fields of ship hydrodynamics, progress is desired in all of them. An overall goal is to establish the best CFD methods to augment or even replace the work that is done with model experiments today. VIRTUE tests existing CFD methods and develops procedures for the best application. In addition the methods will be expanded and improved in view of the accuracy and efficiency required by the marine industry.

Besides a general enhancement of the accuracy of the predictions and resulting “optimal ship designs”, there are many examples of aspects where CFD-enabled progress would contribute to better ships and better competitiveness:

- reduced resistance by improved design of transom sterns, based directly on full-scale prediction of viscous flow with waves;
- reduced propeller borne vibrations and cavitation erosion due to improved control of propeller cavitation;
- improved understanding of hull / propeller / rudder interaction during manoeuvres, leading to more accurate prediction of manoeuvring properties and possibly modifications in design;
- extended range of operation of high-speed ferries due to more complete seakeeping prediction.

These factors are expected to increase the competitiveness of the European shipbuilding and shipping industries. Performance analysis is expected to be speeded up by a factor of 2 at least. Prediction accuracy of most hydrodynamic aspects will be increased, permitting smaller design margins, reduced risk and reduced cost. Integrated multi-criteria optimisation is expected to improve vessel performance in terms of resistance and fuel consumption by as much as 10%, an important target in view of today’s increase in fuel cost as well as environmental conditions.

Integration of CFD tools is a prerequisite for multi-criteria optimisation. VIRTUE will provide an holistic approach to hydrodynamic ship design. Combining the two vital lines of development: i) produce accurate CFD tools and ii) provide a common data platform, will pave the way to a complete simulation of ship behaviour at the design stage. It is this combination that finally allows to address multi objective, over arching optimisation processes.

The work on multi-objective optimisation, which is founded on the enhanced quantitative accuracy of predictions, will further contribute to an innovation and progress in ship design practice in Europe. The work will cause a shift in the techniques used, thus resulting in more refined predictions, closer approach of balanced optimum designs, and the consequently improved efficiency of shipping and competitiveness of European shipbuilding.

2. Project Facts and Organisation

Launched in January 2005, VIRTUE assembles 22 partners from 9 European countries. The partnership comprises HSVA, MARIN, SSPA, Principia Marine, University of Strathclyde, Atkins, TUHH, Chalmers, IST, ECN, Bassin d’Essais des Carènes, Bureau Veritas, VTT, SIREHNA, GL, INSEAN, FRIENDSHIP-Systems GmbH, ZIB, VICOMTech, NAPA, FLOWTECH and HUT. The project is coordinated by HSVA.
VIRTUE is the largest ever Joint European Project focussing on numerical ship hydrodynamics. The work programme has a total volume in excess of 1200 Man Months, subdivided into 5 technical workpackages and 33 major development tasks. This massive effort is spread over a duration of 4 years until the end of 2008. The project structure reflects the principle areas of CFD and integration technology oriented research performed. 4 hydrodynamic / CFD related work packages are centred around an integration work package which combines the results obtained in the different fields of ship hydrodynamics and supplements them with optimisation, data exchange and visualisation techniques.

3. Scope and specific Developments

WP 1, the Virtual Towing Tank, concentrates on general aspects of accuracy, reliability and applicability of existing state-of-the-art CFD codes with a special focus on the prediction of (ship) resistance and propulsive efficiency. Through improvements in problem set-up and methodology, a viable alternative to the physical towing tank testing in the prediction of hydrodynamic performance of ships is targeted. The application of the methods in dedicated optimisation processes is a second main objective. The specific targets addressed in this work package are:
- Enhancement of the predictive capability through improved flow modelling; advanced modelling techniques for turbulence, free surface including transom stern flow;
- Developments of improved basic numerics and verification; discretisation schemes and adaptive grids, and computational efficiency.
- Extensive uncertainty analysis for parameters that influence the quantitative accuracy of performance prediction; a systematic investigation of the effects of grid type, structure and resolution on accuracy and efficiency; test of the effect of different numerical approximation on the accuracy of the predictions, including scale effects;
- Validation of numerical methods and techniques for selected test cases;
- Integration of improved CFD codes with geometry variation/modification modules and optimisation and sensitivity analysis routines for use in early design.

Work performed so far has concentrated on i) wake flow predictions, especially using advanced turbulence modelling, see Fig. 2 for the prediction of the wake flow in the propeller plane for the well known KVLCC2 test case using an explicit algebraic stress model and ii) on improvements for free surface predictions. Fig. 3 shows an improved prediction of the free surface around a Series 60 ship using an moving grid, steady state iterative solution with local grid refinement. Parallel to this type of prediction, alternative methods using a finite volume approach will be investigated and results will be compared.

The importance of validation of CFD results has been stressed already. Although VIRTUE is primarily a CFD development and integration project, a certain amount of experimental / validation work has been allocated in some of the work packages. The details of the flow at a ship’s transom are difficult and time consuming to investigate. On the other hand does the transom flow determine a large portion of the resistance of a ship. Hence, any improvement achieved here does have a substantial influence on the accuracy of the predictions. A novel experimental concept applying optical measurements promises a remedy in this case. The technique is applied during model testing and the results are being used to improve the numerical models applied in free surface modelling. First tests have been performed for a container ship geometry available to all project partners.

Fig. 2: “Wake prediction for the KVLCC2 tanker hull”
Fig. 3: “Free surface prediction using a steady state iterative solution”
Fig. 4: “Experimental set-up and wave cut measurements behind the transom of the “VIRTUE-Container ship” at speed.”
The Virtual Seakeeping Tank in WP 2 addresses all types of developments associated with the modelling of the behaviour of the ship in relation to the constant motions of the free surface, the modelling of waves. Specific effects as breaking waves, cushioning due to entrapped air, can only be taken into account while understanding these phenomena which are rather unique to the marine world. It is especially these “off-design” conditions which will have a significant impact on structural integrity and hence safety of operation of the ship / maritime structure. Where experimental methods often introduce significant uncertainties, CFD is now expected to provide the means for solving those problems in numerical simulations. However, the generic CFD codes often lack features and capabilities to address these problems which require specific tackling. Dedicated marine CFD packages are sought to provide improvements towards the solution of these problems. The challenge for the Virtual Seakeeping Tank is to provide solutions to those specific problems, based on a connection of CFD techniques in the ship design process, automatic connection with CAD, grid generators and hydro-structure interfaces. Validation is performed through specific model tests.

The specific development targets are:

- Accurate wave modelling for use in numerical simulations
- Compute hydrodynamic coefficients from viscous CFD to be used in standard seakeeping codes
- Compute ship motions in critical conditions as severe seas (freak waves, green-water), slamming, coupling with sloshing, water flooding, dynamic instabilities in waves
- Compute dynamic response as springing and whipping which are critical for hull design

Main results obtained in the 1st year of the project are wave modelling algorithms (Adaptation of the “spectral method” for irregular waves) as shown in Fig. 6 for a wave tank with irregular (3-D) wave conditions. A second area of developments covers ship motions due to waves predicted with a RANSE code. Fig. 7 shows a roll motion of a ship with fin stabilisers. A grid deformation method is used to capture free surface effects. /CB/
The **Virtual Manoeuvring Tank** in WP 3 deals with increasingly important manoeuvring predictions. The flow around a manoeuvring ship and the hydrodynamic forces are strongly affected by viscous effects. Hence full RANSE codes are required to determine flow features that influence the manoeuvring properties. This approach is intended to supplement traditional experimental methods, and where possible, replace them. The transient behaviour of the flow around a ship during manoeuvring adds further complexity to the computational prediction. This requires further improvements in prediction quality. The specific targets are

- Improvements in accuracy, efficiency and consistency of computations for simple modes of motion like steady drift, rotation, etc.
- Study of grid dependency of solutions and recommendations for practical applications
- Adequacy of turbulence models
- Performance improvements, especially for transient simulations
- Prediction of the dependency of hydrodynamic coefficients on the amplitude of motions
- Hull – Propeller - Rudder interaction during manoeuvres
- Evaluation of scale effects

This will yield numerically determined inputs for state-of-the-art manoeuvring simulations. As a more ambitious alternative, direct CFD simulation of a free self-propelled ship performing real manoeuvres will be developed. The work package develops in a comprehensive way both methodological and implementation aspects of the methods; extends the applicability of the numerical methods; validates all of the developments against model test results; and renders state-of-the-art methods tools for practical consultancy work.
The Virtual Cavitation Tank, WP 4 aims at the development and validation of promising codes able to predict the flow about both non-cavitating (necessary for cavitation inception) and cavitating propulsors, and are in particular able to compute the adverse effect it has on the propulsion characteristics (such as radiated pressure fluctuations and cavitation erosion).

Both, viscous RANS codes as well as potential flow / BEM or panel codes are applied to predict pressure fluctuations. Benchmark studies will explore the possibilities and limitations of these codes to yield cavitation induced pressure fluctuations. The higher frequency content of pressure fluctuations that are ascribed to tip vortex cavitation can only be obtained from a RANS code with a sufficient resolution in space and in time.

Cavitation erosion is a phenomenon which is eventually determined by micro-scale physics which needs a resolution in space and in time that is currently outside the scope of this project. Based on recently developed empirical relations, VIRTUE will explore the predictive capability of RANS codes for cavitation erosion.

The specific targets of the developments in the Virtual Cavitation Tank are:

- Produce a selection of CFD tools (both RANS and BEM) to address practical problems as vibrations and cavitation erosion in a way that it can be used by the industry;
- Development of an improved RANS code for local flow prediction on propulsors;
- Prediction of hull pressure fluctuations
- Prediction of the risk of cavitation erosion

Initial studies that have been performed in the first year of the project have concentrated on RANSE computations for propellers / lifting surfaces using existing flow codes. Fig. 9 shows an impressive example of the grid dependency of results for the case of a tip vortex roll up on a foil.

![Fig. 9: “Grid Refinement study for the tip of an elliptical foil – Vortex roll-up”](image)

Cavitation extension for the tip vortex of a conventional propeller has been simulated with a general purpose CFD code, although the global characteristics are well captured, the comparison with the experiment indicates the limitations of the present computation.
The Integration Platform, WP 5 finally will provide the backbone of the VIRTUE project through the provision of data and task level management and co-ordination to enable the tools developed within other work packages to be brought together within a holistic environment. The integration platform will provide state of the art techniques to enable users to:

- Operate existing and future CFD software through a common user interface
- Share data between disparate tools.
- Ensure the maintenance of consistency of data across the VIRTUE platform.
- Manage multiple projects simultaneously.
- Communicate using a variety of differing formats to facilitate collaboration.
- Optimise their designs either locally or globally across the entire VIRTUE platform.
- Visualise the data produced from simulations using a common interface that may itself be used within the collaborative process.
- Mine parametric data generated through the use of the tools either manually or experimentally and display the resulting knowledge within an interface to enable the user to explore what-if scenarios.
- Validate the data generated through the simulations with that generated experimentally as a feedback mechanism to further improve the reliability of the simulations.

All of the above areas are addressed in the development work in the Integration Platform. Based on existing integration technologies / wrappers developed in previous projects a general architecture for the VIRTUE system has been developed in the first year. This is presently extended and first applications, i.e. flow codes have been implemented in a test system, the Prototype 0 which has been demonstrated already earlier in 2006. The first real prototype covering a more substantial subset of the intended functionality of the platform will become available later this year.
4. Future Prospects

VIRTUE is expected to continue until the end of the year 2008. During the life cycle of the development project a number of demonstration prototypes will become available and will be shown to the public. Initially based on more simplified, e.g. potential flow methods, the system will gradually emerge and, at a later stage also include more refined, RANSE based CFD predictions methods which will be fully integrated to deliver an integrated system for a holistic analysis of hydrodynamic behaviour. The full potential of the anticipated, final system will be high, and the exploitation of the results will be of fundamental importance for all players involved. Concepts for the use and application of the system and the individual results obtained in the project are presently under discussion and will be presented in the future. VIRTUE will held a number of public workshops in the 2nd half of the project, presenting results and announcing further developments. News can be obtained continuously from the project’s web site at www.virtual-basin.org.

References

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