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VIRTUE

The VIRtual Tank Utility In Europe

Integrated Project (IP)

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VIRTUE

The Virtual Tank Utility in Europe

Integrated Project

List of Participants

1.	Hamburgische Schiffbau-Versuchsanstalt GmbH	HSVA
2.	Maritime Research Institute Netherlands	MARIN
3.	SSPA Sweden AB	SSPA
4.	Principia R&D	PRD
5.	University of Strathclyde	SU-SSRC/CAD
6.	WS Atkins Consultants Ltd	Atkins
7.	Technische Universität Hamburg-Harburg	TUHH
8.	Chalmers University of Technology	Chalmers
9.	Instituto Superior Tecnico	IST
10.	Ecole Centrale de Nantes	ECN
11.	Bassin d'Essais des Carènes	BASSIN
12.	Bureau Veritas	BV
13.	VTT Technical Research Centre of Finland	VTT
14.	SIREHNA	SIREHNA
15.	Germanischer Lloyd AG	GL
16.	Istituto Nazionale di Studi ed Esperienze di Architettura Navale	INSEAN
17.	FRIENDSHIP-Systems GmbH	FSys
18.	Konrad-Zuse-Zentrum für Informationstechnik Berlin	ZIB
19.	VICOMTech	VICOMTech
20.	Napa Oy	NAPA
21.	FLOWTECH International AB	FLOWTECH
22.	Helsinki University of Technology	HUT

Project Management
Hamburgische Schiffbau Versuchsanstalt GmbH – HSVA

Coordinator e-mail:
marzi@hsva.de

Coordinator FAX:
+49-40-69203-345

Project Web site
www.virtual-basin.org

1. Project Execution

INTRODUCTION:

The members of the VIRTUE consortium have been striving for scientific innovation and excellence in a number of technological areas on numerical hydrodynamics with the long term vision of being able to thoroughly complement experimental ship hydrodynamics using numerical methods. Formidable as the entailed problems are, they have been attacked using multiple innovative approaches, leveraging the substantial scientific talent and experience available within the organisations participating in VIRTUE. Attainment of the ultimate vision of fully complementing all the aspects of experimental ship hydrodynamics would indeed extend to activities beyond VIRTUE, but significant progress has been made in the right direction within this project's activities.

Numerical hydrodynamics has attained a good level of maturity in the problems of resistance prediction but the other important performance aspects such as seakeeping, manoeuvring, and propeller cavitation are relatively less developed in terms of numerical methods. The consortium members have been, and will continue, working on evaluation and tuning of variety of numerical methods including boundary element and finite volume methods as well as combinations of these towards addressing the challenging problems of cavitation, dynamic trim, free surface effects, and determination of hydrodynamic derivatives and coefficients.

The activities involved investigation of various discretisation schemes (element sizes, grid types), mathematical formulations (RANSE, large eddy simulation, potential flow, empirical relations, smooth particle hydrodynamics), numerical methods (finite volume, boundary element.).

Significant emphasis has been laid on benchmarking and validation of results. This involved identification of a set of common validation cases, to which the methods developed by each partner were applied. The results so obtained were then cross-compared for an understanding of the relative efficacy of the various approaches used.
The numerical methods so developed within this project's activities have been demonstrated to be superior to the methods that existed before these activities. Uncertainty analysis has been applied by several partners in formalizing the accuracy of their methods. Results have been widely disseminated in workshops and at conferences, and much of the results have been disseminated within the consortium in the delivered technical reports.

Besides extending the scientific frontiers of numerical hydrodynamics, the VIRTUE project also incorporated the active development of an integration platform that addresses organisational management and project management problems that would arise in numerical hydrodynamics projects spanning multiple organisations distributed in different geographic locations. Some working prototypes of the integration platform have been demonstrated in the project meetings and workshops.

The following sections present a summary of the progress made by the VIRTUE project.

TECHNICAL SUMMARY

The technical work of the project is ordered around five work packages:

- The Virtual Towing Tank – Work Package 1 (WP1)
- The Virtual Seakeeping Tank – Work Package 2 (WP2)
- The Virtual Manoeuvring Tank – Work Package 3 (WP3)
- The Virtual Cavitation Tank – Work Package 4 (WP4)
- The Integration Platform – Work Package 5 (WP5)

The following sub-sections summarize the activities performed in each technical work-package.

Achievements in WP1 – The Virtual Towing Tank

At the start of VIRTUE, the subject of WP1, Resistance and flow computations, was the one for which most CFD development in ship hydrodynamics already had been done and the largest maturity had been reached. Nevertheless, in the proposal preparation phase of VIRTUE, participants clearly identified the principal topics on which further work was needed to enhance the benefit of CFD in actual ship design work for the industry:

1. While there had been much focus on more qualitative results such as wake fields, the quantitative accuracy of the ship resistance prediction at model and full scale required improvement. Variable results and a large spread between predictions from different computations were observed prior to VIRTUE. Predicted scale effects raised questions.
2. This was even more so for propeller/hull interaction computations. Different approaches had been proposed and some results shown, but there was no clarity on the best formulation, the detailed modelling and the achievable accuracy.
3. The numerical accuracy and efficiency of the methods still limited the applicability and would need to be improved.
4. While development on optimisation for minimum resistance was being done elsewhere, the practical usefulness of the result hinges upon the accuracy of the resistance computations and was thus limited. After improving that accuracy, CFD-based optimisation clearly was a subject to pursue.

The proposal for WP1 has thus been made so as to make progress on all these points. The following discusses briefly what has been achieved.

Prediction of resistance and wake field

In the first year, a study by ECN led to the estimate that, on grids of 3 million cells, for most turbulence models the numerical uncertainty in their viscous resistance prediction was around 2.5%, but for the Reynolds Stress Model (RSM) it was 14%. Large differences and uncertainties were found in the viscous pressure resistance, confirming previous experiences.

Marin and IST in particular have done detailed studies of numerical effects on the resistance prediction. The discretisation of symmetry conditions, the domain size, outer boundary conditions, and possible resistance corrections were studied in detail and guidelines were derived. Several of these aspects are not considered in usual numerical uncertainty estimates.

This and similar work has led to a clear improvement in resistance prediction accuracy. In a first workshop with comparative computations for KVLCC2 double-model flow, more accurate resistance predictions, smaller variations between the computations and a better control of the accuracy was obtained. In a second workshop in year 3, participants have done computations on common grids, and the origin of resistance differences was studied. If the same turbulence model was used, closely similar results were obtained for the wake field.

For free-surface viscous flow, besides a consideration of the resistance accuracy also some other steps had to be taken. Some groups have improved their methodology for treatment of the free surface, increasing the robustness and accuracy. Work has been done on grid deformation techniques for adjusting the grid to the wave surface or to the motions or displacement of the ship. In a workshop, computations of wave pattern and viscous flow for the 'Hamburg Test Case' containership were compared. Five groups participated, using very different methods. A fairly large spread of wave pattern predictions was observed, resulting from numerical wave damping, spurious transverse waves, reflections, or limited numerical convergence. In a second workshop in the 3rd year, the same case was revisited, but now also for full scale, while additional computations were done to clarify scale effects. The results from the 4 participating groups were now closer together, and the results of ECN and Marin were even very similar, while being obtained with completely different methods. Also for free-surface viscous flows and wave resistance, better control and accuracy had thus been achieved.

Several groups have incorporated a computation of the dynamic trim and sinkage in their method, either by solving body motion equations, or by iterative adjustments based on hydrostatics. Computing trim and sinkage by iterative adjustment appeared straightforward, but the former approach initially caused persistent oscillations and asked long computation times. By deviating from the actual body motion equations ECN has found an efficient approach. A very important aspect of free-surface viscous flow is the stern wave system and the flow off the transom. As not much experimental information on this was available, detailed stern wave measurements for two ships have been done by HSVA. A new measurement technique for stern waves has here been used. The validation data have been used fruitfully and will surely be used for further progress after Virtue.

The improved accuracy of resistance predictions, and the work done on verification, has enabled to study scale effects in resistance components. If ship power and resistance are predicted from model tests, assumptions on scale effects play a crucial role. In short, viscous resistance is supposed proportional to flat plate friction, while the wave resistance coefficient is supposed equal for model and ship. These assumptions could be checked by detailed CFD computations now, and remarkable conclusions were drawn. It appeared that the assumption on viscous resistance was reasonable, but that the usual flat-plate friction line used had a significant deviation. Also a substantial scale effect on the wave resistance was identified, Cw being 20% higher for the ship than for the model in this case. Both differences would sum up to cause a 10% difference in ship resistance; but in practice the prediction from model tests is augmented by an empirical 'correlation allowance' that would make up for that difference. However, in subsequent CFD computations, the wave resistance scale effect has appeared to differ much between ships. These results offer the prospect that full-scale resistance predictions based on model tests can actually be improved in a near future by using CFD computations.

Another important achievement in the project has been a study on modelling hull roughness effects in a numerically accurate way, and its application to full-scale ships. Like the previous steps, also this helps to decompose the overall correlation allowance in its physical components and representing these separately and more accurately.

The achievements in this part of WP1 have a direct application for practical ship design, and are already being exploited in that context.

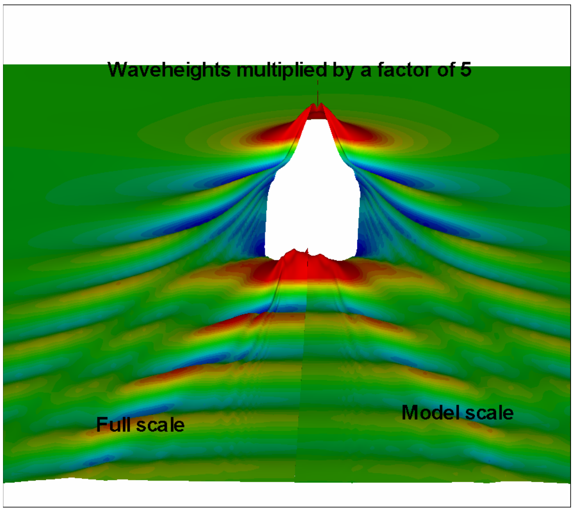


Fig. 1.1: 'Computed scale effects on the wave pattern, for Hamburg Test Case containership. Computations using Parnassos/FS.'

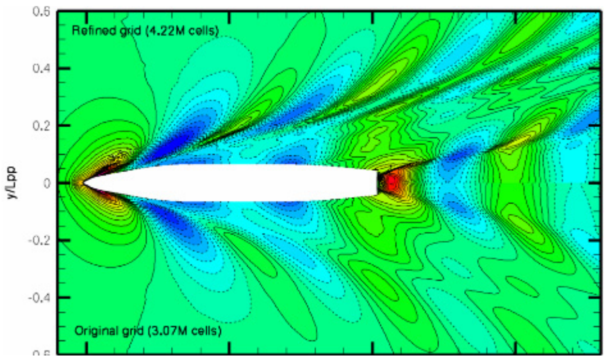


Fig. 1.2: 'Effect of automatic grid adaptivity to refine grid near free surface. Wave pattern of Virtue container ship, computed using ISIS.'

Prediction of propeller/hull interaction, power and propeller rotation rate

On this topic the state of the art was a bit less advanced than for resistance prediction. Different approaches had been proposed to model the effect of the propulsor on the flow, and in VIRTUE several of them have been refined, applied and compared.

HSVA has made computations with a complete RANS modelling of hull and propeller flow, coupled through sliding interfaces. Alternatively, several participants have used a coupling between the RANS computation for the flow around the hull, and a potential-flow propeller code, via body forces. Several intricate details appeared to play a role in both approaches, and much study was needed before good results were obtained.

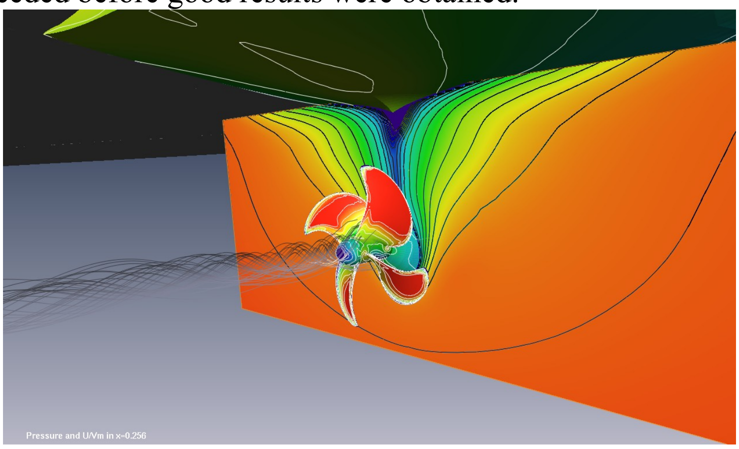


Fig. 1.3: 'Propulsion Prediction using a complete RANS model for ship hull and propeller flow.'

All developments finally led to successful computations, but still with significant differences between the quantitative results. In the course of VIRTUE not all these differences could be clarified and further work is desired. At present, the accuracy of CFD-based power predictions thus is less than that of resistance predictions. For predicting power, RPM, thrust deduction and effective wake fraction, no clear advantage for the more complete but more complicated full RANS modelling could be discerned at this stage, although evidently it can be better for other aspects.

Improvement of numerical accuracy and efficiency

In a task on the numerical accuracy and efficiency of RANS solvers, some different subjects were addressed.

Work has been done on verification procedures. In a workshop in the first year, experiences on uncertainty analysis and Method of Manufactured Solutions were exchanged and compared. Some participants took part in the Lisbon Workshop on CFD Uncertainty Analysis, applying verification procedures to their methods applied to common generic test cases. A detailed study by IST has shown that estimates of discretisation errors based on grid refinement studies may be affected by iteration errors unless the iterative error is reduced to 2 or 3 orders of magnitude below the discretisation error. Flowtech has worked on including tools for automatic reporting of verification studies in their program.

Some participants have worked on parallelisation of their programs. A good scalability of the codes and parallel efficiency greater than 80% were obtained.

Some groups have made good progress in the development of automatic grid refinement/coarsening. ECN in particular in the last year obtained promising results using automatic grid refinement around the free surface in their capturing method, and made progress in grid refinement driven by other criteria. Also others have shown promising results of different approaches for automatic grid adaptation. This work deserves further development after VIRTUE.

Hull form optimisation for resistance and wake field

After the improvements achieved in the previous tasks, the work culminated in the development and application of optimisation capabilities. In initial studies the required grid density and convergence limit for getting the right trends of resistance and wake have been established. Computations were then made by all groups for two closely resembling ships (KVLCC1 and 2) to check the ability to predict the differences; and the 1% resistance difference was well predicted by all, the wake difference qualitatively as well.

Then two successful optimisation contests have been held on the VIRTUE tanker, in which multi-objective optimisation problems were solved: to minimise the viscous resistance at model scale, and to minimise an objective function representing the quality of the wake field from a propulsion point of view. Each group used his own choice of CAD system, hull form variation technique, grid generation and RANS code to find the optimum hull form. In particular in the second round, clear Pareto fronts were found. The automation of RANS computations needed for this, the preceding studies, and in addition, the many cross-computations and detailed analyses, have contributed much to the level of experience. Essential elements for the success of the optimisation again appeared to be the hull form variations and their parametrisation, and the computational efficiency that determined the number of variants that could be tried; while the particular optimisation technique itself appeared immaterial at this stage.

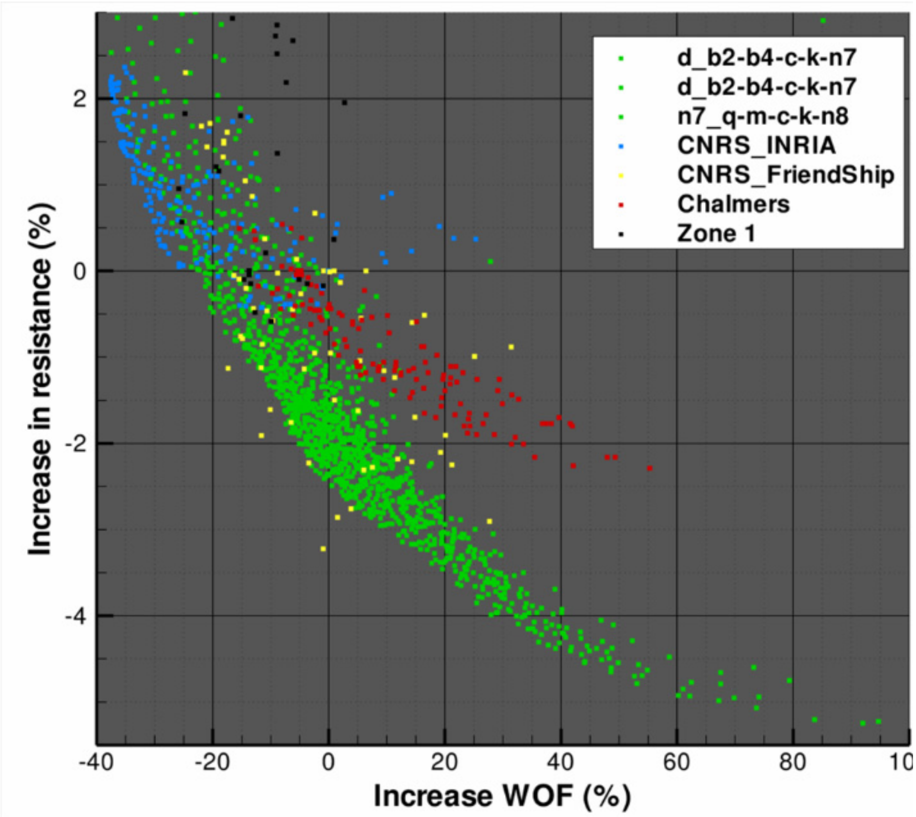


Fig. 1.4: ‘Pareto fronts resulting from multi-objective optimisation by 4 participants: CNRS (blue), SSPA (black), Chalmers (red), Marin (green).’

Ultimately, from the hull forms submitted one with best results has been selected. According to the computations this would have a 3.1% viscous resistance reduction but 8% higher wake objective function. A model was built for this and tested. The measurements confirmed the predictions: 3.4% resistance reduction and 11.5% higher wake objective function.

Thus the final validation of the optimisation study formed a great confirmation of the progress made in WP1 of VIRTUE, in the ability to predict the resistance accurately and to optimise hull forms.

Achievements in WP 2 - The Virtual Seakeeping Tank

At the end of WP2, a lot of numerical results (based on benchmarks) are now available for a wide range of seakeeping applications and for very different numerical models (free surface, waves,…), in both commercial/industrial codes and in-house/R&D codes.

The three deliverables D234, D245 and D256 appear as the key issues of WP2. They contain both the description of the algorithms and codes and all the results of the benchmarks for each method and codes.

The main results and conclusions of these results have been introduced in the WP2 section of the Best Practice Guidelines. As seakeeping analysis includes a various physical problems, pragmatic methodologies are proposed for each specific problem.

The following describes the main achievements carried out in each task of WP2.

Hydrodynamic Coefficients:

Algorithms to derive coefficients from CFD time series have been introduced in specific modules connected to the sea-keeping codes. The developments were focused on the roll damping which is not predicted in standard sea-keeping codes. Fourier analysis and identification techniques in time domain lead to comparable results, even if damping coefficient is highly dependent on the phase between loads and excitation. The retained methodology consists in running CFD codes with imposed ship motions instead of the decay tests approach. Specific modules have been developed (an RSM approach much like used in the tool PROTEUS) to interpolate hydrodynamic coefficients over some physical parameters: roll amplitude and frequencies, ship forward speed and heading.

The existing tool Rollex has been extended to include the required capabilities for roll motions prediction using the following two approaches:

- Frequency domain (FD): Rollex includes a 6 DoF model connected to diffraction-radiation codes. Selection of damping formulation is free. Coefficients derivation modules and RSM techniques are included. Additional developments were done to include the forward speed effect.
- Time domain (TD): Rollex provides damping formulation and associated hydrodynamic coefficients to the standard seakeeping code which solves the ship motions in time domain.

A specific model test campaign was carried out at BEC using a new model test set-up. The 6 DoF motions generator of ECN was installed under the towing carriage of the wave tank B600. The large HTC model provided by HSVA was equipped with bilge keels and rudder, and fixed under the motion generator through a loads measurement system. Pressure close to the bilge keels and load on the rudder has also been measured. The specified test matrix (bare hull, with appendages, with and w/o forward speed) was run to provide the time series of hydrodynamic loads.

Loading cases were selected to perform comparison between CFD. The most realistic one concerns the hull with appendages tested with the largest roll amplitude (15°) and the largest speed (15 knots at full scale). Two CFD codes have been used: (i) Fluent (a commercial code) used by SU-SSRC, and (ii) Eole, (the in-house code by Principia). Comparisons give a quite good agreement for the total loads. Discrepancies appear for the bare hull at the smallest roll amplitude (corresponding to the lowest induced damping). Some difficulties remain in the comparisons of the damping coefficients. This is due to a possible lack of accuracy related on the post-processing of the load time series to remove inertia and hydrostatic components.

Fig. 2.1: 'Model test (HTC) for roll damping coefficients'

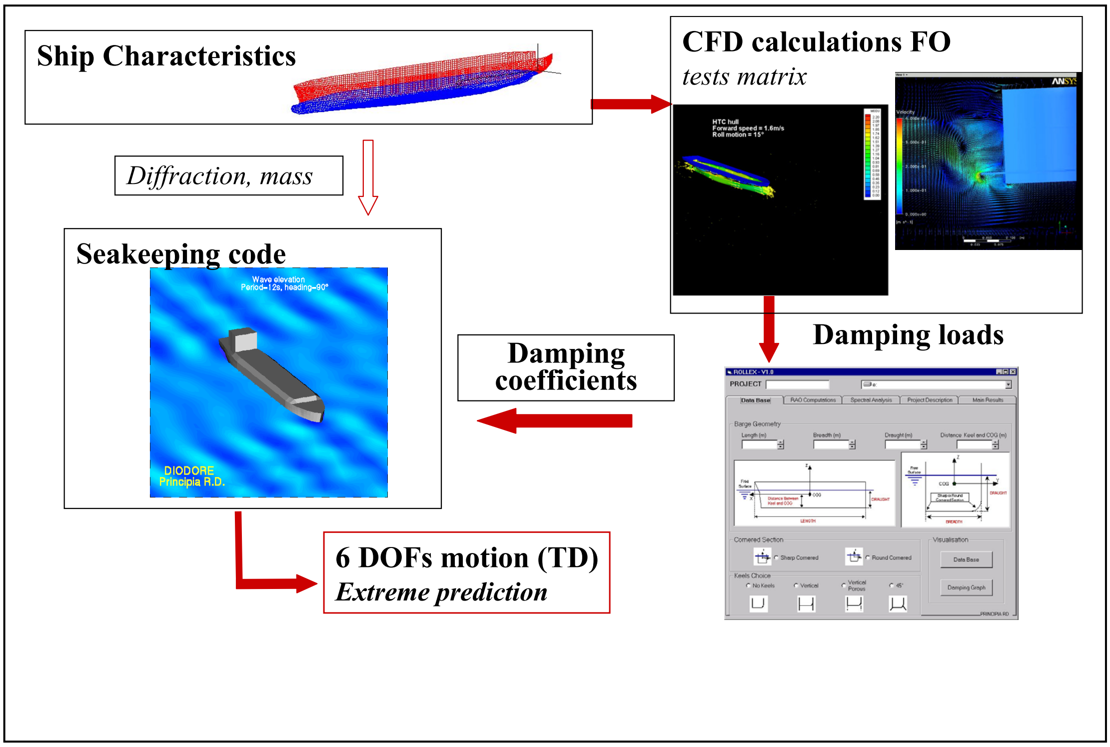


Fig. 2.2: 'General Process for roll damping prediction'

Wave modelling

The Swense method proposed by ECN to couple a non-linear in-coming wave model with a unsteady Navier-Stokes, has been extended to model multi-chromatic waves and wave groups, both in open seas (Higher Order Spectral waves : HOS) and in wave tanks. As the Swense/HOS formulation is directly included in the fluid flow equations, the in-coming wave propagates without loss of energy in time, and the fluid domain is reduced to the minimum required for the efficiency of boundary conditions. Comparisons done with model tests results carried out in the large ocean wave tank of ECN, have demonstrated the good performance of the method to represent a complex waves field. The most spectacular is the reproduction of a “freak wave” just before breaking. The method was also tested for diffraction around vertical cylinders.

The Swense method has been implemented in the CFD code EOLE, but with restriction to monochromatic waves (Rieneker and Fenton formulation). Ambition was to model breaking waves by coupling the Swense method with the VOF algorithm.

In the case of the CFX code, a second approach was developed which consist in applying in-coming wave characteristics (pressure, velocity field) to the “inlet” boundary of the flow and also in the entire fluid domain for initialisation of the flow. The water particle velocity components are derived from the so-called Stokes waves for mono-chromatic waves and from a classical superimposition of these formulations to simulate irregular multi-directional waves. A numerical wave-maker can replace the analytical solution for wave tank applications. “Outflow” boundary condition is based on the numerical beach using both grid stretching and dissipation of momentum to diffuse the waves away before they reach the outflow boundary. The implementation of these expressions in CFX is straightforward as capabilities exist to impose boundary and initial fluid flow conditions using external routines.

Several tests were performed with the two codes to validate the developments of wave models:

(i) Wave propagation in a given fluid domain: verification of mass and energy conservation with space and time.
(ii) Wave propagation and diffraction around simple geometries with linear diffraction effects (typically the vertical cylinders for which analytical results exist in monochromatic waves).

Wave induced loads and ship motions

Algorithms to couple 6 DoF ship motions equations with the URANS/VOF equations have been developed.
The models allow the prediction of the wave loads and the ship induced motions using a full CFD approach.
The two involved partners, Atkins and Principia R&D, have used different approaches: Atkins uses a commercial software and Principia R&D utilizes the EOLE code based on the Swense/VOF methods. Contribution of ECN and BEC with the code ICARE (including the Swense method) was also tested. Implementation of algorithms to simulate large ship motions was done in a common work with WP3.
Several workshops were held during the project for validation of the codes, based on cross-comparisons between the software and some comparisons with experiments when available.
A step by step approach was followed for these validations, starting with simple geometries and flow conditions to reach the case of a real ship moving in waves with a forward speed. Validation material has been identified in the form of a truncated vertical cylinder, a Calm buoy, station keeping of a moored LNG carrier (SBM results) and a container ship with forward speed (jointly with WP3).

Globally, the results are very satisfactory.

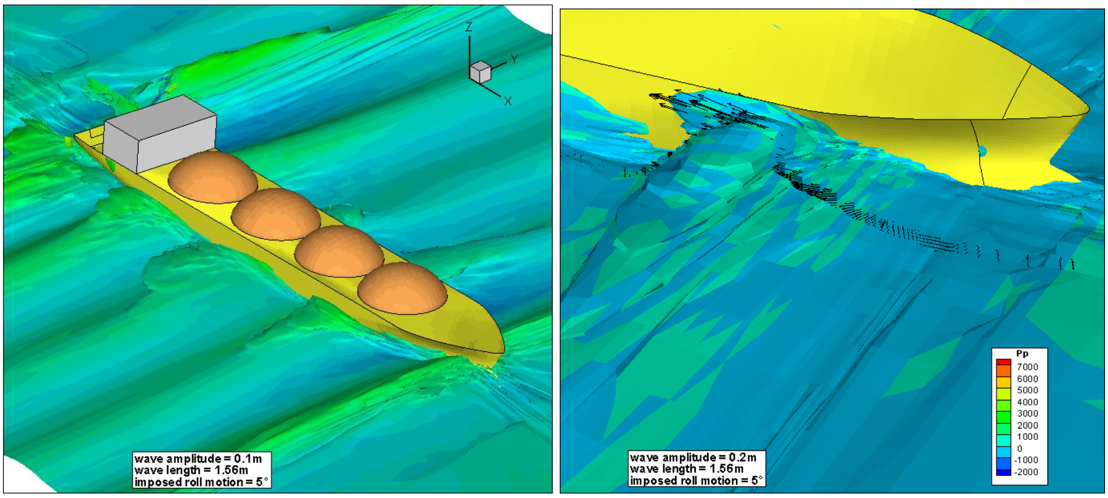


Fig. 2.3: ‘Ship in waves ‘

<u>Slamming loads and hydro-elastic response</u>

A methodology to use CFD codes for slamming/whipping prediction has been developed. Seakeeping panel codes are used to identify the occurrence and conditions of slamming for given hull geometries and wave conditions. Slamming kinematics is imposed in CFD codes to compute the local impact loads. The time history of the loads is then applied on a Finite Element code or on a simple beam model to predict the whipping response.

Several kinds of algorithms have been developed to compute hull / water impact loads: a non linear potential flow theory (implementation in the panel code Hypan / Marin), a VOF method (implementation in the CFD code Eole / PRD) and a SPH method (SU-SSRC).

Benchmarks were focused on the well-known academic configuration of the wedge entry and impact on the still water. Then, impact of container ship bow (with a bulb) was simulated. The comparisons show that the VOF and SPH models give similar results which are close to experiments and the analytical solution.

Interface with standard sea-keeping codes (methodology and hydro-elastic modules) have been developed to simulate the response of ship hulls to wave impact loads.

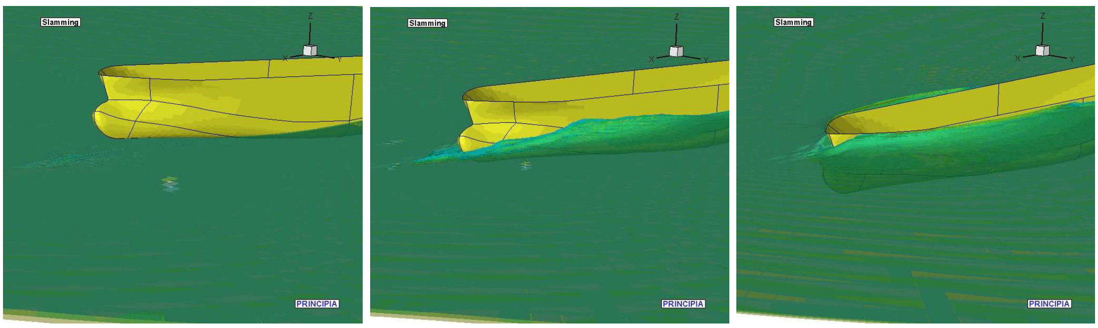


Fig. 2.4: ‘Slamming of a ship bow’

Coupling with internal liquid motions

A methodology was developed to use CFD codes for ship seakeeping with internal liquid motions, both for liquid transportation and for flooded compartment after damage. This methodology involves the use of a standard seakeeping panel code to compute ship motions coupled in time with a CFD code to predict internal liquid motions (and induced loads). The alternative is to solve the entire problem in the CFD code which could lead to very large CPU time.

The two algorithms, VOF and SPH, were implemented in parallel with the slamming algorithms.

Validation of liquid motions simulations was performed for the case of a moored rectangular barge supporting two rectangular tanks, and submitted to regular and irregular waves (existing Gis-Hydro tests). The last validation work of the project concerned the flooded compartment case.

The results are satisfactory in comparisons with the experiments. As for the slamming, the VOF and SPH models give very comparable results for the flooding problem.

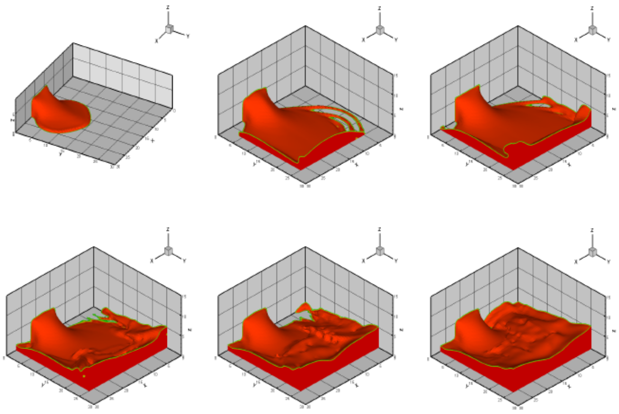


Fig. 2.5: 'Flooding of a compartment'

Achievements in WP3 - The Virtual Manoeuvring Tank:

The overall objective of work package 3 is the development of the approach based on prediction of manoeuvrability performance of ships using a series of numerical flow simulations for prescribed simple modes of motion as in captive model tests to obtain hydrodynamic derivatives of forces and moments with respect to the individual degrees of freedom and subsequent analysis of the resulting time histories of the hydrodynamic forces. The derivatives are then used in manoeuvrability simulators to evaluate ship performance in real manoeuvres for regulatory, design and operational purposes. Once the set of hydrodynamic coefficients has been calculated, all desired manoeuvres could be simulated with little computational effort. This approach follows the current practice of towing tanks, but replaces the experimental and potential methods-based techniques for derivatives calculation with numerical RANSE simulations. The derivative approaches are enhanced by direct numerical simulation of ship manoeuvrability through coupling RANSE with ship motion programs. Overall achievements around five technical tasks each focusing on specific activities at the end of projects are summarised below

<u>Manoeuvrability in calm water</u>

Further developments of solvers and implementations

Most solvers used in the work package 3 were developed / oriented for the application of steady straight-ahead motion, without appendages, free surface and wave, in most cases, with symmetry plane. For the manoeuvring calculations, further developments and benchmarking of solvers were required for all concerning partners. The main achievements in the task are:

- Seven solvers were further developed / upgraded to tackle the complicated calculations of ship manoeuvrability, including steady yaw, turning, oscillatory sway and yaw.
- Intensive calculations on hull form effects, grid density effect, turbulence model effect, scale effects and free surface effects were carried out.
- In total, 5 different ships and over 250 results have been analysed and reported

Verification and validation of numerical techniques against model tests

The numerical results were validated against model test performed by partners.

- The model tests using HSVA and MARIN built models were performed. The valuable dataset includes 6 DOF records of hydrodynamic forces, wave profile and PIV measurement of velocity distributions. All results are presented in the report and available for numerical validation.
- The comparison of results shows that most solvers can predict hydrodynamic loads and flow field with satisfying accuracy. Other solvers were upgraded further to improve the accuracy and efficiency.

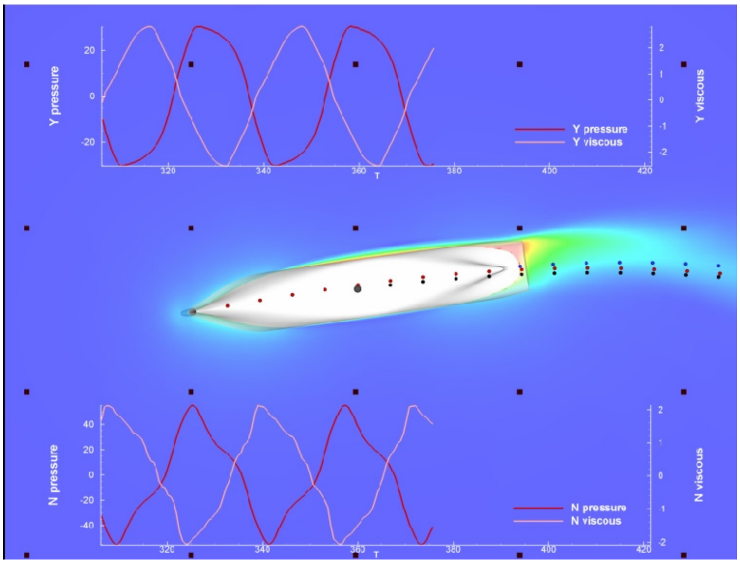


Fig. 3.1: 'Figure Manoeuvring in calm water (oscillatory yaw simulation)'

Manoeuvrability in waves

Influence of seaway was studied in two separate ways. One approach is to neglect instant effect but focus on time averaged effects. The effects of trim, sinkage and heel were quantified based on hydrodynamic derivatives. Another approach is to study dynamic effect of wave on hydrodynamic behaviour.

Verification and validation of numerical techniques against model tests

The technical work to study the influence of trim, sinkage and heel on ship manoeuvring hydrodynamics is as below.

- Four partners were involved in the study of attitude influence on ship manoeuvring hydrodynamics. Three RANS codes were implemented (Fluent by SSRC, EOLE by PRD and PANASSOS by MARIN).
- Model tests designed to study the parametric effect of trim, sinkage and heel on manoeuvring hydrodynamics have been conducted for container hull form HTC (Hamburg Test Case). The valuable database of influence of trim, sinkage and heel was established and available for numerical validation.
- Numerical calculations of attitude effects have been completed. The quantitative influences of trim, sinkage and heel on hydrodynamic loads were predicted. Generally good agreements between calculation and measurement have been achieved.
- It was concluded from both calculation and experiments that trim effects on rotating moments are larger than on translational forces. The influence of sinkage on hydrodynamic forces are large, particularly on vertical force and yaw moment. The influence of heel on hydrodynamic loads is small compared to the influence of drift angle.

Assessment of the validity of the models used in manoeuvring calculations concerning the treatment of free surface, seaway and ship motions; quantification of the ensuing effects.

Dynamic influence of wave on hydrodynamic behaviour of a ship in manoeuvring motion was investigated. The following outcome has been made.

- Four partners (including one volunteer MARIN) were involved in the study of wave influence on ship manoeuvring hydrodynamics. Three codes were implemented. Two RANSE codes (Fluent by SSRC and EOLE by PRD) and one potential code with viscous correction by PANASSOS (by MARIN).
- Regular wave was successfully generated in RANS codes. Wave features including wave length, amplitude, period and propagation were correctly simulated.
- The model tests to study wave influence on hydrodynamic forces in captive and partially restrained modes were completed. The dataset was used for numerical validation.
- The numerical simulations of wave effects on hydrodynamic forces for ship running with and without yaw angles were completed.
- The results of test cases show that X force predicted by RANSE agree better with data than potential solver, while Y and Z forces by RANSE and potential code consist well with the data. As potential results are corrected by RANSE results, the agreement with experimental data should improve substantially (in general, it is difficult for potential solver to predict ship manoeuvring motions on influence of waves with similar accuracy or reliability as RANSE solver).

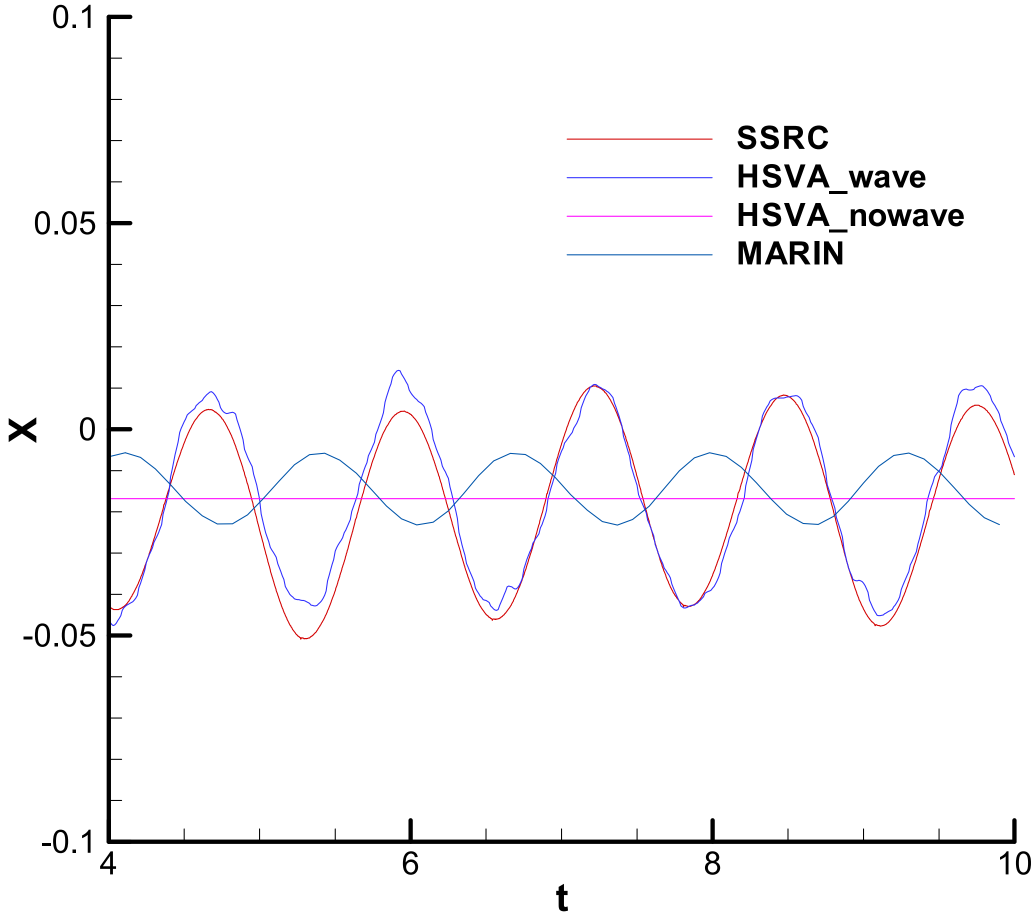


Fig. 3.2: ‘ Wave influence benchmarking and validation’

Control surfaces, appendages and propeller effects

Development of reliable numerical techniques based on RANSE solutions for the prediction of hydrodynamic derivatives of ship hulls in a variety of flow conditions.

The introduction of rudder and propeller into numerical calculations causes extra difficulty on mesh generation. The structured mesh topology is hard to be used. New strategy of mesh generation should be applied. The progress in the task was summarised as below:

- A workshop focusing on the hull-rudder interaction was held. Severn RANSE solvers were invited to present results on calculations of steady turning. All together 43 results were presented. Eight common meshes were generated. The in-depth analysis on mesh density, turbulence models, mesh topology, boundary conditions were made. The computed results were validated against measured hydrodynamics loads on rudder and hull, as well as flow field from PIV measurement.
- Reasonably good quality of meshes with control of yplus value as well as smooth distribution of cells on hull, rudder and propeller were generated for the study of hull-rudder and hull-rudder-propeller interactions.
- The rudder was meshed geometrically without using body forces, while the propeller was modelled by either body force or meshed fully geometrically.

- User coding for body force approach was developed to study hull-rudder-propeller interactions. All solvers were upgraded based on propeller modelling.

Verification and validation of these techniques against model tests

Systematic validation, verification and benchmarking work of a variety of the available RANSE solvers for a wide range of flow conditions was carried out. The following progress has been made:

- A large number of model tests have been performed for container model HTC. The valuable database including hull, rudder and propeller forces was established and available for numerical validation.
- Extensive calculations of manoeuvring motions with rudder and propeller effects have been completed. The accuracies of propeller modelling by body force and fully geometrically modelling were validated at various manoeuvring motions.
- The comparison of results shows that good agreements of hydrodynamic forces between calculation and measurement have been achieved for most solvers.
- Additional to steady yaw and turning, the agreements between calculation and measurements on oscillatory manoeuvring motions are encouraging

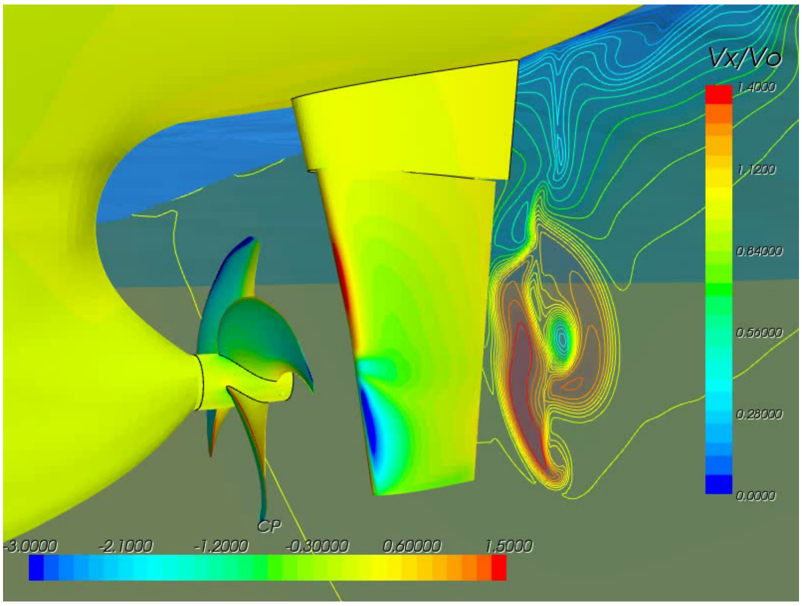


Fig. 3.3: 'Simulation of appendage effect on ship manoeuvring motions'

<u>Direct numerical simulation of ship manoeuvres by RANS modelling coupled with ship motions</u>

Development, validation and assessment of the approach based on direct simulation of ship manoeuvres based on flow solution coupled with ship motions.

There have been few attempts in the research community to undertake a direct simulation of ship manoeuvres, based on coupled numerical solution of flow equations and simulation of ship motions. Therefore, one of the major tasks of work package 3 regarding this task has been the study and assessment of possible numerical strategies for tackling this problem, as well as the incorporation of the necessary updates into flow solvers and testing of the accuracy and robustness of the resulting tools. Besides, there were no tests available in the literature, which were suitable for validation of the developed methods for the kind of problems considered; therefore a dedicated testing program was necessary. Regarding this objective, the following major progress has been made:

- study of various techniques for 3d grid generation using different grid topologies and cell types
- development, implementation and improvement of numerical tools for direct manoeuvring simulation: techniques for tackling rotating appendages, developments to support full 6 d.o.f. motions, actuator disk technique, capability to treat unsteady external forces and strongly non-steady ship motions
- Post-processing of large amount of physical testing data. The experimental results have been analyzed and report was issued for numerical validation.
- Direct numerical simulation by solving RANS equations coupled with ship motion was completed both in calm water and in the presence of wave. The encouraging agreements of turning circle characteristics between simulations and measurements were achieved.

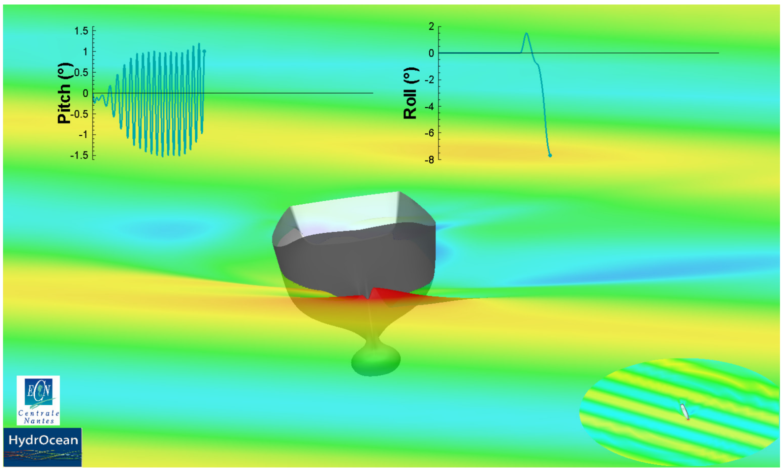


Figure 3.4 Direct simulation of ship manoeuvring in waves

Implementation

Application and verification studies by simulation program

Task 3.1 to 3.4 deals with development, verification and validation of numerical tools. And their application results in a large set of data related to manoeuvrability performance. The main contribution of those tasks is a database of hydrodynamic loads under different ship motion conditions. This database similar to that obtained through physical model tests serves as an input for the manoeuvrability simulators predicting ship behaviour during actual manoeuvres. Results of such simulations are the actual output that designers and customers are interested in. Regarding this objective, the following major progress has been made:

- Hydrodynamic derivatives are obtained through RANSE based calculations
- Manoeuvring simulator originally based on empirical formula is updated using hydrodynamic coefficients from CFD calculation
- Validation of the manoeuvrability quantities was made by comparison of physical free sailing test data
- The results show that some discrepancies were found between manoeuvring simulators. Further analysis on the accuracies of linear, non-linear hydrodynamic coefficients, rudder forces, propeller loads, resistance expression and degree of freedoms are required in the future.

Integration of application program on Virtue Integration Platform

The manoeuvrability simulator was run on both Windows based system and Linux based operating system where VIP is installed. The integration of application program will allow all purpose of users to access the tools and make it applicable in effective way.

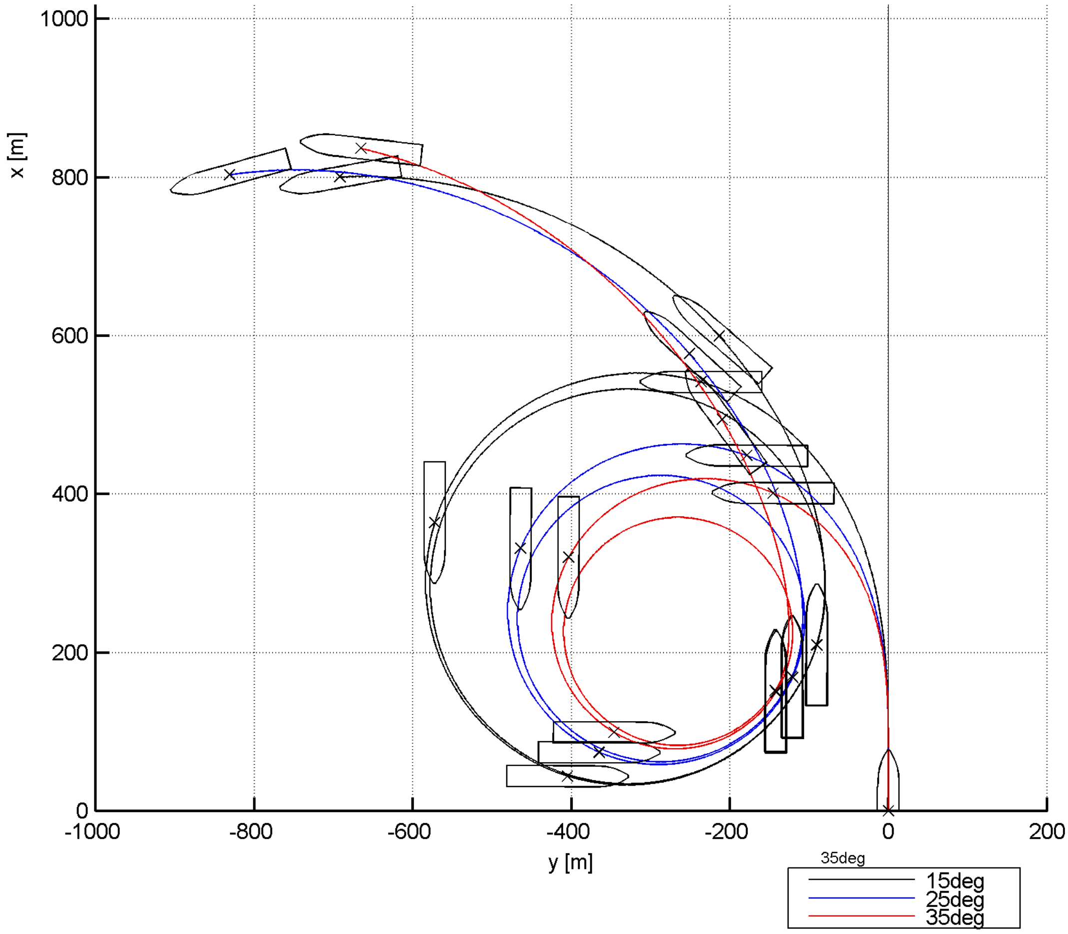


Fig. 3.5: 'Turning circle implementation using computed derivatives'

Based on the practice and experience of extensive manoeuvring calculations, benchmarking and validation by partners involved in work package 3, the Best Practice Guidelines were produced. The main contributions include:

- Description of the theory of ship manoeuvrability, physical and mathematical models, numerical aspects, pre-processing and post-processing.
- Guideline on how to successfully carry out steady and oscillatory manoeuvring simulations for captive models
- Guideline on how to conduct manoeuvring simulations for free sailing models.

Achievements in WP 4 - The Virtual Cavitation Tank

The overall objective of the Virtual Cavitation Tank is to develop and validate a limited number of promising codes that are able to predict the flow about both non-cavitating (necessary for cavitation inception) and cavitating propulsors. In particular should these codes be able to compute the adverse effect of cavitation on the propulsion characteristics, such as radiated pressure fluctuations that lead to vibrations, and cavitation erosion.

The proposed project on the Numerical Cavitation Tank (WP 4) is built up from three major tasks, forming the main building blocks:
Task 2; development of an improved RANS code for local flow prediction on propulsors.
Task 3; prediction of hull pressure fluctuations.
Task 4; prediction of the risk of cavitation erosion.
Initial studies were conducted under Task 1 aiming at reviews of state of the art multiphase CFD codes and suitable datasets for benchmarking and validation. A third subtask here was the benchmarking of existing codes such as FLUENT (at BEC and SSPA), COMET (at HSVA) and EOLE (Principia R&D). A final demonstration task consisted of a propeller design exercise, demonstrating the use of optimizers coupled to a propeller panel code.

RANS codes for predicting local flow
Development and validation work was conducted for three RANS codes, aiming at the prediction of local, non-cavitating flows over propellers and rudders. These codes were the joint HSVA/MARIN VoF code FRESCO, the HUT code FINFLO and the ECN code ISIS. Numerical uncertainty studies were conducted through sensitivity studies and an evaluation of results with a total of 8 codes in the Rome workshop on the 2D NACA 0015 foil. The necessity for such numerical uncertainty studies had become clear from the large scatter in the non-cavitating results of the Delft twisted foil in the 1st WP4 Workshop, organized in 2007. Results of this Workshop are summarized in a separate section below.

A concise review of the RANS codes under development in WP4 is given in the following Table.

		Sol. strategy		Cavitation model		Turb. model	grid type
		VOF transport methods *incompressible with press. correction*	*compressible with preconditioning*	Transport Eq. of vapour	*Energy eq. + EOS*		
FRESCO	MARIN/HSVA	X		▪ Sauer ▪ Kunz		k-ω SST	multi block structured & unstructured
FINFLO[1]	TKK/VTT/FINFLO	X			X		
FINFLO[2]			X	Kunz			
ISIS	ECN	X		Merkle		▪ 1 Eq : Spalart-Allmaras ▪ 2 Eqs: κ- ε, κ - ω Wilcox/Menter, (E)ASM ▪ 7 Eqs: Rij - ω ▪ LES : D.E.S.	multi block structured & unstructured
OPEN FOAM	Chalmers	X		▪ Sauer ▪ Kunz		LES with implicit turbulence model for subgrid scales	structured multiblock
Hybrid Approach	INSEAN						

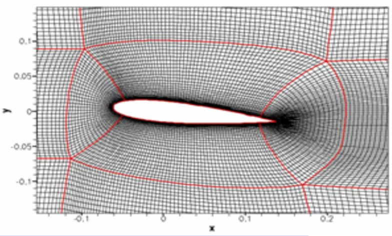
Notes: FINFLO[1] gave problems in convergence
FINFLO[2] is the reaction to the fundamental problems encountered in implementing the full thermodynamic model in the incompressible model FINFLO[1]

Table 4.1: 'RANS codes in VIRTUE - WP 4'

Hull pressure fluctuations

Development of Full RANS codes

A detailed study of two-phase modelling (free surface problems and cavitation) has been carried out for FRESCO. Extensive sensitivity studies were done for the Workshop test cases. The numerical accuracy was checked by grid refinement studies and by comparing the cavity volume variation with the integral of the source term in the cavitation model. The grid refinement studies revealed a high sensitivity of the cavitation behaviour to grid resolution. A finding that has been confirmed by sensitivity studies for other codes. It was concluded that special attention was needed for the grid resolution near the cavity interface. From a study of several cavitation models (Kunz, Sauer and Zwart, all based on Transport Equation models for the vapour or liquid fraction), there appears no clear winner. It was also concluded from numerical studies that the liquid-vapour interface of a partial cavity on a foil is neither a material surface nor an iso-pressure contour, such as assumed in BEM models.



grid	# cells	cell size	# edges on foil
G1	27,808	2.0 h	234
G2	62,568	1.5 h	351
G3	111,232	1.0 h	468

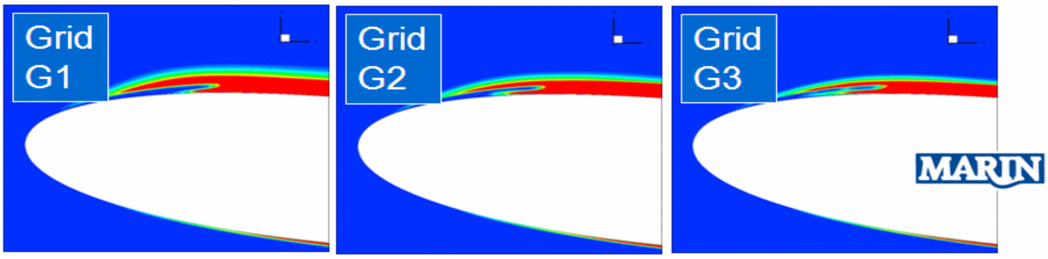


Fig. 4.2 'Effect of grid density on eddy viscosity, computed by FRESCO'

The FINFLO developments have been characterized by insurmountable problems with the implementation of the full thermodynamic cavitation model in the incompressible version of FINFLO (referred to as FINFLO[1] in the review). After more than 1 year of testing and improving, the FINFLO team decided in the third year to abandon the approach and adopt the old compressible code, which was already evaluated in Task 2 (non cavitating flows), and implement in this compressible code a classical cavitation model, based on the transport equation of the vapour fraction. This version is referred to as FINFLO[2]. Both versions have been used in verification and validation studies for the Rome Workshop. The FINFLO[2] code produced solutions for steady cavitating flows over the 2D foil and the INSEAN propeller.

As a result of multiple joint sessions between Workpackage 1 (The Numerical Towing Tank) and this WP4, ECN decided to couple their ISIS code with the inviscid BEM code for propellers, developed by INSEAN. This coupled code has been tested for the test case Containership as a demonstration case for the Virtue Integration Platform (VIP).

Development of the Hybrid Approach

An alternative approach to model these cavitation induced pressure fluctuations, is through the coupling of a propeller BEM code with a RANS code for the hull flow. This latter approach has been pursued by INSEAN with their propeller panel code PFC.

The BEM code PFC has been further developed during the course of the project. Work addressed a further validation of the propeller BEM code "PFC" and the coupling of this code to a hull RANS code based on a generalized body force approach. A general interface has been developed that can be applied to arbitrary hull viscous flow codes using RANS models and to inviscid propeller codes using BEM models. Extensive validation studies of the cavitation dynamics and radiated pressure fluctuations of a propeller in a wakefield were done for the INSEAN E779A propeller and were reported to the Rome Workshop. It was furthermore shown that pressure fluctuations on the hull and radiated noise are better described if the propeller is modelled directly through a BEM code, rather than through a body force model.

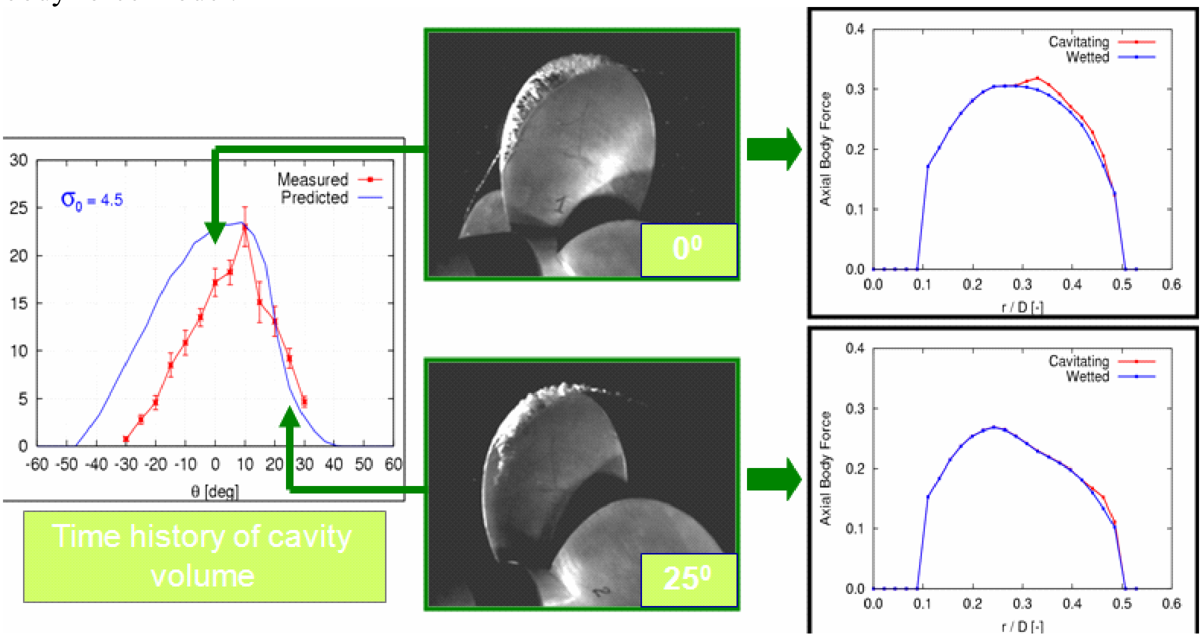


Fig. 4.3 'Validation of INSEAN BEM code PFC for prediction of cavity volume dynamics with experimental results on INSEAN propeller E779A'

The results of these studies confirm that the hybrid RANS/BEM model represents a powerful approach to describe the hydrodynamic interaction between the hull flow and propellers.

Cavitation erosion

The philosophy followed in this Task is to first understand which cavitation mechanisms are responsible for cavitation erosion, and then, to subsequently simulate them. The physical ideas behind the approach are outlined in the EROCAV observation handbook. A further understanding toward the smaller scale dynamics was deemed necessary however, for which further experiments were made at SSPA within the VIRTUE project.

The aim of the experiments was to supplement the EROCAV and other experiments with additional data, particularly as regards the developments of secondary cavities as a result of upstream moving collapses of sheet cavities. The development of the concept of secondary cavities, defined as cavities created by primarily the local collapse induced flow, is a main result of the experiments. Although they did not name it or analysed its creation, Shima et al. (1983) did notice the existence of secondary cavitation and its importance for erosion in the classic paper when they detected that in their experiment the dominating possibly damaging stress in the solid material was created by the collapse of the cloud generated after the micro-jet penetration of the cavity, and not by the jet impingement itself. The SSPA experiments confirmed the importance of secondary cavities. It is therefore concluded that neglecting these secondary structures in flow simulations imposes severe limitations to the interpretation of the cavitation aggressiveness of the flow.

Chalmers have demonstrated with their LES computations on foils (both 2D and the 3D twisted foil) that the early development of the dominating erosive behaviour can be properly simulated for both a better understanding of the physical mechanisms, as well as for engineering problems. A better understanding of the importance of internal jets in the cavity and their importance for the dynamic break up of sheet cavitation has been gained. As with all other CFD codes, the hub and tip vortices suffer from too strong a numerical dissipation. Although this is not regarded as a major problem for erosion assessments for the propeller, this is a significant limitation for the assessment of rudder erosion. From a study with two different cavitation models (Kunz and Sauer), it was found that the best strategy for the choice of the empirical coefficients in the cavitation models was to tune these coefficients so that the simulation results rendered the cavitation dynamics considered relevant for cavitation erosion. With this approach, it appeared possible to capture the main large and medium scale hydrodynamic mechanisms responsible for cavitation erosion.

A number of test cases were studied to learn the modelling capabilities of the multiphase LES code Open Foam. These test cases consisted of a thin foil (2% thickness/chord ratio), a NACA0015 foil, the Delft Twisted Foil and the INSEAN propeller E779A in open water and in a wakefield. During both the Wageningen Workshop and the Rome Workshop, the Open Foam LES code gave the best resolution of the shed cavities compared to the other participating codes and closely resembled the physics.

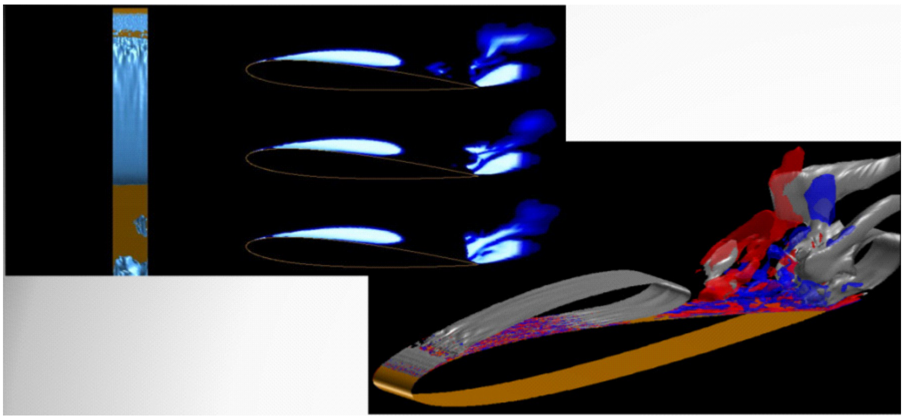


Fig. 4.4 'Cavity dynamics and vorticity predicted for a 2D NACA0015 foil section with Chalmers' LES Open Foam code'

SSPA have done extensive validation studies with the generic RANS solver FLUENT. They also studied the three Workshop test cases, i.e. the 2D NACA 0015, the twisted 3D Delft foil and the INSEAN E779A propeller. From these studies they conclude that it is possible to use a generic RANS solver with Reboud's eddy viscosity modification in a two equation turbulence model to make reasonably good predictions of the transient behaviour of sheet cavitation and cloud shedding. They conclude that "for engineering applications, the predicted results with regard to cavity size, re-entrant jets and shedding frequency seems acceptable".

It is concluded from this task that the LES simulation is so far the most promising research tool to better understand and predict dynamic cavitation. Given the time it takes for a cavitation series without starting up effects included, which is to be counted in CPU months, rather than in weeks, it is concluded that we are still far from an engineering tool.

Design studies for propellers

To demonstrate the design capabilities of propeller flow codes, Strathclyde University undertook a propeller optimization study with the INSEAN propeller BEM code "PFC". The initial idea was to explore the design space with the more robust and fast BEM code, followed by a design verification and detailed exploration by a RANS code. Optimization with a BEM code did however already consume so much time and effort, that optimization with a RANS code had to be abandoned. Instead, a faster way of design optimization was tested and explored, based on the propeller BEM computations (a so called response surface technique).

Starting point for the design case was a containership, dubbed "Hamburg Test Case", which is extensively used as a test case in WP1. Hull geometry and wakefield prediction are taken from this test case, whereas the propeller starting point was taken as a modified INSEAN E779A propeller, adapted to deliver the required thrust. Some seven propeller geometry parameters were allowed to be varied, amongst which pitch, maximum section thickness and chord length. Furthermore goal and limiting constraints were formulated that could be addressed by the propeller BEM code. Simplified criteria were discussed and agreed in WP4, that were considered representative for low frequency radiated pressure fluctuations as well as for cavitation erosion.

Two optimization techniques were tested, one based on evolutionary algorithms, the other following a gradient based approach. It was demonstrated that the gradient based method suffered from poor convergence, presumably because it remained caught in local minima, which can occur through the relatively large number of constraints.

This design exercise based on first principle analysis with the PFC code resulted in a reduction of the cavitation volume by a factor of approx. 2, which can be regarded as an indirect measure of cavitation nuisance. Also the strength constraint was met. This improvement in meeting the constraints was at the cost of efficiency, which appeared to be approx. 0.5% lower than the initial propeller.

In a second design exercise, the faster so called "Response surface based" technique has been used to optimize the propeller. This has resulted in a propeller that was also better from the point of view of cavitation (max cav. volume and shedding period were reduced with a factor of approx. 2), at an increased efficiency of approx. 1.3%. This alternative design technique was concluded to offer a strong alternative design method compared to a first principle optimization technique, shortening the delivery of results from weeks to days.

WP4 – Workshops

Important milestones were reached with the two Workshops, held in Wageningen in the third year, and Rome in the fourth year. The aim of these workshops was twofold. First, to assess the improvements and achievements made in the different codes by the partners since VIRTUE had started in 2005, and secondly to analyse and compare the different methods and to study the differences in an open and informal atmosphere. A limited number of external participants was invited because they were considered to be able to contribute to the discussion with state of the art knowledge.

Three test cases were selected for evaluation of the codes. The first one consisted of a 2D NACA0015 foil. This case was introduced as a result of the relatively large scatter in results (also non-cavitating) that occurred at the first WP4 Workshop in 2007. There was justified suspicion that this scatter was largely due to numerical uncertainty. The second test case was the Delft Twisted Foil, showing a strongly unsteady 3 dimensional sheet cavitation. This test case aimed at a validation of Underlying Flow Mechanisms. The third test case consisted of the INSEAN E779A propeller in both open water conditions and in "behind" condition, in both cavitating and non-cavitating conditions. This latter test case served to demonstrate the suitability of the codes to address an Application Challenge. The second and third test case had also been addressed at the first Workshop in 2007, but these two cases had now also been extended with unsteady flow cases. The table below shows the participation of the different codes and groups to the two test cases:

Code	Partner	NACA 0015 2D foil	Delft Twisted Foil	INSEAN E779A propeller
VIRTUE WP4 members				
FLUENT v6.2	BEC		X	X
Open Foam (LES)	Chalmers	X	X	X
ISIS	ECN			X
COMET	HSVA	X		X
EOLE	Principia R&D	X	X	
FLUENT	SSPA		X	X
FRESCO	MARIN / HSVA	X	X	X
FINFLO	TKK / VTT	X		X
External members				
UNCLE-M	ARL lab – Penn State Univ.	X	X	X
Fine TURBO	Numeca			X
STAR-CD	Wärtsila Propulsion Netherlands	X	X	X
EFD Flow	Twente University	X	X	

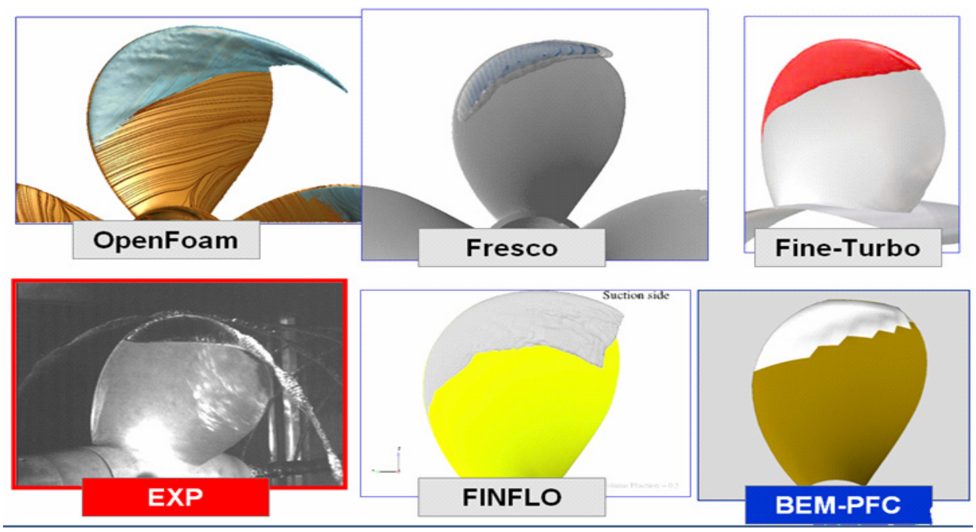


Fig. 4.5 'Prediction of Cavity Extent by five different codes in comparison to experimental observation for INSEAN E779A propeller (iso volume fraction contours $á_V$=0.5)'

Multiphase Flow Codes – State of Art

After evaluating the results from the two Workshops, as well as the final deliverables, the following is an attempt to describe the State of the Art of Multiphase Flow codes:

1. The open-water characteristics (thrust and torque coefficient) from a propeller are predictable with CFD codes within a deviation from experimental results of 3-5%, where the uncertainty in the design point of the propeller is more closely to 5%. It is however noted that incidentally unexpected large errors occurred in the results submitted to the Workshops.
2. Thrust breakdown due to cavitation can be computed.
3. Blade forces and moments in a non-uniform wakefield can be produced.
4. Cavitation inception based on an inception pressure criterion is likely to be predictable with acceptable uncertainty (also a target of the Leading Edge project).
5. The unsteady cavitation that is responsible for radiated pressure fluctuations at frequencies up to the 3rd – 5th Blade Passing Frequency can be simulated. The computation of the resulting radiated pressure fluctuations themselves is yet to be further developed. The so called hybrid approach couples a hull RANS code to a propeller BEM code. This approach was demonstrated to give realistic low frequency cavitation dynamics and pressure fluctuations.
6. It has been demonstrated that the macro structures in unsteady cavitation that are responsible for cavitation erosion can be simulated with an LES code or, to a lesser degree of detail, with a RANS code. The direct computation of material stresses due to the break up of cavitation has so far been demonstrated in the compressible Euler code of TU Munich. The difficulty in producing these material stresses is largely due to the fact that the formation of these stresses is governed by a process involving different length and time scales.

It should be noted with the above status description however, that this is only valid when the code is operated by an experienced user, following the Best Practice Guidelines.

Achievements in WP 5 - The Integration Platform

In WP5, work by the partners was carried out across a range of activities in software specification, design and integration of data structures, and development of the main software platform prototype (Version 0.x). WP5 was subject to major restructuring after the second year review that dramatically altered the mode of delivery of the work from one of pre-planned deliverables to user driven delivery. As a summary, the consequence was that:

- all major pre-planned objectives were met apart from agreed withdrawal of data mining work (original task 5.6),
- thirty-six user requirements resulted from the second year review, growing during the remaining years to seventy-five of which forty of the highest priorities were fully and seven partially completed,
- ten test cases were integrated and demonstrated rather than the originally planned two, and
- three additional partners were integrated into the package.

When considering annual achievement, the key points of progress that were made during the first year were:

- Identification of partners' requirements and data requirements. Investigations were undertaken in the first year to establish partners' requirements. It was identified that the VIRTUTE Integrated Platform (VIP) should have an open architecture for ease of integrating new tools into the platform. Requirements were also established with respect to the behaviours of VIP User Interface (iVIP), system administration, project management, process control and data management. Data requirements regarding accessibility, security and configuration were also established.
- Specification of VIRTUE Integrated Platform (VIP). The specification of the VIP was based upon and addresses partners' application and data requirements. The VIP consists of four kinds of components, namely intrinsic components, internal components, incorporated tools, and ancillary tools. The VIP has a server-client type architecture to hold these components together.
- Development of optimisation integration approach. One of the objectives of the VIP was to support multi-disciplinary optimisation, involving resistance and propulsion, sea keeping, and manoeuvring (Annex 1). A working group was set up to investigate the approaches to integrate the VIP with a selected optimisation tool mode-Frontier, and a preferred solution was defined and adopted.
- Development of visualisation approach. The 3D visualisation software AMIRA, developed at ZIB, was selected and integrated into the VIP prototype Version 0 and tested successfully.
- Development of VIRTUE Prototype 0. VIRTUE prototype 0 was developed using the core elements of the VRShips platform. Three tools, including FRIENDSHIPS modeller, ν-Shallo, and AMIRA, were integrated into the prototype. Prototype 0 supports these tools to run on different machines across a typical network.

The definition and implementation of the data management approach, the development of the VIRTUE integration platform prototype 0.2 (VIP0.2), the user interface (prototype 0.2), the visualisation interface, and initial tests and validation of VIP0.2were undertaken during the second year.

In order to meet the needs of a distributed computational environment for VIRTUE, the VIP0.2 followed the so-called client-server architecture. The achievements, therefore, can be elaborated with respect to the development of VIP0.2 sever and client components.
The highlights of the achievements for the Development of VIP0.2 are summarised as follows:

Server components:

The VIP server consists of three components, viz. account administration server, process control server, and a database system server. The account administration server is used to store all user accounts, to support the creation and modification of user accounts, and it connects with the login interface to validate user logins. The process control server runs the project processes, and co-ordinates the execution of tasks that are undertaken by users who can be located in a distributed environment. The database server is the medium for storage of project data, and it enables the users to make different types of queries to the database.
Client components:

The VIP client provides an interface that enables users to interact with the platform. The users primarily use a software component called the VIP client through which one can launch a number of internal tools that are developed within WP5. The VIP client also provides useful features for project creation, user account administration, and enactment of project tasks, data management, and launching of design and simulation tools. The internal tools include a project creation component, an account administration component, a process control client, and a generic wrapper. The project creation component enables users to define general project information (e.g. project name, code, budget, etc), and project processes.

The account administration component enables the administrative users to create and update user accounts and upload them to the account administration server. Through process control client, a project process running in the process server can be viewed on any local machine. It supports users to undertake tasks in a logical sequence. Users can launch design and simulation tools through the generic wrapper. The generic wrapper has two modes, namely configuration mode and enactment mode. The configuration mode enables users to configure a design or simulation tool (e.g. data requirements, tool executable, etc). The enactment mode supports the execution of a sequence of actions that are defined through the configuration mode (e.g. downloading data, starting a tool, etc).

Initial Test and Validation of VIP0.2:

The VIP0.2 was distributed to partners for evaluation with an evaluation form. Some initial feedback was gathered and analysed. However, comprehensive evaluation was still required with a realistic case study by the end of the year.

Revision of User Requirements:

The user requirements identified in the first year were revised. Updated user requirements will served as the basis for the further development of VIP0.2.

Development of Visualisation Interface:

Data import modules were developed and tested with datasets from HSVA, FriendShip Systems, FlowTech, Marin and Principia. Methods were developed for statistical analysis of a number of fields of a given grid, and for handling adaptive hexahedral grids. A new module was developed that allowed the combination of different fields of the same type (e.g. multiple velocity fields) into a single field.

The work of WP5 encountered some changes in the third year. The WP5 management approach was revised following the review meeting in Brussels February 2007 with a view of making it more objective, responding to partners' requirements. Following the adoption of the SCRUM methodology, the development of VIP was based on a six month rolling plan, which was updated monthly referring to a list of prioritised requirements. The work within the previously statically defined tasks T5.1 to T5.8 were consolidated within three dynamic tasks, namely T5.8.1 Platform requirements; T5.8.2 Platform development and support; and T5.8.3 Case studies and evaluation to T5.8.3, with the aim of providing an agile requirements-driven approach to the development of the VIP.

The key points of achievements of WP5 in the third year are summarised as follows:

- Evolution of platform requirements: The user requirements identified in the first two years were revisited and evolved, resulting in 36 initial prioritised requirements and ending the year with 61. They represented a living document, reflecting the evolving needs from the end users and guiding the developers for platform development.

- Development of the platform: Continuously improved versions (0.3 to 0.4.7) of the platform, addressing the selected prioritised requirements, were released. The following are some of the VIP functionalities implemented: user account administration module to facilitate project management; project definition tool; templates for proven process chains; server-side process template storage; template editors within the generic wrapper; saving existing processes as templates; dynamic server – side tool list; common model data viewer – viewer of different file formats; common model data editor to handle versions and file types to the given data items, a number of other prioritised requirements were implemented. Methods were developed and presented to allow users of the VIP to customise and use the visualisation software Amira from within the VIP.
- Initial development of integrating an optimisation toolkit into the platform: Optimisation was perceived as an integral and important element of the platform to be developed, with the interaction between the optimiser, modeFrontier, and the VIP being the main focus of development. With the focus of the VIP development towards the optimisation, the following optimisation-based case studies: propeller optimisation and calm water optimisation of the ship were defined to test the VIP.
- Test cases demonstrated and tools integrated: Cases were designed to test the VIP. Test cases relating to Hydrofoil design, Multi-objective optimisation, propeller design and hull shape optimisation were demonstrated. The following tools were integrated into the platform to meet the specific requirements of the test cases demonstrated: FS-Modeller; FS-Framework; nuShallo; ppb; RAPID; Precal; SURSIM; EOLE; SHIPFLOW; AMIRA.
- Evaluation: Versions 0.2 up to 0.4.7 of the platform were tested and feedback was provided regarding their functionality, for continued development.
- User support and training: The work package developers conducted three tool-integration workshops for the work package platform users. Additional training and information on the new release of the VIP was provided through online technical meetings, email and phone support.

In its final phase WP5 carried out further development of the Integration Platform based on the evolving prioritised user requirements and six-month rolling work plan based on the SCRUM methodology. The platform was tested by the platform users through ten case studies.

The key points of achievements of WP5 in the final phase are summarised as follows:

- Evolution of platform requirements: The user requirements identified in the first three years were revisited and evolved. Three versions of user requirements v2.7.0, v2.8.9 and v2.9.0 were delivered, which evolve the number of requirements from 61 to 75 with 14 new requirements. Priorities of the requirements were rated by WP5 partners. Based on the prioritised requirements list, 6 six-month rolling work plans were produced to coordinate the platform development.
- Development of the platform: Five continuously improved versions (v0.5.0, v0.5.1, v0.5.3, v0.5.4, v1.0) of the platform, addressing the selected prioritised requirements, were released, which reflect the platform upgrade and development. Requirements with higher priority were addressed by the platform developer. From 1st Jan 2008 to 31st May 2009, 17 requirements were implemented within the platform, which included a number of the highest priority requirements such as optimisation, Linux compatibility, data consistency, and parallel processing (API).
- Test cases demonstrated and tools integrated: Along with the platform development, nine additional tools (AQWA, CFX11, COMET, DIODORE, FreSCo, HEXPRESS, INSEAN-PFC, ISIS-CFD, modeFrontier) were integrated into the platform for testing and development of the case studies. In addition, ten cases (from the originally planned two)

relating to optimisation, hydrofoil optimisation and propeller design were studied, and all ten demonstrations were presented in the past two General Assembly meetings (Jun 2008, Jan and May 2009), September 2008 Shipbuilding Machinery and Marine technology (SMM) conference, and March 2009 VIRTUE exploitation workshop.

- <u>Evaluation</u>: Versions 0.5.0 up to 0.5.4 of the platform were tested and feedback was provided regarding their functionality, for continued development.
- <u>User support and training</u>: The work package developers conducted four tool-integration workshops for the work package platform users. Additional training and information on the new release of the VIP was provided through online technical meetings, email and phone support.

<u>Best Practice Guidelines</u>

The availability of robust commercial Computational Fluid Dynamics (CFD) software and the rapid growth in processing power have lead to an increasing use of CFD for the solutions of fluid engineering problems across all industrial sectors. The marine industry is no exception: computational methods are now routinely used, for example, to examine vessel boundary layer and wake, to predict propeller performance and to evaluate structural loads.
There has been a growing awareness that computational methods can prove difficult to apply reliably i.e. with a known level of accuracy. This is in part due to CFD being a knowledge-based activity and, despite the availability of the computational software; the knowledge base embodied in the expert user is not available. In the past this has lead to a number of initiatives that have sought to structure existing knowledge in the form of best practice advice. Building on these the VIRTUE Best Practice Guidelines expand the scope to the novel state-of-the-art arrived at in the VIRTUE project.
For the four main maritime applications, namely :

- Towing Tank
- Sea keeping Tank
- Manoeuvring Tank
- Cavitation Tank

application cases are discussed which have been chosen to reflect different stages of maturity for applying Computational Fluid Dynamics: Underlying Flow regime and Application challenge. The Best Practise Guidelines support the CFD specialist and/or the naval architect by providing him specific guidelines for each application cases, by providing validation against experiments when available, by comparing with Potential Flow methods and by underlining the challenges faced by the current state of the art modelling. Once published at the end of the project, the Guidelines will be an important contribution to the general distribution of knowledge generated in the project to the maritime CFD community.

SUMMARY / CONCLUSIONS

As addressed in the introductory chapter, the members of the VIRTUE consortium have been striving for scientific innovation and excellence in the most relevant technological areas of numerical hydrodynamics with the long term vision of being able to thoroughly complement experimental ship hydrodynamics using numerical methods. At the end of the VIRTUE project it is evident that the state-of-the-art of numerical hydrodynamics has been advanced considerably and the overall objective to make CFD methods fit for use in either routine work or application to frontier problems in maritime hydrodynamics has been largely achieved.

Based on the developments in all CFD related work packages in VIRTUE, a large variety of CFD tools can be reliably applied to a large range of hydrodynamic analysis tasks arranging from practical problems and considerations in the maritime industry. This is especially important in view of the ever increasing need for improved fuel savings and accompanying reductions of ship emissions which form a major issue in the public discussion today.

New and improved CFD tools together with a comprehensive Best Practice Guideline document which has been produced from contributions from all work packages covering areas such as resistance, propulsion, seakeeping, manoeuvring and propeller / cavitation predictions provide a significant boost to numerical analysis of maritime flow problems.

Together with the software and process integration platform developed in work package 5, VIRTUE tools today offer an unprecedented opportunity to analyse and optimise new ship designs from a hydrodynamic perspective and hence contribute substantially to solving the pressing problems of the maritime industry.

2. Dissemination and Use

2.1 EXPLOITABLE KNOWLEDGE AND ITS USE

The VIRTUE project has generated a wealth of exploitable knowledge and products which benefited and benefits all project partners. Especially the largely improved CFD codes of a number of partners provide a sound basis for future use in consultancy projects which in turn will provide optimal design solutions for the entire maritime industry.
Further principal results of the projects achieved by the entire team are the Best Practice Guidelines which will be made available to the general public via the VIRTUE web site and the Virtual Integration platform (VIP) which will be further developed and maintained through the VIP user group which has been formed at the end of the project. Members of this group will use the VIP for dedicated in-house applications.
The following overview table presents a short summary of the main results and exploitable items of VIRUE.

Overview table

Exploitable Knowledge (description)	Exploitable product(s) or measure(s)	Sector(s) of application	Timetable for commercial use	Patents or other IPR protection	Owner & Other Partner(s) involved
Best Practice Guidelines		Maritime CFD	End of project		VIRTUE consortium
	Improved CFD codes	Maritime CFD, consulting, SW distribution	immediately	IPR with individual partners	All individual VIRTUE partners
	Virtual Integration Platform	Maritime and general Engineering, design integration	End of project	IPR with SU-CAD-C	SU CAD-C, several VIRTUE partners (via the VIP user group)

2.2 DISSEMINATION OF KNOWLEDGE

The following table lists all dissemination activities section should include **past and future activities** and will normally be in the form of a table maintained by the coordinator or any other person charged with controlling the dissemination activities**.**

Overview table

Planned/actual Dates	Type	Type of audience	Countries addressed	Size of audience	Partner responsible/ involved
Press release(press/radio/TV)					
2006	Public Overview progress report	General public – industry	Int.		HSVA
2006	Article: "The Naval Architect"	Mar. Industry	Int.		HSVA / SSRC
2006	Article: "HANSA"	Mar. Industry	Int.		HSVA
May 2007	Press Release, Parliament Magazine	General Decision makers	EU	> 5000	HSVA
August 2008	Press Release, VIRTUE@SMM	Mar. Industry	EU	> 5000	HSVA
2005-2009	Press Release / Newsletter	Mar. Industry	International	> 5000	HSVA
Conferences					
STG-Hydrodynamic Symposium, 2007	Symposium on CFD in Ship Enginnering	Engineers, Scientists (Public)	DE, UK, SE, FR, IT, NL	150	TUHH
Sept 2007	10th Numerical Towing Tank Symposium	Research Industry	ALL	100	Chalmers
Oct. 2007	2nd IAHR International Meeting of WG on Cav. and Dynamic Problems in Hydraulic Mach.	Research	ALL	50	Chalmers
March 2008	RINA – Marine CFD	Maritime Industry, Engineers	International	100	VIRTUE partners
Sept. 2008	VIRTUE public workshop @ SMM	Maritime Industry	Intenational	100	HSVA, VIRTUE partners
Publications					
See chapter 2.3: Publishable Results					
Project web-site					
Since 2005	www.virtual-basin.org	Public part / VIRTUE Extranet (project internal)	Int. / EU		HSVA

Education					
2005 +	Knowledge gained during the project will be part of educational activities	Students	German & Int. Master Students	>100	TUHH
2005 +	Knowledge gained during the project will be part of educational activities	Students	Portuguese & Int. Master Students	50	IST
2005 +	Knowledge gained during the project will be part of educational activities	Master + PhD Students	Italian & EU Students	< 10	INSEAN
2006	Diploma Thesis on Non-Reflecting Wave Boundary Conditions	Students & Scientific Assistants		>10	TUHH
2006	Master Thesis: Implementation and validiation of a VoF based Cavitation-model in the RANS solver FreSCo	Students & Scientific Assistants		>10	TUHH
2005 +	Knowledge gained during the project will be part of educational activities	Students	Int Master's program in Nav. Arch	>100	Chalmers
2006 +	Teaching	Students in Naval Architecture	M.eng	20	SSRC
2007 +	Teaching	Students in Naval Architecture and hydrodynamics	French Engineerin g schools	25	PRINCIPIA
2007 +	Teaching postgraduates in Design Management	Faculty of Engineering students	Int.	>40	SU-CADC
2008/9	Diploma Thesis	Students	German & Int. Master Deg.		TUHH & HSVA
Exhibitions					
SMM 2008	Exhibition / Trade Fair	Maritime Industry	Inter-national	> 50000	HSVA / VIRTUE partners

2.3 PUBLISHABLE RESULTS

The following list is a collection of all publications made by project partners in the course of the VIRTUE project. This comprises more than 100 publications, either individually elaborated or partly jointly presented at international conferences or symposia.

HAMBURGISCHE SCHIFFBAU-VERSUCHSANSTALT GMBH HSVA

J. Marzi: "VIRTUE – Der numerische Schlepptank", EU Statusseminar, 9-12-2005, Warnemünde

D. Schmode, H. Vorhoelter, T. Rung, D. Hafermann: *RANS-Based Flow Analysis for Propellers and its Benefits*, ICHD Conference 2006, Ischia Italy (Joint publication with TUHH)

D. Schmode, J.H. Günther, J. Kaufmann, T. Rung, D. Hafermann: *Investigation of Scale Effects in Exhaust-Gas Tests using RANS Solver FreSCo*, NuTTs 2006,Le Croisic, France, 1 - 3 October 2006 (Joint publication with TUHH)

J. Marzi, D. Vassalos: *The Making of The Numerical Towing Tank,* The Naval Architect, September 2006.

J. Marzi: *Auf dem Weg zum Numerischen Schlepptank – Das EU - Forschungsprojekt VIRTUE*, HANSA, 9, 2006.

J. Marzi: *VIRTUE – The Virtual Tank Utility in Europe - Extending the scope and capabilities of maritime CFD***,** ICHD Conference 2006, Ischia Italy

C. Petz, T. Weinkauf, H. Streckwall, F. Salvatore B.R. Noack, H.-C. Hege: *"Vortex Structures at a Rotating Ship Propeller"*, Presented at the 24th Annual Gallery of Fluid Motion exhibit, held at the 59th Annual Meeting of the American Physical Society, Division of Fluid Dynamics, Tampa Bay, 2006, (Joint publication with ZIB, INSEAN)

A. Duffy, S. Harries, J. Marzi, C. Petz, Z. Wu: *"VIRTUE: Integrating CFD Ship Design"*, Proc. of 7th International Conference on Hydrodynamics, Ischia, 2006.
schia, 2006. (Joint publication with SU-CADC, Friendship Systems, ZIB)

H. Streckwall: *"Numerical Shape Optimization of Appendages",* HSVA Owners Seminar Nov. 2007

H. Streckwall: *"Rudder Cavitation: Numerical Analysis and Shape Optimization",* STG Workshop CFD in ship design, 2007

Salvatore, F., Streckwall, H., Van Terwisga, T.: *"Propeller Cavitation Modelling by CFD – Results from the VIRTUE 2008 Rome Workshop",* First International Symposium on Marine Propulsors SMP'09, Trondheim, Norway, June 2009 (with INSEAN and HSVA)

J. Marzi: *"VIRTUE – The Virtual Tank Utility in Europe*", (in German), Presentation at the STG General Assembly, 2007

J. Marzi: *"VIRTUE – The Virtual Tank Utility in Europe*", The Parliament Magazine, 2007.

D. Hafermann, "*The New RANSE Code FreSCo for Ship Applications",* STG Workshop CFD in ship design, 2007

K.-Y. Chao, D. Hafermann, J. Marzi: *"Accurate resistance prediction – the key to ship power prognosis"*, Int. Conf. Computational Methods in Marine Engineering, MARINE 2007, Barcelona, 2007

J. Marzi: *"VIRTUE – A European approach to developing the Numerical Towing Tank"*, RINA Marine CFD Conference, Southampton, 26-27 March, 2008

J. Marzi: *"VIRTUE- The Virtual Tank Utility in Europe, an Overview*", VIRTUE Workshop at SMM 2008,Hamburg, 24. Sept. 2008

J. Marzi, *"VIRTUE – Press Release 2008*", HANSA, Sept. 2008.

S. Gatchell: *"Coupling CAD and CFD Codes within a Virtual Integration Platform"*, RINA Marine CFD Conference, Southampton, 26-27 March, 2008

S. Gatchell: *"RANS based Ship hullform Optimisations using the Virtual Integration Platform"*, VIRTUE Workshop at SMM 2008,Hamburg, 24. Sept. 2008

K. Chao: *"Numerical propulsion test with rotating propeller"*, HSVA Bericht-Nr. 1665 (2008)

K. Chao: *"Propeller modelling in propulsion test simulation"* HSVA-Bericht-Nr. 1666 (2008)

MARITIME RESEARCH INSTITUTE NETHERLANDS MARIN

Eça L. and Hoekstra M., ``*On the accuracy of the numerical prediction of scale effects on ship viscous resistance"*, MARINE International Conference on Computational Methods in Marine Engineering, Barcelona, 2005 (with IST)

Toxopeus, S.L., ``*Verification and validation of calculations of the viscous flow around KVLCC2M in oblique motion'',* 5th Osaka Colloquium, 2005

Raven, H.C., Ploeg, A.P. van der, and Eça, L., ``*Extending the benefit of CFD tools in ship design and performance prediction'',* ICHD 7th International Conference on Hydrodynamics, 2006 (with IST)

Toxopeus, S.L., ``*Validation of slender-body method for prediction of linear manoeuvring coefficients using experiments and viscous-flow calculations''*, ICHD2006 7th International Conference on Hydrodynamics, 2006

Toxopeus, S.L., ``*Calculation of hydrodynamic manoeuvring coefficients using viscous-flow calculations"*, ICHD2006 7th International Conference on Hydrodynamics, 2006

Eça, L. and Hoekstra, M., ``*On the Influence of the Iterative Error in the Numerical Uncertainty of Ship Viscous Flow Calculations''*, 26th ONR Symposium on Naval Hydrodynamics, 2006 (with IST)

Toxopeus, S.L., ``*Deriving mathematical manoeuvring models for bare hull ships using viscous-flow calculations''*, MARINE International Conference on Computational Methods in Marine Engineering, 2007

Van der Ploeg, A. ``*Treatment of the free surface boundary conditions in PARNASSOS'',* NUTTS symposium Varna, 2005

Van der Ploeg, A. and Raven, H.C., ``*Accuracy of viscous resistance computations for ships including free surface effects'',* MARINE International Conference on Computational Methods in Marine Engineering, 2007

Eça L. and Hoekstra M., ``*On the numerical accuracy of the prediction of resistance coefficients in ship stern flow calculations'',* MARINE International Conference on Computational Methods in Marine Engineering, 2007, and Jnl Marine Science and Technology, Vol.14, Nr 1, 2009. (with IST)

Eça L. and Hoekstra M., ``*The numerical friction line'',* Jnl. Marine Science and Tecnology, Vol. 13, No. 4, 2008. (with IST)
Toxopeus, S.L., ``*Deriving mathematical manoeuvring models for bare hull ships using viscous-flow calculations''*, Journal of Marine Science and Technology, 2008 (online) Vol.14, Nr 1, 2009 (print)

Toxopeus, S.L. and Lee, S.W., "*SIMMAN 2008 Workshop on Verification and Validation of Ship Manoeuvring Simulation Methods*", 14 April 2008

Raven, H.C., van der Ploeg, A., Starke, A.R., and Eça, L., "*Towards a CFD-based prediction of ship performance --- Progress in predicting resistance and scale effects'',* RINA Conference Marine CFD 2008, Southampton, April 2008. and*,* Int. Jnl of Maritime Engineering, Trans. RINA Vol.150 – A4, 2008. (with IST)

Raven, H.C., *"VIRTUE WP1: Enhancing the use of CFD in ship design",* VIRTUE Workshop at SMM 2008,Hamburg, 24. Sept. 2008

Raven, H.C., *'Towards a CFD-based prediction of ship performance",* VIRTUE Workshop at SMM 2008,Hamburg, 24. Sept. 2008

van der Ploeg, A., Raven, H.C., Windt, J.W., Leroyer, A., Queutey, P.,, Deng, G.B., Visonneau, M., ``*Computations of free-surface viscous flows at model and full scale --- a comparison of two different approaches'' ,* 27th Symp. Naval Hydrodynamics, Seoul, oct. 2008. (with CNRS)

Salvatore, F., Streckwall, H., Van Terwisga, T.: *"Propeller Cavitation Modelling by CFD – Results from the VIRTUE 2008 Rome Workshop",* First International Symposium on Marine Propulsors SMP'09, Trondheim, Norway, June 2009 (with INSEAN and HSVA)

Toxopeus, S.L. and Vaz, G.: "*Calculation of Current or Manoeuvring Forces Using a Viscous-Flow Solver*", OMAE2009 28th International Conference on Ocean, Offshore and Arctic Engineering, Hawaii, USA. June, 2009.

Van Oers, B.J. and Toxopeus, S.L.: "*On the relation between flow behaviour and the lateral force distribution acting on a ship in oblique motion*", ICMES 10th International Cooperation on Marine Engineering Systems, 2006

Vaz, G., Rijpkema, D., Hoekstra, M. *"A Theoretical, Numerical and Validation Study on Cavitation Models using a Multi-Phase URANS Code"*. Cav2009 Conference, Ann Harbour, Michigan, USA. August, 2009.

Hoekstra, M. and Vaz, G. *"The partial cavity on a 2D foil revisited"*. Cav2009 Conference, Ann Harbour, Michigan, USA. August, 2009.

Vaz, G., Jaouen, F. and Hoekstra, M. "*Free-Surface Viscous Flow Computations. Validation of URANS code FreSCo"*. OMAE2009 28th International Conference on Ocean, Offshore and Arctic Engineering, Hawaii, USA. June, 2009.

Vaz, G. and Klaij, C., *"From Bare Smooth Cylinders towards Rough Straked Risers"*, Oral presentation at OMAE2008 27th International Conference on Ocean, Offshore and Arctic Engineering, Estoril, Portugal, June, 2009.

Hoekstra, M., Vaz, G., Abeil, B. and Bunnik, T. *"Free-Surface Modelling with Interface Tracking and Interface Capturing Technique"*. ECCOMAS2007 Conference, Barcelona, Spain. June, 2007.

Eça L. and Hoekstra M., "*On the Inclusion of Hull Roughness Effects in Ship Viscous Flow Calculations",* MARINE International Conference on Computational Methods in Marine Engineering, 2009. (with IST)

Toxopeus, S.L. and Vaz, G., "*FreSCo successfully predicts flow around submarine hull*", MARIN Report, No. 95, p22, January, 2009.

Vaz, G., "*New code FreSCo reveals what goes on under the surface*", MARIN Report, No. 96, p23, April, 2009.

PRINCIPIA R&D PRD

R. Marcer, C. Audiffren, C. Dassibat, C. de Jouëtte, "*Validation of a CFD code for ship sea-keeping simulation*", Paper N° 2007-PF-01, ISOPE, 2007.

Marcer, C. Audiffren, C. Dassibat, C. de Jouëtte, "*Sea-keeping modeling in calm water and in waves using the CFD code EOLE*", 11ème Journée de l'Hydrodynamique, 2007.

C. Berhault, C. de Jouëtte, R. Marcer, B. Allessandrini, P. Ferrant, L. Gentaz, "*Application of RANSE-Potential coupling method to Seakeeping Simulations in Irregular Waves*", International Workshop on Ship Stability, Daejeon (Corea), March 2008.

C. Rigbourg, A. Camhi, B. Lécuyer, R. Marcer, C. Berhault, "*Numerical and Experimental Investigations on Deepwater CALM Buoys Hydrodynamics Loads*", OTC 18254 PP, 2006

FPSO JIP WEEK seminar, presentation of "*Virtual Tank Utility in Europe –Benefits to FPSO* ", *(FPSO : Floating Production Storage and Off-loading Vessel)* , Bendor (France), 2006.

A. Sambe, F. Golay, R. Marcer, D. Sous, P. Fraunié, C. De Jouette, V. Rey, "*Two phases flows unstructured grid solver: application to Tsunami wave impact*", Paper TPC 510, ISOPE 2009.

SMM, Poster WP2: Numerical Sea-keeping Tank, Hamburg 2008..

UNIVERSITY OF STRATHCLYDE SU-SSRC/CAD

Q. Gao, V. Shiganov, D. Vassalos "*Numerical Simulation of Yaw Effect*", 4th International Conference on Marine Hydrodynamics, Mar. 2005, Southampton

Q. Gao, D. Vassalos "*Computational hydrodynamic derivative*", ISOPE, Lisbon Paper No 2007-JSC-152, June 2007

Q. Gao, D. Vassalos, "*Computational Hydrodynamic Derivatives by Numerical PMM*", RINA MARINE-CFD, Southampton, 26 March 2008

Q. Gao, D. Vassalos *"Simulation of wave effect on ship hydrodynamics by RANSE"*, STAB, St Petersburg, June, 2009

Z. Gao, D. Vassalos, Q. Gao, *"A multiphase CFD method for prediction of floodwater dynamics"*, STAB, St Petersburg, June, 2009

Vanem E, R Puisa and R Skjong, *"Standardized Risk Models for Formal Safety Assessment of Maritime Transportation"*, Proceedings of the 28th International Conference on Ocean, Offshore and Arctic Engineering, Honolulu, Hawaii, 31 May 2009

L. Shen, Q. Gao and D. Vassalos, "*The Coupled Ship-Floodwater Problem by SPH and VOF Methods*", STAB, St Petersburg, June, 2009

R.Puisa, D.Vassalos, L. Guarin, "*Design for Safety with Minimum Life-Cycle Cost*", Proceedings of the 10th International Conference on Stability of Ships and Ocean Vehicles, St Petersburg, June 2009

CAD

Duffy A.H.B., Harris S., Marzi J., Petz C. and Wu Z., "*VIRTUE: Integrating CFD ship design*", 7th International Conference on Hydrodynamics, Ischia, Italy, 4-6 October 2006, pp10.

Wang W., Duffy A.H.B., Whitfield R.I., Mohamed K, Prins H, Gatchell S, "*Virtual Integration Platform for Computational Fluid Dynamics*", 14th International Conference on Computer Applications in Shipbuilding (ICCAS2009), Shanghai, China. 1-3 September 2009. (Accepted)

Whitfield R.I., Duffy A.H.B., Wu Z., *"Realising intelligent virtual design",* Second International Conference on Design Computing and Cognition (DCC'06), Intelligent Virtual Design Environments workshop, Technical University of Eindhoven, Netherlands, 9th July 2006.

Whitfield R.I., Duffy A.H.B., Coates G., "*Real time resource scheduling within a distributed collaborative design environment*", 16th International Conference on Engineering Design (ICED `07), Paris, France, 28-31 August 2007. Copyright owned by The Design Society 2007.

Whitfield R.I., Duffy A.H.B., "*Collaborative support for distributed design*", Realising Network Enabled Capability (RNEC'08), Leeds, UK, 13-14 October 2008.

Whitfield R.I, Duffy A.H.B., "*Modes of integrated collaborative ship design*", 14th International Conference on Computer Applications in Shipbuilding (ICCAS2009), Shanghai, China, 1-3 September 2009. (Accepted as reserve paper)

Wu Z., Duffy A.H.B., Vassalos D., York P., Whitfield R.I., "*VIRTUE Integrated Platform: Holistic Support for Distributed Ship Hydrodynamic Design*", 16th International Conference on Engineering Design (ICED `07), Paris, France, 28-31 August 2007. Copyright owned by The Design Society 2007.

Gatchell S., Whitfield R.I., Duffy A.H.B., Abt C., "*Coupling CAD and CFD codes within a virtual integration platform*", Marine CFD 2008, Southampton, UK, 26-27 March 2008

TECHNISCHE UNIVERSITÄT HAMBURG-HARBURG TUHH

K. Wöckner, P. Soukup, T. Rung: *Boundary Conditions for Free Surface Flows,* 10th Numerical Towing Tank Symposium, Hamburg, Sept. 2007.

D. Schmode, T. Rung: *RANS Code Verification Using Method of Manufactured Solution*, 10th Numerical Towing Tank Symposium, Hamburg, Sept. 2007.

D. Schmode, K. Wöckner, T. Rung: *Free Surface Modelling in FreSCo, Latest Developments*, 10th Numerical Towing Tank Symposium, Hamburg, Sept. 2007.

O. Hympendahl, T. Rung: *Experimental Investigation and Potential Method Simulation of Transom Stern Flows*, 10th Numerical Towing Tank Symp., Hamburg, Sept. 2007.

J. Kröger, J. Will, O. Hympendahl, T. Rung: *Computation of Flows with Wetted Transom Sterns with a Potential Flow Code*, 10th Numerical Towing Tank Symposium, Hamburg, Sept. 2007.

Schmode, D., Hafermann D.: *Comparison of Wind Tunnel Measurements and Computations with RANS Solver FreSCo*, 8th NuTTS Symposium, Varna, Bulgaria, 2005.

Vorhölter H., Schmode D., Rung, T.: *Implementation of Cavitation Modeling in FreSCo*, 9th NuTTS Symposium,Le Croisic, France, 2006.

CHALMERS UNIVERSITY OF TECHNOLOGY CHALMERS

Persson, T., Bark, G., Bensow, R. E., Berchiche, N. and Fureby, C., (2006), *Modelling the Cavitating Flow Around a 3-dimensional Wing Section Using Large Eddy Simulation*, 9th Numerical Towing Tank Symposium, Le Croisic, France, 1-3 October 2006.

Persson, T., Bark, G., Bensow, R. E., Berchiche, N. and Fureby, C. (2006), *Large Eddy Simulation of The Cavitating Flow Around a Wing Section.* Sixth International Symposium on Cavitation, CAV2006, Wageningen, The Netherlands, September 2006.

Huuva, T. and Bark, G. (2007), *Modelling of the unsteady cavitating flow on a twisted hydrofoil,* 10th Numerical Towing Tank Symposium, Hamburg, Germany, 23 – 25 Sept. 2007.

Huuva, T., Cure, A., Bark, G. and Nilsson, H. (2007), *Computations of unsteady cavitating flow on wing profiles using a volume fraction method and mass transfer models*. Proceedings of the 2nd IAHR International Meeting of the Workgroup on Cavitation and Dynamical Problems in Hydraulic Machinery and Systems, Scientific Bulletin of the "Polytechnica" University of Timisoara, Romania. Transactions on Mechanics. 52 (66) s. 21-34, 2007.

Huuva, T. (2008). *Large eddy simulation of cavitating and non-cavitating flow*. PhD thesis ISBN/ISSN: 978-91-7385-063-6, Chalmers University of Technology, Göteborg, 2008.

Bensow, R. E., Huuva, T. Bark, G., and Liefvendahl M. (2008). *Large Eddy Simulation of Cavitating Propeller Flows.* 27th Symposium on Naval Hydrodynamics, Seoul, Korea, 2008.

Bensow, R. Liefvendahl, M. (2008), *Implicit and Explicit Subgrid Modeling in LES Applied to a Marine Propeller.* 38th Fluid Dynamics Conference and Exhibit. (AIAA-2008-4144), Seattle, WA, USA, 2008.

Lu, N., Huuva, T., Bensow, R. E., Bark, G., and Berchiche, N., (2009) *LES of the Unsteady Cavitation on the Delft Twisted Foil*, to be published at 7th Int. Symp. on Cavitation, CAV 2009, August 17-22, 2009, Ann Arbor, MI, USA, August, 2009.

Bark, G., Grekula, M., Bensow, R. E. and Berchiche, N. (2009) *On Some Physics to Consider in Numerical Simulation of Erosive Cavitation*, to be published at 7th Int. Symp. on Cavitation, CAV 2009, August 17-22, 2009, Ann Arbor, MI, USA, August, 2009.

Bensow, R. E., Bark, G. (2009), *Modelling of the cavitating flow on a propeller,* Chalmers report 09:111, ISSN 1652 – 9189, Chalmers Univ. of Technology, Dep. of Shipping and Marine Technology, Göteborg, 2009, (To be submitted for journal publication).

INSTITUTO SUPERIOR TECNICO IST

Eça, L. and Hoekstra, M., ``*On the Influence of the Iterative Error in the Numerical Uncertainty of Ship Viscous Flow Calculations*'', 26th ONR Symposium on Naval Hydrodynamics, 2006 (with Marin)

Eça L. and Hoekstra M., ``*On the numerical accuracy of the prediction of resistance coefficients in ship stern flow calculations*'', MARINE International Conference on Computational Methods in Marine Engineering, 2007, and Jnl Marine Science and Technology, Vol.14, Nr 1, 2009. (with Marin)

Eça L. and Hoekstra M., ``*The numerical friction line*'', Jnl. Marine Science and Tecnology, Vol. 13, No. 4, 2008. (with Marin)

Eça L. and Hoekstra M., "*On the Inclusion of Hull Roughness Effects in Ship Viscous Flow Calculations",* MARINE International Conference on Computational Methods in Marine Engineering, 2009. (with Marin)

BASSIN D'ESSAIS DES CARÈNES BASSIN

R. Marcer, C. Audiffren, C. Dassibat, C. de Jouëtte, Principia, AREVA Group, La Ciotat, France, P.E. Guillerm, Bassin d'essais des carènes, Val de Reuil, France, B. Pettinotti, Ecole Centrale de Nantes, Nantes, France: *VALIDATION OF A CFD CODE FOR SHIP SEAKEEPING SIMULATION,* Proceedings of the Sixteenth (2007) International Offshore and Polar Engineering Conference Lisbon, Portugal, July 1-6, 2007

A. Drouet, E. Jacquin, HydrOcean, Nantes, France, B. Alessandrini, P. Ferrant, L. Gentaz, C. Monroy, J.M. Rousset, Ecole Centrale de Nantes, Nantes, France, P.E. Guillerm, P. Perdon, Bassin d'essais des carènes, Val de Reuil, France, *SIMULATION OF UNSTEADY SHIP MANEUVERING ON CALM WATER AND IN WAVES USING FREE-SURFACE RANS SOLVER,* 27th Symposium on Naval Hydrodynamics Seoul, Korea, 5-10 October 2008

LE BASSIN VIRTUEL, DEUX EXEMPLES D'APPLICATIONS :
SIMULATION NUMERIQUE DE LA CAVITATION SUR UNE HELICE MARINE
SIMULATION NUMERIQUE POUR DES APPLICATIONS DE MANOEUVRABILITE
CONTRIBUTIONS AU PROJET EUROPEEN VIRTUE
Chantal Rigoux, Olivier Truttmann : *Simulation numérique de la cavitation sur une hélice marine*

Pierre-Emmanuel Guillerm, Aurélien Drouet, Erwan Jacquin : *Simulation numérique pour des applications de manoeuvrabilité,* Bassin d'Essais des Carènes, Chaussée du Vexin, 27100 Val de Reuil, France
ATMA 2008

VTT TECHNICAL RESEARCH CENTRE OF FINLAND VTT

Sipilä T., Siikonen T., Saisto I., Martio J., Reksoprodjo H., "*Cavitating Propeller Flows Predicted by RANS Solver with Structured Grid and Small Reynolds Number Turbulence Model Approach*", CAV2009: 7th International Symposium on Cavitation, Michigan, USA, August 16-22, 2009. (Abstract accepted)

ISTITUTO NAZIONALE DI STUDI ED ESPERIENZE DI ARCHITETTURA NAVALE INSEAN

Salvatore, F., Greco, L., Broglia, R., Di Mascio, A.:
"Development of a Hybrid BEM/RANS Scheme to Study Transient Cavitation on Propellers," Seventh International Conference on Hydrodynamics, ICHD 2006, Ischia, Italy, June 2006.

Salvatore, F., Testa, C., Ianniello, S., Pereira, F.:
"Theoretical Modelling of Unsteady Cavitation and Induced Noise," Proceedings of CAV 2006 Symposium, Wageningen, The Netherlands, September 2006.

Felli, M.,, Greco, L., Colombo, C., Salvatore, F., Di Felice, F., Soave, M.:
"Experimental and theoretical investigations of propeller-rudder interaction phenomena,"

26th ONR Symposium on Naval Hydrodynamics, Rome, Italy, September 2006

Streckwall, H., Salvatore, F.:
"Results from the Wageningen 2007 Workshop on Propeller Open Water Calculations Including Cavitation," RINA Marine CFD 2008 Conference, Southampton, U.K., March 2008.

Salvatore, F., Streckwall, H., Van Terwisga, T.:
"Propeller Cavitation Modelling by CFD - Results from the VIRTUE 2008 Rome Workshop," First International Symposium on Marine Propulsors, SMP'09, Trondheim, Norway, June 2009.

Salvatore, F., Testa, C., Greco, L.:
"Coupled HydrodynamicsHydroacoustics BEM Modelling of Marine Propellers Operating in a Wakefield," First International Symposium on Marine Propulsors, SMP'09, Trondheim, Norway, June 2009.

FRIENDSHIP-SYSTEMS GMBH FSYS

Abt, C.; Harries, S.; Wunderlich, S.; Zeitz, B.: *Flexible Tool Integration for Simulation-driven Design using XML, Generic and COM Interfaces*, 8th International Conference on Computer Applications and Information Technology in the Maritime Industries (COMPIT2009), Budapest, May 2009

Abt, C.; Harries, S.: *Tight and Loose Coupling CAD and CFD – Methods, Practical Aspects, Advantages*, RINA Marine CFD 2008, Southampton, March 2008

Duffy, A.; Harries, S.; Marzi, J.; Petz, Ch.; Wu, Z.: *VIRTUE: integrating CFD ship design*, 7th International Conference on Hydrodynamics, Ischia (ICHD 2006), October 2006

KONRAD-ZUSE-ZENTRUM FÜR INFORMATIONSTECHNIK BERLIN ZIB

C. Petz, T. Weinkauf, H. Streckwall, F. Salvatore B.R. Noack, H.-C. Hege: *"Vortex Structures at a Rotating Ship Propeller"*, Presented at the 24th Annual Gallery of Fluid Motion exhibit, held at the 59th Annual Meeting of the American Physical Society, Division of Fluid Dynamics, Tampa Bay, 2006. **(Joint publication with HSVA, INSEAN)**

A. Duffy, S. Harries, J. Marzi, C. Petz, Z. Wu: *"VIRTUE: Integrating CFD Ship Design"*, Proc. of 7th International Conference on Hydrodynamics, Ischia, 2006.
schia, 2006. **(Joint publication with Friendship, SU-CAD, HSVA)**

O. Rosanwo, C. Petz, S. Prohaska, I. Hotz, H.-C. Hege: *"Dual Streamline Seeding - Method and Implementation"*, ZIB Report ZR-08-49, Zuse Institute Berlin, 2008.

O. Rosanwo, C. Petz, S. Prohaska, I. Hotz, H.-C. Hege: *"Dual Streamline Seeding"*, Proceedings of the IEEE Pacific Visualization Symposium, 2009.

C. Petz, J. Kasten, S. Prohaska, H.-C. Hege: *"Hierarchical Vortex Regions in Swirling Flow"*, Proc. Eurographics/IEEE Symposium on Visualization (EuroVis09), 2009.

FLOWTECH INTERNATIONAL AB FLOWTECH

Björn Regnström, Leif Broberg, Michal Orych, Magnus Östberg, "*Verification and validation of the CHAPMAN incompressible flow solver*", 3nd Workshop on CFD Uncertainty Analysis, Lisbon, Oct. 2008.

Björn Regnström, Leif Broberg, Michal Orych, Magnus Östberg, "*An Uncertainty Exercise for Incompressible Flow*", 2nd Workshop on CFD Uncertainty Analysis, Lisbon, Oct. 2006.

Björn Regnström, "*Conformal mapping potential flow around a wingsection used as a test case for the inviscid part of rans solvers*", European Conference on Computational Fluid Dynamics ECCOMAS CFD 2006, P. Wesseling, E. Onate and J. Periaux (Eds) TU Delft, The Netherlands, 2006

HELSINKI UNIVERSITY OF TECHNOLOGY HUT

Sipilä T., Siikonen T., Saisto I., Martio J., Reksoprodjo H., "*Cavitating Propeller Flows Predicted by RANS Solver with Structured Grid and Small Reynolds Number Turbulence Model Approach*", CAV2009: 7th International Symposium on Cavitation, Michigan, USA, August 16-22, 2009.

CEC Web site references:

http://ec.europa.eu/research/transport/news/article_4294_en.html

http://ec.europa.eu/research/transport/news/article_2639_en.html

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Jochen Marzi