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EU projects contribute to continuing development of ship propulsion

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Abstract

Is funding from the European Commission's Framework Programme an effective investment? And how could you demonstrate the effectiveness? This paper aims to give an answer to those questions from the perspective of MARIN's involvement in several consecutive projects in the field of ship resistance and propulsion. Previous projects such as SMOOTH, MoVeIT, STREAMLINE, GRIP and SONIC have laid a solid foundation for MARIN's involvement in current projects such as MOTOR, LeanShips, HOLISHIP and NOVIMAR. An ongoing research line is recognised through these projects. This paper aims to show how research is brought forward and brought to the market through these EU projects. Suggestions are given into the requirements for future FP projects to continue the development in improving the efficiency of ships and shipping.

Keywords: model testing, numerical simulations, ship resistance, ship propulsion, CFD

Nomenclature

BEM	Boundary Element Method
CFD	Computational Fluid Dynamics
CNG	Compressed Natural Gas
CPP	Controllable Pitch Propeller
DWB	Depressurised Wave Basin
ESD	Energy Saving Device
EU	European Union
FP	Framework Programme
LNG	Liquefied Natural Gas
mwc	Meters water column
PSS	Pre-Swirl Stator
RANS	Reynolds Averaged Navier Stokes
SECA	Sulphur Emission Control Area
URN	Underwater Radiated Noise

1. Introduction

Through the years MARIN has been involved in a wide range of consecutive European research projects all contributing to the ongoing improvement of ship resistance and propulsion. Throughout the framework programmes of the European Commission, the focus of projects have evolved from fundamental research to projects focussing on the applications. The MARIN developments have to some extent followed the same path. Results of fundamental research in FP 6 and FP 7 are applied in a demonstrator project in Horizon 2020.

Ongoing research lines on ship resistance and propulsion lead to widely applied innovative solutions in Horizon 2020 projects. Application focussed projects in Horizon 2020 have picked many low and medium high hanging fruits. In order for future projects to pick the high hanging fruit, fundamental research should be called for in FP 9. In this paper examples of ongoing research lines throughout projects are given, showing how fundamental research results in market ready solutions.

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This paper will give an overview of the completed and ongoing EU projects and show how many of these projects are connected and inspire the follow-up project. The results of earlier projects are used in later projects and collected experience drives the direction of the research. In the last chapter our current view on the future is given. An overview of relevant research topics in EU projects for a future FP 9 is given.

2. The quest for energy saving in ship propulsion – Completed projects

This section gives a selection of the completed EU projects in which MARIN has played a role and shows the development of energy saving measures and underwater noise mitigation in ship propulsion. All these projects contribute to the MARIN long term research goal in the field of ship resistance and propulsion.

2.1. SMOOTH

FP 6 project SMOOTH made important first steps in air lubrication of ships with the aim to reduce the resistance of inland waterway vessels. Several principles of air lubrication have been studied such as air films, micro-bubbles and air cavities. Evaluation of the performance was done using model tests and scale effects have been studied numerically.

Model tests of the air bubbles and air film concepts showed promising results. Full scale tests on these concepts however did not reflect what was found on model scale. Numerical methods were used to study the underlying phenomena of air lubrication. After the early conclusions on air films and air bubbles, SMOOTH focussed on air cavities. Model tests and full scale tests of this concept were done in conjunction with the PELS2 project and showed that savings of up to 15% are feasible with this concept. Numerical methods were not yet used to optimise the design of the air cavities.

Modelling of the air cavity in numerical models is an important development of MARIN in the SMOOTH project. These developments are not only relevant for evaluating air lubrication concepts but also contribute to better modelling of cavitation on propellers. First experience with model testing air lubrication has provided insights into this sensitive phenomenon. Scale effects play a large role and need to be further explored to better design air lubrication for ships.

2.2. MoVeIT

FP 7 project MoVeIT set out to explore retrofitting solutions to increase the environmental and economic impact of the existing inland fleet. In order to achieve this skippers were involved to scout potential fuel saving solutions, this already early on showed that there is no one solution for the complete fleet. Design adoptions such as ESDs, stern tube optimisation and gondola's may have a large effect for some ships while the impact for other ships is limited. As a general conclusion one could say that evaluation per ship is required.

One of the main results of MoVeIT is the economy planner. The objective of the economy planner was to collect and display actual electronic chart information with up to date depth information. This assists the skipper to select the optimal track, maximum loading condition and optimal RPM for the voyage. Each ship taking part in the economy planner collects and shares live data on the river condition such as current speed and water depth. Combining this information of many ships provides an up to date map of the river condition. Ships who want to benefit also need to contribute to the system, in this way large coverage of data is ensured.

For MARIN the economy planner in MoVeIT was the first step in the CoVadem development. MARIN exploited the economy planner in projects following MoVeIT by expanding the number of ships thus increasing the accuracy and range of the system. CoVadem is still frequently used in current research projects to obtain relevant design data and by ship owners and operators in their daily operation.

2.3. STREAMLINE

FP 7 project STREAMLINES set out to achieve a step-change in ship efficiency through radically new propulsion concepts. In order to achieve this step-change numerical methods needed to be updated to better design and evaluation propulsion concepts. Partners subsequently proceeded to apply these numerical methods to various innovative propulsion concepts such as a large diameter propeller and bio mimetic propulsion as well as energy saving solutions such as a twisted rudder and flow improving devices.

Developments of numerical methods mainly focussed on the interaction between the hull and the propeller. In order to incorporate that into one simulation the rotating grid of the propeller needs to be coupled to the fixed grid of the hull. Also the coupling between Reynolds Averaged Navier Stokes (RANS) methods for the hull simulation and Boundary Element Methods (BEM) for the propeller simulation were developed. BEM methods are needed to cover the cavitation extent of the propeller. Figure 1 shows results of a propeller simulation using sliding interfaces between a fixed and a rotating grid for three different grid densities.

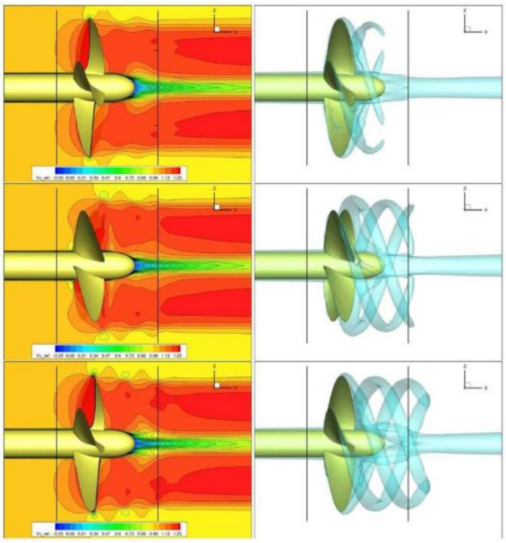

Figure 1. Propeller results using sliding interfaces (from top to bottom) Coarse, medium, fine grid

MARIN has benefited from the numerical developments updating the ReFRESCO capabilities with respect to coupling of rotating grids with fixed grids and grid adaption techniques. Also significant developments have been achieved in the RANS-BEM coupling where PROCAL and ReFRESCO were coupled and applied to propellers. The STREAMLINE developments proved to be an important step in the applications for future EU projects.

2.4. GRIP

FP 7 project GRIP focused on Energy Saving Devices for both new built and retrofit. The project delivered an early assessment tool, with this tool designers can make a quick evaluation of the potential benefit of each type of ESD. Design methods both for the structural and hydrodynamic aspects of an ESD were developed. Using this, partners HSVA, VICUS and MARIN entered into a design competition. These partners all designed an ESD for a bulk carrier, Figure 2shows the resulting ESDs. Based on economic and fuel saving criteria the best ESD was installed and demonstrated on board of Uljanik built MV Valvoline.

The design competition resulted for this specific ship in the Pre-Swirl Stator (PSS) having the best performance improvement. Partner Uljanik built the ESD and installed it on their new built vessel MV Valvoline. MARIN performed speed trials before and after installation of the ESD. The trials were performed in next to perfect environmental conditions. A performance improvement of 6.8% was measured with an uncertainty band of 1% according to Hasselaar & Xing-Kaeding (2017).

Figure 2. GRIP ESD designs: MARIN BSD (left), HSVA Pre-Swirl Stator (middle) and VICUS Rudder Bulb (right)

For MARIN GRIP posed an opportunity to further develop modelling of the hull – propeller interaction in ReFRESCO. Both frozen rotor and sliding interface simulations have been performed in GRIP. For propeller – hull interaction with an ESD so close in front of the propeller, it seemed that frozen rotor simulations we insufficiently accurate. Despite the faster calculation time, the frozen rotor approach was not capable of accurately covering the dynamics.

With this knowledge, the focus of the development for CFD simulations of ESDs would be on finding an approach with the benefit of simulation speed from the frozen rotor approach and the accuracy of the sliding interface.

2.5. SONIC

FP 7 project SONIC focused on understanding and mitigating Underwater Radiated Noise (URN). With the increase in shipping activity, the underwater noise levels have increased. Main sources of URN are propeller cavitation followed by machinery. SONIC partners focused on improving the numerical modelling as well as model testing of cavitation induced noise. Following these studies guidelines for studying URN were developed in collaboration with sister project AQUO.

As a test case University of Newcastle made available their test vessel Princess Royal. Full scale noise measurement trials were done with this vessel as well as numerical simulations and model tests. To evaluate the URN of a ship several steps need to be taken (see Figure 3). As a first step the cavitation extend for the given speed and loading condition needs to be determined, this can either be done using model tests of numerical simulations. Once the cavitation extent is known the noise produced by the cavitation is determined using various empirical models. Based on the water and seabed characteristics the noise propagation is then determined. The URN can then be plotted on a map either for one specific ship at one specific time instance of for all shipping in a certain area.

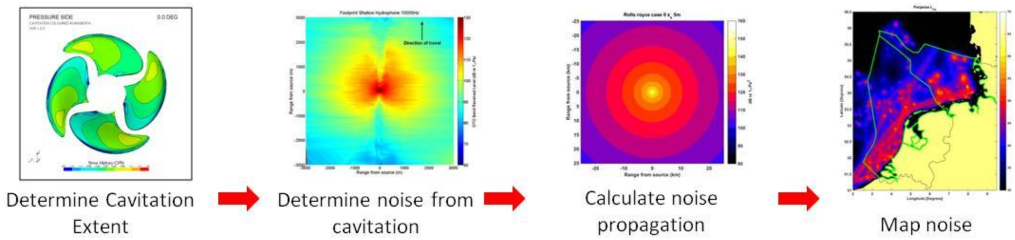

Figure 3. URN mapping steps

For MARIN SONIC contributed to further improving the Depressurised Wave Basing (DWB) for URN measurements. The drive train of the carriage was improved so that it would make less noise and a study of the background noise was done. Using the new setup tests were done to validate numerical methods including a comparison with the full scale measurements. For future projects further research into modelling the cavitation using CFD is proposed as well as studying noise mitigation measures.

3. Integrating CFD in hull-propeller optimisation – Current projects

At present, MARIN is involved in four Horizon 2020 projects in the transport sector. These project all contribute to the long term development for ship resistance and propulsion and follow up on earlier EU projects. The fruits that were harvested in the earlier projects, are currently used in the ongoing projects where CFD starts to become an integrated tool in hull-propeller optimisation.

3.1. MOTOR

Horizon 2020 project MOTOR focuses on creating automatic multi-objective optimisation technologies for fluid energy machines such as a ship propellers, water pumps, aircraft engines and screw machines. Using different techniques automated shape deformation of the base design is done followed by simulations of the design variations.

Developments in MOTOR for ship propellers have resulted in a multi-fidelity optimisation method. Next to the faster but less accurate calculation tools currently used on a day-to-day basis, MOTOR allows for CFD calculations to be included directly in the design phase, challenging the current design methodology. In order to fully automate the CFD step it was necessary to adjust the shape of the propeller blade geometry as well as to deform the grid automatically. This results in a significant reduction in processing time as not every design variant needs to be separately meshed and the CFD calculations of the design variations will continue from where the previous solution has left off. As the differences from design to design are relatively small, this results in much faster convergence of the solution. Figure 4 shows the optimisation process where the geometry and grid for the base propeller is made by a designer. Each variant consists of a modified base propeller where the geometry and the grid are both deformed using MARIN’s geometry tools, based on the input of the optimizer using the low-fidelity design code that quickly scans the entire design space.

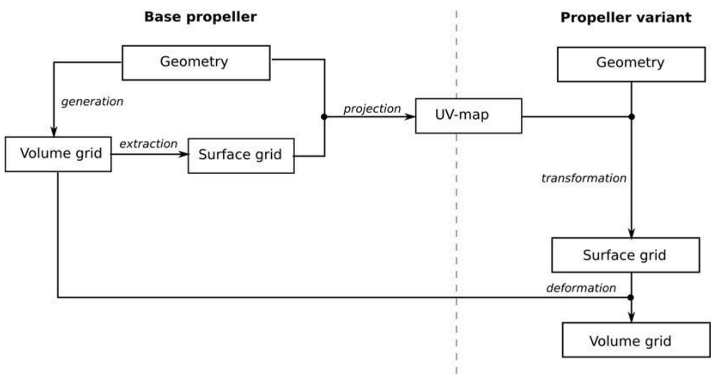

Figure 4. Propeller optimisation scheme MOTOR

For MARIN the MOTOR project contributes greatly to the long term developments. Automating the design process increases the accuracy as more design variants can be calculated at equal costs. During the MOTOR project this is done for the propeller open water condition; a next step would be to optimise the propeller in the behind-ship condition. This however will significantly increase the computation time as the ship hull is also considered.

Developments on hierarchical B-splines and adjoint optimisation by other MOTOR partners may be of interest for MARIN developments to automate the hull optimisation procedure. Developments and first applications of this automated hull design are potentially going to be done in future EU projects.

3.2. LeanShips

Horizon 2020 project LeanShips focuses on putting innovations into practice to come to less polluting new and existing vessels. Innovative solutions include applications of LNG and CNG, methanol as alternative fuel, SECA refit strategies, large diameter propeller design, energy efficiency systems for passengers ships and ESDs for ships with Controllable Pitch Propellers (CPP). The application of all innovations are demonstrated, each demonstrator is an individually operating work package in the project.

MARIN is involved in the demonstrators on the large diameter propeller and the ESD design for ships with CPP. In the earlier STREAMLINE project studies have been done to the possibilities to increase the diameter of the propeller. STREAMLINE chose for solutions where the propeller was either placed aft of the stern or would protrude the keel line. The LeanShips solution is to significantly reduce the tip clearance of the propeller allowing for an increase in diameter. An accurate numerical modelling of the propeller – hull interaction is required to design this propeller. Also the dynamic pressure on the blades is important as the reduced clearance may lead to an increase in vibrations due to pressure fluctuations. To further increase the efficiency gain, MARIN also studied the effect of an asymmetric aft ship (see Figure 5). This design exercise showed it is possible to design an asymmetric aft ship with RANS-BEM coupling.

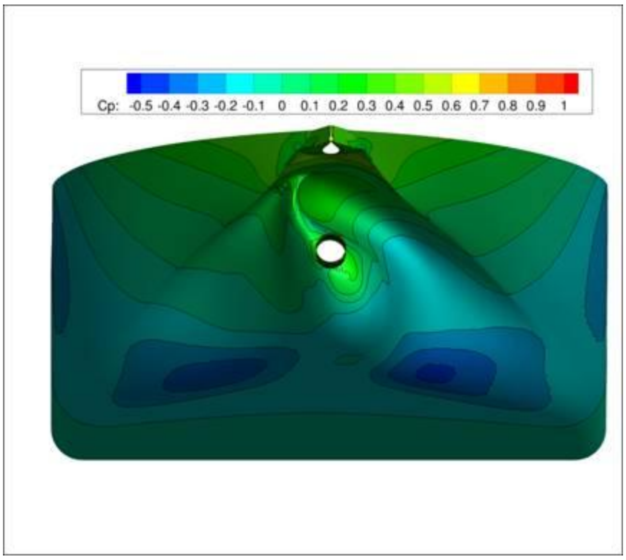

Figure 5. Pressure distribution for asymmetric aft ship

Modelling of the propeller – hull interaction is also important for the ESD for CPP demonstrator. In the GRIP project an ESD was designed for a ship with a fixed pitch propeller. Designing an ESD for a CPP adds complexity in that sense that with changing pitch of the propeller, the optimal inflow angle changes. Design procedures developed in GRIP are applied to the ESD where a range of pitch angles of the propeller are evaluated. The optimal design is chosen based on the operational profile of the ship and the pitch settings at which the ship most frequently sails. A PSS was designed by MARIN, the propeller optimisation procedure developed in MOTOR was adapted to also be applied to stator fins. At the time of writing of this paper, the design is in progress.

Work in LeanShips greatly contributed to the MARIN developments. Model tests will be done on the large diameter propeller in the Depressurised Wave Basin (DWB). In order to do free sailing propulsion tests in that facility, a new system of winches needed to be developed which could accelerate and decelerate the model. First application of this system will be on the LeanShips model tests.

For both the design of the large diameter propeller and ESD in LeanShips a thorough energy loss analysis was done as described by Schuiling and van Terwisga (2016). This approach studies the energy losses of the propeller to identify where an efficiency improvement can be reached.

3.3. HOLISHIP

Horizon 2020 project HOLISHIP aims at holistic ship design, integrating design tools of various applications and fidelity. Two integration platforms will be developed, one design platform and one demonstration platform.

The design platform has the specific aim to assist the ship designer and facilitating a holistic design. This platform will include optimisers and the layout and use is tailored for the design process. In parallel to that a demonstration platform is developed, the aim of this platform is to virtually demonstrate ship designs and innovative solutions.

MARIN leads the work on the virtual demonstrator platform which is developed by partner DLR. DLR has developed a similar tool for the aviation industry, CPACS/RCE, which will be the starting point for the developments and will be made maritime into HOLISPEC/RCE. The main challenge in this is to make HOLISPEC/RCE communicate over the internet. As HOLISPEC/RCE works with relatively high fidelity tools, the owners of these tools are reluctant to share the tool itself. RCE will call the tools from the servers of the owners of the tools if the server is opened up for the user.

In parallel to the HOLISPEC/RCE developments, MARIN is further developing their simulation framework to facilitate coupled simulations. The focus of these developments is primarily on coupling of hydrodynamic modelling extended with simple models of machinery for propulsion and manoeuvring. HOLISHIP developments may contribute to extending the capabilities to other fields. MARIN will furthermore provide hydrodynamic calculation tools to both the design and demonstration framework extending the application range of the tools.

3.4. NOVIMAR

Horizon 2020 project NOVIMAR aims at demonstrating an innovative transport concept: vessel trains. In this concept one leader vessel will automatically be followed by other ships like ducklings following their mother. In order to achieve this control software will be developed for the following ships to follow the leader vessel. Optimisation of the distance between the vessels is done by studying the ship – ship interaction using model tests and numerical simulations. Demonstration of the concept will be done for inland vessels.

At the time of writing of this paper the project has just started, the requirements for the vessel trains are being drafted. Partner DST has started model testing the ship – ship interaction which will be numerically evaluated by MARIN.

MARIN is involved in NOVIMAR on different levels. The aforementioned control software for the vessels is extended with a module which provides instant information on the river conditions. This module is a further development of the CoVadem developments which originated partly from the MoveIT project. CoVadem uses ships and their onboard sensors as measurement devices to provide the latest information on the river condition. Ships will in turn get the information of the complete river back allowing them to more accurately plan their voyage and optimise their fuel consumption. In NOVIMAR the application will be extended to more vessels to increase the accuracy of the prediction and extend the coverage.

To optimise the train composition, the interaction between the vessels needs to be evaluated. Other than for trucks, ships will most probably not benefit from sailing close behind each other due to the propeller jet. To optimise the composition of the train, the ship – ship interaction will be studied. MARIN will perform RANS simulations using in house CFD code ReFRESCO. Using the DST model tests, the interaction component will be further validated resulting in a further improvement of ReFRESCO.

4. Focus on the future

In this chapter future developments building on past and current projects will be discussed. There is a focus on numerical methods as well as model testing with the objective to make ships more efficient and safer.

4.1. Numerical developments

EU funded projects tend to focus more on application and demonstration of solutions such as the large diameter propeller, ESDs or resistance reduction measures. For MARIN it is important to keep up with the numerical developments to be able to model and simulate the innovative new solutions. At this time we see that developments in air lubrication, roughness modelling (with and without aerated flow), cavitation hindrance and further automation in design optimisation are required. In this section these are further elaborated.

4.1.1. Air lubrication

Reduction of the fuel consumption of ships focus on many aspects and one of those is to reduce the frictional resistance of the hull. Air lubrication has the potential to reduce the friction resistance exerted on the flat bottom of the hull. Various methods for air lubrication exist such as air bubbles, layers, air cavities and air chambers. Despite claims of large achieved savings due to air lubrication, reliable validation is still lacking.

Accurate modelling of the two phase flow is required to simulate air lubrication reliably. There is a strong connection with the requirements for cavitation developments described later. Model tests on air lubrication are influenced by scale effects. Reliable full scale tests are needed as well as reliable numerical models to demonstrate the effect in performance by air lubrication. Numerical methods are furthermore needed to optimise the air lubrication design.

Future EU funded research projects should have a focus not only on the design of air lubrication techniques but also on methods to validate the design. Fundamental development and validation of the models are required to better design and predict the benefits of air lubrication systems.

4.1.2. Roughness modelling

Throughout decades hull roughness has been of interest to ship owners and operators. Both the effect of fouling and damages to the paint can contribute significantly to the fuel consumption. Manufacturers of anti-fouling coatings develop methods to keep the hull free from fouling as well as to keep the roughness of the clean coating as low as possible.

The effect of roughness (reduction) on the overall performance can be evaluated globally by using an equivalent roughness model. This model however takes an average over the complete hull, which most probably is not always the case. In order to better predict the effect of roughness, modelling of this roughness is required, including the roughness due to fouling. This requires two basic steps: First the fouling needs to be quantified and secondly this fouling then needs to be adequately modelled

One other promising but yet largely unexplored terrain is that of fouling drag reduction by a combination of coatings and aerated flow. This idea is provoked by a stunning example of Nature on the use of air lubrication by Emperor Penguins (Davenport et al., 2011). It is hypothesized by these authors that penguins capture air in their plumage which is released during the ascent of their dive to reduce the friction drag by air lubrication. The idea to use air lubrication in combination with fouling and/or coating structures is somewhat related to the previous subject of air lubrication, but air flow rates in this case could presumably be much smaller when these structures are used to capture air.

Horizon 2020 calls have already called for methods to reduce the frictional resistance. In order to better support and evaluate innovations to reduce the frictional resistance, developments to better model roughness numerically need to be done. These numerical methods will be used to optimise the hull and propeller roughness and anti-fouling paints resulting in a potential fuel saving of several per cent.

4.1.3. Cavitation

Modelling of cavitation has similar issues as modelling of air lubrication as they are both forms of a multiphase flow consisting of water, vapour and air. Perhaps the most important difference is in the gas pressure which is very low for cavitation (0.2 meters water column (mwc) at 20°C) while for air lubrication the pressure is approximately equal to the draft of the ship (mwc) added to the atmospheric pressure (10 mwc). Accurate modelling of cavitation is important to reduce inboard noise and vibrations as well as underwater radiated noise (URN).

The prediction of URN is becoming important as we start to understand more about the effect of noise on underwater mammals. With shipping density increasing and ships sailing to area's with vulnerable underwater fauna, understanding and reducing URN is a bigger issue than ever. Cavitation is the primary source of URN from ships. The challenge in this is that a propeller design is always a trade-off between cavitation and efficiency. Allowing light cavitation on the propeller will provide higher propeller efficiencies, hence lower CO_2 emissions. Thus reducing the URN by not allowing cavitation will result in increased emissions.

In order to tackle this delicate balance continuous improvement of numerical design methods for propellers is required. Modelling of cavitation is critical in this respect to provide designers with the tools to optimise the propeller for URN and CO_2 emissions.

4.1.4. Automated optimisation

We foresee that typically some 5-15% power reduction can still be gained on most ships by integrating hull and propeller optimization, thereby minimizing for energy losses at acceptable cavitation hindrance. These figures were confirmed by the results from the GRIP project (7% net power saving through a PreSwirlStator) and the LEANSHIPS WP8 and WP9 projects.(unknown yet and 11.5 % net power saving respectively). Next steps in automated optimization address dealing with multi objectives (e.g. multiple loads, speeds and sea states), improving the reliability of the predictions, reducing the computational time and improving the convergence of the design process. It is expected that "Simulation based design" will become more and more important once computational speed, multi fidelity methods and convergence behaviour are under control. The Holiship project will explore the possibilities for improvement with this latter approach.

In the MOTOR project a big step was made in automated optimisation of the ship propeller. After completion of MOTOR a propeller in open water condition can be optimised automatically for efficiency and cavitation behaviour. Two steps logically follow from this, first the propeller optimisation for behind condition and secondly the hull form optimisation.

For optimisation of the propeller in behind condition a heavier calculation is needed as also the flow around the hull needs to be calculated. These are now time (and money) consuming calculations. In LeanShips both for the ESD and the large diameter propeller, the hull – ESD – propeller interaction is evaluated. Part of this work focuses on possible combinations between RANS and BEM models(example of multi-fidelity approach) to reduce the calculation time. Validation of this work needs to be done in future EU projects as well as applications to designs of more efficient propulsion.

Optimisation of the complete hull will require a different approach than for the propeller optimisation alone. Partners in the MOTOR project have looked into b-spline and adjoint optimisation. For hull forms this may be a feasible approach but this is yet to be explored. The challenge here is to describe the hull form in mathematical formulations that can be manipulated to change the shape hence providing a new hull form.

Once both steps have been completed, optimisation of hull and propeller can be done completely automated. Using a base hull and propeller as a starting point and given boundaries of the design, more efficient designs can be explored including asymmetric aft ship designs. The objective of this is to reduce the effort and costs for the design while at the same time increasing the quality of the end result.

4.2. Model testing

Despite the steadily growing accuracy and completeness of numerical models, experimental model testing is expected to remain important. There are two or perhaps three reasons for this.

The first reason is that we are continuously developing the requirements of computations, both for predictions as well as for optimization work. This means that we develop an interest in smaller flow structures and higher frequencies. Examples are e.g. the design constraints imposed on broadband propeller induced pressure pulses (typically between 4th and 7th blade passing frequency) and Underwater Radiated Noise. We do not yet have validated numerical models which are yet to be developed and validated nor do we have well proven experimental procedures. The SONIC project has provided us with insight in the approaches of various facilities to measure the URN. A next step is to get a better control over the accuracy of the measurements and the predictions of the far field radiated noise.

A second reason is that there are phenomena which we do not even fully understand yet, such as the physics of air lubrication by air bubbles and layers. A physical understanding is a necessary condition for the development of reliable numerical models.

And the third reason is that it is likely that there will remain a drive to validate certain aspects of the design, even though there is some confidence in the computations. These final validation tests are then meant to validate the design or certain aspects of the design, for example on the risk of ventilation of the propeller and it's effect on sustained propeller thrust.

We have come to the conclusion that the water quality in terms of dissolved gas content, free gas content (bubble spectra) and surface tension plays a role in all of the examples mentioned above. For some cases we have concluded that the effect of water quality is not negligible (pressure pulses and air lubrication), for others, we have yet to explore the sensitivities (URN and ventilation).

5. Conclusions & Recommendations

Based on the developments in past and current EU projects in which MARIN was involved and our view on the future described in this paper, the following conclusions and recommendations are drawn:

- The European Union has made an essential contribution to an on going research line within MARIN where each following project benefitted from earlier projects.
- Future EU funded projects are essential to continue this research line, without which at best the development pace will be significantly slower or developments may not happen at all.
- Future EU funded projects should include the focus on:
    - Numerical modelling of air lubrication to support the design of such systems in reducing the resistance of the ship.
    - Further improving numerical design tools for propellers focussing on cavitation hindrance.
    - Research on the consequences of ventilating (large diameter) propellers for safety, fuel efficiency and engine wear and the consequence for design optimisation.
    - Numerical modelling of hull roughness and fouling in combination with an aerated flow to study the effects of coating on the performance.
    - Developing automated propeller and hull optimisation tools to reduce design costs and time and increase the quality of ship design.
    - Further improvements in validated methods to both experimental and numerical determination of the URN of ships should focus on water quality and standardisation of procedures.

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