NextProp

EDA CAT B project No B-1466-GEM1-GP

Project officer: Mr. Juan Jesús Díaz Hernández/Mr. Rolf Michels

Start/End date: 14th December 2020/13th December 2023

NextProp Executive Summary

Executive Summary

The project NextProp – "Next Generation of Propellers" – has been run as an Ad Hoc Research & Technology project at EDA under Contract No B-1466-GEM1-GP, from December 2020 to December 2023. The contributing member states have been Norway (lead nation), Italy, and Poland.

Noise is an important aspect in a maritime military context, both in terms of self-noise and radiated noise, with the propeller being the primary source. The use of composite materials is regarded as a possible direction for the next generation of propellers, as there is potential for reduced corrosion and cavitation damage, reduced lifetime maintenance cost, improved material damping properties, and lower acoustic and non-acoustic signature. However, the number of possible design parameters increase significantly, and modelling tools are crucial to be able to obtain the optimal combination of these advantages. Based on this, the goal of the project was to develop and validate hydroelastic tools for the modelling of next generation low noise (non-cavitating) naval propellers, moving from metals to composites. Validation would be a comparison with high-quality experiments.

The project has been based on two main work packages, considering a foil case and a propeller case, respectively. A foil can serve as a simplified, non-rotating model of a propeller blade, and both experimental measurements and numerical simulations are simpler to perform. In both cases, experiments and simulations have been performed on test objects of the same shape, but made from different materials, specifically three different foils and two different propellers. A wide range of numerical methods have been applied to the modelling tasks, performing structural simulations, flow simulations, fluid-structure interaction, and vibro- and hydroacoustic simulations.

Generally, there has been good correspondence between the simulations and the experiments. Extensive experimental results have been obtained, for standard quantities like forces, moments, and noise, but also displacements, strain from integrated fibre-optic sensors, and velocity field data. For some quantities, the difference between experimental results from different facilities has been more significant than between simulation results. This underlines the importance of estimating experimental uncertainty, as well as taking care to model a particular experiment in detail to obtain an accurate validation.

The effect of introducing anisotropic composite materials was clearly observed, as two thin uni-directional layers in one of the flexible foils changed the displacements, strains, and eigenfrequencies. Noise measurements under non-cavitating conditions are strongly affected by background noise from the facilities, but different characteristics for the rigid and flexible foils were observed, with more subtle differences between the two flexible foils. Some propeller noise above the background noise was also measured, but material-dependent differences were much smaller in this case.

To sum up the main objective of the project, the ability to model test objects made of composite material has been demonstrated, fluid-structure interaction simulations have been validated for flexible foils made of isotropic and anisotropic composite materials and for a flexible isotropic propeller, and hydroacoustic simulations have been demonstrated for the foil case and for the rigid propeller. This constitutes all the building blocks to fulfil the objective, and the modelling tools are suitable for investigation of the primary mechanisms for sound generation/propagation from naval propellers.

Introduction

The project NextProp – "Next Generation of Propellers" – has been run as an Ad Hoc Research & Technology project at EDA under Contract No B-1466-GEM1-GP. Noise from propellers has been the topic of EDA project ideas for many years, with different nations taking part, and the plans resurfaced in 2016/2017 with an additional focus on flexible propeller blades and composite materials. During 2020, the contributing member states were confirmed as Norway (lead nation), Italy, and Poland, and the project started in December 2020, with a duration of three years. The final project meeting was held in December 2023.

The goal of the project has been to develop and validate hydroelastic tools for the modelling of next generation low noise naval propellers, moving from metals to composites. The tools include numerical simulation software and experimental techniques for the study of the interaction between rigid or flexible propeller blades and the surrounding water, and the resulting noise generation and propagation. A simplified test case of a foil has also been studied in the project.

Background

Naval propeller design involves a wide range of aspects, including efficiency, weight, durability, cost, and signature. The emerging field of composite propellers has the potential to improve several of these aspects, in particular weight and signature. An important factor in the development process is experimental propeller testing, using a scale model or full-size prototype. The importance of numerical modelling has increased to reduce the cost and time needed for experimental testing. A model of the acoustic field generated by the propeller motion is a complex task, which typically involves: the flow field around the hull and rudders, complete with turbulent boundary layers and possibly separation; fluid-structure interaction at the propeller blades, causing deformations in the structure and structural vibrations that generate sound; and the interaction between hull wake and propeller. This defines a multi-physics and multi-scale problem that must be simplified, or at least separated into different components, in a computational model.

The wide range of material properties and design parameters related to composite materials also points to modelling capabilities as crucial in the propeller design process, and in the understanding of the behaviour of proposed composite material designs. Moreover, as scale models of a composite propeller will not necessarily correspond to the full-size properties, the need for accurate numerical models is even more important.

New materials can open new possibilities for integrating sensors inside the structure of the propeller for structural health monitoring, starting from the production of the propeller and throughout its lifetime. Such sensors will be essential in a condition-based maintenance program, which will reduce the cost and time for repair and overhaul, as well as increase the overall operability of the naval platform.

Advanced modelling tools and the experimental and empirical data obtained from laboratory tests will give European defence entities a potent tool for the design of next generation propellers and for maintenance and analysis of operational issues. The tools are necessary for acoustic signature prediction from the design phase on, but also for investigating manoeuvring effects on a given propeller, as well as indicating the current "health" and the operational time left before maintenance is needed. The tools are therefore relevant both in peacetime and in crisis/war situations.

Project objectives

The main objective of the project was to develop and establish the required hydroelastic software and design tools for the modelling of next generation low noise naval propellers, with the integration of advanced models for new and modern materials, such as composite materials, in the numerical tools to aid the design of composite propellers. The work would include computational fluid dynamics (CFD), finite element analysis (FEA), the fluid-structure interaction (FSI), and theoretical models. The models would be validated through controlled prototype experiments on a generic foil and a typical propeller.

In addition to the main objective, a number of secondary goals were set:

- Improve the current understanding of the primary mechanisms for sound generation/propagation from naval propellers, through the development and validation of modelling tools. This is relevant in an operational setting.
- Improve the competence on composite propellers, how to produce such propellers, and the benefits and new challenges in design and development.
- Study integration of sensors as a first step towards a condition-based maintenance program. Learn how these sensors interact with the structure and its surroundings. The new materials and sensors systems will also provide new experience and knowledge in experimental testing.
- Improve test methods and the experimental set-up for modern propellers.

Participating organisations

The organisations participating in NextProp are listed in Table 1.

Table 1: Participating organisations in NextProp.

Country	Organisation	Location	Role
Norway	Forsvarets forskningsinstutt (FFI) (Norwegian Defence Research Establishment)	Kjeller, Norway	Lead contractor
Norway	FiReCo	Fredrikstad, Norway	Co-contractor
Norway	Light Structures (LS)	Oslo, Norway	Co-contractor
Norway	SINTEF Ocean (SO)	Trondheim, Norway	Co-contractor
Italy	Consiglio Nationale delle Ricerche – Instituto di Ingegneria del Mare (CNR-INM) (Institute of Marine Engineering)	Rome, Italy	Co-contractor
Italy	Centro per gli Studi di Tecnica Navale (CETENA)	Genova, Italy	Co-contractor
Italy	Politecnico di Milano (POLIMI)	Milan, Italy	Co-contractor
Poland	Akademia Marynarki Wojennej (Polish Naval Academy (PNA))	Gdynia, Poland	Co-contractor

Poland	Centrum Techniki Okrętowej (CTO) (Maritime Advanced Research Centre)	Gdańsk, Poland	Sub-contractor
Poland	LQS Energy People (LQS)	Zamość, Poland	Sub-contractor

Main results

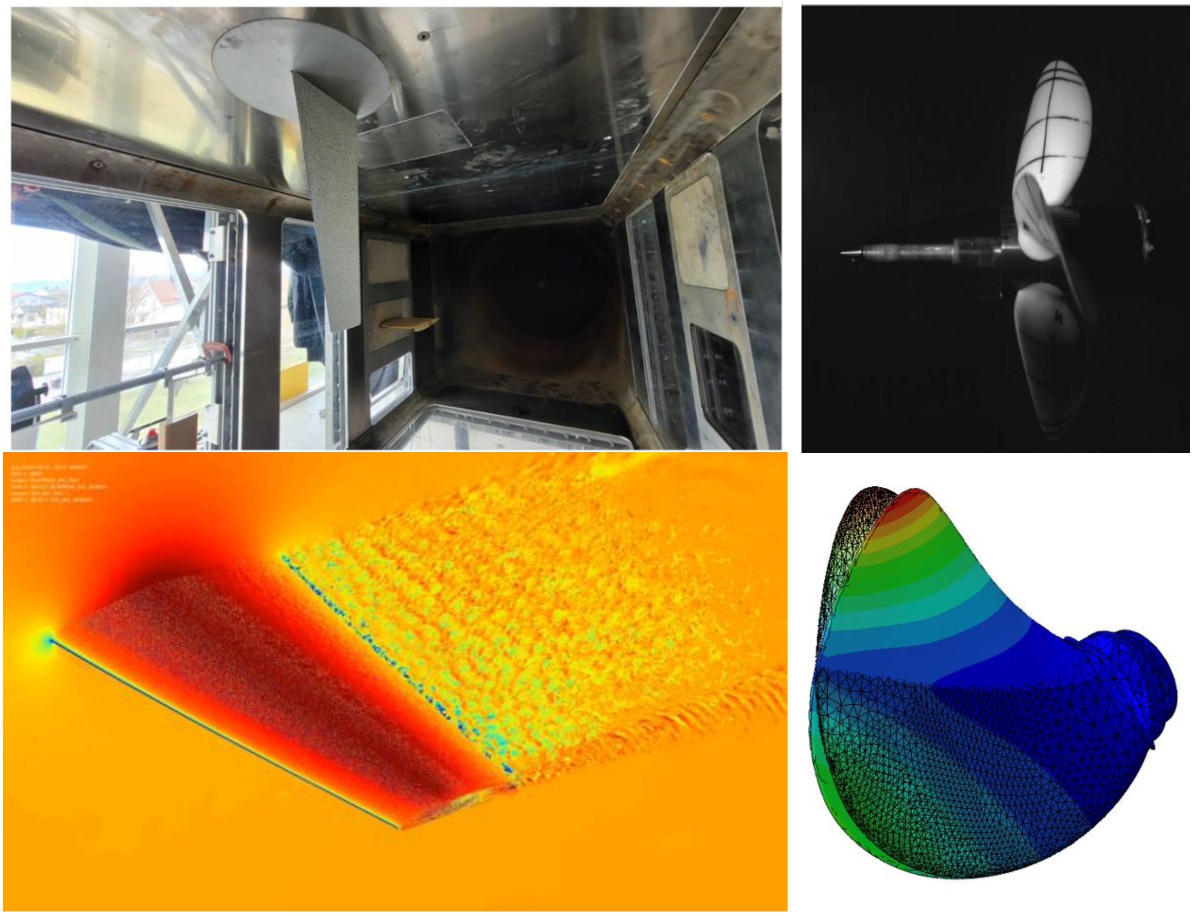

Figure 1: A foil in the cavitation tunnel at SO (top left), the flexible propeller in the cavitation tunnel at CTO (top right), velocity magnitude from a foil simulation at FFI (bottom left), and an eigenmode of the flexible propeller, calculated by POLIMI (bottom right).

A simulation framework for prediction of propagated noise from propellers made by composite material must be validated at all levels, involving structural simulations, flow simulation, their combination to fluid-structure interaction (FSI) simulations, and hydroacoustic noise propagation simulations. All these aspects have been covered in the project, to varying degrees of detail:

- Structural simulations have been performed with various commercial and in-house codes, and the structural properties of the test objects have been well represented, showing that the procedures for obtaining material properties and the simulation programs are well suited for the purpose. The most important factor for structural simulation codes in this project is the ability to model thin objects with sharp edges and composite materials with thin internal layers well enough to give reliable results.
- Different methods for flow simulation have been found suitable for different requirements, such as calculation of forces and moments for design purposes, and detailed turbulent flow field simulations for calculating the sources of propagated noise.

- In an FSI setting, additional requirements for the structural and flow solvers are the ease and efficiency of the data flow between the solvers and the accuracy of the interpolation between the different solver meshes. Different combinations of programs have been used, as well as different strategies for the fluid-structure coupling. This step is not as readily available in terms of software, and the combination of specific structural and flow solvers may require ad hoc solutions.
- Hydroacoustic simulations using the Ffowcs Williams-Hawkings acoustic analogy with a permeable surface using data from scale-resolving CFD simulations have shown promising results.
- The simulation tools have been validated through comparison with experiments, and additionally by applying a wide range of simulation methods to the same problems. A feature of the project has been to perform experiments with the same test objects at different facilities, to explore the variability of the results across facilities. For some quantities, the difference in results between experimental facilities is larger than the differences between simulation results, and it is generally more useful to compare trends in the data rather than absolute values. This is essential knowledge that can also be applied to other validation situations.

To sum up the main objective of the project, the ability to model test objects made of composite material has been demonstrated, fluid-structure interaction simulations have been validated for flexible foils made of isotropic and anisotropic composite materials and for a flexible isotropic propeller, and hydroacoustic simulations have been demonstrated for the foil case and for the rigid propeller. This constitutes all the building blocks to fulfil the objective, and the modelling tools are suitable for investigation of the primary mechanisms for sound generation/propagation from naval propellers.

The fabrication of composite propellers is a specialised task, which was not included in this project. However, valuable experience was gained through challenges with material properties and production methods that arose in the fabrication of composite foils and flexible propeller blades, and the applied strategies to mitigate them.

The three foils were instrumented with integrated Fibre Bragg grating (FBG) based strain sensors that provided high-quality time-dependent data at different locations on the foils. This is an example of structural health monitoring, which is essential in developing digital twins.

The experimental campaigns faced demanding requirements because of the high quality of data needed for simulation validation purposes. In addition to the standard measurements of forces and moments, flow field data and structural displacements were obtained, which in some cases required new instrumentation and post-processing routines. The integrated strain sensors could be operated remotely but required careful handling of the foils. Noise measurements under non-cavitating conditions are also non-standard and provided a test of the background noise of the facilities.

The effect of introducing anisotropic composite materials was clearly observed for the foil case, where the two thin uni-directional layers changed the displacements, strains, and eigenfrequencies. Differences in forces and moments were small compared with changes in flow conditions. The flexible propeller did exhibit different characteristics than the rigid one, even though some of the changes can be attributed to geometric differences.

Noise measurements captured different characteristics for the rigid and flexible foils, with more subtle differences between the two flexible foils. Some propeller noise above the background noise was measured, but material-dependent differences were much smaller in this case.