Propulsion design

From propeller analysis to integrated propeller-aft body design

In the year 2030, the French Naval Architect Monique Lorand was tasked to optimise a preliminary ship design in only 24 hours – a task deemed impossible some 15 years before. The reason that she showed no signs of stress while doing this was that she had great confidence in a toolbox of software with state-of-the-art CRS tools and optimisation techniques. She and her staff had learned how to use these tools within CRS projects and dedicated workshops. In fact, the resulting high quality, integrated design was considered one of the main reasons for the success of her shipyard.

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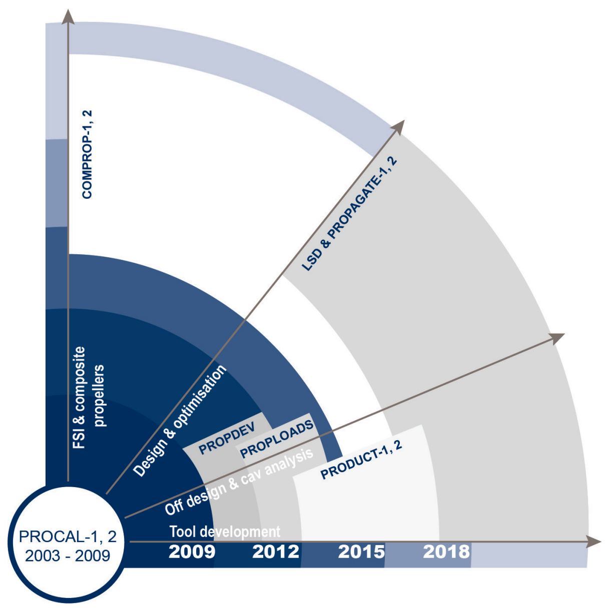
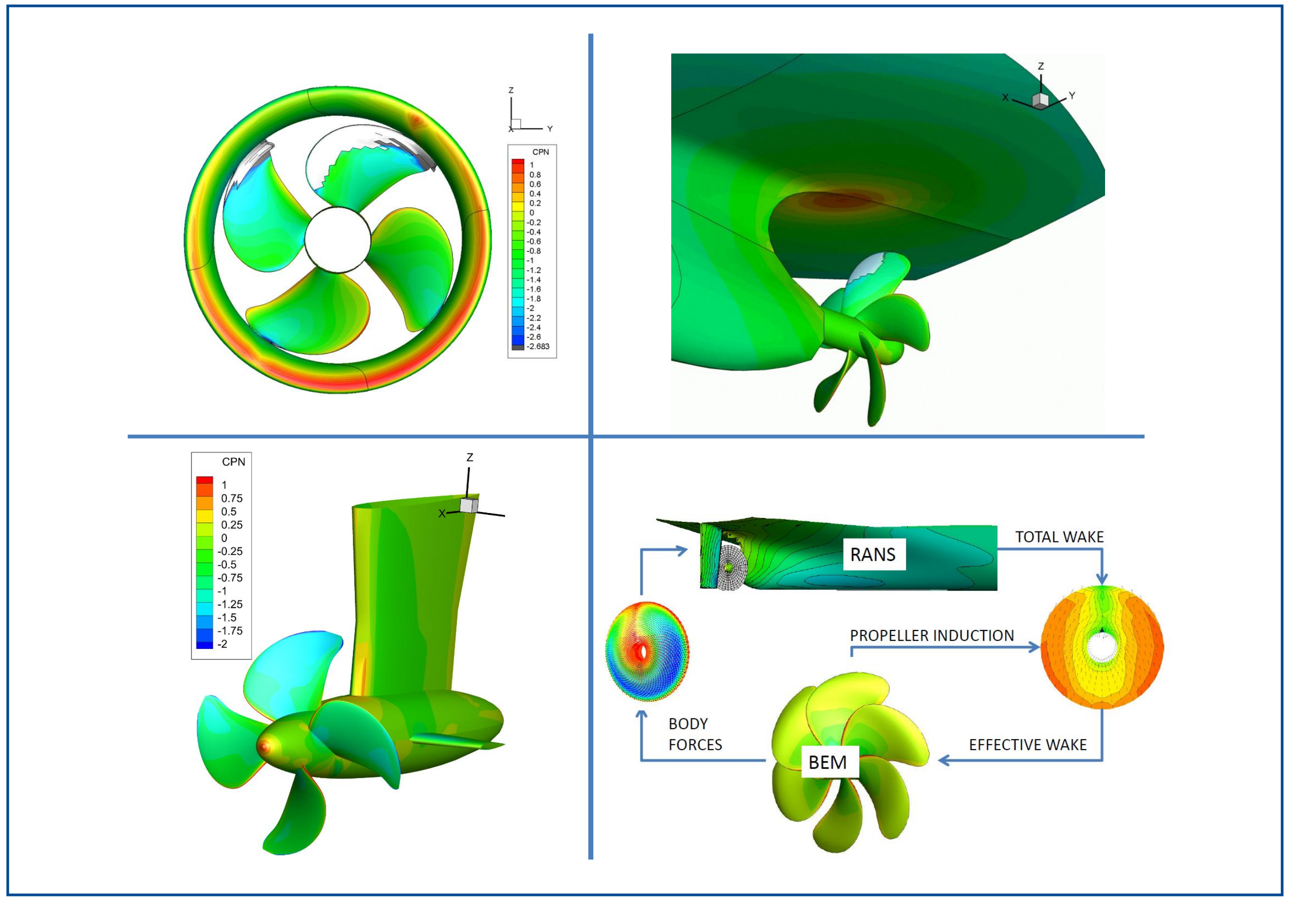
CRS propeller design developments in a nutshell The development of Monique's toolbox had started long before 2030, on a cold and dark December afternoon in 2002 in Wageningen, where some 15 men of different origin had gathered around a projector and screen, discussing a proposed sequel to the PIF working group. The PIF project officially ended that day and yielded three different ways to provide inflow fields for propeller analysis. This discussion appeared to be the perfect breeding ground for a propeller analysis tool, designated PROCAL, for which a three-year project was approved the next day at the AGM.

The PROCAL group started working on a baseline panel code, including a first version of a cavitation model. After three years, further developments and validation appeared necessary (PROCAL-2), resulting in a mature tool for the analysis of open propellers. In 2009, the PROCAL development continued as a side track in PROPDEV and PROPLOADS, realising,



Development of propulsor related tools and applications

amongst other achievements, the coupling of PROCAL to RANS methods. Further developments addressed ducted propellers (PRODUCT-1,2) and the application of



Examples of PROCAL based applications

PROCAL for automated propeller design (PROPAGATE-1,2), as well as for Energy Saving Device designs. The use of PROCAL for flexible composite propellers is another important development, necessitating a coupling of the PROCAL code with a FEM code.

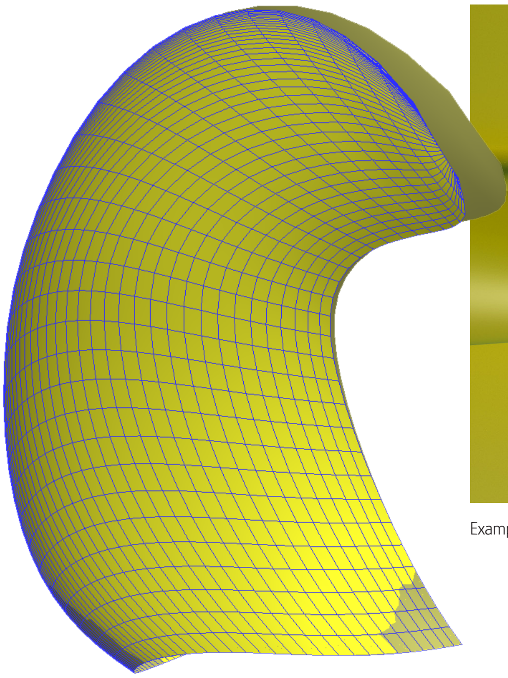
As a result, CRS developments would enable Monique Lorand to produce an optimised design in 24 hours which required only 8 hours of her own time!

No carpenter without a hammer: PROCAL In 2003, MARIN was given the task of developing the BEM code PROCAL. Although work started from scratch, use could be made of multiple BEM codes for propellers that were available at MARIN, as well as knowledge of a BEM developed in cooperation with the University of Lisbon (IST). Important requirements for the PROCAL code were determined to be robustness, low CPU time and easy maintenance. This resulted in a code that could predict unsteady sheet cavitation on propellers operating in a ship wake with the resulting hull-pressure fluctuations. Simultaneously, the graphical user interface PROVISE was developed by which the user can easily import propeller geometries, generate surface panels, perform computations and analyse results. Hull-pressure fluctuations can be computed by the acoustic boundary element method EXCALIBUR, developed at MARIN.

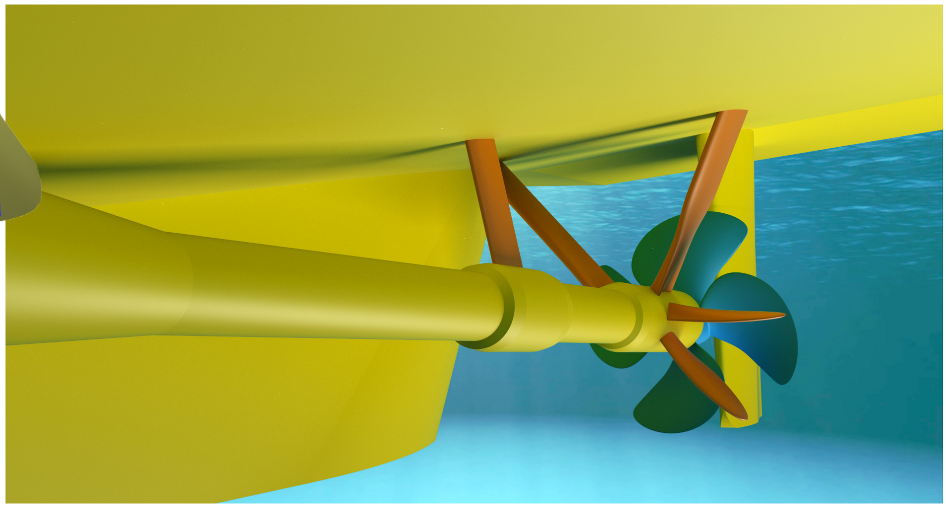
An important input to PROCAL is the effective wake field of the ship in which the propeller operates. At the beginning of the century, this wake field used to be obtained by a model-scale measured wake field that is made effective and scaled to full-scale Reynolds numbers with the tools developed in the PIF group for example. However, with RANS methods becoming mature in predicting the ship wake field, a coupling procedure between RANS and BEM was developed in the PROPDEV and PROPLOADS groups. The coupling was made using PROCAL's body forces in RANS and the effective wake field was obtained by subtracting PROCAL's propeller-induced velocities from the RANS total velocities. The approach was then successfully used in 2013 to analyse the shaft loads from a VLCC in a manoeuvre for which both full RANS and full-scale data were available. For a cruise vessel, the influence of the shaft alignment on the wake field and propeller cavitation behaviour was studied in detail, making extensive use of RANS and PROCAL computations.

The structural response of the propeller to the hydrodynamic loading was analysed through the coupling of PROCAL and FEM packages. Additionally, the structural response of the hull due to propeller-induced hull-pressure fluctuations was studied, using the coupling between EXCALIBUR and FEM.

Ducted propulsors At the end of PROCAL 2 in 2009, there was a strong desire to extend PROCAL's capabilities to ducted propellers. It was estimated that more than 50% of the propellers designed by manufacturers in CRS are to operate



Example of a PROCAL-TRIDENT analysis of a flexible composite propeller blade: deformed blade with bent tip (in foreground with blue grid) versus rigid blade (in background)



Example of the result of an optimisation exercise with a PreSwirl Stator for a twin screw ship

inside ducts. After three more years, thanks to MARIN's close cooperation with IST, it became clear how ducted propellers should be modelled in a boundary element method. It appeared to be very important to iteratively align the wake of the propeller blades with the flow. The reduced velocity in the boundary layer on the duct had to be taken into account when aligning the tip vortex. PROCAL was then extensively validated for ducted propellers. A very interesting validation study was using full-scale observations of cavitation on the propeller of a VLCC with the largest ducted propeller ever built. These observations were made by CRS way back in the seventies.

Optimising propellers CRS propeller tools were put to good use from 2016 onwards within the PROPAGATE group from 2016 onwards, in which an automated propeller design workflow was created. This consisted of a geometry generator, an optimisation routine, a workflow manager and goal & constraint functions. These functions quantified blade stress, radiated noise, propeller-induced hull-pressure fluctuations and cavitation erosion risks - all quantities that are in direct competition with fuel efficiency. Towards the end of the project, workflows emerged that can go toe-to-toe with classical design methods.

Flexible propulsors Monique had been using composite materials in her Pre-Swirl Stator design for some time and used to work in close cooperation with a propeller manufacturer on composite propeller designs. Tools to enable them to do this had been developed a decade before within COMPROP. First, a tool for the analysis of flexible propellers in open water was made. PROCAL and the FEM package TRIDENT, developed by LR-MARTEC, were coupled in an iterative way, including geometrically nonlinear effects. COMPROP-2 then extended this tool by enabling the analysis for in-behind ship conditions, applying the methodology developed at TU Delft using several FEA packages.

Where are we heading? In 2019, Monique was still taking classes at university, unaware of the propeller toolbox and guidelines that were being developed in CRS for hull-propeller-ESD integration. Tools and guidelines that lead to the design of a ship that is ideally suited for its mission. Whilst the vision is there, and early demonstrations of propeller and ESD optimisation have been proven, the tuning of tools, optimisation strategies and skills for using it, is expected to remain a challenge for CRS for another 50 years!