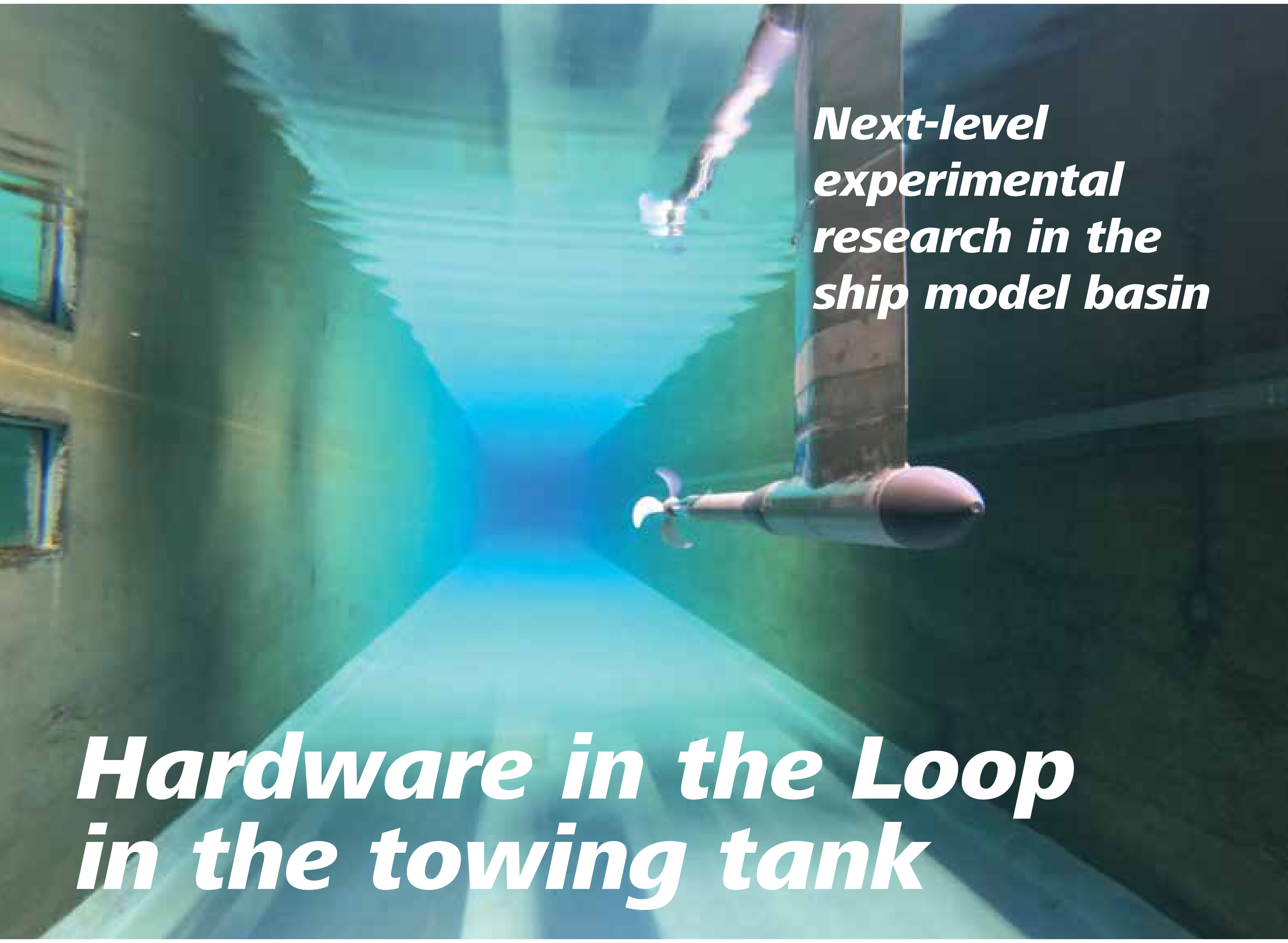



*The HIL open water setup as it moves through the towing tank*

# Hardware in the Loop in the towing tank

## Next-level experimental research in the ship model basin

Limits to installed engine power, different fuel compositions and new technologies such as fuel cells are all being considered to abate maritime emissions. These solutions vary greatly in terms of impact on ship design and supply chains. Yet, they have one thing in common: their potentially profound effect on the ship's capability to deal with the dynamic loads caused by wind, waves, and manoeuvres.[1]

Past encounters with rough seas have shown that the dynamic performance of propulsion systems is a crucial aspect for naval ship operation. As a recent example, the Danish frigate KDM Iver Huitfeldt found itself in a violent storm during an Atlantic Ocean passage in early 2020, having to make its way through 15 metre waves. Had the frigate not been able to maintain propulsive thrust and heading in this hostile environment, the damage sustained would have been far worse than just a few leaking hatches and a torn off sonar dome. Incidents such as with the KDM Iver Huitfeldt show that without a well-designed propulsion system, a naval ship may become more of a danger to its own crew than to its adversaries. In other words: the robustness of the well-known diesel engine and naval gas turbine have been proven over many decades, but will the naval power and propulsion system of the future be just as robust in realistic environmental and operational conditions?

How will 'alternative fuel'-engines, fuel cells, energy storage devices and hybrid combinations of these and other promising components behave in waves and during demanding manoeuvres? How can we ensure that the control and automation systems result in excellent propulsive capabilities, while preventing unexpected and undesired behaviour in case of component failures or degradation? These questions all relate to the inherent risk and uncertainty that new technologies bring. According to the authors this should not be seen as a show stopper for implementing new technologies, but rather as a reminder to carry out different types of system testing, both at component and at system level as will be shown below.

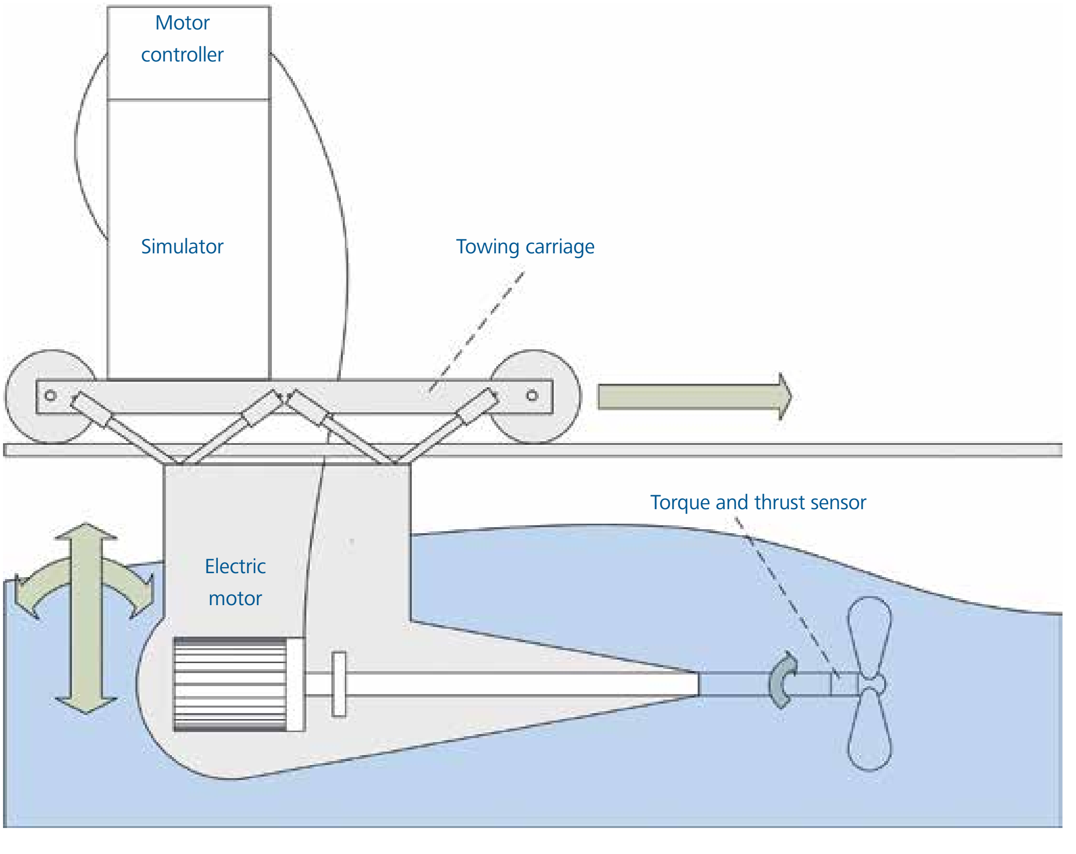
## Future-proof experiments

Noting the uncertainty regarding future ship propulsion systems as well as the importance of these systems for the sustainability, safety and operational performance of naval ships, the department of Maritime and Transport Technology of Delft University of Technology (TU Delft) has developed a new technique to accurately predict the performance of ship propulsion systems in realistic dynamic conditions. By introducing Hardware in the Loop (HIL) functionality into an open water test setup, the interaction between waves, propellers and machinery can be emulated at model scale whilst ensuring correctly scaled dynamic behaviour.

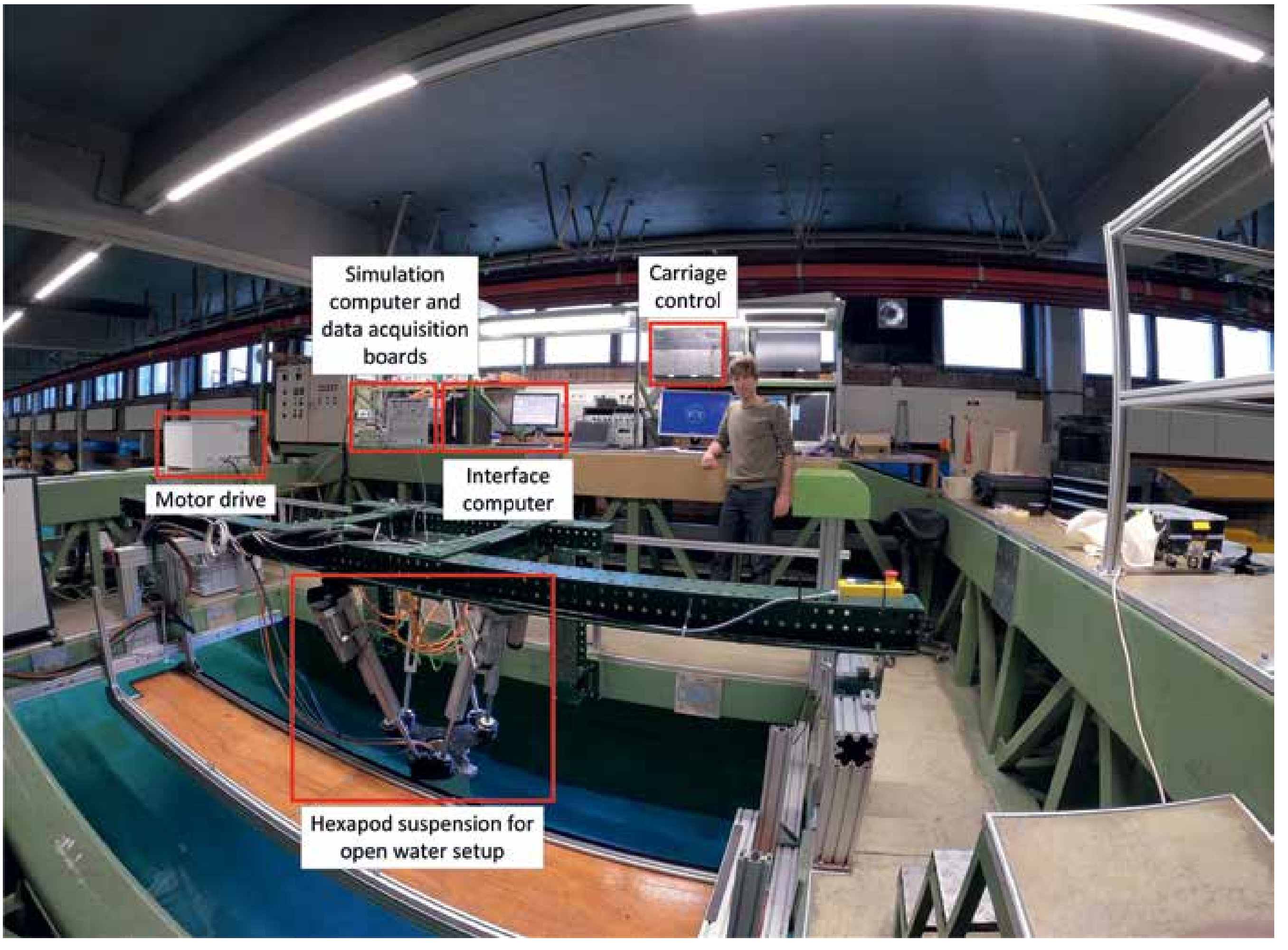
An open water test setup is a specialised tool to measure the static performance of scale model propellers in open water. The setup comprises an electric motor, a propeller and a sensor to measure propeller torque and thrust. HIL experiments, on the other hand, combine simulated and hardware components in a single real-time experiment, and are already common in the automotive and aerospace industries. In the HIL open water test developed by TU Delft, engine room machinery (ranging from traditional diesel driven systems to complex hybrid systems that only exist on the drawing board at the moment) is simulated on a dedicated simulation computer, while the propeller and its environment are physically present; see the schematic drawing of such a setup on this page. On the simulation side, specialised processor boards were used, while a state-of-the-art open water setup was designed and manufactured by MARIN.

‘HIL open water tests allow to study the performance of a wide range of propulsion configurations in realistic conditions’

By combining machinery simulations with complex hydrodynamics around the propeller, HIL open water tests allow to study the performance of a wide range of propulsion configurations in realistic conditions. These conditions range from regular wave fields to highly complex phenomena which are only partly understood, such as propeller ventilation events (where the propeller partly comes out of the water), vessel acceleration capability, effect of manoeuvring on the propulsion system and effect of increased ship resistance on the driving machinery. As such, questions related to the safety, performance and environmental friendliness of future propulsion systems can be answered on a scientific level.




*Schematic drawing of the HIL open water test, demonstrated by TU Delft*




*Simulation and interface computers, motor drives and signal amplifiers required for the HIL open water tests, mounted on a towing tank carriage at TU Delft*

To avoid the detrimental scale effects that are inherent in model scale experiments, several new features were developed and implemented. Without going into the scientific details, the authors have ensured that the observed dynamic behaviour on model scale is representative of the to-be-expected full scale behaviour. One of the innovative features is the so-called 'virtual flywheel' which is a piece of software that allows the experimenter to digitally adjust the polar moment of inertia of the drivetrain to its correct value. This is an important feature because drivetrain inertia is one of the main driving factors for the dynamic behaviour of the propulsion system.

'HIL can deliver a considerable contribution to the energy transition of the Royal Netherlands Navy'

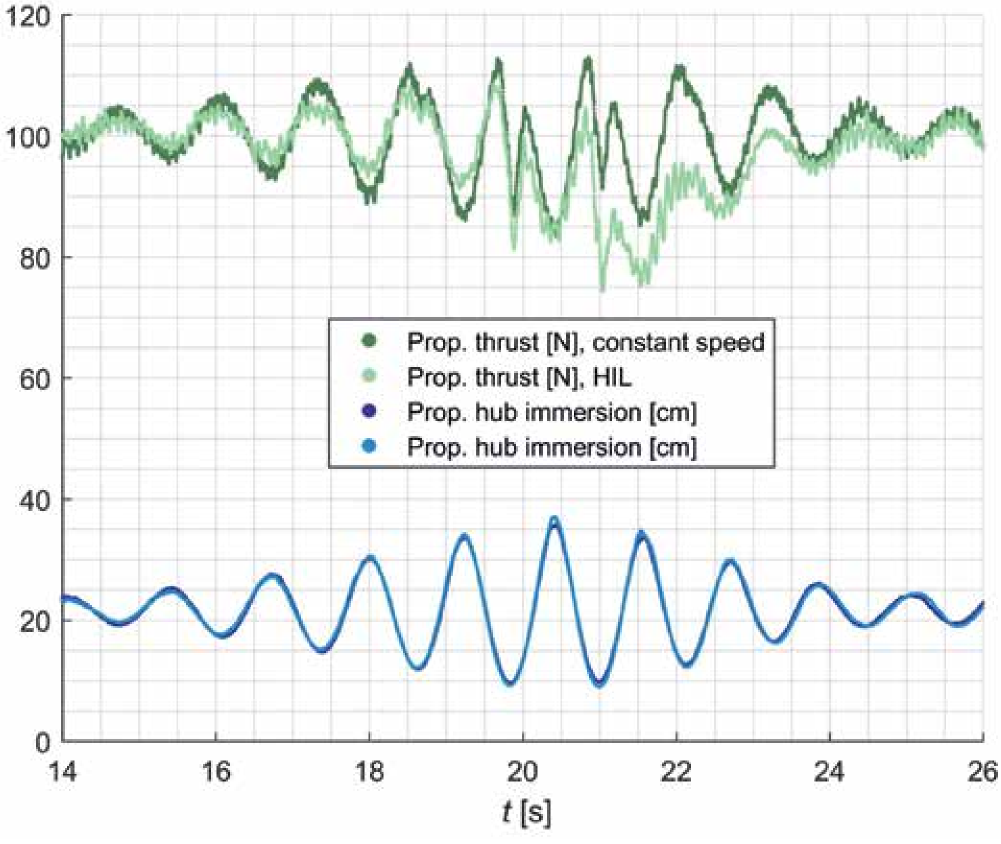
## First results

To produce a proof of concept, first experiments were conducted with a simulated traditional diesel-mechanical propulsion system and a propeller provided by MARIN. From these experiments, it was concluded that HIL open water experiments can indeed accurately emulate the interaction between engine, propeller and waves.

As a second, more advanced experiment aiming to demonstrate the added value of HIL, open water experiments were conducted with a ventilating propeller. In these experiments, the propeller was brought close to the surface and moved through different types of wave fields, causing the blades to pierce the surface and draw air in wave troughs. Measurements from two of these experiments are shown in the graph on the next page. As can be seen, the resulting interaction between rapidly changing propeller load and the propulsion system has a considerable effect on propeller thrust. Such interactions have a large, yet underexposed impact on ship manoeuvrability and seakeeping capabilities, as well as on machinery load and wear.

## Future (naval) application

With this, a wide range of new possibilities to investigate the complex, dynamic interaction between load and drive becomes available. For example, HIL open water tests allow to study the performance of any type of (naval) propulsion system in realistic dynamic environments. This




*Propeller thrust measured while the propeller moved through a wave train, drawing air in the deepest wave troughs. Both HIL experiments and traditional, constant speed experiments were conducted in these conditions. As can be seen, the interaction between the (simulated) diesel-mechanical propulsion system and the ventilating propeller results in a complex, dynamic breakdown of propeller thrust, which cannot be reproduced by traditional open water experiments. This complex interaction will be demonstrated in more detail in the doctoral dissertation by Lode Huijgens*

links up with the ambitions the Royal Netherlands Navy has expressed to decrease its environmental footprint in general and of the foreseen generation of navy support vessels in particular. In the latter case, it might be that there exists tension between ambitions and budget, but when costs are driven by risk and uncertainty regarding component TRL levels, the described setup can support de-risking of integrated hybrid plants of the future, especially when the uncertainty is related to the response to dynamic loads induced by the naval operating environment.

Besides described de-risking activities, the open water HIL setup can also support the development of innovative ship propulsion control systems, aiming at a balanced optimisation of acoustic signature (propeller cavitation), fuel consumption and emissions and manoeuvring capability, again in a realistic naval operating environment. Further scientific advances to increase understanding of dynamic system performance are made possible as well, especially when considering application of the setup within a depressurised towing tank (cavitation and ventilation) or in combination with laser-driven flow visualisation techniques such as Particle Image Velocimetry.

## Conclusion

In summary, two important naval applications are envisioned for the open water HIL setup. First, dynamic open water experiments can accelerate the developments and uptake of new, carbon neutral technologies for ship propulsion. As such, HIL can deliver a considerable contribution to the energy transition of the Royal Netherlands Navy.

Second, the development of advanced ship control and automation systems that aim at a balanced optimisation of acoustic signature (propeller cavitation), fuel consumption and emissions and manoeuvring capability can benefit from the proposed HIL approach.
With this new ‘tool’, the Royal Netherlands Navy has access to a worldwide unique capability which can be a valuable asset for the development of innovative yet robust and safe sustainable naval ship propulsion systems in the years to come. Potential naval stakeholders are welcomed to pick up the ball and to get in touch with the authors.

## Acknowledgements

As a closing note the authors would like to extend their thanks to Jan de Boer and his team of specialists at MARIN, who managed to deliver a worldclass piece of scientific equipment despite all complex requirements. For the experiments conducted at TU Delft, the efforts of Cornel Thill, Peter Poot and the other team members of the towing tank were invaluable.

**Ir. L.J.G. (Lode) Huijgens promoveert op 4 februari 2021 aan de TU Delft.**
**Dr. ir. A. (Arthur) Vrijdag is recent gestart met AVR Maritime consultancy and training.**

**Noot**

1 Dit is een aangepaste versie van het gelijknamige artikel dat is gepubliceerd in het novembernummer 2020 van SWZ Maritime.