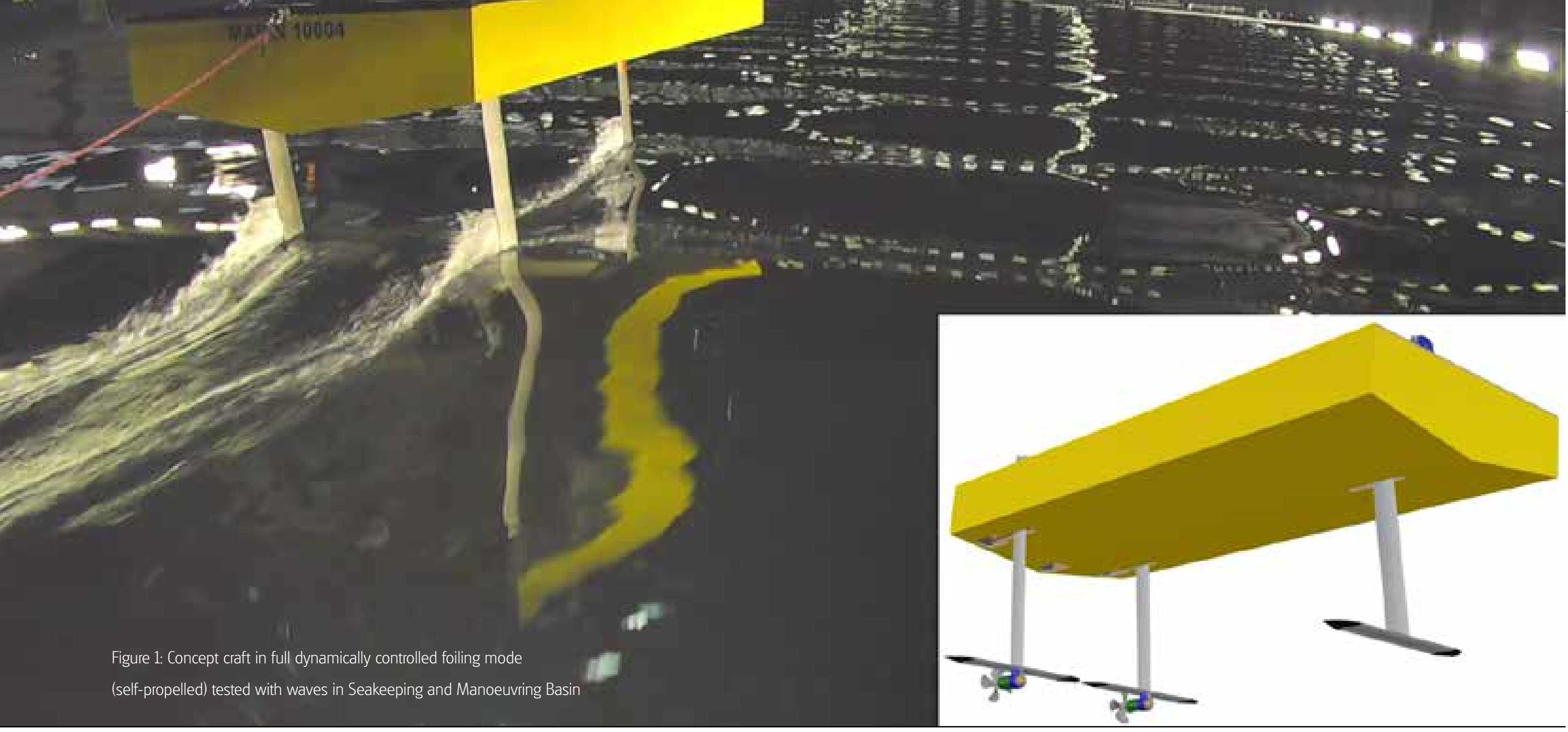

Figure 1: Concept craft in full dynamically controlled foiling mode (self-propelled) tested with waves in Seakeeping and Manoeuvring Basin

Foiling future and the Wageningen Φ-series JIP proposal

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Renewed interest in the use of foiling triggers new research efforts The first concept of a foiling boat was developed way back in the early 1900s on Lake Maggiore in Italy but the real industrial developments started in the 50s, and peaked in the 80s. Despite the obvious advantages in terms of improved seakeeping and resistance reduction at high speed, new development has stalled and the current fleet is slowly fading away.

However, there has been a resurgence in interest in using foiling for passenger transport, naval applications or leisure and top sport activities (such as the America's Cup or the Ocean Race). This new interest comes from better developed and mature technology when it comes to composite materials, light weight structures and improved ride controls. The latter being important for safety, efficiency, ride comfort and health. More advanced structural and hydro-dynamic simulation capabilities have also helped design advanced solutions.

From a long-term perspective, MARIN's main research objective is to develop new concepts for foiling vessels (possibly combined with a foil integrated electric propulsion system), advanced controls and deforming lifting foils. Within the next two years, we aim to provide a complete design methodology that facilitates early design decisions concerning the foils (and controls) for future foiling crafts. Furthermore, simulation strategies will be developed both for optimisation of the control system but also for crew training.

Recent test campaigns in unsteady conditions In 2018, a fully foiling, self-propelled craft was tested in MARIN's Seakeeping and Manoeuvring Basin.

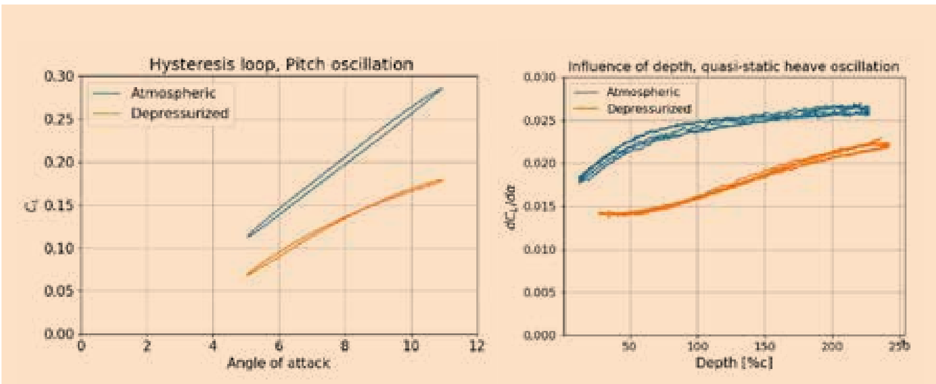

Figure 4: Example of lift coefficient sensitivity to unsteady angle of attack variation during pitch oscillation (left) or sensitivity to depth variation (right) during heave oscillation

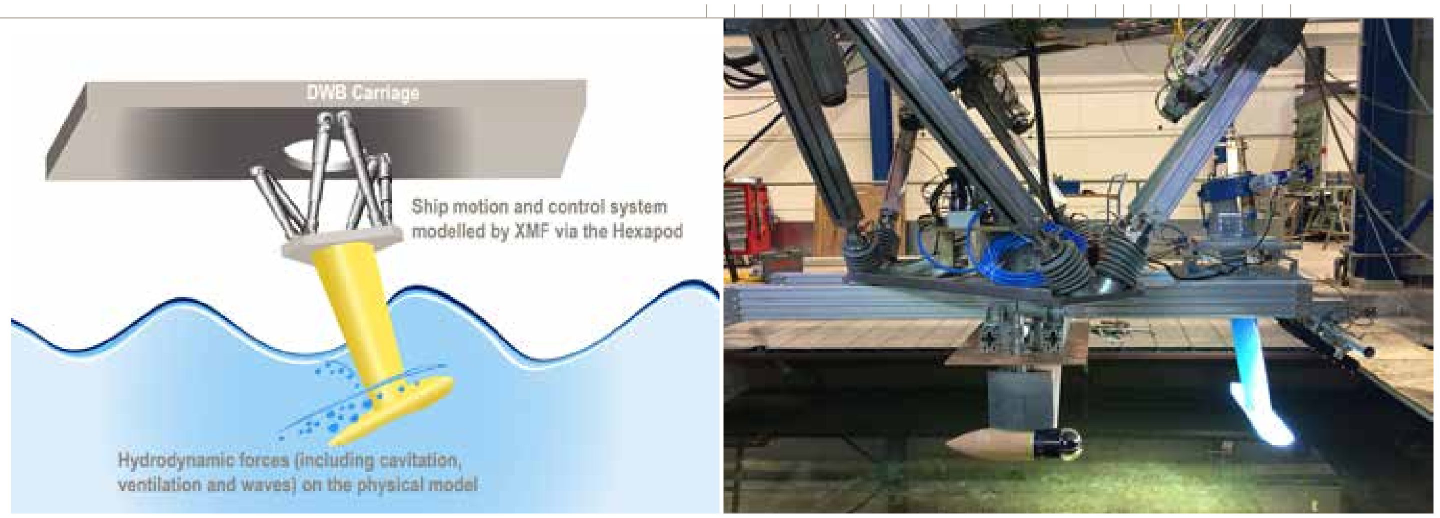

Figure 2: Model test set-up with hexapod and hydrofoil (left) and set-up as tested in Depressurised Wave Basin (right)

In Figure 1 an overview of the setup and model sailing in waves is presented. The test campaign was aimed at highlighting the feasibility of foiling solutions for heavier cargoes and to gain an understanding of the implications of the control system choices. The project also highlighted the importance of a more focused study to better understand the foil dynamics in unsteady conditions such as a foil operating in a seaway with the occurrence of cavitation; where current calculations tools have limitations but they are still very relevant from a safety point of view.

In 2019 a new test campaign was carried out in our Depressurised Wave Basin with an isolated hydrofoil to determine the lifting characteristic in unsteady conditions, both in cavitating and non-cavitating conditions. The setup (Figure 2) involved a hexapod system connected below the basin carriage. Forced motions of pitch and heave at different amplitudes and frequencies were applied to the hydrofoil advancing at constant speed; and similar measurements were performed with the (fixed) hydrofoil advancing in regular waves. Forces developed by the hydrofoil were measured together with the wave height and applied motions, and synchronised video recordings were used to correlate the data (Figure 3).

Preliminary analysis of the results provided insight about the dynamic variation of the lift in cavitating and non-cavitating conditions (Figure 4). In general, a point of attention is certainly the assessment of this variation when operating in a fully foiling mode: a sudden uncontrolled loss of lift due to dynamic stall and/or cavitation/ ventilation is a risk with a big impact on safety and comfort, but also one that affects efficiency.

Future research: Φ-series JIP proposal The research programmes have emphasised the need for detailed knowledge about foil characteristics and their effect on the safe, comfortable and efficient operation of foiling craft at sea in unsteady conditions. Furthermore, better understanding of foil dynamics will contribute to the design of better ride control systems. A Joint Industry Project is proposed to provide insight into the performance and dynamic control in unsteady conditions by the development of a systematic foil series, named Φ-series. This series will be based on both common and contemporary, efficient section profiles and tested to determine the performance limits during different phases (take-off, sailing and landing), both in calm water and in waves, including the effects of cavitation and ventilation. The hydrostructural behaviour, especially when composite materials are involved, could be investigated as well to provide a broad collection of data.

The series will contain a number of foils available from literature but also novel designs developed with the JIP participants and fulfilling their actual needs, which have been obtained with modern design methods. The benefit for the users is that each design in this series results in a practical and contemporary foil design (geometry and performance data are output) and the characteristics in steady and unsteady conditions will also be available. In this way the time and costs needed to study ships equipped with foils are expected to reduce, as risks can be assessed at a very early stage.

Databases, lifting theory, boundary element and Reynolds-averaged Navier-Stokes (RANS) CFD methods will be used in the preparations to establish the steady perfor-mance and evaluate scale effects. The unsteady part of the performance will be established in our Depressurised Wave Basin. Long-crested regular and irregular waves will be produced for different wave directions (Figure 2) using a hexapod to mimic the ship motions.

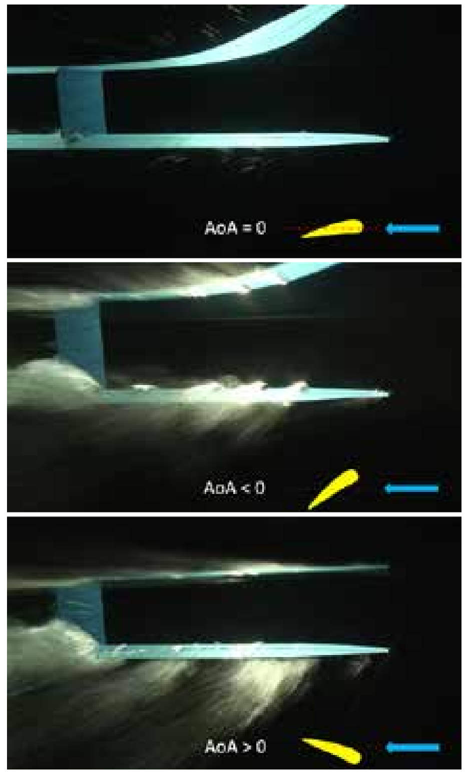

Figure 3: Cavitation observations on hydrofoil oscillating in pitch with cavitation

FOIL Φ-SERIES