Experimental tests of propeller performance under air-lubrication conditions for a catamaran demi-hull

Kristian F. Sagmo[1]; Lucas Yiew[1]; Kourosh Koushan[1]; Luca Savio[1]

[1]SINTEF Ocean, Trondheim, Norway

Ehsan Esmailian, Kumera Marine.

INTRODUCTION

A set of experiments were conducted at SINTEF Ocean's cavitation tunnel investigating the effects of a passive air-lubrication system on propeller performance for a catamaran demi-hull. The air-lubrication system itself is passive, consisting of a series of holes in the hull connected to an air chamber open to atmosphere and utilizing an interceptor directly upstream of the air-vents to draw air at sufficient vessel speed. The full-scale version of the vessel operates as a high-speed passenger vessel on the Norwegian coast, and sea-trials along with model tests documenting the passive air-lubrication system has previously been presented [1]. Questions remained however with regards to the impact of the air on propeller performance, in particular propeller efficiency and pressure pulsations. This abstract describes in brief the experimental setup and initial results from the set of experiments, carried out in the fall of 2023 and 2024.

EXPERIMENTAL SETUP AND PROCEDURE

The model demi-hull was scaled 1:4.5, and further shortened in the bow, to maintain as large a model as possible. The SINTEF Ocean Cavitation tunnel has a rectangular test section of dimensions: 6 m x 1.3 m x 1.2 m, and can accommodate models up to roughly 5 meters in length, due to its large top hatch. The demi-hull itself represented the starboard side of the catamaran hull, with the propeller rotation being left-handed. The model was milled out of styro-foam and painted. Station marking was done at 10.5 cm intervals in model scale, downstream of the interceptor, for reference. The air-injection box and interceptor were 3d-printed in plastic. Five internal channels in the air box allowed for manual control of air to different sections of the hull cross-section via control valves to test for sensitivity of the air-layer formation directly downstream the interceptor. The air flow rate was monitored and controlled via a chocked needle valve, allowing tests on propeller performance as a function of air-flow rate.

Two different scaling approaches for the interceptor height, h, was tested. One matching the non-dimensional height of the interceptor in terms of the friction velocity (h^+ matching) and one matching the height to boundary layer thickness ratio (h/δ_{99} matching, with δ_{99} being the estimated boundary layer thickness). Observing the quantitative behaviour of the air-layer, the latter approach was deemed more appropriate for the present case. Further, two different propellers were tested. One was a model of the propeller used on the full-scale vessel, and the other a redesigned propeller with emphasis on margin to cavitation.

For all tests both pressure pulses on the surface of the propeller tunnel was measured as well as propeller thrust, torque and efficiency. One speed and loading condition was tested for each propeller (specified thrust and cavitation coefficient), with varying steps of mean air-flow rate, including air free conditions. Due to air build up in the circulating water, each tests run was conducted for a constrained period of time and the tunnel was evacuated of air between each run. To gain qualitative insight into the behaviour of the air-layer and bubble

[1] Koushan et. al, Numerical, Experimental, and Full-Scale Investigations of a Passive Air-Lubrication System for High-Speed Craft, SNAME 14th International Marine Design Conference, Vancouver, Canada, June 2022

transport to the propeller the tests were further documented with 4 high-speed cameras placed as shown in Fig. 1. An initial round of testing was conducted to identify the appropriate air-flow rate for matching the approximate quantitative behaviour of the air-layer observed in full scale trials, with further measurements conducted significantly varying the air-flow rate below and above the identified level.

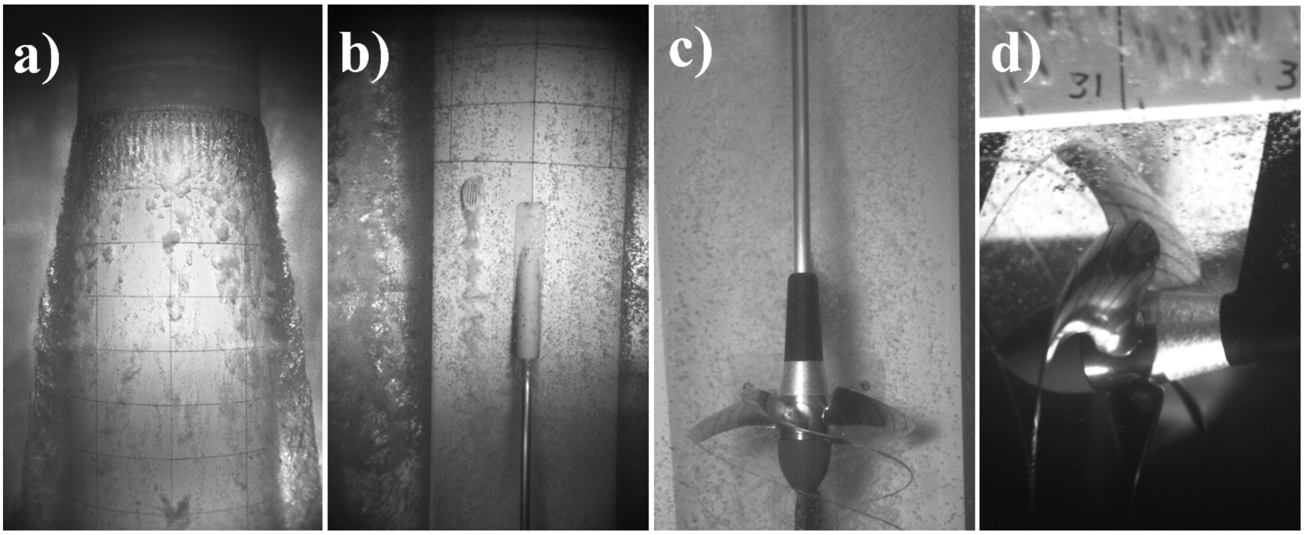

Figure 1: Field of view captured with high speed camera during test.

RESULTS

Overall, the measured efficiency drop for the present propellers under the influence of air compared to air free conditions was up to, but generally less than, 1%. In terms of relative performance, the redesigned propeller with emphasis on margin to cavitation performed somewhat better than the original propeller, suggesting that the interaction between cavitation on the propeller blades and air-mixing can be detrimental to propeller performance under the influence of air. The efficiency for both propellers appeared to drop in proportion to the amount of air impacting the propeller disc-area, in line with expectations, but without quantitative measurements of void fraction this could not be confirmed.

The measured pressure pulsations appeared to be slightly increased on average across the first 3 blade passing frequency harmonics under the influence of air for both propellers, but not to a significant level given the large spread in the results across repeated runs.

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[1] Koushan et. al, Numerical, Experimental, and Full-Scale Investigations of a Passive Air-Lubrication System for High-Speed Craft, SNAME 14th International Marine Design Conference, Vancouver, Canada, June 2022