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Investigation of Air Ingress from a Passive Air Lubrication System on Ship Propeller Propulsive Characteristics

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Introduction

This work considered the potential impact of air ingress resulting from using a Passive Air Lubrication (PALS) System upon ship propeller characteristics. The PALS system introduces air into a vessel's near-wall region, reducing skin friction. The reduction in skin friction can improve fuel consumption and emissions generation. Air lubrication is considered to be one of the most promising decarbonisation technologies currently available for the maritime industry. However, the potential impact of air ingress on propulsive characteristics (thrust and torque coefficient) is poorly understood. Should air ingress significantly affect the propulsive characteristics, this must be given appropriate consideration within the overall business case for the technology. This may require design and operational changes or impact the general uptake in operator use of the technology. This report presents the findings of Computational Fluid Dynamics (CFD) simulations, which have been carried out to investigate the impact of air ingress on the propeller. As the simulations are created based on the operation of the PALS (a venturi system), the air is introduced as a mixture of air and water.

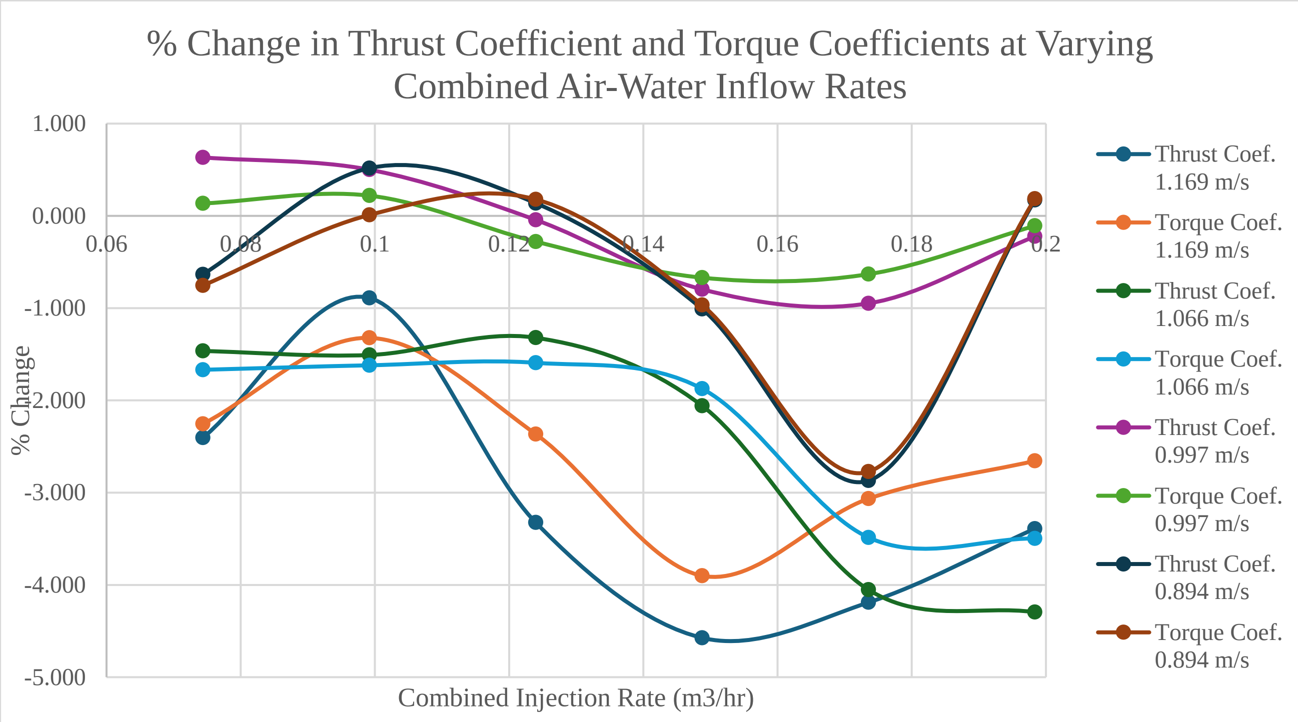
Methodology

This work uses the CFD software STAR CCM+ to carry out the investigation. Rather than the air being introduced as a jet, a plate with a slit is used to introduce the air-water mixture. This representation more closely correlates to how air would be introduced to the propeller in reality. However, the introduction of air is deliberately exaggerated by having the plate and propeller in close proximity. By using a slit in a plate, the quantities of air and water can be varied as required. The air's introduction is facilitated by a small recessed region (termed the pipe or inflow region) through which the air-water mixture is introduced to the freestream water flow in the domain. The interaction of the free stream flow of water with the air-water mixture results in the mixture being carried towards the propeller, which is downstream of the injection point. The slit is located 2.485 m from the downstream edge of the plate, and this edge is aligned with the tip (or nose) of the propeller hub. The propeller is a 5-blade propeller of approximately 0.2 m diameter. The propeller and plate are scaled down to 1:56 from the full-scale versions, with the propeller rotational rate scaled via Froude scaling. The plate represents the Japanese Bulk Carrier (JBC) geometry, which has a maximum beam at the waterline of 45.0 m; therefore, in the scaled version, the plate's width was 0.804 m. In this work, an implicit unsteady approach was utilised due to the unsteady nature of the phenomena. For temporal discretisation, the simulation uses an implicit unsteady approach for a coupled flow and a 1^{st}-order temporal discretisation scheme. The modelling approach used was the Volume of Fluid (VOF) modelling approach, which was used in a single-phase and a multi-phase manner. The chosen turbulence model utilised was the $k - \omega\, SST$ model. The VOF approach to fluid flow modelling is a prominent approach to handling multiphasic simulation; however, it does not allow for the phases to be interpenetrating, representing the phases as having a distinct boundary. It is acknowledged that due to the agitative and mixing effect of the propeller, the assumption of immiscible fluids in the VOF approach limits the replication level that can be achieved using this method. Still, using this model allows for some of the effects of air ingress to be modelled and an assessment of the impact on thrust and torque coefficient.

Cases and Results

The experimental setup was used to develop several sets of cases that varied the quantity of injected air (exclusively), injected water (exclusively), and air and water (concurrently). The changes to the quantity of injected air and water subsequently adjusted the total volumetric flow rate.

In parallel with the air and water quantity changes, the freestream velocity was adjusted to investigate the effects under differing inflow velocity conditions. The results presented here show the percentage change in thrust and torque coefficient at inflow velocities of 0.894, 0.997. 1.066 and 1.169 m/s. The air/water ratio (the ratio of the volumetric flow rate of air to water) is 0.189. The total volumetric flow rate varies from 0.0152 m^3/hr to 0.0608 m^3/hr across the cases investigated. The results are shown in the included figure.



Discussion and Conclusions

This work and the data presented form part of a broader investigation as part of the RETROFIT 55 project, which considers the effect of air ingress on propeller thrust and torque coefficient. From the cases presented here, preliminary indicators indicate that ingress into the propeller plane has a detrimental effect on propeller propulsive characteristics in most conditions. The detrimental effects of the ingress appear more pronounced at higher freestream velocities. Conversely, in the lower freestream velocity cases, there are indications of a minor beneficial effect on the propulsive characteristics. However, the magnitude of this effect is small, so the significance of this behaviour is unclear. It is noted that the volumetric flow rate of the air-water mixture is relatively small. In subsequent cases, the volumetric flow rate was increased in conjunction with separate cases where the air volume fraction in the air-water mixture was increased. Where a reduction in the thrust coefficient is seen, this would indicate that the effect of air ingress compromises the propulsive characteristics of the propeller. A reduction in the torque coefficient could indicate that the propeller requires less torque to rotate at the specified speed. However, given that the reduction in torque coefficient is seen with an accompanying decrease in thrust coefficient, this is not viewed as a positive indicator but instead as an indicator of deterioration in propulsive characteristics for the propeller. The work utilised a VOF multiphase approach, where the air and water are viewed as immiscible fluids. This assumption is insufficient to model the behaviour of the air-water mixture holistically. Therefore, although this work has provided indications of the pertinent areas for future investigation, further investigation utilising alternative simulation approaches is necessary, in addition to experimental testing to confirm the behaviours seen in this work.

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