Performance of a Marine Propeller at High Reynolds Numbers Using a Compressed-Air Wind Tunnel

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This study presents an experimental investigation into the performance of a marine propeller at high Reynolds numbers using a compressed-air wind tunnel facility. Testing large prototypes in conventional water tunnels is physically limited by the scale ratio. As an alternative, small propeller models operating in a compressed-air wind tunnel can replicate full-scale, non-cavitating conditions by matching the key non-dimensional parameters which include Reynolds number and advance ratio. The primary goal of this study is to quantify the propeller's performance (thrust and torque) across a range of Reynolds numbers as a verification of the compressed air testing method for marine geometries. High Reynolds number conditions are achieved by varying the static pressure of the facility (from one to 35 atmospheres), thereby increasing the air density. A series of experimental tests have been conducted at the Pennsylvania State University Compressed Air Wind Tunnel (CAWT) enabling systematic investigation of scale effects.
The DTMB 4119 propeller, a widely studied and publicly available geometry, has been selected for testing. The propeller was mounted on a streamlined test stand, and tests were conducted over a range of tunnel velocities and rotational speeds. An ATI MINI 45 load cell was used to measure thrust and torque, while a tachometer recorded the rotor speed. Tunnel conditions, including pressure and temperature, were continuously monitored to ensure accurate non-dimensionalization of performance data. Key performance metrics measured include advance ratio (J), thrust coefficient (C_T), and torque coefficient (C_Q). A scale-dependence study is performed by systematically varying Reynolds number while holding J constant at the design point of $J = 0.889$ ($J = V_\infty/nD$, where V_∞ is the free-stream velocity, n is the rotation rate, and D is the propeller diameter). The resulting performance curves are compared to examine the validity of scaling laws for a marine propeller.
In conclusion, this presentation highlights the utility of compressed-air wind tunnels for assessing marine propeller performance at relevant Reynolds numbers without cavitation. Ongoing experiments aim to bridge the gap between small-scale laboratory testing and real-world marine conditions. The results will provide valuable insights into how propeller performance scale with Reynolds number, informing future propeller designs and optimization strategies.
Future work will extend to wake analysis, capturing vortex shedding behavior, turbulence intensity, and the influence of blade loading on flow structures. These observations will support the development of more accurate predictive models for marine propulsion, contributing to more efficient and environmentally friendly marine systems.

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