Steady and Unsteady Dynamics of an Azimuthing Podded Propulsor Related to Vehicle Maneuvering

By

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Abstract

While the implementation of azimuthing propulsors powered by internal electric motors (often called "podded propulsors") into the commercial ship market has been swift, the understanding of their hydrodynamics through research, particularly in the area of maneuvering performance, has been very limited.

This thesis research investigates the steady and unsteady dynamic maneuvering forces associated with an azimuthing podded propulsor, and provides supporting theoretical insight toward understanding their mechanisms and prediction. Because of the wide range of potential applications of azimuthing podded propulsion in the marine field, dynamic force phenomena applicable to maneuverability of both large and small scale vehicles are investigated. These include quasi-steady vectored maneuvering forces, of importance to all maneuvering vehicles or ships, as well as unsteady or transient maneuvering forces, which have more significance to the maneuverability of smaller vehicles, particularly for precision control applications. The ultimate goal of the research is to provide a comprehensive understanding of the maneuvering forces associated with an azimuthing podded propulsor, such that future maneuvering and control applications, and computational fluid dynamics studies in the field, can be appropriately focused.

The research efforts are focused in four main areas. First, a number of relevant dynamic models for the maneuvering of a surface vehicle with an azimuthing propulsor are developed. Second, an extensive test program measures and characterizes the nature of quasi-steady vectored maneuvering forces associated with a podded propulsor in azimuth to ±180° for the entire range of forward propeller speeds, as well as unsteady or transient maneuvering forces due to rapid changes in azimuth angle or propeller rate. This test program is aimed at quantifying the steady and unsteady parameters associated with the developed dynamic models. Third, two flow visualization techniques are utilized to visualize, document, and correlate the helical wake characteristics, velocities and forces for both quasi-steady and unsteady propulsor states. A new fluorescent paint flow visualization technique is developed and applied for small, moderate and large propulsor azimuth angles, and a laser particle image velocimetry (PIV) technique is adapted for small and moderate propulsor azimuth angles. Finally, a set of comprehensive physics-based models are developed to foster the understanding of the mechanisms associated with the steady and unsteady force dynamics. The quasi-steady models are based upon a combination of momentum-based, blade-element, and vortex wake propeller theories, as applied to an azimuthing podded propulsor. The unsteady force models are based upon unsteady wake or "dynamic inflow" methods. Additionally, an interesting phenomenon associated with the formation of a vortex ring during rapid propeller rate increase is presented and discussed.

The steady and unsteady test results, flow visualizations, and theoretical models, are shown to be consistent in terms of the magnitudes and character of the azimuthing maneuvering forces. Limited comparisons of quasi-steady propulsor forces at small, moderate and large azimuth angles are also made with forces predicted by a modified combined blade-element-momentum (BEM) method, as well as the unsteady vortex-lattice propeller code MPUF-3A, with and without modified inflows to account for propulsor pod wake. The results illustrate inherent complexities related to use of existing computational fluid dynamics tools with azimuthing podded propulsors.

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