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The Effect of Sail Geometries on the Development of Horseshoe Vortices

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ABSTRACT

The horseshoe vortex, tip vortex, and wake generated by a sail can significantly impact vibrations and noise produced by submarines. This study simulates the flows generated by five different sail geometries mounted on a flat plate. The Reynolds number is 5×10^5, based on the chord length of the wing, and the SST k-ω turbulence model (Menter, 1994) was used for computations (Lee, Chen, and Hsin, 2017). Through the analysis of the velocity distribution, pressure distribution, vorticity, and drag coefficient, we investigated the effects of different sail geometries on vortex structures generation.

The sail with the Rood wing section (Devenport and Simpson, 1990), the simplest geometric design, serves as a baseline for comparing flow field and drag coefficient with those of others. The curved surface design at the top of the Darpa suboff sail (Sevgi, Barlas, and Ünal, 2022) significantly reduces the strength of the tip vortex, resulting in a drag coefficient smaller than others except for the dolphin sail. The streamlined 2D airfoil design of the sail of type XXI U-boat ("XXI sail") deviates from the typical blunt-front and sharp-rear design of standard sails, which weakens and narrows the horseshoe vortex. However, the geometry at its tail causes an interaction between the tip vortex and horseshoe vortex, resulting in a drag coefficient only slightly smaller than that of the Rood wing sail. Interestingly, the unconventional non-streamlined design of the sail of A26 type submarine ("A26 sail") demonstrates excellent wake performance, placing its drag coefficient third among the designs. Finally, the bio-inspired dolphin sail (Parlov, 2003), with no engineering constraints, features an overall streamlined shape and a small, pointed, rounded tip. This significantly reduces vortex strength and overall drag, making its performance in terms of flow field and drag coefficient the best among all geometries.

References

William J. Devenport, Roger L. Simpson. An Experimental Investigation of the Flow past an Idealized Wing-Body Junction: Final Report. Virginia Polytechnical Institute and State University, Report VPI-AOE-172, 1990.

G. Sevgi, B. Barlas, U.O. Ünal. Investigation of the Effect of the Flow Regulators on the Flow around a Generic Submarine Sail. Journal of Naval Sciences and Engineering, Vol. 18, pp. 251-279, 2022.

Vadim V. Pavlov. Wing Design and Morphology of the Harbor Porpoise Dorsal Fin. Journal of Morphology, Vol. 258, pp. 284-295, 2003.

Jun-Pei Lee, Jiahn-Horng Chen, Chin-Yeh Hsin. Study of Junction Flow Structures with Different Turbulence Models. *Journal of Marine Science and Technology*, Vol. 25, pp. 178-185, 2017.

Florian R. Menter. Two-Equation Eddy-Viscosity Turbulence Models for Engineering Applications. AIAA Journal, Vol. 32, pp. 1598-1605, 1994.