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Leidenfrost spheres, projectiles, and model boats: assessing drag reduction by superhydrophobic surfaces

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Abstract

Superhydrophobic surfaces are expected to reduce drag on bluff bodies moving in water through the formation of a thin air layer at the solid-liquid interface, leading to a partial-slip boundary condition. Leidenfrost vapor layers sustained on heated metal bodies provide a reliable means to estimate the maximum drag reduction achievable by such gas layers. This approach has previously been applied to evaluate drag reduction for free-falling heated spheres, where pressure-induced form drag is the dominant contribution to the total drag force. Here, we extend this approach to investigate the effect of thin gas layers on the hydrodynamic drag of free-falling streamlined projectiles and towed model boats, for which form drag is minimal and viscous skin-friction drag is the leading contribution. By comparing the drag on streamlined bodies with and without sustained gas layers, we observe only incremental drag reductions within the sub-critical Reynolds number range investigated. A similar trend is observed for towed model boats. These results are consistent for both superhydrophobic surface treatments and Leidenfrost vapor layers. The results indicate that, over the investigated range of sub-critical Reynolds numbers, skin-friction-dominated drag is considerably less sensitive to the presence of thin gas layers than form-drag-dominated flows. These findings have important implications for the practical potential of energy savings using gas layers sustained on superhydrophobic surfaces.

Keywords:

Drag reduction Superhydrophobic surfaces Leidenfrost vapor layers Skin-friction drag Form drag Fluid–solid interaction