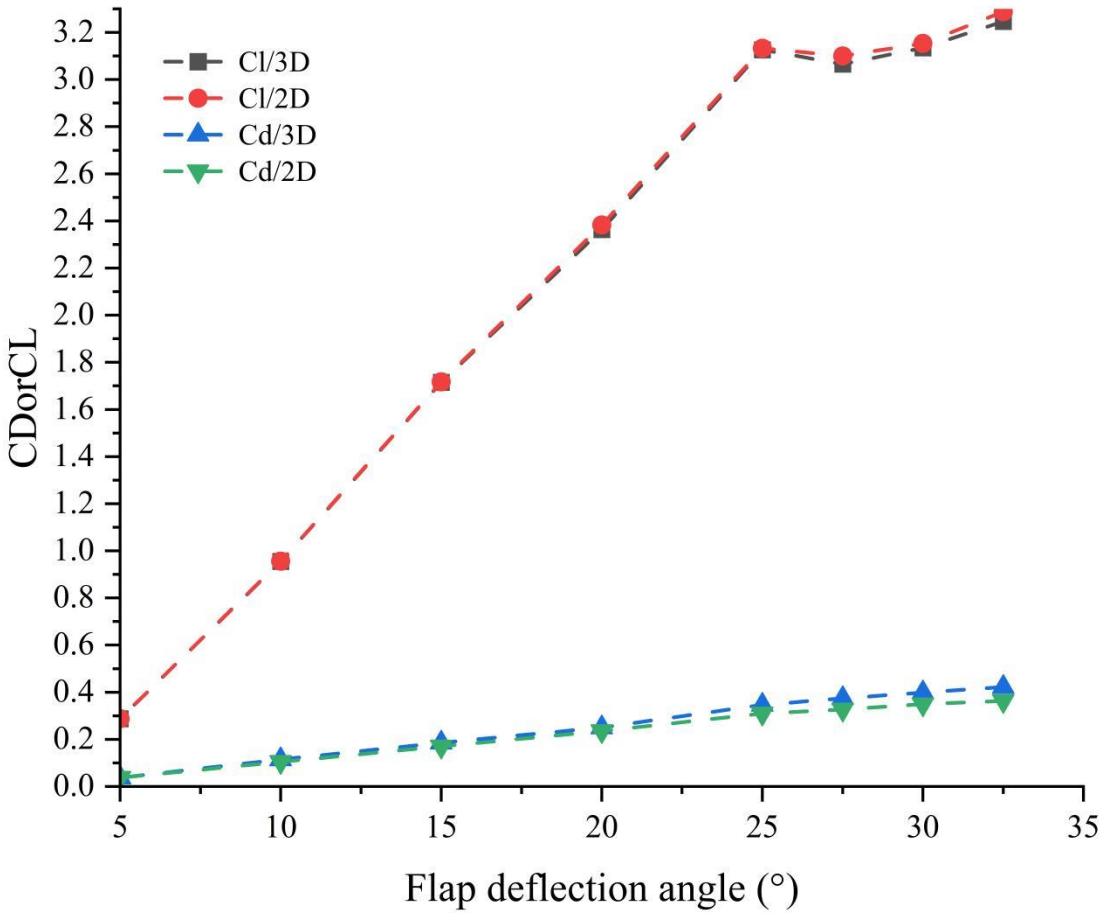


Considering the three-dimensional (3D) effect, the author established a 3D grid model for a two-element hydrofoil system with a chord ratio c1/c2=1.5 and a spacing g=2.4%c1. The comparison of lift and drag coefficients between 2D and 3D grids (as shown in the figure) shows that at low flap deflection angles (<20°), the differences in (CL) and (CD) between the two grids are negligible. This is because the tip vortex is underdeveloped, and the 2D "infinite span" flow field (no spanwise end effect) approximates the 3D actual flow field (weak tip vortex influence) in terms of spanwise circulation distribution, pressure gradient, and separation mode at low angles, leading to converged lift-drag characteristics.

When the flap deflection angle increases (>20°), 3D effects dominate the flow field differences:

Lift Coefficient Decay: In 3D flow, zero tip circulation causes uneven spanwise circulation, while tip vortex-induced downwash reduces the upper-surface effective angle of attack. Premature end separation (due to tip vortex perturbation) disrupts pressure distribution continuity, limiting lift growth. In contrast, 2D simulation overestimates by neglecting tip end effects (infinite span assumption).

Drag Coefficient Increase: In 3D flow, tip vortex-induced induced drag (downwash energy dissipation), viscous drag (turbulent mixing at the tip), and separation drag (end separation zone pressure loss, triggered by tip vortex-flap coupling) collectively elevate drag. 2D simulation, which only accounts for wing-surface friction and 2D separation drag, underestimates 3D end-flow energy dissipation.

These results highlight that while the current study focuses on 2D analysis, future research

must incorporate 3D grid simulations to accurately capture tip effects and vortex-separation interactions—critical for predicting hydrofoil performance under high-load conditions (e.g., large flap deflections). 3D modeling will address 2D approximations' limitations in spanwise flow non-uniformity and vortex-induced drag/lift decay, enabling realistic design optimization.