ABSTRACT

A Velocity Decomposition Approach for

Lifting and Free-surface Flows

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The principle of velocity decomposition is used to efficiently and accurately solve the Navier-Stokes problem for lifting and free-surface flows. The total fluid velocity is decomposed as the sum of irrotational and solenoidal components. The irrotational component is modeled using a velocity potential which satisfies the Laplace equation. It is shown that the conventional *inviscid* velocity potential does not satisfy the Navier-Stokes problem, even in the irrotational regions of the flow. Whereas, the *viscous* velocity potential is the solution to a modified boundary-value problem which satisfies the Navier-Stokes problem everywhere except where the flow is rotational.

If a viscous potential can be found which satisfies the Navier-Stokes problem directly outside of the rotational regions of the fluid, then the fluid domain over which the Navier-Stokes equations must be solved can be greatly reduced. The viscous potential is the Dirichlet boundary condition for the total velocity on the boundaries of the reduced fluid domain.

The primary development in this work is the formulation of the viscous potential for lifting and free-surface flows. Previously, the viscous potential was developed by Edmund (2012) for deeply-submerged, non-lifting bodies. In Edmund (2012), the body-boundary condition was modified to include viscous effects from the body and wake. The viscous potential for lifting flows is modified further to account for the loss of lift due to separation by introducing a condition on the total body-bound circulation. The viscous potential is also modified to account for the presence of an asymmetric flow, such as that which exists downstream of a lifting foil. Finally, free-surface effects are incorporated by implementing a linear free-surface solver into the viscous potential formulation.

The velocity decomposition approach is used to solve for the flow over a deeply-submerged 2D NACA0012 foil. It is demonstrated that by using the viscous potential, the fluid domain on which the Navier-Stokes equations are solved can be reduced to only include the region within approximately two chord lengths from the body. A computational speed-up of up to 7.5× is demonstrated. The velocity decomposition approach is also applied to the free-surface flow over a bottom-mounted bump and a fully-submerged foil.