Flow control simulations of stalled airfoils with electrohydrodynamic body forces

Datta V. Gaitonde & Miguel R. Visbal
Computational Sciences Branch
Aeronautical Sciences Division
Air Vehicles Directorate
Air Force Research Laboratory
Wright-Patterson AFB, Ohio 45433, USA
Datta.Gaitonde@wpafb.af.mil

Subrata Roy
Computational Plasma Dynamics Laboratory
Department of Mechanical Engineering
Kettering University
Flint, Michigan 48504, USA

The response of the flow past a stalled NACA 0015 airfoil at 15° angle of attack and Reynolds number of 45,000 to body forces originating from radio-frequency asymmetric dielectric-barrier-discharges is described. In the first element of the work, a direct numerical simulation is performed by coupling a high-order accurate full 3-D Navier-Stokes solver to a phenomenological model for body force with the goal of exploring various magnitudes and orientations of an average steady body force. The distribution is assumed to be linear, diminishing away from the surface. Various magnitudes and orientations are explored, ranging from vertically downwards (towards the body) to vertically upward (away from the body). The imposed body forces result in a complex sequence of events that influence both the non-linear dynamics and the pressure distribution [1]. It is observed that a significant streamwise component assures the reduction or elimination of stall. Purely vertical forces either have deleterious impact away from body) or yield an unsteady limit-cycle behavior (towards the wall). Relaxation effects are characterized to yield estimates of response times. The absence of breakdown of vortices shed in the 2-D flow simulation results in large coherent structures which respond differently to the applied perturbation. Nonetheless, if the force is sufficiently effective to eliminate separation, the flowfield becomes generally 2-D, and the overall distributions from 2-D and 3-D analyses are similar.

In the second part, the foundation is laid to couple a force field obtained from a first-principles approach [2] to the full 3-D solver. As a preliminary step, the averaged response of the flow to the high-frequency perturbation is compared with that obtained with a mean perturbation input to yield an appropriate model for application in complex analyses.

References

[1] D.V. Gaitonde, M.R. Visbal and S. Roy, "Control of Flow Past aWing Section with Plasma-based Body Forces", AIAA-2005-5302, 36th AIAA Plasmadynamics and Lasers Conference, 6-9 June 2005, Toronto, Canada.

[2] S. Roy and D. Gaitonde, "Radio frequency induced ionized collisional flow model for application at atmospheric pressures," Journal of Applied Physics, Vol. 96, 2004, pp. 2476–2481.