# Numerical Investigation of the Influence of Surface Dimples on Aerodynamic and Aeroacoustic Performance of Airfoils

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Master of Science (Major Component Research)

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# DECLARATION

I declare that this is my own work and this thesis/dissertation does not incorporate without acknowledgement any material previously submitted for a degree or diploma in any other University or Institute of higher learning and to the best of my knowledge and belief it does not contain any material previously published or written by another person except where the acknowledgement is made in the text. I retain the right to use this content in whole or part in future works (such as articles or books).

Signature: Date: 16/03/2026

The above candidate has carried out research for the Master's thesis/dissertation under my supervision. I confirm that the declaration made above by the student is true and correct.

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Signature of the Supervisor: Date: 16/03/2026

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Signature of the Supervisor: Date: 17/03/2026

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# ABSTRACT

Surface-based passive flow-control strategies offer a promising route to simultaneously enhance aerodynamic performance and reduce noise emissions in small-scale aerodynamic applications. This study numerically investigates the influence of surface dimples on the aerodynamic efficiency and aeroacoustic behaviour of a NACA 0012 mid-span airfoil operating at a transitional Reynolds number of approximately $7 \times 10^5$, representative of conditions encountered by unmanned aerial vehicles and small wind-turbine blades. In this region, boundary-layer transition, laminar separation bubbles, and trailing-edge scattering strongly govern both force characteristics and self-noise generation.

An integrated Computational Fluid Dynamic – Computational Aero Acoustic framework was employed, combining Detached Eddy Simulation for unsteady flow resolution with the Ffowcs Williams–Hawkings acoustic analogy for far-field noise prediction. Two parametric investigations were performed, examining the effects of chordwise dimple coverage and dimple diameter. Simulations were conducted at angles of attack of 5°, 10°, and 15°, corresponding to attached, near-stall, and post-stall flow conditions.

The results reveal a strong dependence of dimple effectiveness in improving Aerodynamic and aeroacoustics performance on both flow state and geometry. Under fully attached conditions, dimpling increased viscous losses and degraded aerodynamic and acoustic performance. At near-stall conditions, however, surface dimples energized the boundary layer, delayed separation, and improved suction-side pressure recovery, leading to lift increases of up to 6%, drag reductions of up to 18%, and lift-to-drag ratios approaching 26. In separated-flow conditions, dimples mitigated large-scale separation and narrowed the wake, yielding modest aerodynamic gains. Aeroacoustically, dimpling increased broadband noise at low angles of attack but produced significant sound pressure level reductions up to 23 dB at near-stall and post-stall conditions by disrupting coherent vortex structures responsible for efficient acoustic radiation.

Overall, the study demonstrates that surface dimpling can provide simultaneous aerodynamic and acoustic benefits in transitional flows, provided that dimple geometry and placement are carefully tailored to local boundary-layer characteristics.



**Keywords**: NACA 0012, Aerodynamics, Aeroacoustics, Passive Flow Control, Dimple Surface, UAV, Small-scale wind turbine

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| Abbreviation | Description |
|---|---|
| FAA | Federal Aviation Administration |
| UAV | Unmanned Aerial vehicle |
| LSB | Laminar Separation Bubble |
| CFD | Computational Fluid Dynamic |
| CAA | Computational Aero Acoustics |
| Re | Reynolds Number |
| SPL | Sound Pressure Level |
| $C_l$ | Lift Coefficient |
| $C_d$ | Drag Coefficient |
| $C_m$ | Moment Coefficient |
| LES | Large Eddy Simulation |
| DES | Detached Eddy Simulation |
| AoA | Angle of Attack |
| RANS | Reynolds Averaged Navier Stokes |
| FW-H | Ffowcs Williams-Hawkings |
| SST | Shear Stress Transport |