# High-Fidelity Studies of Unsteady Aerodynamics, Acoustics and Flow Control for Airfoils in Transitional Flow Regimes

**Vladimir V. Golubev*, Lap D. Nguyen*, Reda R. Mankbadi***

* Embry-Riddle Aeronautical University
Florida Center for Advanced Aero Propulsion
600 S. Clyde Morris Blvd, Daytona Beach, FL 32114, USA
Vladimir.Golubev@erau.edu

## ABSTRACT

We discuss our recent high-fidelity numerical efforts examining effects of airfoil geometry, upstream flow conditions, and active flow control on the unsteady aerodynamic and acoustic signatures of NACA0012 and SD7003 airfoils in the transitional flow regimes dominated by the boundary-layer flow-acoustic resonant interactions. Numerical experiments particularly focus on the inherent phenomena contributing to the high growth rates of the boundary-layer instability modes and the role of the laminar separation bubble and its dynamics in the sustained feedback-loop process.

In our previous work [1], experimentally recorded unsteady responses of loaded, transitional NACA0012 airfoil confirmed the presence of the shifted ladder-type tonal structures with dual velocity dependence observed both in the surface pressure and the acoustic signals. High-fidelity numerical efforts employ a 6$^{th}$-order Navier-Stokes solver [2] implementing a low-pass filtering of poorly resolved high-frequency solution content to retain numerical accuracy and stability over the range of transitional flow regimes. 2D and 3D (ILES) numerical experiments investigate the behavior of the boundary-layer statistical moments during the transitional flow regimes characterized by the presence of the separation regions and the formation of the highly-amplified instability waves scattered into noise at the airfoil trailing edge, thus triggering and sustaining the acoustic feedback-loop process. Numerical results are matched against experimental data and the linear-stability analysis.

Parametric studies investigate the effect of upstream turbulence on transitional airfoil response, with the analysis employing a recently developed novel numerical procedure [3] to generate synthetic turbulence in an upstream source region of the computational domain. Furthermore, we examine the effect of active flow control implemented through synthetic-jet actuation on the airfoil surface following the procedure established in Ref. [4].

## REFERENCES

[1] V.V. Golubev, L. Nguyen, R.R. Mankbadi, M. Roger, M. R. Visbal. "On flow-acoustic resonant interaction in transitional airfoil," *International Journal of Aeroacoustics*, Vol. 13, No.1 (2014).

[2] M.R. Visbal, D.V. Gaitonde, D.V. "On the use of high-order finite-difference schemes on curvilinear and deforming meshes," *Journal of Computational Physics*, Vol. 181, pp.155–185 (2002).

[3] V.V. Golubev, J. Brodnick, L. Nguyen, M.R.Visbal, "High-fidelity simulations of airfoil interaction with upstream turbulence," *AIAA Paper 2012-3071*, 42$^{nd}$ AIAA Fluid Dynamics Conference, New Orleans, June 2012.

[4] V. V. Golubev and H. K. Nakhla, "Modeling Synthetic Jets for Low-Re Airfoil Unsteady Flow Control," *International Journal of Emerging Multi-Disciplinary Fluid Sciences*, Vol. 3, N 2+3, pp. 145-158 (2012).