Undulated Leading-Edge Airfoils in Low to Medium Reynolds Number Regime

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Biologically inspired airfoil designs have recently become of increasing interest to the aerospace industry for their aerodynamic versatility. One approach involves mimicking the undulating leading-edge of humpback whale fins. Such airfoils have been shown to improve stall characteristics in specific airflow regimes depending on the relative turbulence of the flow. This research project explored the validity of these biomimetic airfoils in the transitional Reynolds number regime (Re=120,000–500,000). The study featured two NACA 2415 airfoils: a traditional design, and an experimental design with a sinusoidal leading-edge that mimics the tubercle protuberances on the leading-edge of humpback whale fins. Wind tunnel testing was conducted in the transitional regime with 3D-printed prototypes; the coefficients of lift and drag were calculated for both airfoils at varying angles of attack. A numerical study using Computational Fluid Dynamics was also executed under the same conditions to provide flow visualization and a secondary set of data. Experimental data verified numerical predictions that the tubercle airfoil would stall more gently and consistently compared to the control airfoil. However, the wind tunnel testing revealed that the gain in stability came with a slight loss in efficiency in the transitional regime (Re~400,000). Flow visualization highlighted that the troughs in the leading edge acted as streamwise vortex generators, accelerating channels of air and inducing a low-pressure region inside the troughs. This explains the biomimetic airfoil’s stable performance in the post-stall regime compared to the control airfoil, suggesting its potential aviation applications for low-altitude subsonic aircraft.

Awards Won:

Third Award of $1,000

Arconic Foundation: Material Science or Engineering, Second Award of $1,500

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Astronautics: Third Award of $1000.00