THE GEORGE WASHINGTON UNIVERSITY
WASHINGTON, DC

A 3D Iterative Panel Method & Boundary Layer Model for a Bioinspired Multi-Body Wing

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R&D Showcase 2014

INTRODUCTION

During the last decade Unmanned Aerial Vehicles (UAVs) have continued to increase their presence in airborne missions. To date, UAVS are predominately employed for surveillance and reconnaissance operations, where the vehicles are regularly required to fly at low altitudes in cluttered environments where turbulent and gusting flows present a significant risk. Subsequently, the demand for advancements in flight system development to extend the flight envelope, and operate successfully in turbulent conditions, the vehicle requires improvement in three main categories:

1. Maneuverability
2. Stability
3. Controllability

To respond to these needs, focus has been given to the evolutionary adaptation of avian flight due to their wing morphing techniques. By studying the airflow manipulation techniques employed by birds, a new bio-inspired morphing wing geometry has been developed to enable localized flow control techniques to be employed through the integration of biomimetic feathers across a hollow rib and spar wing structure.

Figure 1: A plan view of an albatross wing demonstrating the upper surface feather configuration

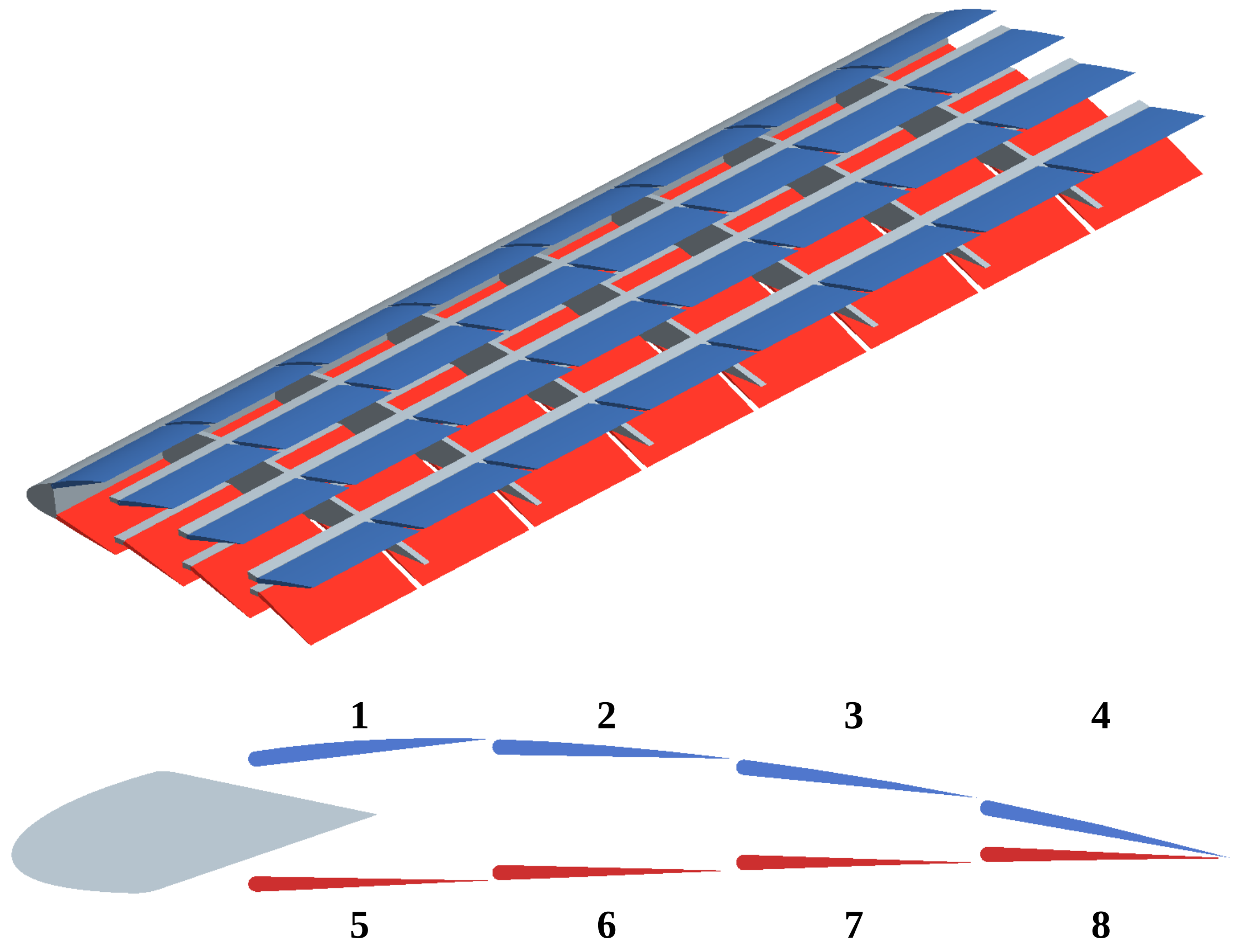
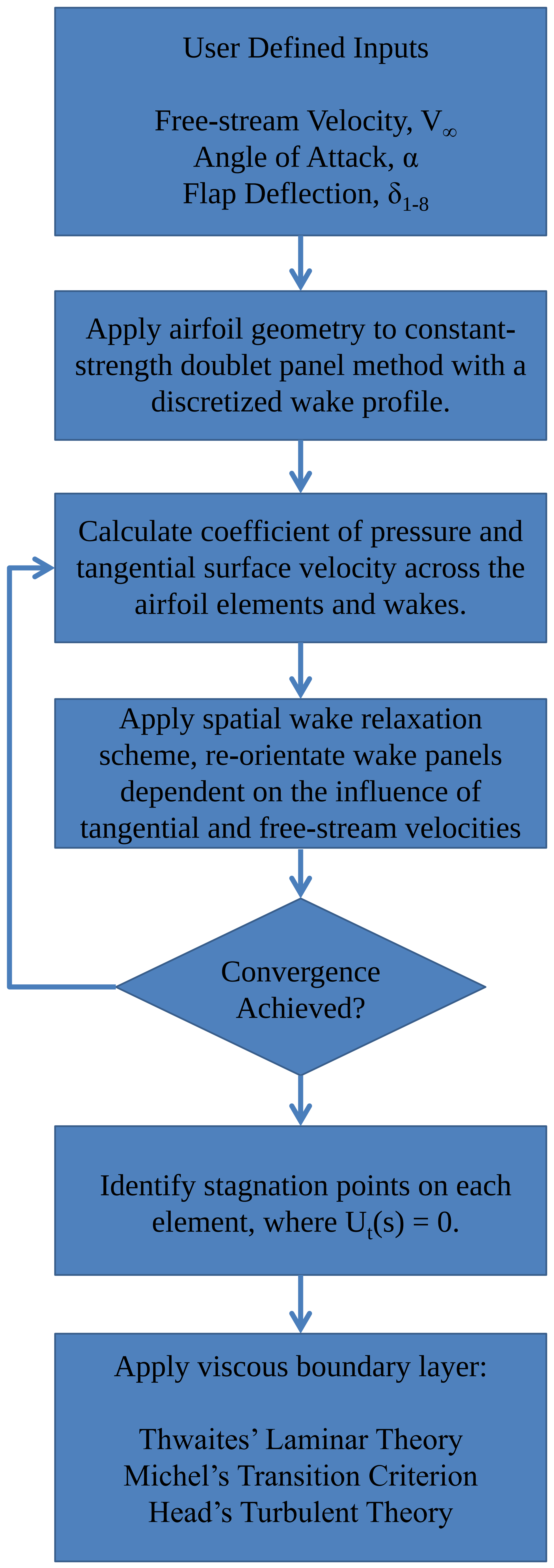


Figure 2: A bioinspired wing with deflected feather-like flaps installed across the upper and lower surfaces (above), the 2D profile at rest (below)

ITERATIVE PANEL METHOD & BOUDNARY LAYER MODELING

This multi-configurable bioinspired airfoil enables a wide array of lift, drag and moment coefficients to be attained due to the number of geometries available. Subsequently, to accommodate feather splaying, similar to that seen on avian wings during flight, an adaptive model is required.



User Defined Inputs

Free-stream Velocity, V_∞
Angle of Attack, α
Flap Deflection, $\delta_{1\text{-}8}$

Apply airfoil geometry to constant-strength doublet panel method with a discretized wake profile.

Calculate coefficient of pressure and tangential surface velocity across the airfoil elements and wakes.

Apply spatial wake relaxation scheme, re-orientate wake panels dependent on the influence of tangential and free-stream velocities

Convergence Achieved?

Identify stagnation points on each element, where $U_t(s) = 0$.

Apply viscous boundary layer:

Thwaites' Laminar Theory
Michel's Transition Criterion
Head's Turbulent Theory

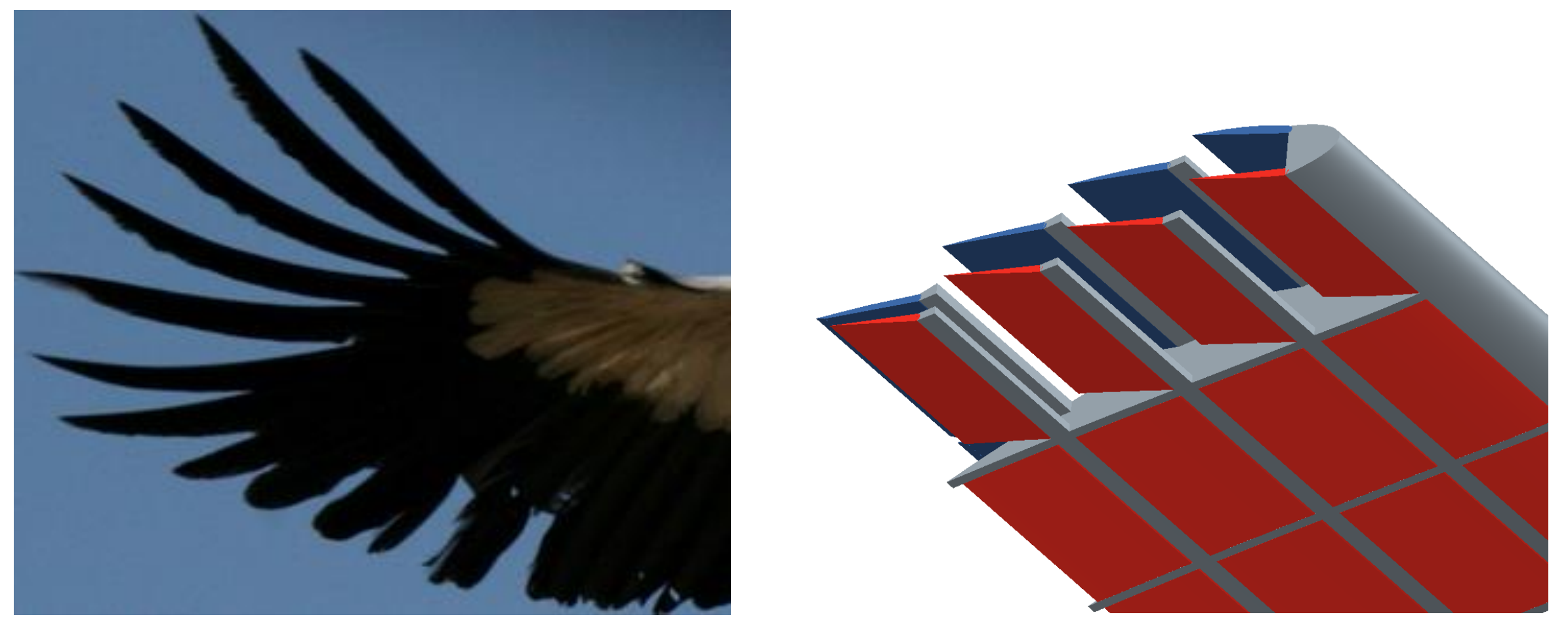


Figure 3: The splayed profile of an avian wing (left) and bioinspired wing (right)

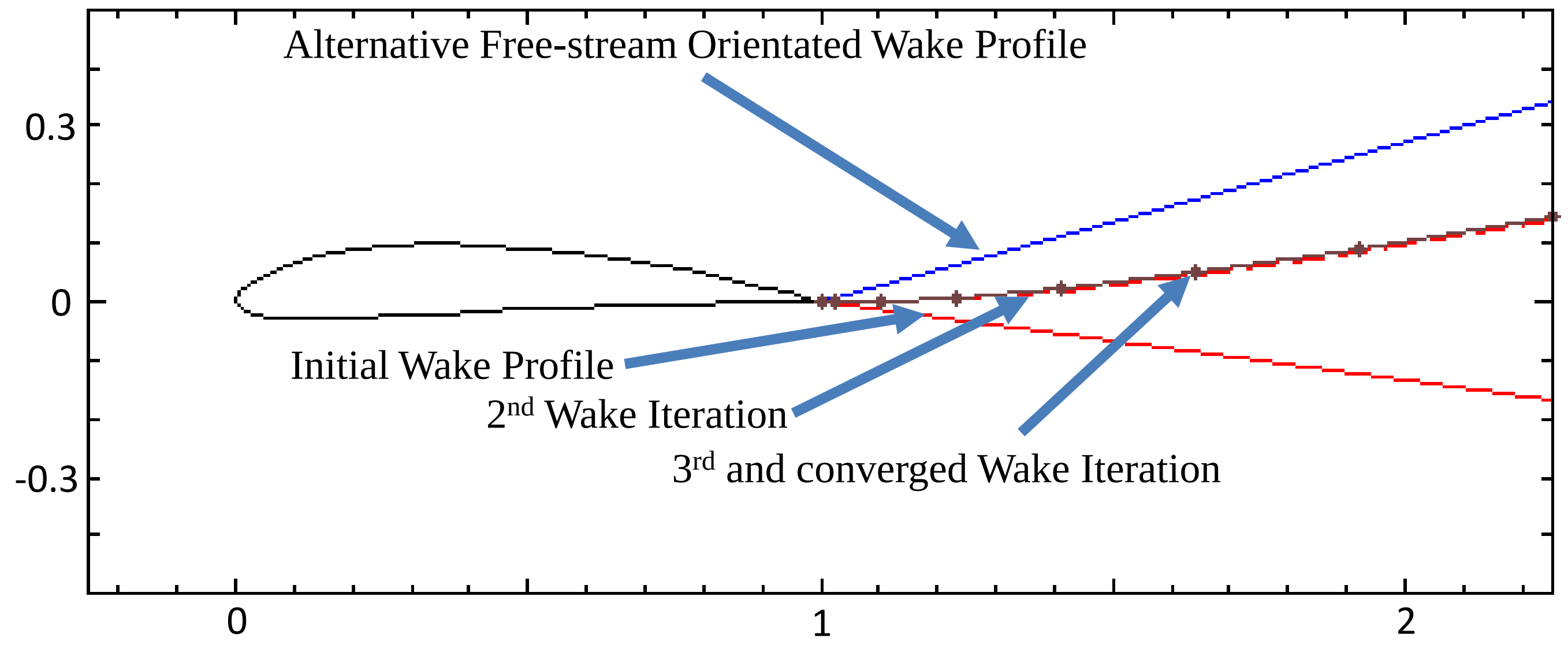


Figure 4: Implementation of the spatial wake relaxation scheme on a NACA 4412 airfoil, Re = 1,000,000 and α = 15°, where the wake is initially orientated to align with the airfoil's trailing edge bi-sector angle.

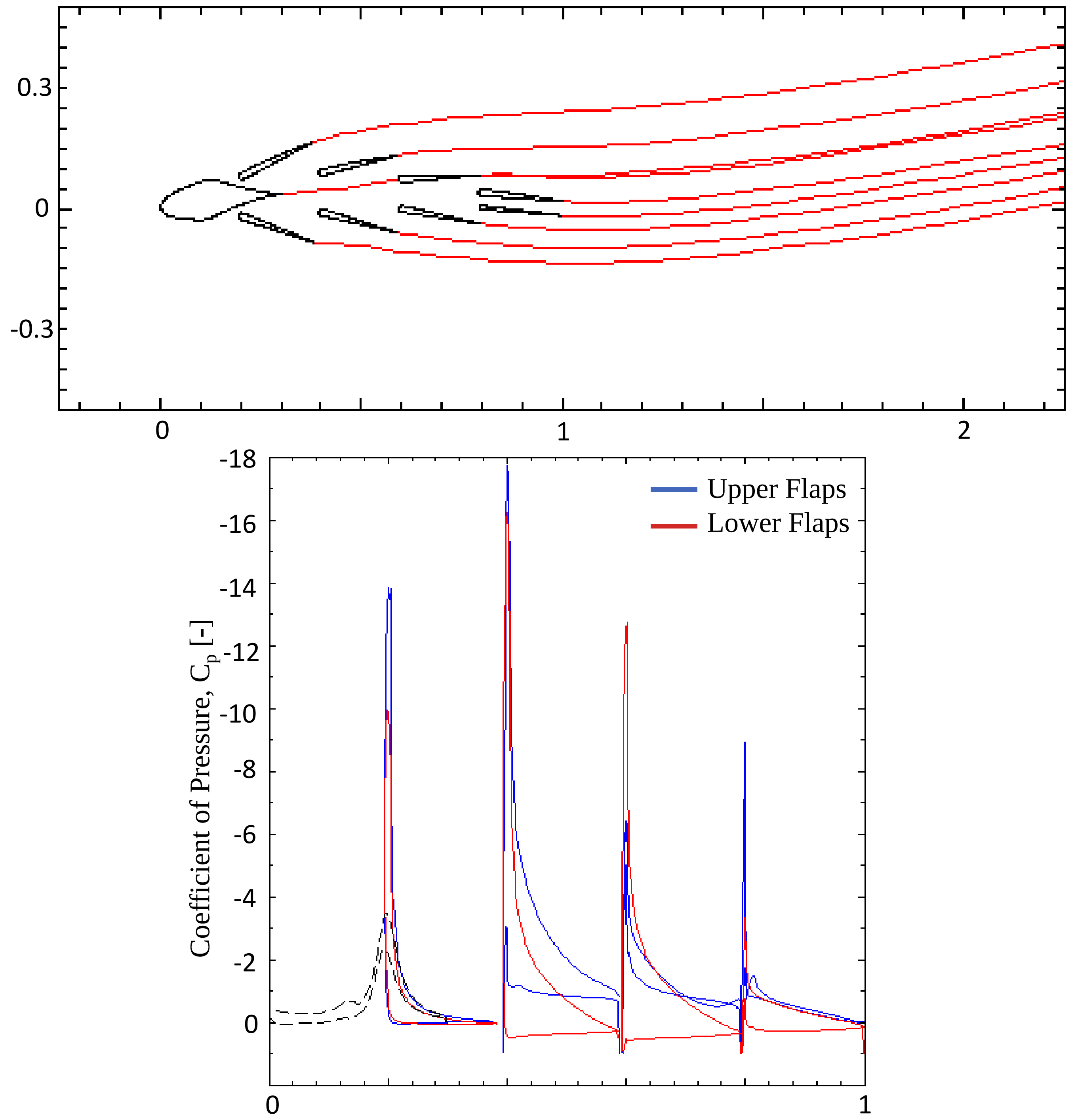


Figure 5: Implementation of the spatial wake relaxation scheme on the Bioinspired morphing wing (Top) and the Coefficient of Pressure distribution across the each element (Bottom), where Re = 1,000,000 and α = 15°, $\delta_1 = 20°$, $\delta_2 = 15°$, $\delta_3 = 10°$, $\delta_4 = 5°$, $\delta_5 = -20°$, $\delta_6 = -15°$, $\delta_7 = -10°$, $\delta_8 = -5°$

RESULTS

During the panel method simulations, a single module of 8-chord-wise flaps were modeled. Due to the spacing caused by the wing's rib structure, the influence between neighboring modules is neglected. Subsequently, this allows complex geometries to be developed piece-wise along the wing's span.

The wake of each flap is individually modeled and the influence on the neighboring elements and wakes assessed. The wake relaxation scheme must achieve convergence for all flaps prior to boundary layer implementation.

A two-dimensional boundary layer theory is employed in the chord-wise direction. The boundary layer is modeled over each chord-wise array and integrated along the wing's span to determine the resultant lift, drag and moment coefficients of the defined configuration.

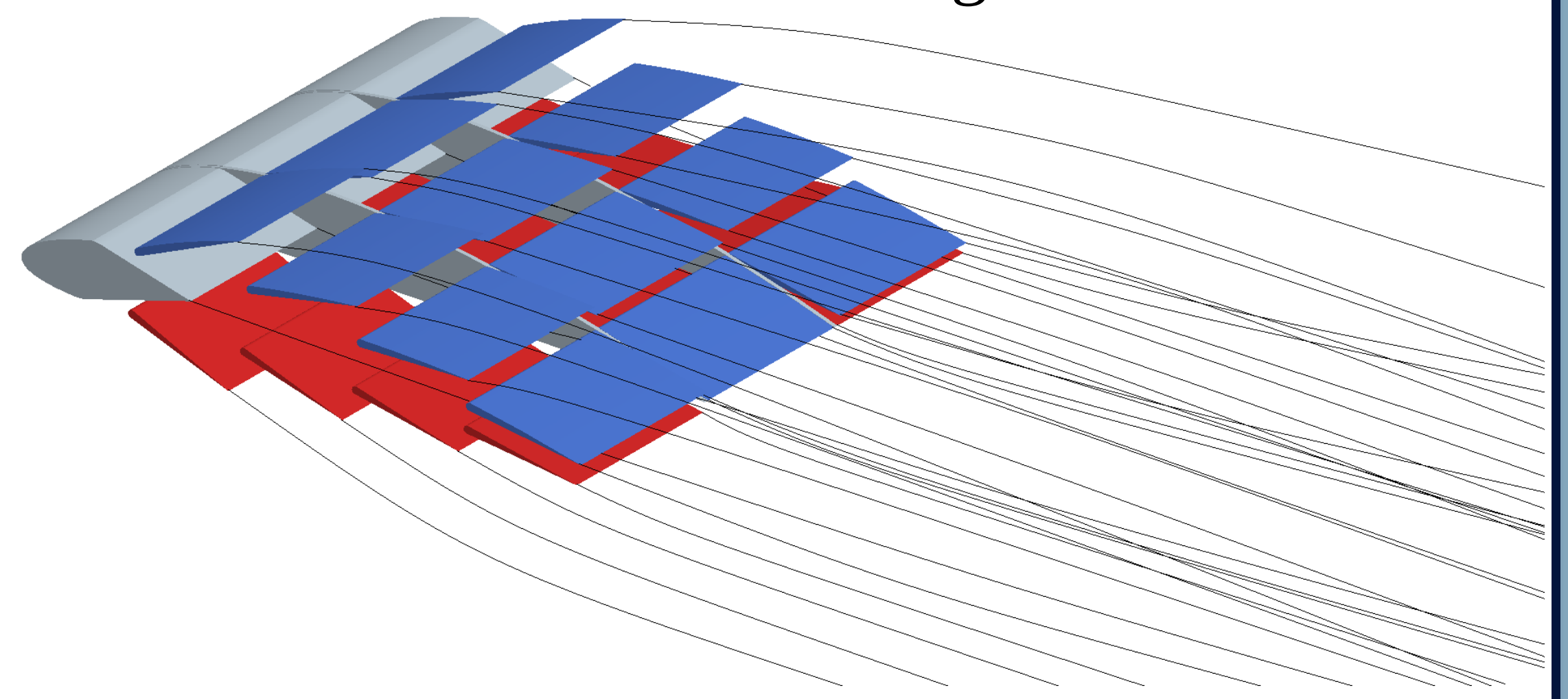


Figure 6: Multi-Element Airfoil with Trailing-Edge Wake Geometry in Complex Configuration:
$\delta_{11} = 20$, $\delta_{12} = 15$ $\delta_{13} = 10$, $\delta_{14} = 5$, $\delta_{15} = -20$, $\delta_{16} = -15$, $\delta_{17} = -10$, $\delta_{18} =-5$
$\delta_{21} = 15$, $\delta_{22} = 10$, $\delta_{23} = 5$, $\delta_{24} = 0$, $\delta_{25} = 0$, $\delta_{26} = 0$, $\delta_{27} = 0$, $\delta_{28} = 0$,
$\delta_{31} = 20$, $\delta_{32} = 15$, $\delta_{33} = 10$, $\delta_{34} = 5$, $\delta_{35} = 15$, $\delta_{36} = 10$, $\delta_{37} = 5$, $\delta_{38} = 0$

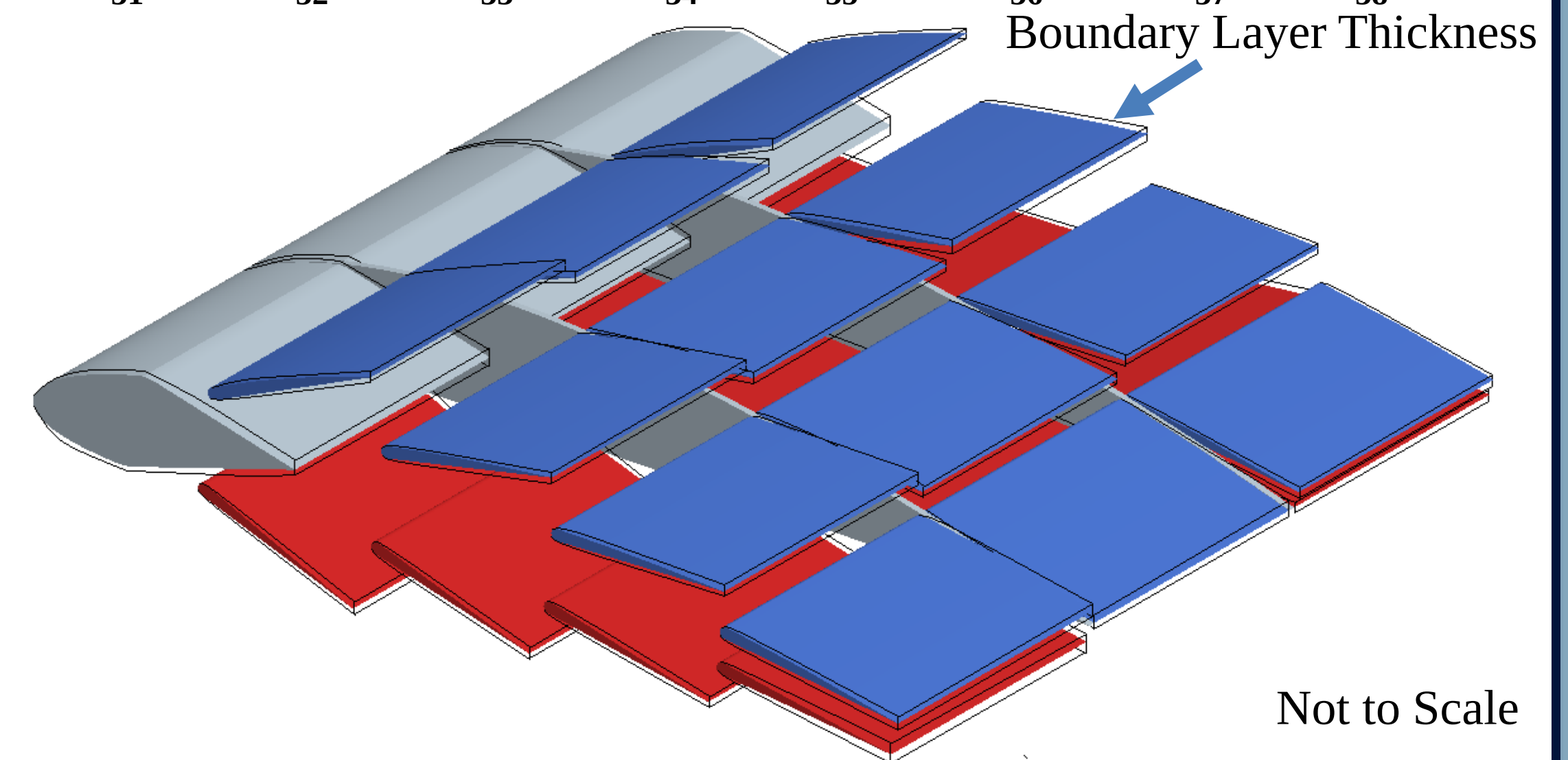


Figure 7: Multi-Element Airfoil with Boundary Layer Thickness applied

CONCLUSIONS

This iterative panel method with a spatial wake relaxation scheme and boundary layer theory enables both inviscid and viscous flow characteristics to be modeled around a multi-element morphing wing. This efficient and robust technique enables complex wing geometries to be assessed for advanced vehicle design.