Mathematical Modeling of Aircraft Wings Encountering Gusts

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Introduction

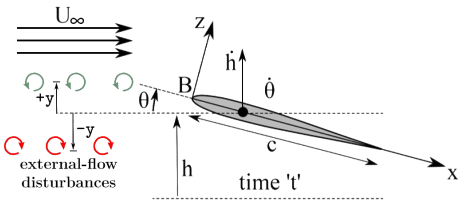
- ❖ Aerodynamic forces are strongly influenced by vortex dynamics
- ❖ Leading-edge vortex (LEV) shedding is a hallmark of many unsteady flows

- ❖ Insects, birds, and man-made micro-air vehicles exploit LEVs to generate lift

- ❖ However, LEVs can also cause flow separation, dynamic stall, and instability — especially in rotorcraft, wind turbines, and aircraft encountering gusts

Objectives

- ❖ Based on Unsteady Thin Airfoil Theory
  - ○ Model Airfoil Behavior in Response to:
    - ❖ Pitching θ(t), Heaving h(t), & EFDs

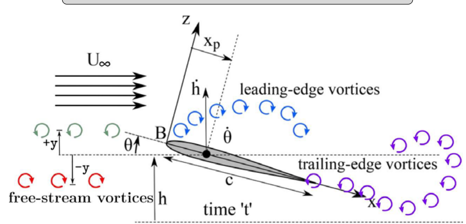


- ❖ Model the flow field using discrete vortices (DVs)
- ❖ Represent the airfoil as a DV-distribution
- ❖ Compute aerodynamic loads on the airfoil

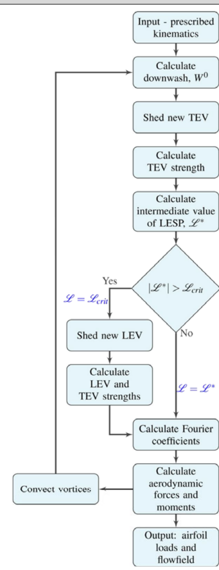
Methodology

- ❖ Release discrete gusts ahead of the airfoil
- ❖ Shed trailing-edge vortices (TEVs) at each time step
- ❖ Trigger LEV formation and shedding via a leading-edge suction criterion

Schematic of the Simulation



Flowchart for the LDVM algorithm

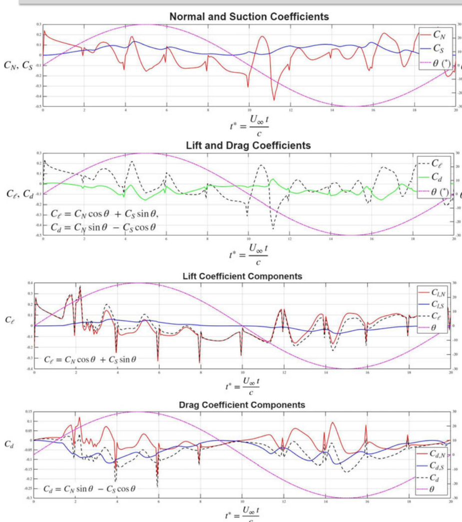


References

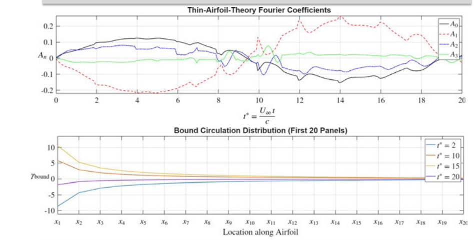
- ❖ **Suresh Babu, A. V., Medina, A., Rockwood, M., Bryant, M., & Gopalarathnam, A**. "Theoretical and experimental investigation of an unsteady airfoil in the presence of external flow disturbances"
- ❖ **Suresh Babu, A. V., Narsipur, S., Bryant, M., & Gopalarathnam, A**. "Leading-edge-vortex tailoring on unsteady airfoils using an inverse aerodynamic approach"
- ❖ **Suresh Babu, A. V., Narsipur, S., & Gopalarathnam, A**. "Lift tailoring on unsteady airfoils with leading-edge vortex shedding using an inverse aerodynamic approach"

Results

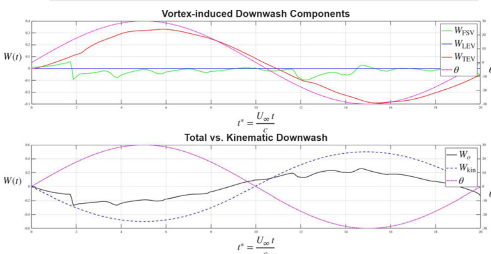
Airfoil Normal, Suction, Lift, and Drag Coefficients



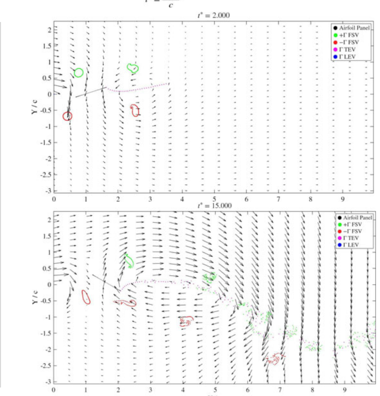
Fourier Coefficients and Airfoil Bound Circulation



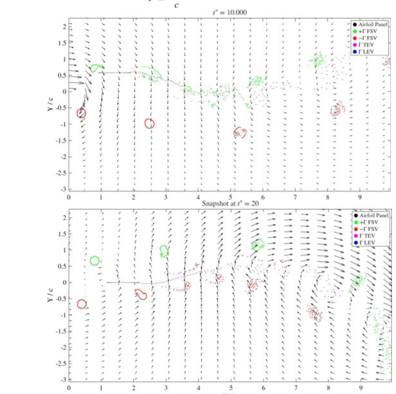
Downwash experienced by Airfoil



Simulation Snapshots



Simulation Snapshots



Conclusions

- ❖ The airfoil's unsteady aerodynamic behavior is a function of its motion, surrounding flow field, and vortex interactions
- ❖ The results demonstrate the dynamic relationship between motion-induced flow features and the resulting aerodynamic loads

Future Work

- ❖ Refine the simulation model to more accurately reflect experimental data
- ❖ Extend the framework to achieve targeted lift profiles under gusty conditions
- ❖ Demonstrate real-time airfoil adjustment in response to external flow disturbances
- ❖ Explore machine learning techniques as an alternative modeling strategy