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Unsteady vortex lattice method for an active morphing airfoil

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The concept of a morphing wing is characterized by continuous surface changing its shape to perform various maneuvers. Additionally, such wing can alter its shape to an optimal shape determined by given flight conditions. This ability leads to improved lift to drag ratio and fuel consumption among other advantages. To model the aerodynamics several methods can be used. This extended abstract will focus only on panel methods based on potential flow to derive aeroelastic models that will be used for control design and optimization in our ongoing research of morphing wings.

The potential flow is characterized by the assumption of inviscid and irrotational flow where the velocity field is obtained as a gradient of a scalar field [1], [2], [3]. This model is applicable to attached flows with large Reynolds number and so it can be used to model the flow around a wing (airfoil) with low angles of attack. Panel methods are boundary element methods that discretize the surface of a body into discrete panels with singularity elements (source, doublet, point vortex) that are solutions to Laplace equation which describes an incompressible flow. Then the boundary condition of flow tangency on these panels is prescribed and the flow is described by linear combination of individual singularity element solutions that satisfies the boundary condition. When only a lifting surface is considered instead of a lifting body the approach is usually called a lattice method [2].

There are two approaches to unsteady potential flow modeling for lifting surfaces. The doublet lattice method (DLM) which uses an acceleration potential to relate the normal velocity at an oscillating lifting surface, described by natural modes, to pressure difference across the surface [1], [3]. DLM is the industry standard for aeroelastic analysis. The results of DLM are in frequency domain and can be transformed into time domain via rational function approximation [3]. The other approach is the unsteady vortex lattice method (UVLM) which uses the velocity potential to describe velocity field of the flow and is directly derived in time domain [2], [3]. However, unlike DLM which only models the lifting surface, UVLM must model the lifting surface and the wake produced by this surface, because the wake influences the velocity field around the wing in unsteady flows (Fig. 2) [2], [3]. This necessity greatly increases the number of states needed to describe the system. However, our goal is to use this high order nonlinear model to generate data which would be used for methods like dynamic mode decomposition, which reduces the model order, to obtain a linear dynamical system for the controller. The aeroelastic model is obtained by using the pressure distribution from aerodynamic model as load in structural model, then the structural deformations are used to adjust the aerodynamic mesh geometry.

Unfortunately, at the time of writing this extended abstract the aeroelastic model isn't working as intended so only the aerodynamic part is presented. The full aeroelastic model of an active morphing airfoil will be presented at the conference. The UVLM aerodynamic model is applied to a sudden acceleration of a flat plate, which can also be viewed as a step change from zero angle of attack. Theoretical lift response of this step change is described by the Wagner function [2]. The normalized lift simply means $L(t)/L(t{=}\infty)$ and nondimensional time is the distance traveled in terms of wing chords. The comparison of lift responses between various models is shown on Fig. 1, while Fig. 2 shows the wake rollup of the UVLM model and the comparison to starting trailing vortex visualized by Prandtl.

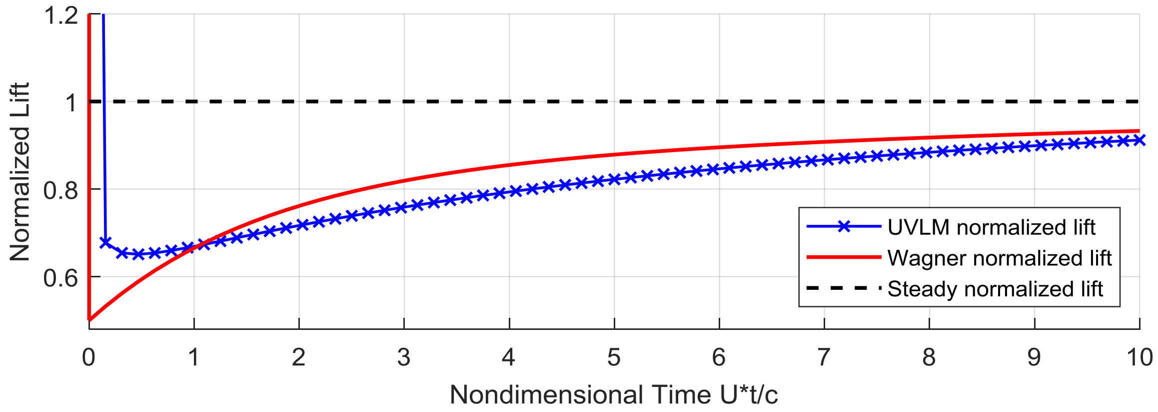

Fig. 1. Comparison of normalized lift response during sudden flat plate acceleration

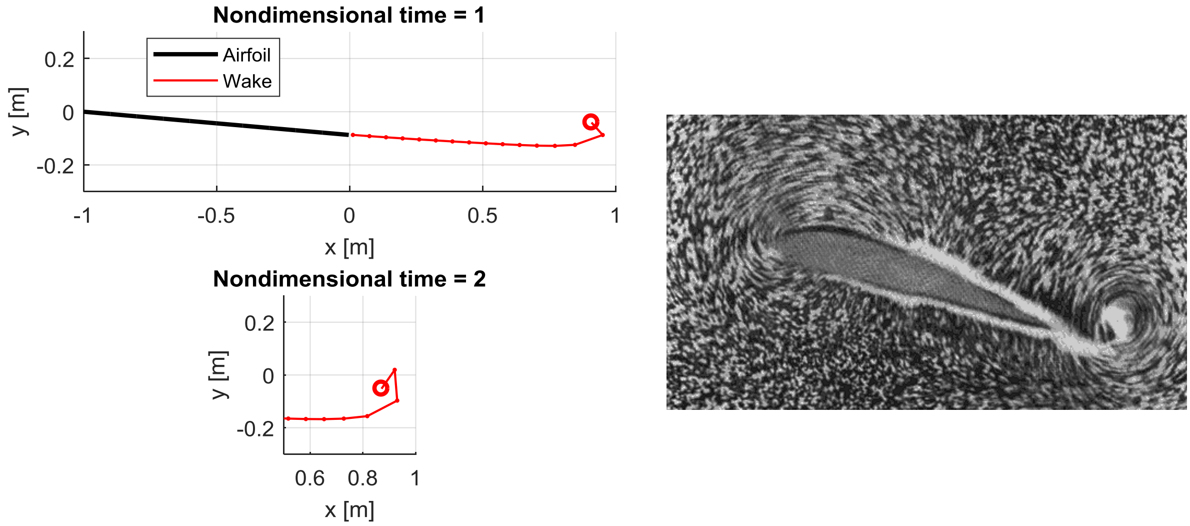

Fig. 2. Wake rollup during sudden flat plate acceleration (left), flow visualization of starting trailing vortex by Prandtl (right)

Acknowledgements

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