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Bayesian sparse learning of the Leishman-Beddoes model of aerodynamic stall using data from aeroelastic wind tunnel experiments

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Abstract

The foundation of the Leishman-Beddoes model is a linear unsteady aerodynamic model, upon which several sources of nonlinearity are superimposed, coupled through the structural displacements and velocities. Namely, the sources of nonlinearity are trailing edge flow separation and leading edge vortex shedding. The semi-empirical model has several levels of hierarchy, consisting of components based on i) the static characteristics of the airfoil, ii) the linear dynamic behaviour of the airfoil under attached flow conditions, and iii) the nonlinear dynamic behaviour of the airfoil through the phases of flow separation and reattachment during aerodynamic stall.

Despite its widespread use, there are parameter values available in the literature for many standard airfoil cross-sections. However, these parameter values are typically reported as point estimates obtained by manual tuning or simple regression methods, using data from experiments with a prescribed motion schedule over a limited range of angles of attack and frequencies. This limits the applicability of the model in operating conditions that vary from the regime of the training data, such as large amplitude limit cycle oscillations (LCO) about a zero-mean angle of attack. While the mechanistic description of the physics underlying aerodynamic stall makes the model appealing, the current work is inspired by the inadequacy of the model in accurately capturing the large amplitude LCO recorded during wind tunnel experiments on an elastically mounted pitching airfoil when using standard reported values. Leveraging a robust Bayesian calibration framework, the parameters of the dynamical model will be estimated from wind tunnel experimental data from aeroelastic experiments. This Bayesian framework incorporates the use of sparse learning to alleviate overfitting and improve the ability of the estimated model to generalize to unseen data. This is particularly relevant to the nonlinear components of the model which invokes a series of discontinuous piecewise functions relying on a number of empirical coefficients to model the effect of the chordwise location of the trailing edge flow separation point and leading edge vortices on the resultant aerodynamic loads. While estimating values for each of these coefficients can improve the average data-fit for a given experiment, the increased model complexity may actually hinder the ability of the model to generalize. The sparse learning component permits the concurrent estimation of the parameters and the optimal sparse representation of model parameters vis-a-vis model complexity.

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