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ACCOUNTING FOR AEROELASTICITY MODEL-FORM UNCERTAINTY IN A BAYESIAN FRAMEWORK

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Uncertainty quantification is of crucial importance in the field of aeroelasticity [1]. Dramatic changes in the critical flutter speed can be observed for inherent small variations of the aeromechanical parameters and models. Although numerous studies deal with the propagation of parametric uncertainties in the physical properties through the modeling process to compute the stochastic response of the aeroelastic system, few works account for the variabilities induced by the aeroelastic model itself.
In this work, Bayesian Model Averaging [2] is employed to quantify and reduce model-form uncertainty in the linear behavior of an elastically mounted airfoil with degrees of freedom in pitch and plunge motions (Fig. 1a). The deterministic flutter boundary is computed using standard $V-g$ analysis. Here, the quantification and calibration of model-form uncertainty concern approximations of Theodorsen circulation function [3] used to describe the unsteady time-harmonic incompressible aerodynamic operator. Instead of considering each approximation separately [4], we cast the most popular Theodorsen's function approximations [5] into two families, depending on their number of states. The coefficients of the two models, which are treated as parametric uncertainties, are calibrated using Bayesian inference with regard to the critical flutter velocity.
The basic steps of the present methodology can be depicted as follows: (i) First, the forward uncertainty quantification process and its corresponding sensitivity analysis, are performed by propagating the prior pdf of the model coefficients through the $V-g$ analysis. (ii) Then, each aerodynamic model is calibrated using standard bayesian inference given a set of experimental data (Fig. 1b-1c). The stochastic model is evaluated using MCMC with Gibbs sampling. (iii) Finally the Bayesian Model Averaging approach is employed to make new predictions (Fig. 1d). Results show substantial reductions in the predictive uncertainties of the critical flutter speed compared to non-calibrated stochastic simulations.

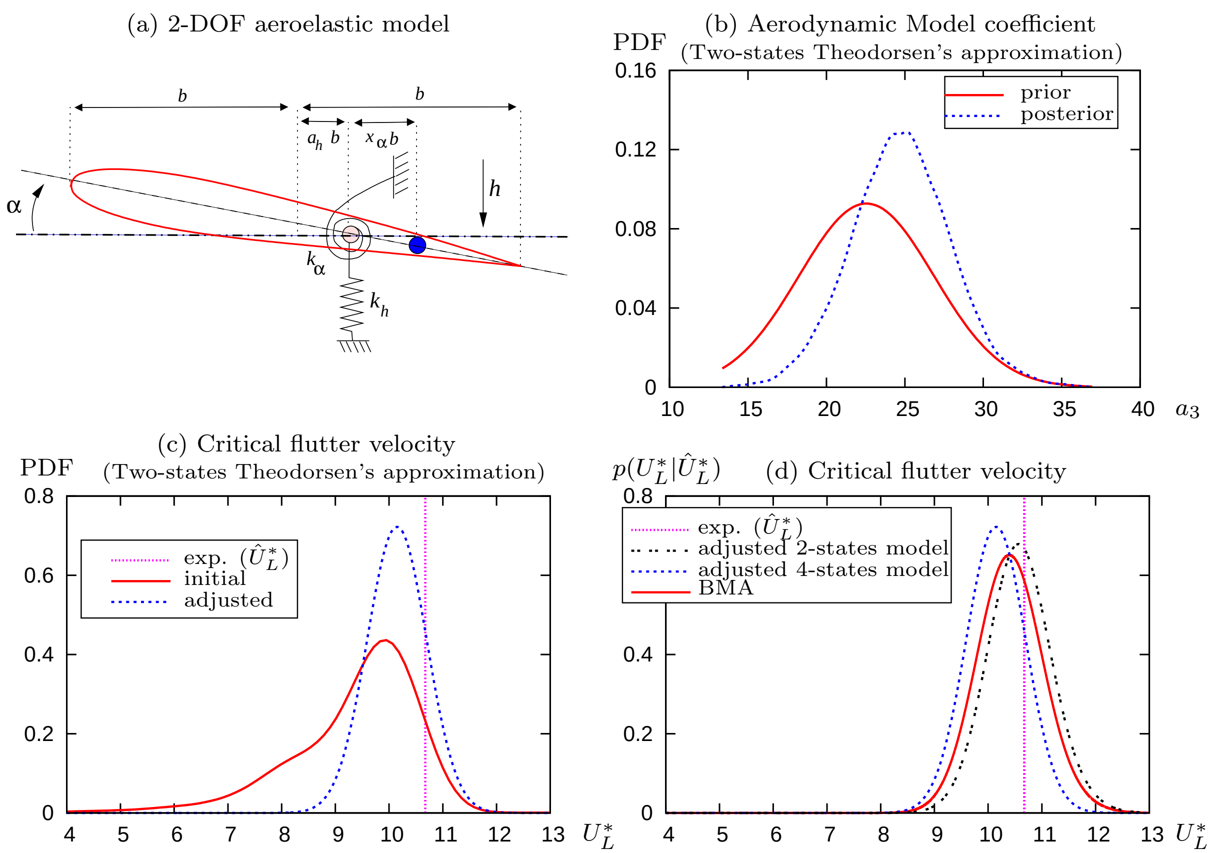

Figure 1: (a) Two-degree-of-freedom pitch-and-plunge airfoil aeroelastic model. (b) Prior and posterior distributions of the 2-states aerodynamical model parameters. The posterior is evaluated by assimilating a set of four experimental values of the flutter speed $\hat{U}_L^*$ in the Bayesian Inference analysis. (c) Flutter velocity predictive distribution of the 2-states Theodorsen's approximation model obtained by propagating the updated distribution of the model parameters. The resulting adjusted aerodynamic model accounts for the estimation prediction error. (d) Predictive distributions of the linear flutter velocity U_L^* and resulting combined model distributions computed using Bayesian Model Averaging.

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