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Model reduction in aeroservoelasticity

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1. Introduction

Aeroservoelasticity is a field focusing on interaction between aerodynamic forces, elastic forces, and control forces acting on a body [4]. To correctly predict these interactions complex numerical models are often used. The complexity of the numerical models can vary however the resulting numerical model is usually nonlinear and of high order. At this stage the model cannot be used for control law design and model reduction is required. Essentially there are two approaches to reduce the order of a model [2]. First approach is to project the dynamics of high-dimensional system onto a low-dimensional subspace. Second approach is system identification which uses collected data, either from experiment or simulation, to construct low order models that match the input-output relationship of the data [2], [3]. Due to the ease of implementation, system identification is often preferred for control law design. The rest of this extended abstract focuses on methods which produce linear models such as eigensystem realization algorithm or dynamic mode decomposition [2].

Eigensystem realization algorithm (ERA) was first introduced in 1985 to identify modal parameters and reduce dynamic systems from experimental data [3]. The method is based on obtaining Markov parameters from impulse response experiment, which are then used to construct a generalized Hankel matrix. Singular value decomposition (SVD) of the Hankel matrix is then performed to reduce the order of the model and obtain the state matrices of linear dynamic system. If the data is collected from a simulation, then obtaining impulse response of the system is quite simple. If the data is collected from an experiment where impulse response might not be possible to perform, then a pseudo random input can be used and subsequently observer Kalman filter identification (OKID) can be used to extract impulse response of the system from the collected data [2].

2. Example: 2D flow over a flat plate with single control input

The data input-output impulse response data is collected from a simulation of unsteady vortex lattice method (UVLM) coupled with linear finite element model. The input is the control force and outputs are coefficient of lift C_L and vertical displacement velocity $\dot{z}$ at the trailing edge of the plate (Fig. 1). ERA is used to extract linear dynamic model from the data. Order of the reduced model is determined by a choice based on singular values of the Hankel matrix (Fig. 2). Fig. 3 shows both simulation model response and reduced model response to a ramp and sine wave inputs. This reduced order model is now suitable for control engineering applications. It should be noted that the states of ERA model are not physical states such as position or velocity. Therefore, use of control techniques which rely on model output is necessary, for example model predictive control, LQR with output feedback, or SHAVO [1].

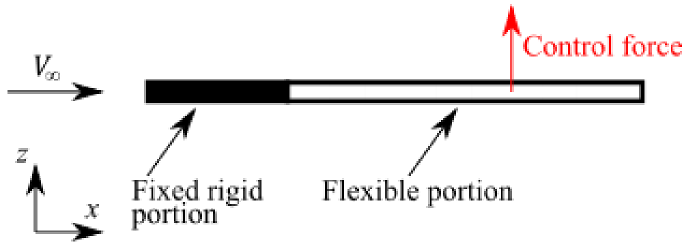

Fig. 1. Illustration of the flow over partially flexible flat plate with a control force input

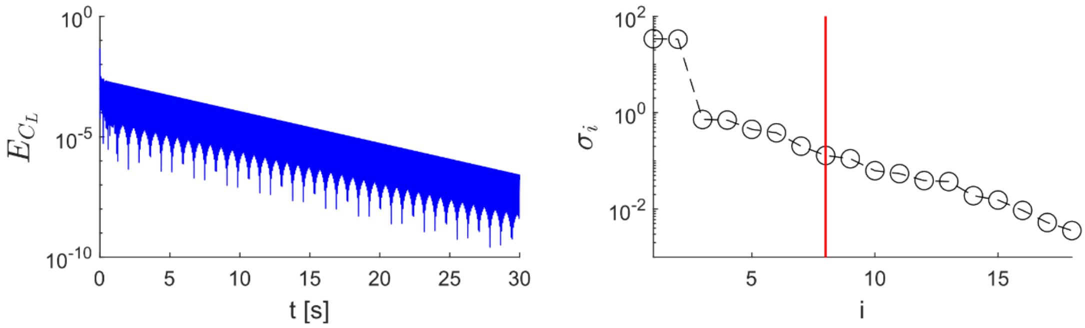

Fig. 2. Lift coefficient error between simulation and ERA outputs for impulse response (left). Several singular values of Hankel matrix and selected model order (right)

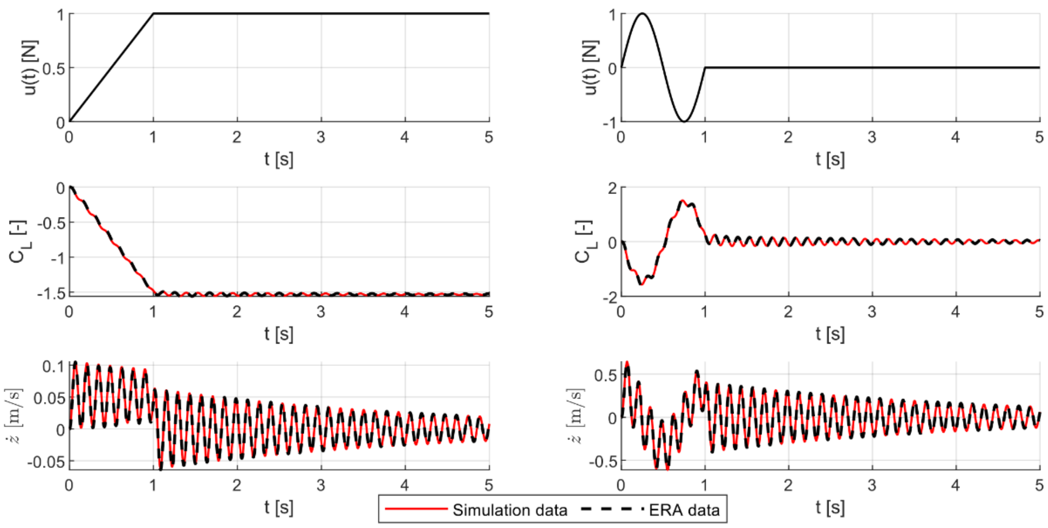

Fig. 3. Model responses to ramp and sine wave inputs

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