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Dissertation:

System Identification of Parameter-Varying Aeroelastic Systems using Real-Time Operational Modal Analysis

Brief popular scientific abstract of the PhD thesis:

The dynamic behavior of complex systems such as civil structures, electrical circuits, biological processes and machinery can be described by a mathematical model consisting of just a handful of *modal parameters* such as damping ratio, eigenfrequency and normal mode. The damping ratio quantifies the vibration amplitude decay or increase due to energy loss or gain. The eigenfrequency is the rate at which a structure oscillates when no driving force or damping is present. A normal mode is the vibration pattern that a structure assumes when excited at one of its eigenfrequencies.

System identification constructs such a mathematical model by analyzing the signals produced by a dynamic system. In particular, the methods of *operational modal analysis* estimate modal parameters solely from the response due to unknown or unmeasurable ambient excitation. Operational modal analysis has several applications in the monitoring of civil structures or aeroelastic systems such as wind turbines and aircraft.

Aeroelasticity studies the interaction between aerodynamic forces induced by the airflow and the elastic forces in the structure. Aeroelastic systems are said to be *parameter-varying* because their modal parameters are functions of airflow variables such as flight speed and altitude. Under certain airflow conditions, *aeroelastic flutter* may arise – a type of self-excited unbounded oscillations occurring when the damping ratio decreases below a threshold. The Tacoma Narrows Bridge collapse is a widely known case of aeroelastic flutter: the coupling between the motion induced by the wind and the elastic response of the structure led to structural failure due to increasing vibration amplitude. Flutter is not to be confused with resonance: the former arises when a structure absorbs energy from the surrounding fluid, leading to a dynamic instability regardless of excitation; the latter is the response amplification due to a driving force having the same frequency as one of the system's eigenfrequencies.

The flutter margin of newly-developed or modified aircraft must be demonstrated within the whole flight envelope with a flight vibration test. In this regard safety and efficiency can be enhanced by monitoring the flutter margin in real-time while flight conditions vary. This can be performed by estimating the aircraft's modal parameters from the measured acceleration response induced by air turbulence.

To this end, this thesis contributes to the theoretical understanding of parameter-varying aeroelastic systems and demonstrates real-time operational modal analysis during flight vibration testing on a research aircraft. The analytical formulations and experimental results illustrate the estimation and tracking of eigenfrequency and damping ratio as functions of time or flight parameters.