System identification of aeroelastic parameter-varying systems using real-time operational modal analysis

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BACKGROUND

The development and testing of new or modified aircraft require the evaluation of the aeroelastic stability to avoid the phenomenon of *flutter*, a self-excited oscillation of the airframe.

Since the analysis of flutter stability comprises coupled simulations of numerical structural models and unsteady aerodynamic loads, the effort is demanding.

Adequate aeroelastic stability must be demonstrated in flight for the whole flight envelope up to maximum speed and maximum altitude (*flight vibration test, FVT*).

OBJECTIVES

This project addresses a technique for fast identification of eigenfrequencies and damping ratios using *operational modal analysis methods* (OMA). Its goals are to:

- determine if pilot input, air brakes and turbulence provide adequate excitation for modal parameter estimation
- monitor the dynamic response of the aircraft during flight vibration testing
- investigate the limits of modal parameter identification within the framework of output-only modal analysis (OMA) for parameter-varying systems.
- track the evolution of eigenfrequency and damping ratio over flight parameters to monitor the flutter boundary

FLIGHT VIBRATION TESTING

Flight speed, temperature and air density influence the modal parameters of aeroelastic systems. In order to monitor the flutter boundary, system responses are acquired and processed in real-time and in flight to estimate the current eigenfrequencies and damping ratios of the aircraft. This allows safe operation during testing.

Figure 1: The DLR Gulfstream G550 HALO research aircraft and some features of the test campaign

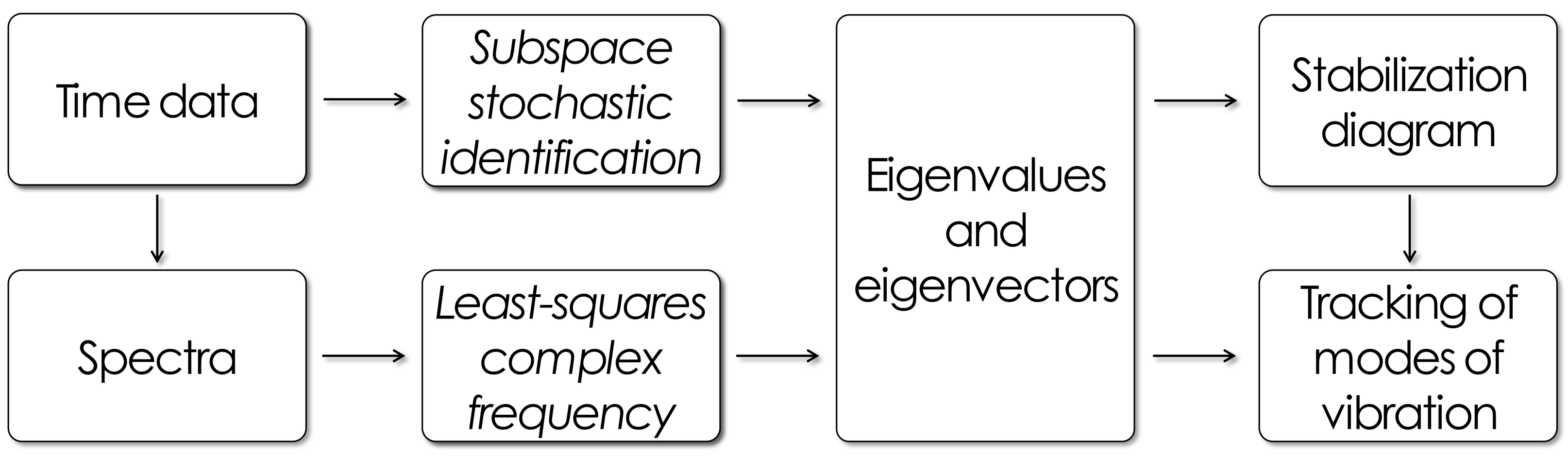

Figure 2: Analysis steps – from data acquisition to modal parameters (see following figures for more details)

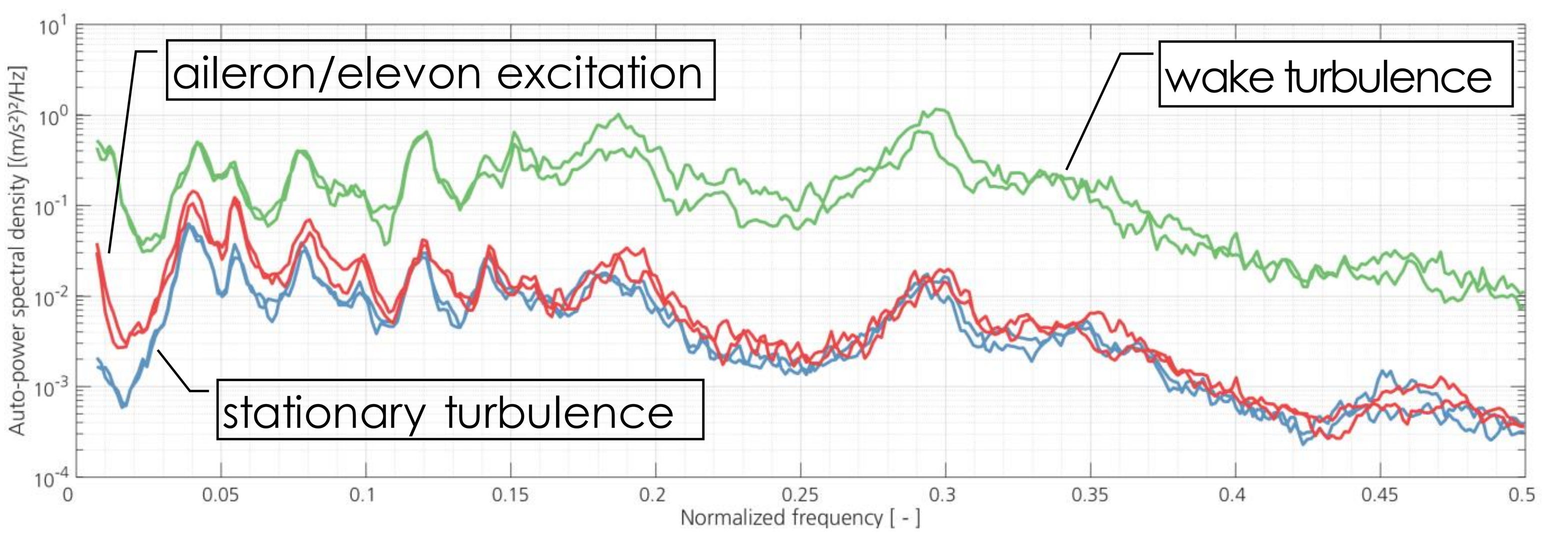

Figure 3: Cross-power spectral densities from about 70 accelerometers are estimated every couple of seconds: this is the input for frequency-domain algorithms

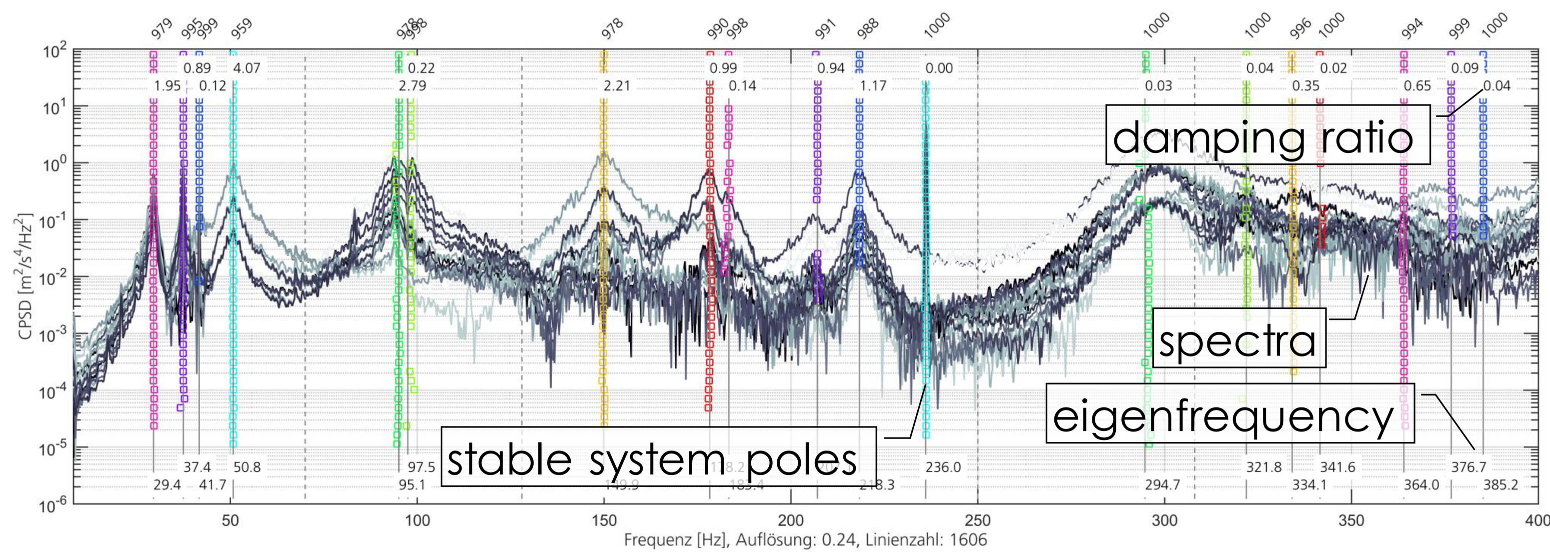

Figure 4: System identification is performed continuously and in real-time using *Stochastic Subspace Identification* (SSI) or *Least-Square Complex Frequency* (LSCF)

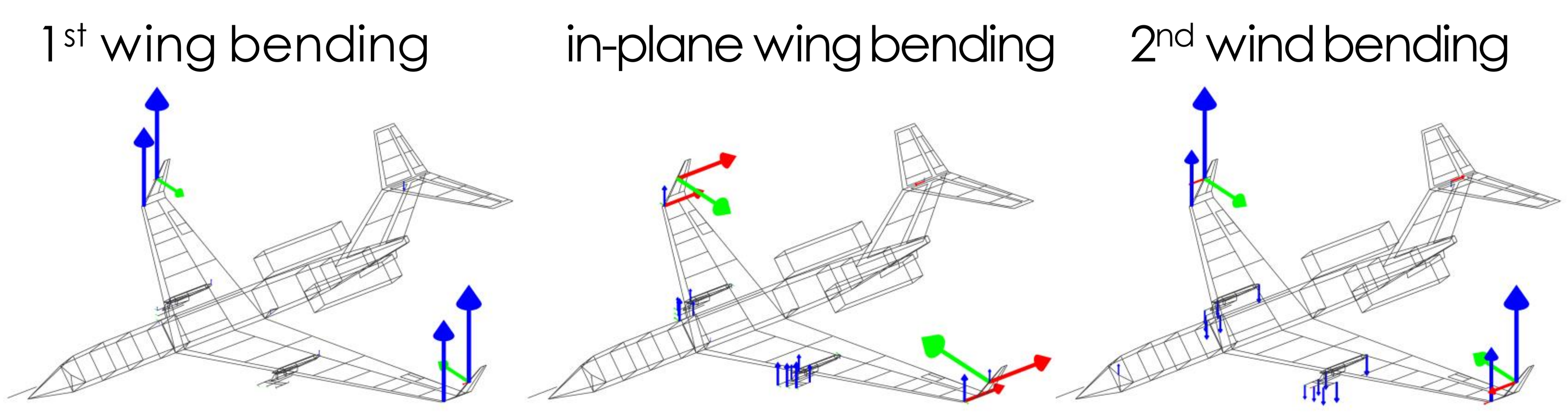

Figure 5: A tracking algorithm recognizes the identified mode shapes by clustering; the relationship between external and modal parameters is then easily inspected (see next figure)

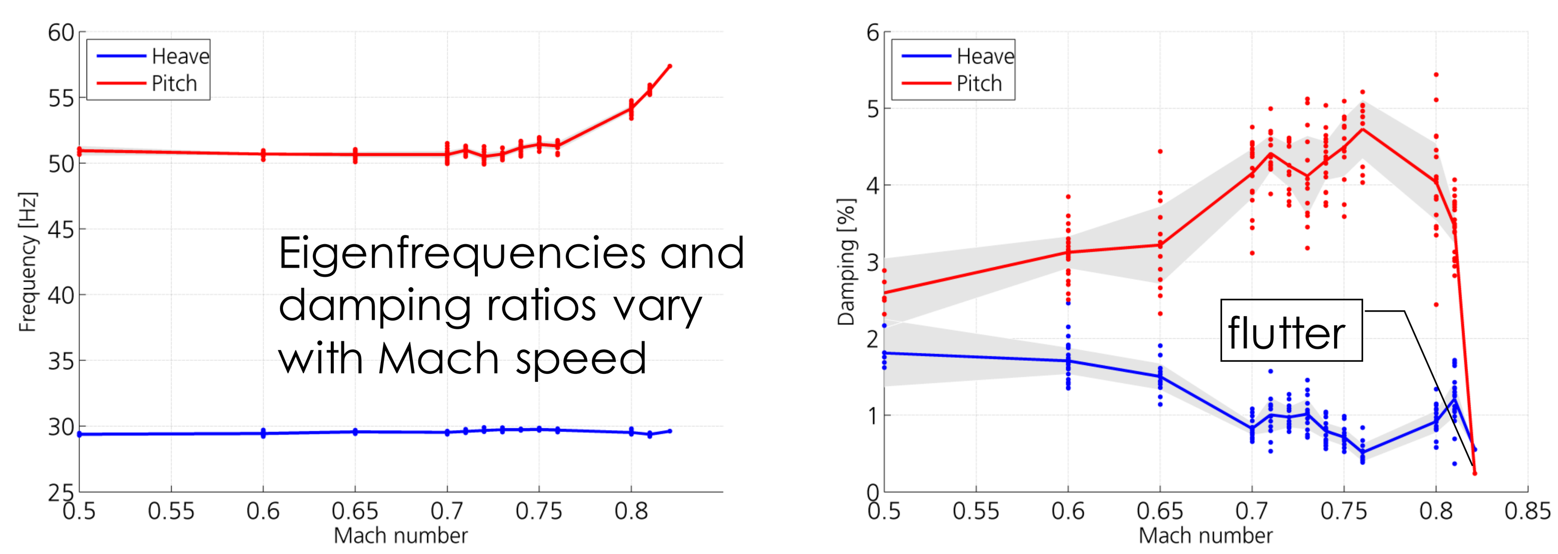

Figure 6 The eigenfrequency and damping ratio variation of two eigenmodes with Mach number is displayed: if the damping becomes negative, flutter arises and vibration amplitudes increase without bound until the structure fails

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