First-Principles-Based Low-Order Modeling of Flight Dynamics and Aeroelasticity for Designing Future Aircraft

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Tighter performance requirements place a formidable challenge to designing future aircraft. Optimizing existing vehicles for increasing efficiency and reducing emissions leads to light-weight, high-aspect-ratio-wing configurations prone to instabilities and showing coupled flight dynamic and aeroelastic response. Moreover, traditional tube-and-wing layouts may not allow to achieve the necessary performance improvements. Therefore, there is a growing interest in unconventional concepts. While innovative designs offer advantages, they may show non-intuitive behaviors that further challenge design and qualification.

The trend towards higher-aspect-ratio wings and unconventional configurations in the next generation of aircraft calls for novel multidisciplinary models suitable for computation-based design. In developing these models, it is desirable to leverage the capabilities of state-of-the-art solvers for describing individual disciplines with high fidelity. This is particularly appealing for exploring novel non-traditional designs due to the lack of past experience and the difficulties in developing simplified models. Using high-fidelity descriptions since the early design while accounting for discipline interactions allows to anticipate negative consequences of couplings and exploit their benefits to achieve target performance with fewer design iterations and lower development cost. However, detailed multidisciplinary models can be too computationally expensive for design, particularly at the early stages. While numerical model order reduction techniques can be used to obtain lower-order representations, they do not preserve a connection with the physics, so limiting engineering intuition and interpretation of results.

My doctoral research proposed a physics-based, low-order formulation for the coupled flight dynamics and aeroelasticity of flexible aircraft in free flight. The formulation was derived from first principles using a modal representation of the aircraft elastic motion superimposed to a fully nonlinear description of the overall (rigid-body) motion. A methodology was presented to evaluate the formulation coefficients using data from off-the-shelf structural and aerodynamic solvers without placing any assumptions on the underlying model representations. As a result, an integrated flight dynamic/aeroelastic analysis framework was implemented that is readily applicable to complex aircraft configurations described by models of variable fidelity throughout the design cycle. The proposed approach thus leverages the capabilities of state-of-the-art single-discipline solvers used in practical aircraft design while accounting for couplings using few degrees of freedom and keeping a first-principles-based approach that facilitates physical insights.

This talk will introduce the proposed formulation and the implementation methodology based on data from off-the-shelf solvers. Results will be presented for the coupled flight dynamic and aeroelastic stability of two existing configurations: the Body Freedom Flutter demonstrator by Lockheed Martin and the X-HALE aeroelastic testbed developed at the University of Michigan, where I conducted part of my doctoral research. Finally, future developments of the work will be outlined and related to my current postdoctoral research on integrating dynamic aeroelasticity into high-fidelity multidisciplinary design optimization of next-generation aircraft.