EFFICIENT COMPUTATIONAL METHODS FOR FLEXIBLE MULTIBODY DYNAMIC SYSTEMS WITH AERODYNAMIC INTERACTIONS

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Key words: Flexible-Aircraft Dynamics, Reduced-Order Modelling, Load Alleviation.

Geometrically-nonlinear beam theories are key in the development of highly-optimised, next-generation aircraft with higher-aspect-ratio wings [1]. To understand the static and dynamic characteristics of such vehicles, one needs to couple composite beam formulations with appropriate aerodynamic models with arbitrary kinematics. This requires efficient computational methods starting with the flexible multibody dynamic description to reduce the numerical burden of solving the coupled geometrically-nonlinear equations of motion (EoM). Only then are such higher fidelity tools attractive (and applicable) in the preliminary design of more efficient aircraft and large offshore wind turbines.

To address this, we have coupled a displacement-based, geometrically-nonlinear flexible-body dynamics formulation [2], as proposed by Géradin and Cardona [3], with a three-dimensional (3-D) unsteady aerodynamics solver [4]. Both ingredients in the coupling are geometrically nonlinear and can be used to assess the effect of wing bending at trim on the vehicle lift distribution its impact on the vehicle dynamic stability characteristics. This is illustrated in Figure 1 which shows the trim deformations of a UAV with increasing wing flexibility. However, even for extremely flexible configurations, the dynamic response is mostly driven by the large static deformations at trim [2].

Hence, this work proposes a novel model reduction approach starting with a linearisation of the structural degrees of freedom (DoF) in the nonlinear flight dynamic response of flexible aircraft with geometrically nonlinear trim deformations. Note that this linearisation is consistent, such that the overall motions of the vehicle are allowed to be arbitrarily large.
and the inertial couplings between the large rigid-body dynamics and small structural
deformations are preserved. As a result, the structural DoF of the coupled (nonlinear)
system can be projected onto the vibration modes of the unconstrained vehicle. This
allows the modal coefficients to be written in constant tensor form with up to cubic terms
in the nonlinear flight dynamics, which are sparse and can be pre-computed.

Such a modal description significantly improves the numerical efficiency of the flexible-
body EoM, but also provides a generic platform for coupling with time-domain unsteady
aerodynamics models of different fidelities. In such a framework the inputs to the aero-
dynamics model are the transient elastic deformations (around a geometrically-nonlinear
static equilibrium) and the aerodynamic inputs including atmospheric disturbances and
control surface inputs. In this work we demonstrate the proposed model reduction ap-
proach using a linearized 3-D unsteady vortex lattice method [4]. This provides a medium-
fidelity description of the nonlinear flight dynamics of very flexible aircraft with model
orders of $O(10^4)$ of the underlying linear aeroelastic system. We address this large system
size using a modified balancing method to arrive at robust small-order representations of
order $O(10)$ even for possibly unstable plants. Numerical examples finally demonstrate
this approach for a complete stick-to-stress description of flexible manoeuvring aircraft for
load alleviation in nonuniform gust events. The focus has been on robust control method-
ologies which require a low-order representation of the full vehicle description, including
geometrically-nonlinear effects, unsteady 3D aerodynamics and wing-mounted actuators
and sensors.

The approach will be demonstrated here for large aeroelastic systems, but applies equally
to multibody systems with nonholonomic constraints, as demonstrated for large wind
turbines with tower dynamics and possible base motions [5].

REFERENCES

geometrical nonlinearities in aeroelastic behavior of high-aspect-ratio wings. Journal

Aircraft Dynamics with Large Rigid-Body Motion. AIAA Journal. [in print].


lattice method in aircraft aeroelasticity and flight dynamics. Progress in Aerospace

Aeroservoelastic Design and Load Alleviation of Large Wind Turbine Blades. In 55th
AIAA Structures, Structural Dynamics, and Materials Conference, National Harbor,
MD, USA, 2013.