Structural Idealization of Flexible Generic Wings in Computational Aeroelasticity

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Abstract. In the present contribution concepts of reduced structural models for Computational Aero-Elastic simulation (CAE) on aircraft wings are presented. Here the idealization approach relies on analytical methods with the aim to shorten in comparison to a typical finite element method computational cost and time, by preserving nearly the same accuracy. Prior to more detailed investigations using higher order models, these simplified models allow an earlier access of insight regarding the aeroelastic and structural behavior of the wing at the very beginning of the design process. At first a one-dimensional idealization that extends the Timoshenko beam by taking into account additional effects due to warping is developed. To better describe the influence of swept, a three-dimensional idealization is derived. Both idealizations yield good agreements in results concerning the global static deformation and the modal behavior of the wing.

1 Introduction

To investigate aeroelastic effects on high capacity aircrafts, computational methods are employed. These procedures enhance the capability to predict the static and the dynamic aeroelastic response of the aircraft. It becomes therefore possible to provide detailed information concerning the aeroelastic behavior of the structure during the preliminary design phase. The present study was conducted within the framework of the collaborative research center SFB401 at the RWTH-Aachen university. A numerical method that combines Computational Fluid Dynamics (CFD) and Computational Structural Dynamics (CSD) to investigate transonic aeroelastic phenomena has been developed. This tool uses partitioned algorithms and staggered coupling to solve the differential equations of the fluid-structure-interaction.
problem in aeroelasticity. The fluid flow is modeled by means of compressible Navier-Stokes equations with associated turbulent RANS models, the structure by means of the Timoshenko beam model. For more complex configurations, finite element models are available as well.

Partitioned algorithms belong to the field of domain decomposition methods since they combine procedures from the fluid and structural mechanics to address the aeroelastic problem. Over the last decades partitioned algorithms in aeroelasticity have widespread and merged to solve growing issues in the framework of Multidisciplinary Design Optimization (MDO). An example here is the aerostuctural optimization. Aerodynamic shape optimization and structural optimization are linked in Computational Aero-Elasticity (CAE). One concern at applying partitioned algorithms for aeroelastic purposes is to minimize computational time. Although great progress has been achieved toward developing efficient aeroelastic tools by including preconditioning techniques, multigrid methods and multiprocessing through parallel algorithms, there is still a necessity to improve the computational time since a non-negligible number of iterations are run until a convergent state is available. Unlike the structural discretization, the flow field discretization is the most demanding in terms of time consumption as higher order fluid models are employed, and a tremendous amount of grid points are needed. Therefore a risk against loss of accuracy is greater for the flow field discretization if time saving is sought at alleviating the mesh size.

Simplified structural models are preferred in the preliminary design stage since they enable a rapid access of useful results, thus helping to accelerate the design process. This approach can also be considered within a numerical aeroelastic environment. By doing so, the preprocessing time of the computational method also benefits, in the sense that the structural preprocessing is minimized. With this respect, concepts based on reduced structural models in computational aeroelasticity were worked out. The objectives behind these concepts have been to develop analytical methods that are capable through simplified models to deliver a high-fidelity structural behavior of the wing, with nearly the same accuracy as their finite element model counterparts. The natural advantage which arises from this approach is that more control on the design parameters is allowed. A systematical variation of the wing planform, and structural properties at fast model generation is then enabled and parametric studies for sensitivity analysis can be easily performed.

The state of the art practices in analytical idealization of aircraft wings include one-dimensional structural models using modified box-beam, plate-beam theories, plate models and three dimensional models based on partial differential equations or the shearing theory. The first work of the research program presented here has focused on a one-dimensional structure using an extended beam theory. So was developed the so called membrane-panel model. This idealization extends the Timoshenko beam by considering warping due to transverse shear and torsion. Though the model can predict the wing deformation quite well, the stress distribution in case of swept wing suffers from shortcomings at the root. In the second work a three-dimensional -cell- model was developed. For its formulation, the wing is discretized using cell elements that are made of panels and truss beams.