Integration of Steady and Unsteady Aircraft Loads into Multidisciplinary Airframe Design Process

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Airframe design as an essential part of aircraft design is inherently multidisciplinary. The complexity of the structural design task emerges not only from the challenges in each of the involved disciplines – loads, aerodynamics, stress, dynamics, mass, aeroelastics, design and manufacturing – but also from the complex and mutual influence of these disciplines. This paper describes a multidisciplinary airframe design process of industrial scale representing a concurrent engineering framework. The Main focus will be on automating sizing and loads loops, i.e. incorporation of aircraft loads analysis into MDO. On the one hand the huge complexity, the scientific challenges and, on the other hand, the benefits expected are discussed.

The structural design of an airframe is determined by a high number of multidisciplinary criteria (stress, fatigue, buckling, control surface effectiveness, flutter, stability and control, CoG position, weight requirements etc.). Several thousands of structural sizes of e.g. stringers, panels, ribs etc. have to be determined considering millions of requirements to find an optimum solution, i.e. a design fulfilling all requirements maximising the aircraft performance, e.g. minimum weight, minimum cost, minimum drag, maximum range, maximum time on station. etc.

One of the most promising strategies for maximising aircraft performance is based on exploiting load control effects (passive and active). For this purpose it is necessary to incorporate aircraft loads analysis into an optimisation framework. Apart from steady aeroelastic manoeuvres and landing gear loads it is important (for several aircraft types) to consider transient aeroelastic loads, mainly due to gusts [1].

For the purpose of incorporating loads analysis of steady (aeroelastic) manoeuvres into the structural optimisation process, it is necessary to establish coupled structure-aerodynamic analysis with simultaneous trimming comprising full structure finite element analysis model, in this case of the whole aircraft and full aerodynamic model. In the presented approach higher order 3D panel methods are used for the aerodynamic numerical solution. These methods show good accuracy regarding lift distribution for the purpose of airframe design. The Coupling model is capable of dealing with full models transferring aerodynamic loads to the structural mesh, and the structure deformation to aerodynamic model. Additionally, it is important to transfer the analytical sensitivities of aerodynamic loads and structure deformations in order to feed into the optimisation algorithm. The coupling model is out of scope in this document. Finally an accompanying trimming analysis, i.e. prescribing and attaining equilibrium in six degrees of freedom for all design-driving manoeuvres during optimisation iterations. Trimming is generally a separate nested optimisation problem, since the number of unknowns e.g. angle of attack, yaw and pitch angles, deflection of aerodynamic surfaces (ailerons, flaps, rudder, etc.) isn't necessarily identical to number of equilibrium equations. Additionally, for the sake of trimming analysis it is necessary to parameterise the aerodynamic model – in addition to the huge number of sizing design variables. An extension of aeroelastic tailoring to dynamic response, i.e. transient aeroelastic (gust) analysis, promises further potential improvements. Not only due to the fact that the gust loads are, in several cases, the deciding factor in the dimensioning of the structure but also because tailoring here not only has the opportunity to redistribute the aerodynamic loads, as in static tailoring, but to decrease their absolute values. The incremental dynamic loads caused by the turbulence as opposed to the trim loads are not required to maintain static equilibrium of the aircraft or fly a given manoeuvre. The entire flight envelope of the aircraft must be scanned for various different mass configurations, flight conditions, gust shapes and sizes to find the critical gust load cases which are subsequently used to size the structure. This enveloping process has been automated within LAGRANGE with the identified cases included in the subsequent optimisation process. To enable efficient large scale optimisation of the structure to dynamic aeroelastic loads with gradient based methods, the analytical sensitivity with respect to the structural design variables of the relevant responses of the aircraft, in particular, stresses, strains and risk of buckling, to gust excitation are calculated. This has been obtained by determining the derivative of the relevant equations of motion with respect to structural sizing variables, taking advantage of the analytical sensitivity of the structural system matrices available in LAGRANGE resulting in a numerically highly efficient sensitivity analysis process.

The multidisciplinary airframe design process is demonstrated by means of the use case of a generic MALE (aircraft with medium altitude and long endurance) reconnaissance aircraft.

References

[1] F. Daoud et al. Multidisciplinary airframe design process: Incorporation of steady and unsteady aeroelastic loads. *12th AIAA Aviation Technology, Integra- tion, and Operations (ATIO) Conference and 14th AIAA/ISSMO Multidisciplinary Analysis and Optimization Conference.*, 2012.