AEROELASTIC OPTIMIZATION FOR DYNAMIC MODEL ADJUSTMENT BASED ON GROUND- / FLIGHT TEST DATA AND INCREASED STABILITY MARGIN

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ABSTRACT

In the frame of aeroelastic stability assessment, a reliable Finite Element Model (FEM) is an essential component. Such a model is usually provided by the responsible Stress teams linked with the associated masses of the components given by the Weight department. For the aeroelastic stability assessment, the dynamic model is composed, which is then the basis to derive the modal behaviour in form of frequencies and mode shapes.

An FEM can be modified by changing its elements, for example element stiffness or mass. This can be done having two different objectives in mind. First, property changes are used to adjust the dynamic model to meet test results. Second, changes of element properties can be applied to propose an aircraft design with increased aeroelastic stability margins.

Addressing the first of these objectives, the adjustment of the dynamic model in the verification and validation (V&V) phase of an aircraft, is currently done in two steps. The first step is focussing on the behaviour during Ground Vibration Test (GVT) which allows not only to capture the frequencies and mode shapes of the real aircraft, but also to derive the structural damping associated to each of the identified modes. In this process step, it is possible to concentrate on the structural parameters to achieve an acceptable matching of the test results while having no interference with aerodynamic forces. The second part of the V&V phase is the Flight Vibration Test (FVT) with different fuel / ballast configurations and at various Mach numbers and speeds.

In the past, the adaptation process was mainly focussing on the quality of frequency and mode shape correlation in the lower frequency band using approved stiffness changes as parameters. This is not sufficient in view of future aircraft development programs with much higher mode density in the low frequency domain. Especially for the purpose of control law design, the dynamic model quality has to be improved considerably. The deficiencies of a dynamic model for that purpose can be assessed on the basis of a transfer function approach. The identification of parameters for the model adjustment in this context is key to achieve highest quality in matching test results.

Dynamic model adjustment can be done with the help of optimization. A tool having been used extensively to meet results gained from ground test is the NASTRAN solution SOL200. The reason for having to restrict the adjustment in the past to ground test results was the lack of opportunity to introduce adequate aerodynamics into NASTRAN SOL200. This shortcoming has been overcome by using a Least Square Approach altered into the solution sequence being able now to also support flight tests. Therefore, it is now possible to use the large variety of numerical approaches available in SOL200 in combination with several optimization options.

Furthermore, the NASTRAN environment offers features allowing to define several subcases within one optimization run specifying excitations at different driving point locations and imposing constraints at various output stations to consider a set of transfer functions which are relevant for instance for control law design.

Prerequisite for a meaningful adjustment of a dynamic model is that the basis model is representing a feasible design, i.e. being in line with certification requirements. If this is not the case, a step before the adjustment phase could be necessary to improve the aeroelastic behaviour by increasing the flutter speed or increasing the damping of a specific mode. For this purpose, the same elements will be used to propose design recommendations by means of the same tool environment.

As soon as a feasible design is found and approved by the Stress team, the subsequent adjustment step in the V&V phase needs to limit the changes introduced in order to match the test results. This is reflected in the optimization set-up by defining the objective function going to be minimized in such a manner that it incorporates the changes expended for the adjustment. With this objective function definition, it is ensured that the adjustment is not bringing the dynamic model back to be an infeasible solution. With this, the development as well as the verification and validation phase is supported by the same tool environment. The paper will outline the process and show an example.

Addressing the second objective mentioned above, i.e. the increase of the aeroelastic stability margins, also makes use of optimization, applying the same tool, NASTRAN solution SOL200. The example presented in the paper is the D2AE, an aircraft with high aspect ratio wings (HARW). Such wings are more flexible and thus susceptible to aeroelastic instabilities as conventional designs. It is therefore crucial for the aircraft manufacturers to minimize the risk of encountering instabilities late in the design process. The contribution towards this risk mitigation is to explore optimization capabilities within the MSC Nastran environment.

Specifically, the feasibility of integrating flutter constraints in the sizing optimization of aircraft design processes has been evaluated. The objective is to increase the flutter velocity with minimal mass increase, using gradient-based optimization. The original aircraft model was modified to include skin fields and spars as design fields. In addition, the pylon was introduced as a separate optimization model. Several optimization algorithms available in NASTRAN were tested and different objective functions were compared. Although all solvers showed consistent global trends in wing thickness distribution, tuning the optimization parameters revealed a high sensitivity toward move limits and constraint scaling. The optimized wing stiffness distribution provided a flutter velocity increase of 4.62% at the cost of approximately 130 kg of additional mass. This demonstrated that local structural modifications can effectively improve flutter stability with moderate weight penalties, and provided a successful proof of concept for flutter-constrained optimization using Nastran on complex models. However, the also highlights the current limits of integrating this process into automated design workflows.

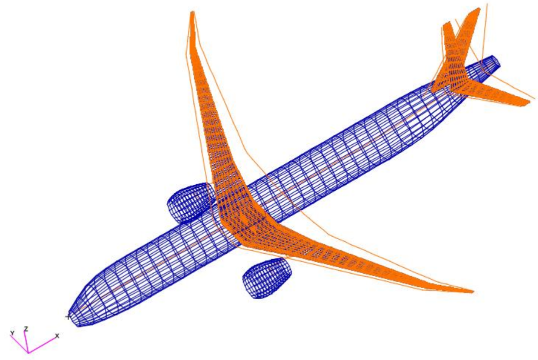

Figure 1: GFEM of D2AE

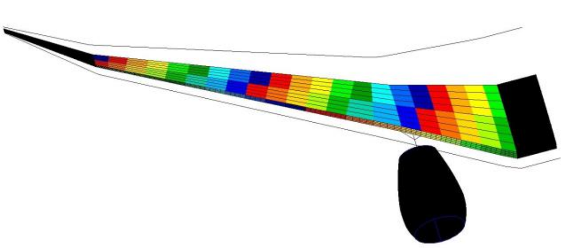

Figure 2: Design fields of the D2AE wing model

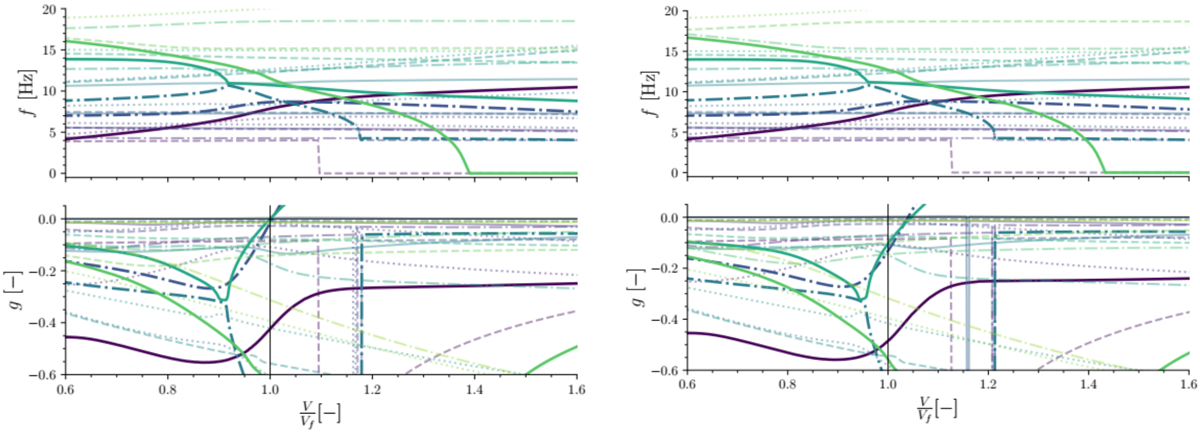

Figure 3: Frequency and damping plots of reference aircraft (left) and optimized configuration (right)