Wingbox adaptive parametric modeling and its application to structural optimization

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I. Introduction

In current research development of parametric wing model and its application to optimization process are considered. Due to high computational cost of the wing structural optimization problem when aerodynamics, structural analysis and dynamic analysis should be considered, makes optimization very expensive. Another problem is possible discontinuities of the optimization problem, due to present integer parameters, e.g. number of ribs/stringers. This research is aimed to address this issues by introducing flexible and fast parameterized wingbox model and using two-stage optimization approach, which combines Evolutionary Algorithms (EA) and local search algorithms.

The wing aerodynamic shape is defined by a set of parameterized NACA airfoils. In general, any closed wing skin surface can be imported into the process, due to the adaptive way of the internal structure definition. Different parameters of internal wing structure can be varied, e.g. number and location of ribs/spars/stringers, their shape, the thicknesses, such as the linear varying of the thickness along the length for skin and spars components. Geometrical and FE models of the wing are generated using Python and ANSYS APDL scripting. In Fig.1 the internal components of wing model are shown, which are used in the current optimization setup.

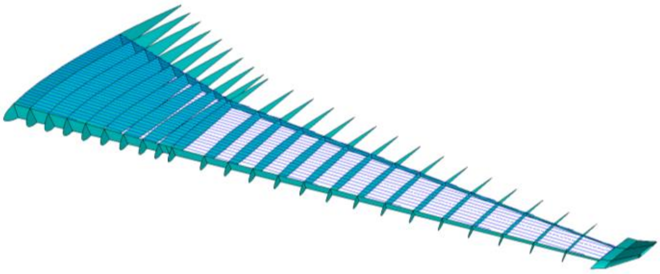

Figure 1. Wingbox components definition for wing

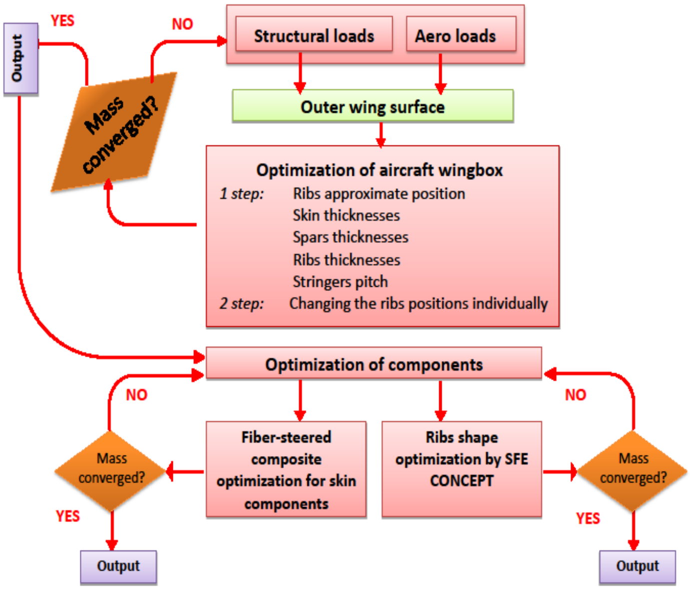

Figure 2. Framework for optimization of wing components

Several types of loads are considered, including acceleration load, engine loads and aero loads. The aero loads can be calculated using ANSYS Fluent CFD or simplified XFOIL 2D code. The flow simulation is calculated for a fixed external shape and obtained pressure distribution is mapped automatically to existing structural model in ANSYS Mechanical.

The two level optimization process is proposed as shown in Fig.2. The first level involves optimization of the "global" parameters of wingbox such as number, position and approximate thicknesses for various components. The objective here is to reduce the mass, while satisfying local skin deflection and buckling constraints. Second level includes optimization of the wingbox subcomponents (ribs, spars, etc.) for fixed global layout of the wingbox, obtained in first level. Subcomponent optimization can include different approaches such as the steered fiber composite optimization for the wing skin [3], optimization of ribs topology and shape [4]. In the current paper only the first optimization level is considered.

At the beginning, the optimal number and positions of the ribs will be determined. In order to reduce the number of wingbox parameters and consequently the computational effort for the optimization, two different parameterization levels are introduced. At the first step, the coarse parameterization is used, when the rib

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spacing for each section is defined using the pitch parameter, which can vary linearly within every section. Thus, two parameters define rib positions for each section (pitch and pitch gradient), resulting in total 4 parameters. Low number of design parameters in combination with fast and flexible wingbox model allow to employ global stochastic optimization algorithms, e.g. EA, which can deal with non-smooth/non-continuous dependencies, which are present in this problem due to the changing number of ribs/stringers.

At second stage finer parameterization is applied, when the position and angle of each rib can be varied individually in the vicinity of the previously obtained solution by moving the rib's start and end points along the spars. Global optimal solution from the first step defines the initial ribs positions for the refined optimization. At this step, local optimization methods (e.g. gradient-based methods, COBYLA) are used to obtain refined design.

II. Sensitivity analysis.

The impact of used design variables (in total 14 parameters) on the structural responses such as weight, maximum local skin deflection between each pair of ribs and maximum critical buckling load is determined for different aero loads computation methods. Two numerical experiments, generated using Latin-Hypercube sampling within the coarse parameters, are performed for the models with XFOIL and ANSYS FLUENT. The resulting Spearman coefficient matrices for correlations between responses and the coarse design parameters are shown in Fig. 3.

As can be seen XFOIL results gives the very similar correlations, compared to the results obtained for Fluent, meaning that it can at least capture general trends accurately. Considering that XFOIL approach is much faster, compared to full CFD analysis, it can be used for the preliminary global optimization studies.

In Fig. 4 shown the exemplary optimal results obtained using two step approach. In this optimization run only ribs locations where optimized, which are defined by four parameters at the course level and two times the number of ribs parameters at the fine level. After the EA optimization with approx. 2800 evaluations, the best found feasible design (see Fig left) has the overall mass of 2907.4 kg. The refinement step with only 230 evaluations further reduces the mass 2828 kg (see Fig. right).

In the current research the adaptive wing model is developed and tested, the first optimal results were obtained. In the further research, the wingbox internal structure will be optimized with the use of implemented model with more realistic outer wing dimensions and shape (similar to the A320 wing).

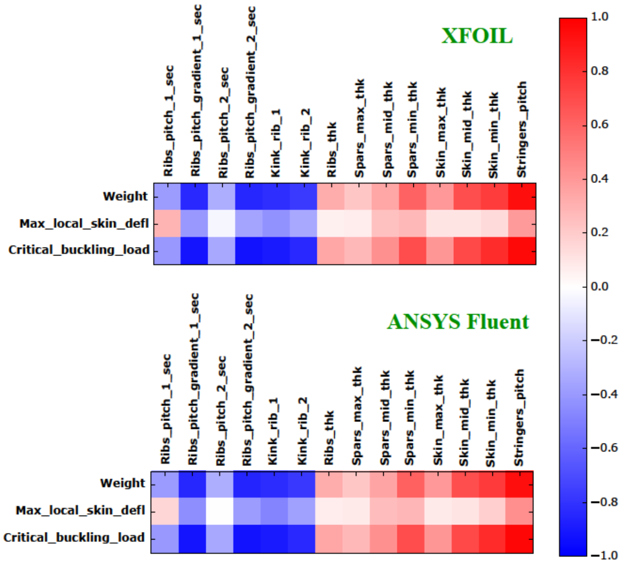

Figure 3. The resulting Spearman coefficient matrices: 300 designs

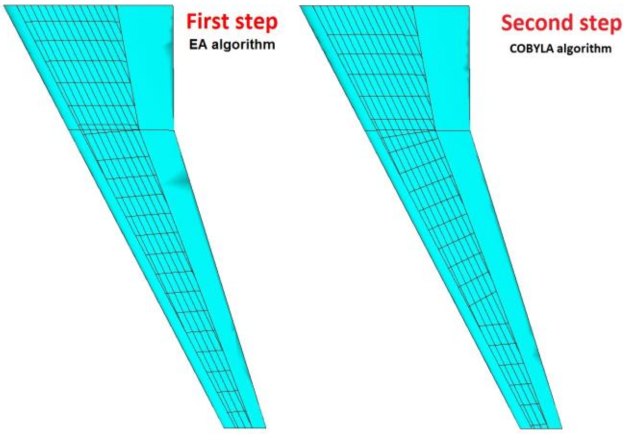

Figure 4. EA results, coarse model, COBYLA refined optimization

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