Optimal design of UAV wing structure

Adam Długosz[1] **and Wiktor Klimek**[2]*

[1] *Institute of Computational Mechanics and Engineering*
Faculty of Mechanical Engineering
Silesian University of Technology
ul. Konarskiego 18a, 44-100 Gliwice, Poland
e-mail: adam.dlugosz@polsl.pl

[2] *Flytronic Sp. z o.o. Gliwice, Poland*
e-mail: wiktorklimek@gmail.com

Abstract

The paper presents optimal design of UAV wing, made of composite materials. The aim of the optimization is to improve strength and stiffness together with reduction of the weight of the structure. Three different types of functionals, which depend on stress, stiffness and the total mass are defined. The paper presents an application of the in-house implementation of the evolutionary multi-objective algorithm in optimization of the UAV wing structure. Values of the functionals are calculated on the basis of results obtained from numerical simulations. Numerical FEM model, consisting of different composite materials, is created. Adequacy of the numerical model is verified by results obtained from the experiment, performed on a tensile testing machine. Examples of multi-objective optimization by means of Pareto-optimal set of solutions are presented.

Keywords: optimal design, multi-objective optimization, evolutionary algorithms, composite structures, finite element method, FEM, FEA, UAV wing, CAE systems

1. Introduction

The problem of optimal design of the aircraft wing has been considered by many researchers. It concerns passenger or military aircraft and Unmanned Aerial Vehicle (UAV) as well [1] [2]. Design process of the aircraft wing have to take into consideration several goals and restrictions. The aerofoils should be characterized by: high lifting force, low aerodynamics drag, low mass, high endurance, etc. Consideration more than one criterion leads to the multiobjective optimization. For real engineering problems, criteria calculated on the basis of results derived from numerical simulations may have many local minima. It complicates greatly solving the optimization problem. Moreover, such criteria can be contradictory. Conflicting objectives cause that one objective function improves and the rest deteriorate. The consequence is fact that, there is no single solution, which is the best with respect to all objectives. The designer has to chose a solution from a set of solutions which are called optimal in the Pareto sense [4].

In a classic approach deterministic methods are used. There are mainly two groups: non-gradient and gradient methods. For many practical problems calculation of the gradient can be very difficult, moreover such methods have tendency to locate local extremes, so an efficient multiobjective optimization method is needed. Evolutionary Algorithms (EAs), as a group of bioinspired methods are free from mentioned drawbacks. The in-house implementation of the multiobjective evolutionary algorithm based on Pareto concept is used in the paper. It is an improved version of the multiobjective evolutionary algorithm, for which some ideas are inspired by NSGA-II algorithm [5]. The in-house implementation of the algorithm was tested on several benchmarks as well as on real optimization problems, showing its superiority on NSGA-II (one of the most popular multi-objective evolutionary algorithm) [6].

The problem of optimal design assumes, the invariable aerodynamic properties of the airfoil (the external shape of the wing is given and it does not change during optimization). The aim of the optimization is to improve strength and stiffness together with reduction of the weight of the structure. Three different types of functionals, which depend on stress, stiffness and the total mass are proposed and defined. This work is an extension of the previous work in which optimization tasks has been solved for simplified model of UAV wing structure [7].

2. Numerical model of UAV wing structure

Numerical model of the wing is prepared on the basis of the real structure. The UAV wing structure, based on typical geometry is considered. Fig. 1 presents the geometry model.

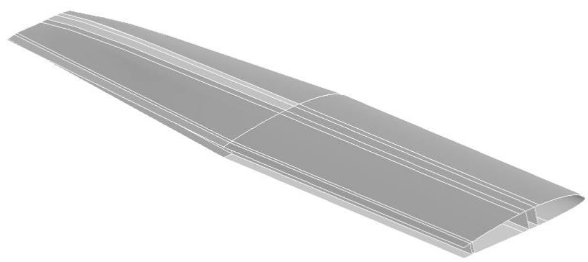

Figure 1: The geometry of the UAV wing structure.

In order to build appropriate numerical model of the wing, the part of the wing (cut from real structure) are tested. Experiment of the three-point bending test on the part of the wing has been performed by means of universal testing machine. The results of from the experiment are compared with results obtained for the appropriate numerical model. The difference between stiffness, calculated on the basis of experiment, and the stiffness calculated on the basis of results

* The research is partially financed by research project no. 10/040/BK_17/0045.

derived from numerical simulation is reasonable [8]. Fig. 2a) presents the part, which has been cut from the wing, while Fig. 2b) presents distribution of the materials. The structure consists of polyurethane foam, carbon and glass fabric. Connections between the spar and the skin are strengthened by additional woven roving (Fig. 2b). The aileron is not considered in the numerical model, because its effect on the load transfer can be negligible.

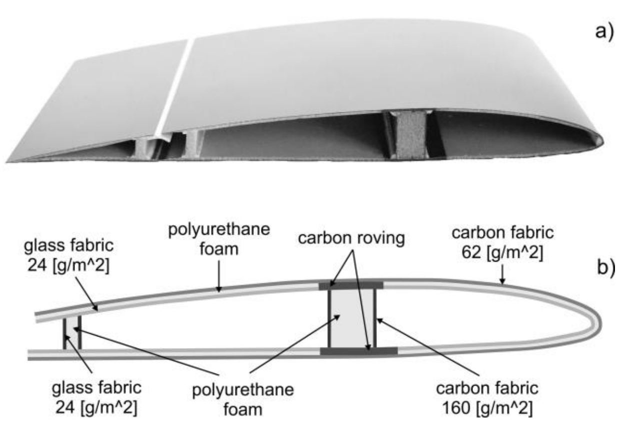

Figure 2: a) Part of the UAV wing structure,
b) Distribution of the materials in the structure

The linear-elastic model with orthotropic properties is used to describe material behaviour [9]. There are four different laminates used in wing construction [8]. Each of them contains combinations of materials with orthotropic properties (different types of carbon fabric, glass fabric and roving) and one isotropic (polyurethane foam - PUR). The numerical FEM model of the wing is build in MSC Patran system, whereas MSC Nastran system is used in order to solve linear static analysis.

3. Multi-objective optimization task

The goal of the optimization is to improve mechanical properties (reduce stresses, increase the stiffness) and reduce the total construction mass. Three different functionals for the optimization of the wing structure are formulated:

- the minimization of the volume of the structure
- the minimization of the maximal value of the equivalent (Von Mises) stress in the structure
- the minimization of the maximal value of vertical displacement in the structure.

Using results obtained from the numerical analyses, fitness functionals are calculated. Every step of geometrical and numerical model creation as well as the calculation of the fitness functional have to be fully automated in order to solve multi-objective optimization task, by means of CAE system. Thousands of fitness function calculations have to be performed in the particular multi-objective optimization task, so execution of this step in a efficient way is crucial. It is done by means of additional ad-hoc software and appropriate scripts in PCL (*Patran Command Language*), which is implemented in the Patran module. For each separate fitness function calculation, several steps of modelling have to performed.

The geometry of the model is created on the basis on design variables. Surface model of the wing structure is supplemented with materials and properties of each model part. In next step boundary conditions are defined and the finite element mesh is generated. With all necessary settings of the analysis, input file for FEM solver (Nastran) is generated. After solving the boundary value problem, the fitness functions are calculated by means of PCL and C++ additional procedures. As mentioned in the first paragraph, an in-house implementation of EAs are implemented and used to solve optimization tasks.

Chromosomes genes in EA represent the vector of design variables in optimization task. Design variables are responsible for the position of the girders, thickness of the girder laminates, length of the roving at the main girder, thickness of the roving laminate, etc. Fig. 3 presents example of the parameterization by means of 11 design variables (V1 – V11) of the cross-section of the UAV wing. In order to parameterized the geometry of the UAV wing structure presented in Fig. 1, in a sufficiently accurate manner, more design variables are used.

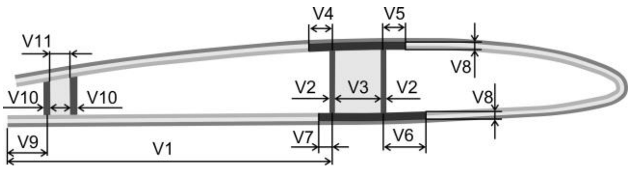

Figure 3: Parameterization of the model of the UAV wing

2-objective optimization variants and the *3*-objective optimization variant are performed. The results of optimization are presented in the form of set of Pareto-optimal solutions (Pareto fronts). Moreover obtained results are compared with the existing design, showing the ability of improvement mechanical properties of the wing structure by means of proposed method.

References

[1] Berci, M., Toropov, V., Hewson, R., Gaskell, P., Multidisciplinary multifidelity optimisation of a flexible wing aerofoil with reference to a small UAV, *Structural and Multidisciplinary Optimization*, Vol. 50, pp.683–699, 2014.

[2] Ceruti, A., Caligiana, G., Persiani, F., Comparative evaluation of different optimization methodologies for the design of UAVs having shape obtained by hot wire cutting techniques, *International Journal on Interactive Design and Manufacturing*, Vol. 7, pp. 63–78, 2013.

[3] Chung, D.L., *Composite Materials: Science and Application*, Springer-Verlag London, 2010.

[4] Collette, Y., Siarry, P., *Multiobjective Optimization: Principles and Case Studies*, Springer, 2003.

[5] Deb, K., Pratap, A., Agarwal, S., Meyarivan, T., A fast and elitist multi-objective genetic algorithm: NSGA-II, IEEE T. *Evolut. Comput*., Vol. 6(2), pp. 181-197, 2002.

[6] Długosz, A., Burczyński, T., Multiobjective shape optimization of selected coupled problems by means of evolutionary algorithms, *Bulletin of the Polish Academy of Sciences, Technical Sciences*, Vol. 60(2): 215-222, 2012.

[7] Długosz, A., Klimek, W., Multi-objective optimization of the UAV wing by means of evolutionary computations, *Mechanika*, Vol. 22(6), pp. 530-536, 2016.

[8] Gibson, R.F., *Principles of Composite Material Mechanics*, CRC Press, 2012.

[9] Jones, R.M., *Mechanics Of Composite Materials*. Materials Science and Engineering Series. Taylor & Francis, 1999.