APPLICATION OF GENERATIVE MODELING METHODS TO THE DESIGN OF THIN LAYER COMPOSITE AIRCRAFT STRUCTURES

Wojciech Skarka(*) , Andrzej Jałowiecki
Faculty of Mechanical Engineering, Silesian University of Technology, Gliwice, Poland
(*)Email: wojciech.skarka@polsl.pl

ABSTRACT
The article presents the method of supporting the design of thin-layer composite load-bearing aerial structures. The automation of UAV wing design allows as early as at the concept development stage to propose an optimal solution and perform verification based on the strength of the structure and also to verify the buckling and instability of the structure and its rigidity, along with examination of the aeroelasticity aspects. The automation of the design process allows not only to take into account the complex and difficult aspects of construction but, above all, tedious and laborious activities associated with typical structural solutions and technological aspects, which usually severely limit the designer's ability to propose more sophisticated solutions. The method is presented on the example of an unusual application - the design of a super-light and ultra-flexible wing for the High Altitude Long Endurance Unmanned Aerial Vehicle, where it is usually impossible to rely on many previous solutions at the design

Keywords: composite structures, thin-layer composite, HALE UAV, generative modelling.

INTRODUCTION
The design of modern aircrafts requires the cooperation of many different specialists from various fields. Large specialized research centers of big aircraft companies have sufficient resources to design complex aircrafts. However, in the case of small teams and companies involved in the development of general aviation aircrafts and UAVs, resources are often insufficient. In particular, modern composite structures open up more and more structural possibilities on the one hand, and impose high demands on the design process of the load-bearing structure on the other. It becomes particularly important in the case of very light and large designs such as ultra-light aircrafts with sophisticated aerodynamics wings and a large span and elongation allowing to achieve long flight duration and in some cases unlimited flight duration – sport gliders and aircrafts, UAVs.

High Altitude Long Endurance Unmanned Aerial Vehicle (HALE UAV) has particularly sophisticated constructions, which operates at high altitudes - even stratospheric - with uninterrupted access to solar energy during the day. The extremely lightweight design, optimized propulsion system and power supply system allow for unrestricted flight and successfully perform part of the satellite mission. Such units are also called High Altitude Pseudo Satellites [1] [2]. Although two solutions are used for this type of construction [2]; the first ships lighter than air and the second ships heavier than air it is the latter, in particular, that has been developing very dynamically, using photovoltaic cells as an energy source. It is also known that similar solutions are used at lower altitudes - Low Altitude Long Endurance - with a similar structure [3]. Due to reduced solar radiation in conditions of variable weather which
difficult to predict, obtaining long flight duration is much more difficult. These types of aircraft are subject to quite specific design criteria and the design process involves overcoming the complex problems arising from the high mass of the power supply and energy storage. The thin-layer composites used for load-bearing elements cause increased flexibility of the load-bearing structure, which requires a detailed analysis of aeroelastic phenomena [4] [5] [6] [7] [8] [9]. In addition, to achieve great excellence, it is necessary to guarantee diligence in developing the aerodynamic concept and also using new solutions such as the morphing wing [10]. All these aspects mean that at the stage of concept development it is necessary to analyze these aspects in detail for many different versions of the structure. Developing many versions of the structure and such analyzes with current methods become expensive and laborious [1] [10] [11].

In order to facilitate the design of large-size composite load-bearing structures, high flexibility and extremely low weight, it was decided to develop tools to assist the designer in designing such structures. The tools are integrated directly in the CAD system and take the form of generative models [12]. They integrate knowledge of composite structure design, composite strength, aeroelasticity of highly flexible structures, aerodynamics, composite molding technology and flight mechanics and aircraft design, and greatly simplify and accelerate the design of aircraft concepts, minimizing the need for specialists to cooperate at this stage. Generative models include solutions that integrate design automation methods, such as: integration of complex structures consisting of many elements, based primarily on experience in the automotive industry [13] [14] [15] [16]; specific rules for the design of composite elements shaped in forms, in analogy to the experience in the field of shaping stamping dies [14] as well as modeling techniques and design automation complex surfaces constituting the basis for modeling in the automotive, aviation and plastic processing industries, in particular the design of unfoldable and non-unfoldable surfaces [15] [17] [18]. Generative models and various aspects of this methodology were used in the development of the experimental HALE UAV project called Twin Stratos (Figure 1).

![Fig. 1 - Twin Stratos experimental HALE UAV](image)

Designing composite load-bearing structures is a complex process. Particularly the stage of concept development usually requires the development and comparison of many versions of solutions and selection of the best option [5] [19] [20] [21]. This process can be tedious, especially in the case of atypical load-bearing structures, where the target idea of the solution may take different forms. Generating many ready-made, pre-verified solutions of load-bearing
structures can be supported by the use of Generative Modeling (GM) methods. This application of GM at the stage of developing detailed concepts for their selection and assessment is particularly useful because it allows the generation of a large number of pre-verified versions of structures that can be subjected to detailed assessment.

THE GENERATIVE MODEL ARCHITECTURE

The wing design process is a complex task that requires a lot of specific design knowledge and experience. Figure 2 presents the scheme of general steps of wing design procedure [14]. Currently, most stages of the design process are made manually and are time-consuming, especially in the case when frequently design changes must be applied. The main idea of using the Generative Models is to speed-up the initial stage of the design process by automating some routine design tasks [22] [16]. Reducing time spent on repeated and rutting tasks allows designer to focus on the creative part of the design, and possibly find a new solution which is far more better than currently used.

In the case of wing design, the majority of time is spent on the load-bearing structure. Currently, aircraft designers use one of the most commonly used structures such as double spar structure or torsion box structure [5]. The fact that there is a limited number of used structures makes it possible to describe them in a form of the knowledge model, which is a crucial element of any Generative Model [6] [23]. Using the knowledge model, designer can at early stage of the GM development define the sets of necessary parameters, geometrical inputs and generation procedure.

Fig. 2 - Scheme of a wing design process

In the further part of this paper, the authors present the concept of the Generative Models for supporting the conceptual design of the wing. The authors’ approach assumes that the whole process is divided into a few main stages. Division of the whole process into smaller steps gives a designer much more control on the final result, and allows to perform some additional engineering tasks such as numerical verification. Figure 3 presents the concept of the process.
The first stage of the design process supported with the GM is devoted to the elaboration of the initial load-bearing structure, which will be used in the process of further detailing. The method proposed for the initial design is to allow a user to choose what type of structure will be the best for a particular application [5] [6] [23] [24]. For this purpose, supportive computational tools were used to allow an approximate calculation, usually used at the stage of concept development, of the basic characteristics of the planned aircraft, including, but not limited to, loads occurring on basic load-bearing elements such as the wing.

The form of design tables as a user interface allows easy integration to control the parameters of the generative model. Additionally, the decision of the structure type can be supported with ruled-based expert system [17] [25] [26]. In the prepared model each part of the wing is defined as a single file that contains a number of the predefined types of particular element. When it is necessary to use a structure that is not predefined, a user can add his/her own configuration which will be accessible in the further projects. Figure 4 shows the way of the selection of a different kind of front spar part. Except the structure definition, a user must input some parameters such as the position of front/back spar, length of overlaps, etc. The result of the first stage is a set of models of single sections of the wing. Here again the authors decided to design a single section of the wing instead of the whole wing at one time. In the next step, all generated parts must be put into a single assembly file (Figure 5).

The model prepared in the first stage of the generation process can be used for initial verification with CFD (Computational Fluid Dynamic) analysis and FEA (Finite Elements Analysis). The use of the predefined types of structures allows a designer for fast development of different solutions with some simplicity which can be quickly and easily verified before adding any further details.
The second stage is used for adding required details to the initial models. Because the developing solution focuses on composite structures, developed features are also specific for this type of materials [13] [4]. Figure 6 presents an example of the structure element after adding the details. At this stage, the model is mainly finished for general purpose, but to make the solution more completed, the authors decided to add an additional step for the generation process which is focused on manufacturing of the modelled elements, especially in the thin-layer composite technique.

The third stage focuses on the manufacturing process of designed parts and is optional. At this stage developed part is divided into single structural members which are separated by specific colour code and naming. Fig presents an example model after the third stage of the generating process.
RESULTS AND CONCLUSIONS

A description of the method for rapid designing, detailed concepts for composite aircraft structures is presented in the case study of High Altitude Long Endurance Unmanned Aerial Vehicle (HALE UAV) and, above all, the load-bearing structure of the wing with a large span and high aspect ratio, as well as an ultra-light structure with a high degree of flexibility. In the process of developing the concept, the methods of calculating the HALE UAV parameters, taking into account energy autonomy and the approximate method of calculating the wing loads based on the regulations customised for specific use at the stage of developing the concept were taken into account. The method uses a statistical approach modified for HALE UAV purposes due to the small number of reference cases. It also integrates structural analysis of composite elements, aeroelastic behaviour based on simplified methods, and rules of designing very flexible wing.

The method integrated directly into the form of the Generative Model (GM) allows for easy generation of wing support structures based on previously identified and saved concepts of solutions and specific solutions proposed by the user. Automatic generation of the wing structural elements is supported by initial strength verification, buckling and instability analysis, verification of selected aeroelastic phenomena as well as technological aspects. Corrections resulting from the verification process are entered automatically or in a dialogue with the user as a part of Knowledge-Based Engineering application.

The development of many detailed concepts of verified solutions of the load-bearing structure is shortened significantly and the number of proposed alternative concepts far exceeds the customarily developed numbers in the classic design process. A much wider field of possible solutions gave the opportunity to develop a better target solution at subsequent design stages.

REFERENCES


