DESIGNING OF ELASTICALLY SCALED MODEL OF A HIGH ACPECT RATIO WING USING DIGITAL TECHNOLOGIES

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Abstract: Designing of an elastically scaled model of a high aspect ratio wing, which made using of digital technologies is considered. Model is made on the basis of rigid core and polymeric material with low modulus of elasticity. It is possible to use numerical control (NC) machines or 3D – printers during manufacturing. The search of required construction is carried out on the basis of finite element method (FEM) with the aid of optimization through influence coefficient matrix.

INTRODUCTION

During wind tunnel tests related to static aeroelasticity, great importance is the production of the model with necessary rigidity with a high degree of accuracy. In this paper approach to design elastically scaled model is considered. It represents the load-bearing element (a plate, with the distributed thickness) connected in a certain way with the shaping low modulus material is used (like polyfoam, balsa or an obomodulan). Ideally, the shaping element of a model is made as removable. Firstly it allows for net free volume inside a model (for variation of mass of model, access to intra model sensors and drives) and secondly to measure (and to consider) contribution of the shaping element to the total model stiffness.

At the present time the main advantage of such type of a model, in addition to its high strength, is its high technological effectiveness, the use for fast and rather inexpensive production (both the core and shaping element) with NC machines or 3D – printers. Such models are well suitable for research of characteristics of static aeroelasticity [1–3].

One more advantage worth mentioning is the use of various optimizing methods while designing that substantially accelerate researches. Finite element method is applied to generate the structure of the model and to carry out calculations. For this task FEM program MSC.NASTRAN is used as the base system [4, 5]. In addition, optimization in this system is carried out, but other optimizers can be also used. Matter of choice the best optimizer is the subject for further researches consideration.

In addition software code written a modern programming language is used. It allows quickly generate an input file for the system MSC.NASTRAN, run the calculations, both static and optimization, consider the results of calculation and carry out comparison with initial data before optimization.

The main difficulty of creation of elastically scaled models seems to be achievement of high accuracy of modeling. It is also necessary to remember about boundary conditions defined in MSC.NASTRAN system during optimization. Thereby the design variables, which are the core thickness, superimposed lower and upper bounds.

In early studies a model of the vertical tail unit was made [6]. In this case good convergence of the solution turned out, but there were technological problems relating to inadmissible thickness of areas of the core. In too thin areas it was decided to use perforation with a necessary step and diameter of holes to provide sufficient durability, which required numerous static calculations.

In this paper high aspect ratio wing is considered which is uncommon solution because it uses plate analogy. Usually in manufacturing elastically scaled models of high aspect ratio wings beam or wing box schematization is used. As a full scale design wing of modern advanced aircraft and for comparing results the current aerodynamic model made with beam schematization are considered. This model duplicates elastic properties of full-scale design taking into account scale of linear dimensions. CAD-model of this aerodynamic beam model is shown in Fig. 1.

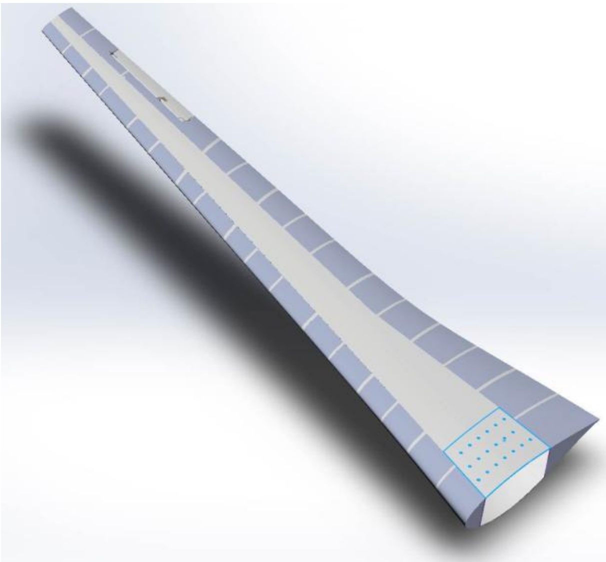

Figure 1: High aspect ratio wing model made of beam schematization.

1 DESIGN METHOD OF STRUCTURAL SIMPLIFIED ELASTICALLY SCALED MODEL

Consider general approach to the problem of designing a full-metal plated core of variable thickness. The core is divided into set of zones with constant thickness which are determined in search for solutions. For this purpose optimizing process on the basis of minimizing difference between coefficients of influence matrices of the bearing surface and its model is based.

The final-element model of the designed existing beam schematization wing model on which control points are set is under consideration. On this set of point the reference influence coefficient matrix (ICM) is defined. On the basis of elements of influence coefficient matrix of beam model and designing model the optimizing functionality is formed:

$$\Phi = \sum_{i=1}^{n}\sum_{j=1}^{n}\left((B_{ij} - A'_{ij}) / B_{ij}\right)^2 \quad (1)$$

where matrix $\boldsymbol{B}=\|\boldsymbol{B}_{ij}\|$ is influence coefficient matrix of the beam model and matrix $\boldsymbol{A'}=\|\boldsymbol{A'}_{ij}\|$ is influence coefficient matrix of designed model scaled to the model being designed.

The problem solution is carried out in two stages. At both stages reference ICM and optimization capabilities of NASTRAN system allowing to establish connection of the minimized functional and design variables through the ICM of the model will be used. Thickness of the core project areas are used as design variables. At the first stage are defined: position of the core areas and its thickness. The choice of thickness of project areas is also connected with the analysis of strength of the core.

On model of the second stage which is based on the basis of three-dimensional final elements and the results of the first stage (an arrangement of project areas and their thickness) further correction of a form of the core is carried out. Shaping material which is used obomodulan is taking into account. The thicknesses of the core obtained in the first stage may vary in accordance with given airfoil. In addition, at the second stage an inspection of structural strength of a model design in experimental conditions in wind tunnels is carried out.

Geometric shape of design of the model defines a number of parameters, some of which can not be changed - the parameters that define its external aerodynamic shape. Another part of the model parameters h_k (k = 1, 2, ..., K; K - the number of parameters) are design variables. These design variables also define its shape (an internal shape), and define its stiffness properties. Technological conditions impose limitations from below on design variables.

On the basis of the functional Φ (1) and boundary conditions (BC) optimization process is based. At each step of the optimization process K direct finite element calculations will be held relating to the determination of the coefficients of sensitivity and, based on them, the choice of iteration $\Delta\boldsymbol{h} = (h_1, h_2, ..., h_K)$.

As a result, the n iteration step after the corresponding choice of a step the functional Φ will receive value:

$$\Phi^n = \Phi^{n-1} + \sum_{k=1}^{K}\frac{\partial\Phi}{\partial h_k}\Delta h_k \quad (2)$$

Convergence criterion of optimizing process is inequality $|\Phi^n - \Phi^{n-1}| \le \varepsilon$.

The value of ε defining the end of iterative process appointed for reasons of sufficient accuracy of approach of objective function and was defined as 5% with respect to the maximum coefficient of this matrix.

In order to simplify of the computer formulation of a task, it is accepted to consider a measure of proximity of matrixes as proximity of their diagonal elements. However it didn't affect convergence of the decision at a preliminary stage and required accuracy was achieved throughout ICM.

2 DESIGN ELASTICALLY SCALED HIGH ASPECT RATIO WING MODEL

Consider use of the developed technique at design of elastically scaled high aspect ratio wing model of prospective aircraft. As reference ICM the matrix of final-element model constructed for current beam model wing is used. Dimension of reference ICM is equal to the number of control points – 12: two in a row in the direction of the chord and six on the wing span.

At the first stage the finite element model of the wing is performed in scale of linear dimensions k_L = 1: 1 with respect to current aerodynamic beam model and in scale k_L = 1: 7 with respect to full-scale structure of the wing of the aircraft. This model is based on 2-D final elements. At the preliminary stage series of calculations with different variants of arrangement of projected areas were carried out. Used for the second stage arrangement scheme is shown in Figure 2.

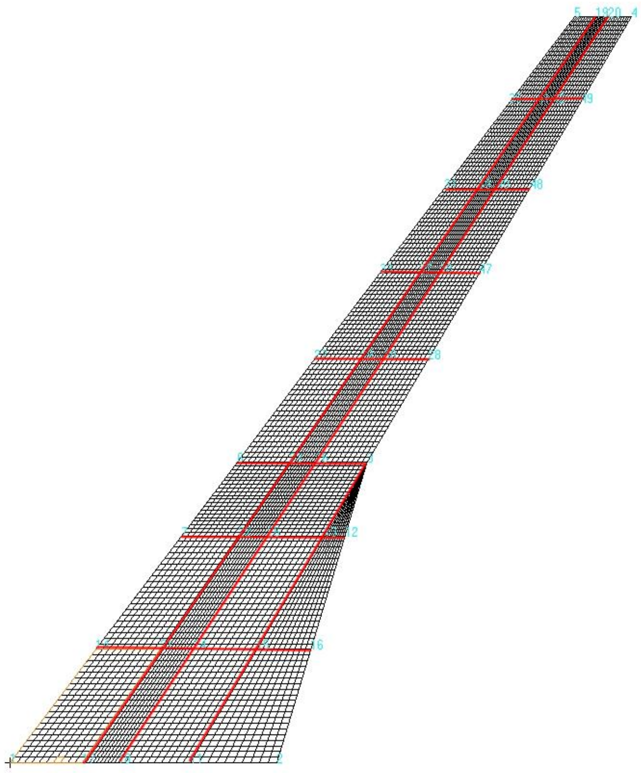

Figure 2: The arrangement of projected areas of the model.

The error ε of convergence of the solution with use of functional (2) and this scheme of arrangement appeared less than 5% that shows good result.

After preliminary calculations on the plate model was held a final calculation based on the model of the wing three-dimensional finite element (see Figure 3).

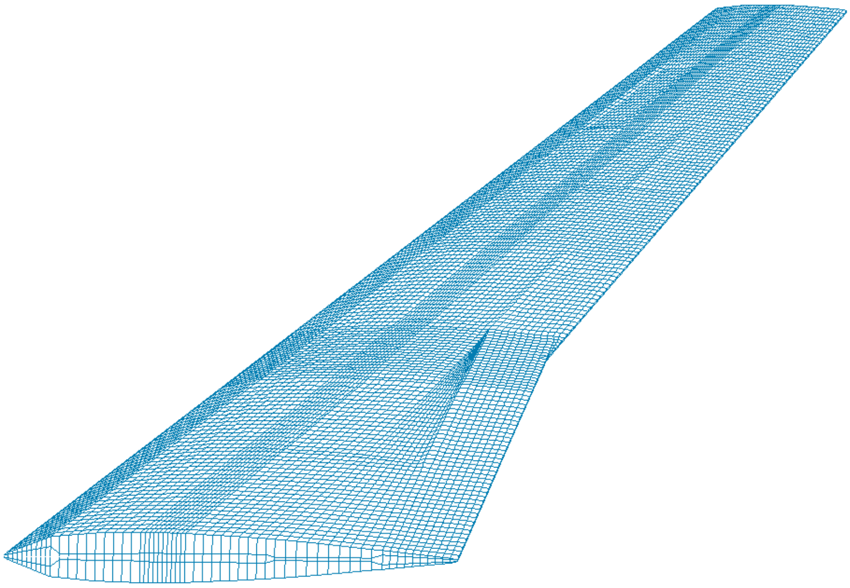

Figure 3: 3-D model of the wing.

The model from three-dimensional final elements has arrangement of projected areas and initial thickness of the core accepted and received from preliminary model. In three-dimensional model areas which are adjoining to leading and trailing edges (and not part of design variable areas) are represented by three layers of final elements of shaping material. Other part of design divided into design variables areas and represented with three layers of final elements — the core in the middle and shaping material at top and bottom.

Special program was developed that prepares a batch file for NASTRAN system for definition finite-element model and for subsequent decision was developed. Background information for the program recorded in the batch file.

In the beginning of second stage static calculations were carried with the thickness values that were reached at the preliminary stage. Comparison of these calculations shows that the transition to a three-dimensional grid is accompanied by a certain loss of accuracy in ICM comparison with the reference model. This difference in the formulation of the problem mentioned above. The relative value of the maximum difference between the diagonal elements of the ICM has increased to 13% and exceeded the set value of 5%.

After carrying out optimizing calculation on 3-D model the relative difference of the ICM elements of model with ICM elements of a reference matrix didn't exceed the established value of 5%.

In addition to symmetric core located in the center of model other type of the core displaced to the top of airfoil was used. This type of model at the second stage was modeled by two layers of final three-dimensional elements. This type of the core is shown in Figure 4.

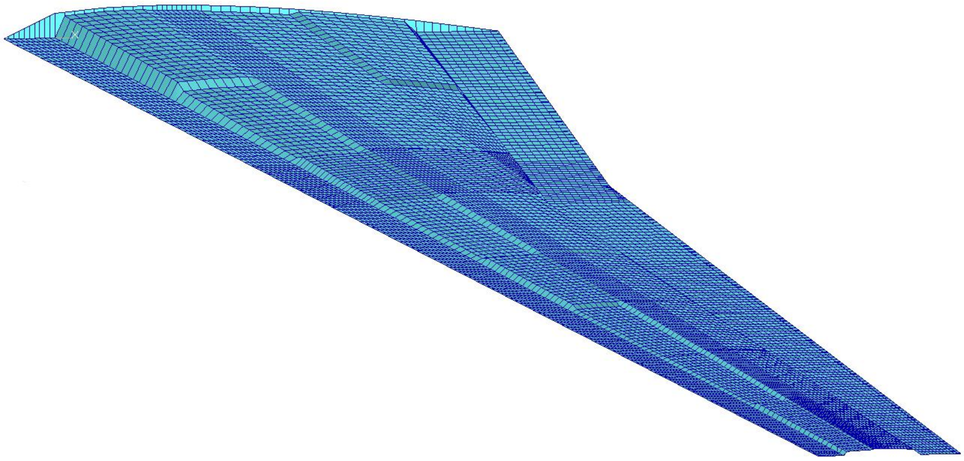

Figure 4: 3-D model of the second type of the core.

Both variants of core position showed good convergence using functional (2) and the results of the convergence solutions are shown in Table 1.

Number of ICM element	Error for symmetrical type of the core, %	Error for displaced type of the core, %
1	1.81%	-0.57%
2	-1.96%	2.01%
3	0.68%	-0.54%
4	0.07%	-0.46%
5	-0.24%	0.18%
6	-0.37%	0.04%
7	-0.57%	0.20%
8	-0.65%	0.15%
9	-0.61%	0.16%
10	-0.08%	0.09%
11	-0.17%	-0.02%
12	-0.24%	-0.10%

Table 1: Results for the two types of core.

The distribution of thickness received during optimization showed that satisfies to technological restrictions and strength conditions. The minimum thickness of projected area was 7 mm at a relative thickness of a profile at this chord of a wing – 25 mm. The maximum thickness of projected area of the core was 24.7 mm at a relative thickness of a profile of 48 mm.

The subsequent static calculations for the two types of the core showed that the selected scheme suitable for the design model.

CONCLUSIONS

The approach to creation of the structurally simplified elastically scaled model consisting of the rigid core and shaping material focused on progressive technology while production on the modern equipment is offered. For received as a result of the designing solution the following main requirements are fulfilled: the core doesn't go beyond a theoretical contour, and its minimum relative thickness not less than 25%. It is shown that for the developed elastically scaled model requirements of durability at tests in a wind tunnel are met. As a result achievement of the estimated error of the ICM elements which isn't exceeding the limit of 5% for the projected model in comparison with reference is provided.

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