INFLUENCE OF COMPOSITE WING ELASTICITY PARAMETERS ON STRUCTURE WEIGHT

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Abstract

The results of new algorithm's validations are presented for composite wing optimization procedure taking into account constraints on structure elasticity characteristics.

Optimal strength and stiffness parameters of the composite wing are determined by using:

1. *Analytical beam model of the wing;*
2. *Parametrical finite element model of the airframe structure;*
3. *Statistical techniques for correction of the structure weight;*

At the first stage the problem of weight optimization is solved in frames of the classical beam model. Optimal values of stiffness parameters obtained from the optimization are transferred to the data base of FEM model. Additional constrains on a stiffness of finite elements are generated there basing on these values.

It was shown during the calculations these constrains were active for lateral parts of wings.

Then the classical (in frames of FEM model) problem is solved for determination of optimal structure parameters to satisfy minimum weight criteria.

At the last stage a refinement of the wing structure weight is performed using a database of statistical correction factors.

The use of such algorithm at initial stage of designing enabled:

- *to reduce significantly work duration and efforts required for calculating the influence of aeroelastics on strength and weight parameters;*
- *to obtain confident estimations of the influence of elastics on the structure weight in frames of linear FEM models.*

Validation of the algorithm was carried out in frames of NACRE project of 6th EC Program for estimating weight of composite flying wing structure.

The results are presented for optimizing of:

- *composite wings of high aspect ratio;*
- *wings with critical areas in interfaces to fuselage zones;*
- *wings with large cutouts.*

Introduction

For the aircraft's designing the criterion of a minimum weight is one of the basic criteria of structure optimality. There are many algorithms and programs [1-2, 4-6] which use this criterion. In frames of the classical approach the task of search of a minimum weight structure is usually solved in frames of linear FEM models when load cases and constraints on geometrical parameters, manufacture demands, stress/strain limits are known.

However, in frames of such approach it is very difficult to solve this task with nonlinear constraints due to high level of a labor input and long work duration:

- buckling and post-buckling of various parts of structure,
- aeroelasticity,
- definition of ultimate loads.

For decreasing labor input a number of algorithms use the so-called two-model approach when calculation of the general strength, strain characteristics is made in frames of the main FEM model and constraints on aeroelasticity loads are being formed in frames of secondary model.

Unfortunately, the given approach has a number of shortcomings which are caused by problems of information's transfer from one model to another. A lot of time is being required for adaptation (validation) of a conventional two-model algorithm to a new aircraft structure. So, at the initial stages of designing these shortcomings can become critical for investigation of stress and weight characteristics of the aircraft.

In frames of the mentioned above approach which was developed in TsAGI it is possible to solve similar problems at the initial stage of designing with a small labor input and within a short time's interval because the approach allows carrying out the procedure of automatic generation of universal parametrical FEM models for any aircraft structure.

Numerous validations of the algorithms on the basis of this approach showed that many classical problems regarding search for the minimum weight of the structure can be solved already at the initial stage of designing fast and correctly.

Workability of the algorithm was shown on an example of solving the classical task of designing the high aspect ratio composite wing taking into account constraints on geometrical parameters and constraints connected with aeroelastic behavior of composite wings.

1 New approach to structure weight analysis of elastic composite wing

This paper presents new approach regarding a well-known two-model algorithm which is usually used for investigation of aircraft structures.

The proposed algorithm has some important distinctive features which allow to designers to solve many difficult tasks with small labor input. The algorithm's main principle is the fully automatic procedure which combines the universal parametrical FEM model of an entire aircraft and the adapted composite beam model of the wing. The procedure is realized on the basis of an automated database developed by TsAGI's specialists. The scheme of the database is presented in Fig. 1.

The database has three envelopes:

- internal one which is responsible for specifying initial data and for analyzing the results of calculations,
- interface's one which is responsible for transferring the information between the internal envelope and the peripheral one,
- peripheral envelope which is responsible for maintaining the conventional programs.

The mentioned above scheme of the database enables to reduce significantly labor input and the time period for solving many difficult tasks.

The database includes a set of the general structure parameters of the entire aircraft.

In frames of the database the FEM model of any airframe is automatically being formed on the basis of the standard set of the structure parameters. The structure parameters consist of four main groups (Fig. 1):

- geometrical data (gray zone),
- inertial values (green zone),
- manufacturing parameters (yellow zone),
- material properties (pink zone).

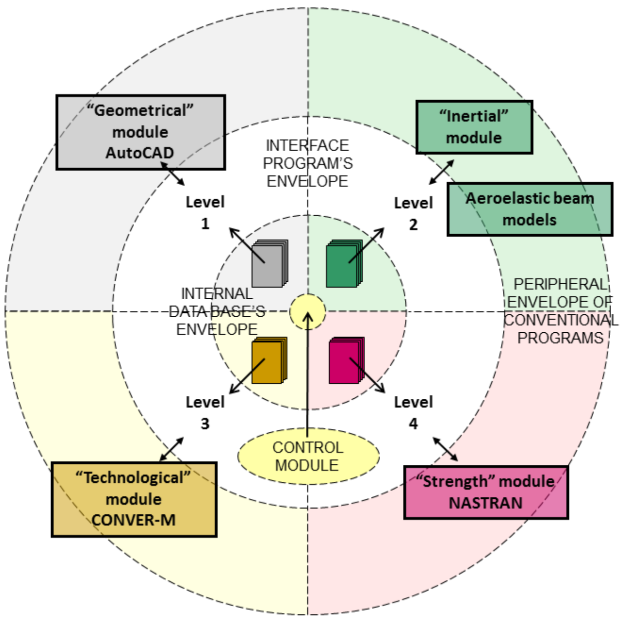

Fig. 1. Block scheme of the automated database

All these parameters are being specified by means of the standard and handy procedure.

After that, several strength models of the airframe are being formed simultaneously on the basis of these parameters. In addition to the main FEM model of the aircraft structure two analytical beam models can be created for solving the quite complicated physical tasks concerning non-linear behavior of a composite wing under different load cases.

What about the beam models these ones were developed in TsAGI more than 20 years ago [3] and have passed through the good validation concerning the analysis of the composite wing's elasticity influence on strength parameters and weight characteristics of many real wings. In frames of these beam models it is convenient to receive reliable solutions for the standard problems of aeroelasticity. These solutions have to be used in the frames of the main FEM structure's model to save significantly labor input and the time needed for getting the correct solution for complicated non-linear tasks.

One of these tasks is the problem of composite wing's weight saving with constraints on aileron efficiency. Another one is a fast calculation procedure of load cases taking into account the aeroelastic behavior of composite wings during the flight.

In frames of the new approach these tasks can be solved fast and correctly in frames of FEM model at the earlier stages of airframe designing.

2 The models of airframe structures

In frames of the database a FEM model is being created automatically if all four groups of the mentioned above structure parameters have been specified. The FEM model contains all main airframe's elements (units and sections). On the basis of the FEM model an equivalent beam model of the caisson is also being formed automatically (Fig. 2).

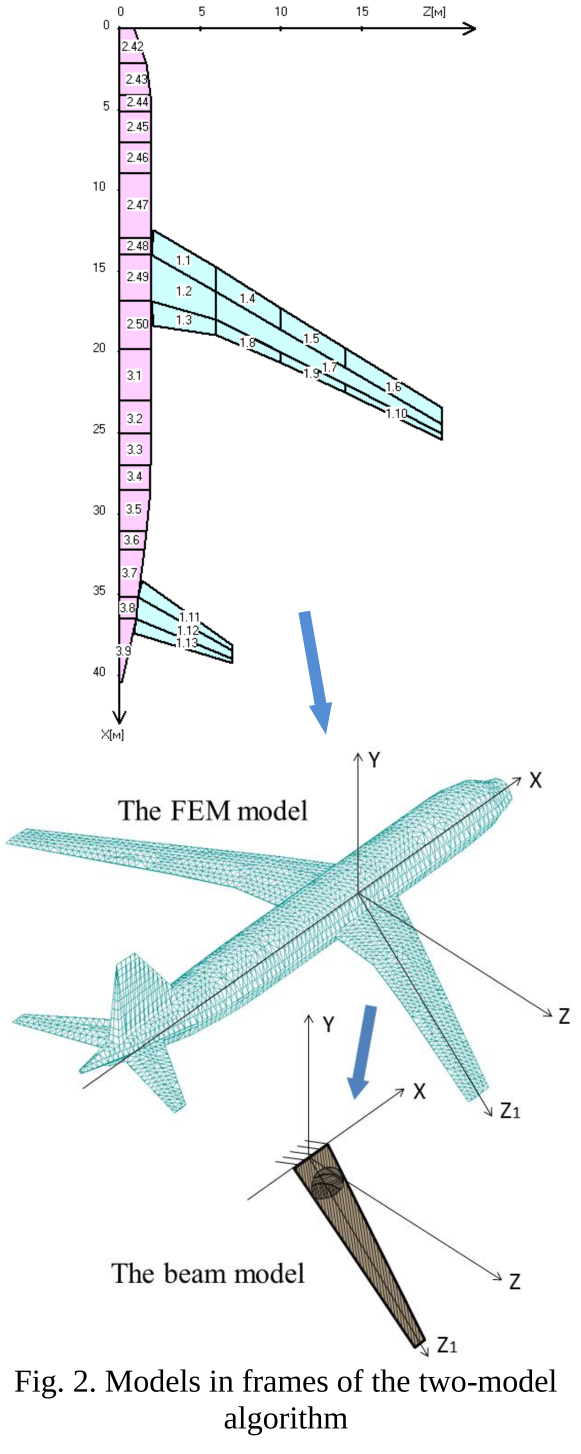

Fig. 2. Models in frames of the two-model algorithm

The algorithm gives an opportunity to form the FEM models automatically also with various limits on a size of a FE that allows creating the FEM model of needed dimensionality. In frames of parametrical FEM model there is the special parameter Δ_{fe} (maximum size of FE) which is responsible for dimensionality of the FEM model. It gives the quite easy possibility to generate suitable dimensionality of the FEM models to satisfy the required level of accuracy of calculated (stress/strain) parameters. In Fig. 3 for hypothetic aircraft the dependence of the Mises stress/strain values on a maximum size of FE of the FEM model is presented for three wing sections.

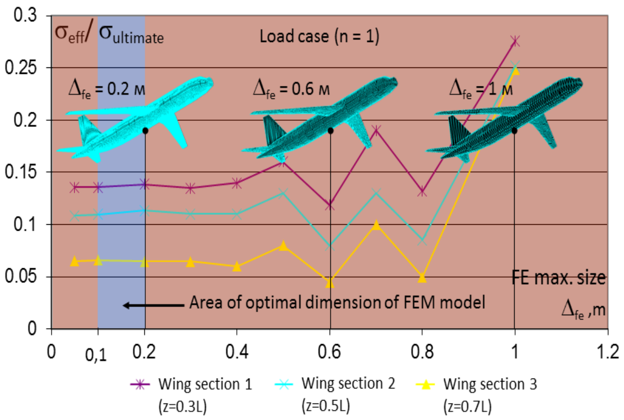

Fig. 3. Dependence of stress level on the maximum value of the FE size

Diagrams presented on Fig. 3 show that there is quite high dependence of Mises stress/strain values if Δ_{fe} big enough. While the Δ_{fe} is decreasing the fluctuation of the stress factors becomes insignificant. It means that there is a zone where the physical results don't depend (the mistakes within required accuracy) on dimensionality of the FEM model. So, in frames of this approach it is possible to define the suitable dimensionality of FEM model for every aircraft structure. In Fig. 3 the suitable zone has blue color.

The FEM model of hypothetic civil aircraft structure with Δ_{fe} = 0.2 was used to solve the tasks of defining optimal aircraft structure taking into account the aeroelactic constraints.

The beam models which used in this algorithm were created on the basis of the classical anisotropic plate model [3]. These models consist of two structure elements (Fig. 4): quasi-isotropic skin – *D* and unidirectional layers – *EI*. Ψ is an angle of the layer orientation with respect to axis *Oz*. The parameter χ is a wing sweep angle. This combination gives the possibility to simulate many variants of composite wing structures. For both models simple analytical solutions were obtained for quite complicated mechanical task concerning influence of elasticity on composite wing behavior during flight.

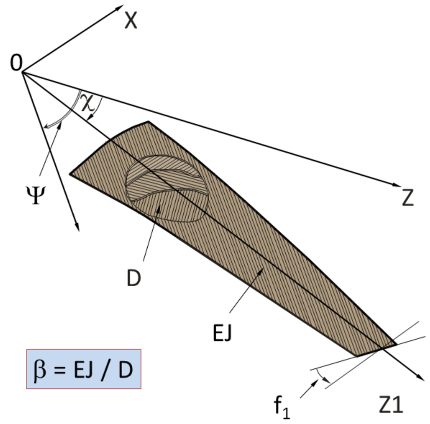

Fig. 4. Composite anisotropic wing beam model

In frames of the beam model it is possible to define the influence of the layer orientation angle on the torsion angle of every section $f_1(z)$ of the wing which represents the effective torsional stiffness. The dependence of $f_1(l)$ on ψ for wing with different ratio of $\beta=EI/D$ and the sweep angle χ is shown in Fig. 5.

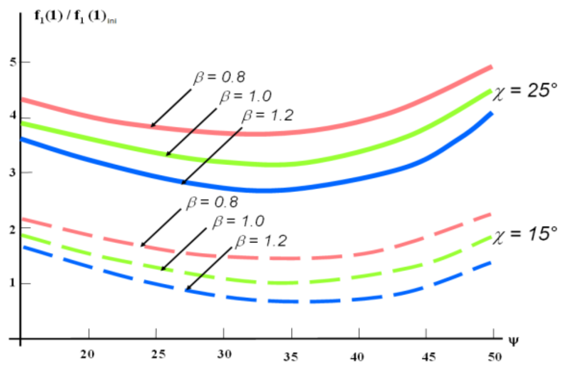

Fig. 5. The dependence of effective torsional stiffness on the layer orientation angle

The validation research has shown that calculation results on the basis of beam and FEM models of the wing are quite close to each other (Fig. 6).

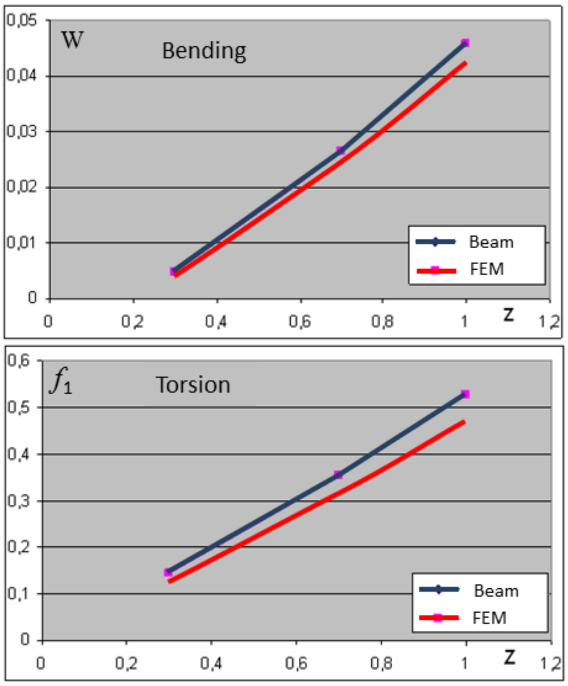

Fig. 6. Comparison of the beam and the FEM models

3 The procedure in frames of the new approach

The solving procedure can be divided into 4 stages.

At the first stage the general parameters of an airframe are being specified in frames of the automated database. The FEM model of the airframe and the beam models of the composite wing structure are being formed simultaneously. In frames of the beam models the classical task of determination of the minimum weight of the structure with the aileron efficiency constraints is being solved. After that the obtained values of stiffness' parameters is being transferred to the FEM model for twenty cross-sections.

At the second stage the obtained stiffness' parameters are used to specify stiffness' minimum values of the FEM for middle and lateral parts of the wing structure. After that the classical task of determination of minimum weight of structure of the FEM model is being solved. The results of new stiffness values are being transferred back to the beam model to satisfy the correct boundary conditions (first of all, root conditions) for getting new beam solutions.

At the third stage the classical task of determination of the minimum weight of the structure with aileron efficiency constraints is being solved again with corrected boundary conditions of the beam model. As a result of this solution the correct stiffness is being obtained and being transferred to the FEM model.

And finally at the fourth stage the classical task of determination of minimum weight of structure is repeated again with new stiffness' minimum values for middle and lateral parts of the wing structure. As a result the optimum distribution of load-bearing material in the wing is being obtained (Fig. 7).

The procedure is fully automated not only regarding as specification of the initial parameters as analysis of results of calculation but also the calculation process.

4 Examples of solving some tasks

On the basis of the proposed approach the task of determination of the minimum weight of the wing structure have been solved for hypothetical civil aircraft taking into account the aileron efficiency constraint.

Fig. 7 shows the optimum distribution of load-bearing material in the wing for four values of aileron efficiency f (light blue curve: $f = 0$, blue curve: $f = 0.22$, red curve: $f = 0.35$, green curve: $f = 0.6$, dynamic pressure $q = 10000\ N/m^2$) which were used as additional constraints. The violet line is the manufacture constraints on the skin thickness.

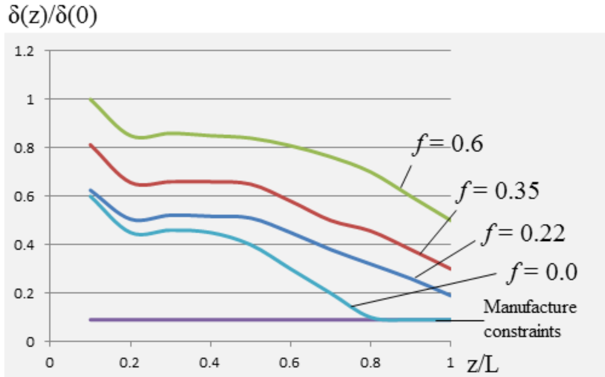

Fig. 7. Distribution of load-bearing material in the wing depending on the aileron efficiency constraint (f)

The next Fig. 8 shows the dependence of the wing structure weight on the aileron efficiency constraint for different dynamic pressures (q). For this case the unidirectional layer orientation Ψ was oriented in direction of Oz_1 axis (and also coincided with the sweep angle of the wing).

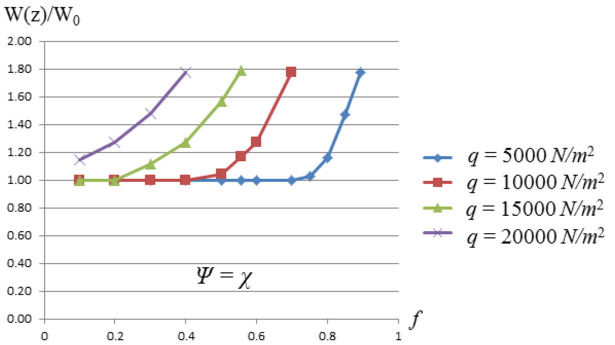

Fig. 8. The dependence of the wing structure weight on the aileron efficiency constraint for different dynamic pressures ($\Psi = \chi$)

The next Fig. 9 shows the same dependence for $\Psi = \chi + 20°$.

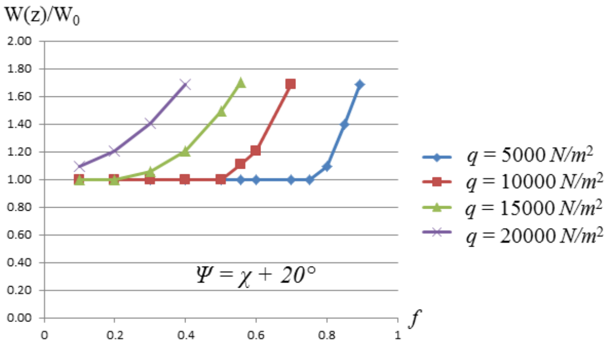

Fig. 9. The dependence of the wing structure weight on the aileron efficiency constraint for different dynamic pressures ($\Psi = \chi + 20°$)

Summary

The proposed approach allows decreasing significantly labor input and reducing the time of designing procedure in times.

The process of solving the task of the minimum structure weight determination including specifying initial data, formation of calculation models and results analysis takes about one working day.

This approach gives an opportunity to solve the weight estimation tasks and strength parameters analysis taking into account nonlinear constraints in the frames of the standard FEM models (Nastran) of high dimensionality (200 000-500 000 FE). And also there is an opportunity to carry out fast and precisely parametrical research of dependence of weight on different structure parameters or their combination.

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