NOVEL APPROACH AND ALGORITHM FOR SEARCHING RATIONAL NONCONVENTIONAL AIRFRAME CONCEPTS OF NEW GENERATION AIRCRAFTS

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Abstract

A new algorithm for parametric building universal FE-models is presented. This algorithm allows carrying out design research of aircraft layouts with change of geometric parameters determining aircraft outer contours.

The algorithm enables to search for rational airframe parameters by means of complex strength analysis including stress / strain state analysis of full airframe using the strain criteria, local and global buckling analysis and calculation of controls efficiency.

Validation of the algorithm showed that the labor input of searching rational airframe with nonconventional concept does not exceed the labor input of searching rational conventional airframe.

Some of nonconventional layouts were investigated on the basis of this algorithm. In this work as an example the results of weight efficiency investigation of the composite "Flying wing" structure and the dependence of structure weight on different wing parameters are represented.

1 Introduction

The long-term experience of designing and creating aircrafts made of metal alloys shows that the further considerable increase in weight efficiency of such structures should not be expected. On the other hand, the experience of creating composite airframes with conventional concepts and layouts didn't result in considerable weight saving of the primary structure [1]. This forces investigators to search for new solutions for both concepts and layouts. Therefore it is necessary to investigate nonconventional concepts for creating perspective airframes with lower weight and cost characteristics [2].

It should be noted that a problem of searching a rational composite airframe with nonconventional layout is considerably more complicated than designing a metal structure with conventional concept and layout because the number of varied parameters is considerably increased first of all at the expense of the design parameters determining aircraft outer contours.

The objective of this paper is to illustrate a simple and reliable algorithm of parametrical generation of the universal FE model which enables carrying out designing investigations with change of aircraft geometry. In frame of this algorithm there is a special procedure of parametrical changing geometrical values which are responsible for outer contours of aircrafts in addition to one for changing airframes parameters.

1 Multidisciplinary approach to strength analysis of airframes

In designing of metal airframes the problems concerning concept, structure layout and airframe strength are solved separately (sequentially). Use of this conventional approach in designing of nonconventional composite structure can lead to the situation when the solution obtained at early stages of designing appears to be unrealizable in frame of available manufacturing technologies. To reduce the risks of obtaining unrealizable solutions the manufacturing constraints should be taken into account even at the earliest stage of designing, and the problems considered separately in the case of metal airframes should be solved simultaneously on the basis of the multidisciplinary approach in designing of composite airframes.

The multidisciplinary approach on the basis of the multilevel algorithm [3] is presented in the paper. The approach consists in combining the four stages of traditional designing of metal structures (pre-design, draft proposal, draft design and detail design) in one multidisciplinary task. This multidisciplinary task in frame of multilevel approach is considered.

The main principle of the approach is building the common 4-level airframe model on the basis of common special database. It enables to combine the tasks of the four design stages in one stage and these tasks are solved sequentially by iterative process (Fig. 1). The approach enables to harmonize the geometrical, structure, manufacture and strength requirements.

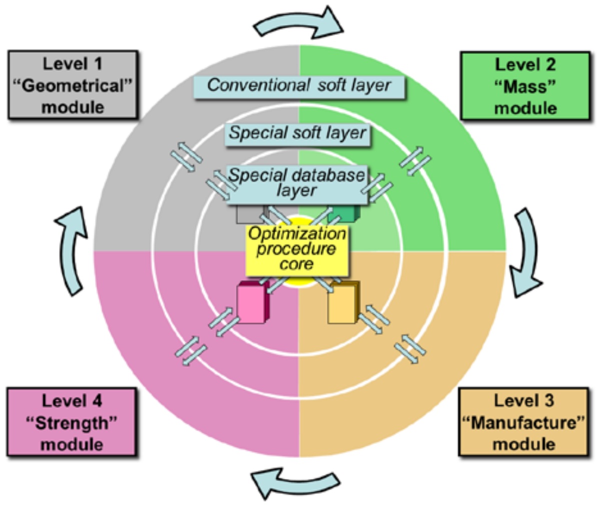


Fig. 1. Block-scheme of the special data base

With such an approach there are much more varied parameters, and it considerably complicates the designing problem. The specialized database including all structure parameters of the aircraft and also criteria of designing is necessary for solving this problem. On the basis of the specialized database the universal parametrical FE models should be generated. These models will allow solving simultaneously a problem of aerodynamics, aeroelasticity, strength etc.

Solving the multidisciplinary task is not possible without the automated connection between the models because it would require a large labor input and would cause significant random errors. To exclude the random errors connected with data transmission from one model to another and also to decrease labor input the numerical models should be generated automatically.

2 Multilevel algorithm of searching for rational concepts

Solving the problem of searching rational nonconventional aircraft concepts became possible in frame of the new approach when the procedure of geometrical parameters definition is based on universal parametrical model (see Chapter 3).

The proposed algorithm has some important distinctive features which allow to designers to solve many difficult tasks connected with changing geometrical parameters, which define aircraft concept, with small labor input. The main principle of the algorithm is the fully automatic procedure which combines the universal parametrical FEM model of the full aircraft and the adapted analytical models for solving particular tasks on different levels (Fig. 2).

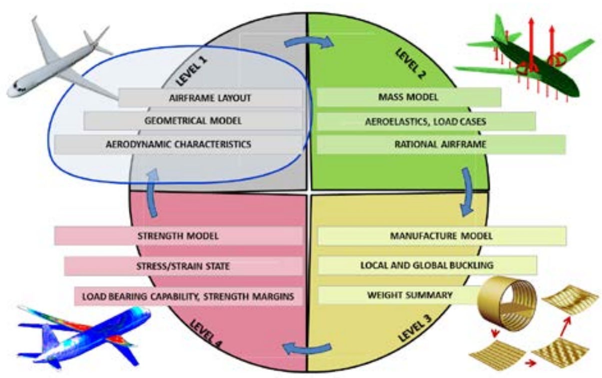


Fig. 2. The main tasks of geometrical level in frame of the multilevel algorithm

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 geometrical parameters of the entire aircraft.

In frames of the database the FEM model of any airframe is automatically being formed using standard set of structure parameters. The geometrical structure parameters are shown by gray zone on Fig. 1 which illustrates all parameters of aircraft structure needed to be defined in frame of the approach.

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

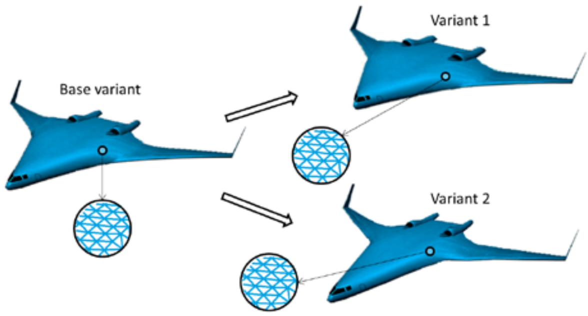
After that, several FE strength models of the airframe are being formed simultaneously. The FE-models of any airframe is generated automatically and the dimensionality of the FE-model is a special parameter.

In addition to the FE-models of the airframe some analytical models can be created for fast solving of local strength/strain tasks of airframe structures using other models. For example, tasks concerning:

- non-linear behavior of a composite wing [4, 5],
- buckling and postbuckling behavior of panels [6].

Non-linear behavior of composite wing can be quickly and reliably investigated using a beam model. Such kind of beam models were developed in TsAGI more than 20 years ago and have passed through the numerous validation researches. 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 frames of the main FE structure model to save significantly labor input and the time needed for getting the correct solution for complicated non-linear tasks.

The another important feature of the algorithm which allows decreasing time of analysis and labor input is the possibility to form alternative FE models having different concept and layouts with the same average size of finite elements (Fig. 3) which allows to perform fast and correct comparison of different concepts because of automatic generating the FE model for each combination of the parameters.



Parameter	Base variant	Variant 1	Variant 2
Wing span, %	100	100	100
Plane area, %	100	100	100
Fuselage width, %	100	130	70
Optimal size of FE, m	0.29	0.35	0.24

Fig. 3. Forming calculation models of aircraft concepts having the same level of accuracy of strength parameters

It enables analyzing different layouts under equal conditions as errors of the FE models can be provided practically identical due to choose of rational FE size when error of calculations does not exceed a specified value.

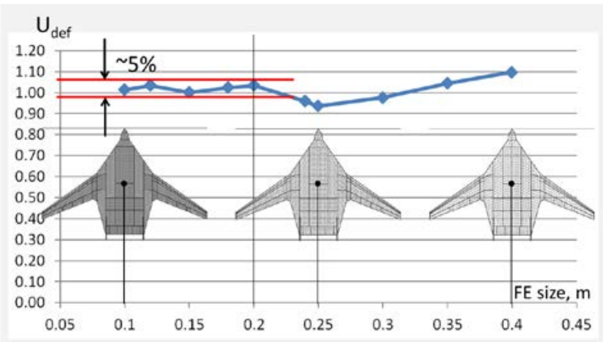


Fig. 4. Deformation energy vs. maximum FE size

Fig. 4 shows the dependence of deformation energy on maximum FE size. The figure shows that for FE size < 0.2 m the error does not exceed 5%. So, this FE size is rational for this model.

The algorithm of building the parametrical geometrical aircraft model of both conventional and nonconventional layouts is described in the next chapter. The algorithm enables to carry out designing calculations of airframe with change of geometrical parameters with small labor input.

3 Building the geometrical model of airframe

The approach on the basis of parametrical procedure of forming the main structure elements is used for building the geometrical aircraft model. The approach enables to provide the specified level of accuracy of geometrical parameters. Such an opportunity guarantees that the use of this model for forming the strength FE model is correct at the initial stage of designing and also it enables to get confident values of strength parameters.

The geometrical airframe model is formed with the use of full automation of specifying the initial data and support of external software. It enables to use fully automated algorithm for building the universal parametrical FE models for different structure variants.

The use of such approach requires developing structure of the initial data which enables to automate the procedures of preparing the initial data and analysis of results. So, the duration of full cycle of specifying the initial geometrical data to the start of solving a complicated problem can be reduced from some weeks to some days.

The first stage of creating the geometrical aircraft model is forming the model in plane view. Forming the geometrical model and specifying the coordinates of all points is done in the global coordinate system. X-axis of this system is directed along the fuselage from the nose to the tail. The beginning of X-axis coincides with the nose, Y-axis is directed upward, XOZ-plane coincides with building aircraft line. For saving time and decreasing labor input the geometrical parameters are specified only for right half of the structure by XOY-plane symmetry. Then the model is symmetrically mirrored and the full airframe model is formed.

One of the geometrical model variants of “Flying wing” structure is showed in Fig. 5. In essence it is a projection of the main units on the XOZ-plane.

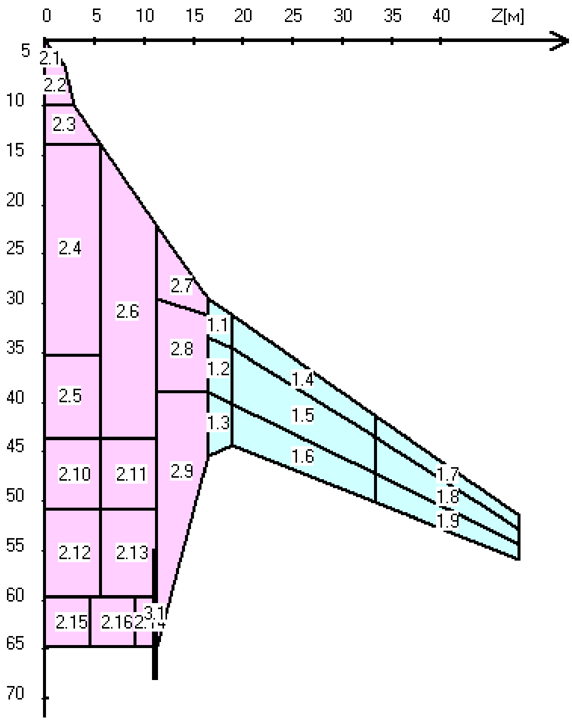


Fig. 5. Geometrical model of the aircraft. Plane view

The unit is a compound element of the structure for forming the geometrical model in plane. The units are chosen in accordance with aircraft concept so that their walls correspond to real walls in the structure. Upper and lower surfaces of the units model the outer aircraft surface. The units can be specified as triangles or convex quadrangles in plane view. So, for example, the units 1.2, 1.5, 1.8 (Fig. 5) are the wing caisson.

The procedure of forming the geometrical model in plane is automated to eliminate random errors of a user. Control of coincidence of coordinates of the neighbor units’ vertices is carried out. For intentional division of the neighbor units’ vertices (for example in case of a unit of a rotary part of the structure – wing flap, leading-edge flap, aileron, and elevation rudder etc.) the distance between them should be not less than previously specified value.

The second stage of forming the geometrical aircraft model is specifying the main fuselage cross sections in Z-Y plane. In frame of the used algorithm up to 18 base cross sections can be specified where one or two internal surfaces (PAX or cargo floor ets.) can be specified in addition to outer surfaces. The surfaces of the specified sections define upper and lower surfaces of the fuselage units. The fuselage sections should be chosen in such a manner that the outer and internal surfaces are specified with sufficient accuracy. Level of accuracy is controlled by comparing the area of the outer surfaces of the geometrical model and the aircraft being modeled. As in frame of strength models the surfaces between the specified sections are formed by a linear law, location of the sections on X-axis should be specified in such a manner that change of the geometrical parameters of the aircraft between the specified sections is close to linear.

For specifying the fuselage sections 4 curves are formed using 21 points equidistant on Z-axis in ZOY plane. Four surfaces of the geometrical model are formed on the basis of these curves. Outer upper and lower surfaces are formed on the basis of upper and lower curves. Two internal surfaces are formed on the basis of the other two curves. The fuselage sections are showed in Fig. 6.

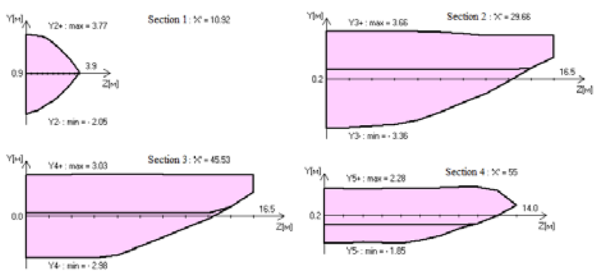


Fig. 6. Fuselage sections 1-4

The procedure of forming the fuselage sections is automated to parametrically and automatically change such geometrical parameters as width, height and shift on Y-axis in the global coordinate system. Coordinates of all specified points in the fuselage sections are updated automatically.

The third stage of forming the geometrical aircraft model is specifying the main wing cross sections in X-Y plane. In frame of the used algorithm up to 6 cross sections can be specified. For specifying the wing sections two curves are formed using 21 points equidistant on X-axis in XOY plane. Upper and lower wing surfaces of the geometrical aircraft model are formed on the basis of these curves. Like the fuselage sections, the wing sections should be chosen in such a manner that the outer surface is specified with sufficient accuracy. Location of the sections (except the wing root and end sections) on Z-axis should be specified by a sharp bend and other point where there is nonlinear change of geometrical parameters. The wing sections are showed in Fig. 7.

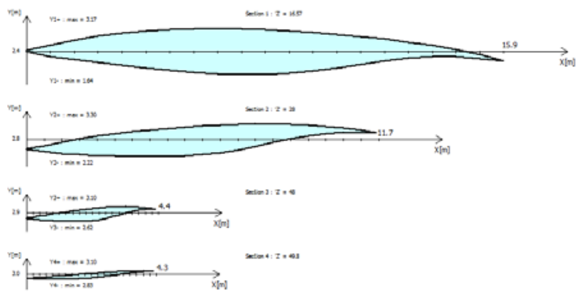


Fig. 7. Wing sections 1-4

The procedure of forming the wing sections is automated as well to parametrically and automatically change such geometrical parameters of the wing sections as width, height, angle of attack and shift on X-axis and Y-axis in the global coordinate system. Coordinates of all specified points in the wing sections are updated automatically.

Correspondence of the approximate geometrical model to the accurate geometrical model (structure being modeled) is determined by the surfaces area. The geometrical model of the “Flying wing” is showed in Fig. 8.

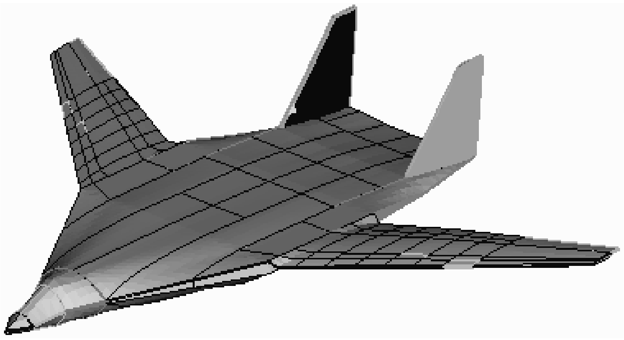


Fig. 8. Geometrical model of an airframe

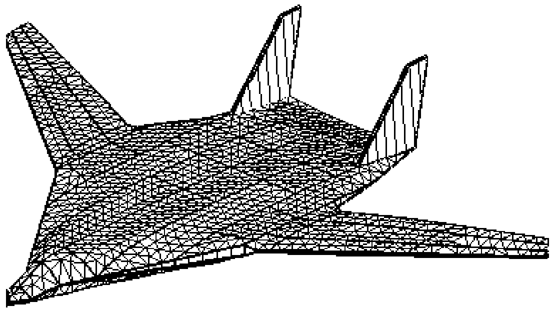


Fig. 9. FE model of the base variant of the structure

4 Searching optimal geometrical parameters of "Flying wing" concept

As an example of working capability of the algorithm of automatically changing geometrical parameters of outer contours, the dependence of weight of the metal "Flying wing" structure on fuselage width was obtained. This task is quite important for "Flying wing" concept because fuselage width (D) is a critical parameter for comfort of passengers.

When varying D other geometrical parameters of the structure such as wing span and plane area of fuselage were constant in this task. Take-off weight (150 tons) and number of passengers were constant as well.

The same task was solved 2 years ago in frame of one of Russian projects using conventional approach. Designers had to investigate more than ten alternative concepts with different fuselage width. Labor input of this task was more than 3 weeks.

Solving this task using the given approach takes one week only and accuracy of the solution (it means accuracy of weight estimation) was the same.

FE structure model of the "Flying wing" base variant is shown in Fig. 9

As an example the stress/strain state of airframes (base variant of "Flying wing") for one of the critical load cases is shown on Fig. 10.

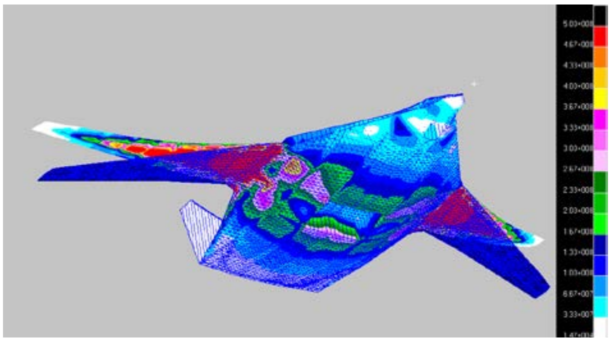


Fig. 10. Stress/strain state of the base variant of the structure

Fig. 11 shows the dependence of structure weight on fuselage width.

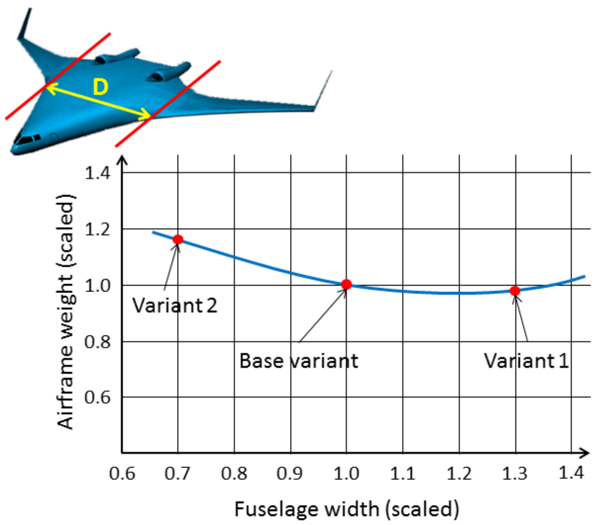


Fig. 11. Airframe weight vs. fuselage width

Summary

Novel approach for searching rational nonconventional airframe concepts by changing geometrical parameters was illustrated. The approach is based on the multilevel algorithm developed in TsAGI.

The algorithm using automatic specifying of outer contours geometrical parameters in frame of the multilevel approach was developed and validated for conventional FE models.

As an example of working capability of the algorithm, the dependence of weight of the metallic “Flying wing” structure on fuselage width was obtained.

Comparative analysis of working capability of the algorithm and the one of conventional approaches to parametrical investigation of aircraft concepts have shown that the new algorithm is more than 10 times more effective in terms of labor input.

Solving this task showed that labor input can be decreased in 10 times at the same solution accuracy.

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