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The Methods of Automated Synthesis of Finite Element Models of Bearing Elements of the Joint Area of the Center Wing with Cargo Aircraft Fuselage

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Abstract
The synthesis methods of finite element model of airframe in the joint area of center wing and fuselage are presented. The methods are based on the object-oriented information technology of data management that allows the using of the functional principle of finite element model decomposition. As the database management system is used ODBMS "SPACE". The application of the decomposition functional principle allows the process automating of FE-models synthesis of complex structures parts and integrating them in the total FE-model.

1. Introduction

One of the most important tasks in the process of cargo aircraft designing is the task of stresses distribution analysis in the joining elements of airframe connected the center wing with the fuselage center section.

The main problem to be solved in the process of designing the joint area of center wing with fuselage is the determining of loads acted on the bearing elements of airframe located in this area. Unlike the joint of wing console with center wing the joint area of center wing with fuselage includes the several bearing elements (Fig. 1): the vertical beams transmitting the vertical loads and the longitudinal walls transmitting the engines thrust and the wing drag.

Furthermore, the structure of joint area of center wing with the aircraft fuselage designed by the "high wing" scheme includes the special connective arcs linked the longitudinal structural elements of fuselage located before center wing with the longitudinal structural elements of fuselage located behind it.

For connection with the joining elements, the center wing and fuselage structures contain the special elements: reinforced frames (Fig. 2) to receive the vertical forces and the reinforced stringers to receive the longitudinal forces.

The existing integral methods of the bearing elements designing to connect the center wing with the fuselage center section, described in [2-4], do not enable to determine accurately the loads acted on the bearing elements of the airframe structure since the calculation integral methods do not permit to consider mutual influence of deformations. In addition, it is practically impossible to define the zones of stress concentration. As the result, it is impossible to provide the fatigue strength of the structure at the minimal weight of bearing elements. To solve this problem the special corrections, which values are defined mainly on the basis of empirical formulas based on the experimental data obtained for the existing classes of structures, are introduced in the results of integral calculations,. But the need to use the empirical corrections reduces the range of structures for which the analysis of stress-strain state (SSS) can be performed.

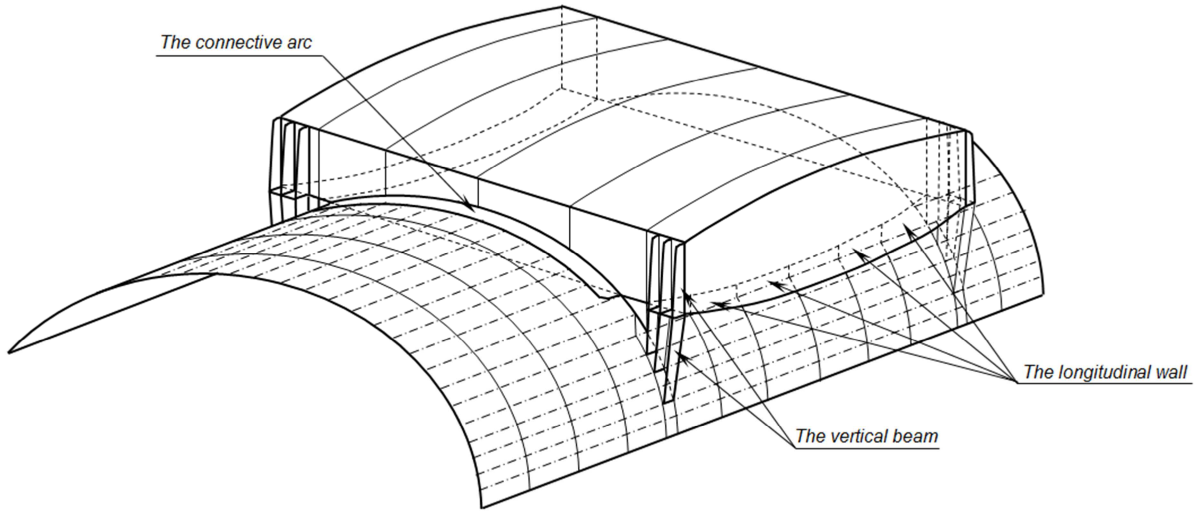

Fig 1. *The structure of the joint area of center wing with fuselage.*

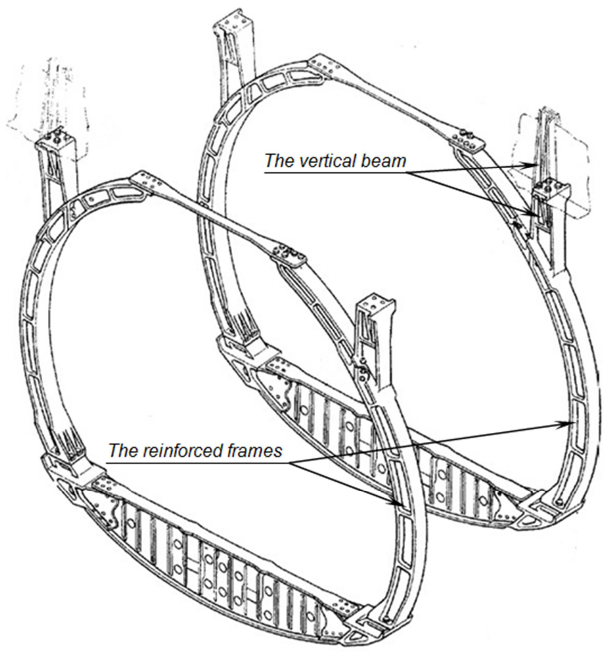

Fig 2. *The reinforced frames.*

The most effective method to solve the task of determining the deformations impact to the stresses distribution in structure is the finite element method (FEM), which is the universal calculation method of SSS of the random structures.

In this paper the synthesis methods of FE-models of airframe structural elements connected center wing with central section of cargo aircraft fuselage, which has the highly located wing, are described.

The methods are developed on the basis of the decomposition functional principle described in [1] that allows synthesizing FE-models of the joining elements on the basis of the data about nodes received directly from connectable models of center wing and the fuselage center section.

It is shown that the proposed methods can significantly reduce the amount of source data needed for the synthesis of FE-models of joining elements by limiting them only by references to the airframe section.

Developing of synthesis methods it was taken into account that unlike FE-model of flanged joint of the center wing with the console described in [5] the synthesized models must provide the preliminary analysis of SSS of the simulated structural elements. The data about nodes translations obtained in the process of analysis are also used for loads and constrains determining needed for SSS calculation of 3D-models.

2. The Problem Analysis

The FE-model synthesis of the complex technical object by integrating FE-models of its parts is more complex problem than the synthesis of 3D-model assembly out of 3D-models parts [6, 7]. This is due to the fact that the integration of FE-models requires not only the matching of their interior structures in the contact areas but also the changing of node numbers in connected finite elements (FE). In accordance with the basic method of FE-models synthesis, used in modern CAE-systems, the models integration is performed by replacing the closely located nodes [8, 9]. This method can not be considered reliable, because if it used the FE-models of the elements, which are not connected in the real structure, can be integrated.

Also, in accordance with this method, the FE-models synthesis is realized by the automatic distribution on the finite elements of the areas defined by the geometrical models. The use of this method for the synthesis of FE-model of the wing box requires the building of a large number of geometrical models that significantly increases the time of FE-model synthesis.

The specified problems and the methods of their solutions are described in detail in [1, 5]. In particular, the method of automated synthesis of FE-models of the flange joint of wing center section with the outer wing box section is described in [5]. It is shown that for the automated synthesis of FE-model of joint it is necessary to provide the direct data exchange between the connected FE-models and FE-model of the joint. It can be realized only with the help of object-oriented information technology (IT).

Unlike the synthesis method of FE-model of flanged joint, correction of FE-model of center wing is required for the joining of FE-models of vertical beams and connection arcs to FE-model of the wing. This includes the following operations (Fig. 3):

- nodes coordinates correction in the ribs models in the areas of the belts location transmit the longitudinal forces;
- the inclusion of the additional cross sections into structure of FE-model of the center wing for the joining of FE-models of vertical beams;
- moving the ribs taking into account the actual location of the longitudinal walls.

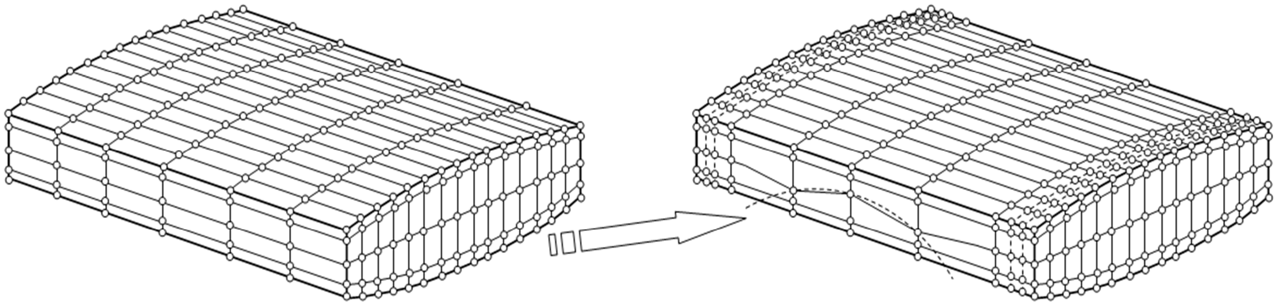

Fig 3. *The correction of FE-model of the center wing.*

So, unlike the FE-model of wing console the synthesis algorithm of FE-model of the center wing must provide the possibility of the automatic model restructuring in the process of integrating with the fuselage model.

3. The Analysis of Unsolved Problems

The synthesis algorithm of FE-model of cargo aircraft airframe in the joint area of the wing box with the fuselage central section provides the automatic data exchange between FE-models of joining elements and FE-models of the connected structure sections.

Thus, the models integration of the joining elements with the wing box models is possible only after the restructuring of FE-model of center wing that must be performed automatically.

Therefore the realization of the synthesis algorithm of FE-model of airframe in the joint area of the wing box with fuselage is possible due to the IT that provides the solving of following problems:

- the synthesis and the support of active FE-models that provide the automatic mutual data exchange;
- the connection of specialized algorithm of restructuring of FE-model of the center wing.

The analysis of IT, which results are presented in [1], shows that the modern CAE-systems do not enable to synthesize the active FE-models, which are capable to exchange the data without CAE-systems. The use of highly specialized algorithms is possible only within the object-oriented data management systems, which are not included in the modern CAE-systems.

4. The Statement of the Problem

The goal of this research is the development of automated synthesis methods of FE-models of vertical beams and longitudinal walls in the area of joining the wing box with the fuselage. According to the research results, presented in [1], the tasks of the synthesis of FE-models of cargo aircraft airframe are optimally solved by the object data base management system (ODBMS) "SPACE", described in [10]. Therefore, the synthesis methods must be developed taking into account the object-oriented IT features realized in ODBMS "SPACE". Thus, the structures of FE-models of joining elements must provide the preliminary analysis of their SSS.

5. Decomposition and the Scheme of the Data Exchange

The functional principle of decomposition of FE-model, described in [1], is used for the solving the problem of modeling methods developing of the structures of bearing elements of the joint area. The FE-models of bearing elements of the joint area integrate the previously synthesized FE-models of aforementioned airframe sections. Therefore, they are located in the upper level of decomposition along with FE-models of integrated sections. The ribs models, according to the synthesis methods of FE-models of regular areas of the structure, described in [1], are located on the lower, more detailed level of decomposition (Fig. 4). All models taking part in the synthesis process of FE-model of the joint area are realized as the objects of "SPACE".

The lists of the source data needed for the synthesis of FE-models of described joining elements depend on the modeling algorithms defined by their functional purpose. The part of data is inputted manually with the help of GUI supported by the corresponding objects. The data about contact zones nodes of integrated FE-models are transmitted via the virtual data structures during the direct data exchange process between them.

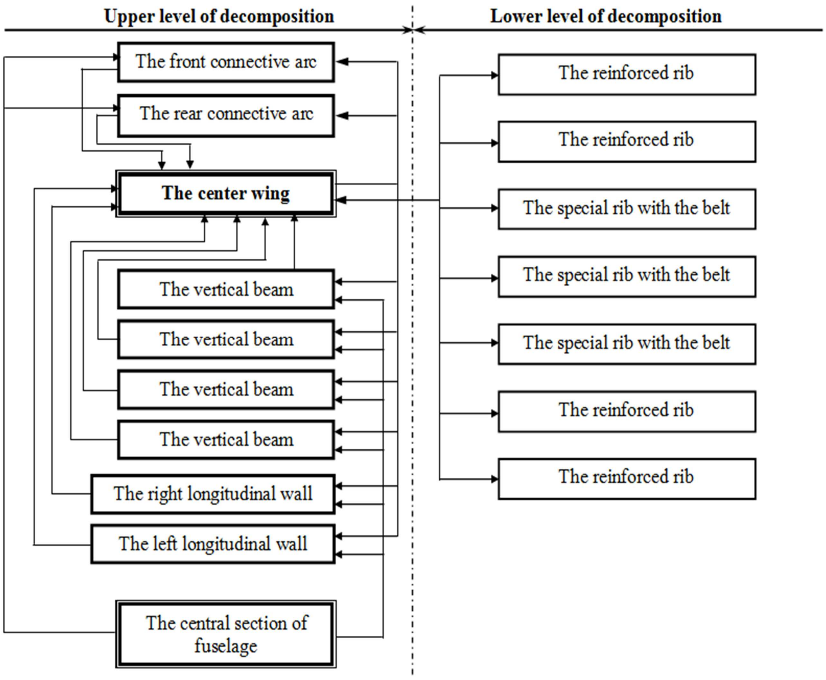

Fig 4. The levels of decomposition and the scheme of the data exchange during the synthesis of FE-models of the joint area of center wing with fuselage.

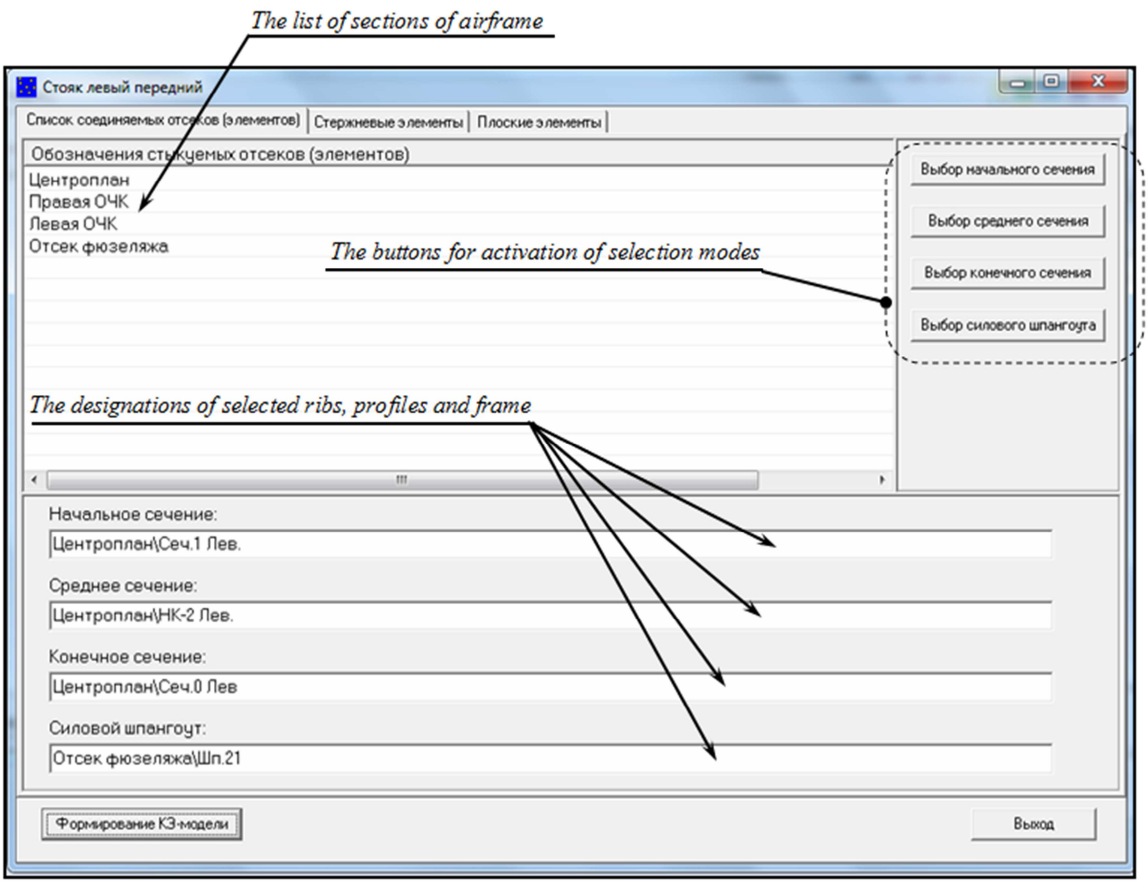

Fig 5. GUI to specify the links to FE-models of ribs, cross sections and frames connected with the FE-model of vertical beam.

The source data required for the synthesis of FE-model of vertical beam, transmitting the vertical force from the wing to the fuselage reinforced frame, are the following:

- the links to FE-models of the ribs and cross sections of the wing box contacted with FE-model of the beam;
- the link to FE-model of the fuselage frame, to which FE-model of the vertical beam joins;
- the nodes numbers of FE-models of ribs and cross sections of the wing box that are located in the plane of spar, which is the nearest to the plane of the selected frame;
- the nodes numbers of the outer contour of FE-model of the frame, to which FE-model of beam joins.

The links to FE-models of ribs, cross sections, and frame are specified manually with the help of special GUI, supported by the functions that are members of the object designed for the synthesis of FE-model of vertical beam (Fig.5). The links to FE-models of the airframe sections, that are the parts of the total FE-model, are transmitted during the process of object generating.

The links to connected FE-models of the airframe sections are transmitted as the individual codes of the corresponding objects and numbers of DB, where they are stored. The nodes numbers of FE-models of the ribs and cross sections are transmitted from the object that contains FE-model of center wing via the virtual data structure (Fig. 6). The nodes numbers of FE-model of reinforced frame, joined FE-model of vertical beam, are transmitted via the virtual data structure from the object that includes the frame model (Fig. 4).

```
//=============================================================
//== The structure for receiving and storage of coordinates and ==
//========== numbers of the nodes of joining profile =============
//=============================================================

char ProfileName[51];

short PNodeCount[2];
short PNodeNumber[2][2][200]; //--> NN of nodes in top and bottom
                     // contours of profile [top/bottom][out/in][]
short VerticalNodeNumber[2][6]; //--> NN of nodes in planes of
                               //    spars [front/back][....]

char SelectFlag; //--> The sign that profile is selected
```

Fig 6. *The format of the structure for data exchange with center wing.*

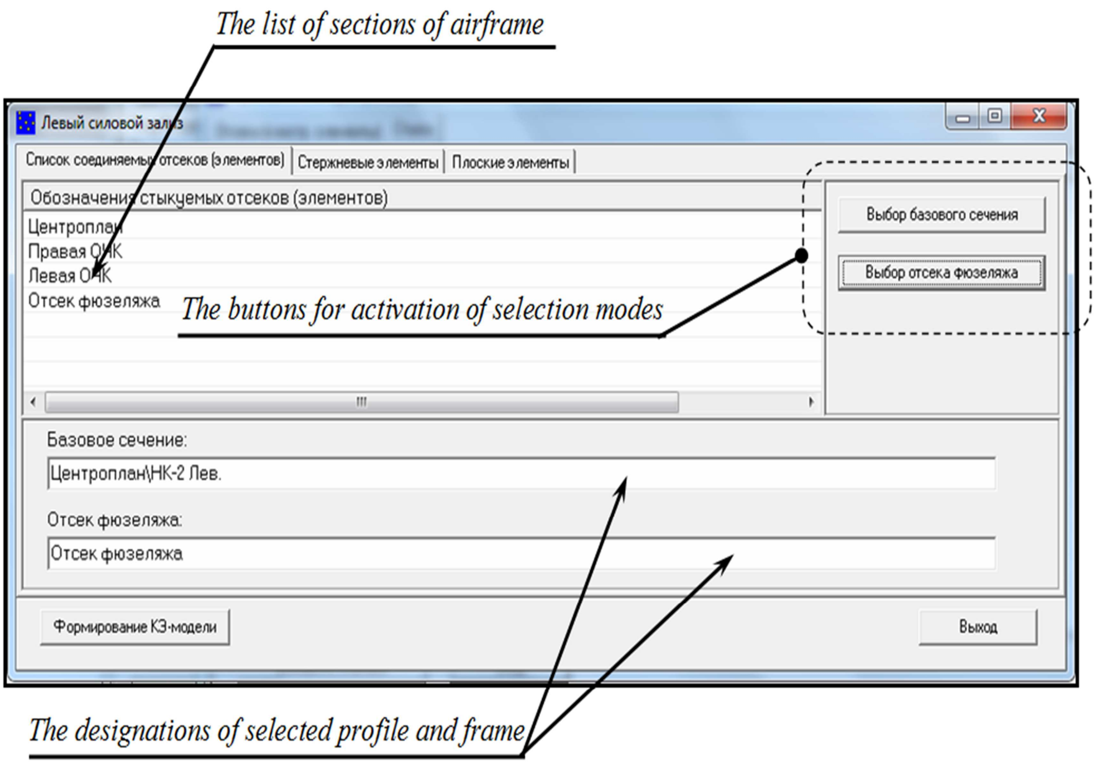

Fig 7. *GUI to specify the links to FE-models of rib and fuselage sections connected with the FE-model of longitudinal wall.*

The following source data are required for the synthesis of FE-model of longitudinal wall, transmitting the engine thrust and the drag of the wing to the longitudinal bearing elements of the fuselage,:

- the link to FE-model of the rib the section of wing box, from which the longitudinal force is transmitted;
- the link to FE-model of the section of fuselage, to which FE-model of the longitudinal wall joins;
- the nodes numbers that are located on the lower contour of FE-model of the rib, from which the longitudinal forces are transmitted;
- the nodes numbers of outer contours of FE-models of frames contacted with FE-model of longitudinal wall.

The links to FE-models of rib and section of fuselage are specified manually with the help of special GUI, supported by the functions that are members of the object designed for the synthesis of FE-model of longitudinal wall (Fig.7). The links to FE-models of the airframe sections, that are the parts of total FE-model, are transmitted during the process of object generating.

The nodes numbers of FE-model of the rib are transmitted from the object contained FE-model of center wing via the virtual data structure, which format presented in Fig. 6. The nodes numbers of FE-models of frames contacted with FE-model of the longitudinal wall are transmitted via the virtual data structure, which format presented in Fig. 8.

```
//=================================================================
//==== Transmission of numbers of nodes of FE-models of frames ===
//=================================================================

short PCount; // The number of profiles
short PNodeCount[200]; // The number of nodes in profile
short PNodeNumber[200][2][300]; // The numbers of nodes in
                                // FE-models of frames
char ReadyFlag;
```

Fig 8. *The format of the structure for data exchange with fuselage.*

6. Structure of FE-Model in the Joint Area of Center Wing and Fuselage

The structure of FE-model of aircraft airframe synthesized according to the proposed synthesis methods of FE-models of the vertical beams and the longitudinal walls is shown in Fig. 9.

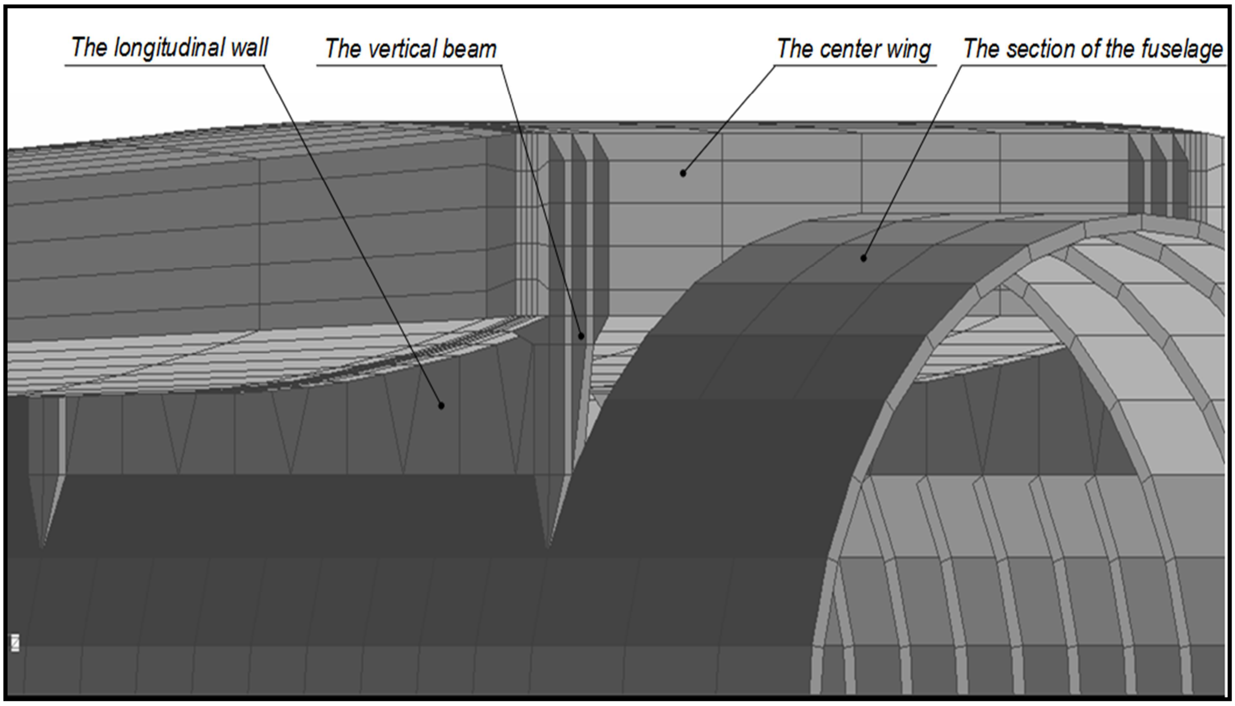

Fig 9. *The structure of FE-model in the joint area of center wing with fuselage.*

This model does not include FE-models of connective arcs since this paper does not contain description of their synthesis methods. Accordingly, FE-model of the center wing does not include the models of the ribs that are include the belts that receive the forces from the longitudinal bearing structural elements of fuselage. Also, the presented model does not include FE-models of reinforced frames since the methods of their synthesis are not described in the paper.

For greater clarity, the number of FE-models of the ribs and stringers is reduced in the wing box and fuselage models.

The proposed methods of automated synthesis are developed with the account of the internal representation of FE-models described in [1]. Thus, the vertical beams models contain not only the contact nodes already existed in FE-models of connectable sections but also own nodes, added to existing array of nodes of the total FE-model. As the result, algorithm of the node numbers definition in the copies of FE-models of vertical beams and longitudinal walls transmitted to the object, which forms the total FE-model, are significantly complicated.

7. The Synthesis Method of FE-Model of Vertical Beam

The synthesis method of FE-model of vertical beam includes three stages. The reading of the contact nodes numbers of FE-models of the ribs and cross sections of center wing contacted with FE-model of vertical beam is performed at the first stage. The reading of numbers is carried out automatically directly in process of ribs and cross sections selection. It is performed in the following sequence:

Step 1. The selection of the wing box section and activation of selection mode of the rib and the cross section that are contacted with vertical beam. The section selection and activation of the rib or cross section selection mode are performed manually with the help of GUI shown in Fig. 5.

Step 2. The selection of rib or cross section contacted with the vertical beam. The rib or cross section selection is performed manually with the help of GUI shown in Fig. 10, displayed as a result of activation of object containing FE-model of the center wing.

Step 3. The transmission of node numbers of FE-model of selected rib or cross section from the object, contained FE-model of the center wing, to the object contained FE-model of the vertical beam. The transmission of node numbers is performed via the virtual data structure, which format is shown in Fig. 6. Initialization of the virtual structure is performed each time when the object containing FE-model of the center wing is activated in the mode of the rib or cross section selection.

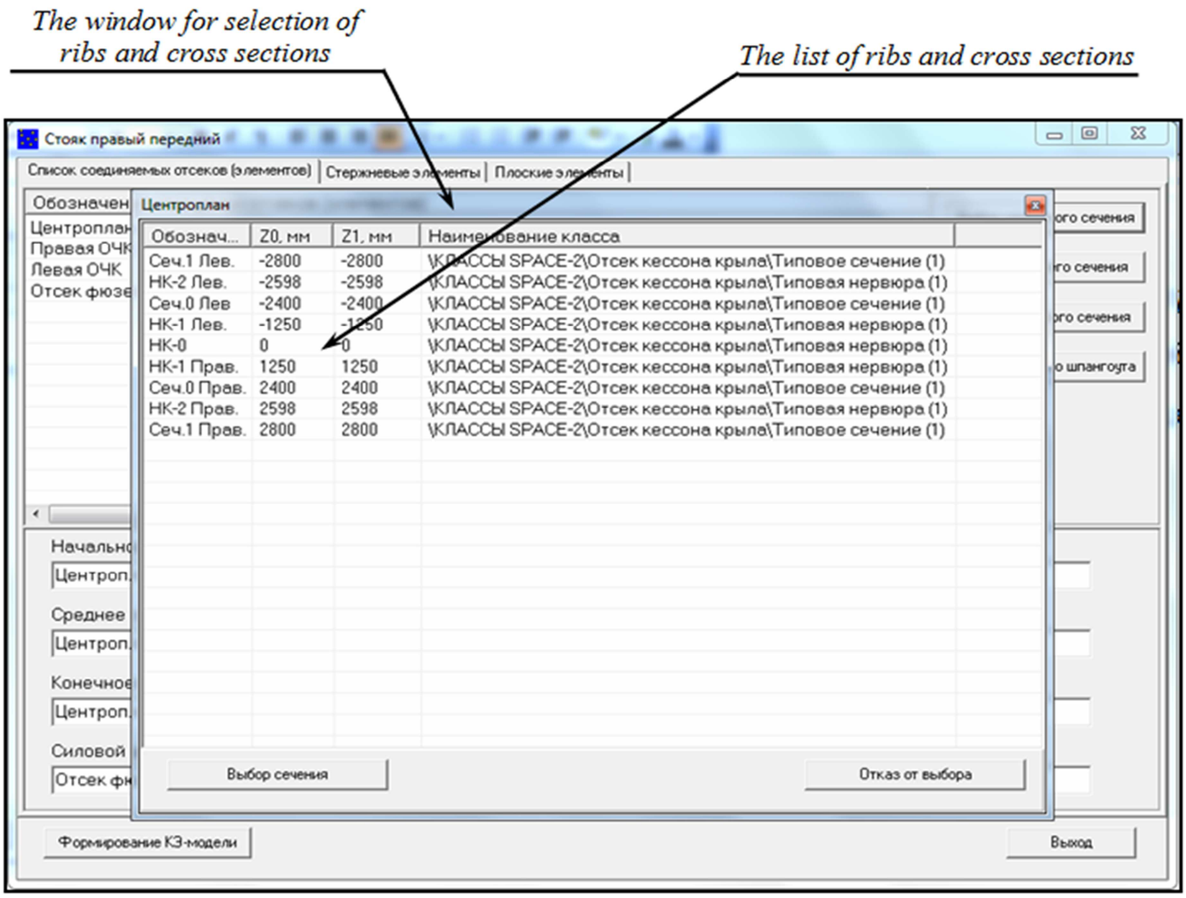

Fig 10. The selection of rib or cross section of the center wing.

Step 4. Go to. If all of the ribs (cross sections) of the center wing are selected then go to Step 5. Otherwise return to Step 1.

Step 5. The selection of the fuselage section and activation of mode of selection the frame contacted with the vertical beam. The selection of the fuselage section and activation of the frame selection mode is also performed with the help of GUI shown in Fig. 5.

Step 6. The selection of frame contacted with the vertical beam. The frame selection is performed manually with the help of GUI shown in Fig. 10, displayed as the result of activation of the object containing FE-model of fuselage.

Step 7. The transmission of node numbers of FE-model of selected frame from the object, which contains FE-model of the fuselage section, to the object contained FE-model of vertical beam. The data transmission is performed via the virtual data structure, which format is shown in Fig. 6. The initialization of virtual structure is performed each time when the object containing FE-model of the fuselage section is activated in the mode of the rib or the cross section selecting.

Step 8. The determining of spar contacted with the vertical beam. The spar, contacted with the vertical beam, is determined with the account of coordinate X of the selected frame.

Step 9. The reading of node numbers of FE-model of the ribs (cross sections). The node numbers of FE-model of the ribs (cross sections) are read from the array of nodes coordinates located in the plane of spar contacted with the vertical beam. This array is filled at the transmission of node numbers from the object containing FE-model of the center wing.

Step 10. The reading of node numbers of FE-model of the frame. The numbers of the three nodes of the external contour of FE-model of the frame, closely located to planes of the ribs (cross sections) of the center wing, that are in contact with the vertical beam, are read. The array of the node numbers of FE-model of the frame is received from the object containing FE-model of fuselage.

Step 11. The end.

The calculation of coordinates of the own nodes of FE-model of vertical beam is performed at the second stage. The calculation is carried out in the following order.

Step 1. The definition of contact nodes coordinates of the connected airframe sections. The coordinates of contact nodes of the connected airframe sections are defined on the basis of their numbers, transmitted into this object at the first stage of the synthesis process of FE-model of the beam. The values of coordinates are read from the common array of the node coordinates which is automatically transferred from the object containing total FE-model of airframe or its fragment.

Step 2. The definition of the outer and internal nodes coordinates of the stiffening ribs models. The number of outer nodes in the model of stiffening rib is defined by the number of nodes in cross section of the spar model, which structure is described in detail in [1]. The coordinates of the outer nodes are differed from the coordinates of nodes, located in the plane of spar, on the constant value ΔX, depended by the height of the spar cross section. For the front spar $\Delta X<0$. For the rear spar $\Delta X>0$. The nodes of the nearest cross section of the wing rib, which plane coincides with the plane of the stiffening rib are used as the internal nodes (Fig. 11):

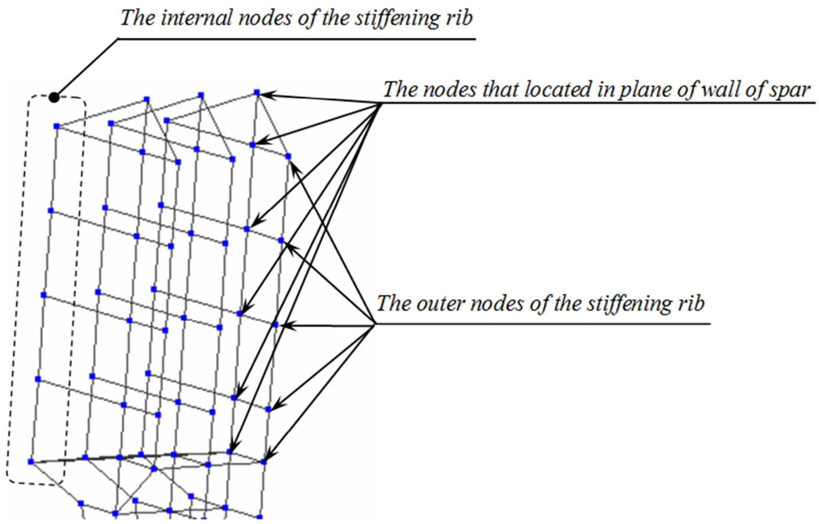

Fig 11. *The nodes of models of the stiffening ribs.*

Step 3. The coordinate definition of the support columns models. The nodes of the support column model connecting the spar model with the reinforced frame model are separated into two groups: the nodes, located in plane of the column, and outer nodes of the stiffening rib of column. The nodes located in plane of the column are also separated into two groups. The first group contains three nodes, which coordinates are differed from coordinates of the lower cross sections nodes of spar by the constant value $\Delta Y<0$. The value ΔY depends on the column width. The second group contains the single node, which coordinates are differed from the coordinates of outer contact node of the frame model by the value ΔZ. For the right vertical beam $\Delta Z>0$, for the left $\Delta Z<0$. The principle of coordinate definition of the column stiffening ribs is similar to the principle of the nodes coordinates definition described in Step 2.

Step 4. The end.

At the third stage the finite elements are described. The FE-model of vertical beam contains only the flat FE that can receive all types of loads, e.g. the elements "Plate" in MSC.Nastran. The general view of FE-model of vertical beam is shown on Fig. 12.

Step 1. The description of the flange joint area. The FE-model structure in the flange joint area consists of rectangular FE which rest on the lower nodes of stiffening ribs models.

Step 2. The description of stiffening ribs models in the spar area. The FE-model structure of the stiffening rib contains rectangular and triangular FE which rest on the outer and internal nodes specified in the description of the previous stage and also on the nodes located in the spar plane. The triangular FEs are located on the top of the model (Fig. 12).

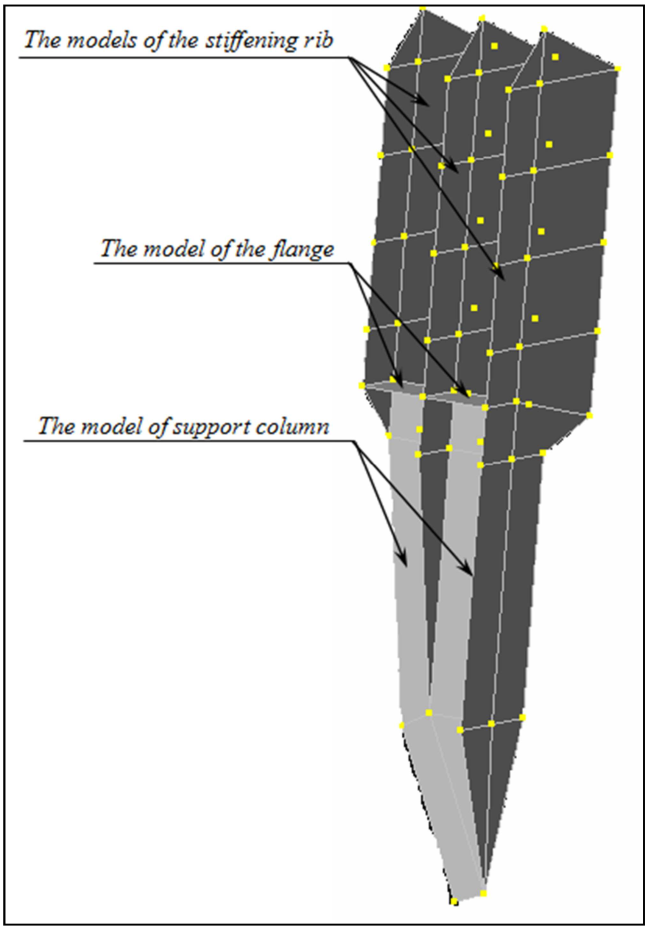

Fig 12. *The FE-model of vertical beam.*

Step 3. The model description of the support column. The structure of FE-model of the support column connecting the spar with the reinforced frame rests on the contact nodes located in the spar plane and on the outer contour of the reinforced frame model and also on additional nodes specified in the description of the previous stage.

Step 4. Stiffening ribs of the support column modeling. The structures of FE-models of the support column stiffening ribs connecting the spar with the reinforced frame contain the rectangular and triangular FE. The triangular FEs are located in the lower parts of the stiffening ribs models in the contact area with FE-model of the spar.

Step 5. The end.

8. The Synthesis Method of FE-Model of Longitudinal Wall

The synthesis method of the FE-model of longitudinal wall contains two stages because the wall model contains only the contact nodes, which are part of the structures of FE-models of center wing and the fuselage section.

The selecting rib and the fuselage section contacted with FE-model of the longitudinal wall and also the reading of contact nodes numbers of FE-model of the rib are carried out during the first stage. The reading is performed automatically, directly in the process of rib selecting.

Step 1. The selection of the wing box section and activation of selection mode of the rib contacted with the longitudinal wall. The section selection and the activation of the rib selection mode are performed manually with the help of GUI shown in Fig. 7.

Step 2. The selection of the rib contacted with the longitudinal wall. The rib selection is performed manually with the help of GUI shown in Fig. 10, displayed as a result of activation of the object containing FE-model of the center wing.

Step 3. The transmission of nodes numbers of FE-model of selected rib from the object, containing FE-model of the center wing, into the object, containing FE-model of the longitudinal wall. The transmission of nodes numbers is carried out via the virtual data structure, which format is shown in Fig. 6. The initialization of virtual structure is performed each time when the object, containing FE-model of the center wing, is activated in the rib selection mode.

Step 4. The selection of the fuselage section contacted with the longitudinal wall, and the link fixing to object containing of FE-model of the section. The selection of the fuselage section is carried out manually with the help of GUI shown in Fig. 7.

Step 5. The end.

The reading of the nodes coordinates of FE-models of frames contacted with FE-model of longitudinal wall and also the synthesis of its FE-model are performed at the second stage. Thus, the following actions are carried out:

Step 1. The definition of node numbers of FE-models of the frames contacted with FE-model of longitudinal wall. The node numbers of FE-models of frames contacted with FE-model of longitudinal wall, transmitted via the virtual data structure, which format is shown in Fig. 8. The transmission of node numbers is performed automatically at the accessing of object contained FE-model of the longitudinal wall, to the object contained FE-model of the fuselage section (Fig.4).

Step 2. The definition of the contact nodes coordinates of connected airframe sections. The contact nodes coordinates of the connected airframe sections are defined on the basis of their numbers transmitted into the object at the first stage of the synthesis FE-model of longitudinal wall due to the reading from the common array of the nodes coordinates transmitted automatically from the object contained the total FE-model.

Step 3. The synthesis of FE. Unlike the vertical beam model the FE-model of the longitudinal wall consists of the flat FE and the rod FE. The flat FEs take all types of the loads. The rod elements simulate the wall columns and must perceive the bending and torsion. The number of contact nodes on the lower contour of FE-model of the center wing rib is more than the number of FE-models of the frames contacted with FE-model of wall. Therefore, FE-model of longitudinal wall except the rectangular FE contains the triangular FE. The general view of FE-model of longitudinal wall is shown on Fig. 13.

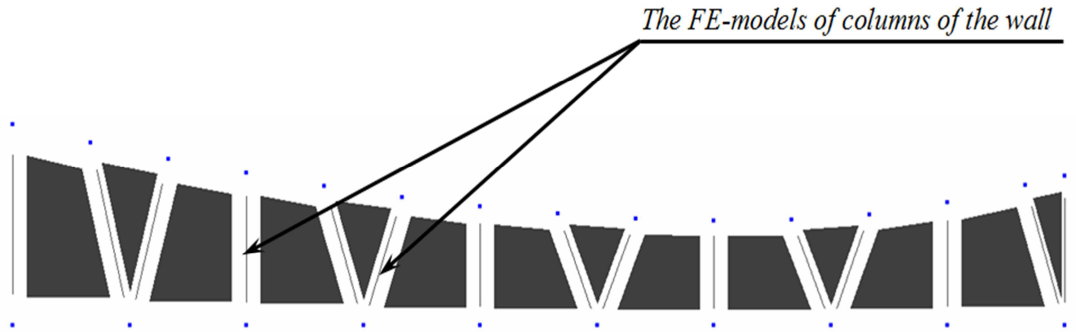

Fig 13. *The FE-model of the longitudinal wall.*

9. The Proposed Methods Realization

The main feature of the proposed methods of automated synthesis of FE-models is the direct data exchange between the joined models without the participation of CAE-system users. The use of direct data exchange permit to reduce significantly the volume of data inputted manually. E.g, the total volume of arrays of the numbers and coordinates of the base nodes for FE-models of vertical beams and longitudinal walls of the average cargo aircraft airframe (22 stringers on the lower surface of center wing and 6 frames in the area of contact of longitudinal walls with fuselage) is 420 values. The number of elements of the source data, which must be entered at the use the proposed methods, is equal to 20 (the links to ribs and cross section and the links to the frames).

10. Conclusion

On the basis of the performed analysis we can conclude that the developed methods allow increasing the quality of designing of the wing box of cargo aircraft (due to the increasing number of explored versions) and decreasing the probability of errors appearing (due to the increasing number of explored versions and decreasing the probability of errors appearing).

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