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THE STRENGTH CALCULATION OF THE TRANSPORT AIRCRAFT CONTROL SYSTEM ELEMENT BY THE FINITE ELEMENT METHOD

Ua Робота присвячена визначенню напружено-деформованого стану елемента системи керування транспортного літака, який служить для передачі руху і є елементом механізму для відхилення руля напрямку та зняття навантаження із проводки керування. У разі руйнування даного елемента система керування не буде функціонувати внаслідок чого будуть виведені із ладу деякі елементи електронної установки літака. Під час дослідження напруженого стану складних деталей та механізмів в авіабудування аналітичні методи не завжди є ефективними, хоча також застосовуються. Для визначення напружено-деформованого стану у роботі застосовувався чисельний метод – метод скінченних елементів, який з великою точністю моделює напружено-деформований стан механічних систем із урахуванням граничних умов та заданого навантаження. У якості скінченного елемента був вибраний чотирьох вузловий тетраедричний елемент. На основі аналізу напружено-деформованого стану було визначено небезпечні місця у конструкції, де є можливість появи тріщини і як наслідок цього – руйнування.

En The work is devoted to determining the stress-strain state of the element of the control system of the transport aircraft, which serves to transmit motion and is an element of the mechanism for deflecting the rudder and removing the load from the control wiring. If this element is destroyed, the control system will not function, as a result of which some elements of the electronic installation of the aircraft will be disabled. Analytical methods are not always effective when studying the stress state of complex parts and mechanisms of aircraft construction, although they are also used. To determine the stress-strain state in the work, a numerical method was used - the finite element method, which models the stress-strain state of mechanical systems with great accuracy, taking into account the boundary conditions and the given load. A four-node tetrahedral element was chosen as a finite element. Based on the analysis of the stress-strain state, dangerous places in the structure were identified, where there is a possibility of a crack appearing and, as a consequence, destruction.

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Introduction

The control system of a transport aircraft is quite complex and important, consisting of many structures. Analytical methods of solving mechanics problems are widely used nowadays [1 – 4]. Due to the fact that analytical methods, solving problems of the stressed-strained state of mechanical systems are not always effective, it is necessary to use numerical calculation methods [5 - 8]. Let's consider an element of the control system of a transport aircraft (Fig. 1). The element under consideration is a rocker in the rudder channel. The rocker serves to transmit motion. The rocker is part of the mechanical control system, which is part of the mechanism for deflecting the steering wheel and removing the load from the control wiring, depending on the forces acting on the steering wheel.

The calculation and study of the rocker at the specified loads is necessary for consideration, since when the rocker is destroyed, this mechanism will no longer function and may disable some elements of the electronic installation of the aircraft.

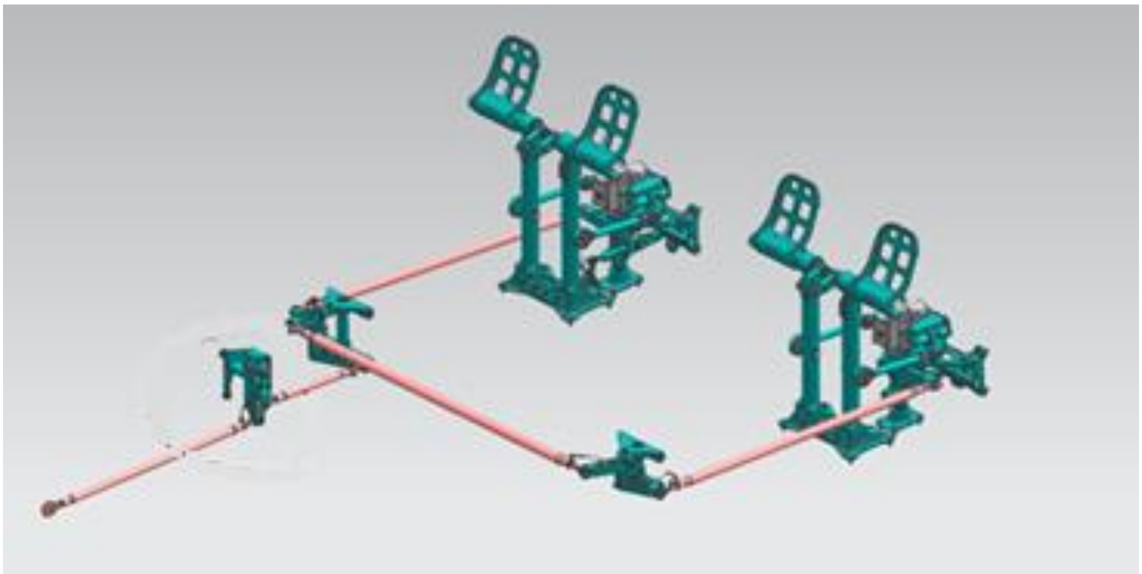

Fig. 1. Element of the control system of a transport aircraft

Problem statement

The rocking chair has 3 nodes (A, B, C) (Fig. 2). It is fixed at node A on the axis and serves to transmit longitudinal force with a reinforcing lever. Subnodes B and C are joined by rods.

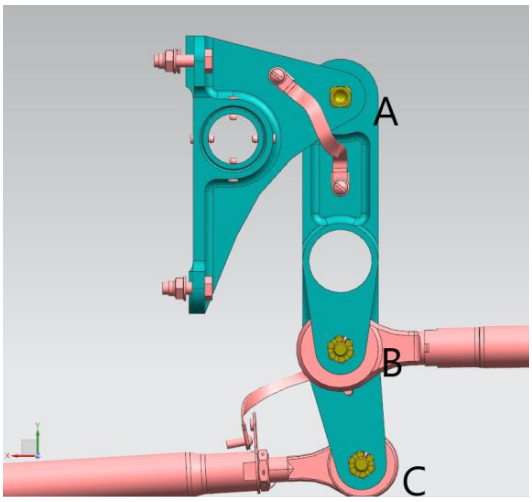

Fig. 2. Rocker in the direction rudder channel

The effort is transferred to the rolling pin in the node B and increased by the lever and then transmitted through the node C per stem. Analyzing the forces acting on the rocking chair we have the following load scheme (Fig. 3)

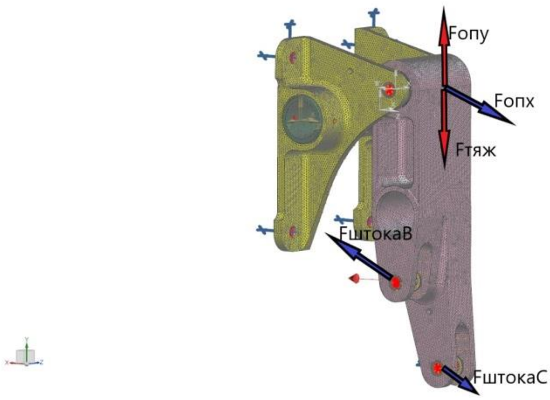

Fig. 3. Load scheme

The most critical position is the position when the rocking chair is vertically down. This is because when the angle changes, the force will act at an angle to the rocking chair and the bending force will be reduced due to the fact that the angle of action changes (that is, given the angle, the force will decrease through the cosine of this angle).

Considering the load scheme, size, profile, material, load concentrators, cross -sectional profiles – we get the next course of solution of the problem.

Creating a model and performing a calculation

The solution will be looking for finite elements that allows a numerical analysis of the stress-deformed state of the structure [5 - 7].

First you need to get a geometric model. For the model we will need input data. Input data for this step is the size of the part itself. The part itself is not standard, so the size is taken from the real model.

A three -dimensional model (geometric model), implemented in Simcenter 3D is depicted on (Fig. 4).

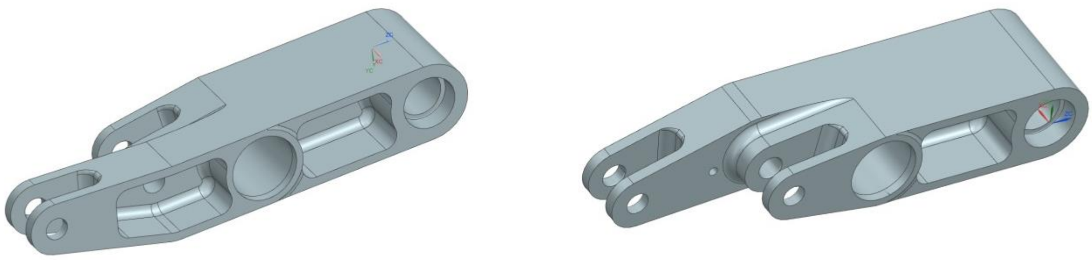

Fig. 4. A trivial model of construction

The first step in constructing any finite-element analysis is the sampling of a geometric model of a relatively complex shape on finishing elements.

Each finite element is a part of the general geometric model (sub-region), which has a relatively simple shape within which the solution is sought. The set of solutions for each finite element gives a common solution for the whole model.

The finishing elements are connected by means of nodes. The combination of nodes and finite elements is called a grid. The density of the grid depends on the number of elements. The main variable in the finite elements is nodal movement. After determining the displacement, you can get deformation in the element, then, using the dependencies between deformation and stresses (for a linear problem – a generalized sound of sound), you can find the field distribution fields. Movement in a real solid is continuous and can be determined at any point, but in the finite-element model of movement are determined only in nodes. In order to determine the movement at any point of the discrete model, namely in the middle of the finite element, the so-called functions are introduced, which are polynomials. In our case, the finite element is tetrahedron.

Consider the element in the form of tetrahedron (Fig. 5). We introduce at each vertex of three unknown movements,, in the directions of the axes x, y, z, accordingly [6, 7].

The vector of displacement at an arbitrary point of tetrahedron is approximated by polynomials

$$\begin{aligned} u &= \alpha_1 + \alpha_2 x + \alpha_3 y + \alpha_4 z, \\ v &= \alpha_5 + \alpha_6 x + \alpha_7 y + \alpha_8 z, \\ w &= \alpha_9 + \alpha_{10} x + \alpha_{11} y + \alpha_{12} z. \end{aligned} \quad (1)$$

After further equating of these expressions for moving nodal points, we get for each of the movements u, v, w by four equations, from which you can express α_i.

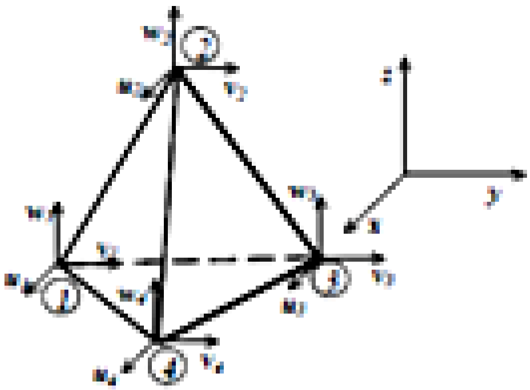

Fig. 5. Tetrahedral spatial finite element

Three moving components are approximated in an element volume by expressions

$$u = \begin{pmatrix} u \\ v \\ w \end{pmatrix} = Nq \qquad (2)$$

$$N = \begin{bmatrix} N_1 & & & N_2 & & & N_3 & & & N_4 & & \\ & N_1 & & & N_2 & & & N_3 & & & N_4 & \\ & & N_1 & & & N_2 & & & N_3 & & & N_4 \end{bmatrix}$$

$$q = (\mathrm{u}_1 \;\; v_1 \;\; w_1 \;\; \mathrm{u}_2 \;\; v_2 \;\; w_2 \;\; \mathrm{u}_3 \;\; v_3 \;\; w_3 \;\; \mathrm{u}_4 \;\; v_4 \;\; w_4)^T.$$

N_i form functions look like

$$N_i = \frac{1}{64}(a_1 + b_2 x + c_3 y + d_4 z)\,, \qquad (3)$$

where

$$v = \frac{1}{6}\left\| \begin{bmatrix} 1 & x_2 & y_2 & z_2 \\ 1 & x_3 & y_3 & z_3 \\ 1 & x_4 & y_4 & z_4 \\ 1 & x_1 & y_1 & z_1 \end{bmatrix} \right\|, \quad a_1 = \begin{vmatrix} x_2 & y_2 & z_2 \\ x_3 & y_3 & z_3 \\ x_4 & y_4 & z_4 \end{vmatrix}, \quad b_1 = -\begin{vmatrix} 1 & y_2 & z_2 \\ 1 & y_3 & z_3 \\ 1 & y_4 & z_4 \end{vmatrix},$$

$$c_1 = -\begin{vmatrix} x_2 & 1 & z_2 \\ x_3 & 1 & z_3 \\ x_4 & 1 & z_4 \end{vmatrix}, \quad d_1 = -\begin{vmatrix} x_2 & y_2 & 1 \\ x_3 & y_3 & 1 \\ x_4 & y_4 & 1 \end{vmatrix}.$$

The values of other coefficients in the functions N_1, …, N_4 are determined by the circular permutation of indexes in the rows of determinants. Determine the deformation vector

$$\varepsilon = (\varepsilon_x \quad \varepsilon_y \quad \varepsilon_z \quad \gamma_{xy} \quad \gamma_{yz} \quad \gamma_{zx})^T .$$

What will we take advantage of Koshi addictions

$$\varepsilon = Au = ANq , \qquad (4)$$

where

$$A = \begin{bmatrix} \frac{\partial}{\partial x} & 0 & 0 & \frac{\partial}{\partial y} & 0 & \frac{\partial}{\partial z} \\ 0 & \frac{\partial}{\partial y} & 0 & \frac{\partial}{\partial x} & \frac{\partial}{\partial z} & 0 \\ 0 & 0 & \frac{\partial}{\partial z} & 0 & \frac{\partial}{\partial y} & \frac{\partial}{\partial x} \end{bmatrix}^T .$$

After the substitution (2) in (4), with (3), we get

$$\varepsilon = Bq , \qquad (5)$$

where

$$B = \frac{1}{6V} \begin{bmatrix} b_1 & 0 & 0 & b_2 & 0 & 0 & b_3 & 0 & 0 & b_4 & 0 & 0 \\ 0 & c_2 & 0 & 0 & c_3 & 0 & 0 & c_4 & 0 & 0 & c_1 & 0 \\ 0 & 0 & d_3 & 0 & 0 & d_4 & 0 & 0 & d_1 & 0 & 0 & d_2 \\ c_1 & b_2 & 0 & c_2 & b_3 & 0 & c_3 & b_4 & 0 & c_4 & b_1 & 0 \\ 0 & d_2 & c_3 & 0 & d_3 & c_4 & 0 & d_4 & c_1 & 0 & d_1 & c_2 \\ d_1 & 0 & b_3 & d_2 & 0 & b_4 & d_3 & 0 & b_1 & d_4 & 0 & b_2 \end{bmatrix} . \qquad (6)$$

Tension for isotropic material according to Hooke law looks like

$$\sigma = D\varepsilon , \qquad (7)$$

where

$$D = \frac{E(1-\nu)}{(1+\nu)(1-2\nu)} \begin{bmatrix} 1 & \lambda & \lambda & 0 & 0 & 0 \\ & 1 & \lambda & 0 & 0 & 0 \\ & & 1 & 0 & 0 & 0 \\ & & & \mu & 0 & 0 \\ & & & & \mu & 0 \\ & & & & & \mu \end{bmatrix} , \qquad (8)$$

$$\lambda = \frac{\nu}{(1-\nu)} , \qquad \mu = \frac{(1-2\nu)}{2(1-\nu)} .$$

The matrix of rigidity

$$K = \int_V B^T DBdV. \tag{9}$$

The nodal forces due to the action of surface loads are determined by the vectors of loads corresponding to each of the faces of the element.

$$F = \frac{S_{123}}{3}\begin{bmatrix} P_x \\ P_y \\ P_z \\ P_x \\ P_y \\ P_z \\ P_x \\ P_y \\ P_z \\ 0 \\ 0 \\ 0 \end{bmatrix} + \frac{S_{234}}{3}\begin{bmatrix} 0 \\ 0 \\ 0 \\ P_x \\ P_y \\ P_z \\ P_x \\ P_y \\ P_z \\ P_x \\ P_y \\ P_z \end{bmatrix} + \frac{S_{341}}{3}\begin{bmatrix} P_x \\ P_y \\ P_z \\ 0 \\ 0 \\ 0 \\ P_x \\ P_y \\ P_z \\ P_x \\ P_x \\ P_x \end{bmatrix} + \frac{S_{412}}{3}\begin{bmatrix} P_x \\ P_y \\ P_z \\ P_x \\ P_y \\ P_z \\ 0 \\ 0 \\ 0 \\ P_x \\ P_y \\ P_z \end{bmatrix}. \tag{10}$$

In the conditions of linear static analysis, a system of static equilibrium is solved:

$$[K]\{U\} = \{F\}, \tag{11}$$

where $[K]$ – is a Global matrix of stiffness of items;

$\{U\}$ – is a vector of nodal movements;

$\{F\}$ – is a vector of external forces.

The matrix of rigidity considered here the four -footed tetrahedron thus looks like (12X12):

$$\left[K_{ij}^{(1)}\right] = \begin{bmatrix} K_{1.1} & \cdots & K_{1.12} \\ \vdots & \ddots & \vdots \\ K_{12.1} & \dots & K_{12.12} \end{bmatrix}. \tag{11}$$

A finite element model of the rocking mechanism of the transport aircraft control system was developed. The number of finite elements was 365384, the number of nodes 96126 (Fig. 6).

One of the questions is also the issue of implementing parts (bolts, rivets, etc.). Our rocking chair is part of the mechanism. Connections can be represented as 3D model [8] (Fig. 7).

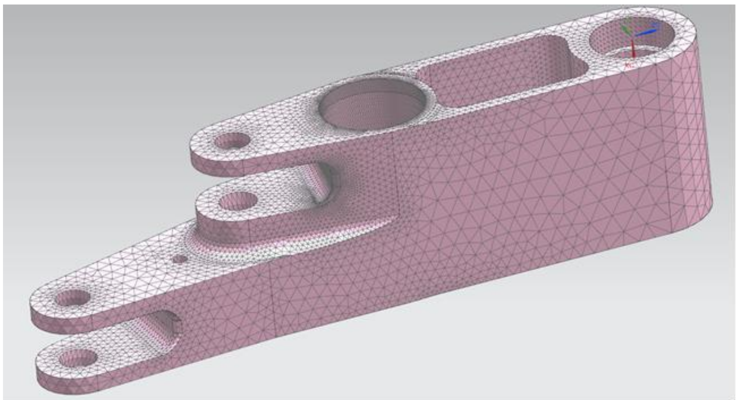

Fig. 6. The net of the finished elements of the rocking chair

Next, in order to solve the problem, we need to set the material. The item is made of AK-6 aluminum ($\sigma_{0.2}$ = 380 MPa).

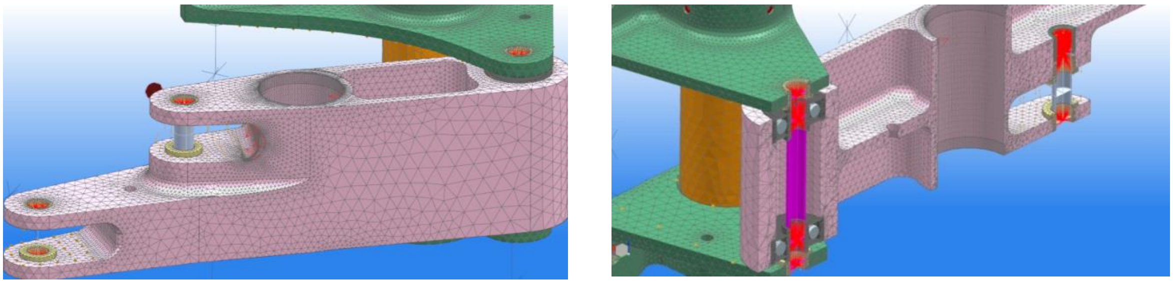

Fig. 7. Finally elemental connection model

The next step will be to set the boundary conditions and loads to get the problem of finding the hazardous places of the workpiece, taking into account the principle of work. From the conditions of load, the force acting in the node B is 7400 N. We place the rolling pin vertically, as it is the most critical position. In the node A the rolling pin is fixed. Draw a linear static analysis- the determination of the stress-deformed state of structures in the conditions of static loads under the given boundary conditions.

Assumptions used for linear static analysis:

– the rigidity matrix does not depend on the deformed state;
– the limit conditions do not depend on the deformed state;
– moving – small; only linear-efficient properties of materials;
– components of tension stresses and tensor deformations are related to linear ratios;
– Dynamic effects are not taken into account.

The finite-element model was investigated by a linear static method and found dangerous places of this model at a given load. Dangerous places are shown in (Fig. 8, Fig. 9). The figure shows equivalent stresses by Mizes.

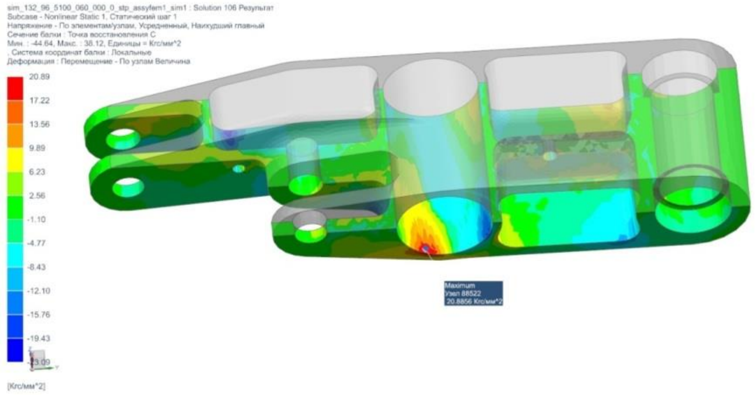

Fig. 8. Equivalent stresses by Mizes (Projection 1)

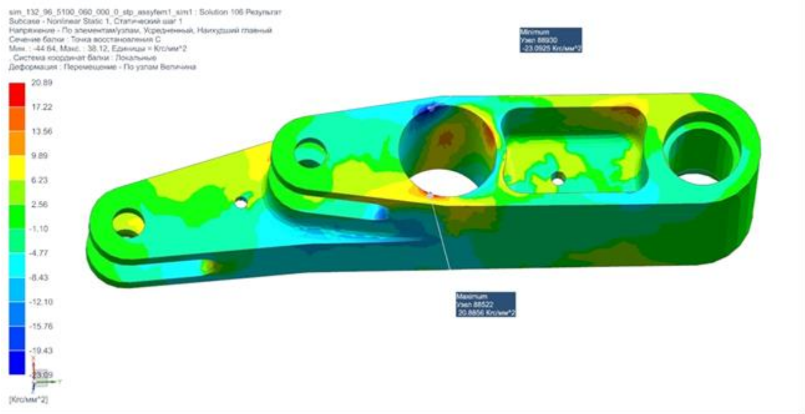

Fig. 9. Equivalent stresses by Mizes (Projection 2)

The results of the calculation show that at a given load, the maximum equivalent voltage did not exceed 208 MPa.

Conclusions

According to the results, we can conclude that the method of finished elements allows to analyze the stress-deformed state of the system of control of the transport aircraft, taking into account real limit conditions and loading and finding problematic places for their further improvement or solving the problem of optimization of the structure in order to reduce stress in hazardous places. This model clearly defined places where the work may be destroyed by overloading, or a crack due to the accumulation of damage.

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