from which we obtain new boundary conditions for the system (1.8). This method expresses the real behavior of the system and makes it possible to attain steady state more rapidly without distorting the overall dynamic pattern. Figure 4 shows graphs of the resistance coefficients $C_p$ of the parachute and the radius of the center section $R_{ce}$ of the canopy for $1/\bar{D} = 0.0$ and $1/\bar{D} = 0.01$ ($\bar{D} = D/\left(\mu_p/F_p\right)$, $F_p$ is the area of the parachute canopy).

Thus the suggested homogeneous mathematical model of the axisymmetric parachute takes into account most of the basic factors influencing its operation, and yields variegated information on the state of stress and strain of parachutes in the process of their inflation.

REFERENCES


STATE OF STRESS AND STRAIN OF BRAKE-CLASS PARACHUTES

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The article describes the special features of the operation of brake-class parachutes. It substantiates the possibility of replacing the solution of the dynamic problem of opening of a brake parachute by the static calculation of its state of stress and strain (SSS). The derivation of the equation of motion of a soft carcassed shell is based on the finite element method. The steady-state solution is obtained by the method of adjustment. As an example the results of calculation of the characteristics of the SSS of a cross-shaped brake parachute are presented. It is shown that in the zone of its lower edge considerable concentrations of tension arise in the tissue, the tissue gradually joins the operation of the carcass; the transverse carcass is unsubstantially loaded. The results of the calculations agree with the experimental data.

Parachutes whose operation is characterized by the condition $G >> Q$ ($G$ is the weight of the load, $Q$ is the aerodynamic resistance of the canopy) belong to the class of brake parachutes. Experiments showed that their full opening occurs at the instant when the maximal aerodynamic load acts. Then the shape of the parachute is close to the static one and the pressure gradient over the canopy may be regarded with sufficient accuracy as constant, with the exception of the regions near the edges. Also in view of the smallness of the forces of inertia of the parachute in comparison with the aerodynamic loads to which it is subjected, the solution of the dynamic problem of the state of stress and strain (SSS) of the canopy in the process of opening can be replaced by the static calculation of the SSS while a constant pressure gradient equal to the maximal dynamic one acts. It is advisable to carry out the calculation on a computer by using the finite element method.
(FEM) modified with the purpose of adapting to the peculiarities of the examined problem of the SSS of a soft carcassed shell. It is expedient to choose as finite elements (FE) simplex elements [1] (triangular ones for the shell and straight-line segments for the carcass). We obtain the equations of motion in explicit nonmatrix form for each node of the system of FE because in the nonlinear case the traditional matrix representation of equations leads to excessive computer times since the problem cannot be reduced to problems of linear algebra.

We introduce the designations: \( \lambda_1, \lambda_2, \lambda \) are the principal relative elongations of the shell and of the element of the carcass; \( T_1, T_2, \) and \( T \) are the principal forces corresponding to them; \( S_e^0 \) and \( \ell_e^0 \) are the initial area of the triangular FE and the length of the unidimensional FE, respectively, in the undeformed state; \( S_e \) is the running area of the \( e \)-th FE; \( \mathbf{n}_e \) is the normal to the \( e \)-th FE; \( p_e \) is the pressure gradient on the FE; \( K_1 \) and \( K_2 \) are the total number of unidimensional and two-dimensional FE conjugated through the \( k \)-th node; \( m \) is the weight of the \( k \)-th node.

The sets of unidimensional and two-dimensional FE each have their own \( e \)-numbering of the elements. For the shell and an element of the carcass the variation of the potential energy amounts to

\[
\delta U_e = \int S_e^0 \delta T_e dS_e, \quad \delta U_{e'} = \int \ell_e^0 \delta T_{e'} dt_{e'}. \tag{1}
\]

The external surface forces act solely on FE of the shell \( P = p_e \mathbf{n}_e \), and the mass forces, except the inertial ones, may be neglected. If we specify a nonzero variation of the position of the \( k \)-th node \( \delta \mathbf{r}_k \), then \( \delta W_e, \delta W_{e'} \) are the variations of the work of the surface and mass forces, and \( \delta U_e, \delta U_{e'} \) will also be nonzero only for those FE which have the \( k \)-th node as one of the apexes,

\[
\delta W_e = \frac{1}{2} S_e \mathbf{n}_e \mathbf{r}_e \delta \mathbf{r}_e - m_e \mathbf{r}_e \delta \mathbf{r}_e; \quad \delta W_{e'} = - m_{e'} \mathbf{r}_{e'} \delta \mathbf{r}_{e'}. \tag{2}
\]

Here, \( m_{ek} \) is the part of the mass of the \( e \)-th FE referred to the \( k \)-th node.

The position of the point \( \mathbf{x} \) lying inside a simplex element is specified in the form if a linear function of Lagrangian coordinates \( \mathbf{x} = (x_1, x_2) \)

\[
\mathbf{u}_e = \hat{\mathbf{N}}_e \mathbf{q}_e, \tag{3}
\]

where \( \hat{\mathbf{N}}_e \) is a linear matrix \( 3 \times 9 \); \( \mathbf{q}_e \) is the hypervector of the displacements of all nodes of FE containing \( \mathbf{r}_k \) of all nodes of the \( e \)-th FE. If only \( \delta \mathbf{r}_k \neq 0 \), then

\[
\delta \mathbf{u}_e = \hat{\mathbf{N}}_{ek} \delta \mathbf{r}_k, \tag{4}
\]

where \( \hat{\mathbf{N}}_{ek} \) is a matrix \( 3 \times 3 \), the part of the matrix \( \hat{\mathbf{N}}_e \) corresponding to the position of \( \mathbf{r}_k \) in the hypervector \( \mathbf{q}_e \). Since

\[
\lambda_i = \frac{1}{\partial u_i / \partial x_i} - 1, \quad i = 1, 2; \tag{5}
\]

it follows from (3) on account of the linearity of \( \hat{\mathbf{N}}_e \) that the elongations in the entire simplex FE are constant

\[
\lambda_i = \text{const}, \quad i = 1, 2; \quad \lambda = \text{const}. \tag{6}
\]

Proceeding from (4), (5), we may write

\[
\delta \lambda_i = \Gamma_{ek}^{i} \delta \mathbf{r}_k; \quad \delta \lambda = \Gamma_{e'}^{i} \delta \mathbf{r}_{e'k}, \tag{7}
\]

where \( \Gamma_{ek}^{i} \) and \( \Gamma_{e'k}^{i} \) are some vector functions depending on the geometry of the FE and its running position. From (1) it follows with a view to (6), (7) that

\[
\delta U_e = S_e^0 \left( \sum_{i=1}^{2} T_i \Gamma_{ek}^{i} \right) \delta \mathbf{r}_k; \quad \delta U_{e'} = \ell_{e'}^0 \delta \mathbf{T}_{e'} \delta \mathbf{r}_{e'k}. \tag{8}
\]

We substitute (2) and (8) into the variational equation