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DESIGN OF AVIATION ENGINE ELEMENTS FOR BIRD STRIKE ACTION

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The approximate engineering method for the calculation of the bird strike action on the blades of the fan or compressor is suggested. This method rests on sufficiently proof substantiations and is suitable for performing the optimized calculations at the design stage. The results of the typical design are given.

While developing the measures directed towards improving the aviation engine reliability at bird ingestion into the gas-air-flow passage, the recent years significant consideration is given to the development of the calculation procedure for the evaluation of the compressor and fan blade resistance to the impact loads resulted from the collision with birds along with a direct experimental test. This permits to predict the bird resistance of the blades as early as a design stage and if necessary to consider potential structural measures of its increase.

In design approaches basically two directions began to show: on the one hand, the receipt of the simplified emperical criteria, or, alternatively, the development of rather complicated analytical methods using the universal computational programs for the numerical calculations ([1,2]and others). However, in our opinion the first approach gives much too general evaluation, the second is excessively complicated if one takes into account a very uncertain data on the bird ingestion conditions and its interaction with the blades. In the given paper the approximate engineering method for the calculation of the bird impact action on the blades is suggested. This method rests on sufficiently proof substantications and at the same time it is relatively simple and suitable for performing the optimized calculations at the design stage.

The theoretical analysis and available experimental results permit to use the following assumptions:

- Compared to the blade, a striking body (bird) is soft, that is absolutely plastic with a negligible strength limit; it is broken as it runs against the blade, the bird piece speed before coming them into contact with the blade remains constant during the whole impact;
- Disintegrated particles do not rebound from the blade surface and do not adhere to it, throwing away by centrifugal forces;
- Disintegrating-particle pulse that is normal to the blade surface is completely absorbed by the blade;
- While moving the bird pieces along the blade, the friction forces are neglected;
- During the impact the blade displacements are small against the bird moving, that allows to determine the impact point position of their particles through an undeformed state of the blade:
- Specific bird configuration which is described with difficulty can be replaced by an equivalent body of the simplest shape, for example, by the parellelopiped, having the same density, volume and length-to-transversal size ratio;
- The estimation of the most possible stresses at the impact is performed without consideration the energy dissipation in the medium while using the simplest model of the elastic-plastic body.

From the mentioned assumptions one of the full transmission of the normal bird particle pulse to the blade is of particular importance.

It follows from the theory of the longitudinal collision of two unstrained elastic bodies with the density of ρ_1 and ρ_2 and with the moduluses of elasticity of E_1 and E_2 that the ratio of the momenta of the body particles adjacent to the boundary will be [3]:

$$L_1/L_2 = \sqrt{\rho_1 E_1/(\rho_2 E_2)}$$

Taking $E_1/E_2 \approx 0.01$ and $\rho_1/\rho_2 \approx 0.25$ for the bird collision with the titenium blade we shall derive $L_1/L_2 \approx 0.05$. Therefore, even with allowance for the bird body elasticity as a liquid the accepted assumption would be justified.

The momentum loss of the bird mass piece for the time of dt, which crosses over the blade along the normal to its surface on the area of dF, is equal to the pulse change of the normal force to this surface $\rho_1 v_n^2 dt dF = p dF dt$, where p is an [illegible] pressure. If the normal component of the relative velocity v_n is constant

$$p = \rho_1 v_n^2$$

The contact area boundaries, defining the value and position of the total dynamic load, are changed with time according to kinematic conditions of crossing over the trajectories of the blade and bird relative movement (See Fig.1, where a is a [illegible] after the impact initiation, b - in the intermediate [illegible], c - before the end).

[illegible] studies of the dynamic blade behaviour the blade can be represented both as a three-dimensional body and as a thin [illegible] shell, [illegible] surface limited by an oblique-angled [illegible] in plan and variably curved and twisted.

[illegible] to turn to the complicated numerical methods of the [illegible] integration of the continual systems some equivalent descrete [illegible] system-model was suggested to consider. This system-model meets the following requirements: the matrix of masses $[\mathcal{M}]$ and their spatial position on the model and in the design points of the nature agree, the matrix of the static pliability $[\alpha]$ is in agreement with the similar matrix formed by the components of the displacement vector $\{y\}$ in the blade design points caused by the components of single forces, applied in all these points.

The matrix of pliabilities can be calculated according to any appropriate programs. In the work it is determined by Ritz for the rotating blade-shell in the statement similar to used previously for the dynamic blade analysis [4].

The system of the motion equations for a discrete model takes the form

$$[\mathcal{M}]\{\ddot{y}(t)\} + [c]\{y(t)\} = \{Q(t)\}$$

where $[c] = [\alpha]^{-1}$. At the given change law of the load vector $\{Q(t)\}$ the change [illegible] law of the displacement vector $\{y(t)\}$ is defined by numerical integration.

For the evaluation of the strength the stress intensity is determined in the surface points. It is convenient to use influence coefficients $\gamma_{jk} = (\sigma_i)_j / P_k$, where $(\sigma_i)_j$ is a stress intensity in j-design point from P_k force, acting in k-point. In dynamic analysis $P_k = Q_k - \mathcal{M}_k \ddot{y}_k$, so that $(\sigma_i)_j = \sum_{k=1}^{n} \gamma_{jk} (Q_k - \mathcal{M}_k \ddot{y}_k)$, n is a number of the design points. The basic calculation is performed in the elastic region but at the strength evaluation the formation of the local plastic zones is considered. According to [illegible] hypothesis for these zones the elastic parameters of σ_e and $\varepsilon_e = \sigma_e / E$ are related to the parameters of $\sigma(\varepsilon)$ and ε on the [illegible] curve as

$$\sigma_e \varepsilon_e = \sigma_e^2 / E \cong \sigma(\varepsilon)\varepsilon$$

[illegible] that the failure occurs at the stress equal to the [illegible] limit $\sigma(\varepsilon) = \sigma_b$ and at the plastic strain equal to the [illegible] elongation $\varepsilon_p = \varepsilon - \sigma/E = \delta$, we shall receive the strength condition expressed in the conventional elastic stresses

$$\sigma_i < \sigma_{e\ rupture} = \sigma_b \sqrt{1 + E\delta/\sigma_b}$$

The method of the variable elasticity parameters [5] is used for more detailed consideration of the blade plastic deformation process as a whole.

Some results of the typical calculation are given below. The relative deflection-time history in three characteristic blade points is shown in Fig.2a: 1 - in the impact initial point, 2 - on the blade tip at the leading edge, 3 - on the blade tip at the trailing edge; Fig.2b gives the stress intensity-time history at the attachment in point 4. The properly blade-bird impact interaction is ended at the moment of $\bar{t}$ =1, however the most blade deflection and maximum stresses are reached at $\bar{t}>1$.

The estimated blade deflections at different moments of time $\bar{t}$ are given in scaled up in Fig.3. The impact direction and the place of the blade collision with the bird are shown by the arrow.

Fig.4 shows the dependence of the relative stresses in the impact point $\bar{\sigma}_{*}$ and maximum stresses $\bar{\sigma}$ max on the angular rotor speed $\bar{\omega}^{*}$ under otherwise equal conditions. This relationship is of a very sharp character due to a significant increase in the normal component of the relative speed of the bird running.

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FIGURE 1. Gl

FIGURE 2. De

FIGURE 3. Bl

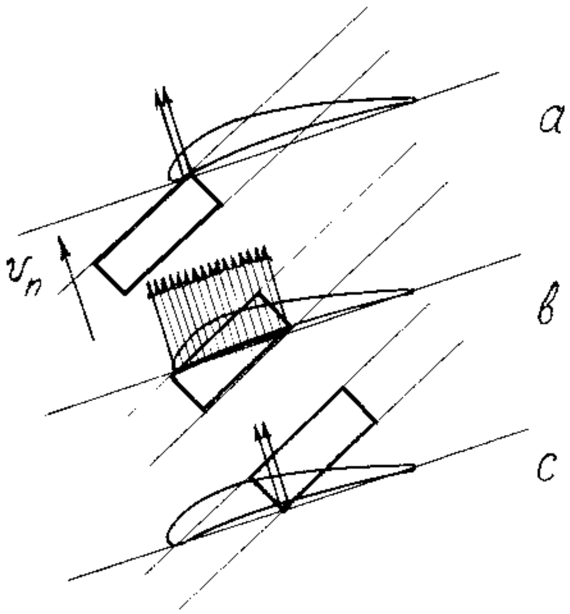
FIGURE 4. De

FIGURE 1. Change of contact area during impact.

FIGURE 2. Deflections $\bar{y}$ and stresses $\bar{\sigma}_i$ -time history in characteristic points of blade.

FIGURE 3. Blade deflections at different moments of time $\bar{\tau}$

FIGURE 4. Dependence of stresses $\bar{\sigma}_i$ on angular rotor speed $\bar{\omega}$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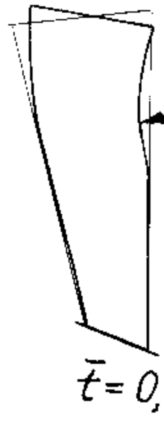
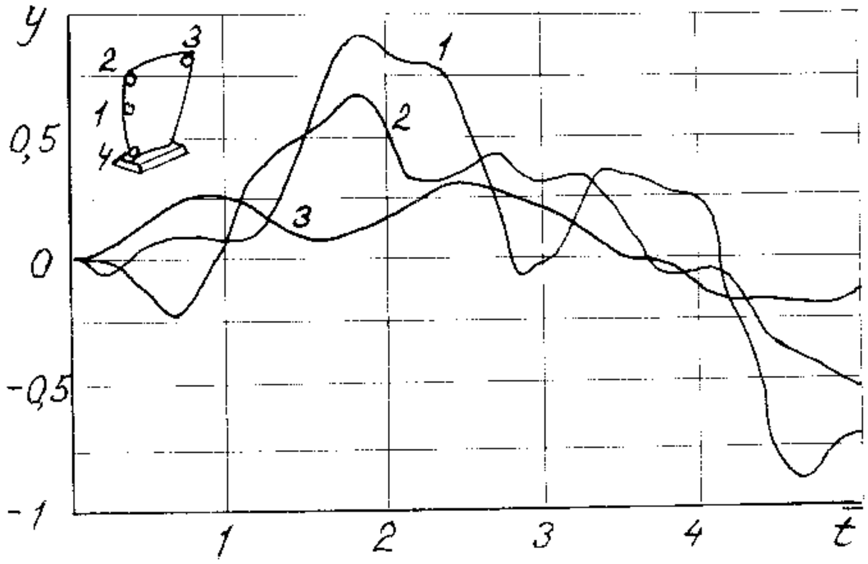
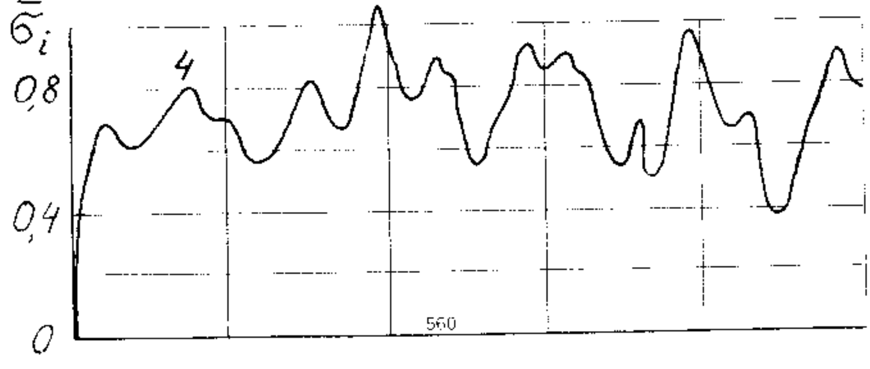
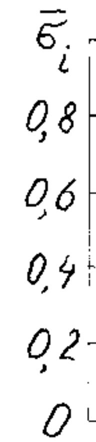
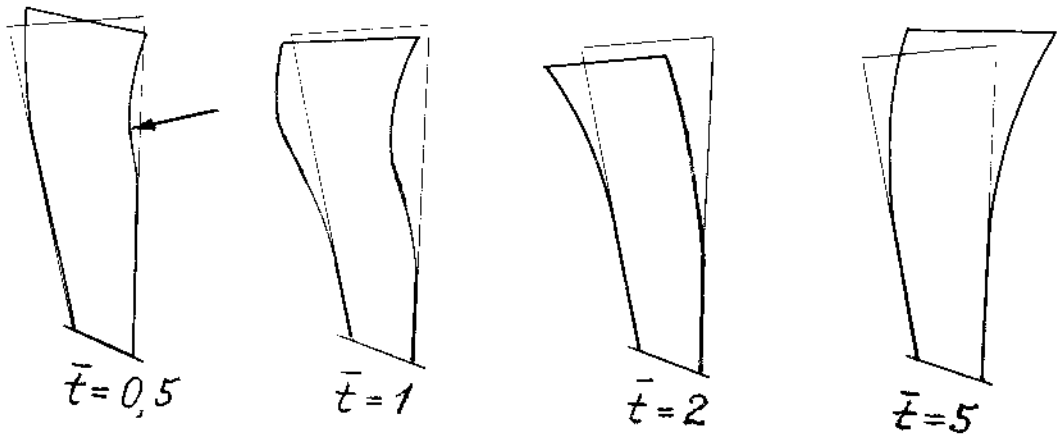

$\bar{t}=0,$

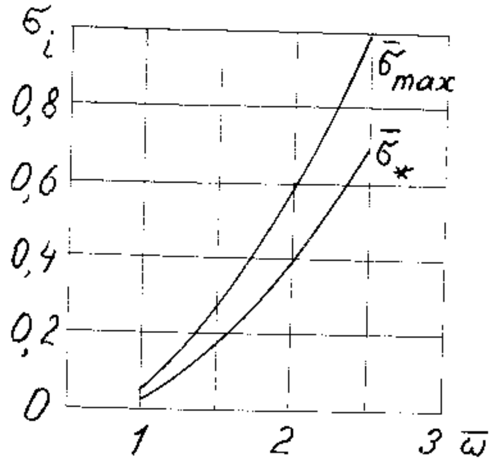

$\bar{y}$
0,5
0
-0,5
-1
1
2
3
4
$\bar{t}$


$\bar{\sigma}_i$
4
0,8
0,4
0


$\bar{\sigma}_i$
0,8
0,6
0,4
0,2
0



$\bar{t}=0,5$
$\bar{t}=1$
$\bar{t}=2$
$\bar{t}=5$



$\bar{\sigma}_i$
$\bar{\sigma}_{max}$
$\bar{\sigma}_*$
0,8
0,6
0,4
0,2
0
1
2
3 $\bar{\omega}$