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NUMERICAL AND EXPERIMENTAL ANALYSIS OF A LARGE BIRD IMPACT ON FAN BLADES FOR THE CERTIFICATION PURPOSE

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Abstract

With the purpose of flights safety, the more and more rigid requirements on fan blades resistance to collision with birds are showed. It is expressed, first of all, in increase of bird mass, which should not result in destruction of engine units or inadmissible changes of its parameters. For new engines, bird ingestion certification tests are exploited. However there are many successfully maintained old engines, which were tested under earlier less rigid certification requirements. To carry out their tests anew it would be very expensive and not too informatively in comparison with the operating experience.

Another acceptable way to confirm blade resistance to bird strike could be based upon a mixture of previous tests, service experience and a numerical bird impact analysis. However, reliability of the numerical method should be validated by comparison to experimental data.

In the paper some results of such numerical-experimental analysis referred to a large bird impact upon a fan blades are resulted for the certification purpose.

For increase of computational reliability some models of bird impact and two program modules have been used: universal system of finite element dynamic analysis MSC.DYTRAN with bird representation as a jelly-like body and the original computational system that develops the earlier checked up approach using bird representation as a solid completely collapsing body [1, 2].

Comparison of computational results of blade damage evaluation with the data of earlier bird ingestion tests has shown satisfactory concurrence.

Key words: fan blades, bird strike, numerical analysis, bird ingestion test, certification

1. Introduction

With the purpose of flights safety, the more and more rigid requirements on fan blades resistance to collision with birds are showed. It is expressed, first of all, in increase of bird mass, which should not result in destruction of engine units or inadmissible changes of its parameters. For new engines, bird ingestion certification tests are exploited. However there are many successfully maintained old engines, which were tested under earlier less rigid certification requirements. To carry out their tests anew it would be very expensive and not too informatively in comparison with the operating experience.

Another acceptable way to confirm blade resistance to bird strike could be based upon a combination of previous tests, service experience and a numerical bird impact analysis. However, reliability of the numerical method should be validated by comparison to experimental data.

In the paper some results of such numerical-experimental analysis referred to a large bird impact on a fan blades are resulted for the certification purpose with more severe requirements. Computation results of blade damage are compared to the data of earlier bird ingestion tests.

2 Calculation models of the bird impact against a blade

All calculations were carried out in 3D geometry and physically nonlinear statement using methods of non-stationary processes analysis and elastic - plastic model of a blade material. As the specified statement of a problem demands very great expenses of machine time even at use of modern high-speed computers, calculations were carried out with reference to one blade with the approached account of its interaction with neighboring blades. Finite - element model of the fan blade with anti-vibrating shrouds that was treated in calculations is shown in Fig.1.

For increase of reliability of calculations two following models of bird shock action against a blade have been used:

1. Impact of a bird as a jelly-like body that spreads over the airfoil during impact (model A). Such model is used in some published works on bird impact modeling and provided in known software packages, for example, in program modulus MSC.Dytran.

2. Impact of a bird as collapsing solid body characterized by the fact that a normal impulse of bird particles is fully absorbed by a blade during impact (model B). Such approach was earlier be approved in [1, 2].

In the first model the bird was represented as a cylinder with the ratio of length to diameter equal to twain. Calculation was carried out using the program package MSC.Dytran with combination of various mesh areas: Lagrangian - for the description of blade geometry, its deformations and fracture at impact; and Euler - for the description of bird model, its position in space, movement and process of destruction from collision with the blade.

In the second model the bird was represented as a parallelepiped with the ratio of length to side of the square base also equal to twain. For the nonlinear analysis of shock process we determined variying dynamic pressure of the bird particles on the blade face using the authors’ program; a change of the bird particles to the blade mutual position at impact is taking into account, and the transient analysis modulus of package ANSYS was used.

Fig.1

Average density of a bird body was accepted, as usually, close to water density. It was taken into account that at collision with a blade row the large bird is slitted to fragments. As orientation of a bird relative to the blades at impact is uncertain, the greatest fragment mass affecting the each blade was introduced into calculation. This corresponds to the case when "axis" of a bird body coincides with a direction of its relative velocity.

3. Impact calculation for the bird of mass 1.8kg in comparison to experimental data

Earlier, in the “Ivchenko Progress Design Bureau” successful tests of a shot of a large bird of mass 1.8kg into the engine fan have been carried out. For approbation of reliability of computation modeling we have operated calculations using two aforesaid models and carried out comparison of results to the tests data.

3.1 Results of computation modeling

For comparison to the test data the calculation model of a bird "was thrown" onto the top part of the blade airfoil directly above the anti-vibrating shroud. Calculation results for full displacements and equivalent stresses distribution over the blade for consecutive moments of time (for model A) are shown in Fig.2 and Fig.3, respectively.

Calculation displacements and equivalent plastic strains in over-shroud part of the blade at the end moment of the bird/blade interaction (for model B) are presented in Fig.4a and Fig.4b, accordingly.

In the beginning, local deformations arise at the leading edge; then they cover the whole over-shroud part of the blade. In the stress concentration domain at a fillet where a shroud transits into a airfoil stresses quickly reach an yield point of the material, and plastic strains by the end of impact come near (for model B) to value of relative elongation of the material at tension.

Under-shroud part of the blade during time of bird/blade interaction is loaded weakly.

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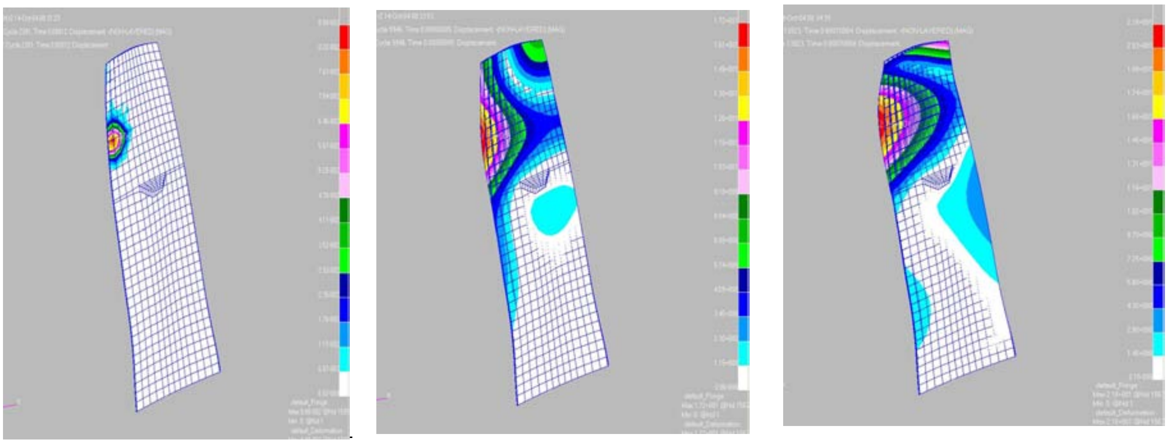
u=0.1mm

t=0.0005s
u=17.2mm

t=0.0097s
u=21.8mm



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u=18.8mm

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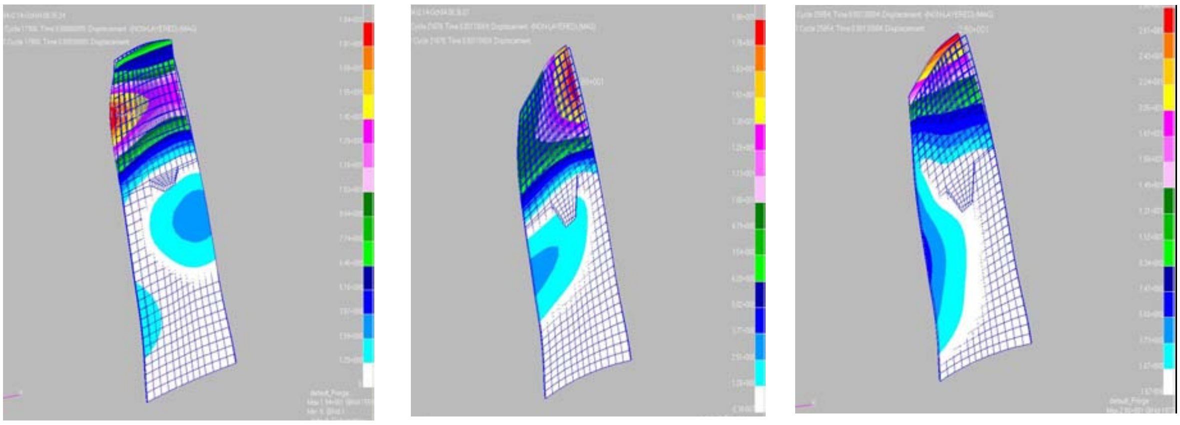

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u=56.7mm

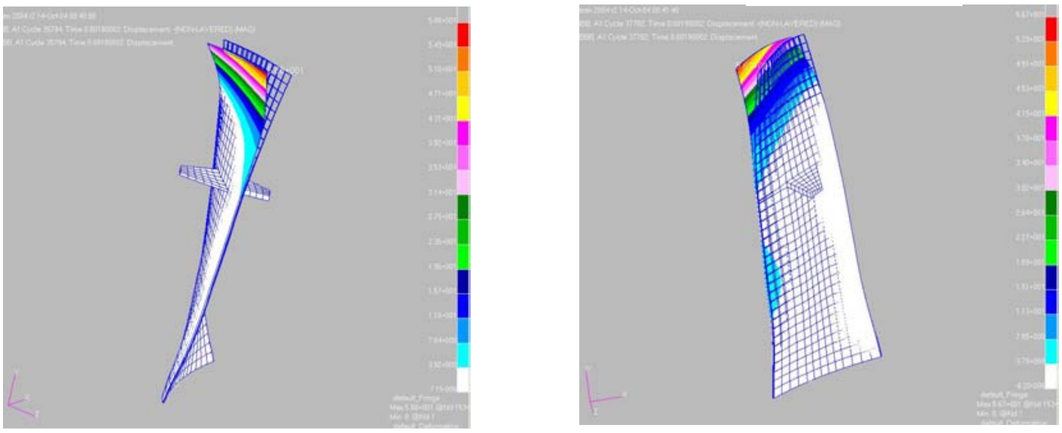
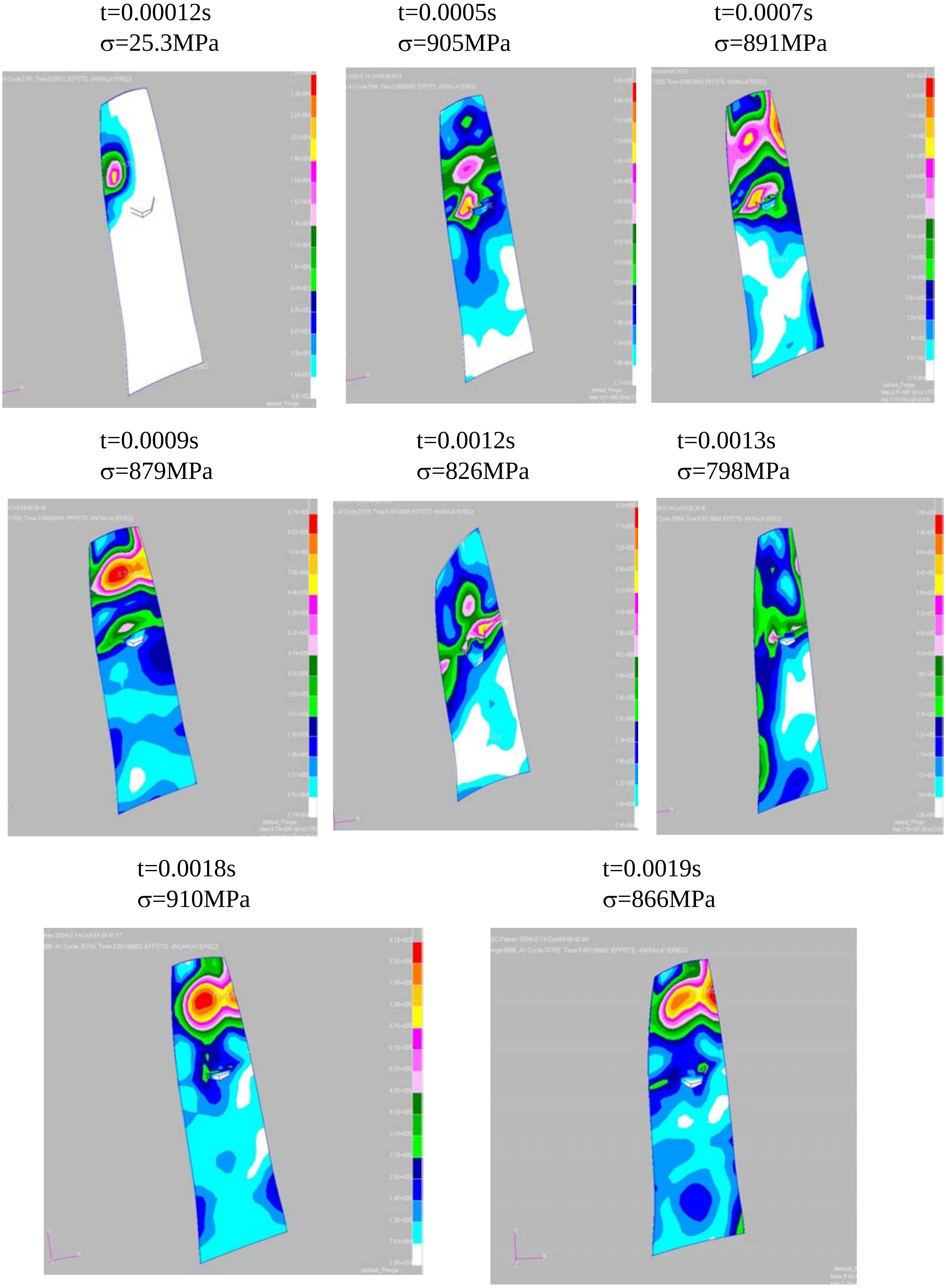


Fig.2



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t=0.0005s
σ=905MPa

t=0.0007s
σ=891MPa

t=0.0009s
σ=879MPa

t=0.0012s
σ=826MPa

t=0.0013s
σ=798MPa

t=0.0018s
σ=910MPa

t=0.0019s
σ=866MPa

Fig.3

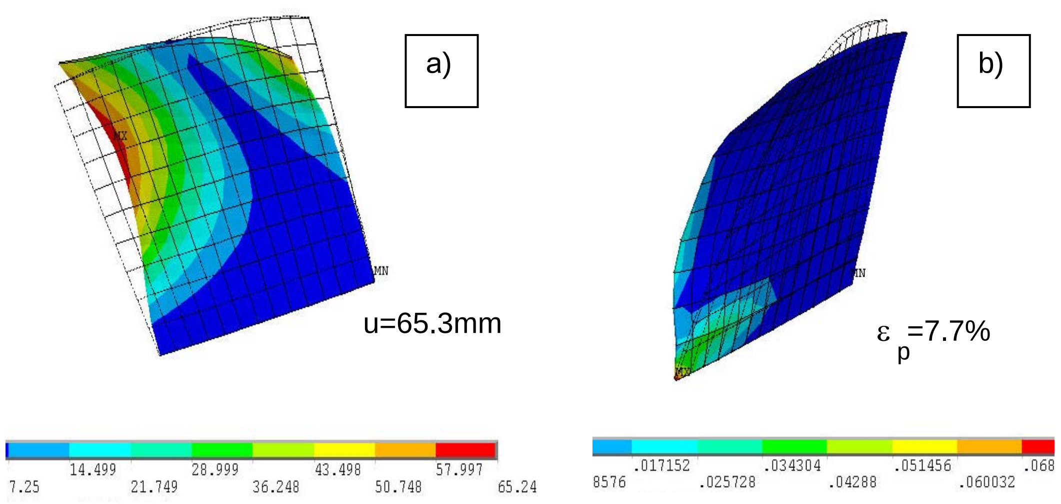

Fig.4

3.2 Comparison of calculation results to the test data

Test for a large bird shot into the engine entrance device was carried out at a station equipped with a pneumatic gun. The large bird (duck) of mass1.8kg was fired at the engine take-off power into the region of anti-vibrating shrouds of the fan blades.

Destruction has taken place at two blades: at the first – a tear of the material, at the second - a crack in the over-shroud part of the airfoil. On half of the blade assembly corners of the blade tops were bended and some dents along a leading edge have appeared. Blades permit carrying out of repair. Damages of a root part of the blades and shroud displacements were not fixed after impact. Character of the fan blade damage is presented in Fig. 5.

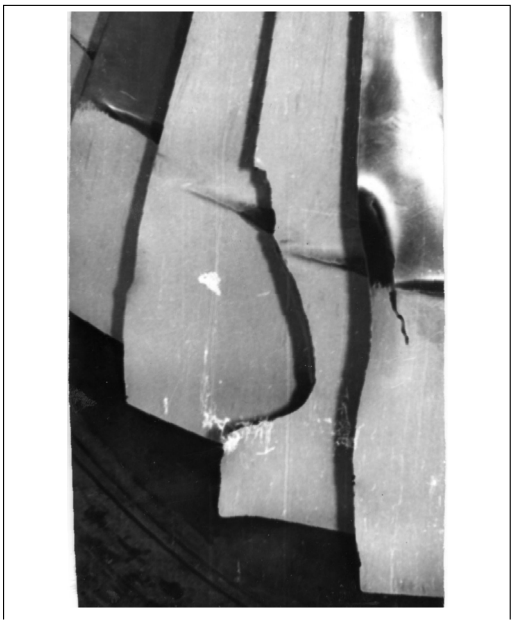

Fig.5

From the submitted data it follows, that both models used for comparison of calculations and experiments gave a satisfactory pattern of an arrangement of tear region in the blade under collision with a bird of mass 1.8kg.

The “rigid” impact model B has practically led to correct quantitative value of equivalent plastic strain at which there could be a shock destruction of a blade material. Distinction between this value and a magnitude of relative elongation at static tension can be quite explained as result of reduction of plasticity for deformable materials at high loading rate, and approximate finite-element computation using a grid that was not too fine. The value $\varepsilon_p = (7 \div 8)\%$ was further accepted as "critical" by forecasting of blade resistance to impact of larger bird.

The “soft” impact model A has also stated a correct estimation of shock destruction at stresses $\sigma = 910 - 920$ MPa exceeding the material yield point; but a value of destroying plastic strain (1-2 %) was set too low. This value may be considered as estimation "from below".

As well as in test, calculated shock deformations under shroud and at the blade root were insignificant.

4. Forecasting of blade resistance to impact of a large bird of mass 3.65 kg

Calculations, similar to described in Section 3, have been carried out for a case of impact by a larger bird.

Displacements of the over-shroud part and plastic strains in a zone of shroud to airfoil transition have increased (Fig. 6a, model B) but the maximal stresses, thanks to plastic deformation, have increased insignificantly (Fig. 6b, model A).

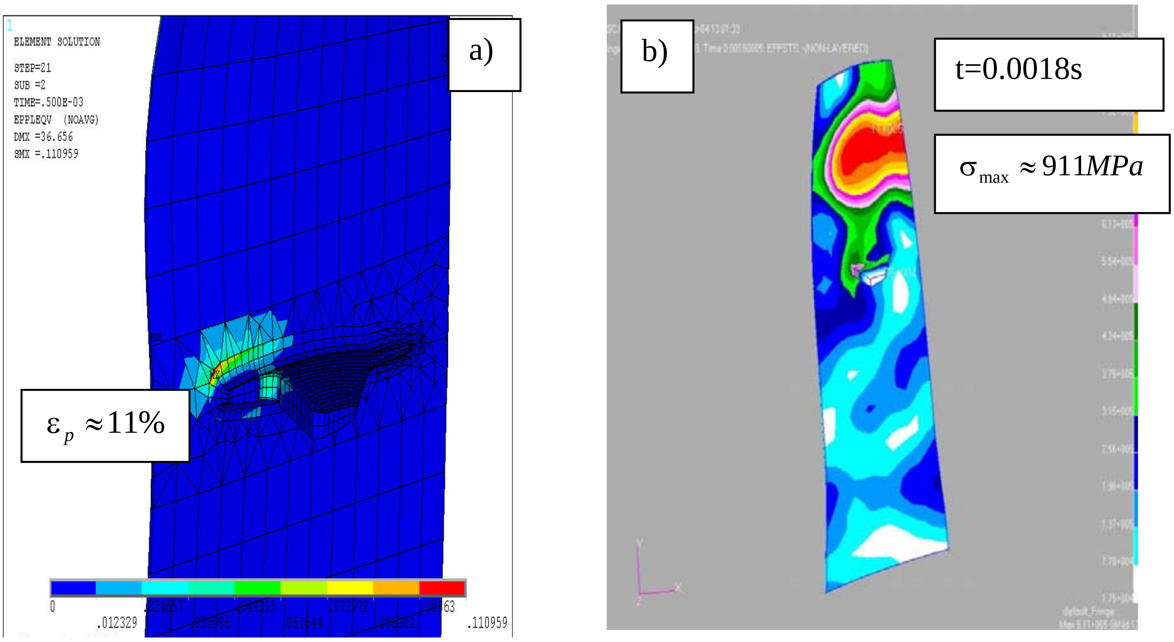

Fig.6

The analysis of calculation data for the fan blade collision with large birds of mass 1.8 kg and 3.65kg using two impact models, “soft” and “rigid”, demonstrates no principal difference in general character which the bird fragments influence upon the blade. The increase in impact force for the larger bird is shown, mainly, in faster growth of strains and stresses and in expansion of a zone under shroud and at the blade root where plastic deformations are formed.

It follows that a maximal fragment from a bird of the mass 3.65kg can strongly plastically deform and, with a high probability, destroy a significant part to a blade airfoil adjoining to the leading edge above the anti-vibrating shroud. However, the stresses near the blade root in time, sufficient for destruction of the over-shroud part, grow insignificantly. Such result remains fair not only if restriction of shrouds displacement on contact faces is full, but also in the case when the shrouds freely move along the radial direction and even in absence of contact between shrouds. Within these time limits the area of plastic deformation in a region of the blade root keeps local character. After the over-shroud part of the blade will be destroyed (even in part), dynamic loading on the other parts decreases.

All this does destruction of the blade as a whole improbable.

5. Conclusion

Comparison of calculation results for fan blade damages using two impact models of birds, “soft” and “rigid”, with the data of earlier shot tests for the bird of mass 1.8kg has shown their quite satisfactory concurrence.

The obtained “critical” values of equivalent plastic strain, which corresponded for each of the model to the moment of the destruction beginning, have allowed reasonably approaching to forecasting of blade resistance to impact of larger bird.

The specified computation-experimental approach has given the sufficient bases to consider that impact of a large bird of the mass 3.65kg will not lead to breakage of the fan blades.

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