Bird Strike Analysis of Aircraft Engine Fan

Y.N. Shmotin [1], P.V. Chupin[1], D.V. Gabov[1]

A.A. Ryabov [2], V.I. Romanov [2], S.S. Kukanov [2]

[1] NPO SATURN, Rybinsk, Russia

[2] Sarov Engineering Center, Nizhniy Novgorod Reg., Russia

Summary:

Safety in accidental conditions is one of the important requirements an aviation jet engine must meet. It is known that one of quite possible and very dangerous accident is a bird strike into the engine in the flight. This case is characterized by the high speed impact of the bird onto rotating blades of the fan, causing large dynamic deformations of the blades and other elements which may lead to disintegration of the construction. That's why numerical investigations of the bird strike are very important and should be implemented during design stage of a development process. The proposed paper presents some results of numerical simulations of dynamic deformations of the fan blades loaded by the bird impact, obtained by LS-DYNA code. There is an analysis of the numerical results and their verification by comparison with experimental data.

Keywords:

turbojet engine, fan blade, bird strike, numerical investigations, finite element method.

1 Introduction

Bird strike incidents are the serious problem for flight safety. It is known that during the period 1912 to 2004 there were 47 fatal bird strike accidents killing 242 people. The total number of aircrafts destroyed due to the bird strikes in that period was 90 [1]. The bird strike incidents cost the U.S. civil aviation industry approximately $495 millions annually [2]. Statistics shows that the major threat (77% of accidents) to Airlines and Executive jets is engine ingestion [1].
That's why numerical investigations of the bird strike are very important and should be analyzed during design stage of a development process. Basing on the results of the analysis the design of the engine must be changed to exclude any serious effects of the bird strike incident.
Because of significance of the problem, the bird strike analysis is widely covered in scientific literature [3-13]. The analysis of these papers shows that currently the most common approach is to represent a bird as a solid cylinder, an ellipsoid or a hemispherical ended cylinder with material properties similar to water. The solution is implemented using Lagrangian, SPH or ALE approach to model a bird.
Paper [14] presents results of the comparative analysis of using these three approaches to simulate the turbojet engine bird strike problem. Comparison of the results, obtained using these approaches, shows that the results, obtained using denoted approaches are quite close to each other for contact forces between the bird and blades as well as for the bird’s deformation behavior. The results, obtained using ALE approach differs from Lagrangian and SPH. The comparison of contact forces shows that ALE approach underestimates loads to the blades. Refinement of the ALE mesh could resolve this problem, but it will result in significant rise of the calculation time. Authors conclude that choosing from Lagrangian and SPH approaches, the first one is more preferable, because both of them give close loads to the blades, but the total CPU time for Lagrangian approach is ~1.5 times lower than for SPH.
It should be noted that the papers [3-14] consists no information about influence of friction between the bird material and blades to deformation of the last once.
The proposed paper presents some results of the numerical simulations of the dynamic deformations of the fan blades loaded by the bird impact, obtained by LS-DYNA code. The paper contents investigations of influence of the friction between the bird and the blades to deformation of the blades. The comparison of the results obtained using Lagrangian and SPH approaches also presented in the paper. The results are verified by the comparison with the experimental data.

2 Statement of the problem

The problem of the interaction of the medium bird and the fan blades of the turbojet engine is considered. The mass of the bird is about 1.5 lb. The bird moves along the axis of the fan towards the blades with velocity of about 80 m/s. The rotary speed is about several thousand rotations per minute. The bird strike simulation is performed taking into account the stress distribution in the blades caused by the stationary rotation as initial conditions. The bird impacts the blades in the upper possible radial distance point. The influence of the friction between the bird and the blades on the level of blades' strains are investigated. The comparison of the results, obtained using Lagrangian and SPH bird models also presented in the paper.

3 Description of the computer models

A detailed finite element model of the turbojet fan was created using ProStar [15] mesh generator. The model represents a half of the fan with the cyclic symmetry boundary conditions on the corresponding surfaces. A view of the fan model is presented in Figure 1. The model consists of 795 000 finite elements and 1 050 000 nodes. Several stress-strain curves defining the elastoplastic behavior of the fan material at various strain rates are used.

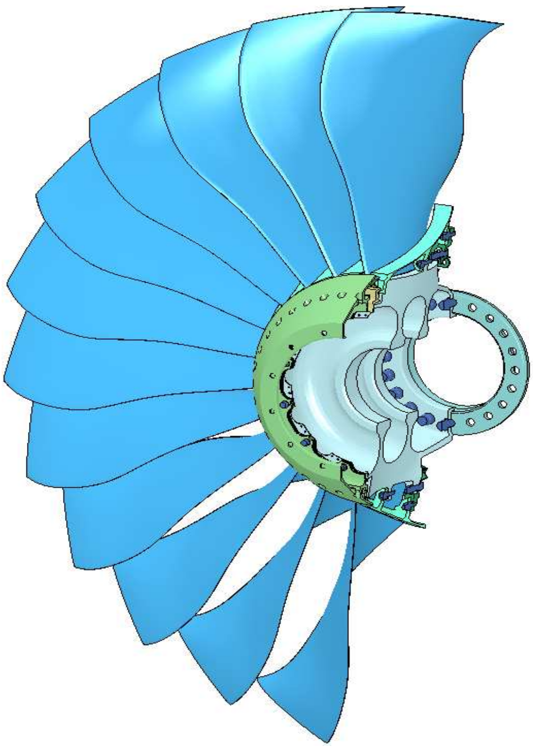

Figure 1: Finite element model of the fan

The bird is modeled as a solid cylinder with truncated coned ends. Lagrangian and SPH bird's models were created for the numerical simulations (see Figure 2). The Lagrangian model consists of about 100 000 finite elements, the SPH model consists of about 65 000 particles.

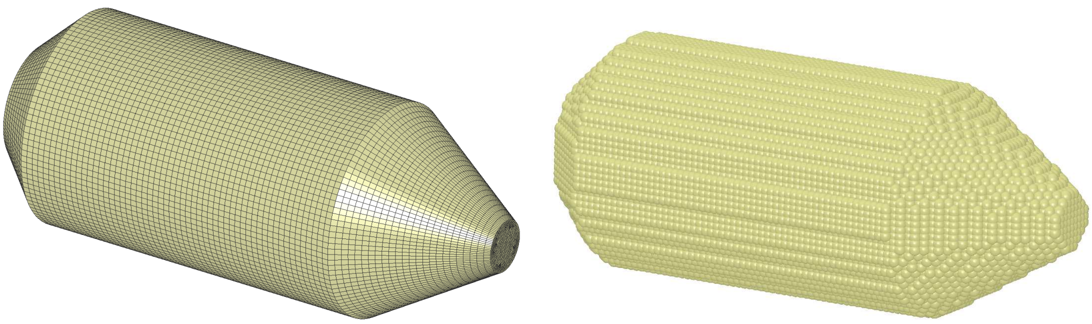

Figure 2: Lagrangian (left) and SPH (right) bird models

The properties of the bird material are assumed to be similar to the properties of water. The bird is modeled in hydrodynamic approximation using LS-DYNA [16] material model *MAT_NULL with equation of state *EOS_GRUNEISEN. Using of this approach seems to be quite reasonable because bird mainly consists of water while muscles and bones of the bird have low shear strength.
The Gruneisen equation of state with cubic shock velocity-particle velocity defines pressure for compressed materials as [16]

$$p = \frac{\rho_0 C^2 \mu \left[1 + \left(1 - \frac{\gamma_0}{2}\right)\mu - \frac{a}{2}\mu^2\right]}{\left[1 - \left(S_1 - 1\right)\mu - S_2 \frac{\mu^2}{\mu + 1} - S_3 \frac{\mu^3}{(\mu + 1)^2}\right]^2} + \left(\gamma_0 + a\mu\right)E$$

where p – pressure, ρ – density, C – the intercept of the v_s-v_p curve, $\mu = \frac{\rho}{\rho_0} - 1$, S_1, S_2 and S_3 – the coefficients of the slope of the v_s-v_p curve, γ_0 – Gruneisen gamma, a – the first order volume correction to γ_0 and E – internal energy.

Erosion criteria of 55 % of maximum principal strain is used in the Lagrangian bird model. This value was chosen for stability reasons due to the high bird model mesh distortion. After erosion of some finite element of the bird model the mass of the element is uniformly distributed between corresponding nodes, which continue to be active in the contact with fan elements. Thus, after erosion of all the finite elements, the bird model will consist of the set of point masses, which moves independently from each other.

In all the calculations the contact between the bird and the fan is modeled using NODES_TO_SURFACE contact algorithm. All the nodes of the bird model are used as the slave set and all the external segments of the fan elements – as the master set. The coefficient of friction between bird and blades is varied in interval from 0 to 1.

4 Investigation of friction influence to blades strains

The simulations with five different values of the coefficient of friction (f_{fric}= 0.0, 0.2, 0.5, 0.7 and 1.0) were performed using Lagrangian bird model. Simulations results were compared with the experimental data, obtained using sensors, installed on different parts of the blades which interacts with the bird.

Quantitative comparison of the numerical results and the experimental data is presented in Table 1. The table contents ratio of the maximum numerical strain to the maximum experimental strain values.

The analysis of the presented results shows no direct dependence between strains in the blades and the coefficient of friction. However, it can be seen that the numerical results obtained for the friction coefficient value equal to zero are slightly better agreed with the experimental data.

Table 2: Numerical to experimental strain ratios

Number of sensors	Coefficient of friction value				
	0.0	0.2	0.5	0.7	1.0
1	0.78	0.85	0.96	0.96	0.74
2	0.74	0.79	0.82	0.82	0.56
3	0.93	1.63	1.36	1.48	1.37
4	1.16	1.23	1.21	1.06	0.92
5	0.96	0.98	0.93	0.98	0.89
6	1.11	0.79	0.74	1.00	1.32
7	0.86	0.68	0.69	0.70	0.64
8	1.00	0.96	0.80	0.92	1.44
9	1.22	1.60	1.63	1.90	1.79
11	1.00	0.95	1.03	1.32	1.14
12	0.78	1.13	0.96	0.91	0.83
13	0.89	0.93	0.78	1.04	0.73
14	1.26	1.43	1.48	1.70	2.49
15	1.32	1.41	1.24	1.35	1.04
16	1.00	0.93	1.00	1.10	0.98

5 Comparison of results obtained using Lagrangian and SPH bird models

Figures 3 and 4 shows strains of a feather and a root part of one of the blades, obtained using Lagrangian and SPH models of the bird. Both calculations were performed with the coefficient of friction equal to 0, which has been chosen as "optimal" for simulations of the bird strike problems in our case.

The comparison of the curves, obtained using these two approaches, shows that in the root part of the blade they are almost coincident. As for the feather of the blade, strains fluctuate almost synchronously, but magnitudes of the fluctuations differ. For the main number of sensors, difference between numerical and experimental strains does not exceed 15%.

However, it can be noted that SPH approach results fit experimental results in feather of the blade better than Lagrangian approach results.

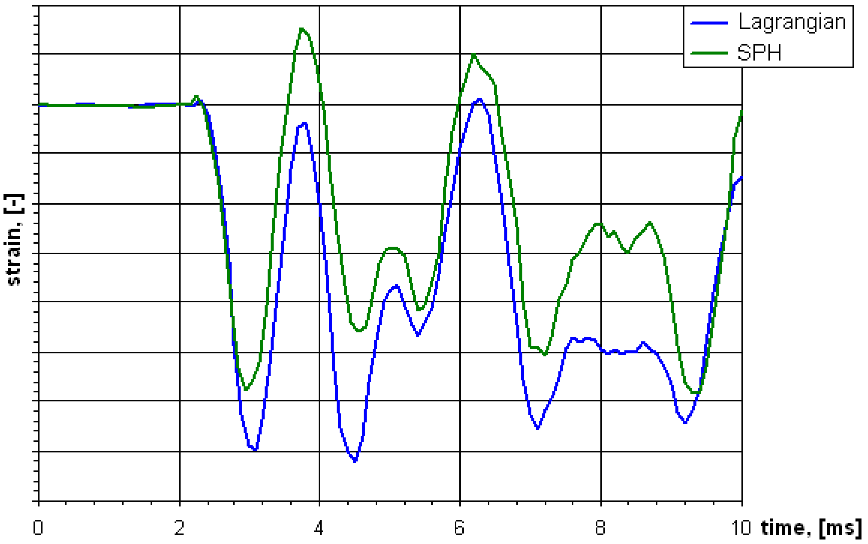

Figure 3: Strains of a blade's feather

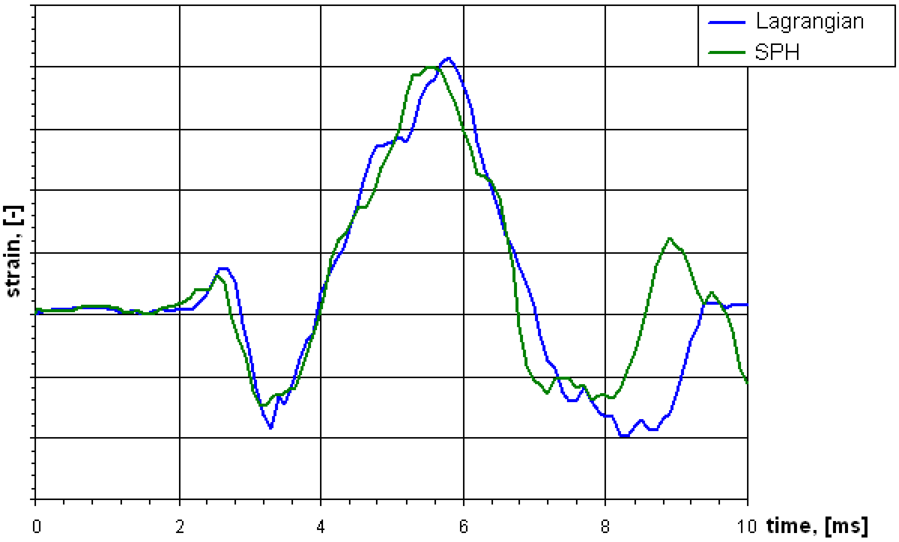

Figure 4: Strains of a root part of a blade

6 Conclusions

Numerical simulations of the turbojet engine fan blades dynamic deformation due to medium bird strike incident were performed using LS-DYNA. The simulations were implemented with Lagrangian and SPH models of the bird and different values of the friction coefficient between the bird and the blades. Basing on the analysis of the obtained results it can be concluded that:

1. Using of properties of water for the bird material allows to obtain the results, which are well agreed with experimental data.

2. The analysis of the calculations shows no direct dependence between strains in the blades and the coefficient of friction. The best general agreement between numerical and experimental data was obtained using the friction coefficient value equal to zero. For the main number of sensors, difference between numerical and experimental strains for this friction coefficient value does not exceed 15%.

3. Strains, obtained using Lagrangian and SPH approaches with the friction coefficient of zero are close to each other and have quite well agreement with experimental curves. However SPH approach numerical results fit experimental data in the feather of the blade look better than Lagrangian one.

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