Fan Blade Bird Strike Analysis Using Lagrangian, SPH and ALE Approaches

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ABSTRACT:

Fan blade bird resistance is one of the most important certification requirements for modern jet engines. The development test to meet the requirement is difficult and costly experiment. The expenses can be significantly reduced by using the numerical simulation of fan blade bird strike problem in the design of jet engine. The common technique for such simulations is modeling of bird as a solid cylinder or ellipsoid with material properties similar to water.

The paper presents some results of fan blade bird strike analysis using LS-DYNA[®] Lagrangian, SPH and ALE approaches to model the bird. The main objectives of the investigations are to compare the results obtained by means of different approaches and to find out the advantages and disadvantages of every approach.

KEYWORDS:

Turbojet engine, fan blade, bird strike, numerical simulation.

INTRODUCTION

One of the main problems in the bird strike analysis is choosing of a shape, material properties and a simulation approach for an object, which model the bird. The common technique is modeling of the bird as a solid ellipsoid, cylinder or hemispherical ended cylinder [1-7]. The material properties are usually chosen to be similar to the properties of water. The simulation approach can be chosen among Lagrangian, SPH or ALE approaches, realized in LS-DYNA® [8].

The paper presents comparison of the fan blade bird strike analysis results, obtained using Lagrangian, SPH and ALE approaches. The parameters to compare are the contact force of interaction of the bird's model and blades, visual bird's deformation behavior during the process and total CPU time, required to complete solution. In frames of Lagrangian approach, different contact algorithms of interaction of the bird and blades are also investigated.

STATEMENT OF THE PROBLEM AND DESCRIPTION OF COMPUTER MODELS

A computer model of the fan blades and three computer models of the bird were created for the numerical simulations. A view of the blades and the bird models prepared for ALE approach is represented in Figure 1.

Solid finite elements and material model *MAT_RIGID are used for the blades' model. The model consists of about 440,000 finite elements. Rigid material is used in order to decrease calculation time and exclude possible influence of blades' deformation process on the total CPU time, required to complete solution. It is assumed that the blades are rotated with constant angular velocity.

For all approaches the bird is modeled as a solid ellipsoid with the properties similar to water. At the start of the calculations, the bird model is given an initial velocity towards the fan blades.

Lagrangian model of the bird consists of 90,000 solid finite elements, SPH model consists of 100,000 particles. ALE mesh consists of 720,000 finite elements and the bird is initially defined in ~25,000 ALE cells. This mesh is chosen as a result of preliminary calculations and consultations with LS-DYNA® developers. In our opinion, this number of ALE elements is close to the minimum, required to obtain relatively adequate results.
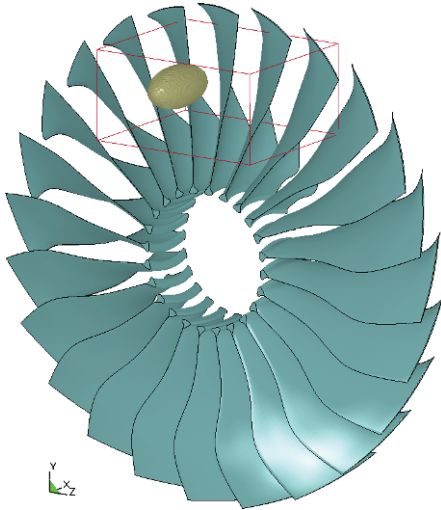
Figure 1: Computer model (ALE approach)

RESULTS OF LAGRANGIAN CALCULATIONS

In frames of Lagrangian approach, different contact algorithms of the interaction of the bird and blades are investigated:

Calculation Lagr1 – CONTACT_NODES_TO_SURFACE;

Calculation Lagr2 – CONTACT_ERODING_SURFACE_TO_SURFACE;

Calculation Lagr3 – a combination of CONTACT_NODES_TO_SURFACE and CONTACT_ERODING_SURFACE_TO_SURFACE.

RESULTS OF CALCULATION LAGR1

In this calculation the contact between the bird and blades 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 blades – as the master set. This technique is allowed nodes to be active in contact even after surrounding elements fail.

The total CPU time for calculation Lagr1 is 3 hours. The results of the calculation are presented in Figures 2, 3. Figure 2 shows dimensionless forces of the contact interaction of the bird and blades. Figure 3 shows the deformed shape of the bird during the interaction with one of the blades. As it can be seen from the picture, the forward edge

of the blade penetrates into the bird's material. This situation appears because the bird is modeled in the contact by nodes, but not by segments. This allows the blade to penetrate through the middles of bird's elements.
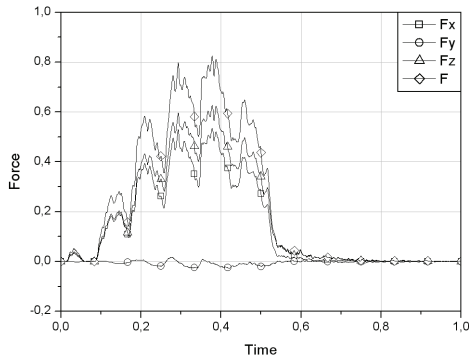

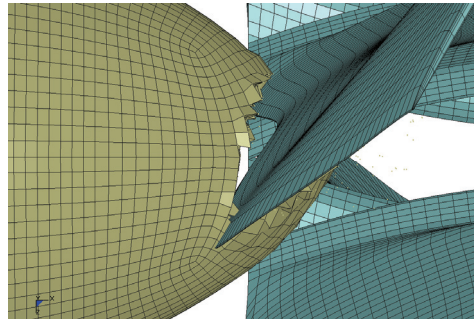Figure 2: Forces of the contact interaction of the bird and blades (Lagr1)

Figure 3: Interaction of the bird with one of the blades (Lagr1)

RESULTS OF CALCULATION LAGR2

In this case the contact between the bird and blades is modeled using ERODING_SURFACE_TO_SURFACE contact algorithm. All the external segments of the bird model are used as the slave set and all the external segments of the blades – as the master set. This technique helps to avoid penetration of the blades into the bird's material.

The total CPU time for calculation Lagr2 is 3 hours. Figure 4 shows dimensionless forces of the contact interaction of the bird and blades. As it can be seen from the picture, all the forces are much less then ones in calculation Lagr1. The cause of this is that eroding nodes are not active in the contact after surrounding elements fail. This leads to underestimation of the contact forces.

RESULTS OF CALCULATION LAGR3

In this calculation the contact between bird and blades is modeled using the combination of ERODING_SURFACE_TO_SURFACE and NODES_TO_SURFACE contact algorithms. The forces of the contact interaction are determined using FORCE_TRANSDUCER_PENALTY algorithm. This technique is both allowed nodes to be active in the contact even after surrounding elements fail and helps to avoid penetration of the blades into the bird's material.
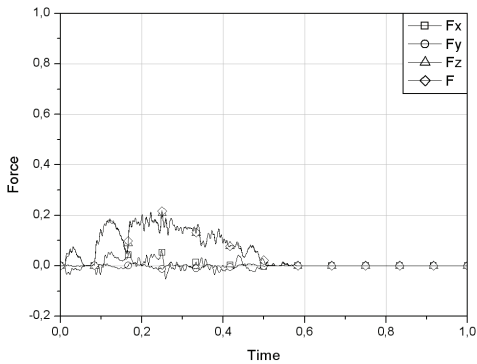
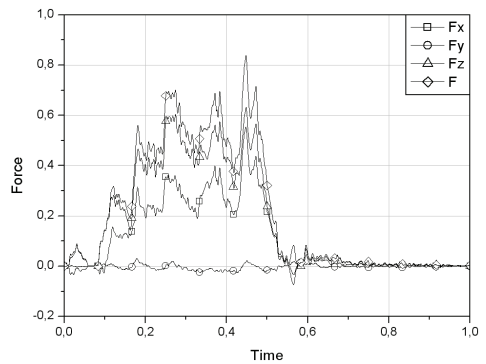Figure 4: Forces of the contact interaction of the bird and blades (Lagr2)

Figure 5: Forces of the contact interaction of bird and blades (Lagr3)

The total CPU time for calculation Lagr3 is 5 hours. The results of the calculation are presented in Figures 5, 6. Figure 5 shows dimensionless forces of the contact interaction of the bird and blades. As it can be seen form the picture, all the forces are quite close to ones, obtained in calculation Lagr1. Figure 6 shows sequential views of the interaction of the bird and blades. The analysis of the pictures shows that there is no penetration of the blades into the bird's material and all the eroding nodes stay active in the contact.
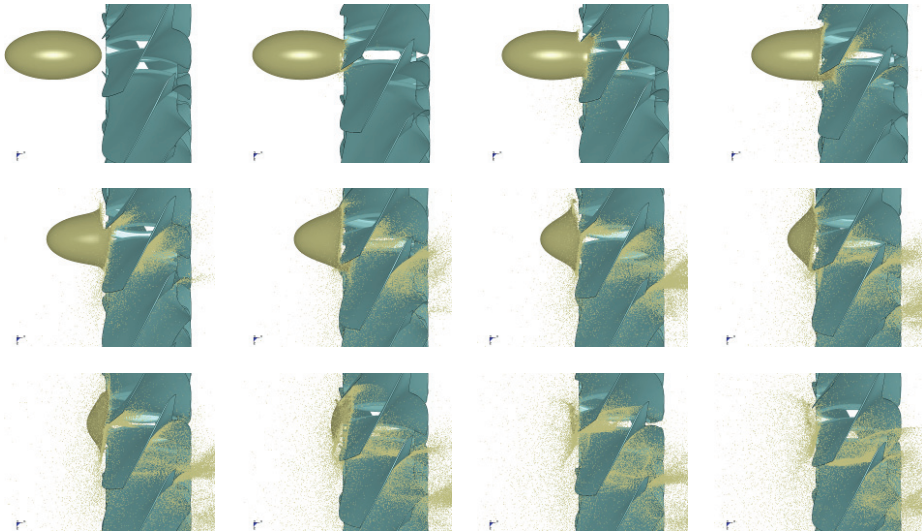

Figure 6: Sequential views of the interaction of the bird and blades (Lagr3)

RESULTS OF SPH CALCULATION

In SPH calculation the contact between the bird and blades is based on NODES_TO_SURFACE contact algorithm, the same as in the calculation Lagr1.

The total CPU time for SPH calculation is 8 hours. The results of the calculation are presented in Figures 7, 8. The analysis of the results shows that they are in a good agreement with Lagrangian results for contact forces as well as for the bird's deformation behavior.
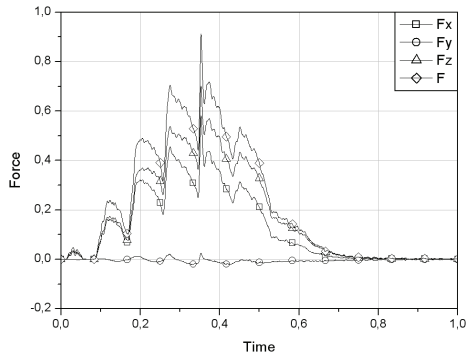

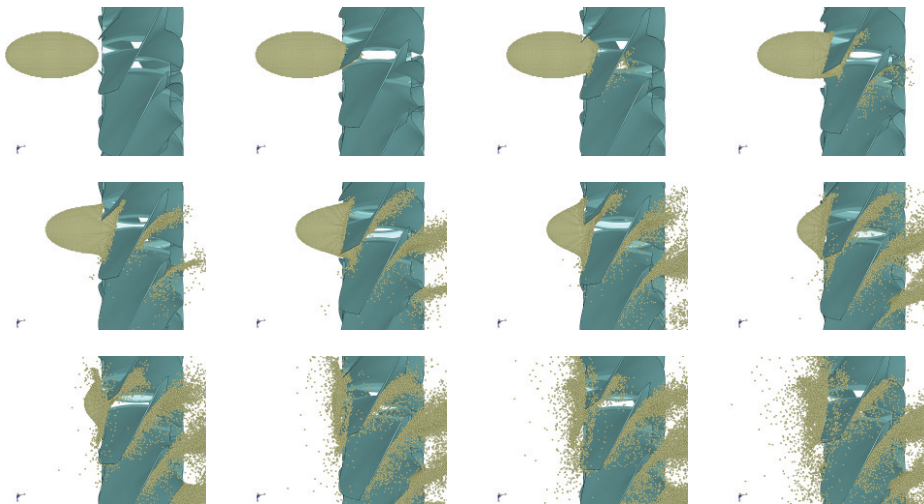Figure 7: Forces of the contact interaction of the bird and blades (SPH)

Figure 8: Sequential views of the interaction of the bird and blades (SPH)

RESULTS OF ALE CALCULATIONS

Two variants of modeling of the interaction of the bird and blades are investigated:

Calculation ALE1 – the interaction of the bird with whole surface of the blade is considered;

Calculation ALE2 – the interaction of the bird with only one of the side surfaces of the blade is considered.

RESULTS OF CALCULATION ALE1

CONSTRAINED_LAGRANGE_IN_SOLID algorithm is used to simulate the contact between the bird and blades. All the external segments of the blades are used as the slave set.

The total CPU time for the calculation ALE1 is 17 hours. The results of the calculation are presented in Figures 9, 10. The analysis of the results shows that ALE1 contact forces, especially the component Fx, significantly differ from ones obtained in Lagrangian and SPH calculations. Moreover there are visible differences in the obtained deformation behavior of the bird. The possible cause of the differences can be that ALE mesh is not fine enough. The size of ALE cells is chosen to be close to the size of elements on the blade's side surface, whereas the blade's thickness near the forward edge is about 10 times less. Refinement of ALE mesh could decrease differences, but this refinement will increase number of ALE cells to several million elements. This will result in significant rise of the calculation time, which even with the current mesh is much higher than in Lagrangian and SPH calculations.
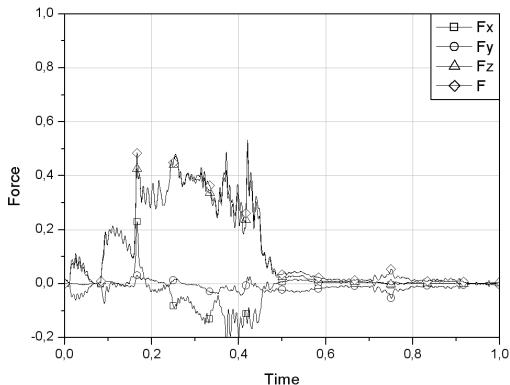

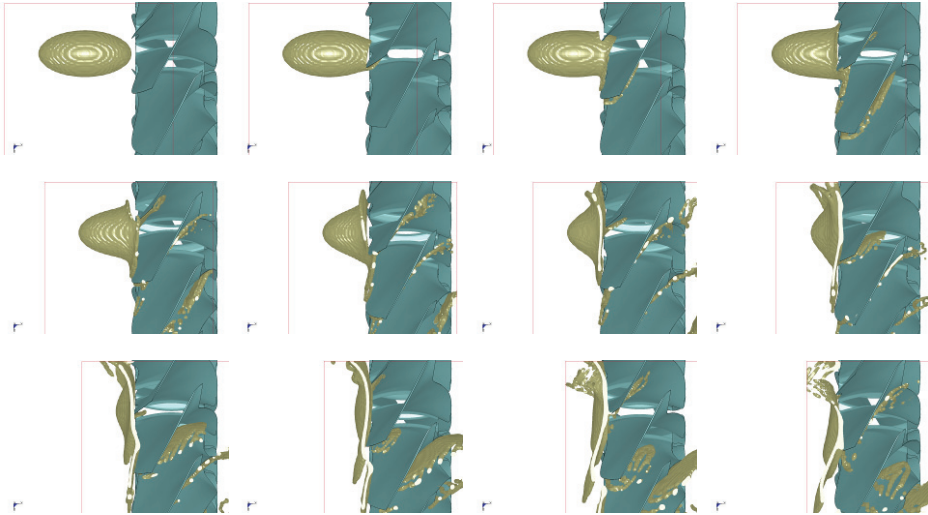Figure 9: Forces of the contact interaction of the bird and blades (ALE1)

Figure 10: Sequential views of the interaction of the bird and blades (ALE1)

RESULTS OF CALCULATION ALE2

In this calculation the contact between the bird and blades is modeled using CONSTRAINED_LAGRANGE_IN_SOLID algorithm. The segments covered only one of the blade's side surfaces are used as the slave set. This technique allows excluding the interaction of the bird with the forward edge of the blade.
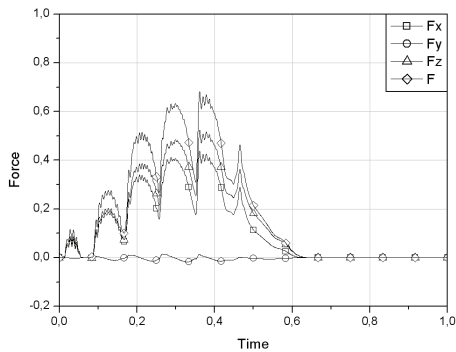

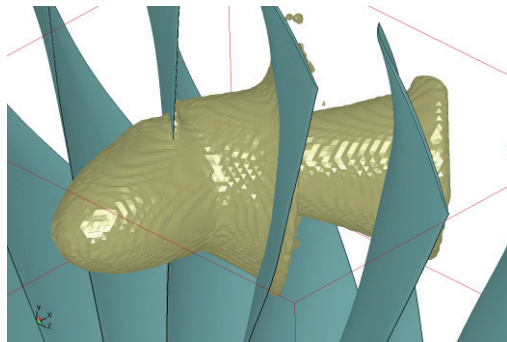Figure 11: Forces of contact interaction of the bird and blades (ALE2)

Figure 12: Interaction of the bird with the blades (ALE2)

The total CPU time for the calculation ALE2 is 18 hours. Figure 11 shows dimensionless forces of the contact interaction of the bird and blades. As it can be seen form the picture, all the forces are quite close to ones, obtained in Lagrangian and SPH calculations. At the same time, analysis of the interaction of the bird and blades shows that obtained results are physically incorrect, because the blades penetrate through the bird's material and the bird is not split into different fragments (see Figure 12).

COMPARISION OF LAGRANGIAN, ALE AND SPH APPROACHES

The main advantages and disadvantages of each approach, which are found out in frames of this work, are presented in Table 1.

Table 1: The main advantages and disadvantages of approaches to model a bird

Approach	Advantages	Disadvantages
Lagrangian	Low CPU time, wide choice of the contact algorithms	Mesh distortion, eroding nodes moves independently from each other
SPH	Mesh-free method, no mesh distortion	Impossible to describe the contact between the bird and blade's edge
ALE	No mesh distortion	High CPU time, requires high number of ALE cells

The comparison of the results, obtained using the different approaches, shows that the results, obtained using Lagrangian and SPH approaches are quite close to each other for the contact forces as well as for the bird's deformation behavior. The results, obtained by means of ALE approach differ from Lagrangian and SPH ones. The comparison of the contact forces shows that ALE approach underestimates loads to the blades. The refinement of the ALE mesh could resolve this problem, but it will result in significant rise of the calculation time.

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.

SUMMARY AND CONCLUSIONS

The calculations of the fan blades bird strike problem were carried out using Lagrangain, SPH and ALE approaches to model the bird. The analysis of the obtained results allows finding out the main advantages and disadvantages of every approach. Basing on the analysis it can be concluded that Lagrangian approach is currently more preferable for such problems.

ACKNOWLEDGEMENTS

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