Investigation of Bird Strike Damage on Fokker 100 Airplane Wing and Nose

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ABSTRACT
Bird strike or the collision of birds to the flying airplane is one of the common threats which reduces the safety of flying vehicles. Numerical analysis is so important to predict the behavior of airplanes body and nose in birds strike and it plays an important role to reduce the project cost and prevent unexpected damages. In this paper, it is tried to study the influence of birds strike on Fokker 100 airplane using the finite element method. In order to verify the proposed method, an experimental bird strike on a plane is studied. Then birds strike on the airplane wing and nose are numerically studied to investigate the amount of damage due to this phenomenon.

KEYWORDS: *Birds strike, airplane wing and nose, Fokker 100, ABAQUS/Explicit*

1.0 INTRODUCTION

The bird strike challenge is one of the common threats that reduce the safety of flying airplanes. This phenomenon can result in considerable damages to the structure, the mechanical systems, control and guidance systems, and the electronic systems. According to FAR 25 standard, wings of big passenger plane should have enough strength to a 4 pound (1.8 kg) bird strike in normal flight situation (Georgiadis et al., 2008). Birds strike mostly happens at the takeoff or landing of the airplane. Figure 1 shows a real bird strike on an airplane.

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Figure 1 : Montenegro airlines Fokker 100 bird strike nosecone damage (Discover ideas about Montenegro Airlines, 2016)

Numerical bird strike modeling can play an important role in the analysis of this phenomenon to reduce structural damage. In recent years, bird strike is modeled for various flight vehicles such as airplane (Allan, 2000; Liu et al., 2018; Riccio et al., 2018), helicopter (Heimbs et al., 2017; Hu et al., 2016; Kim & Kim, 2019), and space vehicles (Hales & Czech, 2017; Mccarty & Smith, 1988). Besides the analytical calculations for bird strike(Cornell, 1976), numerical methods are developed with the improvements of the computers such as Lagrangian method (Airoldi & Cacchione, 2006; Smojver & Ivančević, 2010; Wang & Yue, 2010), Arbitrary Lagrangian Euler (ALE) (Hanssen et al., 2006; Ivančević & Smojver, 2011; Kim & Kim, 2019; Smojver & Ivancevic, 2012), Smooth particle hydrodynamics (SPH) (Liu et al., 2014; Zhang et al., 2018; Y. Zhou et al., 2019).

Orlando and et. al (2018) studied bird strike assessment for a composite wing flap. They investigated the design, analysis, and test of the CFRP flap to check safety standards for bird strike. Numerical SPH simulations had been used for the certification according to the aeronautical requirements. Zhou and et. al (2019) investigated the soft impact loading on laminated glass and aluminum targets from ballistic gelatine and rubber projectiles to check the fuselage and windshield damage of bird strike.

Kim and et. al (2019) numerically investigated the structural damage of a bird strike on a commercial helicopter based on a fluid-structure interaction analysis by considering the Hashin failure criteria in their simulations. In Cai et. al (2019), twofold two-parameter mixed Weibull models are used to verify the characteristic of bird flock, the distribution of the impact energy of bird strike. Caprio and et. al (2019) investigated the strength of a vertical tail leading edge against bird strike phenomenon and to improve the required structural performances by considering different material systems (Antony, Cherouat and Montay (2019) and Dwarakanathan et al.(2015) can also be useful).

In this paper, it is tried to model bird strike on Fokker100 airplane wing and nose. The Fokker 100 is a medium-sized, twin-turbofan jet airliner from Fokker. A total of 113 Fokker 100 aircraft have been used in 25 airlines around the world by July 2017 (Fokker 100). There are still large numbers of this airplane in operation in both Australia and Iran.

On 22 February 2017 in Kish, a southern island of Iran, a bird strike at take-off is believed to have caused a later windshield crack and a diversion to the closest airport for Kish Air Fokker 100 (Bird Strike-Archive 2017).

A series of numerical simulations have been performed using the explicit finite element solver code LS-Dyna in Marulo and Guida (2014). Finite element method is usefull in the presense of complicate geometries, different materials, and etc(Fantuzzi & Tornabene, 2014)(Yayli et al., 2017). ABAQUS software can also be used for bird strike analysis of this airplane. ABAQUS finite element includes explicit and implicit solving methods, various modern behavior models for different materials, fast object modeling and etc. For this purpose, nonlinear transient analysis is performed using ABAQUS/Explicit. Finite element analysis of birds strike is a combination of several complex numerical problems such as contact, evolution models, finite element destruction, removal of failed elements and etc. By considering the advantages and disadvantages of the mentioned numerical method, the Lagrangian method is selected. The advantage of ABAQUS/Explicit analyses can resolve the disadvantages of the pure lagrangian method(Ezzine et al., 2018). At first, the strike of an experimental bird on a flat plane is studied. After the validation of this method, the birds strike on Fokker 100 airplane wing and nose are studied. The rest of the paper is organized as follows: Section 2 presents the constrained equation of motion for bird strike modeling in the Lagrangian method. The verification of the proposed method using experimental results is presented in section 3. Modeling of the bird strike on Fokker 100 airplane nose and wing is studied in sections 4 and 5. Finally, the conclusion is presented in section 6.

2.0 Constrained equations of motion

One of the usual methods for modeling of the bird strike phenomenon is using a solid Lagrangian finite element model. In the Langrangian method, each nodal point is fixed on the element and the material on the element remains fixed with the node points when the element is deformed dut to element motion. In this method, the bird-structure interaction is studied by considering the contact algorithm in explicit finite element methods (Iannucci, 2000). The equation of motion can be combined with Lagrange multipliers to give (Carpenter et al., 1991) :

$$\mathrm{M}\ddot{\mathrm{x}} + \mathrm{C}(\mathrm{x}, \dot{\mathrm{x}}) + \mathrm{H}^{\mathrm{T}}\lambda = \mathrm{D} \tag{1}$$

where *M* is the mass matrix, *C* is the vector of the internal force, *H* is the constraint matrix of the surface contact displacement, x is the displacement vector, *D* is the external force vector and the component of the Lagrange multiplier vector is λ. Due to this fact that the internal forces are proportional to displacement in small displacement problem ($C(x, \dot{x}) = Kx$), the constrained equation of motion at the time t_{n+1} is

$$\begin{gathered}\mathrm{M}\ddot{\mathrm{u}}_{\mathrm{n+1}} + \mathrm{K}\mathrm{x}_{\mathrm{n+1}} + \mathrm{H}^{\mathrm{T}}{}_{\mathrm{n+1}}\lambda_{\mathrm{n+1}} = \mathrm{D}_{\mathrm{n+1}} \\ \mathrm{H}_{\mathrm{n+1}}\{\mathrm{x}_{\mathrm{n+1}} + \mathrm{X}\} = 0\end{gathered} \tag{2}$$

where *X* is the material coordinate vector and *K* is proportional gain. By considering the second-order direct time integration operator as

$$\begin{gathered}x_{n+1} = q_0 + b_0\Delta\ddot{x}_{n+1} \\ \dot{x}_{n+1} = q_1 + b_1\Delta\ddot{x}_{n+1}\end{gathered} \tag{3}$$

$$\ddot{x}_{n+1} = q_2 + b_2 \Delta \ddot{x}_{n+1}$$

where x, $\dot{x}, \ddot{x}$ are displacement, velocity and acceleration vector respectively and $q_0 = x_n + h\dot{x}_n + \frac{1}{2}\, h^2 \ddot{x}_n$, $q_1 = \dot{x}_n + h\ddot{x}_n$, $q_2 = \ddot{x}_n$ where $b_0 = \frac{1}{2} h^2 \beta_0$, $b_1 = h\beta_1$, $b_2 = 1$. In which $h = t_{n+1}$ and $\beta_0 = \beta_1 = \frac{1}{2}$ for the constant-average-acceleration method (Katona & Zienkiewicz, 1985). By substituting equation (3) into equation **(2),** the following equation of motion can be reached (Carpenter et al., 1991):

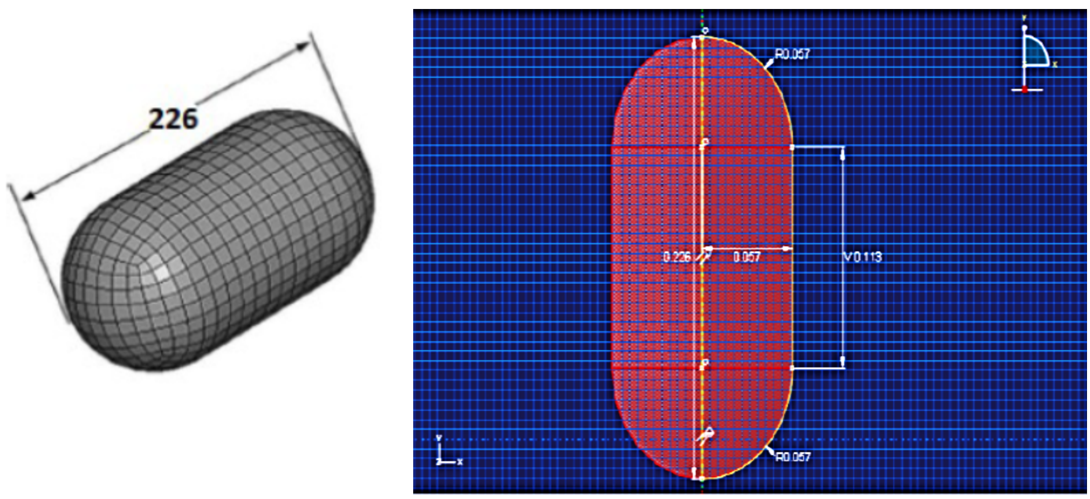
$$\begin{bmatrix} [b_2 M + b_0 K] & {H^T}_{n+1} \\ b_0 G_{n+1} & 0 \end{bmatrix} \begin{Bmatrix} \Delta\ddot{x}_{n+1} \\ \lambda_{n+z} \end{Bmatrix} = \begin{Bmatrix} D_{n+1} - M_{q_2} + K_{q_0} \\ -H_{n+1}\{q_0 + X\} \end{Bmatrix} \quad (4)$$

These equations are solved using ABAQUS/Explicit. The simple model generation and low CPU time are of great advantages of this method. However, large amounts of deformations on the object results in the impractical results and cause the analysis to fail. The advantage of ABAQUS/Explicit analyses such as general contact condition for the contact between the bird and the airplane, eliminating the bird mesh distortion and shear failure model can resolve the disadvantages of the pure lagrangian method.

3.0 Verification of the proposed method using experimental results

The airplane bird strike phenomenon can be modeled by the shooting of a plastic bird on airplane nose and wing. To verify the proposed method, an experimental bird sample (Due to the FAR 25 standard, birds weight should be 1.8 kg and strike speed should be 140 meters per second) is struck on a plane (550*50*5 mm). The bird is a soft gelatin projectile that its geometry is a cylinder that a half-sphere attaches to each end of the cylinder (**Figure 2**). The density of soft gelatin is 950 $^{kg}/_{m^3}$ and bird length is somehow chosen in such a way that its weight becomes 1.8 kg.

Wilbeck (Wilbeck, 1978) conducted some experimental tests in the Air Force Materials Laboratory to define bird impact loads. He measured the striking effect of several materials, including rubber, gelatine, and chickens on a rigid shell. A Hopkinson bar with strain gauges and a flat plate with pressure transducers were used to measure impulse imparted to the target during the impact the temporal distribution of pressure at various points on the plate surface respectively.



(a) (b)

Figure 2: Birds geometry for experimental validation test

Figure 3 shows the experimental results used to verify the proposed method. The maximum displacement value is about 41.3 mm which can be the main factor to check the validity of the proposed method.

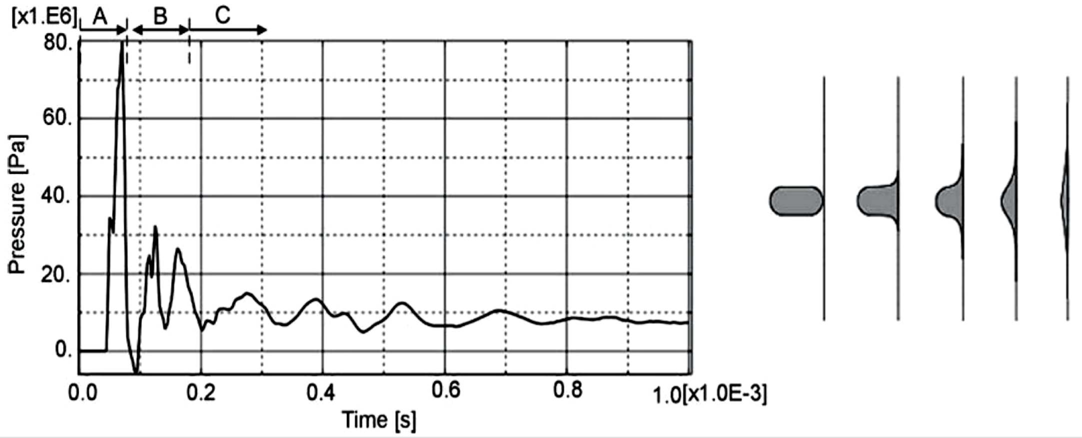


Figure 3: Experimental test results for the validation of the proposed method (Smojver & Ivančević, 2010), (Wilbeck, 1978)

The important factor in bird strike modeling is element deletion in numerical simulation. if the elements distort during simulation, the element deletion will guarantee the elimination of these elements. The general contact condition for the contact between the bird and the plate is chosen due to the complexity of the bird strike phenomenon. The proposed method results are compared to the experimental test results after mesh study. **Figure 4** shows Von Mises stress for bird strike on an aluminum plate to compare with the experimental results. Displacement value is shown in **Figure 5**. As shown in **Figure 5**, the maximum displacement value for the middle point of the plate is about 40 mm and the experimental displacement is about 41.3 mm which can be found that the proposed method is suitable for modeling of the bird strike modeling. If the plane is too thin (thickness is 1 mm), it tears and its element elimination is shown in **Figure 6**. The element deletion can be improved by shear failure setting in the simulation.

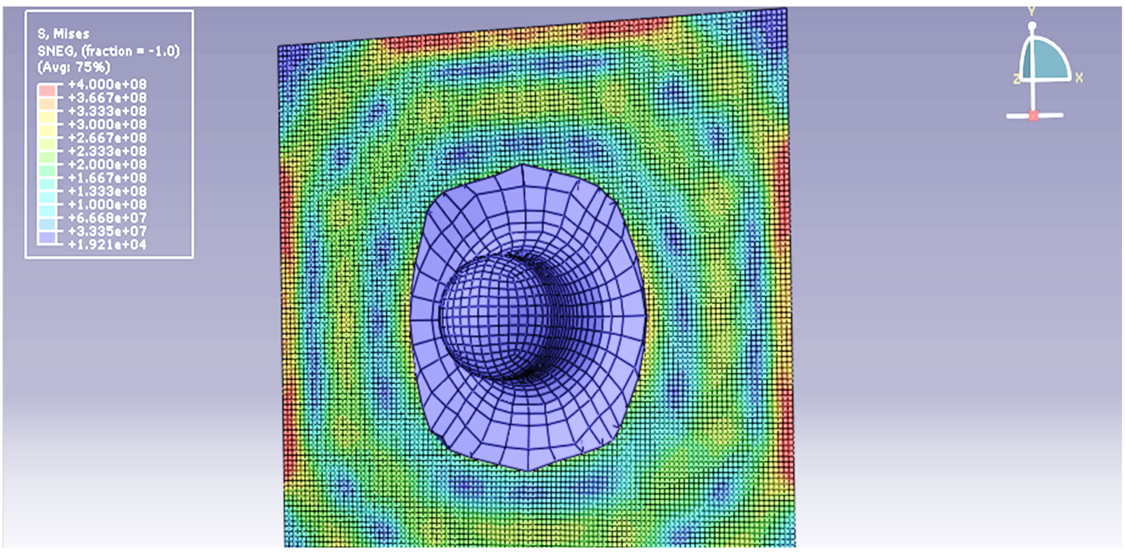


Figure 4: Bird strike on an aluminum plate at t=.5 ms

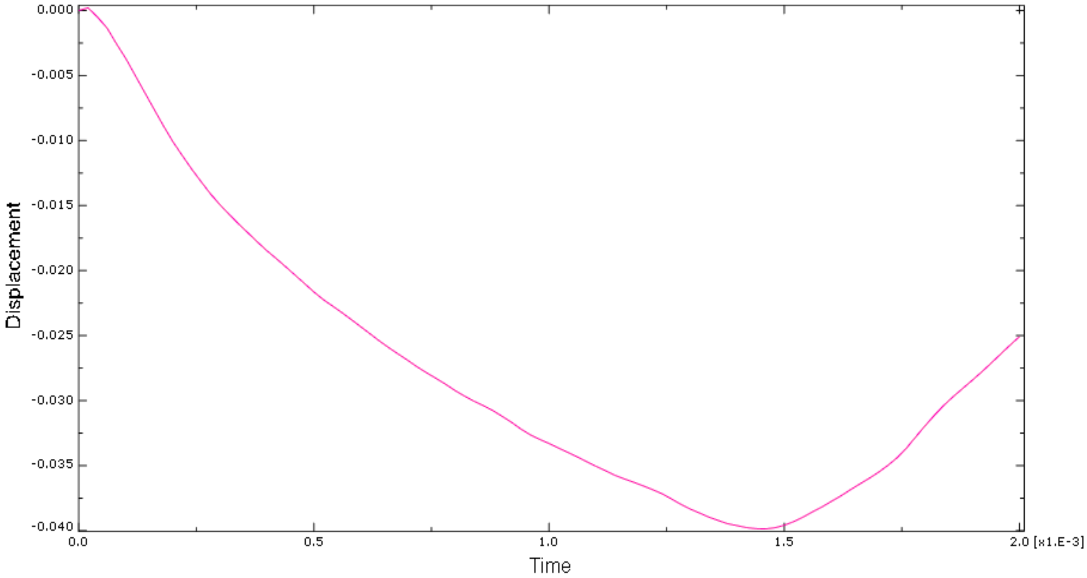


Figure 5: Experimental and simulation accommodation

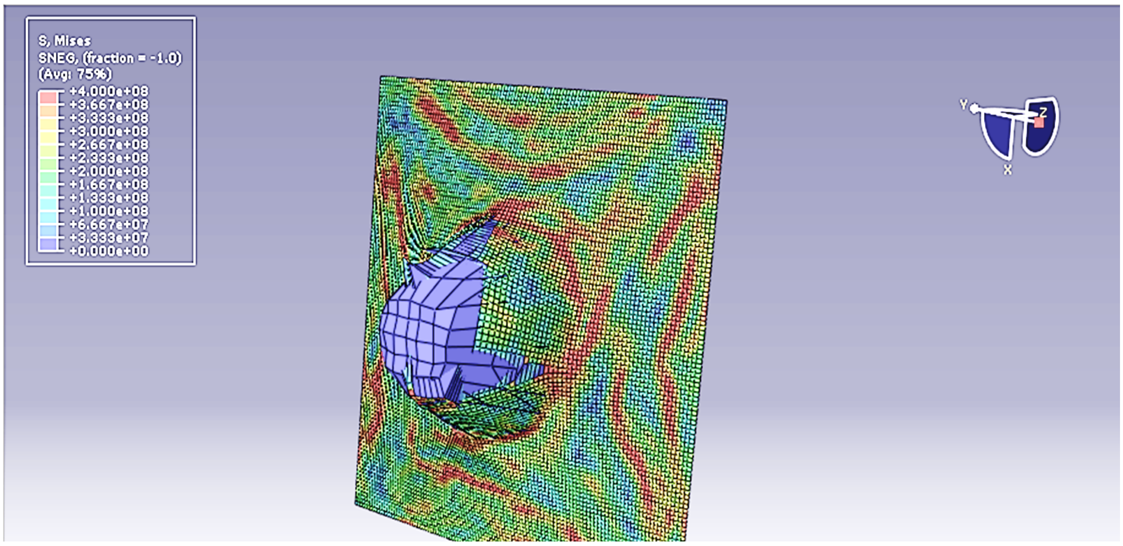


Figure 6: Tearing and elements elimination the elements in the bird strike modeling at t=2.2 ms

4.0 Modeling of the bird strike on Fokker 100 airplane nose

The bird strike on Fokker 100 airplane nose can be modeled by considering the previous conditions and setting and alternating the aluminum plate with a Fokker 100 airplane body. In this part, the airplane thickness is considered as a plate with 3 mm cross-section. The contact algorithm is chosen as the penalty method. This method is suitable for complicated impact modeling such as birds strike. The birds strike on the airplane nose is assumed to be no friction in order to reduce calculations and make the simulation easier to converge. The velocity of the bird is 140 m/s in the contact point. Some of Fokker 100 airplane dimensions are shown in **Figure 7**.

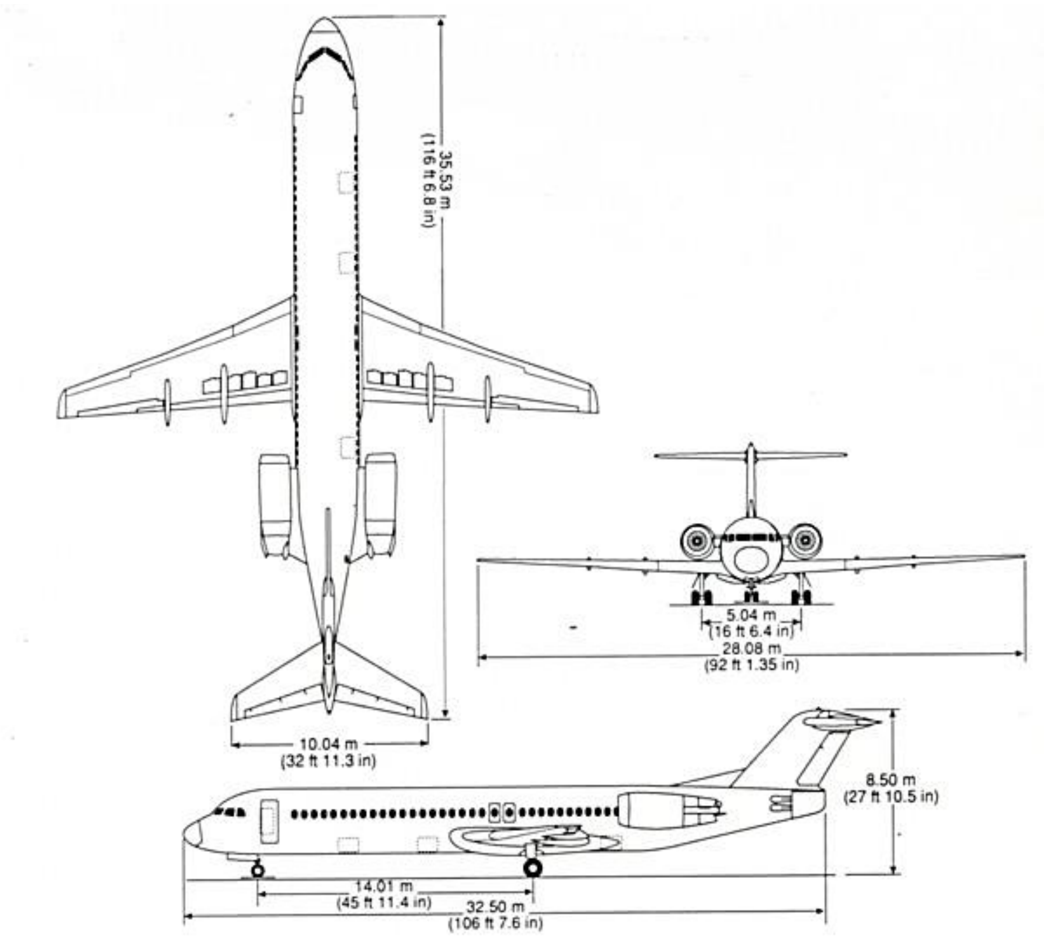


Figure 7: Some of Fokker 100 airplane dimensions (FOKKER 100 GENERAL, 2020)

Figure 8 shows the airplane and the bird meshes. linear quadrilateral elements and linear hexahedral elements are used to mesh the airplane and bird. **Figure 9** shows Von Mises stress at t=4s. The maximum displacement of the nose tip in this situation is about 16.5 cm at 8 ms which can be seen in **Figure 10**. Strike on airplane nose can cause damage to meteorology radar so its mounting place may be important.

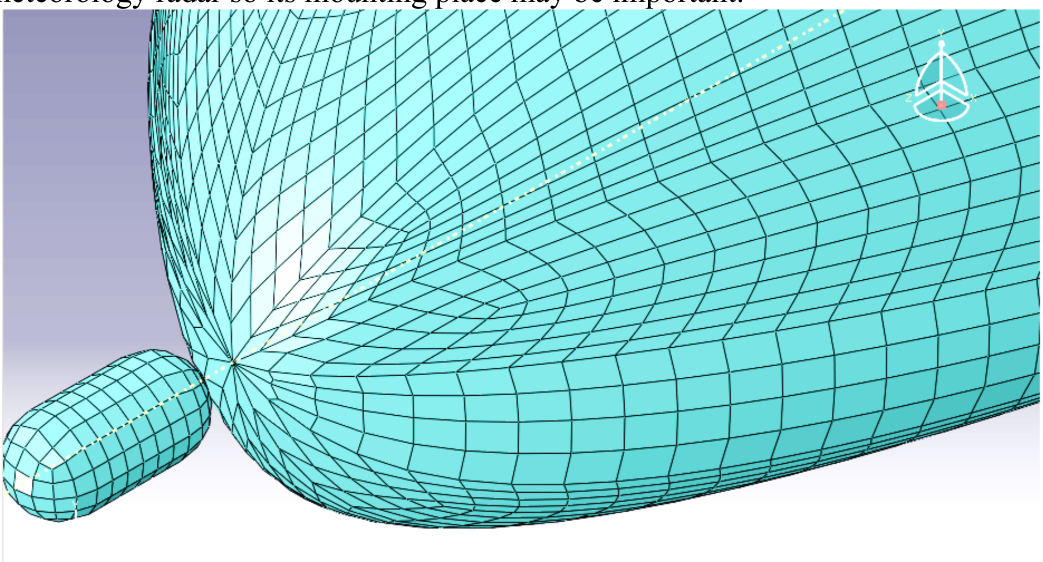


Figure 8: The bird and the airplane meshes

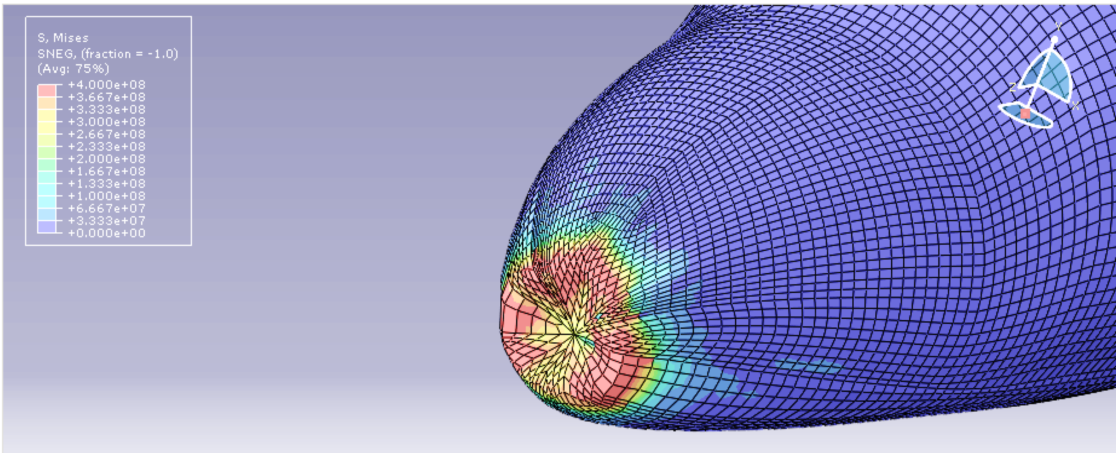


Figure 9: Von Mises stress at t=4s for the bird strike on Fokker 100 airplane nose

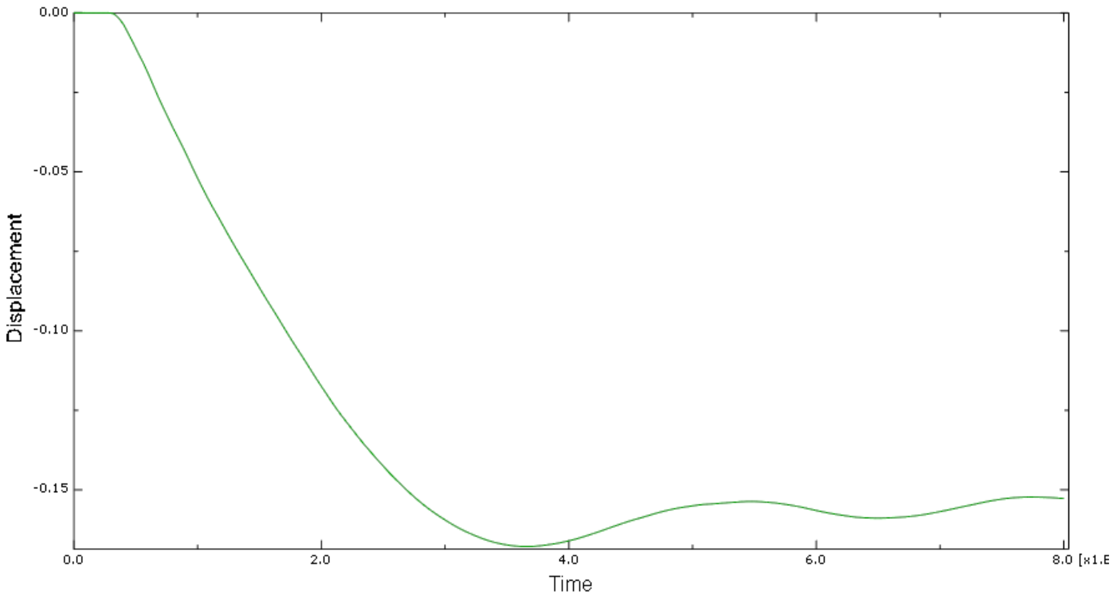


Figure 10: The time history of the displacement of the airplane nose tip

5.0 Bird strike modeling on Fokker 100 airplane wing

In this section, it is tried to model bird strike on the leading edge of Fokker 100 airplane wing. The leading edge is the front part of the wing that directly split the air and it is the first part that is in contact with the air and provides the lift.

According to accident and incident data reports from the Federal Aviation Administration (FAA), 14% of the accident of birds by airplanes are at the wing section. It shows that the wing is one of the major components of airplanes which has the possibility of a bird strike. **Figure 11** shows wing cross-section and its stiffeners which are usually used for more strength and less weight of the airplane.

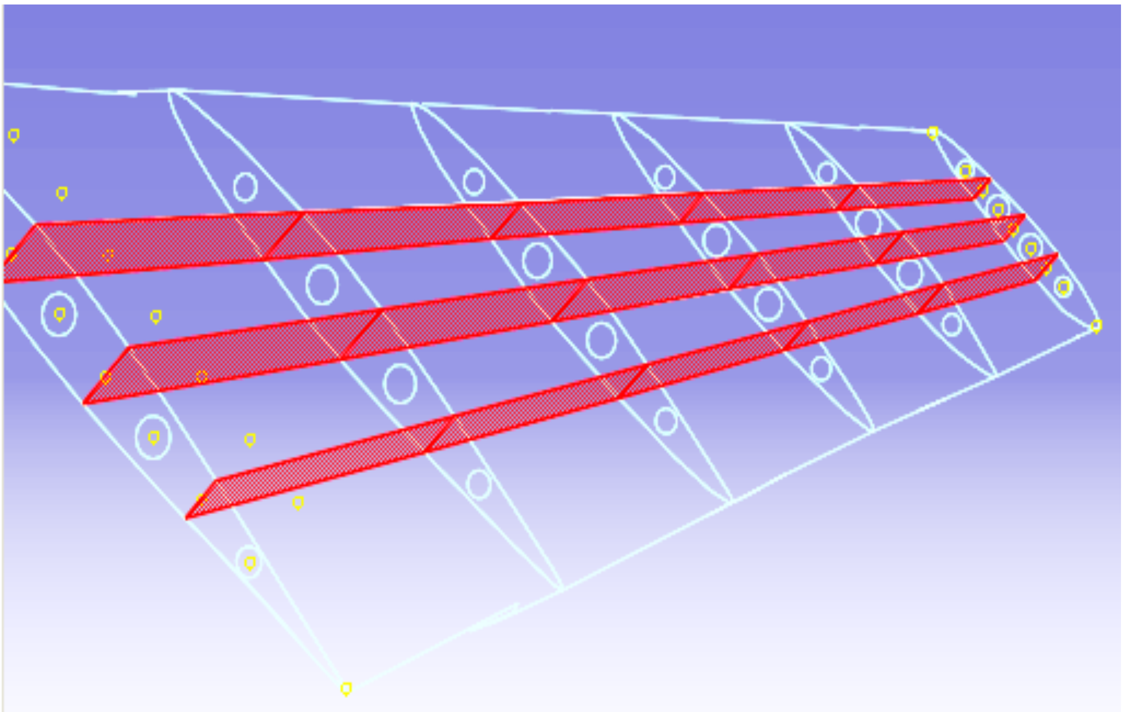
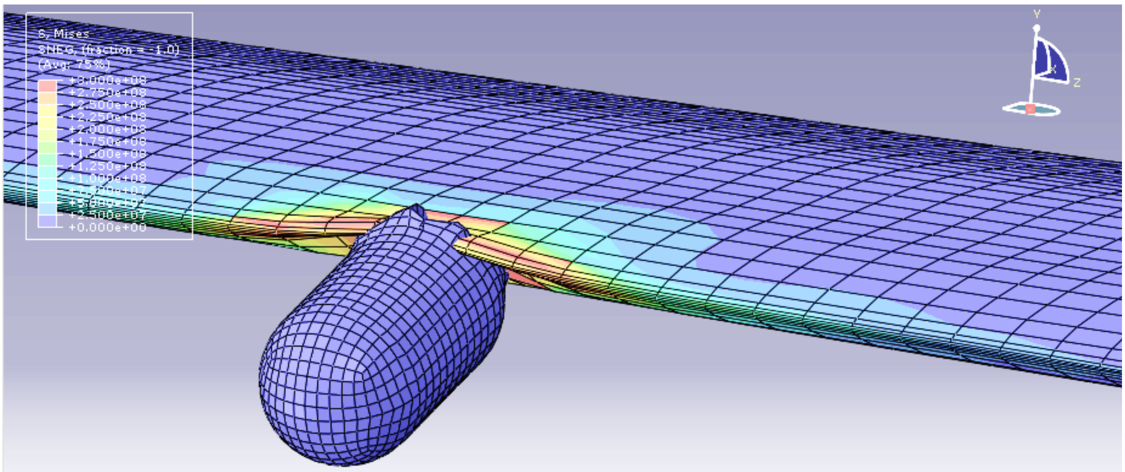
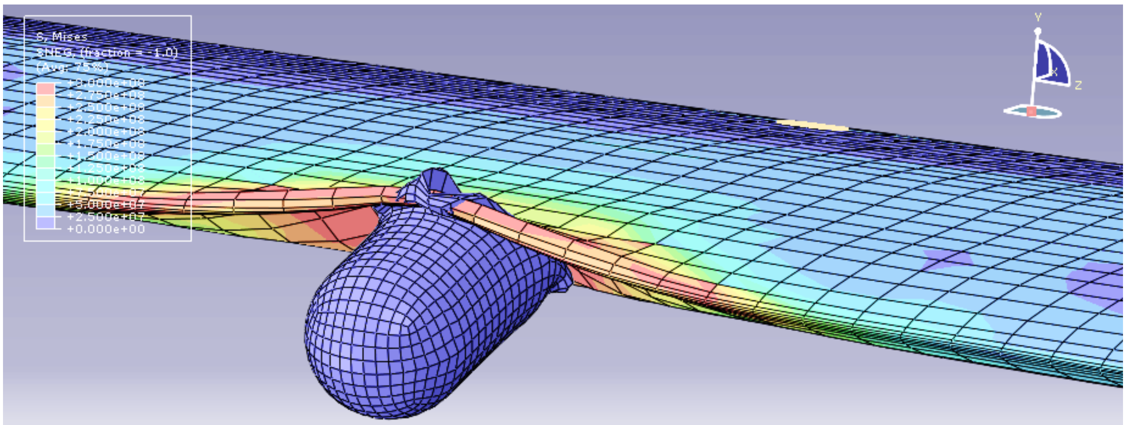


Figure 11: Wing cross-section and its stiffeners

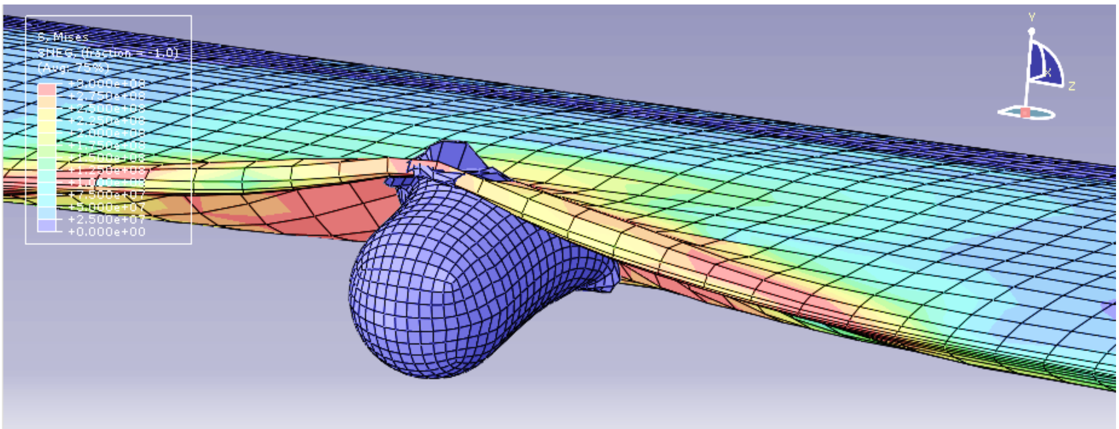
After proper meshing (structural as much as possible), bird strikes on the leading edge of Fokker 100 airplane wing. Figs. 12 shows the bird strike Von Mises stress results at different times with 20 degrees for bird angle with respect to the wing. The deformation of the wing is shown in the last figure at different times for bird strike from t=2ms to t=4ms. Although with the time increasing bird starts to the full failure, the wing shape changes and the wing effectiveness maybe reduces dramatically.



t=1 ms

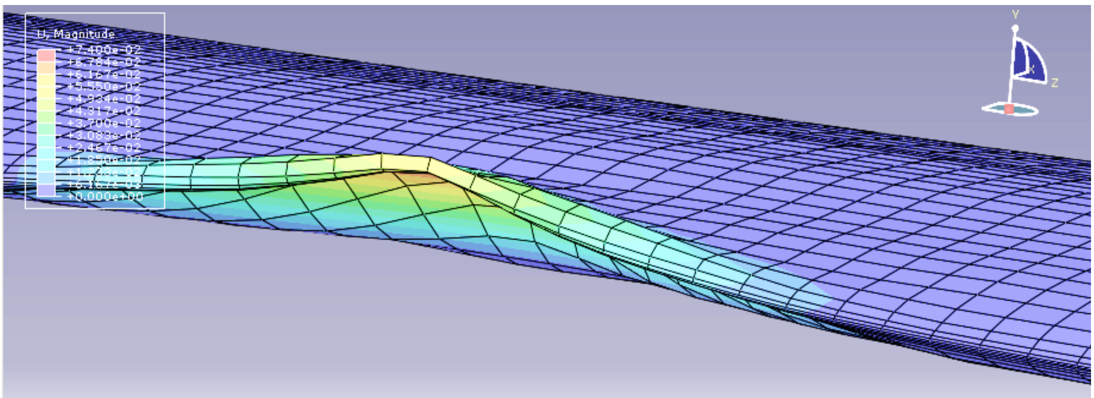


t=1.5 ms

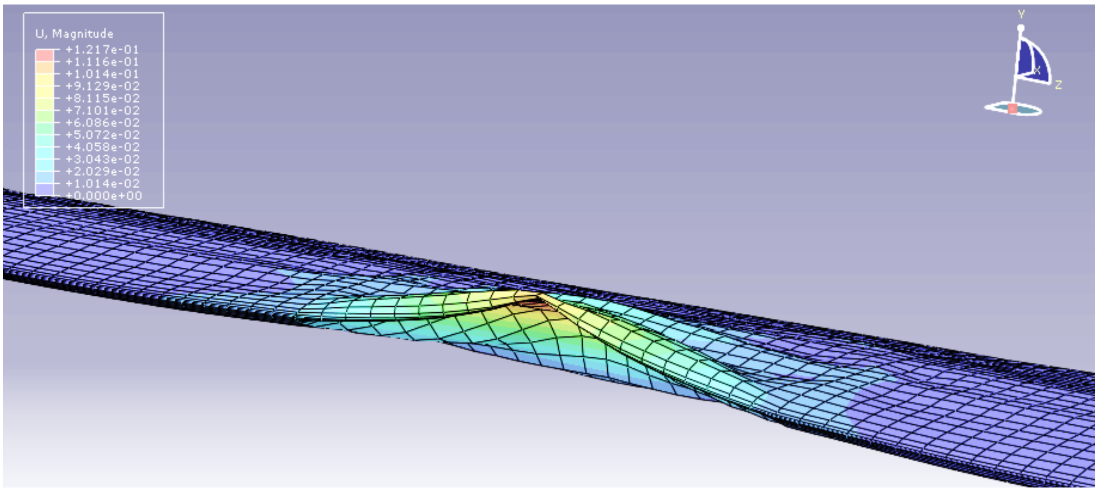


t=2 ms

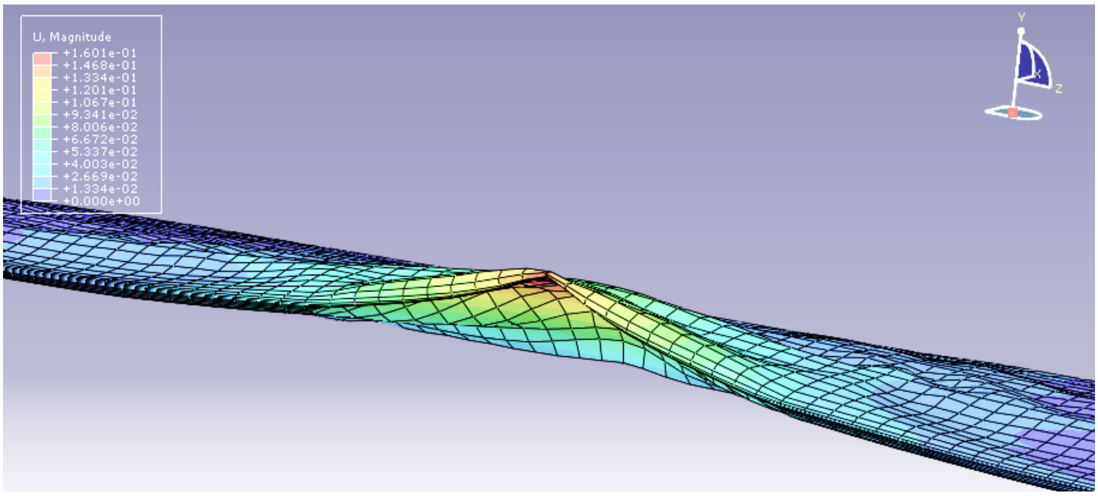
Figure 12: Von Mises stress at different times for bird and leading-edge



t=2 ms



t=3 ms



t=4 ms

Figure 13: Deformation at different times for leading-edge

6.0 SUMMARY

In this paper, bird strike on Fokker 100 airplane wing and nose is investigated. The Lagrangian method is used to analyze this phenomenon with ABAQUS/Explicit improvements. At first, the proposed method is verified with experimental results for bird strike on a plate. Then, the bird strike damage on Fokker 100 airplane leading edge and nose is studied. Results show that birds strike with speeds about 100-140 m/s can cause considerable damage on Fokker 100 passenger airplane in takeoff or landing.

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