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NUMERICAL SIMULATIONS OF A BIRD STRIKE AGAINST A HELICOPTER WINDSHIELD

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Abstract

The article presents simulation results of a bird strike with a helicopter windshield of small helicopter category. It turns out that there are no certification requirements regarding windshield of this category. Therefore Agusta A109 helicopter as a representing this helicopter category has been chosen for researcher. The simulations were conducted on the basis of LS-DYNA software by means of the SPH method for bird model shape of cylinder with hemispherical endings for the speed of $V_c = 285$ *km/h. The analyses regarded various angles of the bird model impact into windshield. As a result of the simulations, comparative analyses in the aspect of time curves of the kinetic energy, velocity, and windshield deformation were achieved. The analysis shows that at smaller angles of attack, the bird's model has a higher speed at the moment of impact, and thus greater kinetic energy, because it did not lose speed as a result of the collision. In addition, the deflection of the windshield is smaller. In some cases, the deflection of the windshield may be observed, which indicates the elastic response of the system. In case of impact in the normal direction to the surface of the glass, the bird's model practically pierces it. The use of a thicker pane translates into less deformation of the pane, but causes its destruction at the connection point with the helicopter carrier structure.*

Keywords: *bird strikes, helicopter windshield, numerical analyses, LS-DYNA*

1. Introduction

Birdstrikes pose a serious threat to the flight safety, since the collisions can lead to serious structural damage to the aircraft. This applies to all protruding parts, such as engine fan blades, engine inlet, windshield, the front part of the fuselage and leading edge of the wing and tail-plane. For helicopters, the windshield, the front part of the fuselage, and the rotor blades are particularly sensitive to bird collisions [1, 2, 3, 9].

For over 30 years, computational numerical techniques have been used to design aircraft resistant to birdstrikes, and they are an effective tool in comparison with costly physical certification tests with real birds. That is why, at present, attempts are being made to replace certification tests for aircraft construction with numerical simulations of collisions with birds. However, acceptance of certification by simulation only requires obtaining test results that coincide with test results for a similar structure that has obtained a certificate. This type of approach was successfully applied in the case of Airbus A380 certification [4].

According to the analysis of the literature on the subject of research, a significant part of damage to the cabin glazing took place in the category of small aircraft and helicopters, for which no certification requirements were specified in this case [3]. Therefore, the windshield of the light helicopter was selected as the collision object for numerical simulations.

It turns out that the majority of numerical analyses concern the impact of a bird on an aircraft element parallel to the longitudinal axis of an aircraft [4]. Therefore, one of the research stages was the analysis of collisions at various angles in relation to the surface of the helicopter's windshield.

2. Research Methodology

2.1. Bird model

On the basis of the tests whose results are documented e.g. in [5, 8, 10], it is possible to state that the most useful artificial material for the bird's body is gelatine with density equalling 950 kg/m^3 and 10% porosity. The densities of the bird material declared by the authors of other studies [7] also oscillate around the value of 950 kg/m^3. Literature study offers various material bird models, used in FEM numerical analyses, starting with the simplest elasto-plastic model with kinematic strengthening [6, 10] to more complex methods, which include equations of state (EOS), for instance in a tabulated form (*EOS_TABULATED) [11], in a polynomial form (EOS_ LINEAR_POLYNOMIAL) [10] and other. The most frequently used equation of state for this type of models is Grüneisen equation.

Within this article we modelled a bird, 1.8 kg in mass (4 lbs) in shape of cylindrical with hemispherical ends (D = 113.12 mm; L = 2D = 226.24 mm (Fig. 1) [2].

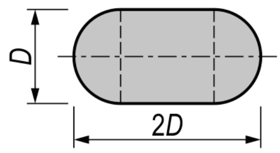

Fig. 1. Shapes and sizes of dummy bird cylindrical with hemispherical ends

The measurements of the above objects have been determined on the basis of the adopted bird mass and material density. We constructed a numerical model for the SPH method. The solid element model was built in the LS-PrePost pre-processor, by means of mesh generators for simple solids such as the cylinder. The dummy bird model had their initial velocity set in the option *INITIAL_VELOCITY. The model exploited the so-called "null" material model (*MAT_ NULL), where we declared Grüneisen equation of state (*EOS_GRUNEISEN). This equation defines pressure for compressed material in the form [6]:

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

whereas for the expanded material as:

$$p = \rho_0 C^2 \mu + (\gamma_0 + a\mu)E, \tag{2}$$

where:
C – bulk speed of sound,
γ_0 – Grüneisen gamma,
S_1 – linear coefficient,
S_2 – quadratic coefficient,
S_3 – cubic coefficient,
a – first order volume correction to γ_0,
μ – volume parameter, expressed as $\mu = (\rho/\rho_0) - 1$,
ρ – density,
ρ_0 – initial density,
E – internal energy per unit of mass.

The material data for the dummy bird model have been listed in Tab. 1.

Tab. 1. Material data used for bird model [6]

*MAT_NULL			*EOS_GRUNEISEN	
density	cut-off pressure	viscosity coefficient	bulk speed of sound	linear coefficient
RO [kg/m^3]	PC [Pa]	MU [Pa·s]	C [m/s]	S1 [–]
950	-10^6	0.001	1.647	2.48

In the model for the SPH analysis, we declared default properties attributed to the particles (*SECTION_SPH). The constant (CSLH) is equal to (1.3), while the scale coefficient for the smoothing length equals HMIN = 0.5 and HMAX = 2 [6, 8].

2.2. Windshield model

We selected the windshield of Agusta A-109, manufactured by the concern of Agusta Westland. The main criterion adopted at its selection was availability of the geometrical model CAD, downloaded from GrabCAD free cross-platform source [13] as well as the accessibility of the strength parameters of the material, which the windshield was produced from. The shell elements had the Agusta A-109 glass thickness declared, i.e. 3.81 mm and 5.00 mm [14]. We used a solid element generator LS-PrePost, which formed a solid element mesh by adding thickness to the existing shell elements.

The Agusta A-109 windshield is manufactured from acrylic glass [14]. The material parameters of this type of glass, mentioned in paper [12], have been listed in Tab. 2. We used the elasto-perfectly-plastic model (*MAT_PLASTIC_KINEMATIC), with the modulus of reinforcement equalling 0.

Tab. 2. Material data used for the windshield [12]

*MAT_PLASTIC_KINEMATIC				
density	Young's modulus	Poisson's ratio	yield stress	failure strain
RO [kg/m^3]	E [Pa]	PR [–]	SIGY [Pa]	FS [–]
1.190	$3.13 \cdot 10^9$	0.426	$6.8 \cdot 10^7$	0.067

2.3. Parameters of the numerical analysis

The conducted numerical analysis exploited the computational code LS-DYNA v.970, in particular the contact model *CONSTACT_AUTOMATIC_NODES_TO_ SURFACE [6]. The function of the master segment was taken by the windshield, whereas the slave segment was the dummy bird. The analyses took into consideration friction coefficient between the contact objects, which equalled 0.1 [2]. The velocity of the object impacting the windshield was determined on the basis of the helicopter cruise speed, which was equal to 285 km/h (79.167 m/s) [14]. This is the speed of the dummy bird striking a fixed windshield. The analysis time was adopted as 10 ms.

In the course of the analysis, we registered the bird's kinetic energy, the resultant of velocity of the point, which overlapped the centre of the bird's mass for the SPH method – the value averaged from eight values in the vicinity of the mass centre as well as total displacement of the theoretical piercing point on the windshield.

3. Results

The influence of the angle of impact of the bird model with the windshield was analysed. As the point of collision (Fig. 2), the "theoretical" windshield pierce point determined for the test analyses was assumed. Tab. 3 presents individual variants of analyses.

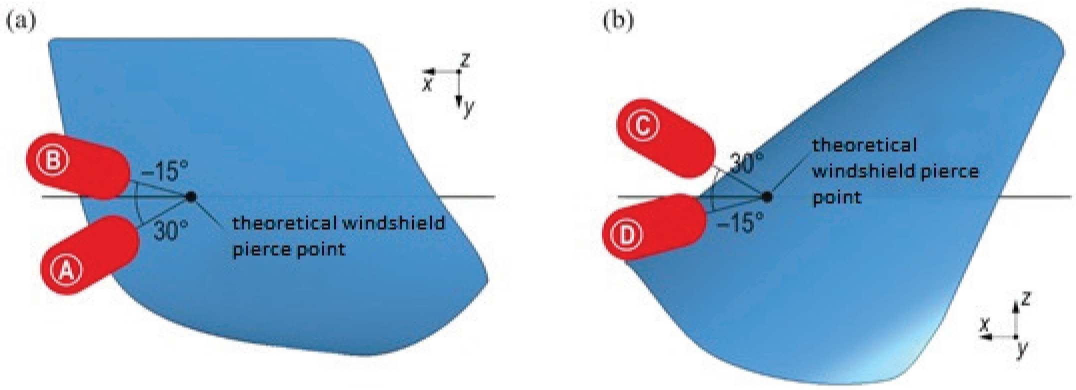

Fig. 2. Directions from which the bird model hit the window - variants for the xy (a) and zx (b) planes

Tab. 3. The variants of the numerical analyses depending on the impact angle of the bird model with the windshield

TEST_131	normal direction, middle of the windshield, nominal glass thickness (3.81 mm) – reference variant
TEST_132	normal direction, middle of the windshield, increased glass thickness (5.00 mm) – reference variant
TEST_13..**A**	as in the reference variant, but with the 30° impact angle in x-y axis (Fig. 2a)
TEST_13..**B**	as in the reference variant, but with the 15° impact angle in x-y axis (Fig. 2a)
TEST_13..**C**	as in the reference variant, but with the 30° impact angle in z-x axis (Fig. 2b)
TEST_13..**D**	as in the reference variant, but with the 15° impact angle in z-x axis (Fig. 2b)

The results of analyses were developed in the form of deformation of the windshield caused by the impact. In addition, time sequences in the form of impact energy, velocity, and deformation curves are summarized.

As shown in Figs. 3-7, the effects of the collision depend on the angle at which the bird model hits the surface of the glass. At a small angle, the bird slides off it without causing its destruction (Fig. 5 and 6, right column). The bird's impact in the most unfavourable way occurs in the normal direction to the surface at a given point, causing its destruction in the middle part, in the immediate vicinity of the "theoretical" breakthrough point (Fig. 3 and 4, central column). At other angles, the glass is destroyed at the place where it is connected to the helicopter carrier structure. The use of glass with a thickness of 5 mm does not affect its penetration resistance in the normal direction to its surface, but smaller damage effects can be observed in relation to the damage of the 3.81 mm thick glass (Fig. 7).

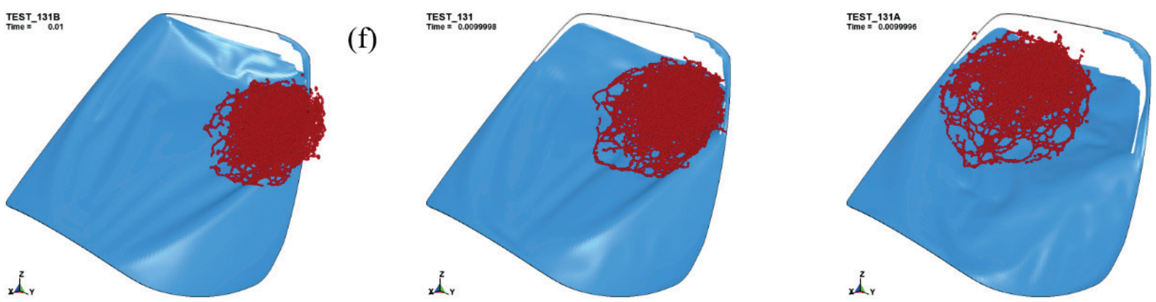

Fig. 3. Deformations of the windshield caused by a bird model strike, windshield with a thickness of 3.81 mm (TEST_131). In the left column – variant B, in the middle column – base variant, in the right column – variant A

The observation of time courses shows that at smaller angles of attack, the replacement bird model has a higher speed, hence greater kinetic energy, because it did not lose speed as a result of the collision. In addition, the deflection of the pane is smaller. In some cases, the deflection of the pane can be observed, which indicates the elastic response of the system (Fig. 8 e, 8 f). In case of impact in the normal direction to the surface of the glass, the bird's model practically pierces it. The use of a thicker pane translates into a smaller tear, but involves destruction at the connection point with the helicopter carrier structure.

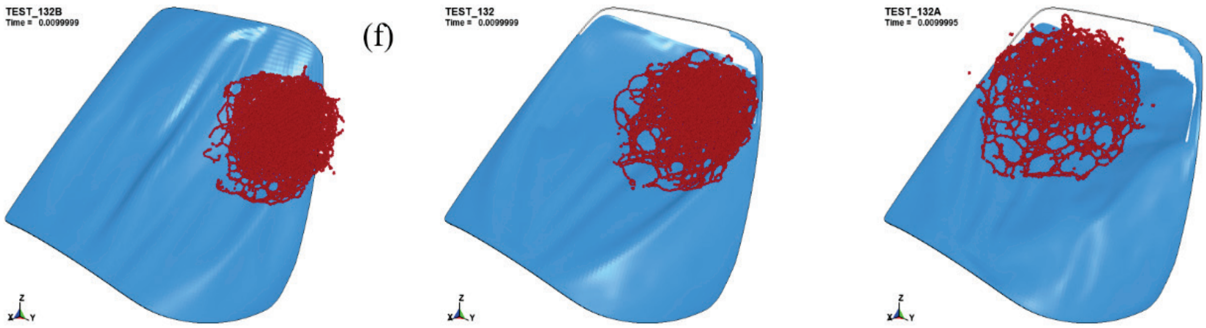

Fig. 4. Deformations of the windshield caused by a bird model strike, windshield with a thickness of 5.00 mm (TEST_132). In the left column – variant B, in the middle column – base variant, in the right column – variant A

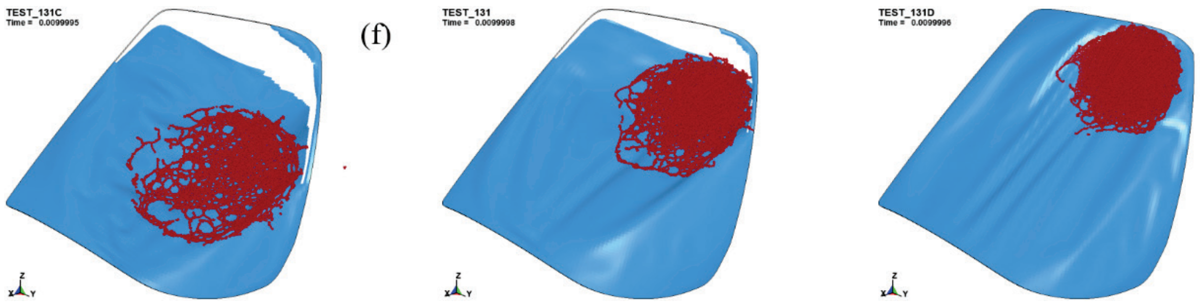

Fig. 5. Deformations of the windshield caused by a bird model strike, windshield with a thickness of 3.81 mm (TEST_131). In the left column – variant C, in the middle column – base variant, in the right column – variant D

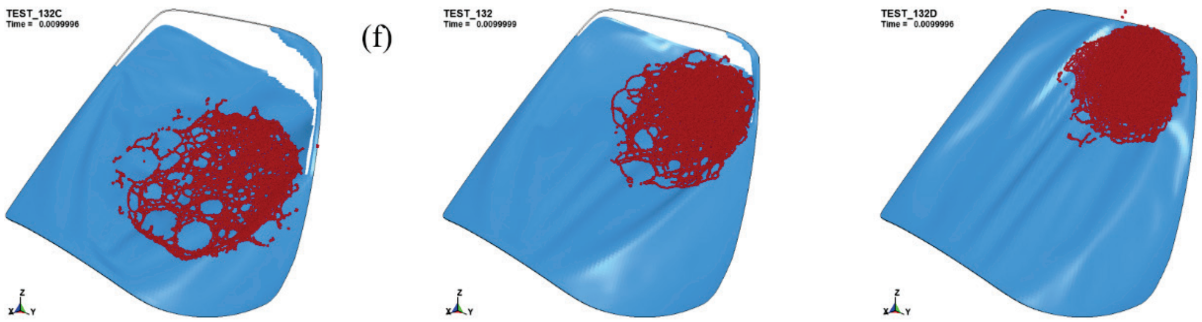

Fig. 6. Deformations of the windshield caused by a bird model strike, windshield with a thickness of 5.00 mm (TEST_132). In the left column – variant C, in the middle column – base variant, in the right column – variant D

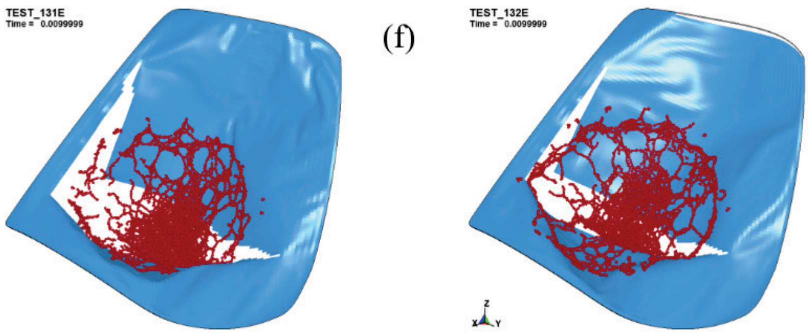

Fig. 7. Deformations of the windshield caused by a bird model strike, (TEST_131). In the left column – windshield with a thickness of 3.81 mm, in the right column – windshield with a thickness of 5.00 mm

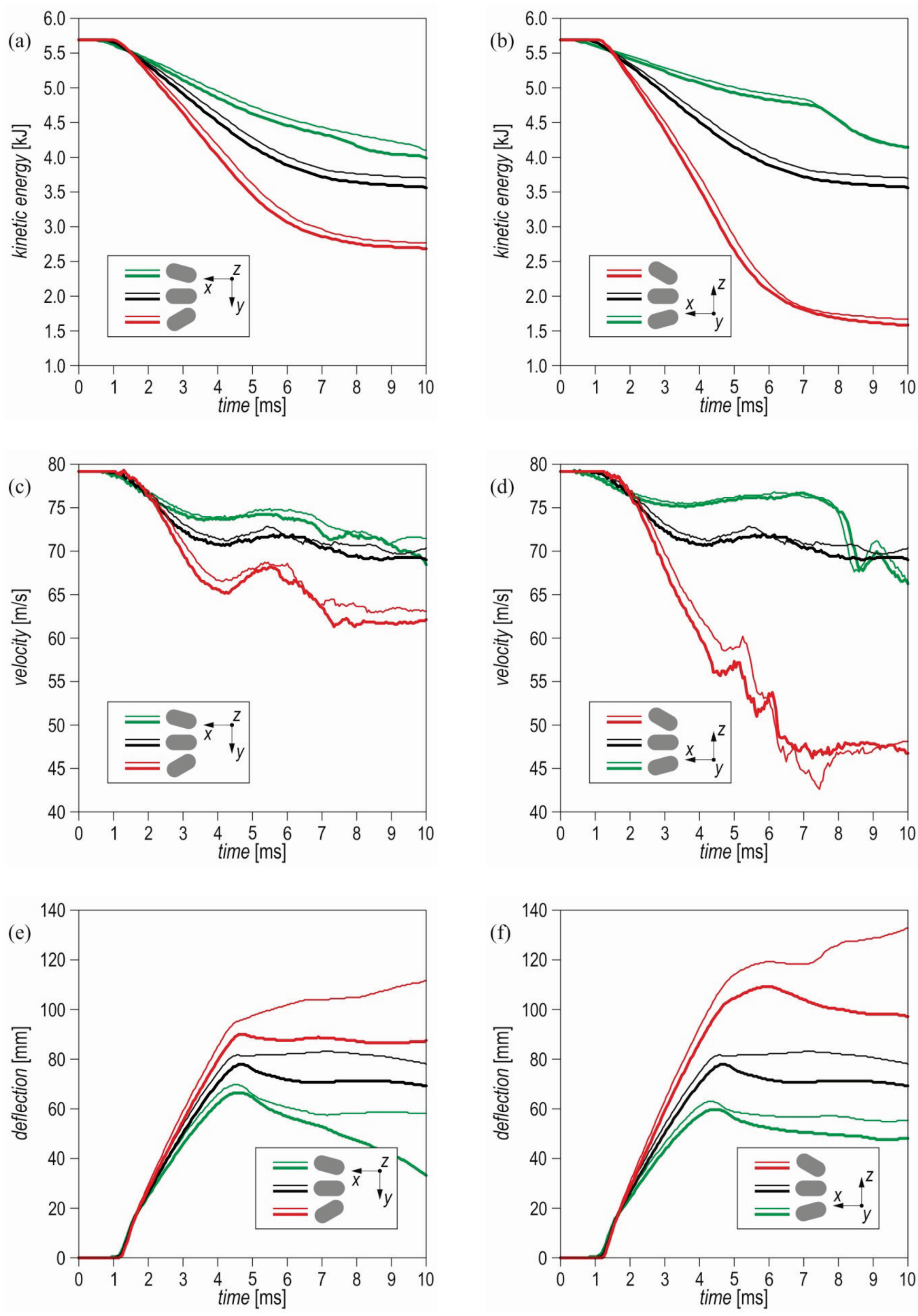

Fig. 8. List of time courses of the kinetic energy of the bird model (a, b), the velocity of the bird's model centre (c, d) and the total displacement of the "theoretical" pierce point (e, f) depending on the angle of the bird's impact on the glass. The right column refers to changes in the angle of impact in the xy plane, while the right column – in the zx plane. Thinner lines the results for the 3.81 mm window were determined, while the thicker ones – for the 5.00 mm pane

Table 4 summarizes the results of variant analyses, taking into account, among others the specific moment of time when the glass was destroyed (erosion of the first element), the final values of the kinetic energy of the bird's substitute model, extreme values of the total deflection and the type of destruction of the glass. The grey colour is used to present the situation in which the glass was not destroyed.

Tab. 4. Summary of the results of the variant analyses

Variant No.	Glass thickness [mm]	Initial damage time[1] [ms]	Final kinetic energy of the bird model[2] E_k [kJ]	Maximum deflection[3] [mm]	Windshield damage type[4]
TEST_131	3.81	5.753	3.702 (35%)	83.1	fixing point
TEST_131A		5.445	2.765 (51%)	111.8	fixing point
TEST_131B		6.181	4.102 (28%)	69.6	fixing point
TEST_131C		5.296	1.665 (71%)	132.9	fixing point
TEST_131D		—	4.150 (27%)	63.0	none
TEST_131E		3.967	1.965 (65%)	398.4	piercing
TEST_132	5.00	5.985	3.568 (37%)	77.8	fixing point
TEST_132A		5.640	2.690 (53%)	90.1	fixing point
TEST_132B		—	3.996 (30%)	66.5	none
TEST_132C		5.474	1.583 (72%)	109.2	fixing point
TEST_132D		—	4.148 (27%)	59.9	none
TEST_132E		4.370	1.034 (82%)	322.0	piercing + fixing point

[1] Initial damage time is interpreted as the time of first damage occurring. Time of the analysis – 10 ms.
[2] The number in the brackets informs about the percentage decrease in the bird model kinetic energy compared to the initial value.
[3] Deflection of the theoretical piercing point (Fig. 2).
[4] Two types of the damage:
a) windshield piercing,
b) damage at the fixing point of windshield with the frame (fixing point).

5. Conclusions

The analyses carried out were aimed at determining the impact of the bird's collision angle with the glass surface and the glass thickness on the helicopter windshields bird strike resistance. Increasing the thickness of the pane from 3.81 mm to 5.00 mm does not ensure its durability during the impact, affecting only the degree of its destruction. Therefore, further testing is planned to determine the recommended minimum thickness of the glass. Taking into account the angle of collision of the bird's model with the surface of the glass, it can be stated that in most cases the glass has been destroyed. Only in cases where the angle of collision was small (below 30 º), the window was not damaged. In practice, this seems unlikely.

In the case of total displacement of the "theoretical" piercing point on the windshield, it is possible to draw a general conclusion that it achieves a mean value of approximately 80 mm. This value sustains throughout the remaining part of the analysis, which may indicate permanent damage of the windshield. In the most of the conducted simulations, the windshield was damaged – it became cracked in its top part, where it was fixed to the helicopter frame. Besides, in one of the analyses it was possible to observe the element erosion in the bottom part of the windshield. It is highly probable that "the bird" after striking and windshield damage will fall inside the aircraft.

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