# Modelling of Bird Strike on Aircraft Structures

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# Problem Analysis

Collisions between birds and aircrafts during the taking-off, cruising and landing phases have become an increasingly serious and catastrophic issues for aircrafts safety.

According to the statistic data from Federal Aviation Administration (FAA), the number of bird strike accidents annually has increased by six times from 1795 cases to 10,856 cases in year 1990 and 2013 respectively, with total accident number of 138,257 cases with 14 years.

Such intensive bird strike accidents have caused huge fatalities, namely, at least 103 aircrafts and 262 lives were lost in civil aviation field from year 1912–2008 where annual property loss was increased from 614 million to 1.28 billion US dollars.

It is estimated that nearly 40% of the major bird strike incidents can be attributed to engine ingestion, 33% to collision with wings, 16% with windshields, 7% with fuselages (for civil aircrafts); for military aircrafts, there are different statistics: engines - 55%, fuselages - 11%, windshields - 10%, wings - 14%.

# Problem Statement

All modern aircraft structures are designed with account of likely collision with birds.
Aviation standards in force require that the aircraft construction would allow the crew to conclude the flight safely after collision with 1.81 kg bird.
Also, the reliable protection from pressurization, viz static loading, which arises through the pressure difference outside and inside the aircraft cockpit, is of great importance for ensuring the normal flight.

Currently, the only way to certify components with regards to bird impact is by performing a physical test. This is an expensive process as several tests may be required to evaluate the effectiveness of the windshield. The goal of thus is to replace the expensive physical testing by computer simulations. If simulation of bird strike is accurately able to predict the behavior of bird strike on windshields, then the windshield design can be optimized before an actual physical test is carried out. This will lower the costs and expedite the design and certification processes.

With the advent of highly effective FEM-based software packages, further consideration was given to the problem of joint deformation of the bird and target. In doing so, the focus was on the accuracy of describing the process of bird damage. Lagrangian, Arbitrary Lagrangian Eulerian (ALE) and Smooth Particle Hydrodynamics (SPH) formulations have found wide application.

The aim of the present study is to devise the method of calculating stress-strained state parameters for laminated aircraft windshields and at bird impact and operating static load.

# Mathematical Model of a Bird Impulse

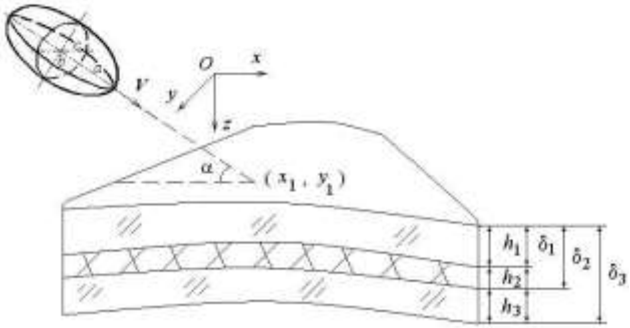

**Fig. 1. Bird collision with a laminated glass**

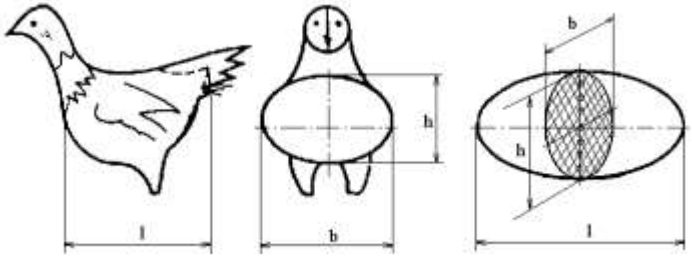

**Fig. 2. Geometrical parametres of birds**

**The bird is modeled by the ellipsoid with the *a*, *b*, *c* semiaxes.**

**The load vector components P may be presented as**

$$p_1 = p_2 = p_{3+i} = p_{3+I+i} = p_{3+2I+i} = 0,\ i = \overline{1, I},\ p_3 = \frac{1}{2}\left[1 + \operatorname{sign}\left(\tau_b - t\right)\right] F\left(t\right) \qquad (1)$$

**where** $\tau_b = \dfrac{2\sqrt{a^2 + k^2 b^2}}{V}, \qquad k = ctg\alpha$

$$u_b = \frac{ab}{a^2 + k^2 b^2}\sqrt{\left(1 + k^2\right)\left(2Vt\sqrt{a^2 + k^2 b^2} - V^2 t^2\right)}, \qquad v_b = c\sqrt{\frac{2Vt\sqrt{a^2 + k^2 b^2} - V^2 t^2}{a^2 + k^2 b^2}}$$

$u_b, v_b$ **are lengths of semiaxes of the elliptical load area**

$x_1, y_1$ **are coordinates indicating the point where the trajectory of motion of the bird's centre of mass intersects the glass**

**According to the fluid dynamic theory suggested, the first approximation of the contact interaction force $P_b$ is assumed represented by the value obtained from the fluid dynamic theory. During normal impact, it takes the form**

$$P_b\left(t\right) = \rho_b V^2 \sin^2 \alpha \pi u_b v_b, \qquad (2)$$

**where** $\rho_b$ **is bird tissue density.**

# Mathematical Model of a Laminated Glass

**We examine the laminated glass as an open-ended laminated cylindrical shell of the *R* radius, which consists of the *I* isotropic layers of constant thickness.**

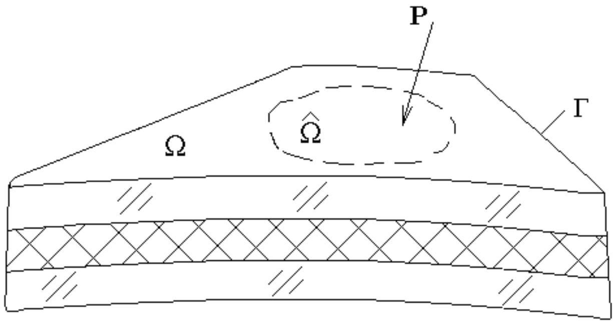

**Fig. 3. Model of a windshield**

**The behaviour of a laminated glass is described by the first-order theory accounting for transverse shear strain, thickness reduction and normal element rotation inertia in each layer.**

$$u_k^i = u_k + \sum_{j=1}^{i-1} h_j u_{3+I(k-1)+j} + (z-\delta_{i-1})\, u_{3+I(k-1)+i}, \; k=1,2,3, \; i=\overline{1,I} \qquad (3)$$

## Hamilton's Variational Principle

$$\int_{t_0}^{t_1} \left(\delta \mathrm{K} - \delta \Pi + \delta \mathrm{H}\right) dt = 0 \qquad (4)$$

## Equations of Motion of the Laminated Windshield

$$\mathbf{\Omega}^{\rho}\mathbf{U}_{,tt} - \mathbf{\Lambda}\mathbf{U} = \mathbf{P}, \; (x,y)\in\Omega, \; \mathbf{U} = \mathbf{U}_{,t} = 0, \; t=0 \qquad (5)$$

## Boundary Conditions

$$\mathbf{B}^{\Gamma}\mathbf{U} = \mathbf{P}^{\Gamma}, \quad (x,y)\in\Gamma \qquad (6)$$

**where**

$$\mathbf{U} = \{u_j(x,y,t)\}, \; \mathbf{P} = \{p_j(x,y,t)\}, \; j = \overline{1, 3I+3}$$

# Solution of the Problem

**The analytical solution of the problem is obtained by the immersion method. According to this method, a non-closed cylindrical laminated shell is immersed into an auxiliary enveloping cylindrical shell with the same composition of layers.**

**An auxiliary shell is one whose contour shape and boundary conditions yield a simple analytical solution. In this case, the auxiliary shell is a simply supported rectangular laminated one, allowing to find the problem solution as trigonometric series. To satisfy actual boundary conditions (6), the auxiliary shell is subjected over the trace of boundary $\Gamma$ to additional distributed compensating loads**

$$\mathbf{Q}^{\text{comp}} = \left\{q_j^{\text{comp}}(x,y,t)\right\}$$

**whose intensities must be defined.**

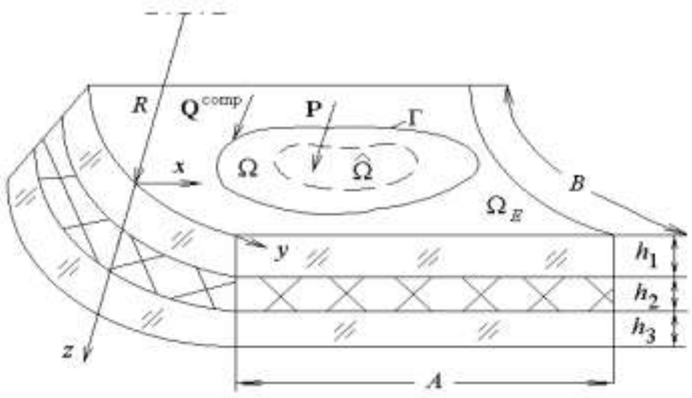

**Fig. 4. An auxiliary shell**

**Based on the condition of satisfying boundary conditions on the boundary $\Gamma$, we form a system of integral equations for determining the intensities of compensating loads**

$$\mathbf{B}^{\Gamma}\mathbf{U}\left[\mathbf{Q}^{\text{comp}}(x,y,t)\right] = \mathbf{P}^{\Gamma},\ (x,y)\in\Gamma \qquad (7)$$

**Displacements and loads are expanded in the auxiliary shell domain in trigonometric series for functions satisfying simply supported conditions. The compensating loads are expanded into a series along the boundary $\Gamma$**

$$q_j^{\text{comp}}(s,t) = \sum_{\alpha=1,2}\sum_{\mu=0}^{\infty} q_{j\alpha\mu}(t)\, b_{\alpha\mu}(s),\ j=\overline{1,3I+3}$$

**Hence, the system of integral equations (7) is transformed to a system of algebraic equations with respect to the expansion coefficients of the compensating loads. The system of motion equations (5) is integrated by a method of expanding the solution into Taylor's series.**

# Experimental Investigation of Strains of Windshields

**To check the effectiveness of the suggested model, the theoretical results were compared with experimental data on investigating the strain of an AN-178 aircraft to the bird strike.**

**Fig. 5. AN-178 aircraft**

**Fig. 6. Windshields of AN-178 aircraft**

**Fig.7. Pneumatic gun for launching birds (the ANTONOV Company)**

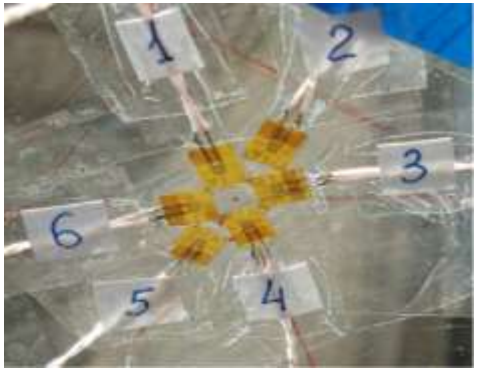

**Fig. 8. A rosette of strain gauges**

**Experimental studies were carried out with dynamic wide-range strain measurement technique**

# Windshields after Testing

# Numerical Results

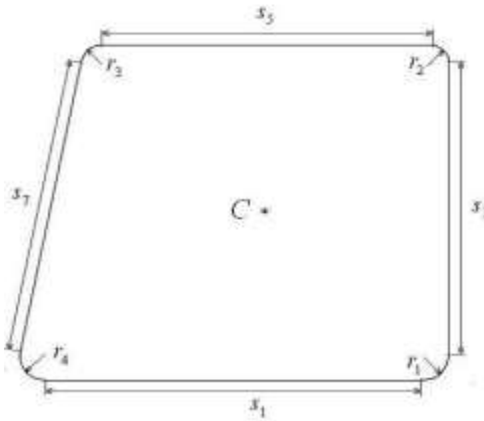

**Fig. 9. Computational scheme of the windshield of AN-178 aircraft**

**Composition of layers 5(4)12(2)6(5)5, *R* = 1,34 м**

**Bird mass is 1,81 kg, bird velocity is 157 m/h,**
**Impact angle is 40°**

**Stresses in layers of the windshield**

| Layer number | Layer hickness, mm | Stress, MPa |
|---|---|---|
| 1 | 5 | 114.3 |
| 2 | (4) | 0.57 |
| 3 | 12 | 133.9 |
| 4 | (2) | 0.74 |
| 5 | 6 | 95.6 |
| 6 | (5) | 0.59 |
| 7 | 5 | 112.2 |

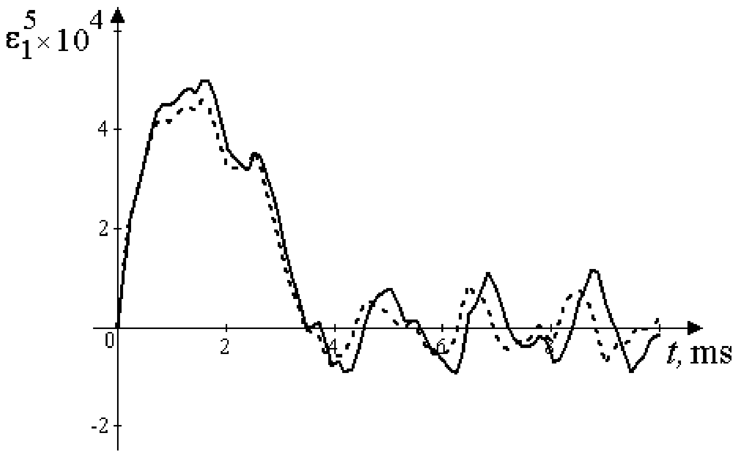

**Fig. 10. Response of the laminated windshield to the bird strike (solid line – calculation data, dot line – experimental results)**

**In accordance with international requirements the cockpit windows should stand a maximum operating excessive pressure (pressurization) of *Pop*=0.0618 MPa and the design one of *Pd*=0.247 MPa**

**Maximum normal tensile stresses under operating and design pressures are 8.6 MPa and 34.3 MPa, respectively**

# CONCLUSIONS

1. The method of evaluating the stress-strained state of laminated aircraft windshield is devised that is based on the refined windshield model accounting for the effect of different operating factors.
The method includes the procedure of strength calculations for laminated aircraft cockpit windows on the bird strike and cockpit pressurization.
2. Based on the experimental data a model of the load impulse arising from the collision of laminated windshields with a bird is constructed.
3. The stress-strained state of the laminated windshield of modern aircrafts was Investigated at real operating loads. It was established that the stresses did not exceed feasible values. Comparison of calculation results and experimental data demonstrates their good agreement.
4. The advanced approach and calculation results can reduce costs and time for calculations, pre-design and full-scale tests of laminated aircraft windshields.

# THANK YOU !