

Ballistic Validation of Honeycomb-Mesh Barriers for Aircraft Engine Bird-Strike Protection

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(Presented by Academy Member Elguja Medzmariashvili)

Abstract. This paper presents the numerical modelling and ballistic validation of a honeycomb-mesh barrier designed to reduce aircraft-engine damage caused by bird strikes. The study focuses on a helicopter-engine inlet configuration with a 40 x 40 mm honeycomb cell, selected for larger-scale applications and not as a replacement for the 30 x 30 mm cells used in smaller ducted-engine aerodynamic optimization. The impact event was simulated in Ansys LS-DYNA using the MAT_NULL material modelling and EOS_GRUNEISEN equation of state for a 100 g soft-body projectile at 70 m/s (250 km/h). Model calibration was supported by static compression testing of a Nylon-CF printed honeycomb fragment, where the maximum force was $F_{max} = 2657$ N. Ballistic tests were conducted on a dedicated launcher and data-acquisition system. After preliminary screening with potato, chicken fillet, bone-in meat, and ballistic gelatin, final validation used commercially obtained, non-living, feathered quail specimens (98-99 g). The combined honeycomb and Dyneema mesh configuration showed approximately 25% higher integral impact-load attenuation than the honeycomb alone, while simulated and experimental peak-force values differed by 5-8%. The results support the calibrated model as a practical tool for further engineering optimization. © 2026 Bull. Georg. Natl. Acad. Sci.

Keywords: bird strike, LS-DYNA, honeycomb-mesh barrier, ballistic validation, aircraft engine protection

Introduction

Bird strikes remain one of the least predictable hazards for search-and-rescue UAVs and helicopters operating in coastal zones. Low-altitude flight, high bird activity, and an open engine inlet increase the probability of foreign-body ingestion and engine damage (Hedayati & Sadighi, 2015; Khachidze & Maisuradze, 2023).

The present study is focused on ballistic validation rather than aerodynamic optimization. Its purpose is to evaluate whether an LS-DYNA-based model can reproduce the real response of a honeycomb-mesh barrier subjected to a 250 km/h soft-body impact and to assess whether the combined barrier reduces the risk of large fragments entering the engine flow path.

A specific distinction must be made between the 30 x 30 mm and 40 x 40 mm cell sizes. In earlier aerodynamic tests on a smaller contra-rotating ducted engine, a 30 x 30 mm cell was selected because of the limited diameter of the outer duct. In the present work, the 40 x 40 mm cell corresponds to the enlarged

honeycomb diameter required for a helicopter-engine inlet and therefore represents a different platform scale rather than a contradictory design result.

Materials and Methods

Physical impact model. During high-speed impact, a bird body can be treated as a low-strength, highly deformable soft body (Wilbeck, 1978). Its response differs substantially from that of a rigid projectile: a pressure wave develops at impact, energy is rapidly redistributed through the tissue, and fragmentation may occur in a very short time.

The engineering concept is that the honeycomb structure receives the primary impact and initiates fragmentation, while the high-strength mesh positioned behind it intercepts the remaining lightweight fragments, in line with protective-grid design concepts (Maisuradze et al., 2020).

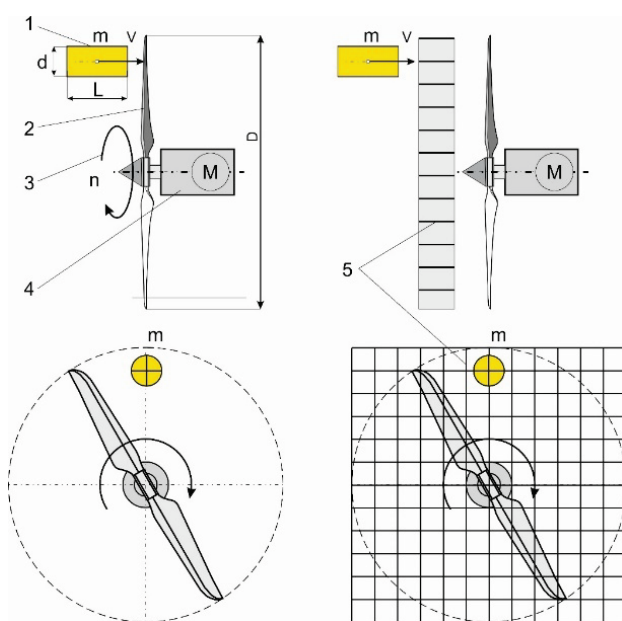


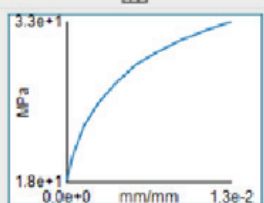
Fig. 1. Basic physical model of the impact process: bird model, propeller, motor, and protective honeycomb structure.

Numerical model in Ansys LS-DYNA. The simulation used the MAT_NULL material formulation and the EOS_GRUNEISEN equation of state, which are commonly applied to high-speed soft-body impact analysis (ANSYS, Inc., 2023; Hedayati & Sadighi, 2015). Initial parameters were selected as follows: density $\rho_0 = 1000 \text{ kg/m}^3$, sound speed $C = 1480 \text{ m/s}$, and Gruneisen coefficient $\gamma_0 = 0.5$. A 100 g cylindrical soft-body projectile impacted a Nylon-CF honeycomb barrier at 70 m/s, equivalent to 250 km/h.

The numerical model was discretized using a three-dimensional finite element mesh composed of tetrahedral elements. The mesh consists of a total element count of 8×10^7 to ensure spatial convergence. To maintain computational stability and control the time-step within the LS-DYNA environment, the minimum element edge length was maintained at 0.3 mm. Additionally, a mesh growth ratio of 1.2 was applied to achieve a smooth transition from highly refined regions to the coarser zones of the computational domain.

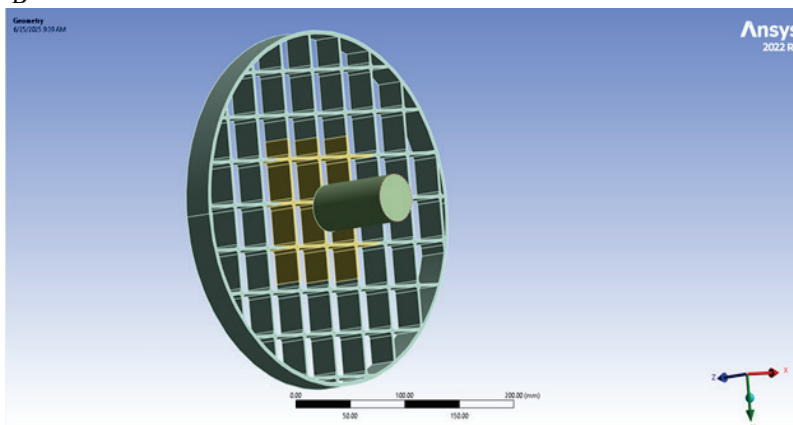
Other	
MAT_NULL	
Pressure cutoff	-10000 MPa
Dynamic viscosity	1e-09 MPa-s
Relative volume for erosion in tension	0
Relative volume for erosion in compression	0
Young's Modulus (used for null beams and shells only)	0 MPa
Poisson's Ratio (used for null beams and shells only)	0
EOS_GRUNEISEN	
Equation of state coefficient, c	1.48e+06 mm/s
Equation of state coefficient, s1	1.92
Equation of state coefficient, s2	0
Equation of state coefficient, s3	0
Equation of state coefficient, gamma0	0.5
Equation of state coefficient, a	0
Initial internal energy, e0	0
Initial relative volume, v0	0

A

Structural	
Isotropic Elasticity	
Multilinear Isotropic Hardening	
	
Isotropic Secant Coefficient of Thermal Expansion	0.0001467 1/°C
Tensile Ultimate Strength	71.89 MPa
Tensile Yield Strength	43.13 MPa

Thermal	
Isotropic Thermal Conductivity	0.0002428 W/mm-°C
Specific Heat Constant Pressure	1.5e+06 mJ/kg-°C
Electric	
Isotropic Resistivity	1.834e+15 ohm-mm
Isotropic Relative Permittivity	14.38
Isotropic Electric Loss Tangent	0.1171

B



C

Fig. 2. LS-DYNA input data and soft-body impact setup: (A) MAT_NULL/EOS parameters; (B) Nylon-CF/PA6-CF material properties; (C) geometry of the impact model.

Static testing and model calibration. To improve the reliability of the numerical model, a static compression test was performed on a Nylon-CF honeycomb fragment produced by additive manufacturing. The fragment was tested using a UTM-1M universal testing machine. The compression curve and the maximum recorded force of $F_{\max} = 2657$ N were used to refine the material parameters applied in LS-DYNA. This static-to-dynamic calibration links the computational model to the measured behavior of the printed material (Mazanishvili et al., 2024).

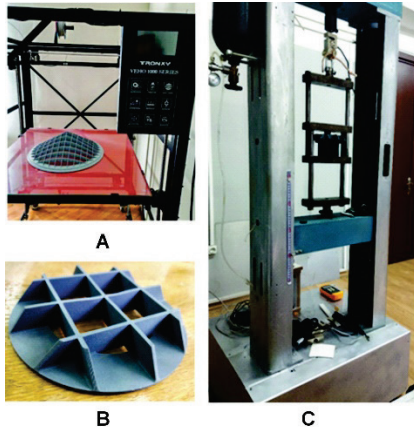


Fig. 3. Honeycomb structure with 40x40mm cells for a helicopter engine, manufactured using a TRONXY VEHO 1000 3D printer (A); test fragment (B); and static testing on a UTM-1M machine (C).

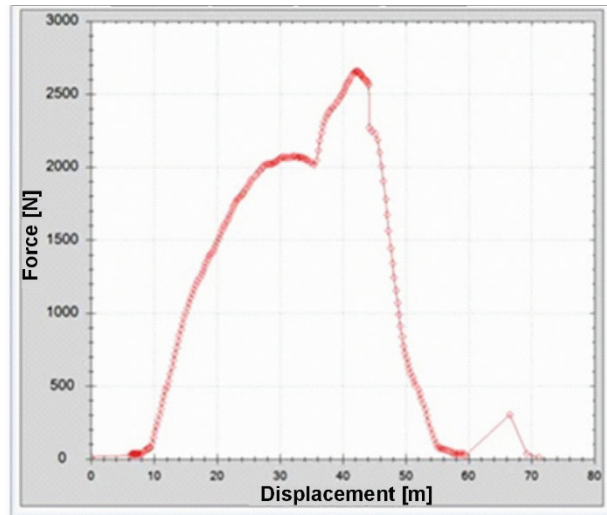


Fig. 4. Compression response of the Nylon-CF/PA6-CF honeycomb fragment; recorded maximum force $F_{\max} = 2657$ N.

Ballistic test rig and projectile selection. Ballistic experiments were carried on a test rig designed at the Scientific Center of the Georgian Aviation University. The rig accelerates the projectile to approximately 250 km/h. Impact force was recorded using a DAQ system with Z-type force sensors, optical-pair velocity measurement, and high-speed video. Negative regions in the force-time response are interpreted as structural resonance and inertial rebound of the test system.

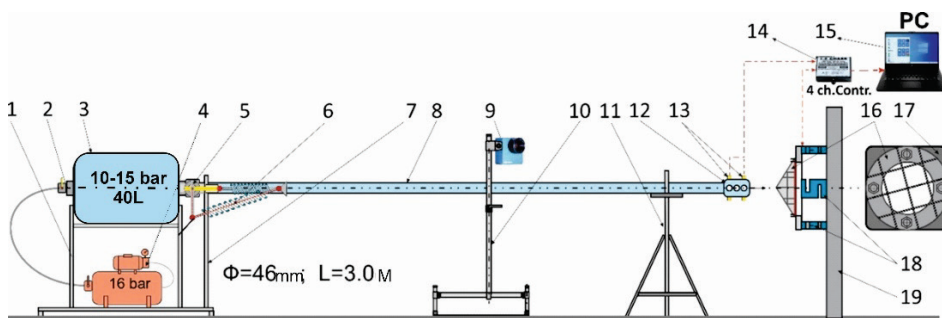


Fig. 5. General layout of the ballistic test rig used to accelerate the projectile up to 250 km/h and impact the honeycomb fragment.

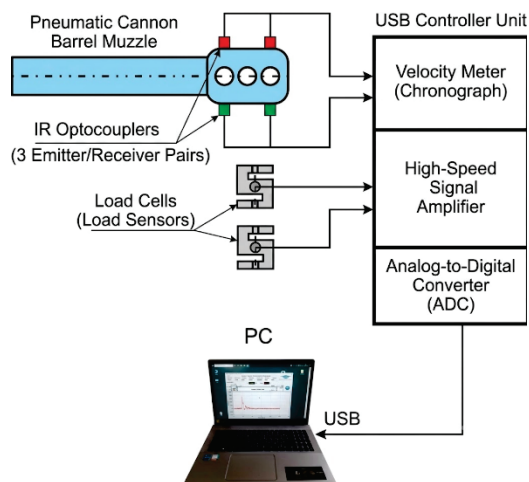


Fig. 6. Schematic diagram of the DAQ system used to record ballistic-test parameters.

Projectile selection was a key methodological issue. Potato, chicken fillet, bone-in meat, and ballistic gelatin were useful for preliminary screening, launcher calibration, and comparative assessment, but none fully represented the impact behavior of a feathered bird. Final validation therefore used commercially obtained, food-grade, non-living feathered wild quail specimens with masses of 98-99 g. No live animals were used in the experiments. This mass closely matched the 100 g soft-body projectile used in the numerical model.

Table 1. Projectile screening and final biological validation object

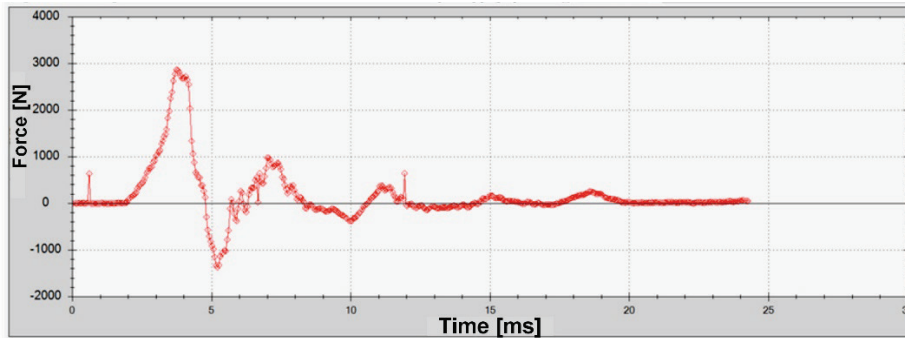
Projectile	Purpose	Limitation	Role in final validation
Potato	Initial launcher calibration and velocity repeatability	Does not reproduce feathered biological structure	Screening only
Chicken fillet	Assessment of soft-tissue-like response	No feathers, bones, or natural heterogeneity	Screening only
Bone-in meat	Screening of heterogeneous biological material	Geometry and mass are difficult to repeat	Screening only
Ballistic gelatin	Standardized soft-body comparison	No feathers or skeletal/internal cavity effects	Comparative stage
Feathered wild quail, 98-99 g	Final validation close to real bird impact	Natural biological variability	Main validation object

It is worth noting that during the trials utilizing the test stand, potatoes were launched three times with a 5% experimental error. Subsequently, chicken fillets and bone-in meat were launched twice each, exhibiting error margins of 8% and 15%, respectively. Finally, four launches were conducted using ballistic gelatin, resulting in an error of 6%.

Results

Two configurations were evaluated: a Nylon-CF honeycomb barrier alone and a combined system consisting of the honeycomb fragment with a Dyneema high-strength mesh placed behind it (DSM Dyneema, 2023; Thomas et al., 2021). Impact of a 99 g quail specimen at 250 km/h showed that the honeycomb structure promoted rapid fragmentation. After impact, approximately 15 g of residue remained on the honeycomb fragment, while only about 2 g remained on the mesh surface.

The integral indicators of the force-time response showed that the honeycomb + Dyneema mesh configuration improved impact-load attenuation and damping by approximately 25% compared with the honeycomb barrier alone. Based on peak-force values, the deviation between LS-DYNA simulation and experiment remained within 5-8%, which can be considered satisfactory agreement for the tested velocity, mass, and geometry.



A



B



C



D

Fig. 7. Result of a 99 g feathered quail impact at 250 km/h on the combined barrier system: A – force-time graph; B – residue on the honeycomb fragment; C – mass of residue remaining on the honeycomb; D – small residue remaining on the Dyneema mesh.

Table 2. Summary of ballistic-validation parameters and observations

Parameter	Value / observation
Numerical projectile mass	100 g
Final biological specimen masses	98g for honeycomb only; 99g for honeycomb + dyneema mesh combination
Impact velocity	70 m/s, equivalent to 250 km/h
Honeycomb cell	40 x 40 mm, helicopter-scale ballistic configuration
Static compression test	Fmax = 2657 N
Combined protection	Nylon-CF honeycomb + Dyneema high-strength mesh
Residual mass on honeycomb / mesh	Approximately 15 g / 2 g
Simulation-experiment peak-force deviation	5-8%
Advantage of honeycomb + mesh	Approximately 25% higher integral impact damping indicator

Discussion

The results indicate that the 40 x 40 mm honeycomb fragment is an adequate ballistic-validation configuration for a helicopter-scale protective system. It does not repeat the 30 x 30 mm aerodynamic configuration selected for a smaller ducted engine; instead, it complements that configuration by addressing the larger-diameter impact-validation problem.

The expression “internal explosion effect” is used here only as a descriptive term for rapid pressure-wave-induced internal fragmentation. Physically, the process is not a chemical explosion; it is fast deformation of a soft biological body, pressure-wave propagation, and tissue breakup into small fragments. The close match between the final biological specimens (98-99 g) and the 100 g numerical model reduces mass mismatch and makes comparison between simulation and experiment more direct.

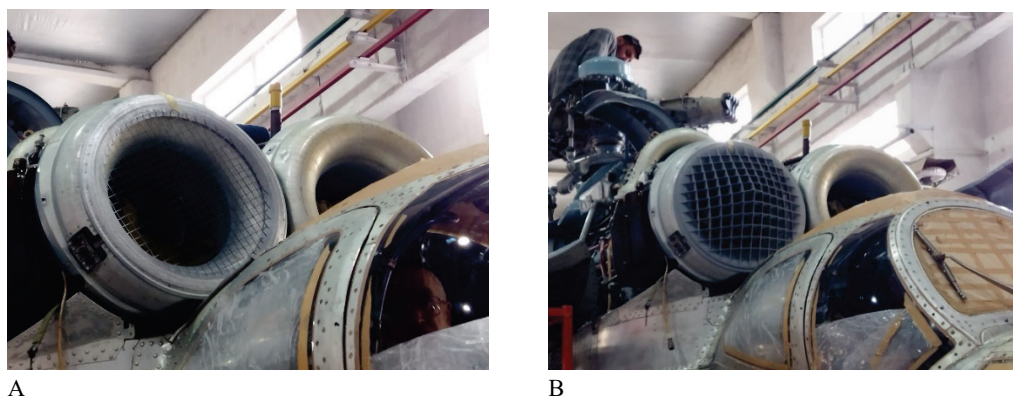


Fig. 8. Integration example of the combined barrier protection concept on a Mi-24 helicopter-engine inlet: (A) Dyneema mesh system; (B) installation of the honeycomb + mesh solution.

Limitations and future work. The work represents a ballistic-validation stage and should not be interpreted as a complete aviation certification test. The results apply to the tested configuration: a Nylon-CF honeycomb fragment with 40 x 40 mm cells, a Dyneema mesh combination, an approximately 100 g biological projectile, and an impact velocity of 250 km/h. Future work should increase the number of repeated shots, test different bird masses and velocities, evaluate temperature and humidity effects, and perform flight and durability tests on actual aircraft platforms.

Conclusions

The 40 x 40 mm honeycomb fragment selected for the helicopter-engine scale was confirmed as an adequate ballistic-validation configuration and does not contradict the 30 x 30 mm aerodynamic configuration used for a smaller ducted engine. The LS-DYNA model calibrated by static testing reproduced the 250 km/h impact of a 100 g soft body with satisfactory agreement; the peak-force deviation relative to the experiment remained within 5-8%. The combined honeycomb and Dyneema mesh system improved impact-load attenuation and damping by approximately 25% compared with the honeycomb barrier alone. Employing 98-99 g feathered quail specimens significantly increased validation realism because their mass closely matched the 100 g numerical model. The prototypes can be considered ready for further laboratory, flight, and technological evaluation; additional repeatability, durability, and certification-oriented tests are required before any serial-production claim.

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საავიაციო ტრანსპორტი

საფრენი აპარატების ძრავების ფიჭა-ბადისებრი ბარიერული დაცვის ბალისტიკური ვალიდაცია

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(წარმოდგენილია აკადემიის წევრის ელგუჯა მემშარიაშვილის მიერ)

ნაშრომში წარმოდგენილია საფრენი აპარატების ძრავების ფრინველებთან შეჯახებისგან დაცვისათვის განკუთვნილი ფიჭა-ბადისებრი ბარიერული სისტემის კომპიუტერული მოდელირება და ბალისტიკური ვალიდაცია. კვლევა ფოკუსირებულია ვერტმფრენის ძრავის შემსვლელი ჰაერსატარისთვის განკუთვნილ 40×40 მმ უჯრიან ფიჭურ კონსტრუქციაზე. Ansys LS-DYNA გარემოში მოდელირებულია 100 გ მასის რბილი სხეულის 70 მ/წმ (250 კმ/სთ) სიჩქარით შეჯახება MAT_NULL და EOS_GRUNEISEN მოდელების გამოყენებით. მოდელის კალიბრაციისათვის ჩატარდა Nylon-CF ფიჭური ფრაგმენტის სტატიკური გამოცდა, სადაც დაფიქსირდა $F_{max} = 2657$ ნ. საბოლოო ბალისტიკური ვალიდაცია შესრულდა 98-99 გ მასის, კომერციულად შეძენილი, უკვე არაცოცხალი ბუმბულიანი ველური მწყრის ნიმუშებით. შედეგებმა აჩვენა, რომ ფიჭური კონსტრუქციისა და Dyneema-ს მაღალი სიმტკიცის ბადის კომბინაცია ამცირებს დარტყმითი იმპულსის კონცენტრაციას და დაახლოებით 25%-ით აუმჯობესებს დარტყმითი დატვირთვის დემოფირებას მხოლოდ ფიჭურ ბარიერთან შედარებით. სიმულაციური და ექსპერიმენტული პიკური ძალების სხვაობა 5-8%-ის ფარგლებში დარჩა.

REFERENCES

- ANSYS, Inc. (2023). LS-DYNA keyword user's manual: Volume II, Material models.
- DSM Dyneema. (2023). Dyneema high-strength, high-modulus polyethylene fiber [Technical data sheet].
- Hedayati, R., & Sadighi, M. (2015). Bird strike: An experimental, theoretical, and numerical investigation. Woodhead Publishing.
- Khachidze, R., Maisuradze, A. (2023). Statistical analysis of damage caused by bird ingestion into aircraft engines during bird-aircraft collisions. *Air Transport*, 1(17).
- Maisuradze, A., Mebonia, S., & Chelidze, M. (2020). Method for calculating the protective grid of the turbojet engine module. *Problems of Mechanics*, 3(80), 23–28.
- Mazanishvili, B., Khachidze, R., Bliadze, N., & Gventsadze, D. (2024). Research on materials of a protective mesh and honeycomb cone against bird strikes on drone engines. *Air Transport*. Georgian Aviation University.
- Thomas, F. D. (2021). Experimental investigation of the influence of dynamic multiaxial transverse loading on ultrahigh molecular weight polyethylene single fiber failure. *Composites Part A: Applied Science and Manufacturing*, 142.
- Wilbeck, J. S. (1978). Impact behavior of low strength projectiles. Air Force Materials Laboratory, Wright-Patterson Air Force Base.

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