

¹Augustina PRUTEANU, ¹Dorin Andrei CÎRSTEA, ¹Dorin Robert CRISTEA, ¹Alexandru IONESCU

AERODYNAMIC EFFICIENCY OF BIO-INSPIRED AERIAL PLATFORMS FOR BIRD DETERRENCE

¹ INMA Bucharest / ROMANIA

Abstract: Bioinspired aerial platforms are an emerging alternative to conventional bird deterrent systems, by integrating aerodynamic performance, morphological realism and advanced adaptive control strategies. This paper synthesizes the recent literature on avian flight biomechanics, collective escape dynamics, wing and tail morphing technologies, as well as intelligent control systems applicable to unmanned aerial vehicles. Empirical studies on predator-prey interaction, including experiments with RobotFalcon, highlight that realistically morphological platforms induce faster collective reactions, longer flight initiation distances, and a reduced level of habituation compared to conventional drones. Aerodynamic analyses demonstrate the essential role of wing tip adjustment, wing-tail coordination, and relative positioning of center of gravity and aerodynamic center in optimizing lift and handling. Agent-based models show that collective escape patterns emerge from simple local rules and can be strategically influenced by optimizing the trajectories of the artificial predator. In parallel, advances in physics-informed reinforcement learning and multimodal deterrence systems open up prospects for autonomous platforms capable of maintaining high efficiency and reducing habituation. By integrating biological, behavioral, and engineering perspectives, this review proposes a unified conceptual framework for the design of aerodynamically optimized bioinspired aerial platforms in bird deterrent applications.

Keywords: bioinspired drones, morphing, collective dynamics, artificial predator, adaptive control, bird deterrent

INTRODUCTION

The interaction between birds and anthropogenic activities generates significant problems in agriculture, airport infrastructure and urban spaces. Conventional methods of deterrence, acoustic, visual or laser, often have limited long-term effectiveness due to the phenomenon of habituation. In this context, bioinspired aerial platforms, capable of mimicking the morphology and behavior of natural predators, represent a promising direction (Durodola et al., 2025).

Experimental studies conducted by Storms R.F. et al., 2022, using RobotFalcon, demonstrated that an artificial predator with realistic morphology produces significantly more intense collective reactions than conventional drones, similar to those generated by real predators. The results highlighted not only the increase in flight initiation distance, but also persistent flock movements, suggesting a high potential for practical applications.

Recent literature indicates that the collective response of flocks is driven by complex emerging mechanisms. Models developed by Papadopoulou et al., 2022, 2023, 2025 and Hemelrijk et al., 2015, show that escape patterns, collective splits and waves of agitation arise from simple local rules of interaction, but are highly sensitive to the trajectory and speed of the predator. Similarly, Sankey et al., 2021 demonstrated the absence of "selfish herd" dynamics, suggesting that the

reorganization of the herd under threat follows different principles than classical hypotheses. These findings imply that optimizing the trajectory of the aerial platform is as important as its morphology.

From an aerodynamic perspective, birds perform better than conventional unmanned aerial vehicles (UAVs), especially in terms of lift-to-drag ratio (Harvey C. et al., 2021).

Fundamental studies on wing morphing (Lentink D. et al., 2007; Cheney et al., 2021) and on the contribution of the tail to the reduction of induced drag (Usherwood J.R. et al., 2020) highlights the ability of birds to finely adapt the geometry of the bearing surfaces according to the flight regime. More recently, Harvey C. et al. 2022, demonstrated that birds can transit in a controlled manner between stable and unstable states through morphological changes, enhancing maneuverability in dynamic situations. Implementation of these mechanisms in bioinspired UAVs (Bishay P.L. et al., 2024; Phan H.V., 2024; Liu G. et al., 2025) opens up prospects for increasing agility and cinematic realism.

In parallel, the development of intelligent control systems, including Linear Quadratic Regulator optimization (Al-Mahturi & Wahid, 2017) and physics-informed reinforcement learning (Vytila E. et al., 2025), allows the adaptation of trajectories in real time, reducing predictability and implicitly the risk of habituation. The integration of these

technologies with extensive morphological data (Weeks B.C. et al., 2025) creates the opportunity for a biologically grounded parametric design.

Thus, the effectiveness of bioinspired aerial platforms to deter birds must be analyzed at the intersection of three major areas:

- biomechanics and aerodynamics of avian flight;
- the collective dynamics and escape mechanisms of the flocks;
- engineering transposition and intelligent control of bioinspired platforms.

This review aims to synthesize these directions in an integrative framework, assessing to what extent aerodynamic performance and behavioral realism contribute to the efficiency of deterrence systems. Fundamental studies on wing and tail morphing, models of collective behavior under predatory pressure, recently developed bioinspired robotic platforms, and modern adaptive control approaches are analyzed. The objective is to formulate a unified conceptual framework to guide the design of future aerial platforms with optimized energy efficiency and maximum behavioral impact.

METHODOLOGY

Figure 1 proposes a systemic model in which the interaction between collective flock dynamics, morphological biomimetics and aerodynamic optimization constitutes a closed functional circuit. The integrative approach suggests that the effectiveness of the deterrence does not depend exclusively on the visual realism of the platform, but on the fine correlation between aerodynamic parameters (CL/CD, stability, moment control) and interception trajectories that maximize the disruption of the collective structure of the flock.



Figure 1. Conceptual diagram on the integration of collective avian behavior, bioinspired design and aerodynamic optimization in the development of aerial platforms to deter birds.

Figure 1 illustrates the integrative conceptual framework of the paper, highlighting the interdependence between the behavioral dynamics of flocks, the principles of bioinspired design and the optimization of aerodynamic performance in

the development of aerial platforms intended to deter birds.

At the top of the diagram is represented the collective behavior of the birds, including flocking dynamics and escape patterns. These components reflect the mechanisms by which birds react to the presence of an aerial predator, generating rapid reorganizations of spatial structure and changes in velocity vectors. This behavioral level underpins the development of Bio-Inspired Drones, represented by a fixed wing platform with falcon morphology. The choice of raptor-inspired morphology aims to maximize visual and cinematic realism, which is essential for triggering an authentic avoidance response.

In the lower area of the diagram is presented the engineering component, structured in two major directions: aerodynamic studies (wind tunnel tests and flight experiments) and efficiency optimization (wing morphing and tail adjustments). They converge towards the central objective of the work: to increase aerodynamic efficiency by improving the lift-to-drag ratio, longitudinal stability and maneuverability in variable flight regimes.

Also in the lower part is illustrated the practical application, the use of bioinspired platforms in airports and farms, where aerodynamic performance and behavioral realism contribute to the long-term effectiveness of deterrence systems. Circular arrows between components indicate the iterative nature of the design process: behavioral data informs aerodynamic design, and engineering tests optimize platform performance, in turn generating improvements in operational efficiency.

FUNCTIONAL AND AERODYNAMIC MORPHOLOGY OF THE WINGS

Studies by Cheney J.A. et al., 2021 on three species of raptors (*Tyto alba*, *Strix aluco*, *Accipiter gentilis*) demonstrated that birds actively modify their wing geometry according to their flight speed. High-resolution 3D reconstructions have shown that shoulder actuation is the key component in controlling the angle of attack and wing twist along the wingspan. As the speed increases, the birds reduce the curvature of the wing and adopt an anhedral configuration (wings lowered below the shoulder), which minimizes drag when advancing.

A similar result was reported by Lentink D. et al., 2007 for the Common Lizard (*Apus apus*). The study demonstrated that the choice of sweep angle can halve the descent speed or triple the rate of turn. The extended wings are superior for gliding and slow turning, while the boy's wings are optimal for high speeds. This discovery confirms that morphing is not just a facility, but a functional necessity for efficient flight.

Klaassen van Oorschot et al., 2016 extended this analysis to 13 species of raptors, comparing the performance of extended vs. balanced wings during takeoff and gliding. Contrary to initial assumptions, during the battery, the extended wings generated a CV:CH ratio (lift coefficient/horizontal force coefficient) 31% higher than the balanced wings. In contrast, during gliding, the balanced wings showed an 11% higher CV, suggesting the existence of different local flow regimes.

Although often neglected in traditional aeronautical design, the tail plays an essential role in stability and efficiency during avian flight. Usherwood J.R. et al., 2020 demonstrated, through soap bubble videogrammetry techniques, that owls and hawks use the tail to generate high lift, contrary to the classic aircraft model where the tail produces negative lift for static stability. This strategy reduces the viscous strength of the profile, a critical factor for flyers with lower Reynolds numbers.

Phan H.V. et al., 2024 investigated the mechanism of tail twisting in birds of prey during steep turns. Using a biologically inspired feathered drone, the authors found that approaching the tail of the wings causes asymmetrical flows, generating enough roll and gyration moments to coordinate precise turns without visible wing movements. Moreover, the twisting of the tail induces a pitch moment with the nose upwards, increasing the angle of attack of the wings and compensating for the loss of lift during turning.

Table 1. Wing and tail morphing capabilities in bioinspired non-flapping UAV designs (Bishay, P.L. et al., 2024; Grant D. et al, 2006)

Design	Bird	Wing Morphing	Tail Morphing
Variable gull-wing aircraft or "WhoopingMAV"	Seagull	Wing craning deflection (inboard and outboard dihedral morphing)	Traditional
Grant et al. [22]	Seagull	Independent inboard and outboard wing sweep	Traditional
"MataGull"	Seagull	Feather folding and dihedral morphing	Pitch, tilt, and feather folding
"Lishawk"	Northern Goshawk	Feather folding	Pitch, yaw, and feather folding
"LisEagle"	Eagle	Wing pitch and feather folding	Pitch, yaw, and feather folding
"PigeonBot"	Pigeon	Feather folding	Traditional elevator and rudder
Bionic albatross aircraft	Albatross	Wingtip sweep	Synchronous extension and retraction

Focusing on non-flapping designs, UAVs were designed based on different species, as shown in Table 1.

A fundamental contribution to the understanding of avian flight belongs to Harvey C. et al., 2022. By analyzing the inertial characteristics of 22 species of birds, the authors demonstrated that wing modification allows the transition between stable and unstable flight states. At the same time, the study shows that both stability and instability are selected evolutionarily, depending on the ecological context. This discovery has major implications for the design of agile drones.

The study by Chae S. et al., 2025, on the species *Pica serica* shows that the posterior movement of the wingtip increases the lift coefficient at low speeds, improving maneuverability in slow flight.

At the biomechanical level, wing-tail coordination plays a crucial role. Liu G. et al., 2025 demonstrated that the collaborative adjustment of wing-to-tail distance and tail attitude in a flapping wing robot allows the manipulation of the relative position of the center of gravity and the aerodynamic center, increasing agility and allowing the realization of 13 Dynamic Flying Primitives (DFPs). The review by Hammad & Armanini, 2024, highlights the current limitations of FWMVs in takeoff and landing, highlighting the need for integrated dynamic control mechanisms for practical applications.

BIO-INSPIRED AERIAL PLATFORMS: FROM CONCEPT TO REALITY

The most extensive and rigorous validation of a bioinspired platform for deterrence birds is presented in the papers (Storms R.F. et al., 2022; Storms R.F. et al., 2024; Hemelrijk, C. K., 2015). The RobotFalcon, figure 2, modeled after the peregrine falcon, was tested against flocks of corvids, gulls, starlings and sandpipers in natural environments. The results were remarkable:

- The RobotFalcon significantly exceeded the performance of a conventional DJI drone and conventional methods (emergency calls, pyrotechnics);
- The treated fields remained free of birds for hours after a single exposure;
- No signs of habituation were observed during three months of testing.

Comparative analysis of collective escape patterns Storms R.F. et al., 2024, showed that flocks of starlings react to the RobotFalcon as frequently as they do to a real peregrine falcon, confirming the predator's perception as authentic. The altitude of attack influences the distance of initiation of the flight, but not the frequency of the collective escape.

Vertua I. et al., 2024, extended these tests to wild pigeons and black-headed gulls, demonstrating that the RobotFalcon induces massive and persistent movements. In seagulls, the number of individuals returned after exposure decreased by 94% during

the tests, and night flight activity decreased by 40% in the following days.

Bishay P.L. et al., 2024, presented CGull, figure 3, a composite drone inspired by the large black-backed gull, which does not flap its wings but uses a coupled transformation mechanism with two degrees of freedom to reproduce wing deformation. The computational model developed in MachUpX confirmed that the transformation of the wing and tail generates the forces and moments necessary for complete trajectory control. The successful flight test of the prototype demonstrates the viability of the concept.

A different approach is taken by Muda N.R.S. et al., 2024 and Muda N.R.S. et al. 2025, who developed an eagle-like drone with flapping wings. With a wingspan of 2 meters and a payload of 1 kg, the drone produces a noise of only 10 dB, making it almost inaudible. This feature is essential for camouflage and reducing the acoustic impact on wildlife. Although initially geared towards military applications, the platform can be adapted to deter birds.



Figure 2. The RobotFalcon (Storms R.F.et al., 2022)

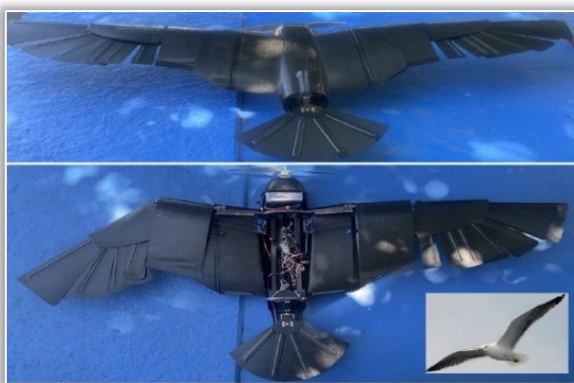


Figure 3. CGull Prototype (Bishay, P.L. et al., 2024)

RESULTS

Usherwood J.R. et al., 2020, carried out a detailed aerodynamic characterization of three species of raptor with different hunting strategies: barn owl (*Tyto alba*), red owl (*Strix aluco*) and pigeon hawk (*Accipiter gentilis*). Table 2 summarizes the main morphological and aerodynamic parameters measured for these species.

Table 2. Mean (\pm s.d.) morphology, flight and aerodynamic parameters for the three study individuals, each for three flights (Usherwood J.R. et al., 2020)

Aerodynamic parameters	Barn owl (female)	Tawny owl (male)	Goshawk (female)
Mass (kg)	0.319	0.347	0.985
Span (m)	0.860 \pm 0.002	0.819 \pm 0.002	1,066 \pm 0,027
Aspect ratio	5.43 \pm 0.11	4.37 \pm 0.03	4.26 \pm 0.04
Span loading (N m ⁻¹)	3.64 \pm 0.01	4.16 \pm 0.01	9.07 \pm 0.22
Wing loading (N m ⁻²)	22.95 \pm 0.37	22.22 \pm 0.26	36.24 \pm 1.42
Velocity (m s ⁻¹)	7.44 \pm 0.07	5.90 \pm 0.11	7.74 \pm 0.46
Reynolds number	75,686 \pm 959	70,954 \pm 1,762	124,339 \pm 5,625
CL	0.69 \pm 0.01	1.06 \pm 0.05	1.01 \pm 0.08
Proportion of weight support calculated from PTV	1.04 \pm 0.14	1.10 \pm 0.08	1.06 \pm 0.04

Comparative analysis reveals significant differences: the pigeon hawk, with its weight about three times greater (0.985 kg), operates at a double Reynolds number (124,000) compared to owls (\approx 73,000), indicating a distinct aerodynamic regime. The red owl stands out for its highest lift coefficient ($C_L = 1.06$) and lowest flight speed (5.9 m/s), suggesting adaptations to slow and maneuverable flight. The barn owl has the highest aspect ratio (5.43), associated with efficient glider flight.

These data have direct implications for the design of bioinspired platforms: the barn owl offers a model for extended autonomy, the red owl for maneuverability, and the hawk for large platforms capable of deterring large birds. The diversity of aerodynamic solutions observed in nature underlines the need for a tailor-made approach to specific operational requirements.

Correlation between aerodynamic performance and operational success

A central aspect of this review is the identification of the relationship between the aerodynamic parameters of bioinspired platforms and their effectiveness in effectively deterring birds. Although the literature does not yet provide studies that directly correlate in vivo parameters such as the lift-to-resistance (L/D) ratio with the deterrence rate, the comparative analysis of the existing works allows the extraction of functional relationships between aerodynamic characteristics and operational performance. Table 3 summarizes these relationships, highlighting for each aerodynamic parameter the effect on the platform, the operational consequence for the deterrence missions and the bibliographic sources that support these correlations.

Table 3. Functional relationships between aerodynamic parameters and operational performance of bioinspired platforms for bird deterrent

Aerodynamic parameter	Effect on the platform	Operational consequence	Bibliography
High Load-to-Strength (L/D) Ratio	Extended range, longer range	Long patrol, covering large agricultural areas	[Bishay et al. 2024, Muda et al. 2024, Harvey & Inman 2021]
Manoeuvrability (angular speed)	Quick attacks, sudden changes of direction	Truthful imitation of the behavior of the natural predator, prevention of habituation	[Storms et al. 2022, Storms et al. 2024, Storms et al. 2022 (bioRxiv), Vertua et al. 2024, Phan & Floreano 2024, Liu et al. 2025]
Low-speed lift	Short-haul take-off and landing	Operation in rough terrain, in close proximity to crops	[Klaassen van Oorschot et al. 2016, Lentink et al. 2007, Chae et al. 2025]
Low noise (<10 dB)	Acoustic camouflage	Surprise of flocks, increased efficiency of the first attack	[Muda et al. 2024, Tanaka et al. 2022]
Asymmetric morphing	Coordinated turns without conventional ailerons	Natural-looking flight, radar signal reduction, enhanced authenticity	[Bishay et al. 2024, Harvey et al. 2022, Phan & Floreano 2024, Liu et al. 2025]
Tail twist	Precise directional control	Execution of complex maneuvers specific to real predators	[Phan & Floreano 2024, Usherwood et al. 2020]
COG (Center of Gravity) ↔ CA dinamic (Center of Aerodynamic pressure)	Longitudinal adaptability in flight	Smooth transitions between different flight regimes (gliding, attacking, escape)	[Harvey et al. 2022, Liu et al. 2025]
Wing twist	Lift optimization according to flight speed	Aerodynamic efficiency in different phases of the mission	[Cheney et al. 2021, Klaassen van Oorschot et al. 2016, Lentink et al. 2007]

Based on the analysis in Table 3, we can formulate some recommendations for the design of bioinspired platforms intended to deter birds:

- Prioritizing maneuverability - angular velocity and the ability to execute quick attacks from different directions (especially from above) are essential for threat authenticity and habituation prevention.
- Optimization of the L/D ratio - for missions that require long patrols over large areas,

aerodynamic efficiency must be maximized, possibly by adopting morphing configurations that allow adaptation to different flight regimes.

- Minimizing noise - taking into account both operational efficiency (flock capture) and the impact on biodiversity, the design must aim for noise levels as low as possible.
- Integration of multiple morphing mechanisms - the combination of wing twist, tail twist and dynamic adjustment COG-CA can provide a wide range of maneuvers, enhancing the authenticity and adaptability of the platform.
- Real-world operational testing - without field validation, even the most sophisticated aerodynamic characteristics remain mere demonstrations of technical feasibility.

■ Correlation of attack-escape dynamics with aerodynamic efficiency of bioinspired platforms

The analysis of behavioral transitions between falcon attacks and types of collective escape in the work Storms R. F. et al., 2019, highlights the fact that the pattern of the flock's reaction is directly determined by the kinematic parameters of the predator: speed, direction of approach and ability to change trajectory quickly. These variables are, in turn, dependent on the aerodynamic efficiency of the aerial platform.

The results indicate that lightning expansion is associated with fast, descending attacks with high kinetic energy. In order for a bioinspired UAV to reproduce this type of collective reaction, it is necessary: a lift-to-resistance ratio (L/D) high enough to allow efficient acceleration, the ability to maintain energy in controlled dive mode, reduced induced resistance in the transition phases. An optimized L/D allows the platform to reach high speeds without excessive energy penalty, increasing the likelihood of lightning expansion, a response identified as directly dependent on the attack.

In the case of wave events and blackening of the flock, associated with medium-speed attacks and repeated interceptions, aerodynamic efficiency influences the UAV's ability to execute rapid turns and successive changes of direction. This involves: dynamic control of the COG-CA relationship for marginal stability, wing-tail coordination to reduce drag in cornering, maintaining an optimal compromise between stability and handling.

Moreover, the observed sequence of type: *Attack* → *Expansion* → *Division* → *Fusion* → *Reorganization*, shows that the aerodynamic pressure exerted on the flock must be sustained, not just initially intense. Therefore, aerodynamic efficiency becomes critical for: increased operational autonomy, repeatability of attacks, maintaining performance in transient mode.

From an application perspective, the results suggest that efficient bioinspired platforms should not only maximize stationary L/D, but optimize performance in dynamic mode, characterized by accelerations, decelerations and rapid variations of the angle of attack. Aerodynamic efficiency must thus be assessed in relation to the ability to generate attack profiles similar to raptors, capable of inducing significant collective reorganisations.

In conclusion, the correlation between the kinematic parameters of the attack and the types of collective escape confirms that aerodynamic efficiency is not only an energy advantage, but a determining factor in the behavioral efficiency of bioinspired deterrence systems.

CONCLUSIONS

This review highlights that the effectiveness of bioinspired aerial platforms for deterring birds results from the integration of aerodynamic optimization with behavioral realism and adaptive control. The literature reviewed demonstrates that the mere use of an unmanned aerial vehicle does not guarantee long-term efficiency; Performance is conditioned by how the platform reproduces both the aerodynamic mechanisms of natural predators and their dynamic attack patterns.

From an aerodynamic perspective, the lift-to-drag ratio (L/D) is a central indicator of energy efficiency and operational range. Studies on wing morphing and wing-tail coordination show that birds continuously optimize pressure distribution and reduce induced drag depending on speed and flight regime. The transposition of these mechanisms into bioinspired UAVs allows to increase autonomy, improve maneuverability and maintain performance in transient regimes. In particular, the dynamic adjustment of the relationship between the center of gravity (COG) and the aerodynamic center (CA) offers the possibility of a controlled transition between stability and instability, enhancing agility and cinematic realism.

At the same time, research on the collective behavior of flocks indicates that the response to predators is determined by parameters such as the angle of interception, the relative speed and the position of the attack in relation to the group structure. Predator-type robotic platforms have demonstrated the ability to induce rapid dispersals and persistent movements, confirming the importance of biomimetic trajectories. Thus, the effectiveness of the deterrence is not only a matter of aerodynamic performance, but also of optimizing the dynamic interaction between the platform and the collective structure of the flock.

Another essential aspect is to reduce the phenomenon of habituation. Static or predictable systems lose their efficiency over time, while platforms capable of morphological and trajectory

variations, supported by adaptive algorithms, can maintain a high level of behavioral uncertainty. The integration of advanced control technologies, including methods based on optimization and machine learning, opens up prospects for the development of autonomous systems capable of adjusting the interception strategy in real time.

Overall, the synthesized results suggest that the optimal performance of bioinspired aerial platforms is achieved at the intersection of avian biomechanics, engineering aerodynamics and behavioral modeling. Future research directions should aim at developing integrated frameworks that correlate aerodynamic indicators (such as L/D and longitudinal stability) with behavioral metrics of dispersion efficiency. Such a multidisciplinary approach can lead to the design of sustainable, energy-efficient systems capable of providing long-term solutions for the management of human-wildlife conflicts.

Acknowledgement:

The paper has been funded by the Program NUCLEU 2023-2026, PN 23 04 01 06 "Intelligent mixed system for protection of agricultural crops against pests according to the Agriculture Concept 4.0", Contract no. 9N/01.01.2023.

Bibliography:

- [1] Cheney J.A., Stevenson J.P.J., Durston N.E., Maeda M., Song, J., Megson-Smith D.A., Windsor S.P., Usherwood J.R., Bomphrey R.J. 2021 Raptor wing morphing with flight speed. *J. R. Soc. Interface* 18: 20210349.
- [2] Storms R.F., Carere C., Musters R., van Gasteren H., Verhulst S., Hemelrijk C.K. 2022 Deterrence of birds with an artificial predator, the RobotFalcon. *J. R. Soc. Interface* 19: 20220497
- [3] Storms R.F., Carere C., Musters R., Hulst R., Verhulst S., Hemelrijk C.K. 2024. A robotic falcon induces similar collective escape responses in different bird species. *J. R. Soc. Interface* 21: 20230737.
- [4] Papadopoulou M., Hildenbrandt H., Sankey DWE, Portugal SJ, Hemelrijk C.K. 2022 Emergence of splits and collective turns in pigeon flocks under predation. *R. Soc. Open Sci.* 9: 211898.
- [5] Papadopoulou M., Hildenbrandt H., Hemelrijk C.K., A Data-Inspired Framework to Simulate Collective Behaviour of Predator-Prey Systems, 2025, vol. 33(5-6) 291–305.
- [6] Al-Mahturi A., Wahid H., Optimal Tuning of Linear Quadratic Regulator Controller Using a Particle Swarm Optimization for Two-Rotor Aerodynamical System, *World Academy of Science, Engineering and Technology International Journal of Electronics and Communication Engineering*, Vol:11, No:2, 2017
- [7] Bishay, P.L.; Rini, A.; Brambila, M.; Niednagel, P.; Eghdamzamiri, J.; Yousefi, H.; Herrera, J.; Saad, Y.; Bertuch, E.; Black, C.; et al. CGull: A Non-Flapping Bioinspired Composite Morphing Drone. *Biomimetics* 2024, 9, 527.
- [8] Muda N. R. S., Fananadila B., Fadilah M.F., Design and Manufacture of Eagle Robot Drone for Reconnaissance, *International Journal of Research Publication and Reviews*, Vol 5, no 2, pp 2006-2014 February 2024,
- [9] Muda N.R.S., 2025, Prototype of shepat drone based on bomb fixedwing, *International Journal of Social Science (IJSS)*, Vol.4 Issue.6 April 2025, pp: 761-770; ISSN: 2798-3463 (Printed) | 2798-4079 (Online); TWO:.
- [10] Klaassen van Oorschot B, Mistick EA, Tobalske BW. Aerodynamic consequences of wing morphing during emulated take-off and gliding in birds. *J Exp Biol.* 2016 Oct 1; 219(Pt 19):3146-3154. doi:10.1242/jeb.136721. Epub 2016 Jul 29. PMID: 27473437.

- [11] Durodola F.O., Eludiora S.I., Owoeye S.O., Omotainse P.O., Oduntan O.O., Alake B.B., Automated bird scaring system: a review, *J. Nat. Sci. Engr. & Tech.* 2025, 24: 99-111.
- [12] Papadopoulou M., Hildenbrandt H., Storms R.F., Carere C., Verhulst S., Hemelrijk C. K., 2024, Mechanisms driving collective escape patterns in starling flocks, *bioRxiv*, pp.2024-10,
- [13] Hemelrijk C. K., Van Zuidam L., Hildenbrandt H., What underlies waves of agitation in starling flocks, *Behav Ecol Sociobiol* (2015) 69:755–764,
- [14] Bartashevich, P., Herbert-Read, J.E., Hansen, M.J. et al. Collective anti-predator escape manoeuvres through optimal attack and avoidance strategies. *Commun Biol* 7, 1586 (2024).
- [15] Harvey C., Gamble L. L., Bolander C. R., Hunsaker D. F., Joo J. J., Inman D. J., A review of avian-inspired morphing for UAV flight control, *Progress in Aerospace Sciences*, Volume 132, Elsevier Ltd, 2022,
- [16] Bomphrey R. J., Usherwood J. R., Avian-Inspired Multifunctional Morphing Air Vehicles: Underpinning Biological Research, 2022, Technical Report, Final Report, The Royal Veterinary College, 36 pages.
- [17] Storms R. F., Carere C., Musters R., van Gasteren H., Verhulst S., Hemelrijk C. K., Improved deterrence of birds using an artificial predator, the RobotFalcon, 2022, *bioRxiv* 2022.05.18.492297,
- [18] Vertua I., Menand C., Musters R. J., Jennings V., Cerritelli G., Gagliardo A., Giunchi D., Vanni L., Carere C., Rubolini D., 2024, Exposure to a raptor-like robot induces collective escape responses in two avian species and can trigger massive and persistent displacements, *Ecol Solut Evid.* 2025; 6:e70078.
- [19] Papadopoulou M., Hildenbrandt H., Hemelrijk CK (2023). Diffusion during collective turns in bird flocks under predation. *Front. Ecol. Evol.* 11:1198248.
- [20] Lentink, D., Müller, U., Stamhuis, E. et al. How swifts control their glide performance with morphing wings. *Nature* 446, 1082–1085 (2007).
- [21] Phan H.V., Floreano D., A twist of the tail in turning maneuvers of bird-inspired drones, *Science Robotics*, 2024, Vol 9, Issue 96,
- [22] Harvey, C., Baliga, V.B., Wong, J.C.M. et al. Birds can transition between stable and unstable states via wing morphing. *Nature* 603, 648–653 (2022)
- [23] Storms R. F., Carere C., Zoratto F., Hemelrijk C. K., Complex patterns of collective escape in starling flocks under predation, *Behavioral Ecology and Sociobiology* (2019) 73: 10
- [24] Warrick D. R., Bundle M. W., Dial K. P., (2002) Bird Maneuvering Flight: Blurred Bodies, Clear Heads, *Integ. And Comp. Biol.*, 42:141–148.
- [25] Harvey C., Inman D. J., (2021) Aerodynamic efficiency of gliding birds vs comparable UAVs: a review, *Bioinspiration & Biomimetics*, Volume 16, Number 3, DOI 10.1088/1748-3190/abc86a, This article is corrected by 2024 *Bioinspir. Biome.* 19, 069501, 2024
- [26] Usherwood J.R., Cheney J.A., Song J., Windsor S. P., Stevenson J. P. J., Dierksheide U., Nila A., Bomphrey R. J., High aerodynamic lift from the tail reduces drag in gliding raptors, *J Exp Biol* (2020) 223 (3): jeb214809.
- [27] Chae, S., Hwang, J., Choe, J.C. et al. Empirical evidence for the functional benefit of intra-specific wing shape variation in a sedentary bird, the Oriental Magpie (*Pica serica*). *Sci Rep* 15, 29495 (2025).
- [28] Weeks, B.C., Zhou, Z., Probst, C.M. et al. Skeletal trait measurements for thousands of bird species. *Sci Data* 12, 884 (2025).
- [29] Liu, G., Pan, E., Sun, W. et al. Agile manoeuvrable flight via collaborative wing-tail adjustment of a flapping wing robot. *Commun Eng* 4, 141 (2025).
- [30] Hammad A., Armanini S., (2024), Landing and take-off capabilities of bioinspired aerial vehicles: a review, *Bioinspir. Biome.* 19, 031001,
- [31] Sankey D.W.E., Storms R.F., Musters R.J., Russell T.W., Hemelrijk C.K., Portugal S.J., 2021, Absence of "selfish herd" dynamics in bird flocks under threat, *Current Biology* 31, 3192–3198,
- [32] Vytla E., Kalavakolanu B., Perrault A., McCrink M., Dreaming Falcon: Physics-Informed Model-Based Reinforcement Learning for Quadcopters, *arXiv:2511.18243v1 [cs.RO]* 23 Nov 2025.
- [33] Tanaka, S.; Asignación, A.; Nakata, T.; Suzuki, S.; Liu, H. Review of Biomimetic Approaches for Drones. *Drones* 2022, 6, 320.
- [34] Grant, D.; Abdulrahim, M.; Lind, R. Flight Dynamics of a Morphing Aircraft Utilizing Independent Multiple-Joint Wing Sweep. In *Proceedings of the AIAA Atmospheric Flight Mechanics Conference and Exhibit*, Keystone, CO, USA, 21–24 August 2006



ISSN: 2067–3809



copyright © University POLITEHNICA Timisoara,
Faculty of Engineering Hunedoara,
5, Revolutiei, 331128, Hunedoara, ROMANIA
<http://acta.fih.upt.ro>