

A systematic review of biomimetic principles inspired by biological flight applied to aircraft and UAV design

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INTRODUCTION & AIM

Biomimetics represents an emerging paradigm of significant importance in aerospace engineering, offering innovative design solutions grounded in the flight mechanisms of living organisms. Given that birds, insects, and bats demonstrate exceptional aerodynamic efficiency, superior maneuverability, and remarkable adaptability, they serve as biological models for the development of bio-inspired aircraft and unmanned aerial vehicles (UAVs). The central objective of this work is to synthesize and critically evaluate existing research regarding biomimetic principles derived from biological flight and their applicability to modern aeronautical architecture.

METHOD

The present research was conducted as a systematic literature review, strictly adhering to the guidelines established by the PRISMA protocol. The methodology involved querying major scientific databases to identify relevant peer-reviewed studies that establish a direct correlation between biological flight mechanisms and aerospace engineering applications. Selected works were systematically classified based on their biological source of inspiration, including avian wing morphology, insect flapping-wing aerodynamics, and the flexible membrane structures specific to chiropterans.

RESULTS & DISCUSSION

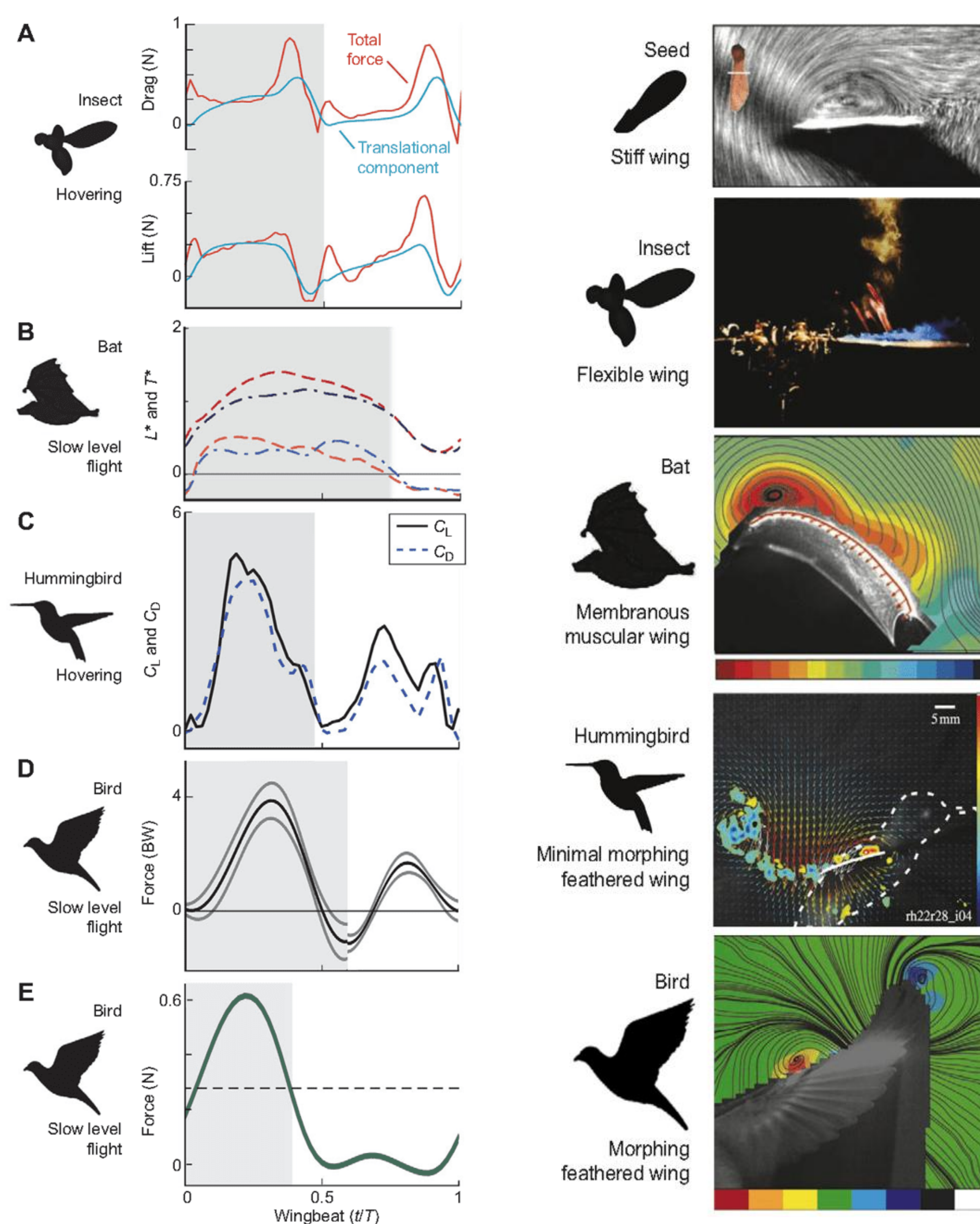


Figure 1. Comparative analysis of aerodynamic force profiles (Lift and Drag) over a single wingbeat cycle. The graphs quantify total force and lift coefficients (C_L and C_D) for various biological models, including (A) insects, (B) bats, and (C-E) birds, highlighting the high force peaks achieved through unsteady aerodynamic mechanisms. **Source:** Chin, D.D. and Lentink, D. (2016). Flapping-wing aerodynamics: from insects to vertebrates. *Journal of Experimental Biology*, 219(7), pp. 920-932.

Figure 2. Phenomenological visualization of the Leading Edge Vortex (LEV) as a convergent aerodynamic solution. The panels illustrate LEV stability across diverse morphologies, ranging from rigid insect wings to membranous wings (bats) and morphing feathered wings (birds), representing a fundamental mechanism for lift generation at low Reynolds numbers. **Source:** Chin, D.D. and Lentink, D. (2016). Flapping-wing aerodynamics: from insects to vertebrates. *Journal of Experimental Biology*, 219(7), pp. 920-932.

Research reveals that the integration of bio-inspired solutions enables performance optimization through the manipulation of the boundary layer and vortical structures. Avian-inspired configurations, such as wing-tip feathers, reduce induced drag by dissipating marginal vortices, while aeroelastic membranes inspired by chiropterans (bats) facilitate adaptive pressure distribution, optimizing the lift-to-drag ratio (L/D). For micro-UAVs, the utilization of unsteady lift mechanisms, such as delayed stall, allows for the achievement of lift coefficients (C_L) superior to steady-state regimes at low Reynolds numbers ($Re < 10^5$). The discussion highlights critical barriers regarding scalability and material anisotropy. The replication of biological kinematics is limited by the rigidity of synthetic composites and the complexity of the actuation systems required to manage aeroelastic coupling. Furthermore, the laws of similarity constrain the transfer of these advantages to high Reynolds numbers typical of commercial aviation. Thus, the current challenge lies in developing morphing structures that reconcile biological functional fidelity with industrial structural integrity.

CONCLUSIONS

This systematic review underscores current trends and research gaps in biomimetic aerospace design, highlighting the vast potential of biological principles to support the development of next-generation sustainable and efficient aeronautical technologies. The integration of these concepts remains essential for the future of aviation, offering a path toward technical solutions that reconcile high performance with the necessity for sustainability.

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