AIAA Journal
Vol. 46, No. 9, September 2008

Introduction: Biologically Inspired Aerodynamics

DOI: 10.2514/1.35949

AERODYNAMICS, structural dynamics, and flight dynamics of birds, bats, and insects intersect with some of the richest problems in aerospace engineering: massively unsteady three-dimensional separation, transition in boundary layers and shear layers, vortical flows and bluff-body flows, unsteady flight environment, aeroelasticity and anisotropic wing structure, and nonlinear and adaptive control are just a few examples. The large flexibility of animal wings leads to complex fluid–structure interactions, and the kinematics of flapping and the often spectacular maneuvers performed by natural flyers result in highly coupled aerodynamics, structural dynamics, navigation, and control systems. The agility and flight performance of natural flyers is of particular interest to the aerospace community from the viewpoints of both fundamental engineering science and the development of miniaturized flight vehicles. For all of the maturity of aerodynamics as an engineering discipline, our understanding of flight in natural flyers presently stands far from complete.

Recent years have seen a tremendous rise in interest in the aerodynamics of animal flight and in the aerodynamics of man-made flight vehicles at the scale of birds or insects. Causes include interest in the so-called micro or nano unmanned air vehicles (MAVs and NAVs) capable of performing missions of interest to military, urban security, environmental monitoring, and human curiosity; increase in the capabilities of the enabling experimental and computational methods; the trend toward more first-principles-based investigation in biology; the miniaturization of flight hardware components such as servos and power plants; and advances in materials and battery technologies.

For flowfield investigations, particle image velocimetry and related experimental methods continue to press toward fully time-resolved, three-dimensional registration of the velocity field, with close counterparts on the trends in numerical simulation. Together, the computations and experiments are enabling correlations between the kinematics of motion such as flapping, the fluid physics, the aerodynamics loads, the structural response, and the flight dynamics.

Meanwhile, zoologists have been turning their attention to quantitative methods in animal aerodynamics, wing structures, flight dynamics, and controls. Both the biological and aerospace engineering literatures on insect, bird, and bat flight and MAVs and NAVs help cross-fertilize the entire field of low Reynolds number flight vehicle research and development [1–6]. Miniaturization of electronic components and batteries, largely driven by consumer applications with no direct connection to aeronautics or biology, has enabled practical MAVs based, in some cases, on biomimetic flapping-wing configurations. This opens the field to flight testing of man-made vs natural flyers. To date, miniature flight vehicle development has been substantially based on intuition and trial and error, rather than on first-principles scientific knowledge. Such practices have achieved notable success, especially for fixed-wing vehicles or for simple missions and under abstracted flight conditions such as the absence of wind gusts. But to enable conceptual breakthroughs in the design of MAVs/NAVs with flight–hover–perch capabilities under unpredictable wind-gust influence and in urban environments with complicated flight paths that are subject to real-time corrections, qualitatively improved understanding of the fluid mechanics, fluid–structure interactions, nonlinear control, and, ultimately, integrated capabilities with the combined aerodynamics–structural–control approach need to be attained. Such questions reside at the nexus between biology and engineering.

This special section of the *AIAA Journal* was motivated by the growing interest in the aerospace community in developing micro air vehicles, as evidenced by invited and contributed sessions to the AIAA Aerospace Sciences Meeting and Exhibit and other meetings and by the number of submissions to engineering and biological journals, including the *AIAA Journal*. In this special section, papers by biologists and engineering researchers present research on insect and bird aerodynamics and flight control, as well as on MAV-motivated aerodynamics issues and flowfield data from mechanical models. Bringing together the disparate disciplines of biology and aerodynamics is essential for giving credence to the sometimes hackneyed, but presently very relevant, term "multidisciplinary," because it is only by a multidisciplinary approach that we can come to understand how animals really fly and how to build aircraft with flight performances approaching those of their inspirations in nature.

Specific topics covered in this section include aerodynamic force production via flapping-wing mechanisms, low Reynolds number aerodynamics (experimental and computational), computational analysis of micro aerial vehicles, computational analysis of insect and fish ambulation, aeroelastic effects for flapping wings, insect guidance and control, and insect flight dynamics.

With growing collaboration between the engineering and biology communities, there are exciting opportunities for the advancement of both. Although the question of "How do birds and insects fly?" is much older than aerodynamics itself, it was only relatively recently that quantitative rigor has been emphasized in understanding natural flight. To truly advance our knowledge in science and technologies in MAVs and NAVs, we need to integrate theoretical, numerical, and experimental approaches to address the following issues: fluid physics of biology-inspired mechanisms that simultaneously provide lift and thrust, enable hover, and provide high flight control authority while minimizing power consumption; active and passive interactions of unsteady aerodynamic loading with flexible structures; flexible, lightweight, multifunctional materials and structures for large displacement and suitability for actuators and sensors; gust-tolerant biology-inspired flight control methodologies incorporating novel sensors and wing structural-property tailoring; power requirements, packaging, and integration issues for flapping-wing technologies relevant to MAV urban operations; the establishment of computational modeling capabilities necessary for understanding and prediction of the coupled fluid and structural dynamics in unsteady low Reynolds number flows, ranging from high-resolution methods for fundamental research to reduced-order methods for rapid parameter-space exploration for engineering design; and implementation of sensing and measurement techniques to probe the interplay between wing kinematics (including frequency, stroke amplitude, and angle-of-attack variations), geometry, and anisotropic structural flexibility.

It is our hope that the papers collected in this special section will help encourage broader, community-wide, research and development efforts so that our understanding of both biological and man-made MAVs/NAVs will experience further breakthrough before long.

References

[1] Mueller, T. J., and DeLaurier, J. D., "Aerodynamics of Small Vehicles," *Annual Review of Fluid Mechanics*, Vol. 35, Jan. 2003, pp. 89–111. doi:10.1146/annurev.fluid.35.101101.161102

[2] Pennycuick, C. J., *Bird Flight Performance: A Practical Calculation Manual*, Oxford Univ. Press, Oxford, 1989.

[3] Lehmann, F-O., "The Mechanisms of Lift Enhancement in Insect Flight," *Naturwissenschaften*, Vol. 91, Mar. 2004, pp. 101–122. doi:10.1007/s00114-004-0502-3

[4] Sane, S. P., "The Aerodynamics of Insect Flight," *Journal of Experimental Biology*, Vol. 206, Dec. 2003, pp. 4191–4208. doi:10.1242/jeb.00663
[5] Ellington, C. P., "Insects Versus Birds: The Great Divide," AIAA Paper 2006-035, 2006.
[6] Shyy, W., Lian, Y., Tang, J., Viieru, D., and Liu, H., *Aerodynamics of Low Reynolds Number Flyers*, Cambridge Univ. Press, New York, 2008.

Gregg Abate and Michael Ol
U.S. Air Force Research Laboratory

Wei Shyy
University of Michigan
Guest Editors