Aeromechanics of Bat Flight I-Team Proposal, November, 2016
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Project Significance

Bats are distinctive in several remarkable ways. They are capable of agile and maneuverable flight in diverse, even unsteady, environmental conditions, and their highly jointed wings are anatomically unlike those of all other flying animals. Bat wings are covered by thin skin that possesses unique and complex mechanical properties, and incorporate a distributed network of hair sensors and thin muscles that are hypothesized to sense and control the shape and motion of the wing during flight. In this project, we propose to use approaches from engineering and biological sciences to explore the functional capabilities of the sensors and actuators in the skin of bat wings. Working with a multidisciplinary team of students, we will identify and characterize key elements of the unique distributed integrated sensing and control system imbedded in the soft, compliant skin wings of bats during flight maneuvers. We will then fabricate materials and structures that embody the biological architecture to mimic features of biological function.

Chameleon tongues, squid and octopus tentacles, and elephant trunks, are just a few examples of soft biological structures with elastic skins, remarkable motor capabilities, and distributed sensing and control, that are able to generate, transmit and redistribute forces; bat wings, too, are examples of this remarkable design mode. The engineering world hopes to use these remarkable appendages to inspire new classes of soft robotics, in which sensors and flexible electronics are embedded in novel multifunctional compliant materials. However, fundamental principles and theory needed for bio-inspired soft robotics are lacking. Major funding agencies (DoD, NSF) have begun to redress this gap by focusing attention in this area; for example, the Office of Naval Research recently supported new projects in a Basic Research Challenge on Distributed Sensing, Actuation and Control in Soft Materials for Flexible Appendages. Our project will carry out the first analyses required to demonstrate feasibility of a larger and longer term project in this expanding research area.

We will conduct experiments in our specialized animal flight wind tunnel. After training bats to fly steadily in the test section, we will expose them to unsteady flight perturbations (vertical gusts, streamwise vortices, etc.), and measure the dynamics of their recovery response [Biology Team Component]. We will model the response using unsteady flight dynamics models that we have developed for highly articulated distributed mass systems (e.g. Bergou et al. 2015, Ramezani 2015) [Engineering Team Component]. After carrying out tests at a baseline condition, we will conduct experiments which we (a) selectively remove wing hair sensors at locations with aerodynamic importance (e.g. removal from wing upper surface, lower surface, leading edge, trailing edge) to change bats’ ability to detect air flow conditions, and (b) selective disable the membrane-controlling muscles using botox injection (this approach disables muscles without compromising sensation; Misiaszek and Pearson, 2002). We will quantify flight performance using multiple-camera high speed high resolution videography, which records the kinematics of the wing/body system during steady and unsteady conditions, and also documents unsteady shape and deformation of the membrane wing during flight. In addition, we will use a Bat Inertial Measurement Unit (BIMU) – a self-contained “backpack” mounted on a bat that records 6 DOF dynamics and muscle activity recordings (electromyography or EMG).
This project will build on currently ongoing work in our joint research group but is distinct from current activity. Our goal is to define research objectives supported by and consistent with existing projects to allow the I-team cohort to work with and learn from other members of our lab community and simultaneously provide a distinct experience.

Interdisciplinary Nature

Work in the Bat Flight Research Lab occurs at the intersection of two research disciplines: Engineering, supervised by Professor Kenny Breuer, and Ecology and Evolutionary Biology, supervised by Professor Sharon Swartz. We are interested in a wide range of research topics related to bat flight, including questions regarding the origin and diversification of flight during evolution, the structure and morphology of the bat flight apparatus, the aerodynamics of flexible wings, and how the dynamics of bats flight can inspire robotic devices and small autonomous air vehicles. Our research is intrinsically highly multidisciplinary and experiments span the range from highly biological to completely engineering-focused. The animal flight experiments demand simultaneous integration of multiple techniques, requiring synchronized high speed cameras, muscle recordings (EMG), Particle Image Velocimetry, bat-mounted inertial measurement units (IMUs), along with in-depth understanding of organismal biology and nuanced evolutionary perspective. Our many years of collaborative experience teaches us that the students benefit from, and greatly enjoy, working closely with colleagues from other disciplines. The environment we create facilitates cross-pollination of ideas, techniques, approaches and perspectives that are impossible to obtain from a single technical perspective.

Our interdisciplinarity is reflected in the fact that we both have appointments in both Engineering and EEB, and are welcome and feel at home in each other’s departments, and spend time in each other’s buildings. Our joint research group meets weekly in the more centralized territory of the Science Center. We feel our professional lives unify life and physical sciences, for ourselves, and for our students at many levels.

Need for larger research cohort

Most projects in our lab require multiple skill sets for different elements and phases of their execution. Such cross-disciplinary research intrinsically benefits from teams of students to provide technical coverage of the multiple disciplines required to properly plan and execute experiments. We therefore seek a team of students with interests and/or background in animal physiology, animal behavior, biology of muscle and or sensory neuroscience, fluid mechanics, robotics, image and signal processing, and/or material science.

Mentoring Strategies and Research Environment

Over more than fifteen years, we have built a collaborative research program that spans the biological and physical sciences, and have created a lab community that encompasses a broad and diverse range of members. Together, we have enjoyed a vibrant and productive research that has encompassed dozens of publications and millions of dollars of research funds from multiple federal agencies. Our philosophy emphasizes mentorship and support among faculty, postdocs, graduate students, and undergraduates. Our multi-level, interdisciplinary community provides a rich learning environment for students, with the multiple developmental stages represented by diverse group members supporting undergraduate learners in different ways, contributing to a fuller, more multi-dimensional learning experience. Our experience echoes recent findings in the scholarship of teaching and learning that shows that faculty tend to play critical roles in helping undergraduate students build identity as scientists and assist them in building a vision of the
direction of a field of study (Linn et al. 2015), and graduate students attend to more specific aspects of research progress, such as experimental logistics and data analysis (Eagan et al. 2013).

We will provide students with both structured and informal mentoring opportunities in the I-Team project. We will develop a set of Core Readings to introduce students to relevant background from biological and physical sciences, and host weekly meetings that include faculty and team students to discuss these topics and also professional development subjects including navigating scientific literature, graduate school experiences, finding and cultivating mentors, attending scientific meetings, and writing in the sciences. Senior members of the lab regularly organize “boot camps” to train newer students in experimental techniques, software tools that may lie outside of their standard disciplinary training. We will pair team students with graduate student or postdoctoral members of the lab who will serve as “buddies” to provide advice and support that complements faculty mentorship. We will also aim to meet one-on-one with each student most weeks. We will help the student team develop a prospectus for the summer, and assist them in presenting this to the lab community. Over the course of the summer, each team member will have a chance to give an individual presentation, coached by faculty and supporting senior lab members, and to receive feedback on their presentation. At the conclusion of the summer’s work, the team will prepare a presentation that summarizes and reflects on their progress, including both concrete scientific progress and individual growth experiences.

References