Toward an Understanding of the Structures of the Hummingbird Wing

Andrew J. Rapoff, Ph.D.*

This research aims to understand the form and function of structures of the hummingbird wing. Its nature is basic and applied, consisting of a detailed quantification and understanding of the biologic system - the hummingbird wing - that will subsequently inform the design of a biomimetic system - the structural components of the wings of micro aerial vehicles (MAVs). Great interest exists in MAVs for applications in the military, for homeland security, extraterrestrial flight, and hobby and play. Extremely agile MAVs are required for particular applications, e.g., reconnaissance flight within a building. Natural and extremely agile MAVs are the hummingbirds, capable of forward, hovering, reverse, and upside-down flight. Their wing structures must enable such agile flight.

Previous NASA-funded biomimetics research of the author and colleagues discovered a unique microstructure about a natural hole in bone. A compliant region near the hole drives the higher stresses into an adjacent stiffer, stronger region of a microarchitecture that retards crack initiation and arrests crack growth. This knowledge, combined with structural optimization, informed structural component designs that are stronger, tougher, and lighter than conventional designs. The key was to first quantify in detail and understand the features salient to the mechanical performance of the biologic system. The research performed during this Fellowship represents a first step toward accomplishing that for the hummingbird wing.

The primary structural components of the hummingbird wing are the feathers (shafts and vanes) and bones. Morphological or mechanical property data for these components are nonexistent for hummingbirds and meager for other birds. Summarizing existing and generating preliminary morphological and mechanical data, and performing simple mechanical and optimization analyses, resulted in the following initial conclusions:

- Feather vanes have highly anisotropic plate-like properties that reflect their construction.
- The thin-walled rectangular cross section of the feather shaft increases bending and torsional stiffness and strength for a given mass and external profile compared to a thin-walled oval cross section.
- A lightweight keratin “foam” fills the shaft to increase its crippling resistance and to compensate for the reduced direct-shear strength offered by its cross section.
- Taper of the feather shafts maximizes shaft stiffness for a given mass.
- Fused elbow and wrist skeletal joints probably tune the wing for desired vibration modes and simplify its actuation and control.

These conclusions represent accomplishments that contribute to the long-range goal of providing MAV wing skin properties informed by feather vanes and MAV wing substructure or batten properties informed by feather shafts and bones.

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* Union College; Department of Mechanical Engineering; Schenectady, NY 12308; rapoff@union.edu