Modelling a feather as a strongly anisotropic elastic shell

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Abstract

Feathers exhibit a highly anisotropic behaviour, governed by their complex hierarchical microstructure composed of individual hairs (barbs) clamped onto a spine (rachis) and attached to each other through tiny hooks (barbules). To investigate the anisotropic properties of a feather vane, we design precise measurement protocols on real feather samples. Our experimental results suggest a linear strain-stress relationship of the feather membrane with orientation-dependent coefficients, as well as an extreme ratio of stiffnesses in the barb and barbule direction, of the order of 10000. From these findings we build a simple continuum model for the feather vane, where the vane is represented as a three-parameter anisotropic elastic shell. However, implementing the model numerically reveals severe locking and ill-conditioning issues, due to the extreme stiffness ratio between the barb and the barbule directions. To resolve these issues, we align the mesh along the barb directions. We extensively validate our membrane model against real-world laboratory measurements, by using an intermediary microscale model that allows us to limit the number of required lab experiments. Finally, we enrich our membrane model with anisotropic bending.

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