Rock and Roll – How flies control their flight

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Flying insects can perform a wide array of extreme aerial maneuvers with exquisite accuracy and robustness, outmaneuvering any man-made flying device. As a physical system, a flapping insect is strongly nonlinear with fast-growing mechanical instabilities that must be controlled to allow flight. Hence, similar to balancing a stick on one's fingertip, flapping flight is a delicate balancing act made possible only by ever-present, fast corrective actions. Understanding the underlying mechanisms of insect flight is a major challenge, since this graceful behavior is highly coupled to complex fluid flows and arises from the concerted operation of physiological functions across multiple length and time scales. As such, Insect flight research involves basic concepts from nonlinear dynamics, fluid mechanics, neurobiology and control theory, and has direct application to the development of small flapping robots.

Here we show how flies control their rotational degrees of freedom: yaw, pitch and roll. We focus on their body roll angle, which is unstable and most sensitive degree of freedom. We glue a magnet to each fly and apply a short magnetic pulse that rolls it in mid-air. Fast video shows that flies fully correct for perturbations of up to 100^{o} within $30 \pm 7\text{ms}$. The roll correction maneuver consists of a stroke-amplitude asymmetry that is well described by a linear PI controller. For more aggressive perturbations, we show evidence for nonlinear and hierarchical control mechanisms. Flies respond to roll perturbations within a single wing-beat, or 5ms, making this correction reflex one of the fastest in the animal kingdom.