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Biophysical Transitions and Unified Dynamics of Periodically Driven (synchronous) and Self-excited (asynchronous) Flapping Flight in Insects and Robots

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ME Seminar Zoom link

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Abstract

The ability to move is a trait of all animals. Yet how do animals, including ourselves, get around in this complex and uncertain world with an ease and agility we find hard to recreate in engineered systems? A particular frontier is centimeter scale locomotion, especially flapping flight. Flapping flight is considered a key evolutionary innovation that led to one of the most explosive radiation events where insects diversified to many forms and ecologies. Underlying these behaviors are compositions of immensely complex physiological subsystems (brains, muscles, bodies), yet what often emerges through evolutionary timescales and environmental interactions is a functional performance that can (sometimes) afford simple analysis on the scale of behavior. In this talk, I will use the agile flight of insects to show how an organismal physics approach can give insights into this emergent, functional simplicity. I will show how insects operate as resonant mechanical systems to power flight but do not necessarily operate at their resonant frequency because of consequences for control. We will explore how insects have evolved two different strategies for powering this resonant flight system using muscles that either provide periodic oscillatory forcing or use a stretch-responsive property to set up self-excited limit cycles. While these two strategies have been known for some time, we find that they can be unified in a single dynamic systems framework that shows how major evolutionary transitions reflect transitions in dynamics. We embody this framework in a dynamically scaled robophysical flapper, where kinematics emerge from mechanics and actuation. We can then test the broad parameter space for flapping flight. We find that these two dynamics regimes are separated by a classic entrainment boundary but also bridged by a region of parameter space enabling smooth transitions between the two flight modes. Finally, we realize this biophysical model in the first at-scale flapping robot that can achieve self-excited oscillations and transition between the two flight modes.

Bio

Simon Sponberg is Dunn Family Associate Professor in the School of Physics and the School of Biological Sciences at the Georgia Institute of Technology (Georgia Tech). He received his B.A. in physics and biology from Lewis & Clark College and his Ph.D. in Integrative Biology from the University of California, Berkeley. Afterward, Simon conducted postdoctoral research at the University of Washington before joining the faculty at Georgia Tech. He and his group (the Agile Systems Lab) has been exploring how neurons precisely orchestrate motor activity at the millisecond scale, how the versatility of muscle arises from the physics of billions of organized tiny molecular motors, how agile flight is powered and controlled at the centimeter scale and how flowers blow in the wind (and what that does to the pollinators around them). His interdisciplinary approach has been supported by three NSF directorates, including a CAREER award in the physics of living systems. He now leads an Air Force Multidisciplinary University Research Initiative (MURI), bringing together neuroscientists and engineers from five universities to understand how the brains of organisms achieve fast, flexible perception and decision-making in complex sensory environments. He has been the recipient of a Young Investigator Award from the International Society for Neuroethology, a Klingenstein-Simons Fellowship in the Neurosciences, and a Hertz Fellow.