Aerodynamic tails in biology and robotics

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1 Background

Animals often use their tails to stabilize their bodies and execute rapid maneuvers [1]. Field observations of animals, analysis of simplified mechanical models, and experiments with robot proxies have collectively revealed that tails can generate both inertial and aerodynamic reaction torques that contribute to such maneuvers [2]. The relative contributions of inertial and aerodynamic effects depend on factors such as the movement dynamics of the organism, its kinematics, and the relative velocity of the surrounding air and are largely unknown. This perspective aims to discuss ongoing research on aerodynamic-dominate tail flicking regimes, emphasizing studies on robotic templates.

2 Recent Advances

While most robotic tail studies have focused on inertia-dominated regimes [3–5], we hypothesize that aerodynamic tails can provide comparable functionality with less mass than inertial tails, particularly at higher speeds where aerodynamic forces increase. To test this hypothesis, we have developed physics-based simulations and built aerodynamic tails for robot prototypes (Fig 1). Preliminary simulations suggest that aerodynamic torques can contribute up to 10% of the total reaction torque in a cheetah-sized robot (0.7 m tail length, 0.8 kg tail mass, 0.5 m tail diameter) with oncoming air speeds of 30 m/s. In addition, experimental robotic prototypes with "supernatural" aerodynamic tails (made from rigid carbon fiber composites and with surface areas many times that of the robot body) were tested in a wind tunnel. These demonstrated stabilization torques up to 4x greater than those generated by inertial effects alone, highlighting the potential of aerodynamic tails to enhance robotic performance.

3 Future directions

Our investigations so far have led to more questions than definitive answers. Ongoing work involves simulating and testing variables such as tail surface area, dimensions, mass, relative air speeds, and control profiles for tail flicking. The interplay of these variables may suggest an optimal design regime for aerodynamic tails. We are also interested in the relative contribution of lift and drag with different tail flicking strategies and air speeds. Future studies aim to uncover the principles that underpin aerodynamic tail dynamics, informing the design of efficient robotic tails.

Furthermore, this research may provide insight into how

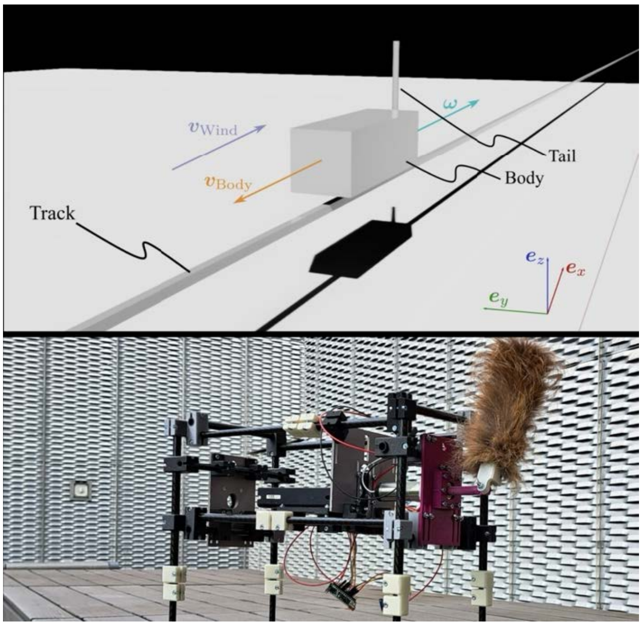

Figure 1: Top - Simulation setup, showing robot proxy accelerated on linear track. Bottom – Robotic prototype for experimental validation, featuring a modular and adjustable tail design.

animals like cheetahs leverage controlled slip, inertial reorientation, and substrate interaction to maintain stability and maneuverability across varying speeds. By analyzing these behaviors through the lens of geometric mechanics and data-driven modeling, we can develop predictive frameworks for bio-inspired robotic locomotion, enabling more agile and adaptive motion planning together with tail as a fifth limb in legged systems.

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