# Tails for Minimally-Actuated Milli-Robots

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Minimally actuated robots such as VelociRoACH [6], which uses only 2 motors, can be limited in maneuverability. Generating differential thrust for turns is difficult, particularly with high forward velocity. However, adding an extra element to generate moments improves maneuverability, stabilizes body motion, or provides recovery from inversion. For the small moment-of-inertia of milli-robots, tails can be particularly effective at changing orientation compared to adding extra degrees of freedom for legs, as surfaces may be low friction. Also due to favorable scaling, aerodynamic control effects can be used in running and even jumping robots.

Tail principles have been explored on a variety of milli-robots at UC Berkeley shown in Fig. 1. While aerodynamic effects are of course dominant in devices such as a 2.5 gram glider [7], at running speeds of 3 m/s, aerodynamic forces are significant and useable for passive stabilization as in the 30 gram VelociRoACH [6], or steering as in SailRoACH [3] (Fig. 1bc). The 100 gram jumping robot Salto [5] uses active thrusters (Fig. 1d), while actively pushing against the ground with a tail can be used for either inversion or turning (Fig. 1g) [2]. Table I summarizes turning performance for several of these robots.

TABLE I
TURNING PERFORMANCE COMPARISON

| **Robot** | # of Actuators | $\dot{\psi} v$ $^\circ ms^{-2}$ | effect |
|---|---|---|---|
| SailRoACH [3] | 3 | 134 | aero. drag |
| TAYLRoACH [4] | 3 | 400 | inertial |
| Salto [5] | 4 | 90 | aero. thrusters |
| Micro glider [7] | 2 | 180 | elevons |
| LoadRoACH [2] | 3 | 30 | ground drag |

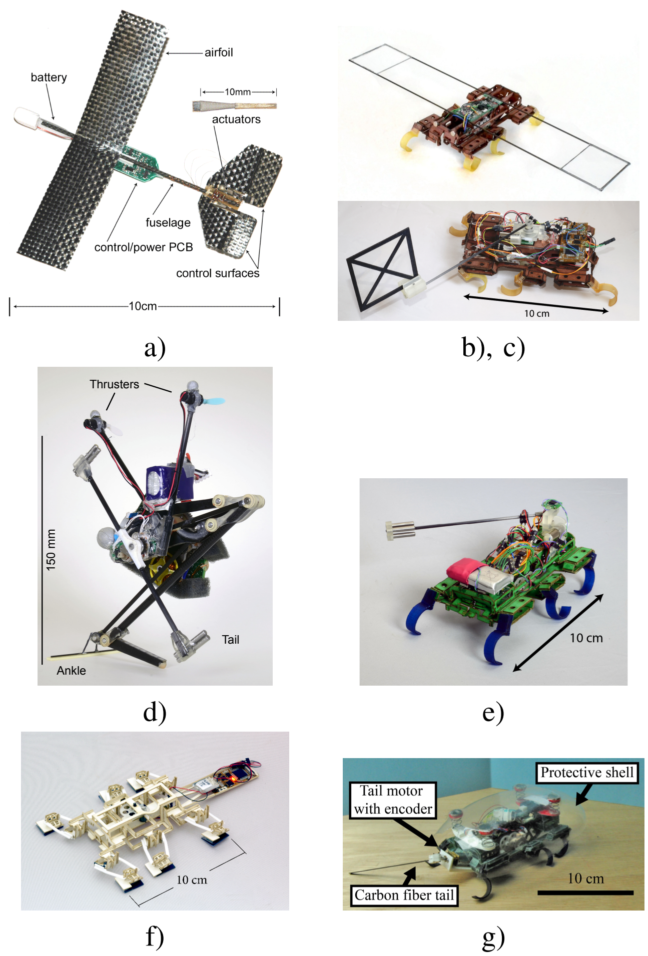


Fig. 1. a) Aerodynamic control surfaces for glider, b) passive aerodynamic roll stabilization appendage, c) active yaw using drag for running robot, d) inertial tail for pitch and aerodynamic thrust vectoring for roll/yaw in jumping robot, e) inertial tail for yaw control, f) passive tail for pitch control in climbing, and g) active drag tail for heading control and roll recovery.

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