On the Conical Motion and Aerodynamics of the Cheetah Tail

Amir Patel & Edward Boje, Department of Electrical Engineering, University of Cape Town

I. INTRODUCTION

The cheetah is capable of incredible feats of maneuverability [1] and these maneuvers generally involve rapid swinging of the animal's lengthy tail. Very little is understood about the cheetah's use of its tail and the common view is that it is "heavy" and possibly used as a "counter balance" or as a "rudder". Ultimately, a deeper understanding of this specialized animal will inspire future high-speed, maneuverable robots.

Our previous efforts have shown that swinging a tail in the roll axis can increase stability during high speed turns on a wheeled robotic platform (*Dima I*) [2]. Additionally, rapid acceleration and braking maneuvers can be stabilized by tail motion in the pitch axis [3]. During these motions, the tail was capable of imparting a large angular impulse despite the short time duration. The limitation to extension to longer duration maneuvers were the tail angular limits. The tail effects were only considered to be inertial.

II. MOTION IN A CONE

Video observations of cheetahs turning at high speed indicate tail movements with a combination of pitching and yawing to generate a cone around the sagittal axis (Fig. 1A): Our hypothesis is that this cone motion imparts a roll torque on the body over the duration of a complete stride. A mathematical model of a simplified two degree of freedom tail, which is capable of pitching and rolling, was developed and trajectory optimization was used to determine if the cone motion is indeed the optimal trajectory for a high speed galloping turn (Fig. 1B). A robot platform, *Dima II*, was developed with a two degree of freedom tail actuator. With insights gained from the optimized open loop trajectories, a feedback controller was designed for the tail which commands it to swing in a cone to achieve commanded torques. Practical measurements demonstrated that this two degree of freedom tail imparts useful roll torque on the robot during high-speed turns.

III. AERODYNAMICS OF THE TAIL

Cheetah necropsies reveal that the tail is not as heavy as may be supposed and as its center of mass is close to the base, the inertia is also modest. In fact, the apparent tail volume is not comprised only of tissue, but is substantially furry. This observation leads to the hypothesis that aerodynamic forces can impart torque on the body during rapid maneuvers as well. Tails were tested in a wind tunnel to measure their aerodynamic characteristics (Fig 2A). Mathematical models were developed to expand the understanding of the aerodynamics of the tail and its effect on the body. Because the cheetah tail is long and the animal is both agile and fast, the aerodynamic effects are significant (Fig. 2B).

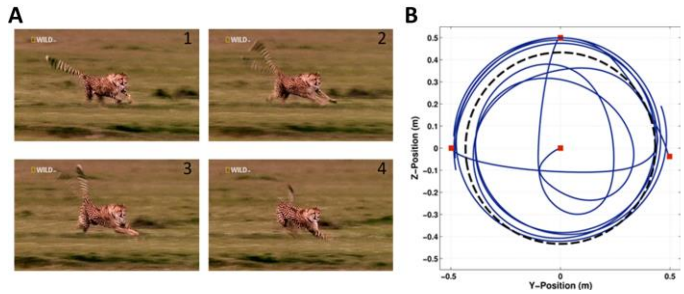

Fig. 1: (A) Cheetah performing cone motion of the tail. (B) Tail position trajectories obtained by the optimization.

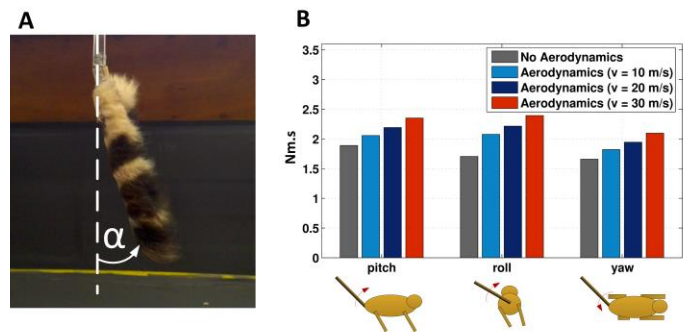

Fig. 2: (A) Cheetah fur placed in a wind tunnel. (B) Angular impulse for various motions with the aerodynamic effects included.

IV. DISCUSSION

By conical motion of the tail, the cheetah could possibly sustain a high-speed turn for much longer, as the tail would not be limited by angular constraints, but only by muscle power limits. Additionally due to the animal's high speed, tail aerodynamics plays a significant role in the total angular impulse imparted on the body. These insights should be assimilated into maneuverable robot designs of the future.

REFERENCES

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[3] A Patel and M Braae, "Rapid Acceleration and Braking: Inspirations from the Cheetah's Tail," in *IEEE International Conference on Robotics and Automation*, Hong Kong, 2014.