Should Satellites Have Tails?

Zachary Manchester
Department of Aeronautics and Astronautics
Stanford University
Email: zacmanchester@stanford.edu

I. Small Satellites

Commercial spacecraft have shrunk dramatically over the past two decades. Thanks largely to Moore's Law, an entire industry of launch providers, component manufacturers, and satellite operators have grown around the shoebox-sized CubeSat standard [3]. There have also been many satellites developed and launched in recent years that are even smaller than CubeSats, including the $10 \times 10 \times 2.5$ centimeter SpaceBees built by Swarm Technologies, the $5 \times 5 \times 5$ centimeter PocketQube spacecraft, and the $35 \times 35 \times 4$ millimeter Sprite spacecraft (Fig. 1) [2].

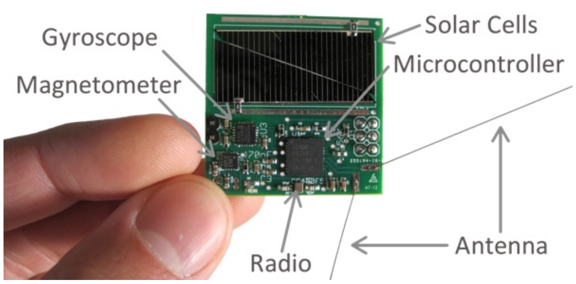

Fig. 1. The 3.5×3.5 centimeter printed-circuit-board Sprite spacecraft.

II. Reaction Wheels and Control-Moment Gyros

Most spacecraft are required to point antennas, solar panels, cameras, and other sensors at various targets, making attitude control an essential capability. While thrusters can be used to provide the necessary torques, reaction wheels and control-moment gyroscopes (CMGs) are the preferred solution for most missions since they do not consume propellant. A reaction wheel is essentially a variable-speed flywheel attached to a motor that spins about a fixed axis, while a CMG is a flywheel whose rotation speed is held fixed, but whose axis of rotation can be gimbaled to provide torque.

While reaction wheels and CMGs are widely deployed on large spacecraft, their relative performance suffers as they are scaled down for use in smaller spacecraft. Figure 2 shows the power-law relationship between the fraction of a spacecraft occupied by its attitude control system and the spacecraft's total mass, ranging from a 3 kilogram CubeSat to the International Space Station (ISS) with a mass of over 400 tons.

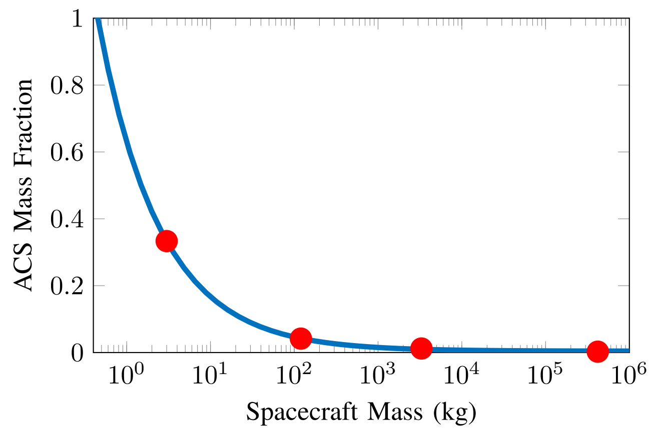

Fig. 2. Attitude control system mass fraction vs. total spacecraft mass.

III. Alternative Actuators

At the CubeSat scale, a set of reaction wheels typically accounts for a third to a half of the mass of the entire spacecraft. Such traditional actuators appear to be all but impractical at smaller scales. None of the sub-CubeSat spacecraft that have flown to date have had active attitude control systems, severely limiting their usefulness. To address this issue, we draw inspiration from biological systems at similar size scales. In particular, geckos are capable of performing impressive attitude maneuvers using their tails [1].

Deployable tail-like appendages could enable full 3-DOF attitude control on tiny spacecraft like the Sprite. Due to their increased moment arm relative to internal flywheels, tail-like actuators could also offer increased performance and reduced size, mass, and cost at the CubeSat scale.

References

[1] Ardian Jusufi, Daniel I. Goldman, Shai Revzen, and Robert J. Full. Active tails enhance arboreal acrobatics in geckos. *Proceedings of the National Academy of Sciences*, 105(11):4215–4219, March 2008. ISSN 0027-8424, 1091-6490. doi: 10.1073/pnas.0711944105.

[2] Zachary Manchester, Mason Peck, and Andrew Filo. Kicksat: A crowd-funded mission to demonstrate the world's smallest spacecraft. In *AIAA/USU Conference on Small Satellites*, Logan, UT, 2013. pubs-conference.

[3] Michael Swartwout. The First One Hundred CubeSats: A Statistical Look. *Journal of Small Satellites*, 2(2):213–233, 2013.