AREA-OF-EFFECT SOFTBOTS (AOES) FOR SURFACE SCIENCE DURING PLANETARY FLYBY. J. W. McMahon[1] and C. M. Kepllinger[2], [1]Smead Aerospace Engineering Sciences Department, University of Colorado, Boulder, CO USA (jay.mcmahon@colorado.edu), [2]Department of Computer Science, University of Colorado, Boulder, CO USA (christoph.keplinger@colorado.edu).

Introduction: This talk investigates the idea of using Area-of-Effect Softbots (AoES) [1] - which are currently in development under a Phase 2 NASA Innovative Advanced Concepts (NIAC) project – to measure the effects of a planetary flyby on an asteroid, see Fig. 1. AoES were initially designed to operate in proximity to, and on the surface of, small asteroids to support mining and planetary defense missions, however the design provides a capable platform that could uniquely measure surface motion and spin state changes. Their unique design and capabilities are dependent on the incorporation of soft, compliant, and lightweight materials. AoES have a large area-to-mass ratio which allows them to take advantage of the peculiarities of the dynamical environment around small asteroids. Specifically, AoES will use solar radiation pressure to sail to the surface of the target. This capability and the associated control laws will be demonstrated, removing the need for propulsion systems. Furthermore, the large, flexible surface area allows for robustness with respect to uncertainty about the asteroid surface structure - it can provide flotation to prevent sinking into a very loose, dusty regolith, and also provide anchoring to the surface through natural and electroadhesion forces.

The enabling technology that will allow the AoES design loop to close is a new class of soft actuators known as HASEL actuators [2]. These actuators harness an electrohydraulic mechanism, whereby electrostatic forces generate hydraulic pressure to drive shape change in a soft fluid filled structure. HASELs provide an extremely power- and mass-efficient mechanism for actuating the large flexible surface areas that are the essential components defining AoES. HASELs also inherently allow for accurate measurement of displacement of the actuators, which could provide a crucial scientific measurement of surface motion.

Combined, AoES provide a unique scientific platform that could be especially useful during a planetary flyby scenario, as in the case of Apophis in 2029 [3]. The surface mobility will allow them to reach the most desirable surface locations. The HASEL actuators, supplemented with other scientific instruments (e.g. scismometers, accelerometers, gradiometers), could provide unique measurements of the surface as the AoES are connected to the surface through electroadhesion so solid contact can be ensured. Finally, adding radiometric tracking capabilities can allow us to make detailed measurements of the asteroids spin state before, during, and after a flyby [4]. Landing multiple AoES can provide simultaneous coverage of multiple locations on the surface.

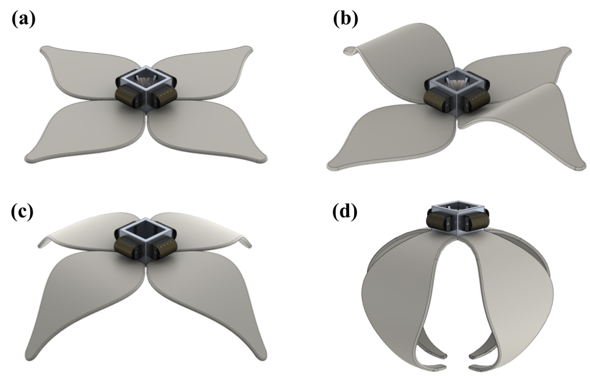

Figure 1 - AoES design in four different limb configurations that promote surface contact and mobility.

AoES Overview: The initial system design of AoES are pictures in Fig. 1. The flexible, actuated limbs are shown in several different states which allow AoES to move across/over an asteroid surface and to solar-sail upon deployment and for landing on the asteroid. Once on the surface, AoES use electroadhesion to artificially stick to the surface. This is particularly important for this proposed application as good contact with the surface will allow for clear sensing of any surface motion. This is pictured in Fig. 2.

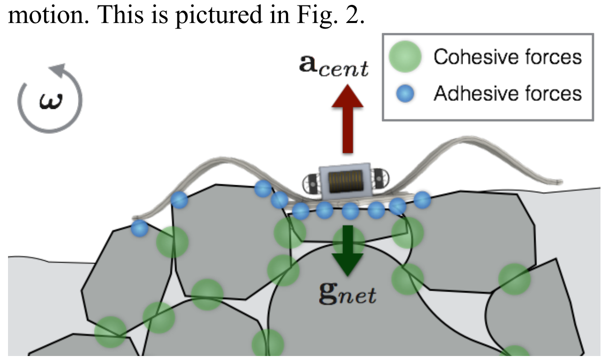

Figure 2 - Concept of AoES sticking to an asteroid surface using electroadhesion.

This talk will demonstrate the expected level of sensitivity to surface motion and spin-state change during the planetary flyby that could be measured if one or more AoES are deployed to the surface of Apophis. While not directly investigated here, it should be noted that these platforms could also be configured to interact with or otherwise measure the asteroids surface and material properties.

References: [1] McMahon, J. W. et al (2019) *IEEE Aero. Conf,* 1-16. [2] Acome E. et al. (2018) *Science,* 359*,* 61-65. [3] Yu, Y. et al (2014) *Icarus,* 242, 82–96. [4] French, A., McMahon, J. W. (2020) *Icarus,* 338.