

Asteroid Capture with a Structured Netted Asteroid Retrieval Envelope (SNARE)

Thomas J. Harvey, P.E., MMA Design LLC, Boulder, CO, tjharvey@mmadesignllc.com

Dr. Sun Hur-Diaz, Emergent Space Technologies, Inc., Greenbelt, MD, sun.hur-diaz@emergentspace.com

Introduction: We describe an innovative asteroid capture system concept called the Structured Netted Asteroid Retrieval Envelope (SNARE) as a viable and compelling solution to capturing a small asteroid (Figure 1). SNARE is an asteroid capture system comprised of CubeSats that are connected by robust extendable/retractable graphite composite tapes which are reeled in and out to change the shape and size of a polyhedron net. This approach provides a lower risk means of enveloping a small asteroid than with an inflatable bag, and its compact design potentially requires less power, mass and volume than an inflatable approach.

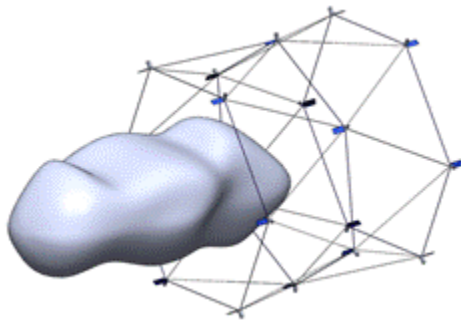


Fig 1 – Structure Netted Asteroid Retrieval Envelope

The basic mission concept for utilizing SNARE to capture an asteroid is depicted in the following figures. A packaged system of CubeSats is separated from a larger spacecraft - the mother ship - that carried the system to an orbit neighboring the asteroid (Figure 2). The CubeSats contain reels of graphite composite tapes that are connected so that when the tapes are electro-mechanically extended, the CubeSats become nodes of an expanding convex polyhedron, which becomes SNARE. The tapes form a 170 degree semicircle cross-section when deployed, producing a high strength column element of SNARE. The attitude and orbit control of SNARE is provided by the CubeSats, which are networked and are centrally coordinated and controlled by software on the mother ship.

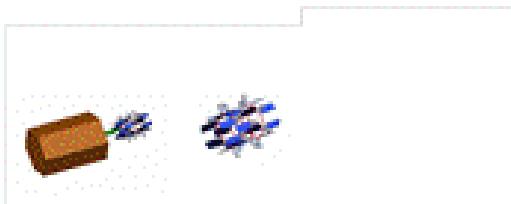


Fig 2 – SNARE Deployment from the Mother Ship

SNARE rendezvous to envelope the asteroid (Figure 3), then as it matches the dynamics of the asteroid; it contracts itself through controlled retractions of the graphite tapes.

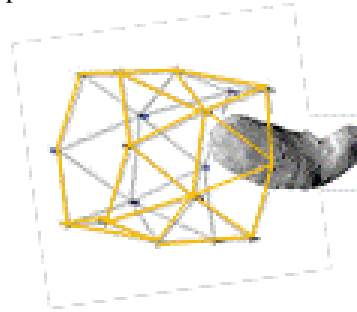


Fig 3 – SNARE Envelopes Asteroid

Sensors on each CubeSat feed data to the control software on the mother ship that “shrink-wraps” SNARE about the asteroid (Figure 4). SNARE can also incorporate a thin membrane to better capture and secure both large and small asteroid particles.



Fig 4 – SNARE Shrink-Wraps Asteroid

The snared asteroid now has multiple docking points via the CubeSats. After the asteroid capture, the mother ship rendezvous to dock with a CubeSat on SNARE to transport the asteroid (Figure 5).

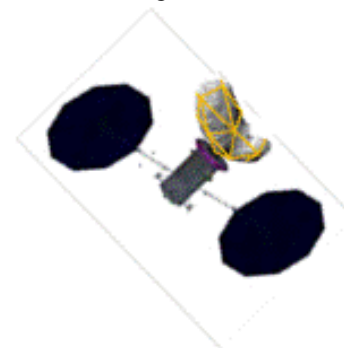


Fig 5 – SNARE Rendezvous with the Mother Ship

System Concept: SNARE is an asteroid capture system that is deployed by a mother ship when in close

proximity to the asteroid. It is composed of multiple CubeSats connected by section-morphing graphite composite tapes that are extended to deploy the CubeSats. The size and shape of the polyhedral net/membrane that is formed can be changed through the extendable/retractable tape mechanisms. The thrusters on the CubeSats provide attitude and orbit control of SNARE once the desired shaped is attained. The system architecture is distributed wherein the high performance computing capability of the mother ship is shared with SNARE through wireless communication between the mother ship and SNARE. Utilizing the mother ship suite of relative sensors, as well as the sensors on the CubeSats themselves, the software on the mother ship determines the state of SNARE and determines the CubeSat thruster and tape reel control commands for the coupled challenge of controlling SNARE's position, attitude, and inertia (size and shape).

SNARE provides a capture system that accommodates relative motion and irregular asteroid shapes until the capture process is completed. Unlike inflatables that are prone to poor deployment control and are difficult to test, SNARE utilizes CubeSats and graphite composite tapes that are controllable and testable. Inflatables have non-repeatable kinematics that are hard to control and not very well understood [1]. This makes predicting actual flight performance difficult even with exhaustive laboratory testing. Composite/mechanical boom systems have usually proven to be more mass and structurally efficient than competing inflatable systems in a rigorous comparison, as was concluded for the DARPA ISAT program.

Concept of Operations: A notional ConOps for the SNARE system is summarized in the steps that follow.

1. SNARE, notionally comprised of 6-12 CubeSats, is carried by a mother ship to the asteroid.
2. Upon arrival at the asteroid, the undeployed SNARE separates from the mother ship which maneuvers away.
3. SNARE turns on, initializes, and performs initial check out.
4. Ground initiates the controlled expansion of SNARE. SNARE performs post-expansion checkout.
5. Ground commands SNARE to rendezvous with and envelope the asteroid.
6. Once the asteroid is inside SNARE, SNARE stays in this configuration for some time to characterize the asteroid (shape, topography, mass, composition, surface structure, attitude

profile) and gather other data in determining the capture strategy.

7. Ground commands contraction of SNARE which also includes matching the attitude rate of the asteroid. The cameras on the Sensor CubeSats provide data to help in this process. Anchors on the bottom of the CubeSats, as well as the tension in the tapes between the CubeSats, help secure the CubeSats to the asteroid surface. Successful capture is achieved once SNARE has no relative motion with respect to the asteroid and becomes one rigid body with the asteroid.
8. The mother ship rendezvous with the captured asteroid and docks with one of the CubeSats of SNARE.

SNARE System: SNARE is a system that is notionally composed of 6-12 3U CubeSats that are structurally connected via composite tapes and collectively have all the components of a maneuverable spacecraft that is geometrically reconfigurable during a mission. Prior to structural reconfiguration (that occurs after jettisoning from a mother spacecraft in the vicinity of the target asteroid), SNARE is stowed in a launch restrained block consisting of three groups of interconnected 3U CubeSats. Figure 6 shows SNARE's stowed configuration and reconfiguration sequence. The key technologies required in SNARE are the graphite composite tape and reel mechanism, the optional thin membrane, the CubeSat, and the control algorithms and software architecture.

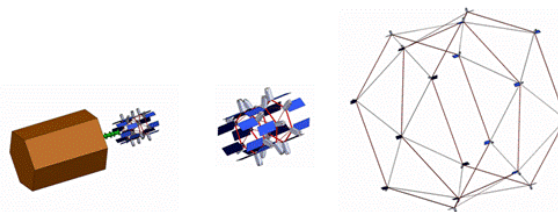


Fig 6 – SNARE Reconfiguration from Stowed to Deployed

CubeSats: The CubeSats comprising SNARE have different capabilities. Some are attitude and orbit control (AOC) CubeSats used primarily for AOC of SNARE, while others are Sensor CubeSats equipped with cameras and other sensors. A few of them are Despin CubeSats that are primarily dedicated to despinning the asteroid with high propulsion capability, yo-yo masses, or by other methods.

Individual Node Responsibilities. Each CubeSat deploys and retracts the tape/reel system by command

from the mother ship. The tape/reel dispenser is equipped with an optical encoder that measures the relative displacement and direction of the tape deployed, which provides information on the relative position and attitude of the individual CubeSat. Each CubeSat communicates this information, along with sensor measurements from the star camera/imaging system, sun sensors, accelerometers, gyros, and other health and status information to the mother ship for centralized processing. As long as the tapes remain rigid, the relative positions and attitudes of all the CubeSats in SNARE are known.

SNARE Responsibilities. In addition to the individual CubeSat nodes, SNARE operates as a single distributed vehicle. Treated as a single rigid body, SNARE's center of mass location and attitude are controlled relative to the target asteroid during the enveloping and shrink-wrapping maneuvers. Individual CubeSat actuations needed to obtain the desired SNARE motion are determined by processing of measurements by the mother ship and issuing actuator control commands to the individual CubeSats from the mother ship. Once motion of SNARE is stabilized with respect to the asteroid, SNARE gradually contracts until the individual CubeSats are "attached" by compression to the surface of the asteroid. Once attached in this manner, the CubeSats provide docking interfaces to allow the mother ship to rendezvous and dock with the asteroid.

CubeSat Design. A notional 3-unit (3U) CubeSat, shown in Figures 7 and 8, accommodates the deployable tape/reel and thruster subsystems. The core bus occupies approximately 2U of the available 3U volume and provides command and data handling, power distribution and storage, communications, and sensing and control functions. The remaining 1U is available for the deployable tape/reel and docking systems.

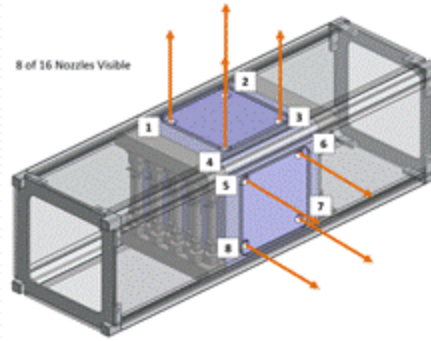


Fig 8 – SNARE Cold Gas Thruster Propulsion

References:

[1] Freeland, R. E., et al. "Large inflatable deployable antenna flight experiment results." *Acta Astronautica* 41.4 (1997): 267-277.

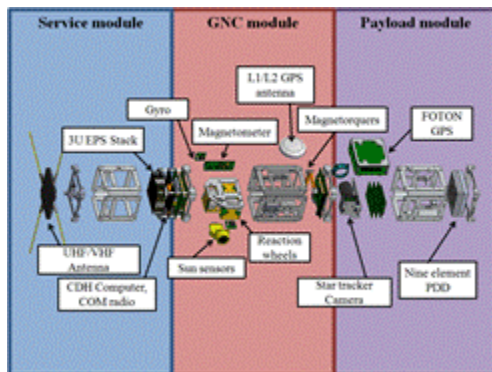


Fig 7 – SNARE Service, GNC, and Payload Modules