NEOSat: An Architecture for Small Interplanetary Craft Development. J. A. Straub[1], R. A. Fevig[2], T. Borzych, C. Church, C. Holmer, A. Komus, R. Lilko, T. Perrin [1]Department of Computer Science, University of North Dakota, Streibel Hall Room 201, 3950 Campus Road Stop 9015, Grand Forks, ND, 58202 [2]Department of Space Studies, University of North Dakota, Clifford Hall Room 512, 4149 University Ave Stop 9008, Grand Forks, ND, 58202.

Introduction: Near Earth Objects (NEOs) present a significant threat to the Earth and its inhabitants. Historic crater presence, statistical models and impact projections all suggest that future impacts are all-but-inevitable. A large Earth impactor (EI) could lead to the end of life on Earth. Smaller EIs could wreak devastation on a local or regional scale. Developing technologies to detect, characterize and effectively mitigate the EI threat is thus a strategic priority for humanity.

Work on the initial characterization of a potential EI is ongoing at the University of North Dakota. We have extended initial efforts by developing techniques for in-situ NEO characterization and mitigation. Specifically, we have developed a program architecture for EI response. This paper focuses on an mission architecture for a precursor mission for characterization. The characterization mission is required before commencing intervention design efforts; the precursor is required to demonstrate and validate technologies required for this missoion.

Mission: The initial design work for the proposed mission generated by the University of North Dakota Earth Impactor Intervention Progam (UND-EIIP) has generated a full mission architecture down to the subsystem level. Figure 1 presents the mission statement for the proposed mission.

Figure 1: Mission Statement
Earth Impactors (EI) may pose a significant threat to life on Earth. In order to mitigate such a threat, the physical characteristics of the potential EI must be established. Using a small spacecraft to make in-situ measurements of a potential EI can offer a low-cost option for obtaining data necessary for threat assessment as well as for the development of mitigation strategies. *Prior to an actual EI rendezvous mission proof of concept for the required technologies needs to be demonstrated. A student/faculty designed mission, EI Technology Demonstrator, will investigate and demonstrate technologies that can be used for a future EI rendezvous mission.*

Objectives: The gap analysis conducted by the UND-EIIP team has identified several areas of focus for engineering, software development, and integration work. The NEOSat spacecraft will provide an orbital test and demonstration platform for the proposed work: it will demonstrate its suitability for a future EI characterization mission. NEOSat will, in Low-Earth Orbit (LEO), remotely sense (using visual light and LIDAR equipment) a deployed sub-satellite, the Earth, and several satellites (prospectively from the Iridium constellation).

Figure 2: Primary Objective
Perform observations of a target object to evaluate technologies for a future EI rendezvous mission.

The sensing technology required for observing these targets is substantially analogous to what is needed for imaging an NEO. The UND-EIIP team has designed the spacecraft and its subsystems for operations in deep space, where possible. Some individual subsystems are necessarily different due to the inherent differences between the LEO environment (where the test mission is being performed) and deep space. However, a key goal is to design as much of the spacecraft as possible for use in both LEO and deep space. To satisfy this objective, the team will collect mission data from spacecraft operations and assess the performance of all elements of the mission architecture during orbital testing. The primary (figure 2) and secondary (figure 3) objectives are based on these NEO mission and educational goals.

Figure 3: Secondary Objectives
1. *Collect mission data pertaining to the target object(s).*
2. *Provide meaningful real-world space mission experience for students.*
3. *Demonstrate that students and faculty at the University of North Dakota can successfully design, build, test, and launch a small spacecraft.*

The initial design process has already served to validate the second and third secondary objectives. Students involved in this process have gained a great deal of systems engineering and design experience as part of developing the NEOSat mission concept and its subsystems. Several iterations of mission concept development and preliminary development work for all of the subsystems have been performed. These efforts have progressed the design to the Mission Concept Review (MCR) level. NEOSat is poised to be the first UND smallsat-class spacecraft and the first student spacecraft designed for deep space operations.

Payload: The mission architecture for NEOSat incorporates several payload elements that are required for a NEO characterization mission. These include a LIDAR, visual camera, magnetometer, radio science package, and subsatellite. Each payload element and is discussed beiefly.

Lidar. On a NEO characterization mission, LIDAR will be used to determine the approach distance and velocity to the target object. It will also be used to map the shape of the target. The LIDAR payload will be tested in the NEOsat precursor mission by making measurements of a small subsatellite released from the spacecraft.

Optical Camera. A visual camera and associated optics will also be included as part of the NEOSat payload. The main requirement that has been established to this point is that the system be capable of 1m resolution at a distance of 100km. In light of this requirement and the limited space available for such a system, folded optics has been used allowing a longer focal length to be incorporated into a space that is roughly 3-times smaller than the focal length of the instrument. Coupled with the optical telescope will be a CCD imager.

Magnetometer. During a NEO characterization mission, a magnetometer will be used to measure the interplanetary magnetic field during the traversal to the target and to study the possible magnetic field of the target NEO. Based on a limited study of previous interplanetary and asteroid encounter magnetometers, the NEAR Shoemaker Magnetometer was chosen as a model. During the NEOSat mission, the Magnetometer will be used to sense the Earth's Magnetosphere. Operational procedures for detecting, mapping, and determining the geometry of fields encountered will be developed.

Radio Science Package. The NEOSat will carry a communications suite that will be used for command and data handling as required for the mission. Due to the mass and volume limitations applicable to a smallsat-class spacecraft, the use of the onboard communication system for conducting radio science experiments will be advantageous.

Subsatellite. The subsatellite will have two key roles in the mission. First, it will be used to test cluster-based gravity characterization techniques. A gravity model for the Earth will be projected via sensing the perturbations of the subsatellite and main satellite's orbits caused by Earth's mass. Second, the subsatellite will be used to test the LIDAR and visual camera systems. A GPS-derived position will be compared with a position generated (separately) from the LIDAR and visual camera imaging.

Subsystems: All spacecraft subsystems are discussed in this paper. While many are conventional smallsat class systems, several key areas of innovation are highlighted.

Onboard Computing. A key component of the proposed mission will be the autonomous spacecraft control technologies. A fully autonomous spacecraft and sub-satellite are planned which will perform only limited communications with Earth. Two key design objectives will facilitate this: goal-based mission definition and command and model-based transmission reduction (MBTR).

Communications. The communications architecture for the proposed spacecraft is designed to demonstrate key principles applicable to deep space flight from Earth orbit. Mechanically, the spacecraft will feature a unique combination of a phased array built on the opposite side of a set of deployed, non-articulated solar panels. This array will cover four 50 cm x 50 cm faces, providing 1000 cm^2 of antenna and 26 dBi of gain.

Propulsion. Due to the high delta V requirements of a NEO rendezvous mission [1], electric propulsion-will be used. This stems from the fact that electric propulsion units, particularly ion and Hall effect thrusters, tends to have an extremely high specific impulse when compared to traditional chemical propulsion, and are therefore able to reach high delta Vs with relatively little propellant, reducing overall launch weight and cost.

Combined operations: The spacecraft is cube shaped with dimensions of 50 x 50 x 60 cm. Deployable solar arrays are mounted on the sides measuring 50 x 60 cm during launch. After launch, two panels will be extended on each side of the spacecraft along a line parallel to the diagonal of the 50 x 50 cm sides. The optical telescope is mounted perpendicular to the long axis of the solar array in order to avoid any interference due to reflection or shadows cast by the panels. The LIDAR is mounted on the same face as the optical telescope to avoid having to reorient the spacecraft for measurements from either payload; the subsatellite is also located on this face. The magnetometer is mounted on a deployable one-meter long boom in order to prevent interference with other subsystems. The arcjet thruster is mounted on the opposite face of the optical telescope to prevent contamination of the optical lens. The propellant tank is located at the center of gravity of the spacecraft to prevent changes in the center of gravity as propellant is consumed. Other subsystems are distributed to maintain the center of mass.

Reference: [1] Perozzi E., Rossi A., and Valsecchi G.B. (2001) Planetary and Space Science, 49, 3-22.