Near Earth Asteroid (NEA) Scout

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NASA is developing solar sail propulsion for a near-term Near Earth Asteroid (NEA) reconnaissance mission that will lay the groundwork for the future use of solar sails. The NEA Scout mission will use the sail as primary propulsion allowing it to survey and image one NEA's of interest for future human exploration. NEA Scout will launch on the first mission of the Space Launch System (SLS) in 2018. After its first encounter with the Moon, NEA Scout will enter the sail characterization phase by the 86 m^2 sail deployment. A mechanical Active Mass Translation (AMT) system, combined with the remaining ACS propellant, will be used for sail momentum management. The spacecraft will perform a series of lunar flybys to achieve optimum departure trajectory before beginning its two year-long cruise. About one month before the asteroid flyby, NEA Scout will start its approach phase using optical navigation on top of radio tracking. The solar sail will provide NEA Scout continuous low thrust to enable a relatively slow flyby of the target asteroid under lighting conditions favorable to geological imaging. Once complete, NASA will have demonstrated the capability to fly low-cost, high ΔV CubeSats to perform interplanetary missions.

Key Words: Solar Sail, Near Earth Asteroid, CubeSat

Nomenclature

U : 1 Unit or 10cm X 10cm X 10cm cube

1. Introduction

The NASA Near Earth Asteroid (NEA) Scout mission will demonstrate the capability of an extremely small spacecraft, propelled by a solar sail, to perform reconnaissance of an asteroid at low cost. The solar sail will be based on the technology developed and flown by the NASA NanoSail-D[1)] and the Planetary Society's Lightsail-A.[2)] Funded by NASA's Human Exploration and Operations Mission Directorate and managed by NASA Marshall Space Flight Center, the NEA Scout mission will be launched on the first flight of the Space Launch System (SLS) in 2018.

Asteroids, along with the moon and Mars, are among the destinations to which it is technically feasible to send people within the next 25 years. Following historical precedent, and exercising common sense, NASA would like to send at least one robotic surveyor mission to an asteroid before committing to send humans. Just as the Surveyor Program used robotic spacecraft to reconnoiter the moon before Apollo and as the current fleet of robotic spacecraft is surveying Mars for possible future human visits, so, too, is it necessary to survey candidate asteroids before committing to sending people. This is the purpose for which NEA Scout was conceived.

The Human Exploration & Operations Mission Directorate (HEOMD) has identified key Strategic Knowledge Gaps (SKGs) that need to be addressed prior to sending humans to a NEA. Given the limited in situ knowledge of asteroids and the limited ability of ground-based assets to address the key SKGs, robotic precursor missions to NEAs, which serve as representative targets for future human exploration, are critical.

The NEA Scout project will demonstrate a low-cost capability to perform this precursor robotic mission to a representative Human exploration NEA target and perform in situ observations to address key SKGs. These observations will be achieved using a camera-equipped CubeSat performing a close (<1 km) flyby. To maximize the science return, a variety of potential targets have been identified based upon launch date, time of flight, and rendezvous velocity. This first application of a Cubesat for precursor observation objectives will pave the way for future reconnaissance missions. An artist concept of the NEA Scout can be seen in Figure 1.

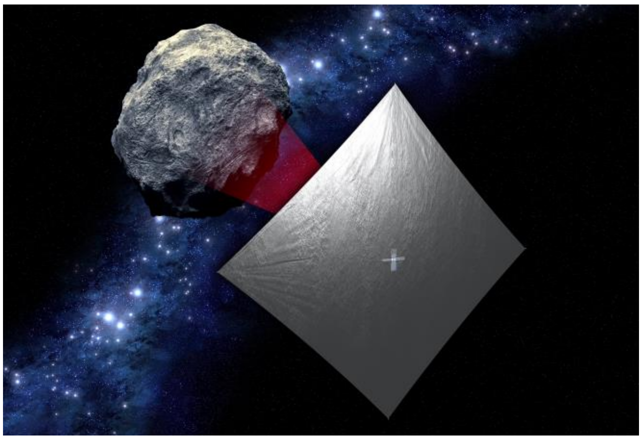

Fig. 1. Artist concept of the NASA NEA Scout during its flyby of Asteroid 1991VG.

2. NEA Scout Mission Concept

The NEA Scout uses a 6U CubeSat form factor, which is being primarily developed by NASA's Jet Propulsion Laboratory, to house a fully functional, though miniaturized, interplanetary spacecraft. The complete NEA Scout spacecraft bus measures 10 cm X 20 cm X 30 cm and weighs less than 14 kilograms. It will be propelled by an 86 m^2 solar sail that is described in more detail below.

The spacecraft will be placed on an Earth escape trajectory by the upper stage of NASA's SLS during its maiden flight in 2018. The primary mission for the flight is a test of the Orion crew capsule, which will be sent into a lunar flyby before it returns to Earth. Within the Multi-Purpose Crew Vehicle (MPCV) Stage Adapter (MSA) are 13 individual CubeSat deployers, each containing a separate 6U spacecraft with their own unique mission requirements. After the Orion is deployed, the 13 CubeSat secondary payloads carried on the rocket will be deployed, one by one, from the MSA. To minimize risk to the SLS, all of these secondary payloads will be launch inert.

The NEA Scout will be ejected from the MSA once the Orion spacecraft is separated from the SLS upper stage and on its way to the moon. Most likely, NEA Scout will be tumbling as a result, and the onboard attitude control system will use cold gas thrusters to stabilize the spacecraft and provide ΔV sufficient for a lunar flyby. Next, its solar panels and antenna will deploy to allow communication with Earth and to recharge the batteries, as needed. Following a lunar flyby, the solar sail will deploy and spacecraft checkout will begin.

The NEA Scout will remain in the lunar vicinity until the low-thrust trajectory to the destination asteroid, 1991VG, can be attained. The spacecraft will then begin its 2.0 – 2.5 year journey to the asteroid. About one month before the asteroid flyby, NEA Scout will pause to search for the target and start its Approach Phase using a combination of radio tracking and optical navigation. The solar sail will provide continuous low thrust to enable a relatively slow flyby (10-20 m/s) of the target asteroid under lighting conditions favorable to geological imaging (<50 degree phase angle). The NEA Scout concept of operations can be seen in Figure 2. Once the flyby is complete, and if the system is still fully functioning, an extended mission will be contemplated, perhaps leading to the reconnaissance of another asteroid or a re-flyby of 1991VG several months later.

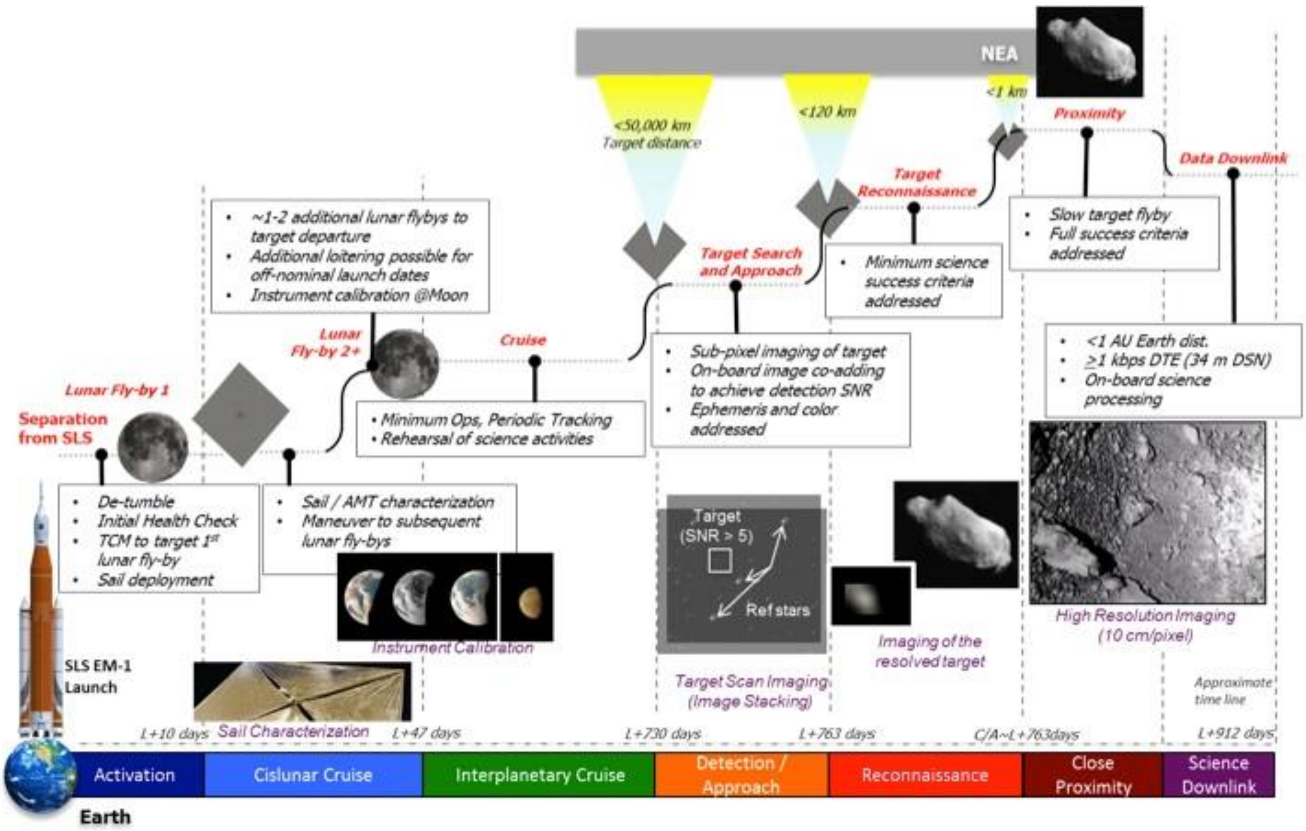

Fig. 2. The NASA NEA Scout will launch from the Space Launch System in 2018 can perform reconnaissance of an asteroid approximately two years later.

3. Science

When thinking of sending people to an asteroid, key properties of the target need to be quantified in order to assess and mitigate risk and optimize operations. Many of these properties can be addressed by simple photo-reconnaissance of the target. One of the most important of these factors is the ephemeris of the target on short and long timescales. Rotational properties are also critical to risk assessment: NEAs can rotate as fast as a few rpms and even tumble about multiple axes.

These conditions present significant hazards in planning and executing proximity operations, especially operations that must be carried out over extended time periods. Another consideration is the physical state of the asteroid itself. Is the surface stable? Does it offer smooth areas for the landing of spacecraft and crew? Does it appear strong enough to support anchoring? Is the asteroid in one piece or is it made of multiple smaller rocks? A coherent structure is unlikely to rearrange its configuration in response to a push by an astronaut or a hardware deployment and will provide a much easier surface in which to plant anchors for astronaut mobility or to hold equipment to the surface. Related to the mechanical nature of the surface, the local environment of an asteroid can present significant hazards, for example the presence of lofted dust or debris ejected upon micrometeorite impacts. The spheres of influence of small NEAs are weak and cannot retain dust and debris for extended periods of time. However, micrometeorite impacting in a timeframe relevant to a precursor mission or crewed mission can create a temporary cloud.

These unknowns and more can be answered by imaging the global morphology at various scales, and under multiple phase angles, to search for landslides, surface overturn, signatures of recent micrometeorite impacts, or crater evolution. Characterization of the local dust environment at the target is also indirect information on the response of the surface to micrometeorite impacting. High-resolution surface imaging will yield critical information on the nature of the regolith, and help forewarn hazards, e.g. the presence of find dust, sharp edges, or points that might result from fractured, glassy impact debris.

During the flyby, NEA Scout's camera will image the resolved asteroid at high and low resolution and make the following measurements:

- Shape and global geomorphology.
- Spin rate, pole position, and tumbling behavior (vs. sing-axis rotation).
- Photometric properties of the target via accurate reflectance measurement.
- Dust and debris density in the vicinity of the target via combination of images obtained for short and long exposures.
- Surface roughness down to 10 cm/pixel resolution for regolith characterization at scales relevant to crew.

NEA Scout's scientific investigations will benefit from other NASA-funded survey activities, e.g., NEO Program Office and ground-based observatories. The study will also leverage expertise gathered in the AES-sponsored Solar Exploration and Research Virtual Institute (SSERVI).

4. Solar Sail Propulsion System

NEA Scout's solar sail will be a single sail deployed on four 6.8 m booms from the center 2U of the 6U spacecraft. [3] The solar sail subsystem consists of a single 86 m^2 colorless polymer (CP1), 2.5 micron thick aluminized sail that will sit on top of and be deployed by 4 Elgiloy (a stainless steel alloy) booms. The boom deployers consist of 2 boom spools, each containing 2 booms. The deployer and booms are based on the successful Nanosail-D solar sail deployer system. However, NEA Scout will deploy a single sail instead of the 4-quadrant sail used by NanoSail-D. The change was made due to the significant thermally-induced deflections of the booms when exposed to full sunlight. The single sail design provides full shade for the booms, eliminating the thermal deflection as a concern. A full-scale solar sail deployment test conducted at NASA MSFC can be seen in Figure 3.

Fig. 3. A full-scale solar sail deployment test at NASA MSFC. A half-scale solar sail can be seen displayed vertically in the background.

The NEA Scout's Reaction Control System (RCS) consists of a set of reaction wheels and uses a slow roll about the solar sail's normal axis to handle attitude control and adjust for imperfections in the deployed sail during the mission. Due to a significant anticipated offset in center-of-mass (CM) and center-of-pressure (CP), an Active Mass Translator (AMT), residing near the geometric center of the spacecraft, was added to the design. [4] Sail flatness, tears in the sail, and asymmetry cannot be quantified until after deployment, and therein lies the concern driving the development of the AMT. NEA Scout's estimated CP/CM offset is large enough (about 2 cm at beginning of mission, 4 cm at end of mission) to overload the control systems and requires a mechanical system to adjust the center of mass and trim the spacecraft. The small forces resulting from the offset also create disturbance torques caused by misalignments in the CM and CP. Although the CM and inertial properties can be easily measured or calculated, the CP of the solar sail is less exact. The AMT can adjust the CM relative to the CP by moving one portion of the flight system relative to the other in the X and Y directions, as needed.

5. NEA Scout Spacecraft

The NEA Scout spacecraft is housed in a '6U' CubeSat form factor and is subdivided into three modules: Avionics, Solar Sail/AMT, and RCS. The Avionics Module houses the majority of the spacecraft electronics and Attitude Determination and Control System (ADCS). The AMT and Solar Sail Module houses all of the components necessary to deploy and operate the solar sail including management of the accumulated momentum from solar radiation pressure. The RCS module houses the cold gas reaction control system and the mounting points for the solar panels, one transmission/receive low gain antenna (LGA) pair, a patch array medium gain antenna (MGA), and sun sensors. The electrical wiring between the assemblies is routed through the center of the Solar Sail Assembly and is required to permit translation between the Avionics and Solar Sail Modules through actuation of the AMT. A graphical representation of the spacecraft subsystems and components can be found in Figure 4.

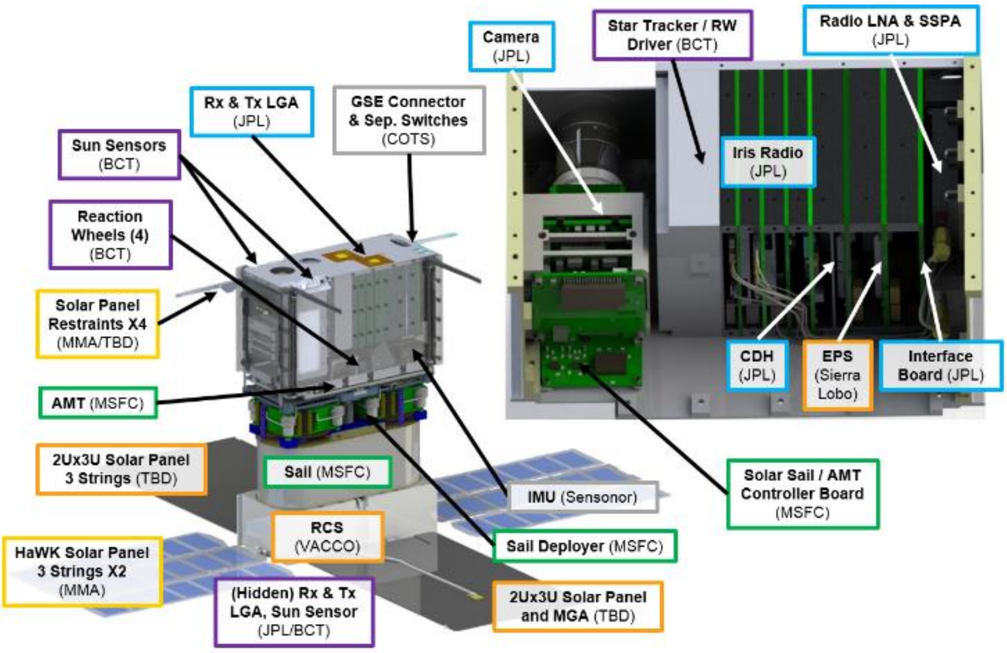

Figure 4. Exploded view of the NEA Scout spacecraft and the major subsystems.

The NEA Scout payload located within the Avionics Module heavily leverages the Orbiting Carbon Observatory 3 (OCO-3) context camera development upgraded for deep space environment and for meeting the more stringent photometric requirements of the NEA Scout mission. The camera will be dual purpose, providing key science data and optical navigation capabilities. The adjacent avionics stack contains all of the electronic boards necessary to control the spacecraft functions including command and data handling (C&DH), electrical power system (EPS), transponder, and interface boards. The electrical power system is spread across the Avionics and the RCS Modules and includes deployable solar panels, two tri-fold arrays and two 2x3U panels. Power generated by the panels is routed through the Solar Sail/AMT Module to the power control boards located in the avionics stack. This power is also used to recharge the battery pack located in the Avionics Module. The telecom system consists of the IRIS transponder located in the avionics stack, two low gain antenna pairs (LGAs), and one medium gain antenna (MGA). The Z+ LGA antenna is located in the Avionics Module while the Z- LGA is located in the RCS Module. Both provide omnidirectional coverage early in the mission. The MGA, used later in the mission, is located on a solar panel and consists of an 8x8 patch array. The spacecraft ADCS is made up of the reaction wheels, reaction wheel controller, star tracker, various sun sensors, AMT, and RCS. Collectively, the ADCS components maintain the desired thrusting attitude and perform momentum management in a manner that minimizes the use of expendable propellant.

6. Conclusion

NEA Scout will demonstrate the feasibility of using a low-cost, solar sail propelled CubeSat on an asteroid reconnaissance mission.

It will not provide the comprehensive science knowledge of a more traditional and costly science-focused mission, but it will provide much of the information required for deciding whether or not to send humans. Mission planners will then have the capability to send affordable reconnaissance missions to multiple targets of interest.

Acknowledgments

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