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## Near Earth Asteroid Scout: Exploring Asteroid 1991VG Using A Smallsat

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### Abstract

After its deployment from NASA's Space Launch System (SLS) in 2020, the Near Earth Asteroid (NEA) Scout mission will image an asteroid on a close flyby using an 86m<sup>2</sup> solar sail as its primary propulsion. NEA Scout, with a 6U CubeSat form factor, is one of several secondary CubeSat payloads to be deployed from the SLS on its maiden flight. The NEA Scout will be ejected from the SLS on a trajectory toward the moon and will use its onboard cold gas propulsion system to attain an elliptical lunar orbit. Once the spacecraft is in orbit, 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, or another NEA of interest, 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 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). Once the flyby is complete, and if the system is still fully functioning, an extended mission will be considered – the reconnaissance of another asteroid or a re-flyby of the first asteroid several months later are both options. NEA Scout is funded by the NASA Human Exploration and Operations Mission Directorate.

**Keywords:** Near Earth Asteroid, Near Earth Asteroid Scout, Solar Sail, CubeSat

### Acronyms/Abbreviations

Center-of-Mass (CM)  
Center-of-Pressure (CP)  
Ground Support Equipment (GSE)  
Jet Propulsion Laboratory (JPL)  
Low Gain Antenna (LGA)  
Marshall Space Flight Center (MSFC)  
Medium Gain Antenna (MGA)  
Multi-Purpose Crew Vehicle (MPCV) Stage Adapter (MSA)  
National Aeronautics and Space Administration (NASA)  
Near Earth Asteroid (NEA)  
Orbiting Carbon Observatory 3 (OCO-3)  
Reaction Control System (RCS)  
Reaction Wheels (RW)  
Space Launch System (SLS)  
Strategic Knowledge Gaps (SKGs)

- By accelerating along the existing velocity vector, the orbital energy of the spacecraft is increased, thereby spiralling it away from the Sun.
- By accelerating opposite to the velocity vector, the orbital energy decreases, spiralling inward toward the sun.
- By accelerating out of the orbital plane, the sail can change inclination.
- By carefully managing attitude control, the sail can perform station-keeping in a desired location near-indefinitely.

### 1. Introduction

Solar sails have the potential to provide high  $\Delta V$  for many types of missions. Solar sails are large, mirror-like structures made of a lightweight material that reflects sunlight to propel the spacecraft. The continuous solar photon pressure provides thrust with no need for the heavy, expendable propellants used by conventional chemical and electric propulsion systems. Solar sails can access many novel orbits by virtue of this unique propulsion method (Figure 1):

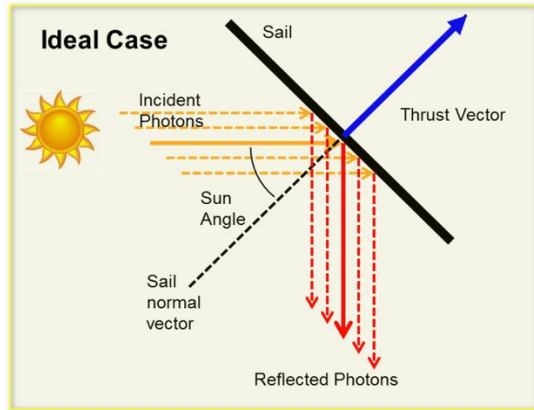


Figure 1. Solar sails are propelled by reflecting sunlight and may change the net thrust vector by orienting the sail relative to the sun.

Using a solar sail, the NASA Near Earth Asteroid (NEA) Scout mission will perform reconnaissance of an asteroid, characterizing it for possible future human exploration, and demonstrate the capability of an extremely small spacecraft to do so at a relatively low cost. Based on the solar sail technology developed and flown by the NASA NanoSail-D2 [1], the NEA Scout mission is funded by NASA's Human Exploration and Operations Mission Directorate (HEOMD) and managed by NASA Marshall Space Flight Center. NEA Scout will be launched on the first flight of NASA's Space Launch System (SLS) in 2020, called Artemis 1.

Asteroids are among the destinations to which it is technically feasible to send people within the next 25 years. In order to minimize risk to any future human crew, NASA would like to send at least one robotic surveyor mission to a candidate asteroid before committing to send people there.

HEOMD identified key Strategic Knowledge Gaps (SKGs) that must be addressed prior to sending humans to a NEA [2]. Given our limited knowledge of asteroids less than 100 meters across and the limited ability of ground-based assets to address these key SKGs, robotic precursor missions to NEAs are an attractive option for characterizing them.

Using a small, space-qualified camera, NEA Scout will image the asteroid during a close (<1/2 km) flyby. The use of a solar sail alleviates mission dependence on launch windows, but it does not eliminate some dependence on phasing and launch timeframe. To reduce overall mission risk, additional asteroid targets have been identified and are being planned for. Regardless of when Artemis 1 launches, an asteroid of interest will likely be within the reach of NEA Scout. An artist concept of the NEA Scout can be seen in Fig. 2.

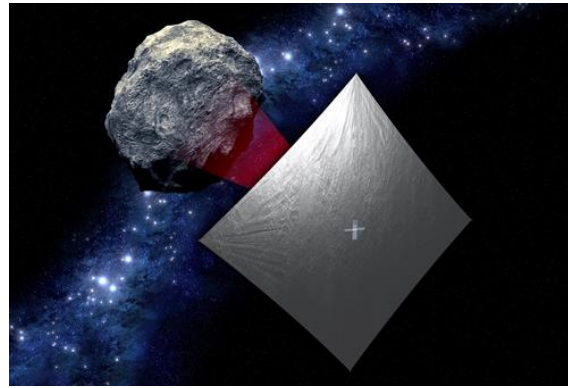


Figure 2. Artist concept of the NEA Scout spacecraft as it flies slowly by the target asteroid (~10 km/sec).

## 2. Mission Concept

Modelled on the industry-standard CubeSat form factor, NASA's Jet Propulsion Laboratory (JPL) developed the NEA Scout spacecraft bus. NEA Scout measures 11 cm x 24 cm x 36 cm and weighs less than 14 kilograms. Though it is the size of a 6U CubeSat, the NEA Scout is a fully functional, though miniaturized, interplanetary spacecraft, including its 86 m<sup>2</sup> solar sail.

The NEA Scout will be launched as a secondary payload on NASA's Artemis 1 mission. The rocket, NASA's SLS, will place the spacecraft on an Earth escape trajectory. NEA Scout is one of thirteen individual CubeSats carried by the SLS's Multi-Purpose Crew Vehicle (MPCV) Stage Adapter (MSA) to be ejected from the SLS after it sends the Orion crew capsule on its way to the Moon.

The NEA Scout spacecraft will be powered on by separation switches that will be toggled upon its deployment. Onboard cold gas thrusters will stabilize the spacecraft and point it toward the sun, maximizing power generation and enabling two-way communication. The thrusters will then provide initial  $\Delta V$  capability to target a lunar flyby. The solar sail will deploy after the lunar flyby, and characterization of the solar sail thrust and torque generation will begin.

The NEA Scout will remain near the Moon until the low-thrust trajectory to the target asteroid can be initiated. The original target, 1991VG, is no longer a viable candidate, due to the mismatch of its orbit with the likely launch window of the SLS. Other candidates, such as 2013WA44, are being considered. Flight time to the asteroid is anticipated to be 2.0 - 2.5 years. One month before reaching the asteroid, NEA Scout will begin the 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 with a <50 degree phase angle, in order to provide lighting conditions conducive to geological imaging. Once the flyby is complete, and if the system is still fully functioning, an extended mission to another asteroid can be considered, thanks to

the unique capabilities of the solar sail propulsion system and its essentially infinite  $\Delta V$  capabilities. (Subject to the remaining propellant available for the attitude control system and long duration of radiation exposure of select components.)

### 3. Solar Sail Propulsion System

The NEA Scout's 86 m<sup>2</sup> solar sail is made from an aluminized polymer (CP1) 2.5 micron thick that will rest on, and be deployed by, four 6.8-m Elgiloy stainless steel booms, which will extend from the center of the spacecraft. When stowed, the sail and booms occupy approximately 1/3 of the total spacecraft volume. The boom deployers consist of two boom spools, each containing two booms. Based on the successful Nanosail-D2 solar sail deployer system, the NEA Scout deployers are scaled for greater boom lengths and are retrofitted with sensors to gauge deployment progress and the state of the spooled booms. NEA Scout's sail is a single sail instead of the more traditionally-considered 4-quadrant sail. The single sail design was baselined due to the significant thermally-induced deflections of the booms when they were exposed to sunlight. Their deformations would have impacted thrust magnitude and vector. The single sail design provides full shade for the booms, minimizing the thermal deflection and reducing risk [3]. A full-scale solar sail folded and rolled prior to a test deployment can be seen in Fig. 3.

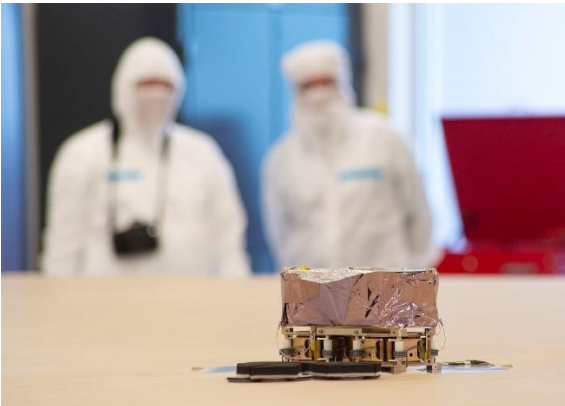


Figure 3. The 86 m<sup>2</sup> NEA Scout flight sail folded and rolled, awaiting its final deployment test.

An Active Mass Translation (AMT) device was added to the design to compensate for an initial offset in Center-of-Mass (CM) and Center-of-Pressure (CP) and a requirement to minimize or eliminate momentum generation while sailing at various attitudes. When combined with sail irregularities such as sail flatness uncertainties, tears in the sail stemming from deployment, micrometeoroids or simple design anomalies, the sail thrust vector alignment to the spacecraft CM will vary with the spacecraft's attitude relative to the solar incidence angle. The AMT will translate roughly half of

the spacecraft relative to itself along two axes and change the CP/CM relationship. This will enable the desired range of flight angles and maximize the use of the limited on-board propellant, momentum generation and minimize any required desaturations of the reaction wheels.

The full NEA Scout flight sail was deployed and tested in the summer of 2018 (Figure 4).

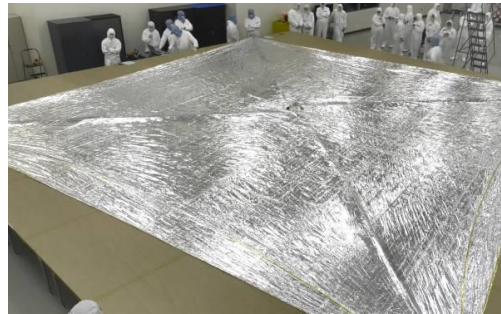


Figure 4. The fully-deployed NEA Scout solar sail undergoing its final pre-flight checkout.

### 4. Mission Science

NEA Scout will address key SKGs that will help reduce risk and facilitate operational planning for a future mission to an asteroid measuring less than 100m across. Asteroids in this range have not yet been explored by spacecraft. Imaging with a science-grade camera will yield the asteroid's global shape and regional morphology, its rotational properties, albedo, a characterization of the target's immediate environment (dust, debris), and high resolution imaging of the surface at closest approach for regolith characterization. The flyby velocity will allow observations of the asteroid for well over an hour. This information will help assess the strength of the surface for geotechnical purposes, as well as slope stability.

Figure 5 (see end) shows the NEA Scout mission profile and timeline from launch to decommissioning, post-flyby.

### 5. NEA Scout Spacecraft

The NEA Scout spacecraft is housed in a 6U (10 cm X 20 cm X 30 cm) CubeSat form factor and is divided into three modules: Avionics, Solar Sail/AMT, and RCS. The Avionics Module houses the majority of the spacecraft electronics and the Attitude Determination and Control System (ADCS). The AMT and Solar Sail Module contains all of the components necessary to deploy and operate the solar sail. 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 must allow translation between the Avionics and Solar Sail Modules when the AMT is operating. A graphical representation of the spacecraft subsystems and components can be found in Figure 6.

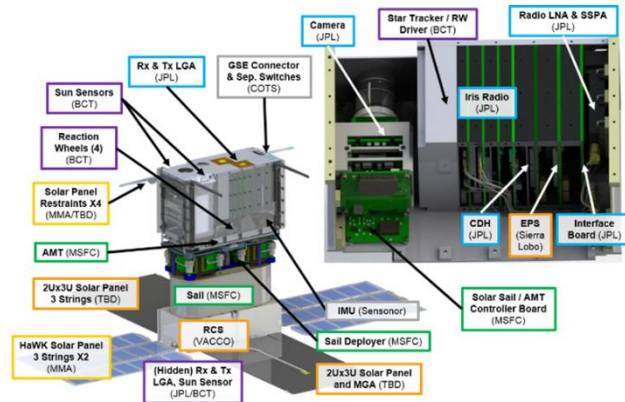


Figure 6. The NEA Scout spacecraft and the major subsystems are highlighted.

The camera is mounted with the avionics and is based on the Orbiting Carbon Observatory 3 (OCO-3) context camera, though it has been upgraded for use in the deep space environment and for meeting the more stringent photometric requirements of the NEA Scout mission. The avionics contains all of the electronic boards necessary to control the spacecraft functions, including command and data handling, the electrical power system, the radio, and all of the interface boards. The electrical power system includes two deployable solar panels. Power generated by the solar arrays is routed to the power control boards located with the avionics. The telecommunications system consists of the JPL-developed IRIS transponder, two LGA pairs, and one MGA. The spacecraft ADCS is made up of the reaction wheels, the reaction wheel controller, the star tracker, various sun sensors, the AMT, and the RCS.

Collectively, the ADCS components maintain the desired thrusting attitude and perform momentum management.

## 6. Conclusions

NEA Scout is a pathfinder. As the USA's first interplanetary solar sail mission, it will demonstrate the ability of a solar sail propulsion system to provide usable  $\Delta V$  for navigating from one heliocentric location to another. In the process, NEA Scout will show the feasibility of using innovative technologies in low-cost spacecraft for interplanetary reconnaissance at a fraction of what most deep space missions cost.

Finally, should NASA decide to send astronauts to an asteroid, the NEA Scout mission will have provided the capability for a low-cost, robust approach to characterizing an asteroid prior to sending humans.

## Acknowledgements

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## References

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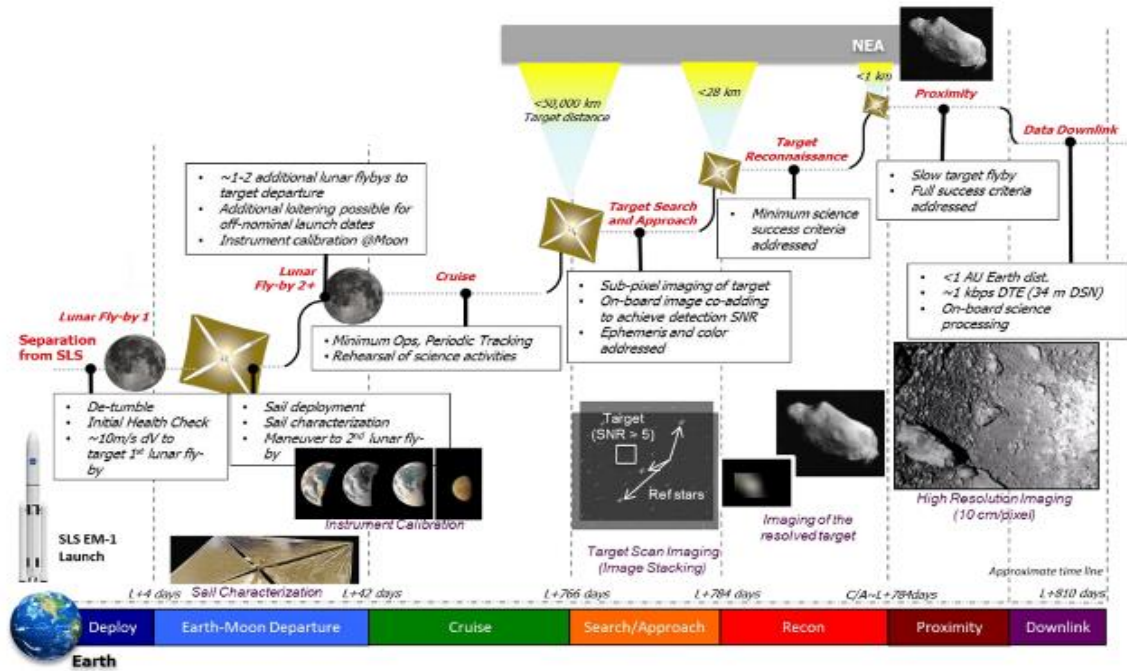


Figure 5. The NEA Scout's 2.5 year mission is shown by phase, from launch through to post-flyby.