Near Earth Asteroid Scout: NASA's Solar Sail Mission to a NEA

Les Johnson[a]*, Julie Castillo-Rogez[b], and Jared Dervan[c]

[a] *Science and Technology Office, NASA George C. Marshall Space Flight Center, Mail Code ST03, Huntsville, Alabama 35812*, les.johnson@nasa.gov
[b] *Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA*
[a] *NASA George C. Marshall Space Flight Center, Mail Code ES11, Huntsville, Alabama 35812*
* Corresponding Author

Abstract

NASA is developing a solar sail propulsion system for use on the Near Earth Asteroid (NEA) Scout reconnaissance mission and laying the groundwork for their use in future deep space science and exploration missions. Solar sails use sunlight to propel vehicles through space by reflecting solar photons from a large, mirror-like sail made of a lightweight, highly reflective material. This continuous photon pressure provides propellantless thrust, allowing for very high ΔV maneuvers on long-duration, deep space exploration. Since reflected light produces thrust, solar sails require no onboard propellant. The Near Earth Asteroid (NEA) Scout mission, funded by NASA's Advanced Exploration Systems Program and managed by NASA MSFC, will use the sail as primary propulsion allowing it to survey and image Asteroid 1991VG and, potentially, other NEA's of interest for possible future human exploration. The NEA Scout spacecraft is housed in a 6U CubeSat form factor and utilizes an 86 m^2 solar sail for a total mass less than 14 kilograms. The mission is in partnership with the Jet Propulsion Laboratory with support from Langley Research Center and science participants from various institutions. NEA Scout will be launched on the maiden flight of the Space Launch System in 2019. The solar sail for NEA Scout will be based on the technology developed and flown by the NASA NanoSail-D and flown on The Planetary Society's Lightsail-A. Four ~7 m stainless steel booms wrapped on two spools (two overlapping booms per spool) will be motor driven and pull the sail from its stowed volume. The sail material is an aluminized polyimide approximately 2.5 microns thick. As the technology matures, solar sails will increasingly be used to enable science and exploration missions that are currently impossible or prohibitively expensive using traditional chemical and electric propulsion systems. This paper will summarize the status of the NEA Scout mission and solar sail technology in general.
Keywords: Near Earth Asteroid, Near Earth Asteroid Scout, Solar Sail, CubeSat

Acronyms/Abbreviations

Active Mass Translator (AMT)
Center-of-Mass (CM)
Center-of-Pressure (CP)
Exploration Mission (EM)
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)

1. Introduction

Propelled by 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 very 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 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 2019 called Exploration Mission (EM) 1.

In addition to the Moon and Mars, 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. In the 1960's, NASA's *Surveyor* Program performed robotic reconnaissance of the moon before

Apollo [2]. Today's robotic spacecraft are surveying Mars for possible future human visits.

The Human Exploration & Operations Mission Directorate (HEOMD) has identified key Strategic Knowledge Gaps (SKGs) that must be addressed prior to sending humans to a NEA [3]. Given the limited in situ knowledge of asteroids in the 10-100 m size range and the limited ability of ground-based assets to address the key SKGs, robotic precursor missions to NEAs are critical.

The NEA Scout is outfitted with a camera that will image the target asteroid during a close (<1 km) flyby. Small spacecraft are inherently limited in the amount of propellant they can carry, hence hampering their ability to adapt to new launch windows and still reach their targets. While the use of a solar sail alleviates this considerably, it does not eliminate some dependence on phasing and launch timeframe. To reduce overall mission risk, two asteroid targets have been identified. Regardless of when EM-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. 1.

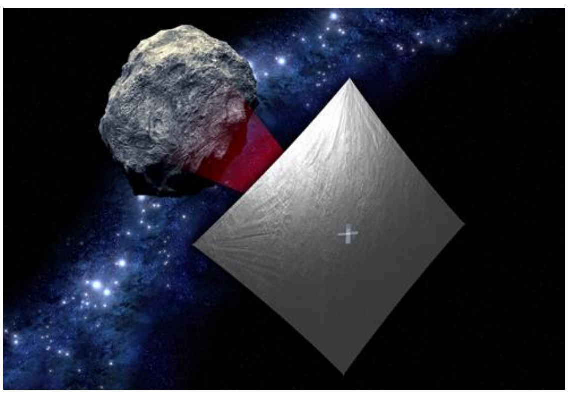

Fig. 1 Artist concept of the NEA Scout spacecraft during the asteroid rendezvous.

2. Mission Concept

NASA's Jet Propulsion Laboratory (JPL) is developing several very small interplanetary spacecraft modelled on the industry-standard CubeSat form factor. NEA Scout will use the 6U form factor, measuring 11 cm x 24 cm x 36 cm and weighing less than 14 kilograms. Though it is the size of a CubeSat, the NEA Scout is a fully functional, though miniaturized, interplanetary spacecraft. It will be propelled by an 86 m^2 solar sail, described below.

The NEA Scout will be launched and placed on an Earth escape trajectory by the upper stage of NASA's SLS on its maiden flight in 2019. NEA Scout is one of thirteen individual CubeSats housed in the SLS's Multi-Purpose Crew Vehicle (MPCV) Stage Adapter (MSA) to be ejected from the SLS after its primary mission, the launching of the Orion crew capsule, is complete.

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. The NEA Scout spacecraft will be launched powered-off, utilizing separation switches that, once toggled upon deployment from the CubeSat dispenser, will power on the spacecraft. The spacecraft's onboard attitude control system will use cold gas thrusters to stabilize the spacecraft and sun-point, maximizing power generation and enabling two way communication. The thrusters will then provide initial ΔV capability to target a lunar flyby. Following a lunar flyby, the solar sail will deploy 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 baselined destination asteroid, 1991VG, can be initiated. Flight time to the asteroid is anticipated to be about 2.5 years. One month before reaching the asteroid, 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 with a <50 degree phase angle in order to provide lighting conditions conductive 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 ΔV capabilities. (Subject to the remaining propellant available for the attitude control system and long duration radiation exposure of select components.)

3. Solar Sail Propulsion System

NEA Scout's solar sail consists of a single 86 m^2 colorless polymer (CP1), 2.5 micron thick aluminized material that will rest on and be deployed by 4, 6.8-m Elgiloy stainless steel booms. The booms will slowly deploy from the center of the spacecraft consisting of approximately 1/3 of the total volume. The boom deployers consist of 2 boom spools, each containing 2 booms. The deployer and booms are based on the successful Nanosail-D2 solar sail deployer system, scaled for greater lengths, and retrofitted with sensors to gauge deployment progress and state of the spooled booms. NEA Scout's sail differs from other square solar sails in that it is a single sail instead of the more traditionally-considered 4-quadrant sail. The change was made due to the significant thermally-induced deflections of the booms which impact thrust magnitude and vector when exposed to full sunlight. The single sail design provides full shade for the booms, minimizing the thermal deflection and reducing risk [4]. A full-scale solar sail folded and rolled prior to a test deployment can be seen in Fig. 2.

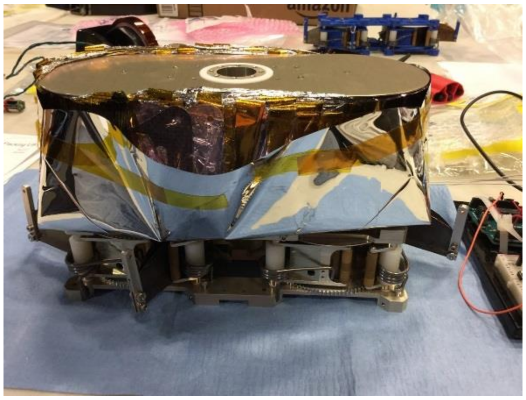

Fig. 2. A full-scale, 86 m^2 NEA Scout solar sail folded and rolled, awaiting a deployment test.

Due to a 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 numerous attitudes, an Active Mass Translator (AMT) device was added to the design. Coupled with sail irregularities such as sail flatness uncertainties, tears in the sail stemming from deployment anomalies or micrometeriods, and asymmetry, the sail thrust vector alignment to the spacecraft CM will vary with the spacecraft's attitude relative to the solar incidence angle. In order to enable the desired range of flight angles and maximize the use of the limited on-board propellant, momentum generation and any required desaturations of the reaction wheels must be minimized. Therefore, the AMT was incorporated to translate roughly half of the spacecraft relative to itself in two axes ultimately changing the CP/CM relationship. This system is operated on closed-loop control, permitting autonomous adjustment to building disturbance torques. The flexibility offered by this functionality is necessary to enable a deep space mission with more limited communication opportunities and considerations of round-trip light time. A full-scale deployment test of a development sail is seen in Fig. 3.

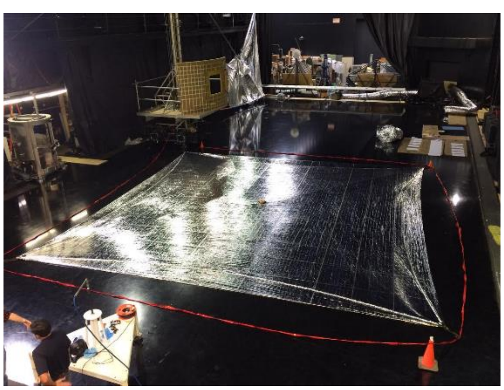

Fig. 3. A fully-deployed test sail at NASA MSFC.

4. Asteroid Science

Asteroids in the 10 to 100 m range have not been explored by spacecraft. They are believed to be fast rotators and too small to retain a fine-grained, dusty regolith, but otherwise very little is known about these bodies.

NEA Scout will address key SKGs that will help reduce risk and facilitate operational planning for a future mission to an asteroid in the 10-100 m range. Imaging with a science-grade camera for a total of about 2.5 hours (thanks to the low relative velocity) 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. This information will help assess the strength of the surface for geotechnical purposes, as well as slope stability.

5. Spacecraft

To call the NEA Scout a CubeSat would be a dramatic understatement. While it is true that the spacecraft shares the same form factor (6U) as a conventional, Earth-orbital CubeSat, this is where the similarity ends. NEA Scout is a fully functional, single-string interplanetary spacecraft designed to operate in deep space for at least 2.5 years.

The NEA Scout spacecraft is divided into three modules: Avionics, Solar Sail Propulsion System, and RCS. The Avionics Module contains imager and the majority of the spacecraft electronics and Attitude Determination and Control System (ADCS). The Solar Sail Propulsion System includes all of the components necessary to deploy and operate the solar sail, including management of the accumulated momentum from solar radiation pressure. The RCS section contains the cold gas reaction control system, mounting points for the solar panels, a low gain antenna (LGA) transmit and receive pair, a solar panel integrated medium gain antenna (MGA), and sun sensors. The electrical wiring between the assemblies is routed through the center of the spacecraft where the solar sail is mounted. This is required to allow translation between the Avionics and Solar Sail Modules through actuation of the AMT. A graphical view of the spacecraft can be found in Figs. 4 and 5.

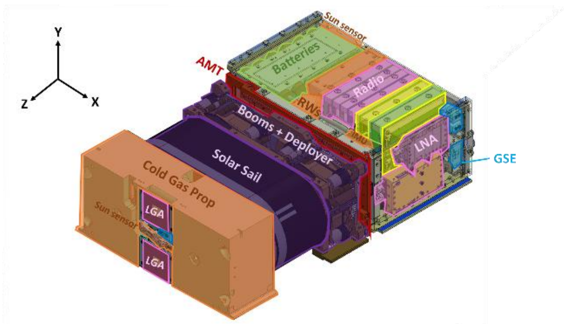

Fig. 4. Component view of the NEA Scout spacecraft (stowed configuration).

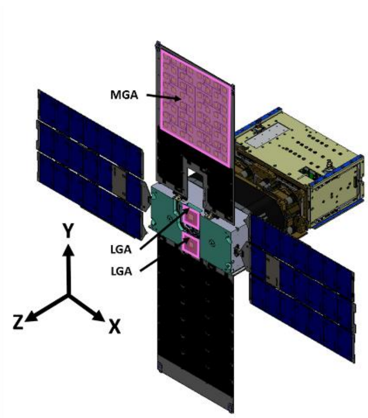

Fig. 4. Component view of the NEA Scout spacecraft (antennas and solar arrays deployed configuration).

NEA Scout's camera is mounted with the avionics. The camera 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 camera will provide observational data and support optical navigation capabilities. 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, two tri-fold arrays and two 2U x 3U panels. Power generated by the panels is routed through the Solar Sail Propulsion System to the power control boards located with the avionics. Spacecraft generated power will be used to recharge the batteries, also 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, reaction wheel controller, star tracker, various sun sensors, AMT, and RCS. Collectively, the ADCS components maintain the desired thrusting attitude and perform momentum management.

6. Conclusions

NEA Scout will demonstrate the feasibility of using innovative technologies in low-cost spacecraft for interplanetary reconnaissance at a fraction of what traditional deep-space spacecraft missions cost.

NEA Scout will not provide the same quantity or quality of science as these more robustly funded missions, but it will provide enough data for mission planners to assess the viability of an asteroid target for future human exploration.

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