Near-Earth Asteroid Scout

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Near-Earth Asteroids (NEAs) are an easily accessible object in Earth's vicinity. Detections of NEAs are expected to grow in the near future, offering increasing target opportunities. As NASA continues to refine its plans to possibly explore these small worlds with human explorers, initial reconnaissance with comparatively inexpensive robotic precursors is necessary. Obtaining and analyzing relevant data about these bodies via robotic precursors before committing a crew to visit a NEA will significantly minimize crew and mission risk, as well as maximize exploration return potential. The Marshall Space Flight Center (MSFC) and Jet Propulsion Laboratory (JPL) are jointly examining a mission concept, tentatively called 'NEA Scout,' utilizing a low-cost CubeSats platform in response to the current needs for affordable missions with exploration science value. The NEA Scout mission concept would be a secondary payload on the Space Launch System (SLS) Exploration Mission 1 (EM-1), the first planned flight of the SLS and the second un-crewed test flight of the Orion Multi-Purpose Crew Vehicle (MPCV)

Nomenclature

AU	=	Astronomical Unit (roughly the distance from the Earth to the Sun; 1.4960×10^{11} m)
GSD	=	Ground Sampling Distance
NHATS	=	Near-Earth Object Human Space Flight Accessible Targets Study
NHATS target	=	Target relevant for future human exploration
m	=	meter
mNm	=	millinewton-meter
µm	=	micrometer
Px	=	pixel
SNR	=	Signal to Noise Ratio

I. Introduction

The NEA Scout project proposes to analyze, design, develop, and fly a controllable solar sail spacecraft, capable of encountering Near-Earth Asteroids (NEAs). The goal is to develop a capability that can retire knowledge gaps at a NEA identified as human exploration target by Human Exploration and Operations Mission Directorate (HEOMD). Observations will be achieved using a Cubesat performing a close (~10km) flyby, equipped with a camera. To maximize the science return, a variety of potential targets will be identified based upon launch date, time of flight, and rendezvous velocity. This first application of a Cubesat for precursor observation objectives will pave

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the way for future reconnaissance missions. The spacecraft architecture of the proposed Cubesat follows the CubeSat design mentality and approach, and is primarily based on the use of Commercial Off-the-Shelf (COTS) parts. Screening and testing of the COTS components allows for a more reliable design and added material to the bus structure will provide adequate shielding for these components. The NEA Scout mission will use NASA's Deep Space Network as the primary component for communications and tracking. As plans for the Mission Operations System and Ground Data System evolve, other ground stations may be used to augment or supplement these functions. NEA Scout is manifested as a secondary payload on SLS EM-1 mission, scheduled to launch in December 2017.

II. Relevance to Human Space Flight

A. Exploration Objectives

The goal of the investigation is to measure the physical properties of a Near-Earth Object Human Space Flight Accessible Targets Study (NHATS) target with the purpose of addressing key strategic knowledge gaps (SKGs) as defined in the report delivered to HEOMD (Rivkin et al. 2012[i]) that serves as a reference for the official SKG database (Connolly 2014[ii]).

The derived measurement requirements are fully aligned with the highest priority SKGs as a function of the risk these gaps represent to the safety, mission operations, performance, and cost of a crewed mission (Tables 1 and 2).

Table 1. Strategic Knowledge Gaps NEA Scouts Objectives. *Based on the Rivkin et al. (2012) report and the SKG Database (J. Connolly, January 8, 2014 version.*

SKG Summary Title	ID (from Connolly 2014) / SKGAT ID	Measurement Addressed by NEA Scout
NEO Orbit Distribution	SBAG SKG 1.B / 39.0	Target ephemeris (position/prediction)
NEO Composition/Physical Characteristics	SBAG SKG 1.C / 41.0	Global physical properties Rotation rate and pole position Mass/Density
Particulate Environment	SBAG SKG 2.A / 44.0	Mapping of particles and debris field in target vicinity
NEO Water Resources	SBAG SKG 2.A / 42.0	Albedo and asteroid spectral type
Local and Global Stability	SBAG SKG 3.D / 47.0	Surface morphologies and properties
Small Body Surface Mechanical Properties	SBAG SKG 4.C / 50.0	Regolith properties Regional and local morphology

Table 2. *Contribution of NEA Scout to retiring key strategic knowledge gaps for Near Earth Asteroids and the benefits of retiring these gaps to support Human exploration of NEAs.*

HEO-Defined Strategic Knowledge Gaps	Expected Performance	Risk Reduction or Benefit
Location (position prediction/orbit)	OCC decrease to 0	Crew/Mission, Operations, Cost
Size (existence of binary/ternary)	High accuracy on size, detection of satellites	Crew/Mission, Operations, Cost, Performance
Rotation rate & pole orientation	High accuracy on pole and velocity	Crew/Mission, Operations, Cost, Performance
Particulate environment/Debris field	Characterization of particle density in target vicinity	Crew/Mission, Operations, Cost, Performance, Science/Engineering
Regolith mechanical & geotechnical properties	*Indirect (imagery interpretation)*	Crew/Mission, Operations, Cost, Performance, Science/Engineering
Mass/density estimates (internal structure)	*Indirect (based on taxonomic characterization)*	Operations, Cost, Performance
Surface morphologies and properties	Morphology at resolution of astronaut's foot	Crew/Mission, Operations, Cost, Performance, Science/Engineering
Mineralogical & chemical composition	*Indirect from taxonomic characterization*	Crew/Mission, Operations, Cost, Performance, Science/Engineering

Crew/Mission Operations Cost Performance Science/Engineering

B. Potential Targets

The NEA Scout Mission Design Team has performed a broad search of possible targets that meet a variety of requirements and in particular the targeted launch date, telecom capability, and lifetime relevant to a Class-D mission (Figure 1 and Table 3).

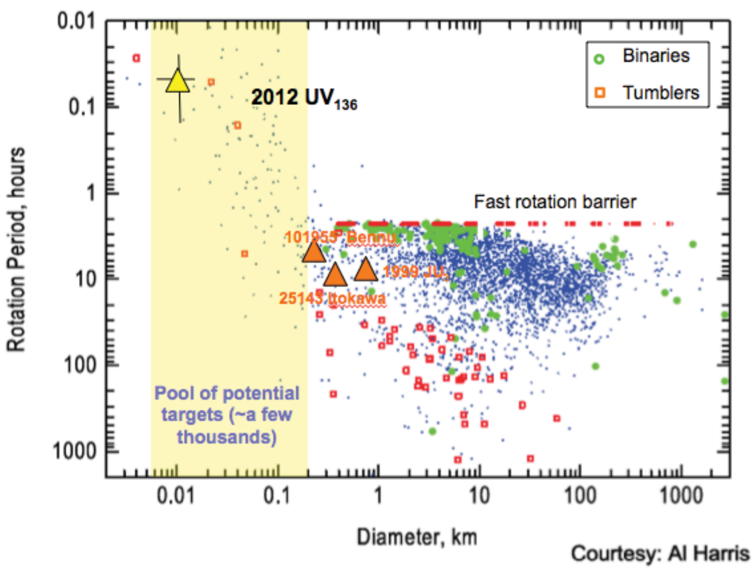


Figure 1. Pool of Potential NEA Targets. *The yellow box shows those considered for NEA Scout with current reference target 1991 VG. Orange triangles point to the targets of the OSIRIS-REx mission (NASA"s New Frontiers program) and JAXA's Hayabusa and Hayabusa 2 missions. Note that the baseline target of the NEA Scout mission is representative of a singular class of objects that has not been explored in situ before.*

Table 3. List of Potential Targets Identified for NEA Scout. *The current baseline target is 1991 VG.*

NEA	Absolute Magnitude	30% albedo Diameter (m)	5% albedo Diameter (m)	Orbit Condition Code	Observation Opportunity Prior to Launch
1991 VG	28.5	5	12	2	2017-07 (Optical)
2001 GP2	26.9	10	25	6	Depends on launch date 2020-10 (Optical)
2013 BS45	25.9	11	51	0	none
2007 UN12	28.7	4	11	4	none
2008 EA9	27.7	7	17	5	none
2012 UV136	25.5	19	47	1	2014-08 (Optical) 2020-05 (RADAR)

Asteroid 1991 VG is being used as a reference for the development of reference trajectories for a nominal launch in December 2017, a mission lifetime shorter than 2.5 yrs, and telecom distance at encounter of less than 0.75 AU. However, we are considering other possible targets as they are discovered.

C. Mission Concept

The science investigations are based on imaging at high and low resolution (Fig. 2). The concept of operations is summarized in Fig. 3. Specifically, NEA Scout will accomplish:

- Astrometric measurements of the unresolved target through accurate positioning
- Characterization of the resolved target through geological imaging
- Characterization of the photometric properties of the target via accurate reflectance measurement in the visible and four color filters

NEA Scout's scientific investigations will benefit from Advanced Exploration Systems (AES)-sponsored asteroid characterization with ground-based RADAR assets as well as other NASA-funded survey activities (e.g., space observatories NEOWISE and *Warm Spitzer*'s *ExploreNEOs* Program, and ground-based observatories). The study will also leverage expertise gathered in the AES sponsored Solar System Exploration and Research Virtual Institute (SSERVI).

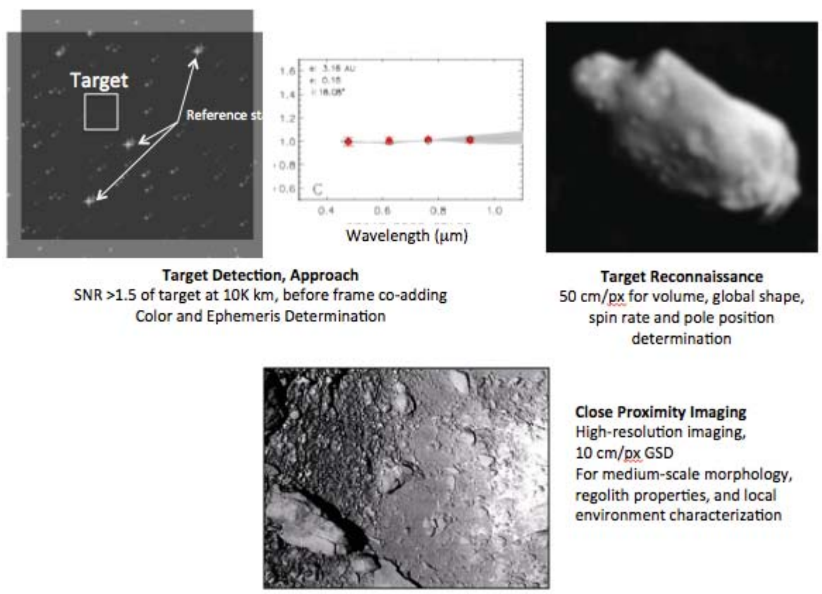


Figure 2. Summary of the Science Observations to be Obtained by NEA Scout.

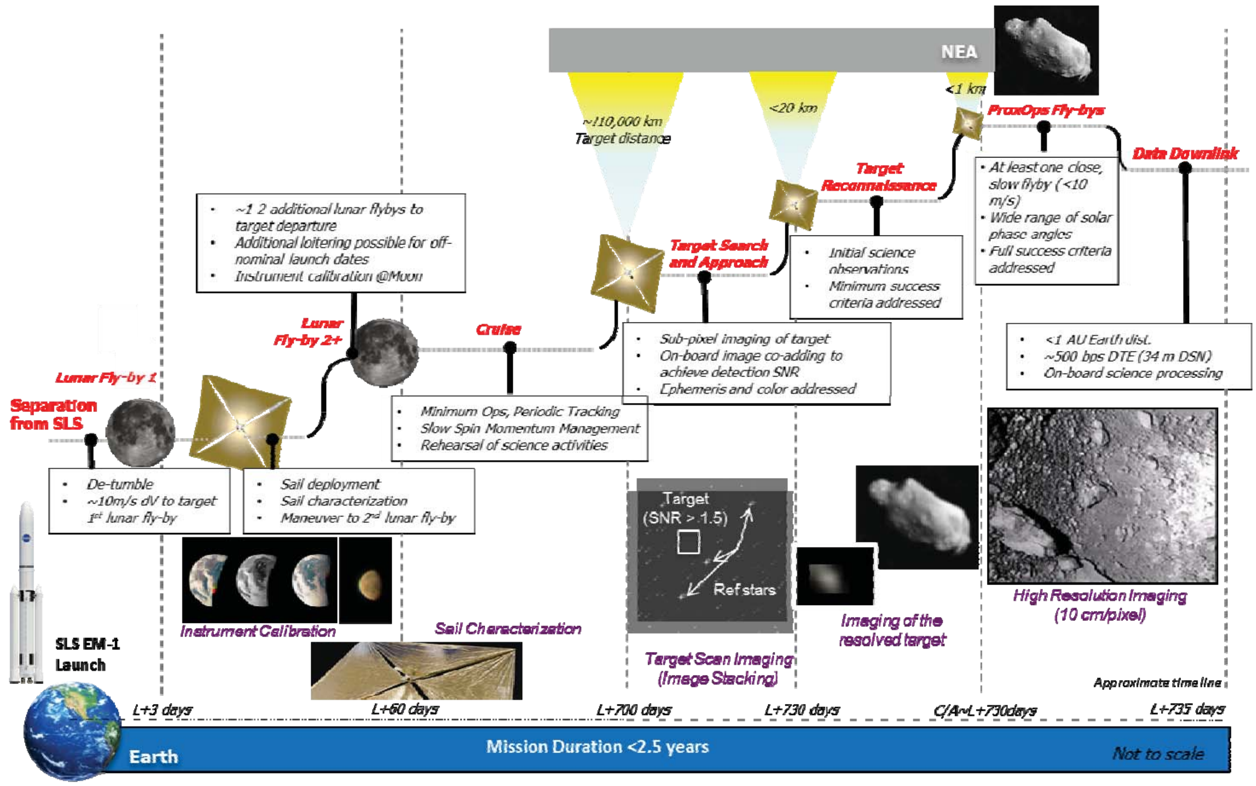


Figure 3. Summary of the Concept of Operations for NEA Scout.

D. Outcomes and Benefits

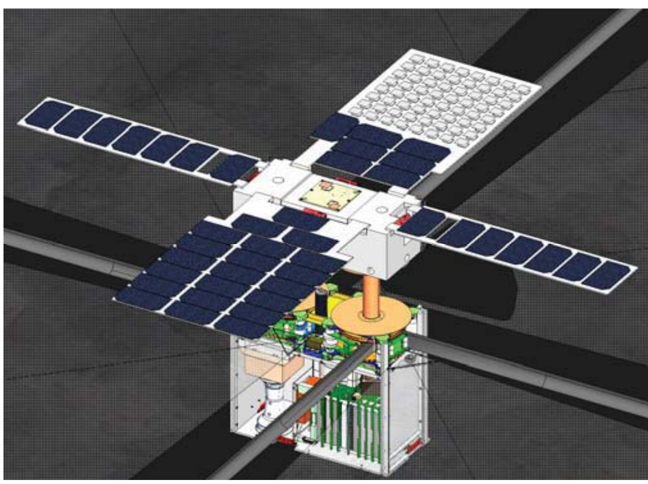
The particular value of this investigation to advancing NASA AES program goals and objectives and the HEOMD Strategic Knowledge Gaps is that it will perform gap-filling activities in a relevant micro-gravity environment, and is thus aligned with the recommendations of the Rivkin et al. report. More generally, the realization of NEA Scout science objectives would represent a milestone for the SKG program and asteroid science with the exploration of the first Near-Earth Asteroid (NEA) in the 1-100 m range. That class of object is poorly characterized due to the challenges that come with detecting, observing, and tracking these small NEAs from Earth for extended periods of time. It has been thought that objects in the 1-100 m size range are fragments of bigger objects. However, it has also been suggested that these objects could actually be rubble-piles. The analysis of the recent disruption in Earth's atmosphere of the small 3-4m large asteroid 2008 TC_3 tends to support the latter model, with the inference of 20-50% macroporosity prior to disruption (e.g., Kohout et al. 2011[iii]). Hence, the characterization of NEAs that are larger than 20 m in diameter is also of great relevance to inform mitigation strategies for Planetary Defense. Finally, the NEA Scout target still represents a relevant proxy whose characterization will help inform the Asteroid Redirect Mission (ARM).

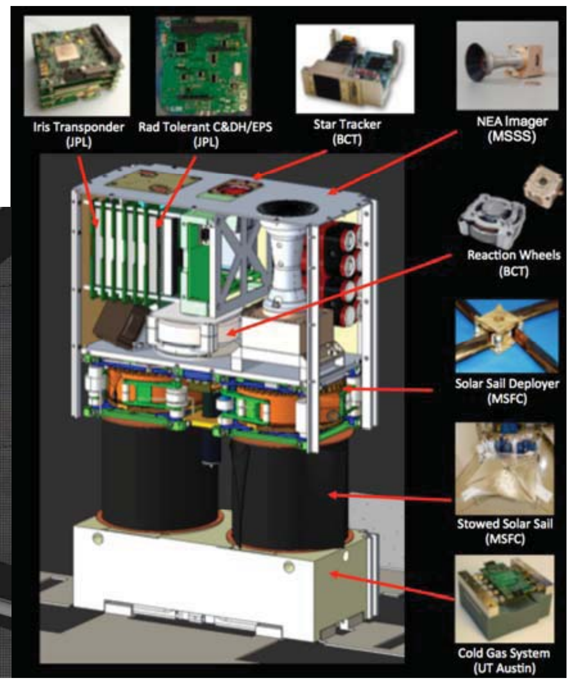
III. Technical Approach

A. Flight System

The NEA Scout flight system is based on a “6U” CubeSat form factor, with a stowed envelope slightly larger than 10x20x30cm and a mass of less than 12 kg, per specifications determined by the deployment system chosen by the launch service provider. The flight system follows a modular configuration, roughly divided into three sections stacked along the longest axis: the avionics module, the solar sail system, and a cold gas propulsion system. The avionics module accommodates a “stack” of typical CubeSat-sized (~10x10 cm) printed circuit boards for the telecommunications, power distribution unit, command and data handling system (C&DH), and a star tracker. This module also includes reaction wheels, batteries, and optical payload, and may be enclosed by additional shielding to manage the total ionizing dose on the most sensitive components. Situated close to the spacecraft center of mass between the cold gas and avionics module is the solar sail propulsion system, which is described in more detail in the corresponding section. The cold gas system is situated below the solar sail and provides detumbling, initial impulsive maneuvers (required for lunar-assisted escape trajectories), and momentum management by desaturating the reaction wheels. Solar arrays are deployed in the plane of the solar sail, which also serves as the mounting location for a planar patch antenna array. The spacecraft configuration, along with reference components is shown in Fig. 4.

Figure 4. *Notional configuration of the NEA Scout flight system with reference components (right), and deployed configuration showing solar panels and patch antenna array (left).*





NEA Scout will leverage experience and hardware developed from JPL’s Interplanetary NanoSpacecraft Pathfinder In Relevant Environment (INSPIRE[iv]) mission, which is slated to become the first CubeSat to operate in Deep Space in 2015. Among systems manifested on INSPIRE, NEA Scout currently intends to leverage JPL’s Iris transponder, providing telecommunications and navigation via the Deep Space Network in the X-Band, Blue Canyon Technologies’ Nano Star Tracker, UT Austin’s Cold Gas System, Lithium batteries, and parts of the watchdog radiation effect mitigation strategy. Due to the longer expected mission duration and processing requirements compared to INSPIRE, NEA Scout is investigating a radiation tolerant C&DH architecture based on the LEON3-FT processor core. Furthermore, the capabilities of the Iris transponder can be upgraded to 2 W RF power output and a scalable (notionally 8 by 8 element, 20x20 cm area) patch array antenna providing approximately 25 dB of gain. The arrayed antenna would serve as a directional high gain antenna and is augmented by two pairs of omnidirectional low gain patch antennas inherited from INSPIRE. With these capabilities, NEA Scout is expected to accommodate an asteroid rendezvous mission with a total duration of up to 2.5 years and at distances approaching 1 AU from Earth. However, the architecture is scalable based on the accessibility of suitable target asteroids during the specified launch period.

NEA Scout is developing a deep-space CubeSat attitude control architecture that responds to the unique attitude control considerations imposed by the solar sail while leveraging commercially available hardware. Detumbling and safing maneuvers rely on an inertial measurement unit, sun sensors, and the system actuators. Momentum management is primarily accomplished by spinning the solar sail slowly about the norm of the sail to average out – over the course of hours – the momentum build up due to any small but persistent offset in the solar sail's center of pressure of the system and the center of mass. In order to avoid spin-stabilizing the system (which would make it more difficult to maneuver) and to enable the system to stop spinning without expending cold gas, a larger (100 mNms) reaction wheel is used to absorb the momentum associated with the spinning sail. Smaller reaction wheels (15 mNms) are used to maneuver and point the spacecraft based on the current slewing/pointing commands. When these wheels saturate, the system uses the cold gas to dump the momentum in the system. Pointing and slewing is accomplished primarily with a star tracker and gyro for attitude knowledge, and the smaller reaction wheels for attitude control. The inclusion of a large flexible body that increases the system's sensitivity to solar radiation torques clearly impacts the Atitude Control System (ACS) pointing error budget and thus the subsystem design.

B. Payload

The payload is a science-grade monochromatic camera augmented with color strip (static) filters. That camera plays a dual role, for science capture and detection and target-relative navigation near the asteroid. This dual science/engineering role drives the instrument performance requirements. In particular, this is reflected in the selection of a field-of-view (FOV) that must be large enough for the instrument to accomplish optical navigation, without impacting the imaging resolution required for science applications. The ECAM M-50 imager with narrow FOV optics from Malin Space Science Systems (MSSS) (Fig. 5) has been selected as the reference imager. This product meets volume and mass allocations and meets sensitivity requirements for detection, as well as resolution requirements for proximity science.

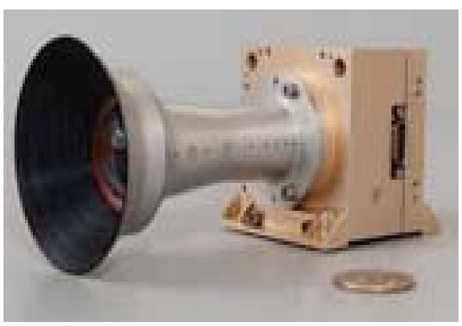


Figure 5. *Picture of the ECAM camera under consideration for the NEA Scout spacecraft, shown with its baffle and electronics box. The ECAM uses the Aptina MT9P031 sensor that is certified for deep space.*

As part of the science payload, NEA Scout will carry software designed to increase science return under constrained telecom resources: compression, triage, selection, and "cookie-cutting" of science features.

C. Solar Sail

The sizing of the NEA Scout solar sail depends not only on the physical factors imposed by being stowed within approximately 2U of a 6U cubesat, but also the desired mission parameters. Size roughly equates with performance and therefore with trip time, an increase of the sail size would shorten travel time and a decrease would lengthen it – depending upon the orbital characteristics of the target NEA, which also vary with time. After assessing the likely NEA targets and estimating the spacecraft component lifetime limits, an approximate 2.5-year maximum mission duration was adopted, which in turn set the overall sail performance goals and size.

IV.

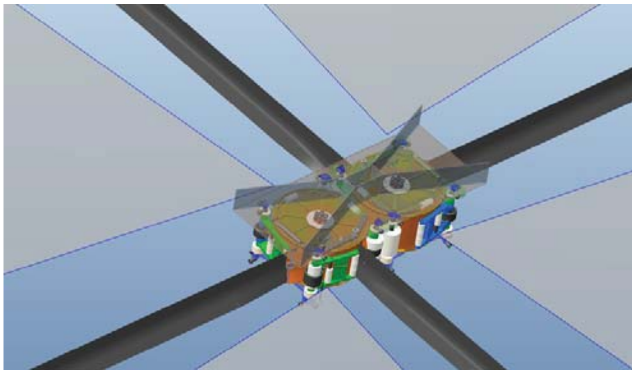


Figure 6. *Four 7-m booms will deploy, unfurling the 83 m2 aluminized polyimide solar sail.*

V. The NEA Scout solar sail will be based on the technology developed and flown by the NASA NanoSail-D[v] and soon-to-be-flown Lightsail-A (The Planetary Society). Four 7 m stainless steel booms wrapped on two spools (two overlapping booms per spool) will self-deploy after their release due to their coiled strain energy. The booms will pull the sail from its stowed volume as they deploy. The sail material will be 3 μm CP1, an aluminized polyimide that was extensively tested for solar sail applications and used in NASA's 20 m solar sail ground demonstrator project[vi]. Based on the trade study outcome, the sail will spooled.

VI.

The baseline reflective sail area (Fig. 6) required to meet the mission's DV requirements is 78 m^2. Since part of the sail's surface will have its reflectivity reduced due to structural reinforcement needs, and taking into account that a few small tears in the sail are almost inevitable, the actual deployed sail area will be approximately 83 m^2, providing some propulsive margin.

VII. Partnering Approach

The team will utilize the unique capabilities and skills of MSFC, JPL, GSFC, JSC and LaRC to develop and fly the Near-Earth Asteroid Scout mission. MSFC is the lead organization with overall responsibility for management as well as development of the Solar Sail Propulsion element of the mission. JPL is responsible for mission design as well as development of the flight system. Mission operations will be implemented jointly with the operations team comprised of personnel from both organizations. The science team includes representatives from many fields in NEA exploration science from JPL, JSC, and GSFC.

VIII. Conclusion

In developing a long-lived, deep-space capable nanosatellite bus, the NEA Scout flight system straddles the line between current interplanetary spacecraft and traditional Earth-orbiting CubeSats in terms of cost, risk, and capabilities. In doing so, NEA Scout enables a novel way to explore Near-Earth Asteroids, and paves the way for future low cost planetary exploration.

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[7] NASA, Johnson Space Center
[8] NASA, Marshal Space Flight Center
[9] Jet Propulsion Laboratory
[10] NASA, Goddard Space Flight Center
[11] NASA, Langley Research Center

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